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SPACELAB DATA ANALYSIS AND INTERACTIVE CONTROL STUDY

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ABSTRACT

Personnel of the Lockheed Palo Alto Research Laboratory have performed the Spacelab Data Analysis and Interactive Control Study under contract to the Spacelab Payload Integration and Rocket Experiment (SPIRE) Project of NASA's Goddard Space Flight Center. The study consisted of two main tasks, a series of interviews of Spacelab users and a survey of data processing and display equipment. This final report presents findings from the user interviews on questions of interactive control, downlink data formats, and Spacelab computer software development. Equipment for quick-look processing and display of scientific data in the Spacelab Payload Operations Control Center (POCC) was surveyed. Results of this survey effort are discussed in detail, along with recommendations for NASA development of several specific display systems which meet common requirements of many Spacelab experiments.

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1.0 INTRODUCTION

In March, 1978, Lockheed Palo Alto Research Laboratory (LPARL) completed a study on data analysis and display requirements for the mature Spacelab era. More specifically, the issue was real-time and quick-look requirements for scientific data in the Spacelab Payload Operations Control Center (POCC). The technique used was an extensive series of interviews of scientific users of Spacelab. The major result of this survey was that many experiments in different disciplines of space science shared common requirements for data display and processing in the POCC. A blend of ground support equipment supplied by the experimenters (EGSE) and NASA-supplied standard services was recommended. Specific common requirements and general software and hardware approaches to meet them were listed.

Since that report was submitted, the standard services to be supplied by the JSC POCC have become better known. Since they do not meet a large number of the common requirements discovered previously, the need for more careful study of the GSE option became apparent. The Spacelab Payload Integration and Rocket Experiments (SPIRE) Project of Goddard Space Flight Center funded this follow-up study to examine this option. In particular, the use of NASA-supplied GSE (so-called shared or common GSE) to meet common requirements was a possibility to consider.

The present study began in February, 1979, with a clearly defined set of tasks and objectives. The prime task has been to evaluate data analysis and display equipment of potential utility in the POCC. This evaluation has covered: software and hardware; commercially available components and integrated systems at scientific institutions around the country; existing equipment and also technologies in development which will be available in the mature Spacelab era. The study has been performed by Lockheed scientists familiar with Spacelab, in consultation with the larger community of Spacelab users. A key feature of this survey was the actual testing of existing systems using scientific data similar to that which will be generated by Spacelab experiments. As a result of this survey, five potential common systems have been designed and costed at the block diagram level of sophistication; three of these are recommended for immediate development by NASA. In addition, a few areas where further development is needed to meet all of the common requirements have been identified.

A secondary purpose of the study has been to establish the users' requirements for interactive commanding of Spacelab experiments by POCC personnel. The two-way interaction between needs for real-time displays and desires for interactive control capability surfaced in the previous study. Many scientists assume they will have complete control of their instrument from the POCC, whereas the NASA standard systems expect greater reliance on the payload crew, Spacelab computer, and experiment microprocessors. A modest survey of Spacelab users to elucidate this matter further is part of the present effort. An extension to the original contract added consideration of some related command and data handling issues to the survey task. These matters are: the proposed packet transmission format for the Spacelab High Rate Multiplexer (HRM) downlink; the development of Experiment Computer Applications Software (ECAS); miscellaneous matters regarding Spacelab 1 and 2 data flow and the SPIRE Project information system. Findings from the scientific user interviews are presented in this final report.

2.0 SPACELAB SCIENTIFIC USER INTERVIEWS

2.1 Results of the Previous Study

The Spacelab era opens new vistas for scientific research and simultaneously presents challenges to the traditional means of performing space experiments. Multi-center interaction will increase significantly and multiple experiments from different disciplines will share a given flight. Experiment control will be split between Payload Specialist Control, Payload Operation Control Center (POCC) control, and autonomous control by dedicated processors within the experiments.

The potential exists for the possibility of a POCC for one flight containing many experiments (10 to 20) of diverse nature followed in a few weeks or months by the next flight consisting of entirely different experiments. The support provided by NASA in the POCC and the means of providing this support could vary over wide ranges. One means of attacking this problem consists of identifying functions within the POCC which are limited enough in scope to be tractable and pursuing those functions in a logical manner.

A set of functions, real-time scientific quick-look data analysis and display, was so identified by the Spacelab Payload, Integration, and Rocket Experiments (SPIRE) office. The approach chosen was first to establish requirements and ascertain the commonality of requirements with the possibility of NASA-supplied common hardware/software systems being provided to satisfy common requirements. Next, a trade and system study would be undertaken to prove the technical feasibility and to define better the cost of some Nasa-supplied common systems. Finally implementation of a common system would occur.

The first study (referred to henceforth as the previous study) on requirements was completed in March 1978 and will be summarized in this section. The second step regarding system feasibility and cost is the current study for which this is the final report.

The previous study covered four disciplines for which GSFC had mission management responsibility: Ultraviolet (UV)/Optical, Solar/Terrestrial, Atmospheres, Magnetospheres, and Plasmas in Space (AMPS), and High Energy Astrophysics. An Applications study final report was also included. Experimenter groups were visited, the experiment discussed and the status of the experiment at that time established. Spacelab 1 and 2 proposals, OFT proposals, and the Instrument Control and Data Handling Working Group (ICDHWG) were used as sources of experimenters to include. A mature, all-up Spacelab operation was to be considered. Selection of experimenters was attempted to lean toward experienced space experimenters. A total of 26 experiments were included in the study.

The information obtained from the experimenters defined the experiment data rate, the display update rate desried, the display devices required, the data processing required to drive the display, and the purpose or use of the display. The results of this survey for each of the experiments in the four disciplines is given by discipline in Appendix A. A summary of the requirements for each discipline was then prepared. From that a summary of requirements for all 26 experiments was prepared.

The results were that the data could be broken into four categories: analog, serial digital, analog video, and digital image data. The vast majority of the data consists of digital image data. Common processing requirements which were established for serial digital data included engineering conversion, addition or subtraction of spectra, background subtraction, integration of one channel with time, intensity versus time, curve fitting, peak and average signal, calibration, and statistics to determine signal-to-noise values.

Common processing requirements which were established for digital image data includes multi-image arithmetic, statistics (histograms, mean value, standard deviation, power spectrum), background subtraction, gray level compression, stretch, clip, geometric distortion removal, radiometric calibration, and image storage. For analog video data, scan conversion is required for non-standard TV.

Common equipment requirements include standard, color, and high-resolution TV monitors; monochrome, color, and high-resolution CRT's; oscilloscopes; scan converters; video tape recorders; storage scopes; and hard-copy units. These pieces of equipment in several representative POCC configurations were presented. Specific equipment identification and compatibility are performed in the present study.

Not all the potential common hardware and software was recommended for NASA development as shared GSE. A distributed processing approach was recommended which can be gradually developed in modular form and inserted into the POCC. In this way, one small system could be developed, used and later expanded or upgraded when technologically superior equipment is produced. These modular systems would be developed in close association with the experimenters and using equipment with which the experimenters are familiar.

Several special problems were uncovered in the previous study, some of which are included in this present study. A video uplink capability was requested. A full parallel control concept was endorsed by most experimenters. Parallel control consists of having control capability over the experiment frcm both the AFD and the POCC, in a parallel manner; a block diagram would show two equal control modes. Full parallel control then is having equal control from either position; one position (POCC or AFD) does not have a significantly different control capability. Closely associated with this is the experimenter's desire for interactive pointing control from the POCC. Consideration of interactive pointing control from the POCC is included in the present study. Fast Fourier transform capability was regarded as a unique requirement for an initial NASA standard system but is discussed in more detail in the present study. High-speed multi-frame digital image memory is an area in which technological advancement is necessary; its current progress is discussed in this present study.

2.2 Interview Approach

This study is a logical continuation of the previous one. One task is a modest effort to continue the user interviews which formed the entire substance of the previous one. Experimenters from Spacelab 1 and 2 experiments and authors of proposals for future Spacelab flights were interviewed. Unfortunately, the interview effort was largely completed when a new set of investigators was announced in September, 1979. It was found that these new investigators were not familiar enough with Spacelab systems to respond to some of the more technical questions at issue. In addition, the Investigator's Working Group meetings for Spacelab 2 were attended, and MSFC and JSC personnel working on command and data handling were contacted. LPARL personnel also met with the Spacelab 2 payload crew. Appendix B lists the users interviewed.

The question list used in many of these interviews is given in Appendix C. In actual practice, this list was used as a general basis for the discussion, not as a rigid checklist. Some questions or whole categories were completely irrelevant to some experiments. In general, the experimenters were cooperative and freely volunteered suggestions for improvements to Spacelab.

2.3 Findings on Interactive Control

Sources of control for Spacelab experiments include crew members on the Aft Flight Deck (AFD), investigators in the POCC, stored time-based commands in the Experiment Computer (EC), and software in a dedicated experiment processor (DEP). In this section, the issue is control by POCC personnel and, more specifically, interactive control. This can be defined as control by sending multiple commands which are selected on the basis of data received from the experiment in real time. The link between interactive control and the rest of this study is made clear by this definition: Interactive control is impossible without the proper real-time displays.

Before the interview findings are discussed, one fact should be made very clear. Every experiment which was surveyed has an on-board DEP on some sort, and every investigator plans to have a minicomputer system in his EGSE in the POCC. These minicomputers are usually of the same family as the DEP, and they are a major factor in anv consideration of POCC operations. It is only a slight exaggeration to say that experimenters would like to do all data analysis, display and commanding using these familiar computers, in whose software they have made a major investment.

In the interviews, a wide variety of interactive control requirements have been stated. Some control functions can only be done by the crew (initial deployment of the Instrument Pointing System--IPS--or of a subsatellite, for example). Others can only be done by the POCC personnel; typical reasons are that the correct plan of action can only be determined by specially trained observers or after extensive data processing which is not available onboard. A common requirement is for parallel control: Crew control is preferred, but when the crew is not available, POCC personnel can take over. Although the operations may be limited somewhat with POCC control, the alternative is lost observing time. Another scenario for parallel control is to let the crew initiate an experiment and then turn control over to the POCC for intermittent maintenance or modification of the observing sequence.

In the previous study, the need for interactive pointing control was voiced by many investigators in each of the four disciplines. It was one of the stated purposes for most of the video displays requested, and TV cameras dedicated solely to this function are included in many experiments. In the more recent interviews, interactive pointing control from the POCC is still desired, even though investigators concede that it may not be possible with the present uplink. Three reasons for POCC control (as opposed to exclusive crew control) of pointing are: (1) to choose targets of interest at the beginning of an observing sequence; (2) to change targets during an observation when data analysis reveals a particularly interesting feature for additional study; (3) to monitor and correct pointing drift routinely when the crew is busy with other duties. The first two reasons derive from the special training of POCC personnel and the more informative displays available to them. Reasons (2) and (3) indicate the desire to make most efficient use of observing time even when the crew is not available.

The investigators' perception of the present command uplink is that it can't support the requirements for interactive commanding. Specific complaints about it include the following. The availability is not predictable because of STS priority. When payload commanding is allowed, it is too slow because of the manual authorization required before a terminal is enabled to send commands. Commands are not queued or pipelined automatically, reducing throughput by a large factor. If several experiments need the uplink at sunrise and/or sunset, the low rate will waste potential observing time. Command loads can't be built in an EGSE computer terminal; this makes DEP debugging very difficult and DEP reloads effectively impossible. Whether or not all of these criticisms are well deserved, they represent the experimenters' low opinion of the uplink capability.

On Spacelab 1 and 2, experimenters are reducing their plans for full parallel control because of their opinions of the uplink. One reaction is to automate more control functions: This means more DEP memory and software. The extent of automation is quite remarkable in some cases; the article by Westerhout (1974) on "the ideal automated observatory" is valuable reading on this matter for both scientists and engineers. Experimenters are also planning more reliance on directing the crew using the voice link. Plans for reaction to targets of opportunity are being shelved in some cases.

Naturally, suggestions for improving the uplink capability have been made in the interviews. One is to use the voice link for sending data from an EGSE minicomputer to a DEP by installing modems at both ends. Another is to implement an automated command queue in the POCC computers, so that a string of commands can be entered into memory; then they can be sent by the computer at the maximum possible rate, without delays caused by cumbersome manual procedures. A serial data link between EGSE terminals and POCC commanding terminals is also a common request.

The MSFC personnel working on POCC operations suggest some compromise solutions to alleviate the uplink problems. The concept of building command loads in an EGSE computer and transferring them to the POCC terminal on a floppy disk has been accepted as a requirement. Software to solve the disk format compatibility problems for the common types of EGSE minicomputer would be a significant contribution. Clever command structures and proper design of the commanding display pages, with emphasis on human engineering, are also needed to make most efficient use of the capability available. Multiple commands can be predefined and then sent with virtually no delays. Telemetry data can be displayed on the commanding terminals, and some computational capability is promised. Working with the payload crew, MSFC personnel have previously done an outstanding job in streamlining AFD command procedures. They may yet show that the uplink is more powerful and useful than the investigators think.

2.4 Findings on HRM Packetization

The digital data link using the High Rate Multiplexer (HRM) is an essential Spacelab resource for many experiments in the space sciences. It provides the user an allegedly transparent channel for data transmission at rates up to 50 megabits per second. Most experiments use one of the 16 experiment channels which can support rates up to 16 megabits per second. Data sent over an experiment channel is recorded in the POCC and the GSFC Spacelab Data Processing Facility (SDPF), and it can also be furnished to EGSE in a POCC user room in real time. In addition, POCC decommutation equipment and computers can pick out a limited number of parameters from the data stream, process them, and display the results. The existence of this high-speed downlink makes the operation of digital imagery and interferometry experiments conceivable. The real-time channel to EGSE makes their operation reasonable, by enabling quick-look processing and display of large volumes of data.

The HRM downlink is designed to operate without placing constraints on experiment data formats (MSFC-STD-630). However, if decommutation and display by the POCC computers are desired, then a set of format constraints must be met, dictated by the decommutation hardware and software. A similar (but somewhat less restrictive) set of constraints is required on (at least) the first three Spacelab missions for compatibility with Level IV Integration equipment and with the SDPF at GSFC. Basically, these format requirements configure the downlink as a conventional time-division-multiplexed (TDM) system. This means that the data stream in one HRM experiment channel is organized into major and minor frames synchronized to an external clock. The major frame consists of a fixed number (between 4 and 256) of sequentially labelled minor frames, each of identical length (between 56 and 8192 bits). Some details of sync patterns, major and minor frame labels, and time codes are also specified. If POCC processing is desired, then the words to be processed must appear periodically in the data stream; the frequency of occurence must be an integer multiple of the major frame frequency. Thus, although each investigator has considerable freedom in constructing his major and minor frame formats, the system is best suited for instruments which generate data steadily at a predictable rate.

The packet telemetry approach has been developed by GSFC and JPL personnel as an alternative to the TDM mode described above. It is intended to provide more flexibility and convenience to HRM users with minimal impact on POCC hardware and software; its use is also expected to simplify the task of the SDPF. In the packet mode, the instrument creates variable-length source packets instead of fixed-length, periodic major frames. The length and content of each source packet can be defined in real time by the DEP; thus, the state of the instrument determines the amount and nature of data telemetered at any time. Header words in the source packet give its length and format label so that ground processing equipment can handle it accordingly. For the purposes of transmission, each source packet is incorporated into one or more fixed-length transport packets (similar to the minor frames of the TDM mode), with proper header words for the HRM downlink.

Beyond the variable length and format advantages, the packet approach is intended to simplify post-flight processing and speed data distribution to the user. These benefits can be realized if each source packet contains all scientific, engineering, and ancillary data required for its analysis. The proposed format includes a secondary header for ancillary data acquired on-board. Alternatively, utility packets of ancillary data could be inserted into the data stream periodically by the experiment computer; these would be delivered to each user along with his own source packets. Eventually, the source packet is seen as a standard format for data transmission in all phases of mission activity before, during and after the flight. An interesting discussion of packet communications in a broader context is given by Kleinrock (1978).

The Spacelab users contacted for this study have discussed their use of the presently available HRM formats and, in a general way, the effects which a packet approach might have in the future. Spacelab 1 and 2 experiments have tailored their data streams to fit major and minor frame requirements with usually minor inconveniences. Generally, those experiments which generate scientific data at a steady rate during operation are quite satisfied. At least two experiments have invented their own packet mode: a single major frame format may contain scientific data, engineering data, or DEP memory dumps under DEP control. These users concede that a NASA-supported packet mode would probably be more convenient, but they are rather apathetic about the matter. For other experiments, the scientific, engineering, and ancillary data are interleaved in a constant data stream format. Since every experiment has a DEP and most communicate with the experiment computer to get ancillary data, this merging causes no significant problems.

Two experiments which produce data asychronously, in randomly occurring bursts, have experienced slightly more serious problems with the TDM mode. Both are forced to downlink large amounts of fill data when no scientific data is ready for transmission. Ground processing and recording equipment can recognize and ignore major frames labelled as fill, but engineering data in these frames is lost. If the engineering data is desired, then an occasional frame of fill must be labelled as real data so it can be recorded. This inefficiency could be avoided with a packet format. Furthermore, when scientific data becomes available on-board, it can't be transmitted until the next major frame frame begins. This problem is solved at the expense of another full-frame buffer (128 kilobytes) in the instrument.

