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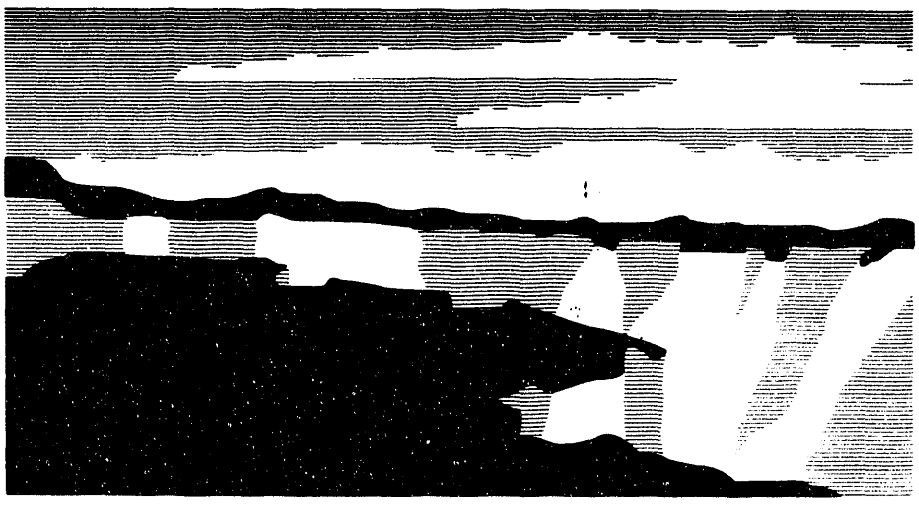

Los Alamos
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RECENT MINIATURE MCA TECHNOLOGY DEVELOPMENTS AT LOS ALAMOS*

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Abstract

We have developed a new spectroscopy-grade, 4096-channel multichannel analyzer (MCA) for use in the domestic nuclear industry with application in domestic and international nuclear safeguards. It is based on a building-block philosophy (hardware and software). The oversized "blind" prototype for the miniature and modular MCA fits in a box 10 by 20 by 9 cm including bias supply and batteries. Its low power consumption is a third unique feature. Our goal is to provide MCA hardware and software building blocks that people not technically knowledgeable of the internal details can use to build solutions to a wide variety of problems independent of computer platform or operating system.

1. Introduction

The purpose of our work is to develop a set of tools to be used by the Safeguards Assay Group to solve safeguards and domestic nuclear industry problems as well as problems requiring similar hardware and easy-to-implement software for environment, defense, or other areas of national and international interest. The current development was begun when problems were encountered for which solutions were becoming more and more difficult to implement using existing hardware and software.

The first phase of the current development began when we were asked to replace an existing, small NaI pulse-height analysis (PHA) and control system. The replacement was necessary because the old unit was too noisy and high-resolution capabilities were needed. The application required only low count-rate capability. This development is described in a paper entitled "Miniature-MCA Technology Developments" /1/.

Tightened regulations for material holdup at a DOE facility that measured uranium holdup was the impetus for the present round of development /2,3/. Parts of an existing holdup measurement system were brought to Los Alamos by the developer and were interfaced to the PHA system just described. A couple of hours after the developer arrived, region-of-interest (ROI) information was being transferred between his data logger and the PHA system. The success of this interaction and discussions with other facilities and groups lead to the present multichannel analyzer (MCA) development program by the Safeguards Assay Group in Los Alamos.

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Our development goals are

- to provide a set of software and hardware building blocks that would allow one to quickly, economically, and reliably configure instruments for solutions to safeguards and domestic nuclear industry applications;
- to provide as general an interface to this system as possible that has minimal requirements for hardware interface specifications; and
- to create a software tool kit for MS-DOS computers to allow programmers to create application-specific software without knowledge of the technical operation of the interface to the building blocks.

To attain our goals, we have made extensive use of advances in hardware and software since our last MCA development activities over a decade ago.

2. The System We Are Developing

Our system contains a basic building block composed of hardware and firmware plus a software library that provides an interface between high-level languages and the building block. We call the basic hardware and firmware the miniature and modular MCA (M^3CA).

The M^3CA provides general support to applications. It must include the necessary hardware as well as control for the hardware, and it must provide general functional support for applications. Figure 1 schematically shows the M^3CA where the processor hardware, amplifier, analog-to-digital converter (ADC), and power and bias supplies are held together by the firmware.

