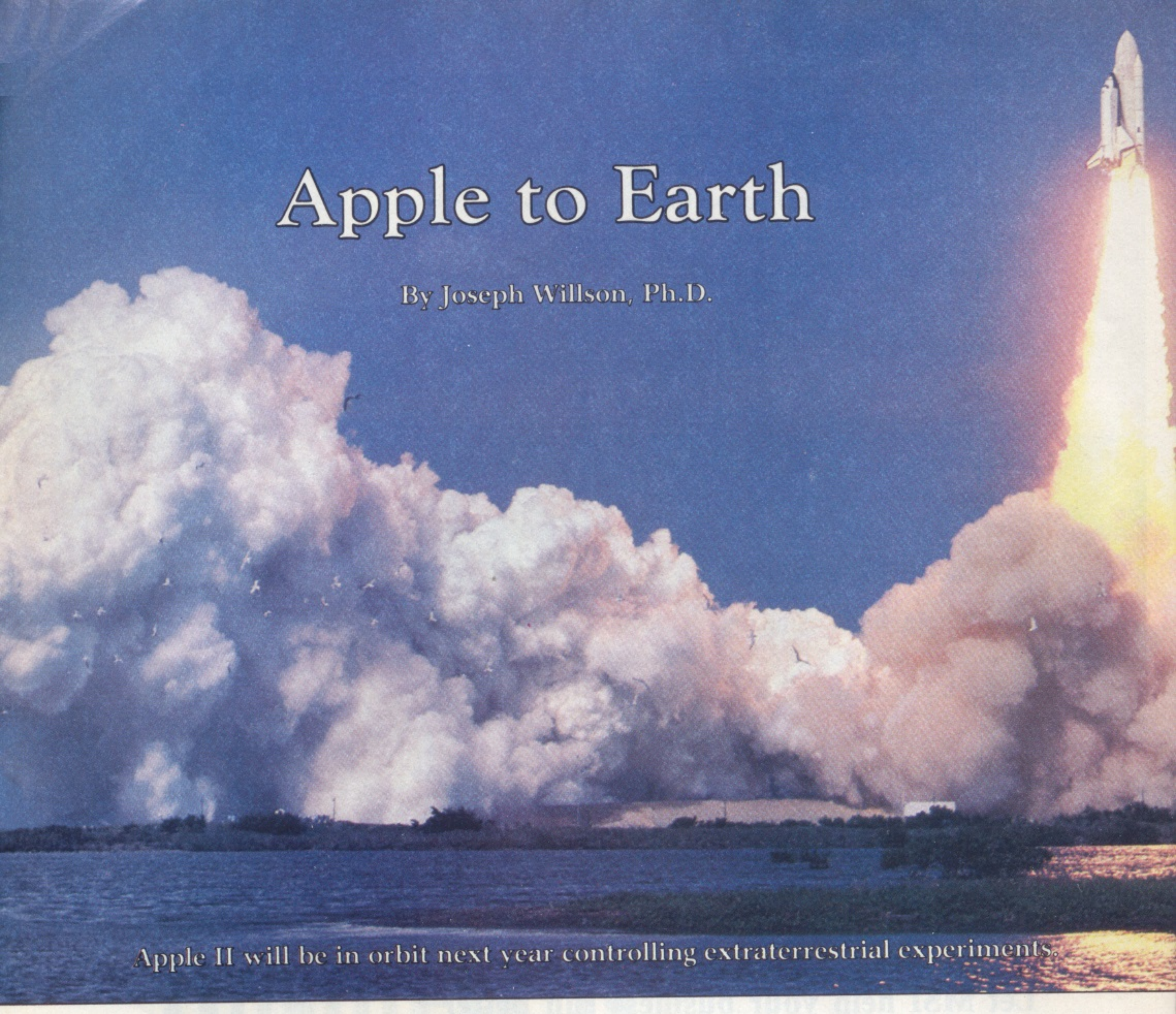
Apple to Earth

By Joseph Willson, Ph.D.