None of the Spacelab experiments contacted has problems with the size limitations on major and minor frames. However, when larger solid-state imaging arrays become widespread, digital images containing more than 2 megabits will be generated. In particular, there is no doubt that focal plane instruments on the Solar Optical Telescope (SOT) will produce images larger than the upper limit for major frames. The implications (if any) of this are not yet clear.

Finally, several users expressed very strong complaints about one feature of the HRM downlink unrelated to data formats or packetization. This feature is the restriction of the composite digital data rate to 2 megabits per second when analog TV is also transmitted. The AMPS experiments on Spacelab 1 and the solar experiments on Spacelab 2 would like to operate their TV cameras and digital diode-array cameras simultaneously. The difficulty and data loss involved in changing HRM formats precludes the possibility of rapid switching between analog video and digital modes. An obvious solution to this conflict, a video digitizer, is discussed in Sections 3.4 and 3.6.3.

2.5 Findings on ECAS Development

The Experiment Computer (EC) is a MITRA-125 general purpose computer on Spacelab. It is the main link between crew and POCC personnel and experiment hardware. For many command, display and data management functions, the standard features of its operating system (ECOS) are sufficient. For more specialized requirements of an individual experiment (or a small group), modules of application software (ECAS) must be written and integrated into the complete software load for the mission. It is reasonable to expect that a library of ECAS module will evolve, that ECOS will absorb some of the more popular ones, and that the dividing line between ECOS and ECAS will always be shifting and somewhat uncertain.

The question under consideration here is whether the experimenter prefers to develop his own ECAS or to specify it for development by the integrating contractor. Conditions are: (a) that if he developed his own software it would be in a high-order language (such as FORTRAN); (b) he would be supplied a convenient and accessible means to debug his software (equivalent to a telephone link to an EC or good simulator); (c) he would get extra funding for the extra effort.

The general consensus among the experimenters is to make as little use of ECAS as possible. For those cases where ECAS is unavoidable, the large majority prefer that it be developed by the integrating contractor and not by the experimenters. Following are typical objections to experimenter development of ECAS:

- o High-level language is not always suited to this task.
- o The experimenter's software people are busy with the DEP. It would be preferrable to use an ECAS expert who could devote full time to the Experiment Computer to obtain the best code.
- o The Experiment Computer is a Spacelab resource interacting with many experimenters. Its programming should be done by the integrator.
- o Even if the experiment had no DEP, experimenter would prefer to have the coding done by a NASA/Integrator software specialist with close supervision by experimenter.
- o Experimenter does not want to spend time learning the internal details of the ECOS required to write working ECAS.

o Even if access to a MITRA-125 or simulator were provided for purposes of debugging, the real operating environment for ECAS would not be seen until every experiment had its ECAS debugged and running. A central contractor can anticipate this environment better than individual experimenters.

o Multiple experiments on the same mission can share ECAS modules for common requirements if they are developed by a contractor. In other cases, the purpose of the ECAS module is to analyze interactions among experiments (collision avoidance, for example).

o A central contractor can more easily develop software to satisfy mission requirements within the memory limitations of the MITRA-125. Experimenters would use too much memory for their individual desires.

o Finally, a noticeable paranoid reaction to this question by more than one experimenter should be mentioned. They feel that mission management is trying to unload a troublesome task onto them. Because of the difficulty in estimating software costs for an unfamiliar computer system, they are not convinced that sufficient funding will accompany the responsibility.

On the positive side, one experimenter would prefer to write an ECAS module which performs complicated numerical processing of data. However, the general conclusions from these findings are clear. Maximum use of ECOS and DEP software to avoid ECAS can ease the tasks of specifying and writing ECAS modules. When neither of these alternatives is viable, the experimenter should provide detailed requirements for each ECAS module to the integrating contractor. These requirements should include descriptions of the input data needed, computational algorithms, and output results. The algorithms should be described in a form equivalent to detailed flowcharts, so that they can be faithfully coded by a contractor who is not an expert in the experiment's internal details.

3.0 DISPLAY EQUIPMENT SURVEY

3.1 Survey Approach

The previous study showed that a large body of display and processing requirements are shared by multiple experiments in the four disciplines considered. It sketched in very general terms some of the software and hardware components which can meet these common requirements. The main task of the present study is a direct continuation of this initial attempt to recommend equipment of broad utility in the POCC. Two significant objectives are: (1) to provide critical descriptions of a variety of relevant display and processing components; (2) to recommend a number of integrated systems for development by NASA. To these ends, a survey of display equipment has been performed.

The survey effort has been organized by addressing a set of benchmark problems for each data type. The data types considered in the previous study are analog, serial digital (non-image), analog video, and digital image. For each of these, a set of benchmark display and/or processing problems is presented, based on the user requirements of Appendix A. Since the requirements are often vague, flexible, and somewhat variable from one experiment to another, these benchmarks are not as rigidly defined as the term implies in the computer sciences. On the other hand, the problems are representative and are not by any means least common denominators. In fact, several are chosen to push the state-of-the-art.

For each benchmark problem, operational systems around the country which meet some of the common requirements have been identified. The best way to evaluate a system for scientific data processing is to use it with real data. Therefore, a number of interesting and potentially useful systems have been visited and exercised, using real data insofar as is possible, to see how they perform on the benchmark problems. When this has not been possible, estimates of system performance on the standard problems are derived from discussions with scientific user and vendors, published system specifications, and engineering judgement. In this way, relatively objective measures of the strengths and weaknesses of each system for POCC use are made. Individual hardware and software components of particular interest are also evaluated. Since data processing hardware is improving so rapidly, some components which are still under development are considered.

Several assumptions and limitations of the survey effort also deserve mention. The study is limited to real-time and quick-look processing, display, and commanding functions and only considers the four disciplines studied previously. The approach is user-oriented, considering only scientific data. It is assumed that experimenters will have micro- or mini-computer systems of their own choosing in the POCC; factors affecting these choices will not be discussed here.

Detailed engineering designs and cost analyses of data processing systems are not made. Rather, emphasis is on existing systems which could be imitated in a straightforward manner and on individual components which could be integrated into a system without great difficulty. The recommended systems presented below are designed and costed at the block diagram level of sophistication. They stand as a menu of options for future NASA development as "common GSE." The alternative, of course, is to support each experimenter who shares the common requirement in the development of his own EGSE to perform the same tasks. The duplication of cost and effort implied in this alternative will be clear.

3.2 Analog Data

Analog data can be downlinked with a 4.5 MHz bandwidth. Only one experiment in the previous study indicated use of this data mode, not counting the requirements for analog video (i.e., live TV). Consequently this study does not regard this as a common requirement, and no further consideration is given to this data. It is presumed that it will be treated in Experimenter's Ground Support Equipment (EGSE), because POCC Standard Services do not include any recording or display capability.

3.3 Serial Digital Data

For the purposes of this section, serial digital data is limited to numerical scientific data, with the exclusion of digital images. Examples are the output of a spectrometer, a one-dimensional record of intensity vs. wavelength, or of a charged-particle detector, count rate as a function of time. The output of a scanning photometer could be considered here, if it were treated as a one-dimensional time series, or else it could be accumulated in a two-dimensional buffer memory and then displayed as a digital image. In general, the types of data for which this section is intended require simpler displays, smaller computer memories and less processing speed than digital imagery.

There are two important routes by which serial digital data reaches GSE in the POCC. First, an experiment with a dedicated High Rate Multiplexer (HRM) channel can receive this data stream directly from the High Rate Demultiplexer (HRDM) at rates up to 16 megabits per second. This link is supposed to be transparent to the user, so the data will appear in the format created by the on-board experiment. The second route is via the Experiment Computer I/O channel (ECIO). ECIO data for at most four experiments can be stripped out of the composite stream by the POCC computer. It is sent to GSE in formatted blocks at a specified rate. Although a bewildering variety of other channels are described in the POCC documentation, these two seem to be the most promising for scientific data.

Two benchmark problems have been chosen: interactive plotting and fast Fourier transforms. The former is an obvious choice because most experiments require it in some form and because the display technology has made great advances in recent years. Section 3.3.1 is a tutorial essay explaining the different basic approaches and options found in the immense selection of commercially available graphic display terminals. Fast Fourier transforms were only required by three experiments contacted in the previous study. Although this may not be a genuine common requirement, it has been selected for study as an example of intensive numerical computation necessary for quick-look evaluation of scientific data. The speed requirements exceed the ability of most general purpose computers, and so Section 3.3.2 focuses on array processors as a low-cost source of extraordinary computational power.

3.3.1 Interactive Plotting

The benchmark problem to be solved for interactive plotting involves plotting simple graphs of up to 10,000 data points in a response time of 10 seconds. Multiple graphs must be displayed simultaneously. Interactive control is required over the plotting format, data selection, and graph position on the display. There must be a user-assisted curve-fitting capability available which uses a cursor, trackball, or similar input device to select data or data segments to be curve-fit. Software or firmware must be available to produce statistical analyses, such as on time-series data. Similarly a data-set comparison capability must be provided as well as the ability to recalibrate data through a look-up table or polynomial conversion. Data-set comparison refers to the ability to present simultaneously on the same display two or more data-sets distinguished by separate curves, graphs or by different symbols. Finally the capability to produce a hard-copy of the display presentation is needed.

POCC Standard Services do not meet most of these requirements. Real-time plots of a parameter vs. time or vs. another parameter are possible on the POCC computer displays. These displays lack most of the interactive features required and appear to be more useful for engineering rather than scientific data. Near-real time graphics capability on POCC computer displays is TBD. Only GSE will be considered below.

The hardware necessary to satisfy the benchmark problem consists of: interface to the HRDM or to the POCC computer; microprocessor or minicomputer system; keyboard; hard-copy unit; graphics display terminal.

The interface to the HRDM or POCC computer will be custom designed and produced. This hardware (with software drivers) will be dictated once the GSE computer and graphics display terminal are chosen and either the HRDM or POCC computer is selected as the data source. If the HRDM is used, this interface will also be needed for integration and testing, since the HRM downlink is a transparent communication channel. An interface with the POCC computer will probably not be used elsewhere. If a significant number of experiments need them, duplication of effort may be avoided if the mission manager develops these interfaces for the most popular varieties of GSE minicomputer.

The keyboard is a standard item which will be purchased with the graphics display terminal. The hard-copy unit will transpose the display information to a representation of the display on paper or film for permanent retention.

Graphics display devices provide the means to display data in a graphical form and also to manipulate and modify the data presented. In a computerized display the image on the display screen is formed in lines joining specified points in a matrix. The matrix is held in the computer memory with position coordinates corresponding to an overlay on the image display screen. Points between which the lines are drawn are under software control. Additionally, transformations, statistical treatments, conversions, and other processing may be easily and quickly applied to the data generally through software but in some cases through firmware. An excellent trade survey of graphics terminals is given in Datapro (1979). Also, see Machover et al. (1977).

Two types of display technology are currently in use: refresh technology or storage technology. Refresh technology produces a visible light display with a short duration (less than one second) for each visible point produced. Each point must be created (refreshed) many times per second to create a continuous, non-flickering image. Two types of refresh technique are currently in use: stroke writing and raster scanning. In stroke writing a line is drawn on the display screen by positioning the electron beam to connect the two end point coordinates of the line directly with the electron beam "on". In a raster scan system, the beam is moved over the entire face of the display (in a raster pattern) and turned "on" only when it crosses a point on the line. The raster scan system requires more memory space than stroke writing (a complete map of the display face in memory) but offers more versatility and flexibility.

Two types of storage technology are currently in use: storage tubes and plasma panels. A storage tube can store and display an image for several minutes without refreshing. Two electron beams are used: one to write and one to sustain the image. A plasma panel uses a matrix of electrodes within the panel's glass plate to position each element. Storage tube systems require erasing the entire image and then writing a new one, while lines or sections of a display may be selectively erased on a plasma panel.

The graphics display must be driven by a computer. In many cases the computer is internal to the display housing itself and so the system appears complete by itself except for data input capability (aside from keyboard entered data). Some displays are driven by minicomputers while others are run directly from a large, main-frame system.

Displays may be either color or monochrome. The primary benefit of color is contrast discrimination enhancement. This has two related advantages. First, a quicker association of information or recognition of data is possible with color. If all of one data type is r ;, for instance, the data type, as well as the data, will be immediately obvious upon glancing at the screen. Second, the operator can distinguish details in the data more easily. This reduces operator fatigue and increases operator accuracy (and reliability). This latter point is particularly important for control center applications as most control center and spacecraft control problems are due to human error.

A list of characteristics important to considering a graphics display device for a particular application will be defined and discussed below. Then tables showing several representative graphics display devices (including minimum, maximum, and intermediate capability devices) will be presented and discussed in terms of the characteristics defined.

There are four classes of charactoristics: Physical Configuration, Display Characteristics, Software Support, and Cost.

Characteristics included under Physical Configuration include the host computer, operator interaction, joystick, light pen, trackball, thumbwheels, hard-copy unit, and plotter. These characteristics are given in Table 3.1. The host computer refers to the principal application processing source. Operator interaction lists the types of devices available by which the operator may affect the display. These will include keyboards, function keys, joysticks, light pens, trackballs, and thumbwheels.

A joystick is a device similar in appearance to a large toggle switch which can be moved left/right and up/down. This movement causes a cursor to move in two dimensions on the screen. Thumbwheels can be used instead of a joystick but are less convenient. When a point is located on the screen, depression of a key causes the coordinates of that point to be transferred,

Physical Configuration	Tektronix 4010	Ramtek 6110	Lear Siegler, Retro-Graphics	Tektronix 4014/4015	Imlac Dynagraphic 3205	Ramtek 6310	IBM 2250
Host Computer	Remote via RS-232C or parallel to DEC, Nova, HP	Remote via RS-232C or freestanding	Remote via RS-232C	Remote via RS-232C or parallel to DEC, Nova, HP	Remote via RS-232C	Remote via RS-232C or freestanding	IBM 360/370
Internal Processor	None	Proprietary	Z-80A	None	Proprietary	Proprietary	None
Operator Interaction	Joystick, Keyboard, Thumbwheels	Keyboard, Function, Cursor, Joystick	Keyboard, Cursor, Function	Joystick, Keyboard, Thumbwheels	Keyboard, Lightpen, Joystick	Keyboard, Function Cursor, Joystick	Lightpen, Function, Keyboard
Plotter	Hard-copy unit; plotter optional	–	–	Hard-copy unit; plotter optional	Tektronix 4662 Versatec	–	–

Table 3.1 Physical Configurations of Graphical Display Devices

indicating "do it here" to the system. A light pen performs the same function: the operator merely points to the desired location on the screen with a pen-like object. A trackball looks like a billiard ball in a bowl; when it is moved with the palm of the hand, a cursor moves on the screen. Sometimes the speed of the cursor is sensed in addition to its location, providing another dimension of control.

The hard-copy unit reproduces the image on the display screen on a permanent storage medium, usually paper. These devices may be purchased with the display device or bought separately and interfaced to the display device. The most common hard-copy technology is electrostatic printing. Other technologies employed include thermal, ink-jet, electrophotographic, film, impact printers, and pen plotters. A good summary of hard-copy technologies is given in Dawes (1979).

Display Characteristics, given in Table 3.2, include the viewing area, addressable and viewable matrices, window, maximum number of symbols displayable, and color. The viewing area specifies the size of the display screen, The addressable matrix specifies the number of points in the logical image whereas the viewable matrix is the number of points which can actually be displayed at one time on the visible screen. The logical image may be larger than the viewable image in which case the viewable image is seen as through a "window" to the logical image.

The performance capability of the display device is addressed in the maximum number of symbols displayable, which is a combined measure of the buffer space available and of the capability for a refresh-type tube to present elements without flickering. The entire image must be rewritten every 1/30 to 1/40 second or the display phosphor will decay to the point that the new image is noticeably brighter, resulting in a flicker.

Software Support, given in Table 3.3, identifies the existing software available to interface and drive the display device from a host processor. Residency specifies the location of the executing software. The source language entry provides an indication of the ease of modification and of the transportability of the software. At least three levels of software are required for graphical display of scientific data. The lowest level, often implemented in firmware, allows the host computer to write alphanumeric

Display Characteristics	Tektronix 4010	Ramtek 6110	Lear Siegler, Retro-Graphics	Tektronix 4014/4015	Imlac Dynagraphic 3205	Ramtek 6310	IBM 2250
Viewing Area, Inches	8.24 x 6.375	13	12 diagonal	11 x 15	19 diagonal	19	12 x 12
Addressable Matrix	1024 x 1024	320 x 240	512 x 250	1024 x 1024 or 4096 x 4096	2048 x 2048	1024 x 1024	1024 x 1024
Viewable Matrix	1024 x 780	320 x 240	512 x 250	1024 x 780 or 4096 x 3120	1024 x 1024	800 x 600	1024 x 1024
Window	–	Software offset	No	–	Via software	Pan 800 x 600 in 1024 x 1024	–
Maximum Number of Symbols Displayable Simultaneously	2590; more on request	3072	1920	8512; more on request	–	19,200	3,848
Color	No	8-color display, 2 tables	No	No	No	16 optional tables	No

Table 3.2 Display Characteristics of Graphical Display Devices

Software Support	Tektronix 4010	Ramtek 6110	Lear Siegler, Retro-Graphics	Tektronix 4014/4015	Imlac Dynagraphic 3205	Ramtek 6310	IBM 2250 Model 3
Residency	Host Processor	System Processor	Host Computer	Host Processor	Host Computer	System Processor	Host Processor
Source Language	FORTRAN, Assembler	COLOR GRAPHICS	Tektronix software compatible	FORTRAN, Assembler	FORTRAN	COLOR GRAPHICS	Wide range of software available from several sources
Engineering/Scientific Data Graphing Routines	Yes	Yes	No	Yes	Yes	Yes	Yes
Software Pricing	Separate	–	Separate	Separate	Separate	–	Standard and extra cost
Purchase Price	$4,950	$5,500	$2,120	$11,650 to $12,700	$14,750	$25,000	$34,830 up

Table 3.3 Software Support and Cost of Graphical Display Devices

characters at arbitrary locations and to draw vectors (line segments). One step higher in utility and sophistication is the set of system modules or subroutines known as the plot package. Each of these performs a single basic function in graph preparation such as defining a coordinate system, drawing borders and axes, plotting an array of data points, or writing labels and captions. These two levels of software are usually supplied by the vendor of the display terminal. The third level, integrated programs to plot given data records according to various options chosen interactively by the user, is almost always written by the user when scientific data is concerned. The detailed characteristics of the data, computer system, display terminal, and the user's taste generally require a custom-tailored program.

