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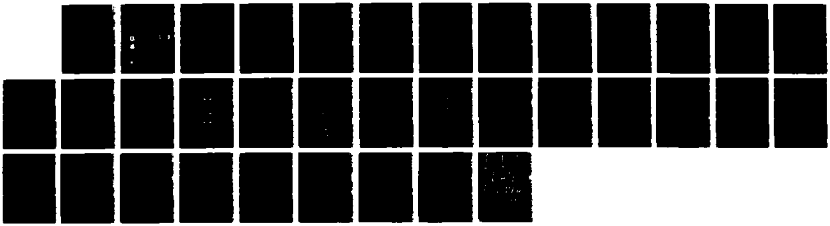

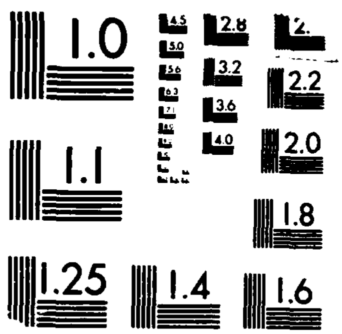

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The Design and Development of the AFGL Vibro-Acoustic Measurement System

HOWARD E. MICHEL

24 April 1987

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EARTH SCIENCES DIVISION
PROJECT 7600
AIR FORCE GEOPHYSICS LABORATORY
HANSCOM AFB, MA 01731

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This technical report has been reviewed and is approved for publication.

FOR THE COMMANDER

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The Vibro-Acoustic Measurement System is a distributed computer network designed for monitoring environmental motions. The heart of the system is a master control unit to centrally manage the network as well as to continually record data. Closely coupled to the master is an array processor for the massively parallel data processing required in digital signal processing. Five slave units are coupled to the master. Each slave can handle 16 sensors; the system capacity is 80 channels. The network will function using only one voice grade telephone line between the master and each slave. [illegible] launching sites, Vibration monitors

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Preface

The vibro-acoustic environment at V-23 on Vandenberg AFB must be monitored during STS launches to insure integrity of the ground support equipment structures, particularly three mobile buildings: the Payload Changeout Room (PCR), the Shuttle Assembly Building (SAB), and the Mobile Service Tower (MST). However, this effort is constrained by several factors: limited power and communications lines in both the park and forward positions; and the requirement for a near real time data display.

Consequently, the Air Force Geophysics Laboratory was asked to design and fabricate a system that could efficiently and reliably monitor STS launches.

This report describes the system developed by AFGL, with particular attention to its physical components and its capabilities and limitations. In Appendix A to this report the installation details of the system at Vandenberg AFB are described.

Contents

Illustrations

The Design and Development of the AFGL Vibro-Acoustic Measurement System

1. INTRODUCTION

The Mobile Service Tower (MST), Payload Changeout Room (PCR) and Shuttle Assembly Building (SAB) at Vandenberg AFB are mobile structures with very limited power and communications links to the outside. However, the Air Force requires near real time monitoring capabilities of the vibro-acoustic environment from these buildings during STS launches. In addition, the Air Force requires substantial data analysis following the launch to determine system weaknesses that will warrant further monitoring, and thus affect placement of sensors in subsequent launches.

Further, because of the short interval between launches, flexibility of the system was a major design concern. Major system redesign between launches had to be avoided. Therefore, AFGL's objective was to develop an easily reconfigurable, flexible, distributed computer network that would enable efficient vibro-acoustic monitoring of the launches.

This report describes the system network, its several components, and the capabilities and limitations we anticipate from the system.

In meeting these technical requirements, AFGL has designed and built the VAMS, which consists of the following computers linked in a network:

— Node 1, The Master
— Node 2, The Number-cruncher
— Node 3-7, The Slaves

Figure 1 illustrates the relationships among the components.