The firmware in the M^3CA is divided into three basic areas:

- Setup and control,
- General measurement functions, and
- Communication.

In general, anything that is accomplished by setting bits in a hardware register is termed setup and control. Examples of setup and control are setting coarse gain or amplifier polarity. When the processor is used to move bytes or make calculations we say it is doing a general function. Examples of the general functions are ROI activities or

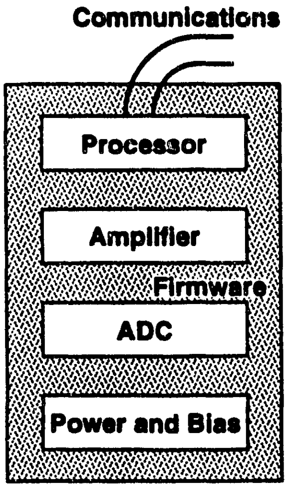

Fig. 1. Conceptual diagram of basic M[3]CA building block.

dumping data. One communications package handles receiving commands and sending responses.

The choice of general functions to be implemented in the M[3]CA is somewhat arbitrary, but we use the principle that a function should be generally usable in a number of applications. Anything that is application specific does not qualify as a general function in the M[3]CA.

For the most part, interfacing detectors to the M[3]CA is straightforward and numerous people can handle this task. Lack of such experience is generally not a significant impediment to using the M[3]CA for an application.

The user interface requirements are rapidly and fundamentally changing. In the past, MCAs have generally been used in manual applications where the user was present and tasks were accomplished using standard front-panel features. We feel that more and more applications will require specialized user programs, some of which will involve remote or unattended operation or both.

To enhance the M[3]CA's applicability and adaptability, the end user must be able to effectively and efficiently develop specialized application programs. To this end, we also provide a software library so the programmer does not need technical knowledge of the operation of the M[3]CA. This library is easily used with Microsoft's MS-DOS higher-level languages.

Hardware Features

The hardware is arranged on four main boards (96 mm by 198 mm) as shown in Fig. 2. The top board is the amplifier board, under which is the ADC board. The processor board is between the ADC board and the power supply board. The bias board is a piggy-back board on the lower side of the power supply and shares the lower space with the internal battery. The boards are separated according to function. This allows new boards to be exchanged with original boards when different features are required. All boards have 8-bit readable ports that may be used for board IDs or for configuration sense switches. In addition, all boards except for the processor board have switched power inputs. The processor board goes into low-power mode when the processor chip is placed in the sleep mode. The features of the individual boards are given below.

Amplifier

- Two selectable differentiation and integration time constants
- 4-pole Gaussian filter
- Coarse gain settings: 1, 2, 4, 8, 16, 32, 64
- Fine gain settings: 4095/4096 to 1/4096 with 12-bit resolution
- Gated base-line restoration with automatic threshold
- Pile-up rejection with automatic threshold in fast channel
- Adjustable pulse-width-rejection*
- Additional 12-bit fine gain setting for digital gain stabilization*

ADC

- 100-MHz Wilkinson ADC
- Conversion ranges of 4096 k and 512 channels
- Programmable digital pedestal
- Hardware differential nonlinearity reduction capability

*Not implemented in the first prototype.

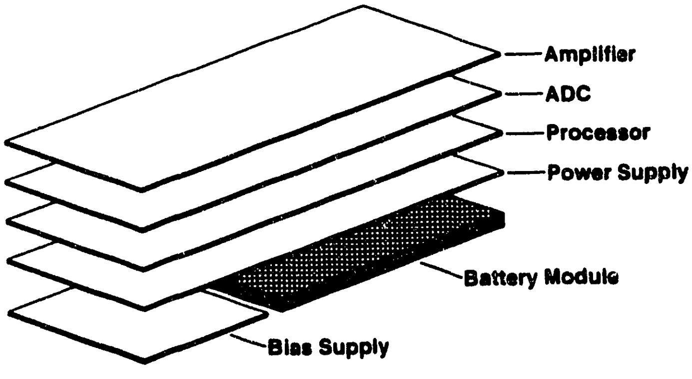

Fig. 2. Board configuration of basic M[3]CA building block.