A range in technology, capability, and cost is shown in Tables 3.1, 3.2, and 3.3. The Tektronix 4010 is a storage-tube type display which is in wide use and is relatively inexpensive. The Ramtek 6110 is comparable in price but a more current refresh-type display having color display capability. The Lear Siegler is the most recent and cheapest entry shown in these tables, evidencing the decline in cost with time. It is actually a combination of a Lear Siegler ADM-3A terminal with the Retro-Graphics modification made by Digital Engineering, Inc. The latter provides plotting capability consistent with the Tektronix 4010 software. The combination makes a low-cost, portable graphics terminal nicely suited to testing and integration use in the field.

The Tektronix 4014/4015 and the Imlac Dynagraphic 3205 represent intermediate-priced displays of considerable capability. They are larger displays capable of high resolution. The Ramtek 6310 and IBM 2250 represent the upper end of display devices. The next step upward would be image processing systems which incidentally are capable of graphics display; these are discussed extensively in Section 3.5

It is clear that hardware and software exist to meet the requirements for interactive plotting. Most experimenters have some knowledge of the available technologies, and they can be expected to use them not only in the POCC, but also during instrument development, testing, integration, and post-flight data reduction. EGSE is the logical solution to these requirements.

3.3.2 Fast Fourier Transforms

Fast Fourier Transforms (FFT's) require a powerful number-crunching capability to be performed in a timely manner for control center applications. Several experiments require FFT capability. In addition, several other requirements such as image rotation and distortion removal may also benefit by use of the hardware designed especially for cost-efficient computational power.

For modest amounts of data (up to, say, 30,000 data points), a minicomputer can perform FFT's in a few minutes or less, if it is not busy with other tasks. If off-line processing of large amounts of data is acceptable, then the POCC IBM computers can be used, with time delays of an hour or more. Some interferometer experiments desire near real-time processing exceeding the capability of a minicomputer. Among the computer peripherals available today, array processors are the logical solution and are discussed in detail below. Other solutions of great promise (specialized single-chip FFT processors, surface acoustic wave devices, and optical processors) are being developed for military applications, and so considerable progress in the next decade can be expected.

An array processor is a computer peripheral which is designed to perform arithmetic operations at high speed on large arrays of numbers, such as vectors, matrices, or images. This device is used with a minicomputer to produce a system capable of large-scale scientific computation comparable to a large main-frame computer but at a fraction of the cost. This performance improvement is achieved through changes in the architecture of the array processor as compared to a standard computer. The improvements realized amount to an increase in processing speed of between 20 and 200 over the speed of the minicomputer alone.

The fundamental concept employed to achieve this improvement is parallel processing. In a standard computer, operations are performed sequentially and communications between various systems elements occurs over a single data bus. In the array processor, a multi-bus communication occurs and the systems elements perform their specific functions simultaneously, or in parallel.

Further improvements are additionally realized by techniques which become device specific (Hufnagel, 1979). Two array processors will be described in some detail as typical of the various techniques used. The two array processors to be used as examples are the Floating Point Systems AP-120B and the Computer Signal Processing, Inc. (CSPI) MAP-300.

A second form of parallel processing called pipelining is applied in the AP-120B. The basic arithmetic operations (addition, multiplication, etc.) are divisible into suboperations. In a conventional computer, all the suboperations to perform one operation must be completed before the next operation can be initiated. In the process called pipelining, the second operation is initiated when the first suboperation of the first operation is completed. The total time to add any two numbers is not decreased by pipelining, but the total throughput time when adding many numbers is reduced by an amount equal to the number of suboperations. A two-stage adder is used in the AP-120B so one cycle time is saved by pipelining.

The technique employed in the MAP-300 is asynchronous processing. The MAP-300 consists of two arithmetic processors, each controlled by its own microprocessor. The two microprocessors are run asynchronously from one another so that each arithmetic unit may be most efficiently applied to the arithmetic processing required. The two microprocessors communicate through a handshaking protocol and must be programmed independently and simultaneously. This allows the user to build an optimally efficient processing system but at the expense of considerably more complicated programming. The AP-120B is run in a synchronous fashion such that all conditions are known beforehand, such as the result of adding a number requires two cycle times from entry to exit from the adder. This greatly simplifies the programmer's use of the device but limits its ultimate efficiency.

Programming an array processor may be done in either assembly language or in a higher order language, usually FORTRAN. Programming in FORTRAN may be done in either of two ways. A FORTRAN compiler for the array processor may be used to program in a conventional manner; the compiler converts instructions into a parallel program in assembly language which can be executed in the array processor. The other approach is to write a program in the front-end computer in FORTRAN consisting of a series of calls to array processors math library. Large packages of FORTRAN-callable subroutines are supplied by the vendors for this use. It is considerably more difficult and costly to program the array processor in assembly language. The trade-off between the programming ease of FORTRAN and the running efficiency of assembly language must be made for each user application.

Interfaces to the common minicomputers and large-scale computers exist as well as direct interfaces between the array processor and a storage medium, usually disk.

For a FFT the processing time varies as N $\log_2$ N where N is the number of data points to be transformed. The time required to perform a 1024-point complex FFT is 4.8 milliseconds in the AP-120B and 4.5 milliseconds in the MAP-300. The AP-120B uses a 38-bit floating point data word of which 28 bits are the mantissa and 10 bits the exponent. The MAP-300 uses a 32-bit floating point data word consisting of a 24-bit hexadecimal mantissa, a 7-bit hexadecimal exponent, and a sign bit.

The computational efficiency improvement of an array processor augmented system is great, particularly when costs are considered. A minicomputer-array processor system is reported to be 100 times faster than the minicomputer alone (Robinson 1979). An array processor based computing system at UCLA was found to be 200 times more cost effective than an IBM 360/91. Costs for array processors typically range from $10 to 50 K, with a few more expensive (Caspe, 1978). Hundreds of array processors are being actively used today, with heaviest application in the fields of geophysical research and signal processing.

3.4 Analog Video Data

Three sources of analog video data in the POCC are potentially useful for displaying scientific data. The POCC closed circuit television (CCTV) network will broadcast any orbiter-compatible TV signal which is downlinked in the analog mode. This broadcast can be displayed on standard overhead monitors controlled from the POCC standard display terminal. As a second alternative, analog video downlink can be furnished to EGSE either as a baseband video signal or as a commercial RF (radio frequency) broadcast signal.

The analog downlink has a severe problem: When it is used, the digital HRM downlink is limited to a total data rate of approximately 2 megabits per second. Thus it is not possible to use a video image for pointing information in the POCC with a high-speed digital experiment (e.g., interferometer or imager) running simultaneously. This conflicts with stated requirements of several experiments contacted in the previous survey, and it has caused a great deal of trouble for mission planning and operations on Spacelab 2. If this conflict is not resolved, selection of future payloads in the four disciplines will be complicated greatly.

The third source of analog video presents the obvious solution. Digital images can be received in GSE from digital HRM channels and converted to analog TV in the POCC. Some experiments will use array-type digital cameras to obtain images of high sensitivity and large dynamic range. For such imagery, the digitization procedure, downlink formats, and digital-to-analog conversion (scan conversion) will be fundamental features of the experiment design; clearly, EGSE will do the job. Many other experiments, particularly solar and atmospheric instruments, will use commercial analog TV cameras, when these images are not the prime data of interest. Furthermore, the payload crew will often use analog TV displays for experiment control, and these are usually desired in the POCC also. In these cases, a video digitizer facility on-board is the simplest and most efficient answer to an obvious example of common requirements. Furthermore, such a digital link can easily be made to accommodate several channels to satisfy multiple simultaneous experiment operations.

Recording, display, and frame summation are discussed as benchmark problems in this section. The first two are inevitable, and the main issue to be resolved is the proper blend of POCC Standard Services, NASA-supplied common GSE, and EGSE to meet the common requirements. Frame summation is a more technical processing problem whose solutions provide a natural transition into the area of digital image data.

The terminology of video display systems can be very confusing to the user. Therefore, before the benchmark problems are discussed, this section gives a glossary. More details can be found in the IEEE Standard Definitions of Terms for Television (1979).

RF Video: radio frequency broadcast video, which must be demodulated from its high frequency carrier before display on the screen.

Baseband Video: the pure video signal without a carrier wave.

CRT: cathode ray tube, usually referring to a display screen used only for alphanumerics and graphics.

Receiver: a normal TV set, which accepts RF video.

Monitor: a TV display which accepts baseband video.

Composite Video: a signal which includes not only the picture intensity levels but also the horizontal and vertical sync patterns. Non-composite video is more convenient for analog signal processing, but an additional sync signal is needed for display on a monitor.

EIA Standards: Electronic Industries Association Standards for voltage levels and other details of the video signals. Standard RS-170 refers to monochrome television studio facilities. RS-330 defines "American standard video" for CCTV systems. It requires frames of 525 lines composed of 2 interlaced fields at rate of 60 fields (30 frames) per second. RS-343-A gives standards for high resolution video of 675, 729, 875, 945, or 1023 lines per frame.

Resolution: according to the standards, vertical resolution in pixels is roughly 2/3 the number of lines, or 350 for 525 line video. Horizontal resolution is proportional to the bandwidth divided by the number of lines. It is also about 350 for the orbiter standard of 525 lines and 4.5 MHz bandwidth.

Monochrome: black and white (BW).

RGB Color: three synchronized standard monochrome signals which control the red, green and blue intensities in a color monitor.

NTSC Color: a single color video signal compatible with monochrome or NTSC color monitors. This is less commonly used in display monitors than RGB color.

3.4.1 Recording

The basic requirement is the ability to record a standard video signal of indefinite duration and to play it back under user control. This requirement refers both to video received directly from the downlink and to regenerated signals created in the POCC by scan conversion or other processing. Some experiments can generate several channels to be recorded simultaneously. Single frame recording at a rate of one frame every 10 seconds or more is also desired. Lastly, playback should incorporate fast-forward and stop-frame options.

POCC Standard Services satisfy some of these requirements with their video tape recorder (VTR) facilities. All downlinked video is recorded and can be replayed on the POCC CCTV network. This replay may lack the required user control. Alternatively, the recorders can be set up in the user rooms; slow motion and stop-action capability is promised. If these recorders can accept video from both the CCTV network and from GSE scan converters, they they can fulfill most of the requirements. Clarification of the nature of the CCTV network and of the status of GSE-generated video is needed. Compatibility between POCC-supplied VTR's and users' equipment at their home laboratories is another possible problem; EGSE may be desired to guarantee playback capability after the mission.

If GSE recorders are desired, then cassette recorders (Mennie, 1978) represent a convenient, low-cost solution. The lowest priced cassette units intended for home entertainment may lack the image quality desired for scientific data. However, several vendors offer a complete line of industrial and professional studio quality recorders which should be adequate. If rigorous fidelity is required, then digital recording is more desirable anyway. As an example, the SONY SLO-320 Videocassette recorder costs $1500 and stores one hour of standard color video with approximately 300 x 375 lines of resolution (not line pairs). Image quality is noticeably better than that of a normal Betamax. Cassettes can be replayed on any Betamax compatible VTR. Although the two widespread cassette recording schemes are incompatible (the other scheme is called VHS), cassettes are generally more portable than reel-to-reel recordings.

Magnetic video disks are an alternative for low volume recording with better linearity and signal-to-noise ratio. These are most familiar as the slow motion replay units of commercial television. A typical unit holds 10 - 20 seconds of normal video or 300 - 600 frames. Reading and writing is under micro-processor control, allowing single frame recording, random access of stored frames, and external computer control, if desired. Unfortunately, the disk drive and writing head assemblies are very delicate mechanically, and their reputation for reliability is not good. Because of the critical alignment tolerances, removable disk packs are not available; thus, the capacity of one system is limited to that of its fixed platters. Prices start at about $20,000 for a 300 frame unit.

Optical disk systems for the home entertainment market have generated a great deal of publicity lately. Their advantage over VTR's is that disk copies can be replicated from a master version quickly and cheaply. No plans to market an inexpensive disk recorder are expected, and so they are not relevant for the POCC application. Digital video disk recorders are an exciting prospect discussed in Section 3.5.1.

3.4.2 Display

The basic problem is to display monochrome and color imagery on TV monitors. Standard and high resolution monitors are required. As many as four channels displayed simultaneously are required for a single experiment. On some missions, different experiments need to display each others' video signals; considering the shortage of floor space, cabling from one room to another may be required. Although standard video signals are used, the displayed images rarely change significantly more than once per second; for many experiments these update rates are even slower. Therefore, image storage and video regeneration (scan conversion) are needed. The only known requirement for full-speed (30 frame per second) video is to watch crew deployment of an experiment (a large telescope or subsatellite, for example) in a crowded shuttle bay.

To meet these requirements, a multi-channel downlink and a video distribution network within the POCC are needed. Since the multi-channel downlink must be digital, scan conversion is needed before video distribution. It may be done using an analog storage tube or a digital image memory.

The PEP 500 Lithocon Solid State Image Memory is an excellent, low-cost analog scan converter. One to four images are written on the tube using either digital image or analog video input at rates up to 1/30 sec per image. They are stored indefinitely, and an output TV signal is generated with user control of gray scale and zoom. The tube will also connect directly to a Tektronix 4010 or similar graphics terminal to permit annotation and overlays on the video image. Costing approximately $5000, this scan converter is well suited for GSE to support testing and integration as well as POCC operations.

Digital memories can also be packaged with sync generators and D/A converters for scan conversion. Colorado Video, Inc., offers a line of digital frame stores with various options. The model 270A Video Digitizer is the cheapest, at $4000 plus computer (or HRM) interface. The image displays discussed in Section 3.5 also perform this function.

After scan conversion, distribution of video to users throughout the POCC is needed. It it not known if the POCC CCTV network will support inputs from GSE. If so, it can help with room-to-room distribution; however, discussion with JSC personnel familiar with it do not inspire confidence. Thus, a GSE distribution network is probably required. It can easily be configured for each mission from a general supply of cables and video switches, both manual and remote control.

Finally, monitors are required for the actual displays. Surely, each imaging experiment will have one or more portable monitors in its EGSE for testing and integration. Monochrome monitors come in all sizes from 5" to 25" diagonal and all prices from a few hundred to a few thousand dollars. High resolution monitors claiming 1024 x 1024 pixels are available for typically $3000. Color monitors accepting RGB or NTSC standard (rarer) input range from $3000 to $7000 for standard resolution and as high as $20,000 for 1024 x 1024 resolution. This expense for a high resolution RGB monitor is not justifiable for image display: extreme care is required to avoid a weak link in the video system (or the monitor itself) which degrades the ultimate resolution of the display. If very high resolution is desired, it is wiser to use a high quality standard monitor and a scan converter with a zoom option to magnify desired subregions of the image.

The use of more expensive color displays can sometimes (not always) be avoided similarly. One major advantage of a color image is the greater dynamic range (more distinguishable intensity levels) which can be displayed <u>on a single frame</u> by false-color coding. However, a monochrome scan converter can store a large dynamic range of intensities. If the user has interactive control of the gray scale transformation from stored intensity to screen brightness, he can explore just as large a range as with color. The cost savings and simplicity of video equipment of this option are worth considering. Color still has advantages for displaying different properties of an object in one image (e.g., red = temperature and yellow = density) and for public relations.

One type of color "monitor" deserves special mention, the Advent Model 1100 Video Beam Projector. This accepts any input (RF, RGB, NTSC color, BW; options for digital graphics) and projects the image onto a large screen, 52" x 70". When properly installed, image quality is very good, and audiences of several dozen people can be accommodated easily. These displays have been used successfully in the International Ultraviolet Explorer (IUE) Operations Control Center. The Model 1100 costs $7000, while the Model 1000 (no RGB or digital input) costs $4500.

3.4.3 Frame Summation

Individual video frames have effective exposure times of 1/30 second, far too short for photometric accuracy in many applications. Electronic noise and interference may also corrupt the video signal. Frame summation is the ability to add successive video frames to produce an integrated image of higher signal-to-noise ratio. A related requirement is to generate and display the difference of two integrated frames. This permits detection of small differences between colors or polarizations and of motion or other temporal changes.