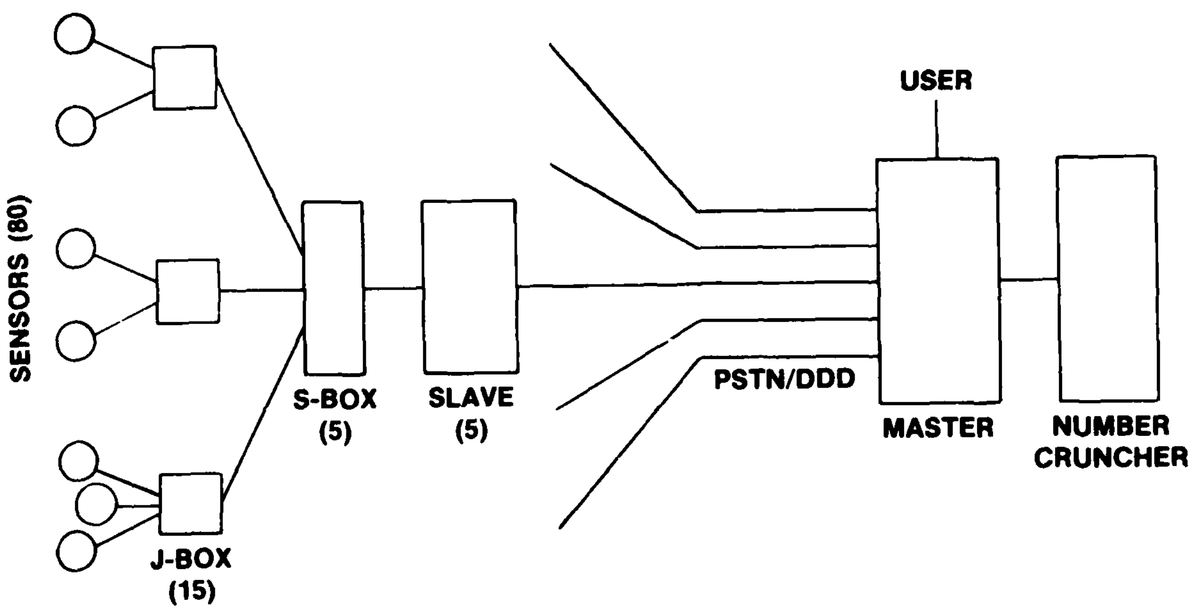

Figure 1 — The AFGL VAMS

2. THE SYSTEM

The Vibro-Acoustic Measurement System (VAMS) is an easily reconfigurable, flexible, distributed computer network of seven nodes connected in a star configuration. The heart of the system is node 1, "the master", a super-fast micro-processor to centrally manage the network and peripheral processors, as well as to continually record data. Closely coupled to the master is node 2, a standard micro-computer for serial code execution, and an array processor for the massively parallel data processing required in digital signal processing. We call node 2 the "number-cruncher." Nodes 3 through 7 make up the front end of the system. Each node, an instrumentation slave unit, or just "slave", consists of a micro-computer, non-volatile memory for data storage, an analog-to-digital converter, and an analog front end. All nodes run the Digital Equipment Corporation RSX-11M operating system.

2.1 The Network

The network consists of two types of communication paths. First, nodes 1 and 2 are connected by a super high speed, direct memory access line, allowing each node virtually unlimited access to the memory, mass storage, and peripheral equipment of the other node. These two nodes almost function as one, but, operating independently and executing different instructions on the same data, allow extremely efficient use of the major computing power of the network.

Second, is used to connect nodes 3 thru 7 are connected independently to node 1 through a medium speed communications system described as "long haul". Presently, we are using state-of-the-art long-haul synchronous modems capable of transferring data at 9600 baud half duplex over one direct distance dial public switched telephone network (DDD/PSTN) (that is, 3 KHz conditioned) phone line. With this equipment, the distance between slaves and the master is virtually unlimited. Over shorter distances, the modems are capable of 9600 baud full duplex over two conditioned phone lines, or one unconditioned (that is, direct) phone line.

This network can be used to monitor or alter the status of the slaves from one central location, or to pass the digitized data from the slaves to the number cruncher for near real time reduction, or simply to back up the data in case of catastrophic failure of a slave.

2.1.1 LOCAL HIGH SPEED. The primary hardware used to implement the local high speed communications between nodes 1 and 2 is two direct memory access (DMA) controllers, one on each of the nodes' system busses. The DMA units can read and write into any memory address on their respective busses without the main processor intervening. The two DMA units are connected by a parellel bus capable of exchanging data in excess of 500K bytes/sec. In a hardware sense then, data in either node's memory is available to be used or copied by the other node.

Sitting on top of this hardware will be system software currently in development. These programs will allow the DMA hardware to expand its reaches into the entire system at each node. References to devices outside the local node will be treated as system global references and passed through the DMA hardware to the other node. Programs running on either node then will have access to the peripherals of the other node. This operation is intended to be transparent to the user. Additionally, one high speed serial link is provided between nodes 1 and 2 for coordination and communications, thus allowing the high speed parallel link to function efficiently.