Apple II will be in orbit next year controlling extraterrestrial experiments.

When a sunflower sprouts and begins to grow, it doesn't simply push its way straight up out of the soil—it moves in a spiral.

This process, called circumnutation, is common to many plants, and nobody is quite certain why. But researchers hope to get a better idea next year with Spacelab, a joint project of NASA and the European Space Agency. This compact laboratory will be carried into space by NASA's Space Shuttle. And on board, helping to control the experiment, will be an Apple II.

The story began in 1977 in the laboratory of University of Pennsylvania biologist Dr. Allan Brown. Brown is one of many scientists studying what factors affect plant growth. In particular, why do so many plants follow a helical path? Is it just an extraneous bit of behavior which entered by accident into the evolutionary process, or does it serve a purpose? How much do the forces of gravity come into play?

Brown focused his attention on the effects of gravity. But the study of gravity presents a problem in the lab. While a scientist can change the direction of the g-force by rotating the plant, he can never completely eliminate gravity itself.

It became clear that experiments had to be done somewhere other than in an Earthbound laboratory. NASA looked at the problem and agreed that this was, indeed, a prime example of an experiment which needed to be done in space. But one problem presented itself. Brown's experiment would require a precision centrifuge, video cameras and recorders, lighting, temperature regulation, and controlling electronics and instruments, and it would have to be condensed into a miniature self-sufficient package about 2×2×6 feet.

So the University asked Interactive Structures, Inc. of Bala Cynwyd, PA, to design, develop and build an experiment controller which would manage every aspect of a seven-day experiment aboard the shuttle.

Old Tech, New Tech

The conservative approach to development of experiment controllers and instrumentation in 1977 was to design custom circuit boards for the timing, control and measurement circuits, and to provide a generous helping of trimming adjustments and

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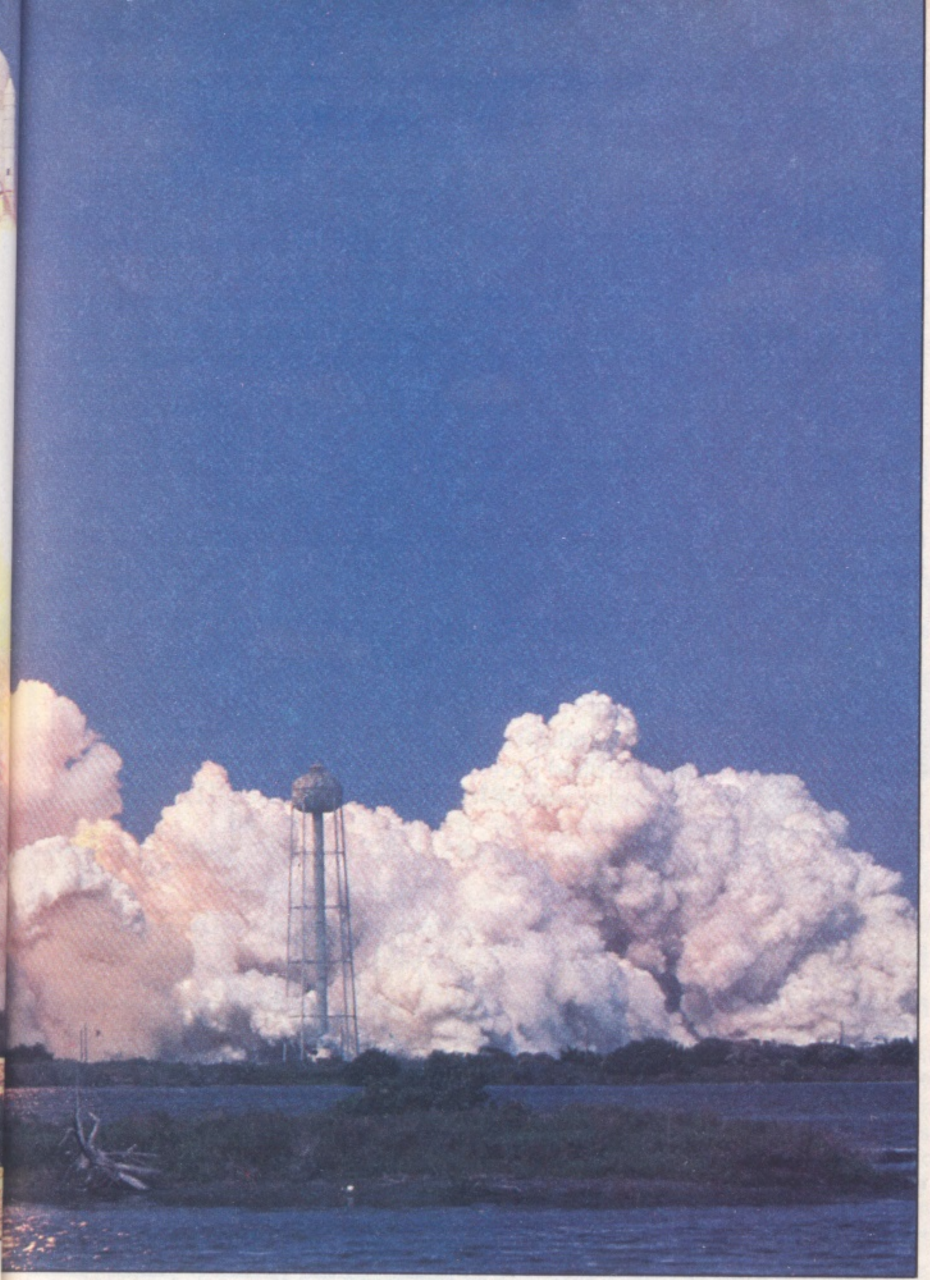