- Programmable logic arrays used to provide greater functionality and reduce size
- First in first out buffering between PHA circuitry and direct memory access storage
- Two individually addressable conversion memories
- Processor and PHA circuitry with concurrent, interleaved access to conversion memories

Processor

- MC68HC11 single-chip microcontroller
  - Asynchronous serial port (125 k baud max.)
  - Synchronous serial interface (1 M baud max.)
  - 8-bit ADC with 8-channel multiplexer
  - 256 bytes internal RAM
  - 512 bytes electrically erasable read-only memory (EEROM)
  - Power-down modes
- Application-specific programmable gate array for control and decoding
- Bus interface
  - 8-bit multiplexed address/data lines
  - Three external select lines
  - One interrupt line
  - One reset line
  - 3-line synchronous serial interface
  - Two system clock signals
- Unique, processor-readable 48-bit serial number
- 128 kbytes of RAM organized in 64 kbytes for system memory with four additional 16-kbyte pages.
- 128 kbytes of ROM organized as a "ROM DISK"
- 1 kbyte of EEROM for nonvolatile parameter storage
- Additional UART for "system" serial communications (Maximum data transfer asynchronous rate 1 M baud times 1 mode)
- Battery-backed-up real-time clock
- Ambient temperature monitor
- Power supply monitors
- 12-bit buffered binary output
- 8-bit binary input
- One buzzer output
- +5-V power supply

Power Supply

- ±12-V and ±24-V low-voltage power supplies
- standard 9-pin connector pinout
- +5 V
- 200–1200-V positive-bias supply with 125-μA capability and SHV connector
- 300–3500-V bias supply*
- High-rate battery charger*

Battery

- Quickly replaceable Ni-MH 2.2 A-h 12-V

*Not implemented in the first prototype.

The hardware will be controlled by commands issued by a controller through the processor board's serial interface. The firmware on the processor board contains "macros" to control all the parameters that can be set by the user. If the user interface of the controller requires a display, the controller must provide this capability. In many applications there will be no need for a front panel, hence no classical front panel is shown in Fig. 2.

Examples of external controllers are intelligent data loggers (Fig. 3), palm-top computers (Fig. 4), or personal computers—MS-DOS compatibility is *not* required. Any device capable of issuing ASCII commands by a serial interface can be used as the external controller.

For those applications where a classical front panel is needed, an additional board could be internally interfaced to the M^{3}CA by the serial port (Fig. 5). By using soft keys defined by the liquid-crystal display (LCD), a powerful interface can be implemented with a limited number of buttons (Fig. 6). With present day technology, the processor for such a board would be a "DOS processor." By this we mean one of the very large scale integration circuits that contain not only the processor but standard DOS interfaces as well. Figure 7 shows the front of a commercially

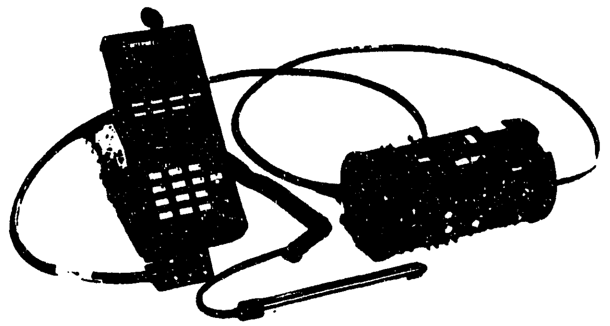

Fig. 3. Intelligent data logger used with prototype of early building block.

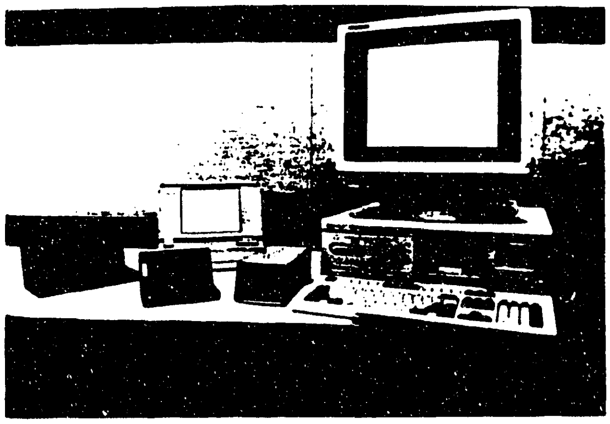

Fig. 4. Array of computers that are easily interfaced to basic building block.