Summation requires an accumulating memory for one image or more, which may be stored in analog or digital form. The PEP Lithocon Scan Converter described above is an appropriate analog memory. It can integrate either standard analog video or slow scan inputs merely by overwriting on the storage tube. If the difference of two images is desired but not the originals, then one can be stored as a positive, the other overwritten as a negative after electronic inversion. Thus the scan converter can also be used as an analog subtracter. It can also invert the output (i.e., display the "photographic negative") of the stored image, so two tubes with an electronic mixer can store two frames and display either one or the differences.

Naturally, all of these functions can also be done digitally. Digital memories are more expensive but are dropping steadily in price. With or without computer control, more flexible processing is possible. The Quantex DS-20 Digital Image Memory/Processor is a good example of a stand-alone unit which meets all of these requirements. It can accumulate input frame in a 512 x 512 memory with 6 - 10 bits per pixel. Various options for image subtraction or more general gray scale transformation of the output are selectable by front panel switches. This performs a limited subset of the functions of the digital displays discussed in Section 3.6; its advantage is the avoidance of computer, interface and software costs. Typical price for an 8-bit DS-20 is around $30,000; more modest versions start at $12,000 for a 256 x 256 x 6 bit unit. Similar hardware components are also made by Colorado Video, Inc.

Finally, the benchmark problem for frame summation can be solved by most of the computer-controlled digital image displays, as long as they have "frame-grabber" analog-digital converters. Their power for interactive display generation and multi-image arithmetic so greatly exceeds these modest requirements that they are described in detail in the next section.

3.5 Digital Image Data

The growth of digital image processing technology is creating a revolution in the fields of astronomy and remote sensing of the earth's environment. A digital image is a two-dimensional matrix of numbers, each representing some physical attribute ("intensity") at that point in the image field of view. One advantage over conventional image media is the accuracy of storing intensities for each point ("pixel"). Another is the ease of computer processing for diverse goals, ranging from simple calibration to flexible interactive display or extensive numerical analysis for comparison of theory and observation. The specialized image processing equipment which is commercially available today is becoming an integral part of the measurement process in every active observatory. The POCC will be no exception.

The origins of the boom in digital image processing lie in several developments in electronics and computer science. Electronic sensors, both television tubes and solid-state arrays, have undergone rapid development in the past decade (see Ford, 1979). Micro- and minicomputers to control these sensors and to record and process the data have become widespread. The spectacular results obtained by the Image Processing Laboratory at JPL on planetary missions have publicized the power and flexibility of digital techniques and have caught the attention of ground-based astronomers (Lorre and Lynn, 1978). They have also demonstrated the feasibility of digital transmission of imagery from spacecraft to control center. The HRM downlink on Spacelab is ideal for this purpose.

Large-scale integrated circuit technology has created a new phase of digital image processing in the last five years. Semiconductor memory is cheap enough (and dropping in price steadily) that high-speed multi-image memories are affordable. These memories are the basis of extremely powerful image display terminals, which function as processors and scan converters simultaneously: images are manipulated with cycle times of 1/30 second and the results displayed continuously on a TV monitor. The internal processors are now capable of precise numerical analysis of multi-band imagery, a development stimulated largely by LANDSAT data. They make it possible to analyze three-dimensional data, i.e., series of images referring to the same spatial field as seen in different wavelength or energy bands.

From multi-band data, new "generalized" images can be derived which show interesting physical quantities such as temperature, density, or Doppler shift instead of observed intensity. In this way, an image processing system can derive measurements of immediate scientific interest on a quick-look timescale. Such results enable the crew and POCC personnel to operate experiments most efficiently, maximizing the scientific return from limited observing time.

This section discusses four sets of benchmark problems: recording, hard copying, interactive display, and numerical processing of digital images. Two points which appear repeatedly in these sections deserve mention. First, there are no accepted standards for digital imagery as there were for analog video data. Images come in all sizes, from 16 x 16 pixels to 800 x 800 or even 10 x 2048; furthermore, the number of bits of precision for each intensity varies from 4 to 16. These diverse requirements make specification of a standard system very difficult. Second, some of the components discussed are still in development or are changing rapidly in capability. Both of these points are symptoms of the adolescence of image processing technology.

Excellent surveys of digital image processing can be found in the special issue of Computer (August, 1977) and the books by Castleman (1979) and Pratt (1978).

3.5.1 Recording

The volume of data in a digital image makes recording and storage a special problem. For this discussion, the standard image will be defined to have 512 x 512 pixels and 16 bits per pixel, a total of 4.2 megabits. The precision of 16 bits is rarely needed but often used for software convenience; if fewer than 8 bits are really needed, analog video recording is recommended. For digital recording, the benchmark problem is to record images at variable, bursty rates of up to two images per second (8.4 megabits/sec.). The capacity to store several hundred images (a few billion bits) is required, along with the ability to recall any one image in less than a minute and consecutive images in a few seconds. The source of the data will be either an HRDM Experiment Output Channel or a GSE digitizer with analog video input.

POCC Standard Services include recording and delayed playback of the composite HRM data stream. Thus, all the data is recorded and can be replayed for processing in GSE. This is valuable insurance but it does not meet the benchmark requirements for retrieval. It is not a useful recording medium for interactive display and processing.

Table 3.4 summarizes the options considered for digital image recording. It is assumed that a GSE minicomputer system is available for overall control of the image processing activity. High density magnetic tape refers to 16-track, 6250 bit per inch computer tape. It is the most common medium for archival storage today but is limited in utility for interactive display because of the long retrieval times. The magnetic disk is an 80-megabyte model which is a standard minicomputer peripheral. The Lockheed Spacelab 2 Experiment will use such a disk to record digital images at a 1.36 megabit/sec. rate. Large disk drives for IBM and CDC mainframe computers have about 8 times the capacity of this unit. Optical disks for digital recording are not yet commercially available but are in development by several companies; they are discussed in more detail below. All of these recording devices will probably require special HRDM interfaces with buffer memories.

The digital optical disk is a very exciting prospect for image recording. According to Drexler (1979) and Rolph (1980), more than 20 companies have experimented with optical disk recording, and at least five are considering marketing them as computer peripherals: North American Philips, Thomson CSF, RCA, Magnavox and Drexler Technology. Philips has working prototypes whose properties have been published (Kenney et al., 1979); the rest of the section will describe this DRAW (Direct Read After Write) information system.

The Philips disk is a tellurium-coated plastic disk which looks like a translucent phonograph record. Data is recorded by modulating the intensity of a laser which burns micron-sized pits in the tellurium film. Recording is permanent, durable, and non-erasable; since 10,000 images can be stored on a $10 disk, this is not a drawback. Reading is accomplished by laser scanning and detection of a pit by absence of reflection from the disk. Error-correcting coding provides a bit error rate of one in ten billion. Philips personnel say that read-only units could also be marketed at greatly reduced cost. Should both recorders and readers be marketed at affordable prices in the next few

Hardware Option	Recorder Cost	Storage Medium Unit Cost	Unit Capacity Bits (Images)	Maximum Rate (megabit per sec)	Bursty Data Recording ?	Quick Retrieval	Availability
POCC Standard Recording Services	–	–	–	50	Yes	No	Standard
High-Density Magnetic Tape	\$ 20,000	\$ 20	1.5×10^9 (500)	3	No	No	Now
Magnetic Disk CDC Model 9762	\$ 13,000	\$600	6×10^8 (125)	10	Yes	Yes	Now
Optical Digital Disk Phillips DRAW	\$100,000 (?)	\$ 10	4×10^{10} (10^4)	5–10	Yes	Yes	1982 (?)

Table 3.4 Options for Digital Image Recording

years, they would be an excellent solution to this benchmark problem.

3.5.2 Hard Copying

The benchmark problem here is to make faithful paper or film copies of digital or video images quickly and conveniently. In particular, permanent copies should be made in at most 30 seconds without disrupting normal POCC operations (by darkening the room, for example). Minimum specifications are 256 x 256 pixels with at least 8 shades of gray perceptible in the copy.

Polaroid photography from the display screen is very successful for copying oscilloscope traces or other CRT displays. It is considerably more difficult to copy gray-scale video images without serious shading and distortion problems (Frei, 1979). If crude snapshots are good enough, then direct photography may still be unacceptable because of room lighting. These problems are certainly solvable, but modular hard copy units are much quicker and more convenient.

Several options for hard copying are listed in Table 3.5. The dot matrix printer is already a standard peripheral in many computer systems. With proper software, it can copy small digital images at low speeds; these copies have been accepted for publication on occasion, but the quality leaves something to be desired. The Muirhead Systems device seems to be designed for weather facsimile reception, but it has been used at JPL for video copying with reasonable success. The Tektronix Model 4634 produces very impressive monochrome copies from standard video input. It is much better than the Model 4632 Video Hard Copy in image quality, and neither should be confused with the graphics hard copy units, which have no gray shade capability.

Finally, the Dunn Instruments 631 Camera makes beautiful color prints of RGB input on 8 x 10 Polaroid film ($6 each). It is a free-standing floor unit with an internal color CRT and microprocessor controller. These allow the three video signals for red, green and blue to be supplied sequentially or simultaneously; thus, false color prints could be made from a monochrome display. Options permit the use of 35 mm film and Polaroid SX-70 film.

3.5.3 Interactive Display

The advantages of digital over analog imagery are not realized in a control center unless the user is able to perform numerical processing and to

Device	Cost	Consumable	Speed	Maximum Image Size (pixels)	Gray Shades	Subjective Quality	Color
Dot Matrix Printer	$ 5,000	Paper, toner	Few minutes	200 x 250	8	Fair	Some
Muirhead Electrostatic Facsimile Recorder	$12,000	Paper	Few minutes	800 x 1000 at least	~12	Good	No
Tektronix 4634 Image-Forming Module	$ 6,000	Paper	26 sec	500 x 500 at least	~12	Very Good	No
Dunn 631 Color Camera System	$13,000	8 x 10 film 35-mm film SX-70 film	2 min	500 x 500 at least	Color	Excellent	Yes (RGB input)

Table 3.5 Image Hard-Copy Devices

see the results promptly. This fact motivates the benchmark problem for interactive display. First, high-speed memory to hold at least one 512 x 512 x 8 bit image is needed; memory for one 800 x 800 x 8 bit image and several 512 x 512 x 8 bit images is highly desirable. Continuous display on a BW or color monitor is required. Transfer of a new image into memory should take no more than a few tens of seconds. User control of the display options in a high-level command language is required. These options should include: interactive control of the gray scale or false-color mappings with instand response; zoom capability on any part of the image; ability to compute and display histograms of the whole image or a chosen subregion; cursor capability for the user of position and intensity for user-chosen points; and, the ability to blink two images sequentially, if multiple image memories are available.

Before discussing the specialized digital image displays, it is worth noting that a low-cost analog processor can meet several of the requirements. This is true <u>only</u> if the images are intended for viewing by the user and <u>not</u> for quantitative analysis. The PEP Lithocon scan converter discussed in Section 3.4.2 gives user control of gray scale and zoom; it holds four video frames, and an automatic switch could allow blinking. The VP-8 Image Analyzer of Interpretation Systems Inc. (ISI) provides much more flexible gray scale control. It can also give digital readout of a cursor-chosen point or of the area of an image in a certain intensity band; thus, simple histograms can be generated. If a CRT is also available, it can plot the intensity along a line or a three-dimensional isometric projection of the intensity. Price is about $9000.

For fully digital interactive display, the following hardware is needed: source of the images, either a storage device, video digitizer, or HRDM interface and buffer; an image display terminal, containing the memory, processing logic, and scan converters; a micro- or mini-computer system to control the display, with keyboard and CRT; a high-speed data link between storage, computer and display; TV monitor and POCC distribution system interface. In this section, only the image display terminal will be discussed in detail.

Digital image displays which are commercially available fall into three rough categories. The first consists of rather simple video digitizer systems which store and display one to three images and process them with an internal microcomputer. These are often aimed at biomedical or materials science applications. Vendors include Bausch and Lomb, Hamamatsu, Leitz, Joyce Loebl, and Spatial Data Systems (SDS). The SDS Model 109-PT is a good example: it costs $20,000 for a 640 x 480 x 8 bit monochrome display. Addition of an LSI-11 computer ($11,000) would make a complete digital image analysis system; two more memories ($11,200) would add false-color capability. Table 3.6 compares this with the other image displays.

The second group consists of sophisticated computer peripherals which implement their display options with internal logic on receipt of commands from the host computer. Although the distinction is not always clear, members of the third group (discussed in Section 6.5.4) also contain arithmetic processors for ambitious number-crunching of the stored images. Examples of the second category are Grinnel Systems' GMR-27, DeAnza Systems' ID Series, and the COMTAL 8000-S; other vendors include Aydin, Genisco, Hazeltine, ISI, Lexidata, and Ramtek.

The core of these displays is the refresh memory, high-speed semiconductor memory in a user-defined configuration of multiple images and graphics overlays. Figure 3.1 shows a block diagram for reference. Refresh memory is read out (not erased) 30 times a second to generate the standard video signal for the monitor. After readout but before analog conversion, the intensity data may be transformed by look-up tables and addition or logical combination with the other stored images. In this way, gray scales and false-color mappings can be changed rapidly without rewriting the entire memory; also, images can be combined segmented, and overlayed. Zoom is accomplished by reading out pixels repeatedly in a subsection of the image. Most of the other options discussed in Section 3.3.1 on graphics displays are also available.

Image displays in the second and third groups can easily satisfy all requirements of the benchmark problem with two possible exceptions: many of them will not hold 800 x 800 images; and, histogram computation is exceedingly slow in some cases when the host computer must read through the entire image. Most of the second-level peripherals will require considerable software development by the user, however. Since they are peripherals, the vendors do not usually supply high-level software support beyond a demonstration program. At

Display	Cost	Image Size	High-Level Software	Gray Scale Control	False Color	Zoom	Blink	Histogram
PEP Lithocon, VP-8 Image Analyzer	$14,000	4-analog video frames	–	Fast	No	Yes	Yes (add-on)	Very Slow
SDS 109-PT	$20,000	640 x 480 x 8	Yes	Slow	No	Yes	No	Slow
Grinnel GMR-27	$32,000	3 images 512 x 512 x 8	No	Fast	Yes	Yes	Yes	Slow
STC Model E-70	$80,000	4 images 512 x 512 x 8	Yes	Fast	Yes	Yes	Yes	Fast

Table 3.6 Representative Interactive Image Displays

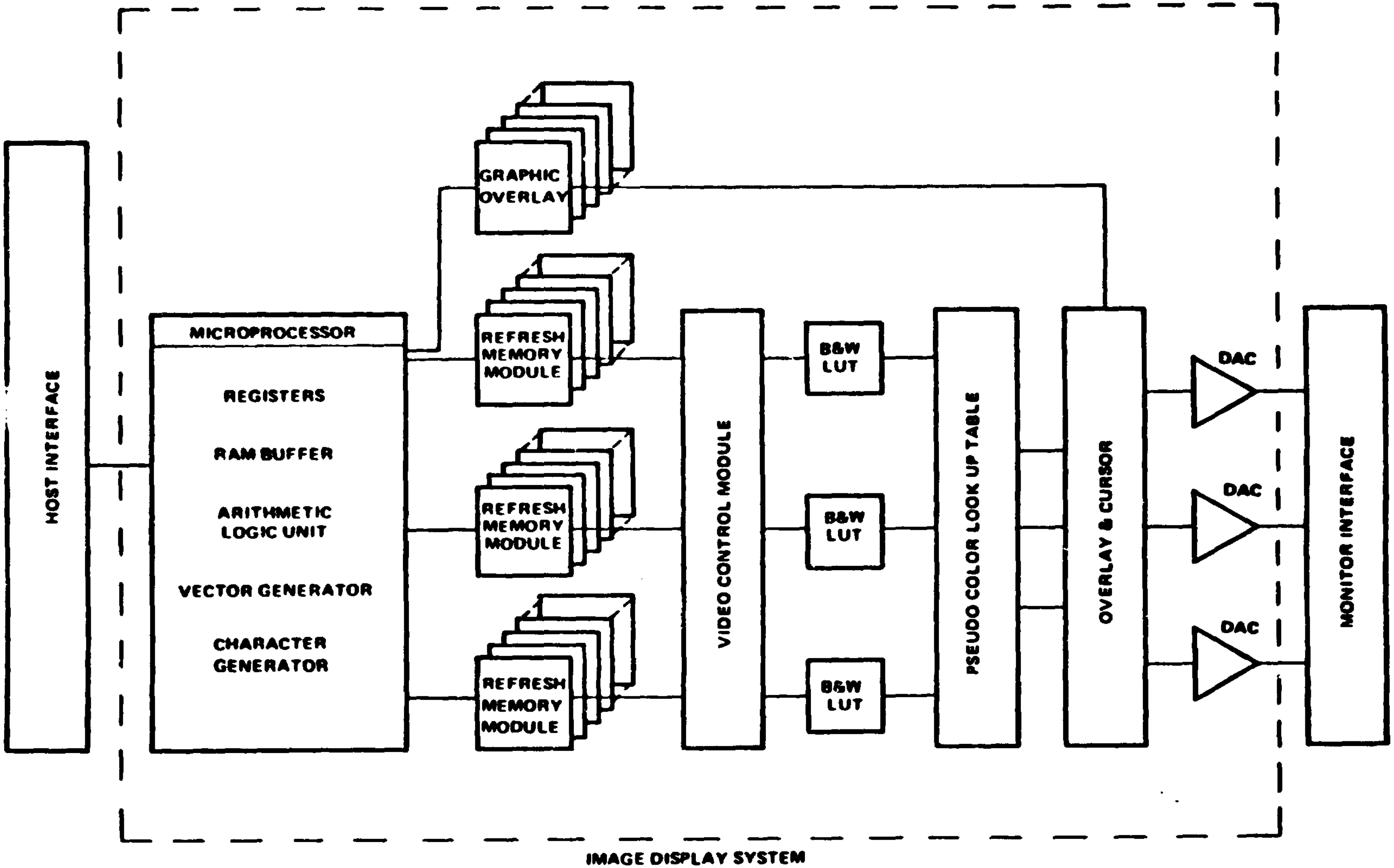

Figure 3.1 Representative Image Display of the Second Type

best, a set of FORTRAN-callable routines for the elementary operations (e.g., loading a look-up table, reading the cursor coordinates) is available. The system programmer must then integrate these into a user-oriented control program for the particular applications of interest. If a high-level command language (usable by a person unfamiliar with the details of that device and minicomputer system) is desired, then a complete image processing system must be purchased at greater expense. Such systems are discussed next.

