# Using the PCMCIA Standards in Space

Douglas W. Caldwell
Jet Propulsion Laboratory, California institute of Technology
Pasadena, California 91109

## 1. Abstract

**PC** *Cards*[1] provide examples of commercial technologies and standards which can be exploited for spacecraft electronics elements. The technology offers a very compact and mature packaging approach, a simple communications interface which supports fault-isolation, and an existing product base which supports rapid prototyping and module development. This document describes the origins of the PCMCIA standards, the high-level characteristics of the interface specification, the benefits possible for space applications, and an overview of some of the many modules presently available. A recent addition, Cardbus, which marries the PCMCIA form-factor and the PCI high-speed parallel bus is discussed.

## 2. History

The Persona] Computer Memory Card Industry Association (PCMCIA) originated to serve the manufacturers of memory expansion products for the nascent notebook computer industry. As such, they were required to be low power and very small; the first cards were 54x84x3.3 mm, almost exactly the size of three stacked credit cards. Soon, innovators took advantage of the availability of the “expansion slots” provided for memory cards and implemented other functions such as fax-modems and Ethernet adapters. New functionality sometimes required additional height and a “Type 11” form factor was added. Later, a “Type III” was added to codify the practice of taking advantage of two adjacent slots to provide an even thicker card (such as for disk drives). As “plug and play” became a popular concept, software services were added to standardize the interface bet wcen u ser soft ware and the cards. Today, some 500 companies are members of PCMCIA and a similarly large number of commercial products are available.

[1] *PC Card is* a trademark of PCMCIA, the Personal Computer Memory Card International Association.

## 3. Overview of the Standard

This section provides a synopsis to introduce the reader to the PCMCIA standards. The complete standards [1] are available from PCMCIA. A more readable introduction is available from PCMCIA and may be also found in technical bookstores [2].

### 3.1 Physical Characteristics

The PC Card Standard, 1995 Release, [1] is the most current revision of the standards. As stated above, three physical form factors are defined. Table 1 lists important dimensions of the three form-factors. In all cases, the card guide rib is 3.3 mm tall. Approximate] y 45x70mm is actually available for internal circuits although circuit boards are often double-sided and some cards contain multiple boards.

**Table 1. Mechanical Form Factors**

| Designation | Height [mm] | Length [mm] | Width [mm] |
|---|---|---|---|
| Type I | 3.3 | 84 | 54 |
| Type II | 5.0 | 84 | 54 |
| Type III | 10.5 | 84 | 54 |

The electrical interface is across a 68-pin (2 x 34) connector on the narrower end of the card. In the terminology of PCMCIA, a *card* plugs into a *socket* which is managed by a hardware element called a *socket controller.* The socket controller is part of a *host adapter* which bridges from host environment to PC Cards. Table *2* lists the various types of pins in the interface and the quantity associated with each. Although these signals look like the signals commonly found on a parallel bus, the PC Card interface is not a bus interface. Supporting live-insertion requires independent, isolated connections between the a controller and each socket. While this increases the wiring complexity, it also increases system fault tolerance as will be described shortly. Since most PCMCIA hosts support exactly two card sockets, many socket controller ICs provide two sets of socket pins, one each for the two independent sockets.

Table 2. **Electrical Interface Overview**

| Pin Functions | Pin Mnemonics | Pins in Memory Mode | Pins in 1/0 Mode |
|---|---|---|---|
| Address | AO..A25 | 26 | 26 |
| Data | D0..D15 | 16 | 16 |
| Power | Vcc, Vpp1..2 | 4 | 4 |
| Ground | GND | 4 | 4 |
| Card Detect | CD1..2 | 2 | 2 |
| Card Selects | CE1..2, OE, WE/PGM | 4 | 4 |
| Card Status | WAIT | 1 | 1 |
| Battery Detect | BVD1..2 | 2 | |
| Memory Control | WP, RDY/BSY | 2 | |
| 1/0 Control | 10RD, IOWR, 101S 16, IREQ, INPACK, STSCHG | - | 6 |
| Other 1/0 | SPKR | | 1 |
| Other Control | RESET, REG, RFSH | 3 | 3 |
| Reserved | RFU | 4 | 1 |

Vcc is the primary card supply and may be either 3.3V or 5V. The newest standard supports two even lower voltages. Cards may be individually powered-down so Vcc may also drop to ground. Vpp was originally a programming voltage (e.g., for Flash EEPROM); it can be used as a general-purpose secondary supply but its use is limited because most host adapters provide only low-current Vpp supplies (< 50 mA). Vpp may be 12V, equal to Vcc (default), grounded, or non-existent. Single-chip power switches now exist (e.g., TI TPS2201IDF, [3]) which provide power multiplexing of Vcc and Vpp for two independent sockets. The standard specifies current-carrying capacity of 0.5 A/pin which would allow SW at 5V. Most cards draw less than 1W.