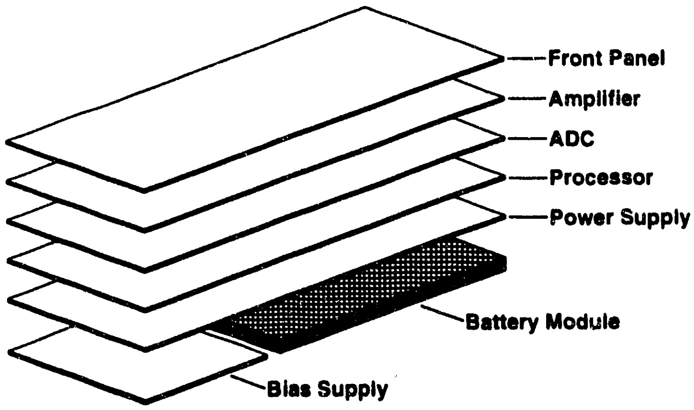

Fig. 5. Basic building block plus an attached front panel.

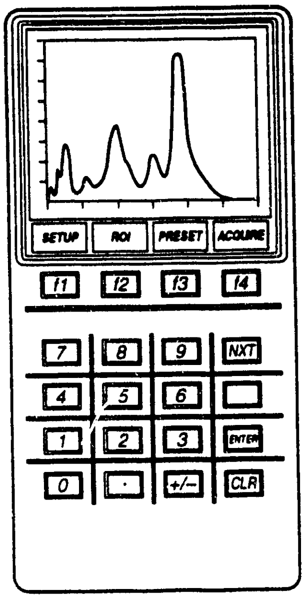

Fig. 6. Conceptual layout of a limited front panel.

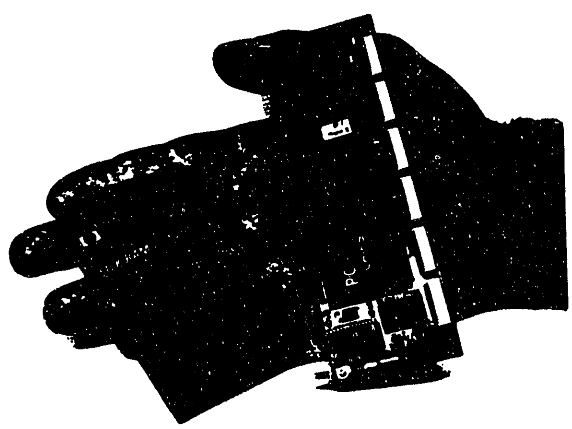

Fig. 7. A commercially available* DOS processor board with video and LCD interface, memory, keyboard interface, bias, and PCMCIA interface.

*Produced by Dover Electronics, Longmont, Colorado.

available implementation of a DOS processor and a credit-card-sized memory module that plugs onto the back of the board. This implementation contains standard DOS video, LCD, keyboard interfaces, bus and PCMCIA interfaces, bias, and memory. A clear advantage to this approach is that software for this front-panel board would use the software libraries developed for the larger DOS-based computers. This software could be developed and debugged on the larger computers and then downloaded into the front panel. The hardware advantage includes large memory maps and existing interfaces to DOS devices and to the PCMCIA devices such as memory cards and modems.

The rich array of macro commands virtually eliminates the need for total spectrum transfer except for spectral display. It is clear that the real-time display of an accumulating spectrum will not be seen with this system. With this system, 1–2 s would be expected to update a 512-channel spectrum. However, there are very few nonlaboratory applications that require a real-time display.

At the time of this writing, the first prototypes are just being tested. While no test results from this new system are available, we expect the amplifier and ADC to perform as well as the Davidson 2056-SA and a Canberra system composed of a 2020 amplifier and 8075 ADC (Fig. 8).

Software Features

There are two levels of software associated with the M^{3}CA. The first is software contained in the EPROM on the processor board that controls the hardware. The second is a library that runs on any IBM-PC-compatible computer to provide the application programmer with C functions that perform the most commonly used functions. This library handles all the timing and communication protocol of the interface between the PC and the M^{3}CA.