3.5.4 Arithmetic, Statistics, Geometric Correction

While the previous section was concerned mainly with image display, the discussion here concentrates on numerical analysis of digital images. The benchmark problem in statistics is aimed at deriving objective measures of image quality, an essential function in the POCC to verify proper experiment operation. Requirements are: to compute and display the histogram and its moments and percentiles in a few seconds; to compute a Fourier power spectrum (one or two-dimensional) in a few minutes, at most; to display scatterplots and compute regressions with two input images. Multi-image arithmetic includes calibration operations, derivation of "physical" images (e.g., temperatures, Doppler shifts) from raw data, and image enhancement functions. The requirements are: radiometric correction using stored or derived calibration frames; arithmetic operations on multiple 16-bit images with no loss of precision and with interactive control, storage and display of the results; enhancement by convolution, low and high-pass filtering, and background subtraction. Finally, geometric correction involves: image rotation; coalignment by uniform shift; removal of known distortion; interactive removal of image-specific distortion.

All of these requirements can be met by a simple minicomputer system which includes disk storage for multiple images. Very powerful software packages exist for all. The only problem with this solution is its low speed. Several images must be read from and written onto the disk a little bit at a time, because the computer memory can't hold them. Therefore, a simple operation like adding two images and storing the result might take 30 seconds. For this reason, special processors have been developed which perform hundreds of times faster than the general purpose computer. These include the array processors of Section 3.3.2 and the third level image processing displays mentioned above.

Before discussing the special processors, a few words about software are in order. The VICAR image processing system of JPL is available in a PDP-11 minicomputer version, called mini-VICAR. It sells for $1500 (COSMIC, 1979) and includes routines for all of the requirements listed above. Furthermore, it does not even assume the existence of an interactive display device. This is a very attractive package which, if combined with a custom-tailored interactive display program, makes a cheap, powerful and somewhat portable image processing system. Two similar packages sold commercially are the System 500 of Stanford Technology Corporation (STC) and the IDIMS software of ESL, Inc. Both of these are more powerful, much more expensive ($12,500 for System 500), and designed for specific interactive displays. Another interesting software package is the Forth system used at Kitt Peak National Observatory (Wells, 1977).

Image displays with high-speed arithmetic processors are made by COMTAL, DeAnza Systems, Grinnel Systems, and STC. Extremely valuable descriptions of these can be found in Adams and Wallis (1977), LaPado et al. (1978), and Hubble and Reader (1979). In addition, the Lockheed Spacelab 2 Image Processor has arithmetic capability of interest.

The commercial image displays mentioned above perform arithmetic operations in 1/30 second. Their refresh memories are read out at that rate into a series of look-up tables and pipelined adders, as indicated in Figure 3.2. The output of these adders can be put back into one of the memories via the feedback loop. By loading different functions into the look-up tables, a large class of operations can be performed at these high speeds. The ability to shift images in the x and y directions before adding them allows convolution and spatial filtering to be done. Note that more complicated spatial transforms (such as FFT's, image rotation, or geometric distortion removal) are not handled conveniently and that the 8-bit depth of most refresh memories seriously limits the arithmetic precision. It should be emphasized that all of these displays also perform all of the interactive display functions of the previous section. The cost of these systems is dominated by the price of memory: the STC Model 70 costs about $32,000 plus $10,000 for each refresh memory of 512 x 512 x 8 bits.

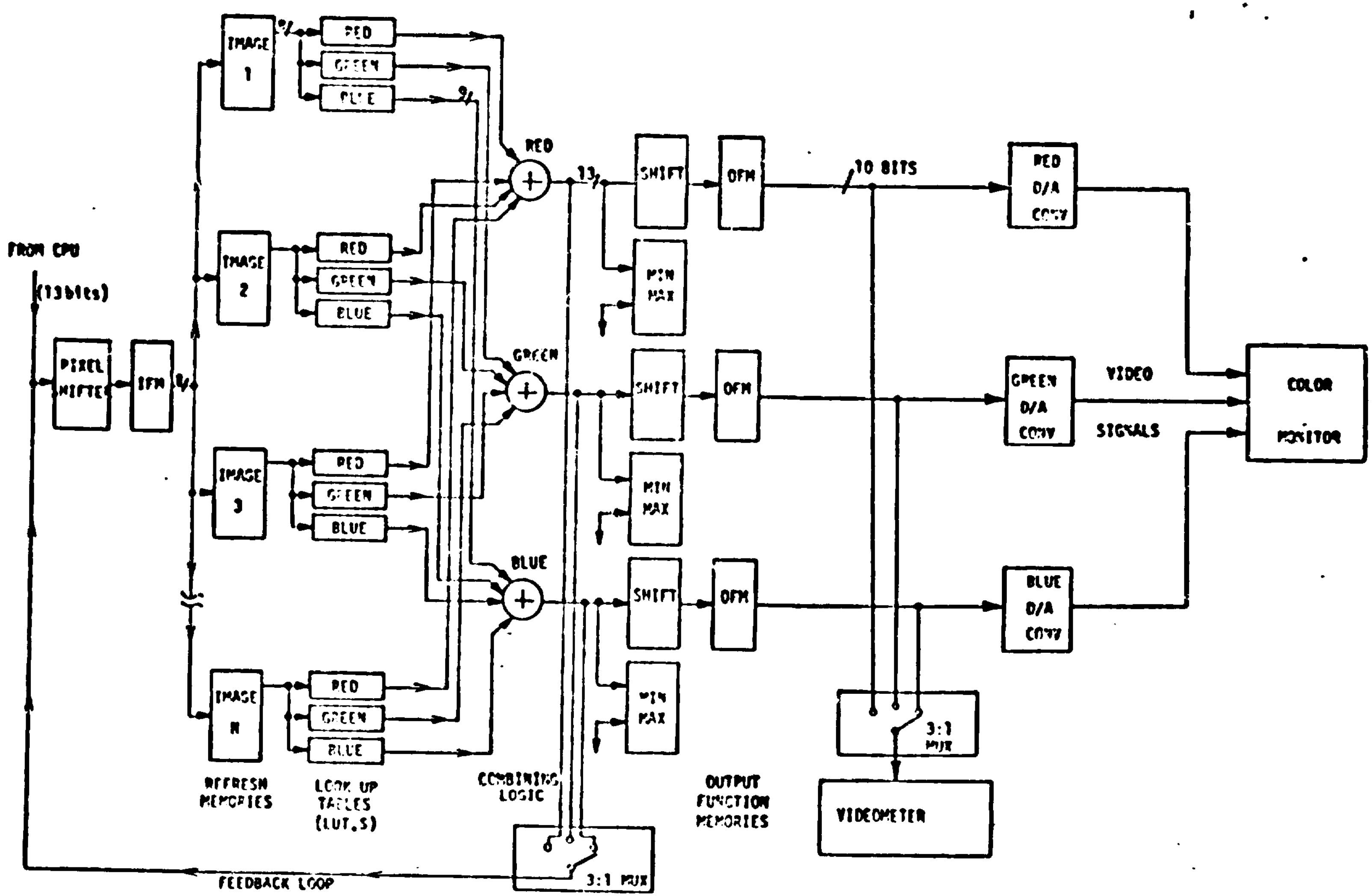

Figure 3.2 Schematic Diagram of the STC Model 70 Image Processing Display

Device	Memory Size	Interactive Display	Histogram Hardware	Arithmetic Processor	Feedback Loop
COMTAL ONE/20	512 x 512 x 8 64 images	Yes	No	8-bit	8-bit
DeAnza IP 5000	512 x 512 x 8 4 images	Yes	Yes	16-bit	16-bit
Grinnel Model 270	512 x 512 x 8 4 images	Yes	Yes	16-bit	16-bit
STC Model 70	512 x 512 x 8 12 images	Yes	Yes	13-bit	16-bit
LPARL SL2	256 x 256 x n 6 images	Limited	No	32-bit	16-bit

Table 3.7 High-Speed Image Processing Displays

The Lockheed Spacelab 2 image processor uses quite a different approach. It has 6 image memories, only one of which generates the video displays. The others are used entirely for storing data, calibration, and arithmetically derived images, which may have different depths from 8 to 16 bits per pixel. Arithmetic is done by a fast microprocessor with 32 bits of precision. The result is slower but more accurate arithmetic, with savings of power and memory cost as well. Multiplying two 256 x 256 x 16 bit images takes about 0.5 secs. Various properties of the image processors are compared in Table 3.7. Cost comparisons are not made because they are too dependent on options chosen.

It is obvious that a very powerful quick-look image processing system can be built around any of these devices. However, no single one meets all of the interactive display and numerical processing requirements. In particular, improvement is required in the following areas.

o Software control over image size and depth: the COMTAL system allows "virtual" images of any size to be defined and manipulated; adding the Lockheed depth flexibility would be very useful.

o Video-rate arithmetic with no loss of precision: feedback and storage of 16-bit results is needed.

o Clever architectures to permit more complicated spatial processing: perhaps only better software is needed for existing displays.

o Two-dimensional FFT's: this capability in the display, perhaps using a dedicated memory and microprocessor, would eliminate the need for an array processor in addition to the display.

o More bits per chip: to bring down the cost of the gigantic memories.

3.6 Potential Common Display and Processing Systems

The equipment survey which has been described at great length shows that most of the common display and processing requirements can be met. Commercially available components exist for most of the functions; many of them are in routine operation at scientific and engineering laboratories around the country. Thus, there is a substantial reservoir of experience which has been and can continue to be exploited in designing POCC displays. Based on these findings, a set of five candidates for common GSE display systems have been developed. They are all intended to meet well-established common requirements and to be modular and evolutionary in nature. Each system has growth potential to accommodate future requirements which may appear and to be upward compatible with improved components, avoiding premature obsolescence.

The first two systems provide displays to aid POCC personnel in interactive pointing. They should be considered primarily as support facilities for the IPS (or other pointer) and not as direct replacements for EGSE, although a modest savings in EGSE software does result. The other three systems provide general purpose displays of increasing sophistication which do reduce the need for EGSE by significant amounts. As long as the experimenters are aware of the power of the standard GSE displays and the ease of using them, their EGSE costs can be reduced without loss of capability.

3.6.1 Graphics Display for Interactive Pointing Control

This common system is intended to assist POCC personnel in several phases of pointing control. Although it is intended primarily to support IPS pointing, there is no reason why graphic displays to aid pallet mounted experiments could not be developed. With its own microcomputer, the system can be reprogrammed at will by contractors or experimenters to support future requirements. Incidentally, when the equipment is not in use to support pointing control, it can be used for general color graphics display and may have applications in crew training.

The hardware produces a color graphics display with alphanumeric annotation. It appears on a display terminal with keyboard and also generates an RGB color video signal which can be monitored anywhere on the POCC video distribution network. Each display shows: (1) an appropriate coordinate grid (solar ecliptic, declination and right ascension or terrestrial latitude and longitude); (2) the present aimpoint of each pointed instrument; (3) the present location of multiple user-selected targets. Different colors and symbols can be used for different experiments. For the solar targets, the computer must correct for solar rotation if requested by the user. Similar corrections may be needed for some terrestrial targets.

One task of POCC personnel will be to supply the crew with coordinates of desired targets for each revolution. A large-scale display mode (showing the entire solar disk or a large part of the celestial sphere) should be available for this function. Once targets are acquired (or nearly so), a small-scale mode showing perhaps one arc minute is appropriate. This can help POCC personnel detect slow drift and fine pointing errors. With a monitor visible from a commanding terminal, slow interactive pointing may be possible.

The equipment required is listed below and is sketched in Figure 3.3. The specific models chosen are plausible; equally good alternatives could be found.

o Minicomputer: PDP 11/23 with 64K words of memory, dual floppy disks, RT-11 software, FORTRAN, DECwriter low-speed printer; total cost approximately $15,000.

o Color Graphics Terminal: Tektronix 4027, 96K bytes color graphics memory, video output (RGB), PLOT 10 software; total cost approximately $13,000.

Software is needed to accept the IPS pointing data from the ECIO HRM channel; this will be supplied to GSE by the POCC computer roughly once per second. The minicomputer must update the display at this rate. It must also accept user commands from the terminal to enter or delete targets and to change the display scale. The software cost is estimated at 3 months of labor by a scientific programmer.

3.6.2 Video Display for Interactive Pointing Control

This system is intended to be an upgrade of the previous one. Its purpose is to allow the graphics display to be overlayed on the analog video

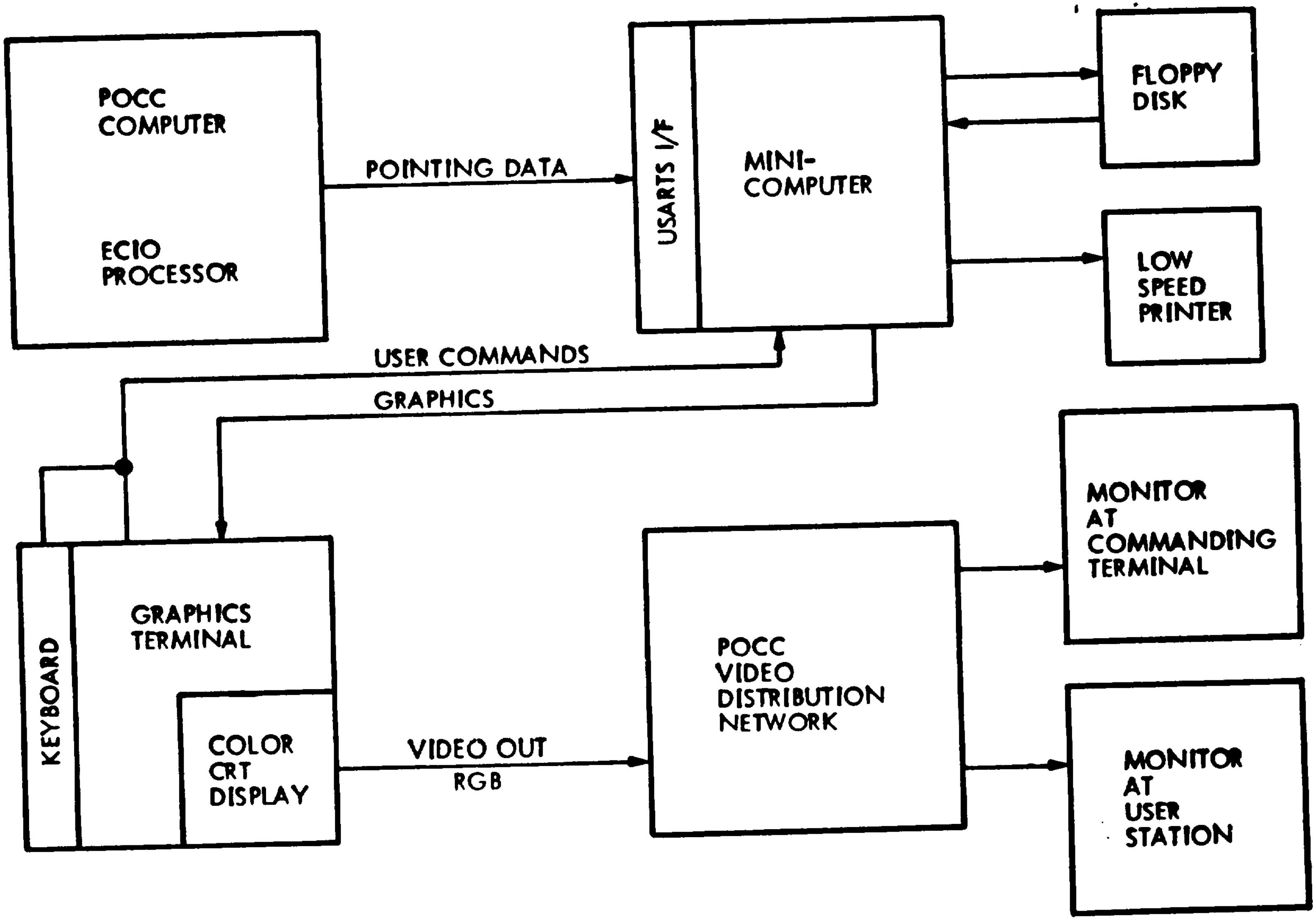

Fig. 3.3 Graphics Display for Interactive Pointing

signal of the experiment which is being pointed. In this way, targets can be selected from the video image and their coordinates determined from the overlay. A hairline cursor under user control allows direct reading of target coordinates by the computer. Thus one unified display satisfies all pointing control requirements.