PC Cards are generally housed in metal cases and, if ungrounded, such cases can allow static charge buildup in a radiation environment. The standard does not specify case grounding although it would seem necessary to avoid static buildup even for terrestrial applications and to meet the standard's static discharge tests.

The interface is capable of supporting transfer rates of at least 20 MB/s. (The standard specifies memory read and write timing down to 100 ns. Data transfers can be 8-bit or 16-bit.)

### 3.2 **Software: Card and Socket Services**

The PCMCIA standards do not stop with mechanical and electrical compatibility; software is required to implement a plug-and-play system. *Socket Services is* the device-driver software layer. It presents a hardware-independent interface to the next-higher layer of software, *Card Services.* This allows Card Services to remain independent of the details of the actual socket controller used in the host adapter. In practice, socket controllers are relatively simple and the register set of the original Intel 82365 has become something of a *de facto* standard. While not eliminating the need for Socket Services, the usc of a such a register-compatible socket controller can save Socket Services development costs.

Card Services provides generic PC Card functionality such as detecting (and signaling) card insertion, determination of voltages and compatibility, and querying of the Card Information Structure (CIS). These generic functions are provided to developers who write *Card Applications* to handle particular PC Cards. In a plug-and-play system, the socket controller first detects the insertion of a card and signals the host with an interrupt. Socket Services fields the interrupt and signals Card Services. Card Services then queries the CIS to determine what kind of card has been inserted and invokes the appropriate Card Application as a task. Through the Application, the PC Card and associated software become an integral, possibly transient, part of the system.

Although the use of PC Cards does not necessitate implementing the standard software layers, their use in custom systems should not be dismissed. Shielding hardware from software with device drivers isn't necessary either, but established software engineering practice suggests that such functional partitioning is a good idea, even in a custom system. While individual projects could benefit from PC Card technology, widespread use of the software layers would encourage reuse from system to system, even for spacecraft.

## 4. PCMCIA in Space

### 4.1 Advantages

The most readily apparent benefits of PC Cards arc their small size (23 $cm^3$ for Type 11) and consequent low mass (< 30 gm, typical for Type 11). Their functional density is on par with that achievable with MCMS for most applications (at substantially lower cost). Their primary use in batter-y applications (notebook computers and personal digital assistants) has lead to intrinsically low-power designs which are further augmented by reduced-power modes (e.g. standby, idle, or reduced-functionality). Typical cards draw between 0.1 W and 1 W. The inclusion of support for supply voltages below 3.3 V will further reduce power. The cards' use in portable applications (i.e., the battery applications listed above) and their frequent handling during card swapping requires robust ness. The standard specifies an operating vibration level of 15 g RMS and shock of 50 g (six axes) although many cards can withstand significantly higher levels (e.g., 1000 g shock).

As mentioned earlier, supporting live insertion of PC Cards simultaneously provides fault containment. Although called "hot swappi rig", this is from the host's perspective; the socket is usually "cold" when a card is inserted. This requires power switching for each individual socket. Further, since signal lines should not be connected to unpowered circuits, all the signal lines are tri-state buffered on the host side. The signal lines are switched on only after a card is detected and powered (with Vcc). The use of current limiting and current sensing on the power supplies for each socket (as is typical ) supports over-current detection. The point-to-point, non-bus nature of the interface results from these considerations. The side-effect of all of this is that any faulted card can be isolated from the rest of the system, either permanently or temporarily (to isolate faults or to perforn n hard reset). This capability also allows cold-sparing or card-wise power reduction to be trivial 1 y implemented. Although no signal-level fault tolerance is supported (e.g., not even parity!), this may be a price that must be paid for the many other cost benefits. A new specification augmenting the attributes of PC Cards with fault tolerance features would negate the majority of the benefits of using the standard as-is. It is unlikely that developing such a standard would be cost-effective.

The physical and functional advantages get us past the hurdles of technical acceptability within the space community. The real advantage of the PCMCIA standards is their cost reduction potential. An industrial-grade 175 MB (1 Gb) Flash memory card costs around $5000 (qty. 1). A 360 MB (3 Gb) hard disk costs about $1000. Most 1/0 cards are $200- $1000. Clearly, if these off-the-shelf items can be used (without substantial upgrading or qualification), significant savings could be realized. Large production volumes allow manufacturers to amortize their (large) development costs across many units and would also be expected to yield higher quality products.