Photo by James L. Long Associates

oscilloscope test points for the unlucky engineer assigned to repair, or worse yet, to modify the system.

The company's experience with this technology showed that the only hope of meeting the size constraints and readying for the inevitable revisions was to look to the newly emerging technologies. In addition, NASA had directed the experiments should make use of existing technology and avoid costly custom development.

The slightly more-daring approach in 1977 was to go with one of the recently-introduced 16-bit single-board minicomputers. But that single board didn't include any way of getting the information in or out; it still needed a serial interface board and a complete video terminal just to determine if the machine was working. Putting together a system on which Interactive Structures could efficiently develop software and hardware involved a string of other expenses, starting with several thousand dollars just for operating system software.

In 1977, the microcomputer industry was barely off to a start. Several companies had marketed rectangular boxes with sets of switches and red lights on the front panels. Everyone knew the microprocessor was the coming thing but nobody knew just how soon or in what form. It would obviously have a place in the laboratory, but to go with one of these early arrivals seemed risky at best.

The Apple II was unique. No rectangular box, no switches, no lights. It really was a single-board computer, since the keyboard, video image generator and interfaces for future devices were all included. Rather than promising future add-in boards and add-on chassis for the memory, Apple included space for up to 48K of memory. When you turned it on, it spoke to you in Basic instead of binary. Why, these folks had even thought about interrupts and direct memory access data transfer!

Interactive Structures had evaluated these points in the context of general-purpose laboratory computing, and had already launched a family of interface boards which would connect the Apple directly to sensing devices and other lab equipment. For the NASA application, the Apple added up to a single device that could function as both a development system and as the eventual experiment controller itself.

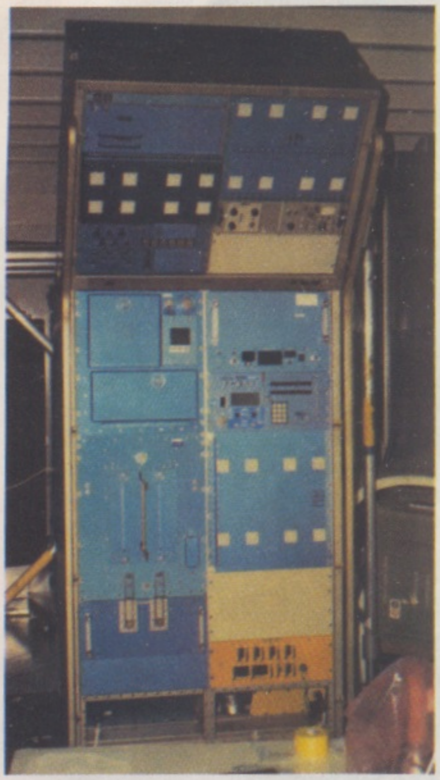
In addition, it was off-the-shelf, readily-available technology, just the type NASA was eager to show in use aboard the shuttle. An Apple II-based system became the experiment controller for the project.