2.1.2 LONG HAUL. The long haul network uses available phone lines to connect nodes 3 through 7 to node 1. To operate at the maximum rate possible using existing public switched telephone network direct distance dialing (PSTN DDD) 3KHz conditioned phone lines, we are using state-of-the-art synchronous modems. The modems use a combination of phase and amplitude modulation, and are capable of transmitting information at a data rate in excess of the Nyquist signaling rate by forcing each sample to transfer a vector of information rather than a single bit. We are thus able to transfer data at 9600 baud, half duplex, through the 3KHz signal conditioning equipment at phone company switching centers.

If two such phone lines are available, 9600 baud, full duplex is possible, but the master will have trouble sustaining five such data streams. Additionally, if the network is limited in geographical spread, and dedicated or unconditioned lines (through the same phone exchange) are available, the network can operate at 9600 baud, full duplex, but again the master will be the bottleneck.

Finally, between the modems and their respective nodes is an error checking and correcting buffer that insures error-free transmission between the nodes. An added benefit incorporated into this device is its ability to interface an asynchronous device to the synchronous modem, thus allowing a simple interface to the computer.

Originally, operating system utilities and "device drivers" were to be used to implement these functions. For example: the command "PIP TT5:=TT2:" would transfer input typed onto terminal "TT2:" to port "TT5:", and if "TT5:" was connected to a modem, the information would be transferred to a remote location. If "PIP" was running at the remote computer, this information would be transferred in a similar manner to a file or terminal. Two obvious benefits of this scheme are: 1) the user does not need to learn a new set of commands and, 2) the procedure is already documented. Unfortunately, what sounds good in theory often doesn't work so well in practice. If the above method is used to transfer files, the terminal device driver does not throttle the information flow and the system crashes. Three solutions are possible: modify the device driver, manually slow down the transfer rate, or develop a communication software package. All are being investigated.

2.2 Node 1, The Master

The master has two functions. Its primary function is to oversee the network. Its secondary function is to provide access to the VAMS by the operator. It is central, both logically and conceptually, but not necessarily physically, to the network. The master is the heart of the network, and the heart of the master is a Digital Equipment Corporation LSI 11/73 microprocessor.

2.2.1 HARDWARE AND SOFTWARE. The physical layout of the components in the master is shown in Figure 2, and represents a compromise between cooling needs of the equipment and operator convenience. Figure 3 is the arrangement of cards in the ADAC 1200 backplane. Ideally the boards would be placed in the daisy-chain sequence leading from the processor in the upper left, to the right, then down, then left, then down, etc. corresponding to the interrupt priority desired. This ideal must be tailored by the real world constraints of: 1) size, that is, no space can be left vacant and, 2) hardware quirks. Specifically some of the boards are "DEC compatible" and they do not implement the Direct Memory Access grant 100% correctly.

Appendix B is a copy of the "SYSSAVED.CMD" file used during the "system generation" procedure. A close examination of this file reveals the software options selected as well as the hardware supported, however, not all of this software capability is used by the hardware detailed in Figure 3. Some of this capability is available for specialized jobs like "sys-gen", when the resources are reconfigured into a "computing center" rather than a data acquisition system.

2.2.2 NORMAL OPERATIONS. In the course of normal operation, the operator would configure and verify the status of the slaves through the master. Then the operator, the master, or the slaves

MASTER

MODEM 9600 A/B
MODEM 9600 A/B
MODEM 9600 A/B
MODEM 9600 A/B
MODEM 9600 A/B
ADAC SYSTEM 1200 LSI-11/73 COMPUTER
DSD-440 DUAL FLOPPY DISK
QUALOGY CYCLONE WINCHESTER DISK and MAG TAPE
POWERLINE FILTER

Figure 2 — Master, Layout of Components

MASTER
CARDS IN CPU BOX

<table>
<tr><td>LSI-11/73</td><td>256 KB RAM</td></tr>
<tr><td>DSD-440 FLOPPY DISK DRIVE CONTROLLER</td><td>ECC LOGIC</td></tr>
<tr><td colspan="2">QUALOGY CYCLONE DISK AND TAPE CONTROLLER</td></tr>
<tr><td colspan="2">AVIV TFC-909 TAPE CONTROLLER</td></tr>
<tr><td>DLV 11/J SERIAL PORTS</td><td>DLV-11/J SERIAL PORTS</td></tr>
<tr><td>C-TIMER</td><td>DLV-11/E MODEM PORT</td></tr>
<tr><td colspan="2">DA-11 Q-BUS DMA LINK</td></tr>
</table>