However, even if existing cards cannot be used, the standards can and should be leveraged. Virtually all the reasons for using standards [4] are applicable: knowledge reuse, industrial infrastructure, long-term maintainability and upgradeability, etc. A large number of vendors have already wrung out the standard; it is mature. A large infrastructure supports development, prototyping, and production of the cards; a knowledge base exists. Existing commercial software and test hardware can be used for developing aerospace-unique cards. The size of the industry and the lack of credible competitors suggests that the standards will be supported for a significant time. Considering that VME has been around since the late '70s and is still strong, and that PCMCIA is less than five years old, it would seem reasonable to predict its viability for at least the next ten to fifteen years.

## 4.2 Issues

Thermal issues present the most obvious problem with using PC Cards in a space environment. While a typical space temperature range is -34 - +71 'C [5], the standard requires only the commercial range of O - +55°C. Although some industrial grade (-40 - +85°C) cards are produced, they are not common, Additionally, there is often not a high-conductivity thermal path from devices to the case. This is somewhat mitigated by the very low power consumption of the devices. One simple technique for largely resolving this problems is to simply remove a card's cover, apply thermally-conduct i ve epoxy to each device to bridge the gap to the cover, and then replace the cover. Cover removal may also be required to replace materials (e.g., a plastic card frame) which are not vacuum- compatible. Hermeticity requirements can be accommodated similarly. An example of an industrial device which has been upgraded for thermal conductivity and hermeticity is Raymond Engineering's Sentinel memory card (although this device unfortunately violates the standard by stretching the package by about 10 mm). in this case, the result is approximately twice as heavy as the "bare" commercial device.

Card retention is normally achieved by the friction of the pins. For space applications, additional force is required but the mechanisms used to ensure thermal conductivity will often add sufficient retention forces. Of more concern are the external 1/0 connections which must be made opposite the 68-pin connector for communications, data acquisition, antennas, etc. At present, there are no standards for these cables. Some are permanently affixed to their cards, others are attached with connectors (which generally have no positive retention). As with any assembly, cable harnesses present a problem which cannot be ignored. However, although irritating, the connectors and cables do not appear to present intrinsic problems.

Some minor issues should be mentioned for completeness but which do not detract from the standard. The point-to-point nature of the interface incurs a penalty in interface circuits. The penalty is not severe because of the relatively small number of connections (-60) and the availability of single-chip dual-socket controller chips; this is a small price to pay for the fault tolerance gained. Radiation is an ever-present issue but has nothing to do with the standard; it applies to all commercial electronics. Finally, no

PC Cards have ever flown in space; the consequent distrust of "unproven" hardware is, again, not unique to PC Cards and is, fortunately, easily rectified.

### 4.3 Memory

A large number of memoty cards are available. The simplest of these are accessed as linear memory and provide from 64 KB to 4 MB of memory. Their primary applications are memory expansion (DRAM), "solid-state floppy" (SRAM and Flash), and software distribution (ROM and OTPROM). These are of limited interest in spacecraft systems.

Nowhere is the power of evolutionary improvement more evident than in the $10011 hard disk industry. Rapid improvements in linear recording density and simultaneous reductions in platter and head sizes have enabled traditional rotating media to fit into the PCMCIA form-factor. Presently, 320 MB disks are available (MiniStor, 94Q4); only 6 months previously, the largest drives were only 80 MB (94Q2). Since these drives are used in portable applications, they must withstand more abuse than desk-bound disks. As an example, the MiniStor 340 MB drive can withstand 200 G operating and 900 G non-operating. Although they use rotating media, the angular momentum of the devices is typically low because of their small size. While the first PC Card hard disks were only found in Type 111, as of early 1995, they are also available in the Type 11 form-factor.

Relatively new to the scene are very high capacity Flash disks, ranging from 2 MB to 175 MB (April 1995). These solid-state devices present the user with an interface which is identical to a hard disk and similarly non-volatile (and SEE immune). in this way, a great deal of internal sophistication can be incorporated into the devices which cannot be used in traditional linear memories. The SunDisk line. of Flash disks [6] are accessed either as a linear array of logical blocks or as ATA (AT Attachment) disks complete with "sectors", "heads", and "cylinders". Blocks (sectors) are 512 bytes. The logical addressing scheme allows $2^{28}$ blocks to be addressed or $2^{37}$ bytes (128 GB or 1 terabit). A (56,64 ) Reed-Solomon code protects data. The use of' an abstract (disk) interface allows the device to hide details from the user such as physical sector mapping, error detection and correction, block erasing and writing, and storage element replacement (remapping). This, in turn, obviates the need for wear-leveling operations in software as part of the operating system (Flash File System or FFS.). In fact, because SunDisk was free to implement internal details, the device performs no wear-leveling. Cells arc allowed to decay until their performance is no longer acceptable; the RS code is then used to correct errors and the 64- bit sub-block is remapped elsewhere. ']'bus, one mechanism is used to accommodate wear-leveling, random bit failures, and manufacturing defects (which effectively improves chip yields). SunDisk's aggressive technology has been so successful that the majority of such disks which are on the market are actually re-labeled SunDisks. Raymond Engineering's Sentinel card is a ruggedized SunDisk.