The System

The system has a tough assignment. The hardware houses a stationary plant growth station and two miniature rotating precision centrifuges which will spin some of the plants and selectively re-create a gravity-like force (Fig.1). The speed of rotation must be held constant, since it will generate a force of 1 g. The motor selected will accept an eight-bit number from the controller to determine speed, and also return a series of pulses which the controller can monitor to verify that the speed has reached the requested value. These signals are interfaced using the company's bidirectional DI09 digital interface (Fig. 2).

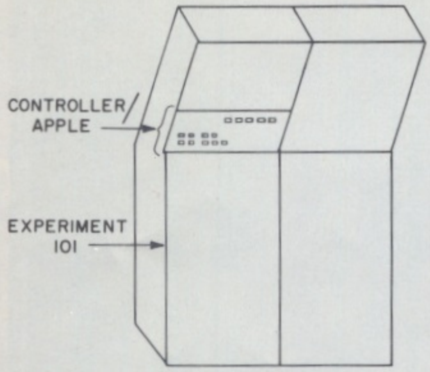
Three video cameras will collect pictures of the growth at regular intervals. Solid-state CCD array cameras were chosen since they are light, compact and sturdy. Infrared lighting will minimize any stimulus to the plant. The equipment will switch on only while recording to conserve power. The project decided on a conventional video cassette recorder, interfaced through its remote-control facility. The controller will select a camera and request a recording, and a modification will allow it to monitor the current in the recording head to verify that recording was taking place. The DI09 will switch cameras, recorders and lighting.

Temperature has to be monitored



Spacelab Experiment 101 enclosure, processor and AI02 interface.

and regulated so that it will not be a factor. A complete closed-loop temperature regulation system was designed for the three plant-growth areas. An integrated circuit temperature sensor in each chamber will produce a linear range of analog voltage indicating the temperature. Here, Interactive Structures used its AI02 analog input system to provide multiple channel analog-to-digital conversion (Fig. 3). The firmware will check the temperature against



Schematic of Experiment 101 photo.

the allowable range and control heating panels accordingly.

Certain operations, such as getting new plants from storage and inserting them into holders in the rotor, will be done by the operator, the onboard payload specialist (PS). The PS will use a front panel with indicator lamps for each of the controlled portions of the system to display experiment status and allow him to enter instructions. Membrane switches allow the PS to enter requests and acknowledge instructions from the controller. Here again, the bidirectional DI09 will handle both the lamps and the buttons with a single card.

Temperatures, speeds, video system operation and the PS's actions are to be logged for analysis after the experiment, so the experiment needs a one-way communication link. The project will use the shuttle's on-board remote acquisition unit (RAU), essentially another computer devoted to managing communications between the experiments and Earth (Fig. 4). The predefined format for communications is a serial scheme, clocked by a 1 MHz signal from the RAU, transmitting a burst of 16 16-bit words at a time. Here a special Apple interface is necessary and will include the buffer for a complete burst of data, and the control circuits to request a transmission using the RAU.