Figure 3 — Master, Cards in CPU Box

independently at some pre-configured set of conditions (time and/or signal input), would start the VAMS taking data. The slaves would then send data and status back to the master where it would be stored on a 88 Mbyte Winchester disk. This capacity represents approximately four hours of data at the maximum data transfer rate of the network. Data from the disk can be dumped to magnetic tape cartridges, and since these are removable, total system capacity is unlimited, although this requires an operator to be present. Simultaneously, data would be made available to the number cruncher, and a short time later preliminary processed data from the number cruncher would be given back to the master for display on a text terminal, color graphics terminal, printer or color plotter.

Figure 4 represents the hardware abstraction of normal operations. Data generally flows from left to right and commands flow from right to left. The CPU sits on top controlling the bus, arbitrating between its own requirements and Direct Memory Access requests. RAM is essential to all operations and thus anchors the bus.

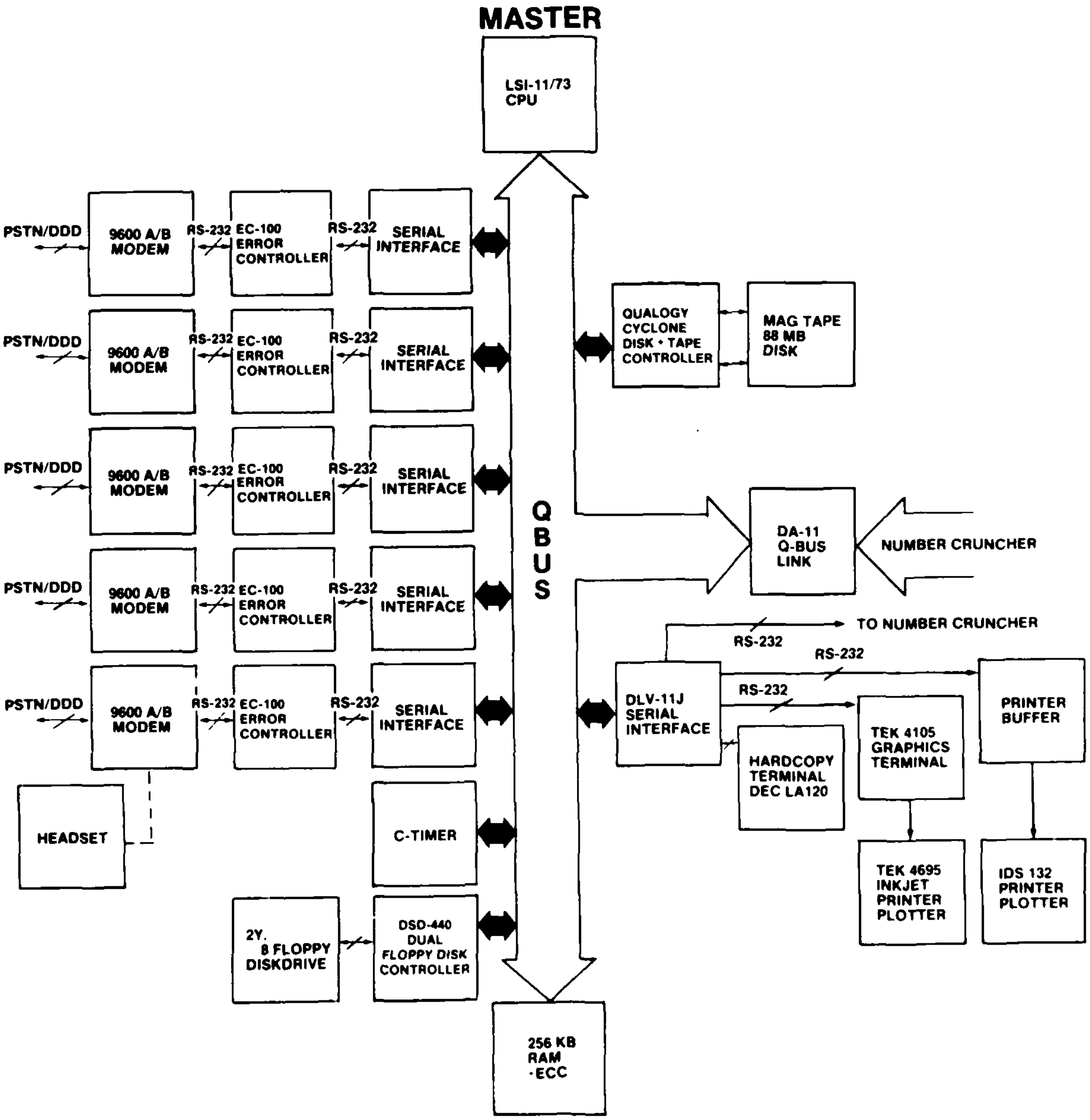

Figure 4 — Master, A Functional View of the Hardware

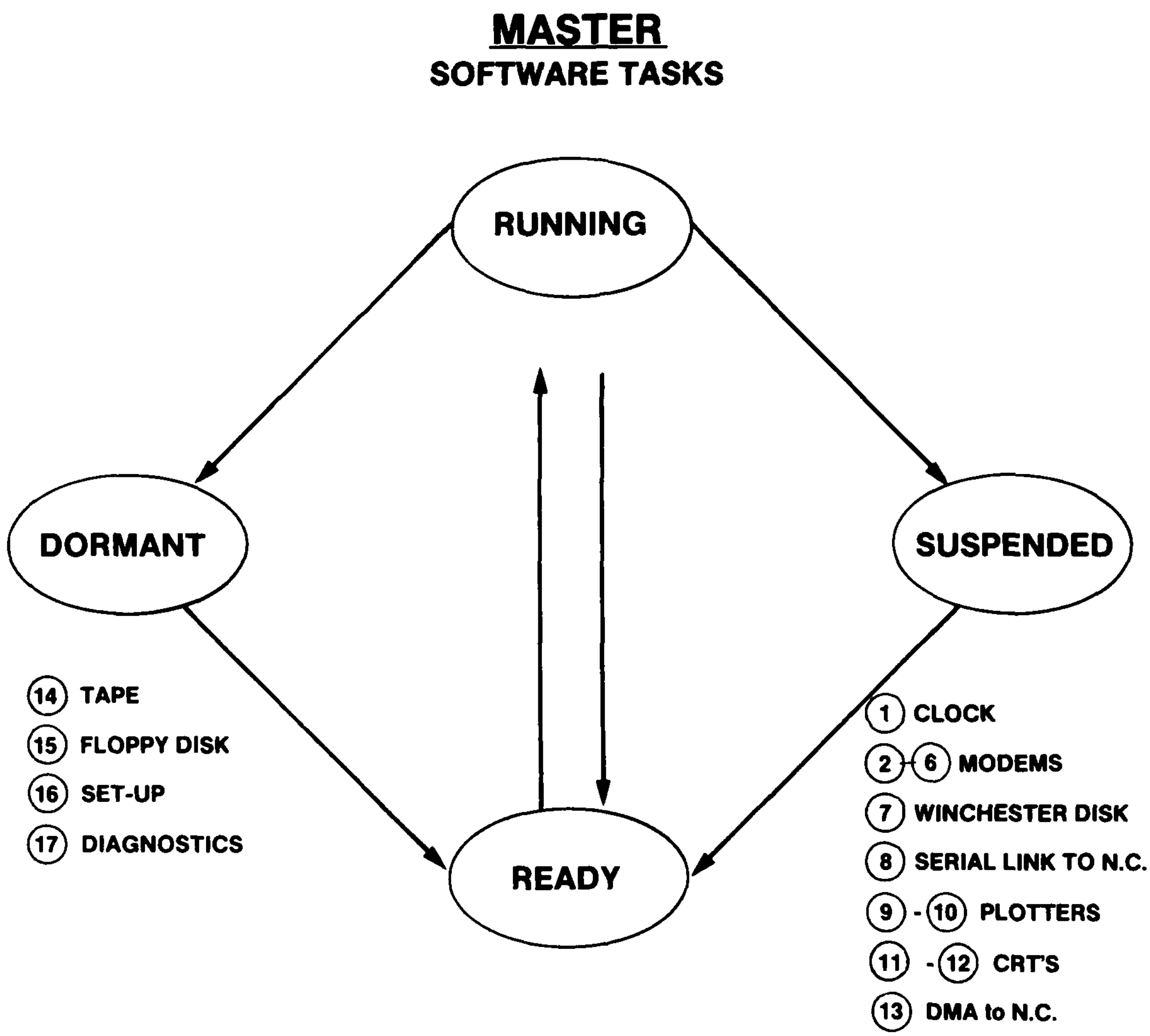

Figure 5 — Master, A Functional View of the Software

Figure 5 is a time slice view of the software; the number associated with a task is its priority. Tasks move between various states depending on their priority and ability to run. "Suspended" tasks are waiting for some event in hardware, for example, a clock interrupt or I/O completion. When this happens a task moves to the "ready" state. If this task is higher in priority than any other "ready" task and higher than the "running" task, it becomes the current "running" task. If a running task is thus preempted, that task drops back to become a "ready" task. When a "running" task completes it generally drops back to the suspended-task queue, and the highest priority task in the ready queue becomes the "running" task. The "dormant" task queue contains tasks not needed for the current application.

2.3 Node 2, The Number Cruncher