The cheapest way to do this is to use all the hardware of the previous system. When the video overlay mode is desired, the experiment video signal and one output of the color graphics are added in a two-channel mixer to get the monochrome sum signal. The Tektronix 4027 terminal can generate one hairline cursor which appears on the video image; a user at that terminal can select targets using the keyboard cursor control. To allow remote users to mark targets, separate cursor generators at each commanding terminal would be useful. The Colorado Video Model 622 X-Y Digitizer ($4500) adds a white dot cursor to the image and provides digital outputs of its position which can be bed back into the computer. Figure 3.4 shows the system block diagram.

Although the additional hardware requirement is modest, the software increases significantly in complexity. A different graphics mode is required for each experiment video used, because of the differences in image scale, field of view and orientation. Furthermore, each experiment may have different overlays (spectrograph slit, photometer aperture, etc.) to draw on the image. A potential problem here is that of time delays between receipt of the video and of the pointing data from the ECIO stream: a small loss of synchronization could make a disastrously confusing display, if the experiment is scanning or moving for any reason. This software problem appears to be non-trivial.

3.6.3 Basic Video Display System

The shortcomings of the analog video downlink were described in Section 3.4. The need for a multi-channel video digitizer was also explained. This custom-built unit is the first major feature of the basic video system. The second feature is an instrument pool of monitors (monochrome and RGB), video cassette recorders, hard copy units, and switching and cabling equipment. For each mission, a POCC video distribution network can be assembled using this store of equipment, based on experiment requirements for analog video displays. In this way, the NASA supplied GSE serves each mission, and complete

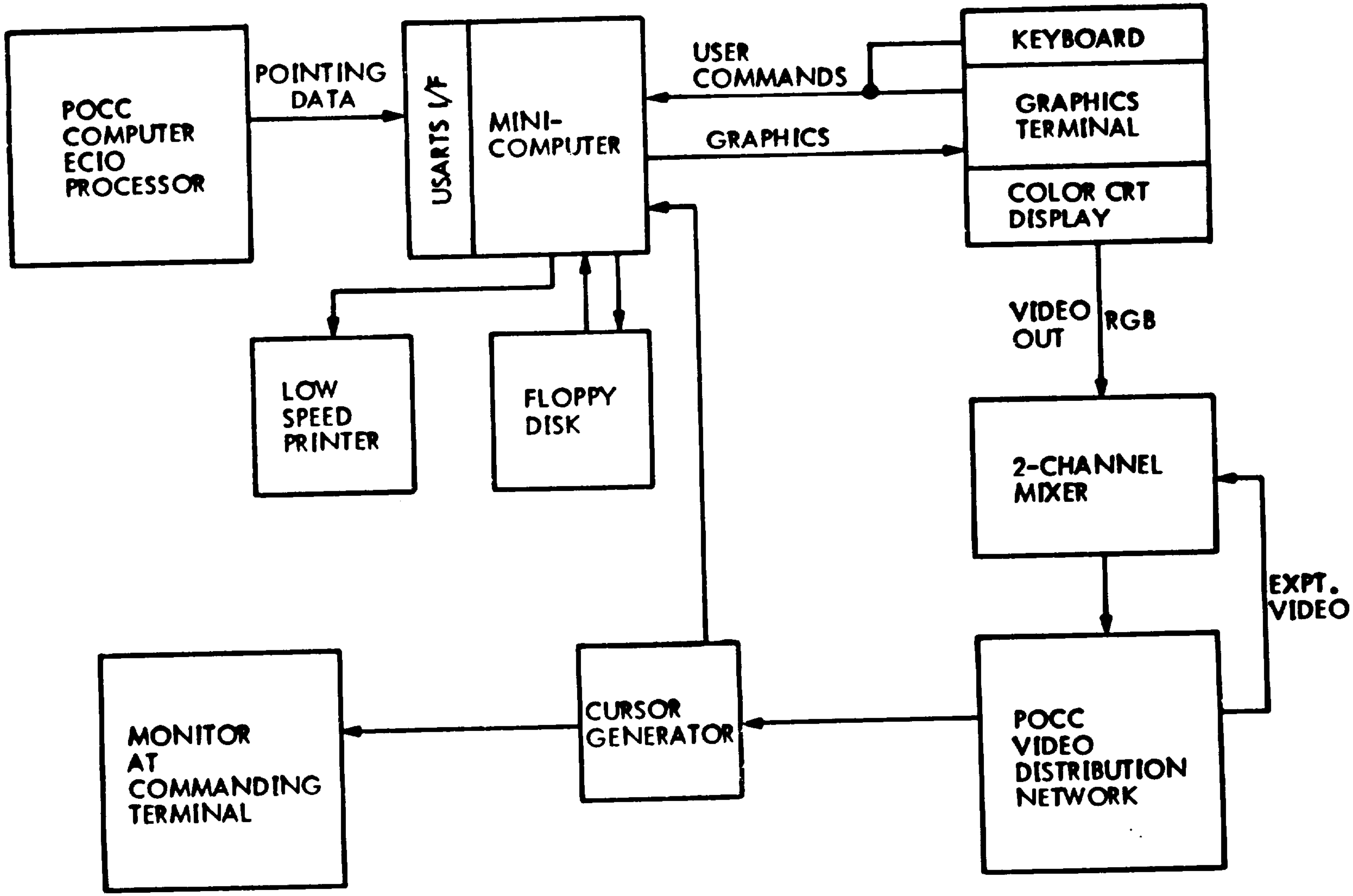

Fig. 3.4 Video Display for Interactive Pointing

individual sets of EGSE are avoided; only the minimum EGSE to support testing and integration need by purchased by each experiment. Figure 3.5 shows a sample configuration.

The video digitizer system requires some specialized hardware not commercially available and so a cost estimate is not attempted. A general list of the hardware components needed on the orbiter is as follows: interface to the orbiter CCTV system to receive up to four video inputs; control logic based on front panel switches or EC command; video multiplexer and digitizer; buffer memory; HRM output interface. It is important to maintain a constant HRM rate but allow flexible control of the number and frame rate of inputs. In the POCC, the following components are needed to regenerate the video signals: HRDM interface and buffer; demultiplexer and switching logic, feeding the data to four scan converters along with proper X-Y coordinates of each point; analog scan converters, for inexpensive regeneration of video signals. Equipment which is similar in principle to some of these components is made by Colorado Video (the Model 280 Video Transceiver, for example) and by LeCroy Research Systems (CAMAC Model 8258 High-Speed Video Digitizer).

The instrument pool from which to construct the video display system for each mission can be built up gradually, by purchasing components as the need arises. The following will be of general use:

o Monochrome monitors, from 5" to 17", costing from \$300 to \$1200;

o RGB monitors, high quality, 19"; CONRAC Model 5411, \$5600; also made by Tektronix, SONY, Toshiba;

o Video tape recorders, either supplied as a POCC Standard Service or as standard GSE; if the latter, the SONY SLO-320 cassette recorder, \$1500, can be recommended;

o Hard copy unit, Tektronix Model 4634 Image Forming Module, \$6000.

For display of scientific data, there are no hard requirements for a video beam projector. However, on missions when several experiments share use of the IPS, projection of the pointing display on a screen visible to all will make cooperation easier. It also has obvious applications for publicity and for displaying mission events of general interest to a large number of POCC personnel (Deployment of a SOT, for example). Therefore, add to the list:

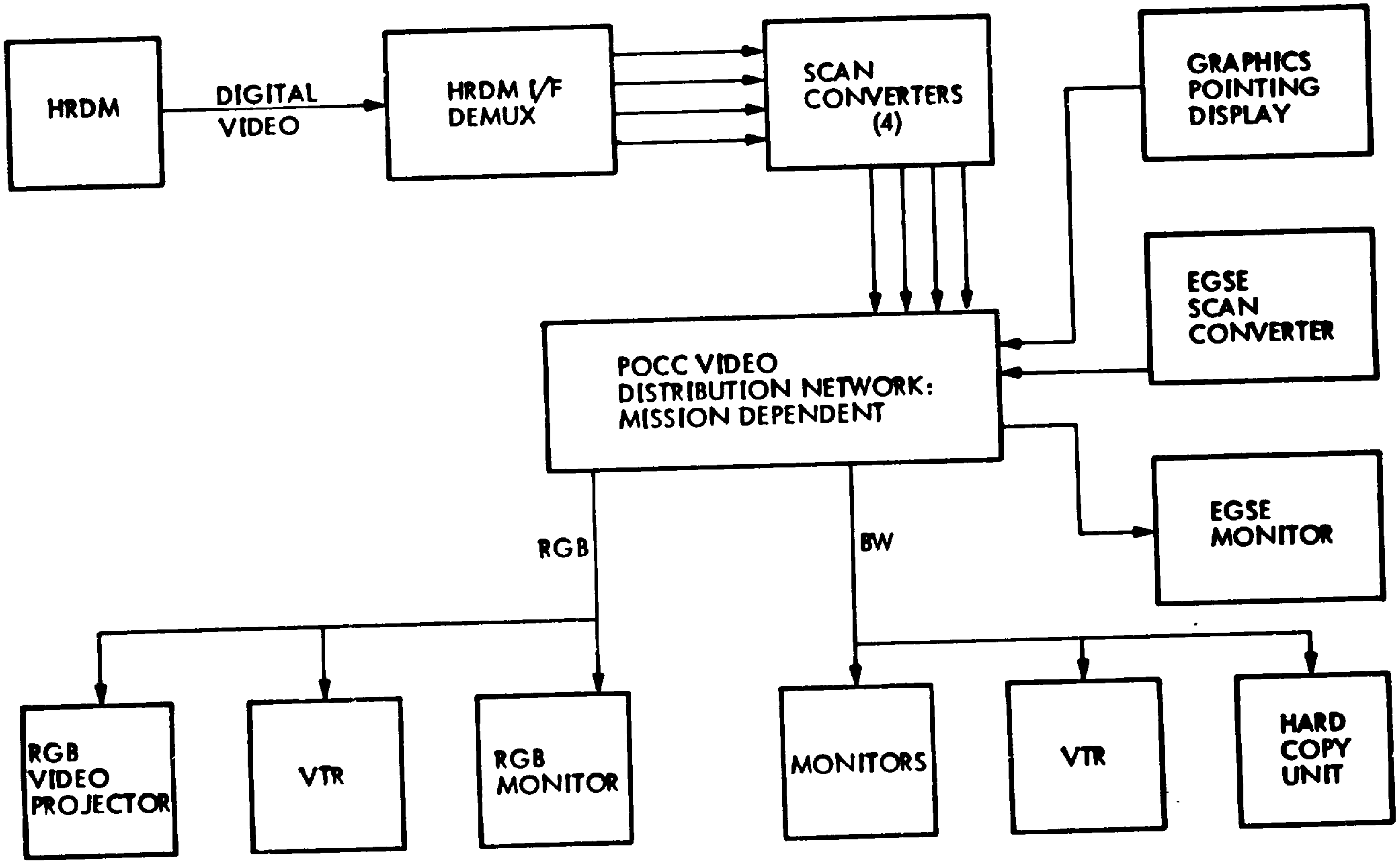

Fig. 3.5 Basic Video Display System

o Advent Video Beam Television, Model 1100, RGB projector with large screen, $7000.

The growth potential of the basic video display system is obvious. The most interesting direction for growth is to incorporate more analog video processing equipment: the ISI Model VP-8 Image Analyzer ($8,000) would be a powerful addition for interactive display. A PEP Lithocon Scan Converter ($5,000) with a custom timer switch would permit blink comparison of up to four analog images. These possibilities lead into the next potentially common system.

3.6.4 Hybrid Analog-Digital Image Display System

The purpose of this system is to provide a powerful interactive display for digital imagery. At the same time, system cost and complexity is reduced by avoiding the problem of interfacing to either the HRDM or a variety of EGSE minicomputers. Also, different image sizes and formats of different experiments do not affect the processing and display capability. The system meets all of the requirements in the interactive display benchmark problem and some of the statistics requirements as well. Growth potential is excellent, with the option for future expansion into a complete image processing system.

The technique which avoids all the interface problems is the use of analog video as the input channel. Figure 3.6 shows the approach. EGSE generates the video signal in a scan converter. The common system is built around an image display with a video digitizer, which stores images in its refresh memories. The user can include test patterns in his video signal to allow faithful reproduction of his image to 8-bit accuracy. Once the frame is captured in refresh memory, it can be manipulated using any of the options discussed under interactive display. Up to three images can be stored, to permit false-color displays or color coding of different variables. Image data can be read back into the host minicomputer system for a limited statistics and image arithmetic capability.

The hardware required for this system is as follows:

o Image display: Grinnel Systems GMR-27, including 3 refresh memories of 512 x 512 x 8 bits, image function memory card (look up tables and blink

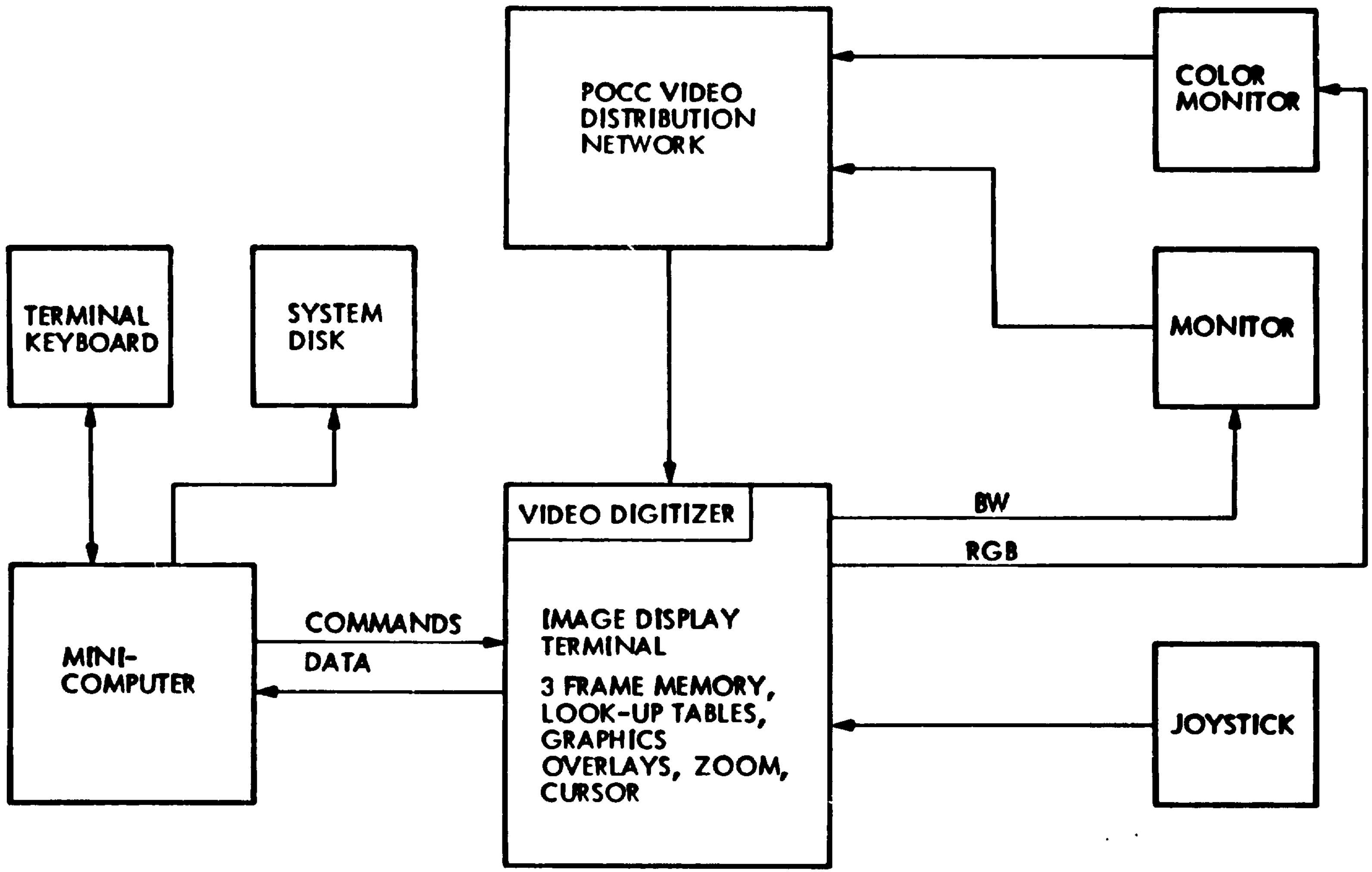

Fig. 3.6 Hybrid Analog-Digital Image Display

capability), image zoom and pan card, 8-bit video digitizer, and joystick cursor control unit; total cost, $27,000;

o RGB monitor: 19" CONRAC 5411, $5600;

o Host minicomputer system: PDP 11/34 computer, with 128K bytes memory, DMA interface, 5 Mbyte system disk pack, RSX-11M operating system, floating point processor, F4P FORTRAN, DECwriter low-speed printer, alphanumeric CRT terminal; total cost, $45,000.

The costs listed above include the computer operating system software and the FORTRAN-callable control routines. Higher level control software is not supplied with the GMR-27 display, which is chosen because of its superior hardware design among displays in this price range. Thus, an integrated control program with a simple menu-oriented command structure is needed. This will allow a user to operate the display without any detailed knowledge of the software involved. New options can be added to this program gradually as they are requested by users. Six months of effort by a scientific programmer could produce an excellent control program.