The embedded software on the processor board is written in C; we use the Introl C-68HC11 Cross Compiler System. Software is developed on an IBM-PC-compatible computer, downloaded into the system RAM chips for testing, and finally programmed into EPROM for the final system. The functions for the PC-based library are written in Microsoft C and these C functions can be easily called from

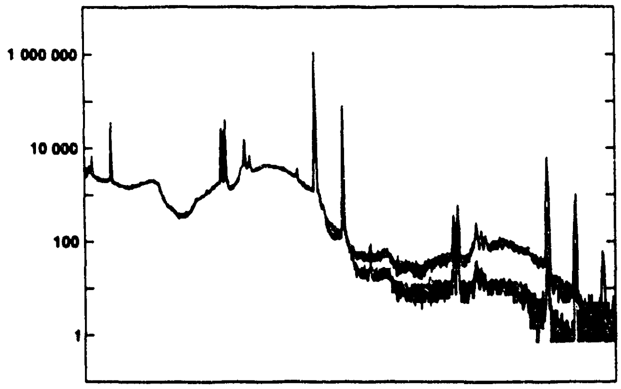

Fig. 8. PMCA pile-up rejection tests

^{57}Co source:	count rate = 60 000 counts/s input
Top trace:	CI2020 w/2 μs TC, 8075 ADC
Bottom trace:	PMCA PPRT = 105

any other Microsoft language such as BASIC or FORTRAN.

All communications with the M^{3}CA are through the serial port (Fig. 9); the M^{3}CA responds to commands received from external controllers and all responses are sent out the serial port. The M^{3}CA acts as a slave in the system and only responds to commands from the master (external controller). The M^{3}CA parses each command, sets or reads the appropriate hardware to execute the command, and then sends the appropriate responses to the serial port. Normally only external controllers interact with this level of M^{3}CA communication; typically, the user interacts with the special program in the external controller. For diagnostics, it is possible to interact with the M^{3}CA through a terminal. The protocol for the serial communication is well defined; it was designed to be a simple, straightforward interface so many types of external controllers could easily interface to it. The external controller is only required to have a serial port; no special interface card or operating system is required. Commands are entirely ASCII strings and consist of an opcode, optionally followed by one or more arguments and terminated by a carriage return. All responses except the binary spectral dump are also in ASCII. The commands logically fall into five categories: commands for parameters that can be set and read back, commands for parameters that are read only, commands whose response must be calculated and sent back, commands with no response, and commands with unique responses. The command set allows the user to set or read all the usual MCA parameters such as high-voltage discriminators, and ROIs; it also contains the control commands to start and stop the acquisitions and dump the spectra or ROIs only. The command set has the capability to calculate the centroid of any ROI and commands to compensate for gain-drift through software. To compensate for the non-real-time nature of the display, M^{3}CA can continually acquire data in one memory group while the data in another memory group are being sent to the external controller—there is no pause in the acquisition while the spectra are being transferred to update the external controller's display. At the present stage of development, over 100 commands are defined.

Because most controllers will probably be IBM-PC-compatible computers, we provide a library of C functions that communicate with the M^{3}CA (Fig. 10). This relieves the application programmer from having to decode all the serial port commands and responses. The library consists of about 13 functions; these provide the capability to set up the M^{3}CA, start an acquisition, check if the acquisition is complete, stop the acquisition, and read the spectrum from the M^{3}CA. The library contains an I/O control function that allows the programmer to access any of the 100 low-level commands defined at the serial port level. The library handles the communication protocol between the PC and the M^{3}CA; thus the application programmer never has to worry about the actual format of such things as the strings and time-outs. We believe that with this set of tools the application programmer should be able to fairly easily build an application. The application programmer needs to understand the functionality of an MCA but does not have to specifically learn how that functionality is implemented for this specific MCA.

To do the checkout of the blind unit we have developed an MCA emulation program that runs on a PC. This program allows us to read and set all M^{3}C A parameters; acquire spectra in either single or continuous acquisition mode, transfer spectra to the PC, and save in a Canberra S100-compatible DOS file; plot spectra from the M^{3}CA or disk file and perform standard MCA front-panel functions such as expand, move the cursor, set ROIs, make energy calibrations, change vertical scales, and print hard copies of the spectra; load spectra from a disk file into the M^{3}CA and from the M^{3}CA into a disk file; and adjust the

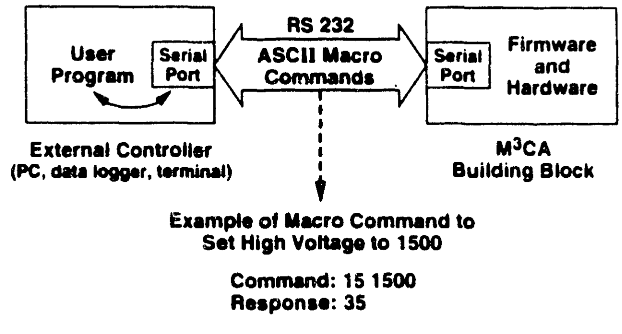

Fig. 9. Interface to M^{3}CA at lowest level; user must implement the ASCII macro commands and responses.