Time will be extremely important, since the growth of the plants is slow and the time in orbit is limited. (Sometimes more limited than expected, as in the second flight of the Shuttle.) The experiment therefore will need every minute, even if the system's 28-V power goes off accidently, and even during the reentry free-fall time when power will be turned off intentionally. Both space and weight are limited, and the essential components (camera, lights

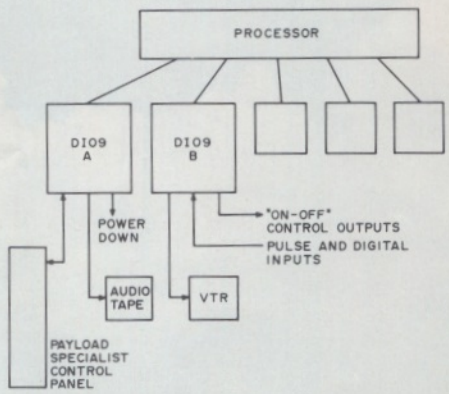


Fig. 2. Digital interfacing for the experiment.

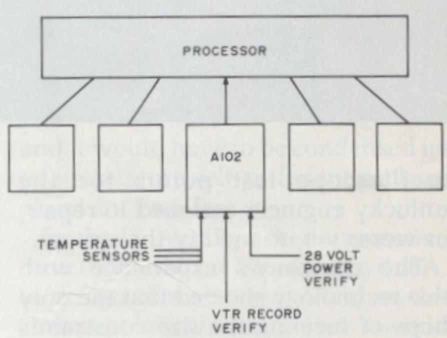


Fig. 3. Scheme of analog data acquisition from the experiment.

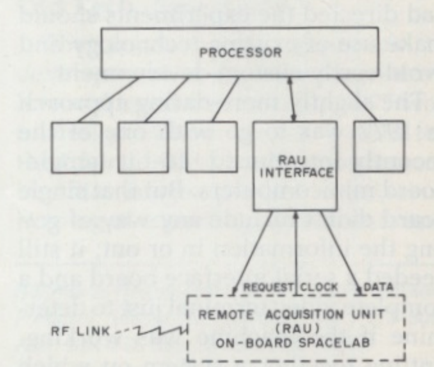


Fig. 4. Apple to Earth communications system.