This system has the potential to grow into a complete digital image processing system, if demand warrants it. A natural course would be to upgrade the computer system with a large disk for image storage, a tape drive, and more memory. Then the mini-VICAR software developed at JPL could be installed to provide complete image arithmetic capability. The mini-VICAR image format could become the POCC standard, so that users could send their data to this facility with minimal interface problems. Such a grand design is certainly not required at this time, however.

3.6.5 Digital Image Processing and Display System

The design for this common system is presented merely as an example of a nearly complete solution to the common requirements using today's technology. It is not recommended for development in the POCC at this time (although this is no reflection on the equipment involved). In conjunction with the basic video display system, this system satisfies all of the benchmark problems for digital imagery (Section 3.5) with two exceptions. First, the image display does not hold images larger than 512 x 512 pixels; 16 bits of depth can be accommodated with some additional software. Second, high-speed image arithmetic is of limited precision; low-speed arithmetic could be done in the computer with additional software.

Figure 3.7 shows the block diagram. The hardware needed is the following.

- o Image Processing Display: STC Model 70-E with 4 memories of 512 x 512 x 8 bits, graphics overlays, trackball, hardware histogram generator, feedback arithmetic-logic unit, host computer interface, and rack; total cost, $75,500;
- o RGB Monitor: 19" CONRAC 5411, $5600;
- o Host minicomputer system: PDP 11/34 computer with 256K bytes memory, DMA interface, 5 Mbyte system disk pack, RSX-11M operating system, floating point processor, F4P FORTRAN, electrostatic printer-plotter, 9-track 800/1600 track tape drive, 80 Mbyte disk, CRT terminal for alphanumeric and graphics displays; total cost, $90,000.

STC, the display vendor, sells a complete software package called System 511 for $12,500. This includes the FORTRAN-callable primitives, file management, and a user interpretive language enabling unsophisticated users to control the display completely. Even so, software support is needed to interface this system with the various sources of digital images in the POCC. For example, specialized routines may be needed to read a data tape written by a user's minicomputer, if it is not in the PDP 11 series. Six months effort by a systems programmer is estimated for system integration and interface support.

Considering the expense of this system, the complicated interfaces with various EGSE computer systems, and the number of potential users on future Spacelab missions, development should not proceed without further study. In particular, the impact of the Solar Optical Telescope (SOT) instruments and of any other imaging facility class instruments upon the common requirements must be considered in more detail. Furthermore, the state-of-the-art in image processing displays is advancing rapidly, so it would be premature to acquire such a system at this time.

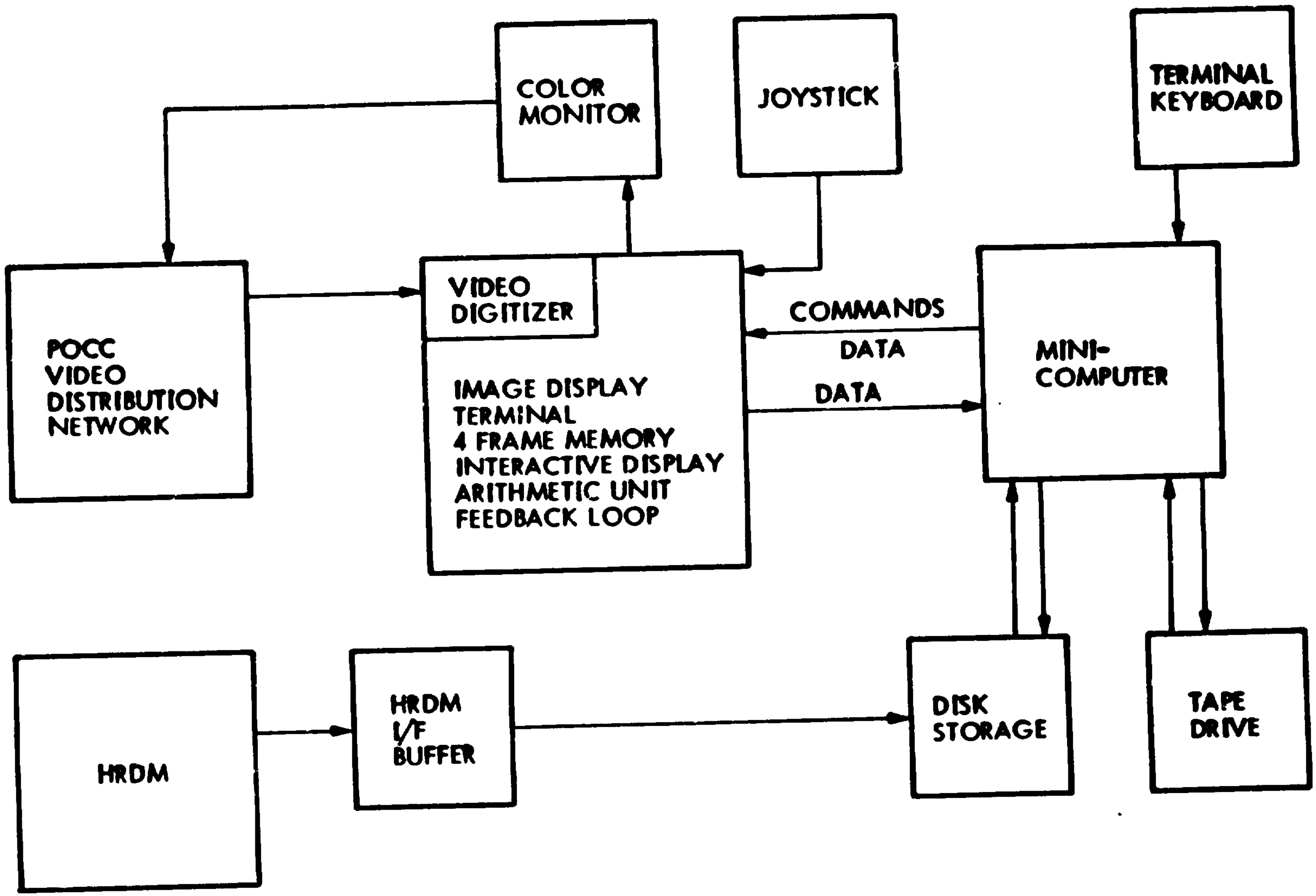

Fig. 3.7 Digital Image Display and Processing System

4.0 CONCLUSIONS AND RECOMMENDATIONS

4.1 Summary and Conclusions

This study has been a logical continuation of the previous quick-look data analysis study completed by LPARL in March, 1978. One of the tasks has been a modest effort to continue the user interviews which were the core of the previous study. Experimenters from various Spacelab 1 and 2 experiments and authors of proposals for future Spacelab flights were interviewed. In addition, the Investigators' Working Group meetings for Spacelab 2 were attended, and MSFC and JSC personnel working on command and data handling were contacted. The topics for these interviews were interactive control of Spacelab experiments from the POCC, the command uplink system, the proposed packet transmission format for the HRM downlink, the development of ECAS, and experimenter plans for GSE and image processing in the POCC.

The findings and conclusions of these interviews can be summarized in the following points.

o Interactive Control: Spacelab experiments have a broad spectrum of interactive control requirements, including some functions which can only be done by the crew and others which require trained POCC personnel with real-time data displays. Furthermore, some requirements are essential, without which the experiment is impossible to perform; others are matters of efficiency of operation or avoidance of idle time which could be used for observing.

o Interactive Pointing: Many experiments desire some sort of interactive pointing control from the POCC. Reasons include target selection at the start of an observing sequence, correction of pointing drifts during an observation, and reaction to transient events of interest. Investigators are not entirely confident that crew members will be available to do all necessary pointing or that they will be able to react properly to transient phenomena.

o Command Uplink: This is perceived as being too slow and unreliable to meet requirements. As a result, more tasks are being off-loaded to dedicated experiment processors (DEP's) and some ambitious observing plans are being down-graded. Suggestions to NASA for improving the uplink include sending data over the voice link using modems and providing an automatic queueing and enabling capability in POCC computers.

o EGSE minicomputers: Virtually all experimenters plan to have their own minicomputers in the POCC. They want very much to be able to build and send commands from their own terminals; DEP reloads are considered impossible without this capability. A potential solution is to build command loads on EGSE terminals and transfer them to POCC commanding terminals via floppy disks. NASA could assist by developing standard software to create these floppies in the proper formats. Such software could solve the interface problem between the POCC terminals and the most common varieties of EGSE minicomputers.

o HRM Packetization: Investigators are generally apathetic towards this issue, with the exception of a few experiments which are forced to transmit large amounts of fill data to satisfy present HRM formats. The packet approach may alleviate this problem. At least two experiments have developed their own packet formats to send science data, housekeeping data or DEP memory dumps in the same major-minor frame format.

o ECAS Development: Nearly all experimenters agree that ECAS should be developed by NASA or a contractor and not by themselves. ECOS and DEP software should be used in place of ECAS whenever possible. If ECAS is unavoidable for some function, then the experimenter should specify his requirements in detailed algorithmic form.

The major task of this study has been the equipment survey described in Chapter 3. Its purpose has been to discover the hardware and software components and systems relevant to the common requirements established previously. Only real time and quick-look display and processing of scientific data were considered. The framework for the survey was the set of benchmark problems created for serial digital, analog video and digital image data. Selected existing systems have been tested with real scientific data to ascertain their utility in the POCC. Some components which are in development but not yet available were also considered. The following conclusions have been drawn from this survey effort.

o Analog data: No common requirements exist.

o Serial digital data: The combination of minicomputer processing and display on monochrome or color graphics terminals can easily meet all requirements, except for the quick-look computation of fast Fourier transforms on large data records. Array processors are one possible solution to this exception, but other promising technologies are also under development.

o Analog video data: Basic requirements can be met only if a digitized video downlink and a reconfigurable POCC video distribution system are implemented.

o Digital image data: Existing hardware and software systems can meet most but not all of the requirements for POCC processing. Sophisticated high-speed image displays controlled by dedicated minicomputer systems are needed. Improved technology is needed for high-speed image recording, for display of large format digital images, and for precise multi-image arithmetic. Future developments to expect are optical disk digital recorders and more powerful image displays using advanced semiconductor memories.

4.2 Recommended Display and Processing Systems

Following the equipment survey, a set of five potential common display and processing systems was designed. These are intended to be developed by NASA as shared GSE systems, to be used in place of EGSE by any experiment that needs them. They are designed specifically to common requirements for scientific data and pointing information display. Therefore, they can be shared among different experiments on a given mission and used repeatedly on different missions. Furthermore, more powerful and flexible displays are provided than will be necessary for testing and integrating. Therefore, the common use of the shared systems will allow hardware and software savings on EGSE.

Three of the potential common systems provide displays for scientific data. Table 4.1 compares them with the POCC Standard Services in terms of which requirements are met; technical definitions of these requirements can be found in Sections 3.4 and 3.5. Table 4.2 summarizes more information about all five systems. Costs are based on the specific configurations given in Section 3.6. No cost estimate is attempted for the basic video display system for two reasons: (1) a major part is a digitized video downlink whose design is beyond the scope of this study; (2) the rest of the system is an instrument pool whose size and contents will evolve as the requirements of different missions are met. Modular growth potential refers to the ability of each system to absorb new software and hardware components as user requirements evolve and as new technology becomes available.

Three systems are recommended for immediate development: the graphics pointing display, the basic video display system, and the hybrid analog-digital display system. These recommendations are based on the contents of Tables 4.1 and 4.2 and on one additional judgement: namely, the equipment needed for these systems is available now and is not likely to change so dramatically in a few years as to justify postponement. The video pointing display is not recommended until some experience with the HRM downlink, the IPS and the graphics display system is obtained; the best way to upgrade the graphic system (if necessary) will be evident then. Finally, development of the digital image processing system should be postponed for two reasons: (1) the detailed requirements of the SOT instruments and other imaging instruments in active development should be considered; (2) the state-of-the-art in image processing will change significantly in the next five years, yielding much greater capability at lower cost than is presently available.

System	Analog Video Data			Digital Image Data			
	Recording	Display	Frame Summation	Recording	Hard Copy	Interactive Display	Arithmetic, Statistics
POCC Standard Services	some	some	none	some	none	none	none
Basic Video Display	all	all	some	none	all	some	none
Hybrid A-D Image Display	none	some	all	none	none	most	some
Digital Image Processing and Display	none	some	all	all	none	most	most

Table 4.1 Requirements Met by Common Image Display Systems

System	Hardware Cost	Software Labor (man-months)	EGSE Replacement	Processing Capability	Aid in Interactive Control	Modular Growth Potential	Recommend For Development
Graphics Pointing Display	$ 28,000	3	Little	Limited	Yes	Fair	Yes
Video Pointing Display	$ 33,000	6	Some	Limited	Yes	Fair	Not Now
Basic Video Display	Unknown	None	Much	None	Yes	Excellent	Yes
Hybrid A-D Image Display	$ 80,000	6	Much	Great	Limited	Excellent	Yes
Digital Image Processing and Display	$185,000	6	Much	Very Great	Limited	Fair	Not Now

Table 4.2 Summary of Common Display Systems

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APPENDIX A

TABULAR RESULTS OF PREVIOUS STUDY

SPACELAB QUICK-LOOK SCIENCE DA

Discipline	Group	Experiment	Data Rate	Display Updat Rate
AMPS	U. Iowa	Plasma Diagnostic Package	10 kHz analog, 16 kbps digital	10 seconds
AMPS	NASA/LaRC	Light Detection and Ranging (LIDAR)	32 kbps to 320 kbps	–
AMPS	GSFC	Cyrogenically Cooled Limb Scanning Interferometer Radiometer (CLIR)	0.5 Mbps, 200 bps	15 seconds
AMPS	LPARL	Atmospheric Emissions Photometric Imager (LLLTV)	4.2 MHz video, 300 kbps digital	1 second
AMPS	Southwest Research Center and NASA/MSFC	Space Experiments with Particle Accelerators (SEPAC)	4.2 MHz video, 256 kbps digital	1 second (vide few seconds digital
AMPS	NASA/JPL	Atmospheric Trace Molecules Observed by Spectroscopy (ATMOS)	16 Mbps	10 seconds

FOLDOUT FRAME

SCIENCE DATA DISPLAY REQUIREMENTS SUMMARY

Display Update Rate	Processing Required	Display Device
) seconds	Analog: intensity versus time, frequency versus time for 32 seconds for any of the 16 channels of the sweep frequency receiver, curve fit this data. Digital: engineering conversion, peak and average signal. Images: geometrical distortion removal and contrast enhancements	TV monitor (color) 1 CRT color 2
–	Engineering units conversion, calibrate, concentration (column density) from intensity versus altitude (from time delay).	CRT monochrome showing concentration versus altitude (1).
5 seconds	Interferometer: raw data or FFT Radiometer (25 channels): engineering conversion, channel comparison	CRT monochrome high-resolution (2) Oscilloscope
second	No processing of video, engineering conversion and display formatting of digital data. Addition of video images and storage of selected video images.	TV monitors (standard) (4 required)
second (video), w seconds igital	No processing video signal; for digital data: engineering conversion, curve fitting, power versus frequency, frequency versus time, calibration.	TV monitor (standard), CRT monochrome (6–8 req) strip chart recorder, hard copy output.
) seconds	Fast Fourier transform, engineering conversion, display up to 8 spectra displaced 2 inches each, roll off as more spectra are displayed.	CRT color with overlays (Comtal)

FOLDOUT FRAME 2

SPACELAB QUICK-LOOK SCIENCE DATA

Discipline	Group	Experiment	Data Rate	Display Update Rate
High Energy Astrophysics	Mullard Space Sciences Laboratory	Focussing Iron-Line Crystal Spectrometer (FICS)	5 kbps	
High Energy Astrophysics	NASA/GSFC	Gamma Ray Astronomy in the Medium Energy Range 7 to 100 MeV	10 kbps	
High Energy Astrophysics	LPARL	Soft X-Ray Telescope (SXT)	25 kbps	30 seconds
High Energy Astrophysics	JPL/Stanford	High-Sensitivity X-Ray Spectrometer	10 kbps to 16 kbps	1–10 minutes
High Energy Astrophysics	NASA/GSFC	Measurements of Energy Spectra of Cosmic Ray Nuclei: Protons to Iron.	10–100 kbps	
High Energy Astrophysics	LPARL	High-Sensitivity High-Resolution Measurements of Cosmic Gamma-Ray Spectra	64 kbps	few seconds
High Energy Astrophysics	NASA/GSFC	A Large Area High Resolution Experiment for Gamma Ray Line Astronomy	50 kbps	few seconds

CK-LOOK SCIENCE DATA DISPLAY REQUIREMENTS SUMMARY

Display Update Rate	Processing Required	Display Device
	Engineering conversion, wavelength calibration, bin slippage, expand selected spectral region, compute statistics of spectra, interactive data processing control.	CRT monochrome, interactive capability
	Reconstruct particle track through grid of detectors, produce total energy histogram.	Storage scope (such as Tektronix 4001 or 4006), CRT monochrome, interactive alphanumeric keyboard.
30 seconds	Pass data through an image storage tube with video readout to generate an image on a TV monitor. Generate images in 3 energy intervals, ratio or difference images, display results, interactive experiment pointing control, interactive data processing control.	TV monitor (color)
1–10 minutes	Engineering conversion, accumulate spectra over variable time intervals, interactive to control variable integration interval, background subtraction, sort into spectral bins.	TV monitor (standard), CRT monochrome, hard copy capability, computer print-out.
	Track and pulse height information on an event by event basis.	CRT monochrome (high resolution)
few seconds	Engineering conversion, dead time corrections, hold intensity versus time in buffer or core, integrate on one energy channel as a function of time, interactive to select processing mode.	CRT monochrome, print-out
few seconds	Store 8192 channel spectrum over variable time intervals, normalize against time. Reformat data from binary to decimal but do no engineering conversion. Peak detection analysis, event detection statistical error analysis.	CRT monochrome (high resolution), interactive control, no color or gray scale requirement, hard copy from electrostatic printer and line printer.