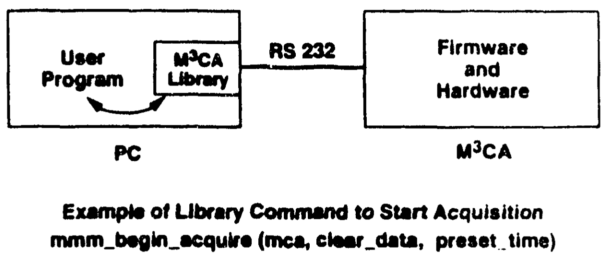

Fig. 10. Recommended interface to M^{3}CA at library level, details of M^{3}CA/PC interface are invisible to applications programmer.

spectra counts based on the energy calibration and normalize the counts in each channel so two spectra can be overlapped for analysis. This program can be used to perform some of the more standard MCA setup functions; the actual application would be written separately. We are working toward making the spectral display and its associated actions a function that would be callable from another program; this would relieve the application programmer of having to write these "front-panel" type routines.

We hope that when a front panel is needed we can use the same MCA emulation program that currently runs on the PC with a palm-top computer. The limited display and keyboard capabilities of another type of a front panel might require some minor modifications to the emulator program. By keeping the front panel a DOS-compatible device, we believe a broad range of programmers should be able to develop application-specific programs.

3. Future Visions

In mid calendar-year 1993, we will begin shrinking the size of the electronics boards for new applications. The target size is 60 mm by 150 mm. This will be done through the development of hybrid analog circuitry and the use of surface-mount technologies. A lower-powered, combined low-end amplifier and ADC board could be developed to replace the existing high-end amplifier and ADC board pair. Such a board would be useful in environmental and some safeguards applications.

New approaches to gamma spectroscopy can be easily adapted to this building block. For example, a board that applies digital signal processing techniques could replace the existing amplifier and ADC boards without changing the package or the connectors and with very little change to the basic building block software.

With the existing neutron coincidence/multiplicity counting electronic technology, it is straightforward to add a neutron coincidence/multiplicity board to the building block set. This would allow all the necessary information for a plutonium meter to exist in a small, self-contained, stand-alone package. Replacing the PHA electronics blocks with the neutron board would result in a coincidence/multiplicity counting package that is rugged, self-contained, and stand-alone, but most importantly the resulting package would be able to use the protocol philosophy developed and refined for the M^3CA.

In fact, it is conceivable that the present personality boards associated with the GRAND electronics package /4,5/ could be shrunk, made intelligent, and interfaced to the processor and power supply. Again the result is an integrated package using a single protocol philosophy.

Such an instrumentation family would not only allow single instruments to be simply integrated into a user program but multiple instruments as well.

If we are successful in achieving our goals, this system could function for a wide spectrum of applications from low-end and low-power to high-performance applications such as high-count-rate plutonium-isotopic analysis systems. One may choose this system for one or several of the following reasons:

- For all systems
  - The ruggedness and reliability of this system should be greater than larger systems because of the use of high-density low-powered programmable logic arrays. Lower operating temperatures resulting from the low-powered circuitry should also increase reliability.
  - This system has a powerful set of software tools to make writing application programs comparatively simple. We hope the commercial implementation will be competitive with or cheaper than existing commercial systems.
- For facilities where both high- and low-end applications exist, a system that covers the total spectrum
  - Minimizes the number of systems on which users must be trained,
  - Minimizes the number of systems on inventory,
  - Minimizes the number of systems which must be supported by maintenance, and
  - Allows a single software interface to be used for all applications.
- For remote or unattended operation or both that requires uninterruptible, stand-alone operation, the low-power and internal batteries coupled with an intelligent front panel with a user function provide a small, self-contained nucleus that can execute a function while the unit is temporarily isolated from power and communication with a central computer system.

A question that is invariably asked is why would one use such a system in a high-performance application where ac power is readily available. Our answer is given in the reasons above.

- For facilities with only high-end applications and plenty of ac power—why not?!

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