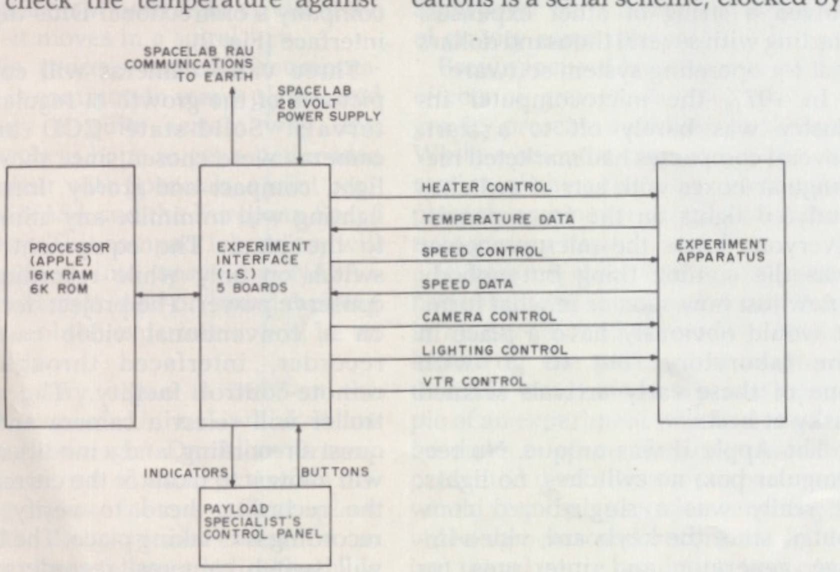
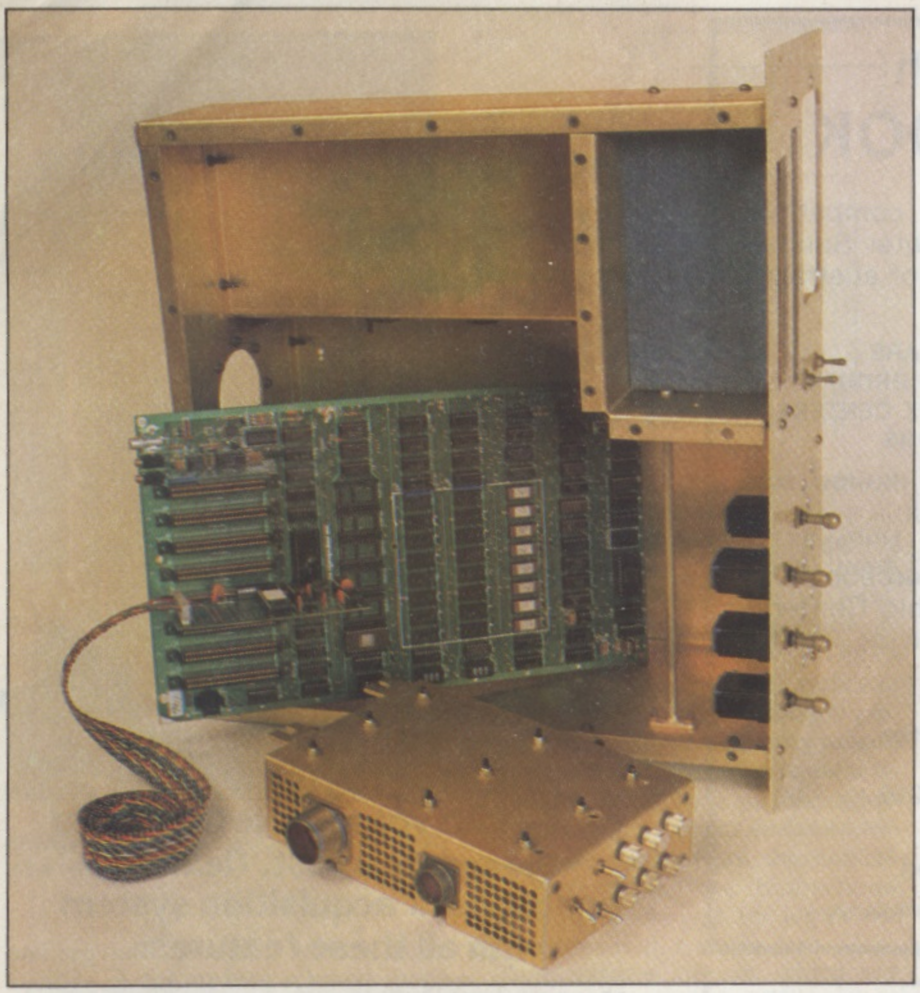


Fig. 1. Block diagram of the Space Shuttle experiment configuration developed by Interactive Structures.



Interactive Structures' DI09 bidirectional digital interface and AI02 analog input system used in Experiment 101.

and recorder) also use the most power, so a simple reserve battery system was not feasible.

The experiment therefore was designed with a special battery backup system which includes its own alarm clock (Fig. 5). This clock can power the entire experiment down for ten minutes, then power up and record video data, power down again, etc., with a resulting power savings of 10-to-1.

Packaging

Of course, the packaging of the system also needed some attention. The experiment is rack-mounted, so a metal enclosure was needed (Fig. 6). The vibration levels during lift-off and re-entry dictate that all connectors and plugs be held together firmly; all unnecessary connectors such as (you guessed it) IC sockets are a no-no. Also, in the absence of gravity, dirt, liquids and even metal particles may be found drifting through the air, so each and every exposed circuit element is coated with an insulating film. An entire custom-constructed Apple was created.

The project progressed, and it was time to test the Apple RAU interface. However, the RAU itself was still under construction in France, so an actual test was impossible. Interactive Structures pressed another Apple into service and outfitted it with an interface card which simulated all the timing and signal levels of the RAU. The RAU simulator (SRAU) would play the part of the shuttle's communications system and verify that Experiment 101 was transmitting information properly.

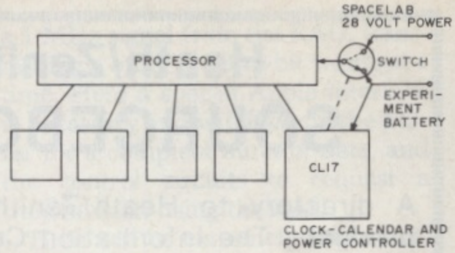


Fig. 5. Clock, power down and wake up system.