FOLDOUT FRAME 2

SPACELAB QUICK-LOOK SCIENCE DATA

Discipline	Group	Experiment	Data Rate	Display Update Rate
Solar	LPARL	Experimental Investigation of the Solar Corona and Transition Region (X-Ray/EUV Telescope)	4.2 MHz video, 30 kbps digital	1 – 5 seconds (TV)
Solar	UC San Diego and NASA/GSFC	Hard X-Ray Imaging Instrument (HXII)	100 – 500 kbps, 2 kbps quick-look	10 seconds
Solar	LPARL	XUV Solar Monitor	500 kbps if digital standard TV if video	1 – 5 seconds
Solar	Stanford University	A Soft X-Ray Telescope Spectrometer for Solar and Cosmic Observations	1 Mbps	10 seconds
Solar	LPARL	A Solar Magnetic and Velocity Field Measurement System	2 Mbps	30 seconds
Solar	LPARL and NASA/GSFC	Solar Optical Telescope (SOT)	10 – 50 Mbps	Few seconds

FOLDOUT FRAME

)K SCIENCE DATA DISPLAY REQUIREMENTS SUMMARY

Display Update Rate	Processing Required	Display Device
1 – 5 seconds (TV)	No processing of TV data. Digital data requires engineering conversion, integrate spectral data, interactive experiment pointing control.	TV monitor (standard) 3 CRT monochrome 1
10 seconds	Engineering conversion, image construction by iterative algorithm, interactive experiment control.	TV monitors (standard) 2 required.
1 – 5 seconds	Conversion from digital to analog TV format if sent digitally, interactive pointing capability with cursor cross-hairs for experiment pointing.	TV monitor (standard).
10 seconds	Engineering conversion, subtract images, interactive data processing control, light pen or pixel to obtain the intensity of that pixel, display graphically counts in one pixel versus time, support software to predict solar feature locations several orbits later, compress data due to high dynamic range, selectivity store images.	TV monitor (color) (3) – be able to access a pixel by light pen, CRT monochrome. Color display would better handle large dynamic range instead ot data compression and gray shading.
30 seconds	Addition and subtraction of images, storage of selected digital images, simple image statistics (histograms, mean value, standard deviation, power spectrum).	TV monitor (standard) 2 required, video tape recorder, scan converter.
Few seconds	No data processing, only scan conversion, interactive experiment pointing control with adjustable cross-hairs.	TV monitor (standard) (5 or 6 required) TV monitor (color), TV monitor (high resolution), scan converters, alphanumeric keyboard.

FOLDOUT FRAME 2

SPACELAB QUICK-LOOK SCIENCE DATA

Discipline	Group	Experiment	Data Rate	Display Update Rate	
UV/Optical	NASA/JSC	STARLAB Planetary Camera	5 Mbps	10 seconds	Engine tractio stretch
UV/Optical	NASA/JSC	STARLAB Echelle Spectrometer	70 kbps	2 – 3 minutes	Engine intensi profile, format, superim
UV/Optical	U. Wisconsin	STARLAB Planetary Camera	1 Mbps	10 seconds	Engine
UV/Optical	U. Wisconsin	STARLAB Spectrophotometer	1.7 kbps 1 frame/minute (10^5 bits/frame)	1 second to 1 minute	Engine of spect active c instrume
UV/Optical	U. Wisconsin	Ultraviolet Photometry Polarimetry Explorer (UPPE)	Few 10's of kbps	1 second	Enginee of 100 versus w
UV/Optical	UC Berkeley	Far Ultraviolet Space Telescope (FAUST)	No science data down. Science data on film cassette		Enginee
UV/Optical	UC Berkeley	EUV Telescope/Spectrometer (ECOM 721)	32 kbps	0.1 second to 1 minute	Serial d buffer w version,
UV/Optical	NASA/ARC	Spacelab Infrared Telescope Facility (SIRTF)	1 – 4 Mbps	Few seconds	Parallel 1. Dis 2. Dis vol 3. Gr fer 4. Gr cha req tra 5. Int ma

FOLDOUT FRAME

OOK SCIENCE DATA DISPLAY REQUIREMENTS SUMMARY

isplay Update Rate	Processing Required	Display Device
10 seconds	Engineering conversion, image ratios, image subtractions, background subtraction, gray level stretch, display only portion of image.	TV monitor (color), hard copy from electrostatic printer and polaroid camera.
2 – 3 minutes	Engineering conversion, extract an order, rough intensity calibration, correct for instrumental profile, geometrical corrections, display Echelle format, interactive data processing control, superimpose preconceived ideas of spectrum.	TV monitor (high resolution), CRT (monochrome), interactive control over data processing and display.
10 seconds	Engineering conversion, radiometric calibration.	TV monitor (high resolution), interactive pointing control.
1 second to 1 minute	Engineering conversion, addition and subtraction of spectra, flat background subtraction, interactive data processing control, interactive instrument pointing control.	TV monitor (high resolution), with graphics, interactive pointing control.
1 second	Engineering conversion, linear Fourier transform of 100 points, intensity versus time, intensity versus wavelength.	CRT (monochrome).
	Engineering conversion.	
0.1 second to 1 minute	Serial digital data into shift register, to latch buffer with time signal, digital to analog conversion, amplifier, analog output.	Storage oscilloscope (256 by 256) or buffer. Hard copy: print out and Polaroid or similar image reproduction.
Few seconds	Parallel data processing required to: 1. Display star tracker field. 2. Display raw (analog) interferogram data, voltage versus time. 3. Graphical display of transformed interferograms (maps, spectra). 4. Graphical display of 100 – 1000 grating channels, intensity versus time; not required simultaneously with Fourier transform. 5. Interactive graphics capability to manipulate data	

FOLDOUT FRAME 2

APPENDIX B. LIST OF USERS CONTACTED

Name	Institution	Field/Spacelab Connection
L. Acton	LPARL	Solar, HE, SL2 CO-I & Crew
J.-D. Bartoe	NRL	Solar, SL2 Co-I & Crew
J. Breckinridge	JPL	AMPS, SL1 Expt.
R. Catura	LPARL	HE, SLn PI
R. Drummond	GSFC	AMPS, CLIR Facility
M. Harrington	MSFC	SL2 Mission Ops.
K. Henize	JSC	UVO, SL2 Crew
A. Jackson	MSFC	SL2 POCC Ops.
W. Kilpatrick	MSFC	SL2 C&DH
J. Ladner	MSFC	SL2 POCC Ops.
S. Mende	LPARL	AMPS, SL1 PI
P. Meyer	U. Chicago	HE, SL2 PI
K. Norman	MSSL	Solar, UVO, SL2 Expt.
J. Parker	JSC	POCC Data Systems
D. Prinz	NRL	Solar, SL2 Co-I & Crew
S. Shawhan	U. Iowa	AMPS, SL2 PI
G. Simon	AFGL	Solar, SL2 Co-I & Crew
R. Smithson	LPARL	Solar, SOT FDT
T. Stecher	GSFC	UVO, SLn PI
A. Title	LPARL	Solar, SL2 PI
M. Torr	U. Michigan	AMPS, UVO, SL1 PI

APPENDIX C

QUESTION LIST FOR USER INTERVIEWS

SOME QUESTIONS ON INTERACTIVE CONTROL OF SPACELAB EXPTS. FROM THE POCC

(1) TO WHAT EXTENT DOES YOUR EXPT. REQUIRE HUMAN INTERACTIVE CONTROL FOR FUNCTIONS SUCH AS FOCUSSING, POINTING, SETTING OF EXPOSURE TIMES OR AMPLIFIER GAINS, OR THE LIKE? CAN THESE BE CONTROLLED JUST AS WELL BY A MICRO- OR MINICOMPUTER? CAN THEY BE DONE EXCLUSIVELY BY THE CREW, TAKING INTO ACCOUNT THE FACT THAT CREW MEMBERS MAY NOT ALWAYS BE AVAILABLE ON DEMAND?

(2) CAN YOUR EXPERIMENT DO MEANINGFUL SCIENTIFIC WORK WHEN THE CREW IS NOT PRESENT AT ALL? WHAT IF THE CREW IS PRESENT ONLY TO PERFORM INITIAL POINTING AND STARTUP OPERATIONS? IF YOUR EXPERIMENT CAN FUNCTION UNDER EITHER OF THESE CIRCUMSTANCES, WHAT SORT OF UPLINK OF DATA AND COMMANDS IS NEEDED TO SUPPORT IT?

(3) DO YOU EXPECT TO OBSERVE TRANSIENT NATURAL PHENOMENA WHERE QUICK REACTION IS ESSENTIAL? WHAT KIND OF TIME DELAYS ARE TOLERABLE? WHAT SORT OF CHANGES IN THE INSTRUMENT'S OPERATING MODE ARE NEEDED? CAN A CREW MEMBER RECOGNIZE THE ONSET OF SUCH A TRANSIENT AND TAKE PROPER ACTIONS OR IS A SPECIALIST IN THE POCC ESSENTIAL?

(4) HOW DO YOU EXPECT TO SEND COMMANDS AND/OR DATA FROM THE POCC TO YOUR INSTRUMENT? IS A CENTRALIZED COMMAND TERMINAL, AS OPPOSED TO YOUR INDIVIDUAL DISPLAY TERMINAL, A SATISFACTORY ARRANGEMENT? IS IT POSSIBLE TO CREATE AN EXHAUSTIVE COMMAND LIST PRE-FLIGHT? DO YOU NEED TO SEND COMMANDS OTHER THAN SERIAL DIGITAL WORDS (E.G., IMAGE OR TEXT UPLINK, ANALOG INPUTS FROM A JOYSTICK, OR WHATEVER)?

(5) DO YOU NEED TO COMMUNICATE WITH AN ON-BOARD MICRO- OR MINICOMPUTER? WHAT SORT OF UPLINK REQUIREMENTS DO YOU HAVE FOR MEMORY RELOADS OR INTERACTIVE COMMANDING (DEBUGGING, PERHAPS)? ARE THESE REQUIREMENTS PART OF NORMAL OPERATIONS, INSTRUMENT SHAKEDOWN, AND/OR CONTINGENCY OPERATIONS?

SOME QUESTIONS ON HRM USAGE BY SPACELAB EXPERIMENTS

(1) A "BURSTY" SOURCE OF DATA IS ONE WHICH PRODUCES DATA AT A HIGH RATE FOR VARIABLE SHORT PERIODS OF TIME WITH QUIET PERIODS IN BETWEEN. THE DATA BURSTS ARE PSEUDO-RANDOM IN TIME AND THEREFORE CANNOT BE SCHEDULED DOES YOUR EXPT. PRODUCE BURSTY DATA? ARE THERE DIFFERENT TYPES OF BURSTS CORRESPONDING TO DIFFERENT TYPES OF DATA (SUCH AS HOUSEKEEPING, ENGINEERING DIAGNOSTICS, MEMORY DUMPS, SCIENCE DATA FROM DIFFERENT MODES)?

(2) "STREAM" DATA IS THE OPPOSITE OF BURSTY DATA: IT IS PRODUCED AT A PREDICTABLE STEADY RATE FOR A KNOWN DURATION. IT MUST BE RECEIVED AT THE SAME RATE WITH NO DIFFERENTIAL DELAYS OR RESHUFFLING. ANALOG VIDEO IMAGERY IS AN EXAMPLE. HOW MUCH STREAM DATA WILL BE PRODUCED BY YOUR EXPT.?

(3) HOW IMPORTANT IS THE NEED TO CHOOSE ONE'S OWN RATES AND FORMATS FOR THE HRM, AS OPPOSED TO CHOOSING ONE OF A VARIETY OF STANDARDS, WITH FILLING AND BUFFERING?

(4) THE PRESENT HRM DOWNLINK IS A TIME-DIVISION MULTIPLEXED SYSTEM IN WHICH DATA IS TRANSMITTED IN A FIXED SEQUENCE OF MINOR FRAMES WHICH REPEAT IN EACH MAJOR FRAME. THE ALTERNATIVE "PACKET" APPROACH WOULD ALLOW AN ARBITRARY SEQUENCE OF MINOR FRAMES, WHOSE CONTENTS AND SUBSEQUENT PROCESSING IN THE POCC COMPUTERS ARE IDENTIFIED BY A ONE WORD LABEL. ARE THERE ANY ADVANTAGES OF THE PACKET APPROACH FOR YOUR EXPT.?

MISCELLANEOUS QUESTIONS

(1) WOULD YOU PREFER TO HAVE A NASA CONTRACTOR WRITE EXPERIMENT COMPUTER APPLICATIONS SOFTWARE (ECAS) TO YOUR SPECIFICATIONS, OR WOULD YOU PREFER TO WRITE IT YOURSELF IN A HIGH-LEVEL LANGUAGE (GIVEN EXTRA FUNDING AS NEEDED)? WHY? IF YOU PREFER A NASA CONTRACTOR, WOULD YOUR ANSWER CHANGE IF YOU WERE PROVIDED A CONVENIENT TELEPHONE LINK TO AN EC SIMULATOR, TO ALLOW ESSENTIALLY UNLIMITED TIME FOR DEBUGGING?

(2) DO YOU PLAN TO USE YOUR OWN GROUND SUPPORT EQUIPMENT (GSE) FOR DATA ANALYSIS AND DISPLAY IN THE POCC? IN LEVEL IV INTEGRATION? IS IT THE SAME HARDWARE OR DO YOU PLAN A MORE SOPHISTICATED SYSTEM FOR THE POCC?

(3) DO YOU PLAN TO USE THE POCC CLOSED-CIRCUIT TV SYSTEM? IF THE STANDARD CCTV SYSTEM INCLUDED IMAGE MANIPULATION AND ENHANCEMENT FUNCTIONS FOR ANALOG VIDEO IMAGES, WOULD YOU USE THEM? THE SAME, FOR DIGITAL IMAGES? WOULD IT SIMPLIFY OR ELIMINATE ANY OF YOUR GSE IF THESE FUNCTIONS WERE PART OF THE STANDARD SYSTEM?

APPENDIX D. SOURCES FOR DISPLAY EQUIPMENT SURVEY

Chromatics, Inc.
The Bendix Corporation
Megatek Corporation
Princeton Electronics Products
Information Displays, Inc.
Vector General
Lear Siegler, Inc. and Digital Engineering, Inc.
Tektronix, Inc.
Ramtek Corporation
Intelligent Systems Corporation
IBM Corporation
Imlac Corporation
Hewlett-Packard
DeAnza Systems, Inc.
Genisco Computers
Aydin Controls

Graphics Software:

SOL at University of Colorado and LPARL
Flight Test Data Processing System at LMSC
MIPS at MSFC
PLOT 10 Interactive Graphics Library by Tektronix
VERSAPLOT by Versatec

Array Processors:

Data General
CSPI
ESL, Inc.
Analogic Corporation
Floating Point Systems, Inc.
Goodyear Aerospace Corporation
Signal Processing Systems, Inc.

Analog Video Recording Equipment:

Interpretation Systems, Inc. (ISI)
Information Processing Systems (IPS)
Teknekron
Sony Corporation
Panasonic Company
RCA Corporation
Philips Laboratories

Analog Video Display and Manipulation Equipment

- Princeton Electronics Products (PEP)
- Hughes Aircraft, Industrial Products Division
- Colorado Video, Inc. (CVI)
- Quantex Corporation
- Sony
- Conrac
- Tektronix
- Toshiba
- ISI
- Vidicom
- Advent Corporation
- LeCroy Research Systems of California
- Panasonic
- Hamamatsu Corporation

Digital Image Processing Systems

Recording:

- IPS
- ISI
- Teknekron
- Philips

Hard Copying:

- Versatec
- Trilog, Inc.
- Polaroid Corporation
- Muirhead Systems Ltd.
- Tektronix
- Edo Western
- Dunn Instruments

Institutional Systems:

- IDIMS at ESL, Inc.
- Image Proc. Lab. and VICAR at JPL
- IUESIPS at GSFC
- SIDS at Harvard College Observatory
- IPPS and FORTH at Kitt Peak National Observatory
- IDAPS at MSFC

First Level Image Displays: (see Section 3.5.3)

- Bausch and Lomb
- Hamamatsu
- E. Leitz, Inc.
- Joyce Loebl
- Spatial Data Systems, Inc. (SDS)

Second Level Displays:

- Grinnell Systems
- DeAnza Systems
- COMTAL Corporation
- Aydin Controls
- Genisco Computers
- Hazeltine Corporation
- ISI
- Lexidata Corporation
- Ramtek

Third Level Processing Displays:

- COMTAL
- DeAnza Systems
- Grinnell Systems
- Stanford Technology Corporation (STC: also known as I^2S)
- Aydin Controls
- Genisco Computers
- Hazeltine
- ISI
- Lexidata
- Ramtek
- ESL