In 1994, about 2 million PC cards were sold [7]. The memory card market alone is projected to be 8M units and $1 B in 1997. Both Flash and disk vendors are anticipating an annual doubling of available density although SunDisk also projects an additional factor of two from '96 to '97. The base factor of two for Flash is apparently due to increases in packaging ability while the additional factor is due to increases in actual chip density. Table 3 shows capacities of existing devices and projections for the next couple of years.

**'1'able 3. PC Card Memory Capacity and Projections.**

| Memory Type and Packaging | '94 [MB] | '95 [MB] | '96 [MB] | '97 [MB] |
|---|---|---|---|---|
| Flash, Type II | 40 | 80 | 175 | 500 |
| Flash, Type III | n/a | 175 | 350 | 1000 |
| Disk, Type II | n/a | 170 | n/g | n/g |
| Disk, Type III | 120 | 260 | 500 | n/g |

Data compiled from [7] and various other sources.
n/a Not Applicable (cards did not exist).
n/g Not Given (presenter did not discuss).
1994 values are actuals to this author's knowledge.
1995 values represent recently (as of April 95) released products (Flash) and soon-to-he released products (disks).
Other years are vendors' projections [7].

## 4.4 Other Functions

In addition to memory cards, a large number of 1/0 and communications adapters are available in the commercial marketplace which could be useful in space applications. Typical data acquisition cards support 8 to 16 channels of 8- to 12-bit analog inputs at up to 100 kHz, a small number of discrete (digital) lines (e.g., 8 inputs and 8 outputs), and one or two counter-timers. Some cards support digital-to-analog conversion. At least one vendor provides a 33 MFLOPS DSP with 4 MB of DRAM and audio-quality analog 1/0 in a Type 111 package. Integrated GPS receivers are available which require only an external antenna. Available communications cards support RS-232, MIL-STD-1553B, SCSI-2, Ethernet, GPIB (IEEE 488), CAN. Various modems and wireless adapters, both infrared and spread-spectrum radio, also exist,

## 5. Extensions

The success of the PCMCIA standards has led to a number of follow-on standards, derivative products, and technologies which leverage the investment of the PCMCIA vendors.

The 1995 release defines a new card architecture called Card Bus which is fundamentally different from the 16-bit PC Card interface. A simple characterization of CardBus is that it might be seen as an answer to the question "how would one fit the essence of the PCI Bus into the 68 pins of a PC Card while maintaining the plug-and-play philosophy?" The solution is very similar to the 32-bit address/data version of PCI.

The use of CardBus cards would allow modular systems to be built around a simple backplane and card cage. This will enable implement at ion of desktop-performance computers but which occupy a fraction of the volume. Using today's packaging technology, for example, a processor card, expansion DRAM (e.g., a couple of 8 MB Type II cards), a couple of large secondary memories (e.g., 350 MB of Flash), and some external interfaces (e.g., Ethernet, SCSI, and 1553) would occupy about ten Type 1 I slots. A card cage containing these cards and an appropriate power supply would occupy about 750 $cm^3$.

## 6. Conclusions

The PCMCIA PC Card standards define specifications which support small, rugged, low-power hardware modules. Additionally, the interface intrinsically supports fault isolation and the supporting software standards encourage true interoperability. The acceptance of the standard by the large portable electronics industry provides a rich infrastructure and virtually guarantees its longevity. The few minor issues of concern in space applications can be readily addressed. Existing dense, low-power, non-volatile mass memory modules may be immediately exploited. The spacecraft avionics industry should adopt this standard, learn to mitigate its few deficiencies, and reap the benefits of an established standard which supports the type of miniature electronics form-factor needed to reduce mass in a cost-effective fashion.

## 7. Acknowledgments

This work was performed at the Jet Propulsion Laboratory, California Institute of Technology, under a contract with the National Aeronautics ancl Space Administration.

## 8. Bibliography

[1] *PCMCIA Standards*. Personal Computer Memory Card International Association. Sunnyvale, CA.

[2] Michael T. Mori, W. Dean Welder. *PCMCIA Developer's Guide, 2nd Edition. S* yCard Technology. 1995.

[3] *TPS2201IDF, Dual-Slot PC Card (PCMCIA) Power Interface Switch.* Texas instruments. 1994.

[4 Douglas W. Caldwell. *The Role of Standards in Spacecraft Avionics.* AIAA Computing in Aerospace 10. San Antonio, TX. 28-30 March 1995.