The payload specialists will play an important part in the experiment, since they are responsible for an extensive detailed script of all events during the seven-day mission. They will certainly be able to refer to the script as they use it, so memorization was not necessary. However, efficiency and accuracy were critical to the success of the mission. The project needed a training program so that realistic trial-runs could be made. Interactive Structures interfaced yet another Apple to a simulated front panel using DI09s, and developed software to conduct the trial-runs and watch for digressions from the script.

The experiment controller system underwent a series of functional tests (to verify that it managed the experiment properly) and environmental tests (to be sure it could withstand space flight conditions, mainly vibration and temperature extremes). Having passed all these tests, it now awaits a 1983 voyage. The combination of Interactive Structures interfaces and Apple microcomputers produced such a comprehensive instrumentation, testing and training capability at such a low cost that the same approach is now being considered for several new Spacelab experiments.

Conclusions

If we ignore the special preparations necessary for space flight, the experiment controller is not an unusual laboratory Apple installation. Interactive Structures interfaces are being used to make Apples into vibration monitors, chemical

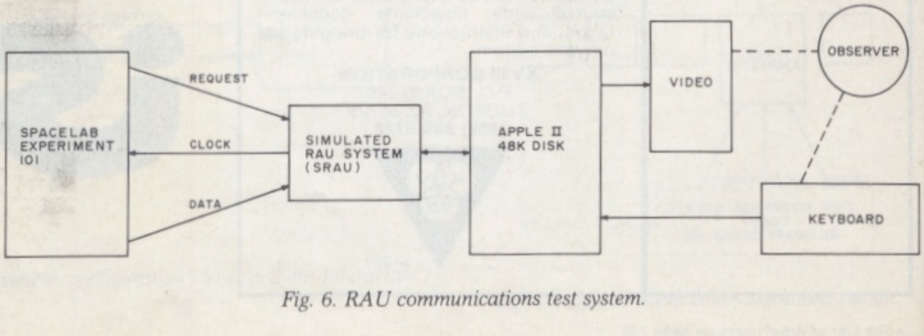


Fig. 6. RAU communications test system.

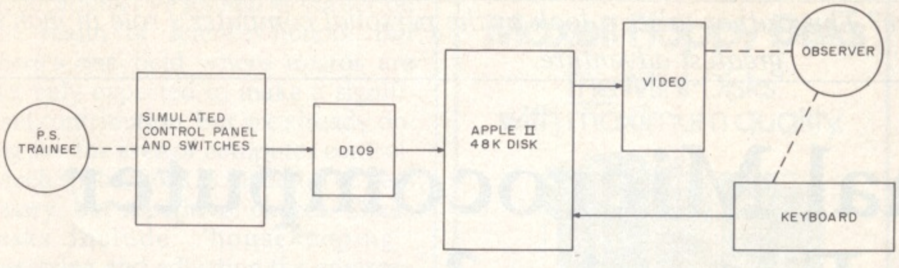


Fig. 7. Payload specialists' training system.

analyzers and temperature controllers, with new applications being added to the list daily.

The components are low in cost. They are modular so capabilities and expenditures expand only where needed.

For example, the AI13, a 16-channel, 12-bit analog data acquisition system which allows the software to independently select the input range for each reading, is now available from stock for $550. The DI09, used extensively in the experiment controller, provides 32 lines of digital I/O, plus eight other lines for handshaking, for $330. Apple Computer now offers an IEEE-488 interface card, and other companies are beginning to enter the Apple-based lab system market.

If the microprocessor was the first chapter in the story of the low-cost techniques which have been "spin-offs" from the space program, then laboratory and scientific capabilities for personal computers may be the second. Just as the microprocessor has brought the cost of computation out of the $10,000-and-above range, these interface modules allow all but the most unusual measurement or control applications for significantly less than $1000.■

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