The sole purpose of node 2 is to process large amounts of data in a short time. Operations such as Fourier transforms, convolution, scaling, and correlation can be accomplished. Additional computations are required for graphical display of the data; the number cruncher handles these too. The number cruncher gives the VAMS a near real-time data analysis capability, at least for a limited number of channels.

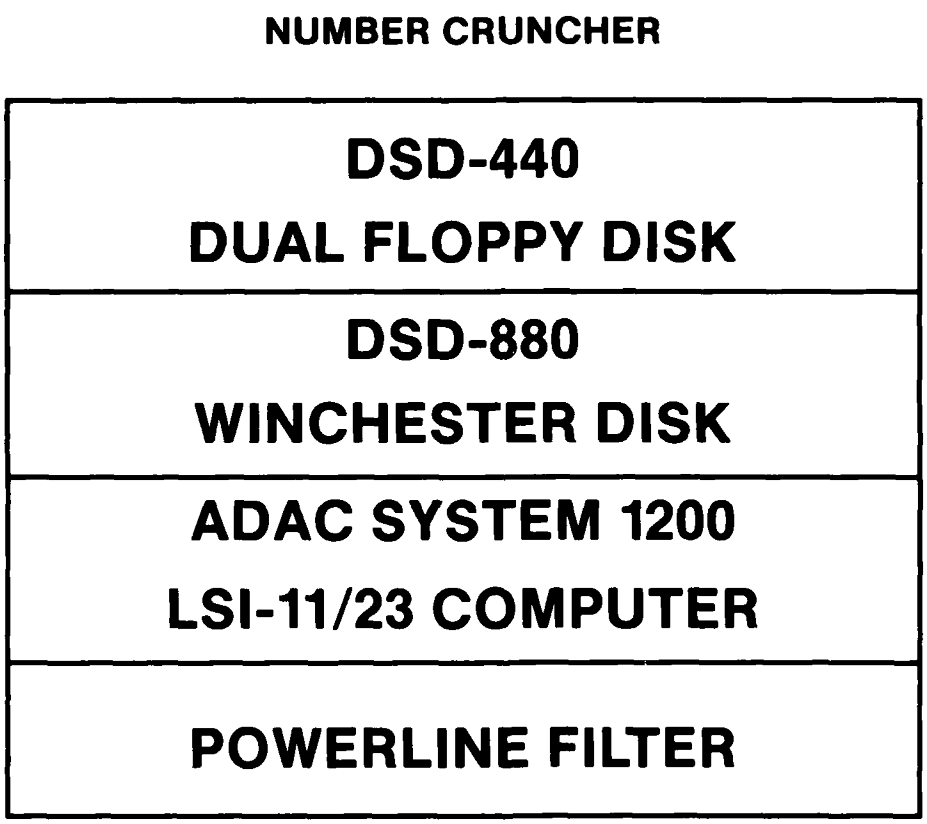

Figure 6 — Number Cruncher, Layout of Components

The physical layout of the components in the number cruncher is shown in Figure 6, and represents a compromise between cooling needs of the equipment and operator convenience. Figure 7 is the arrangement of cards in the ADAC 1200 backplane. As in Node 1, the board arrangement is the daisy-chain sequence leading from the processor in the upper left, to the right, then down, then left, then down, etc. corresponding to the interrupt priority desired. The constraints of size (no space can be left vacant) and hardware quirks may cause alteration of this order. Specifically, some of the boards are "DEC compatible" and they do not implement the DMA-grant 100 percent correctly.

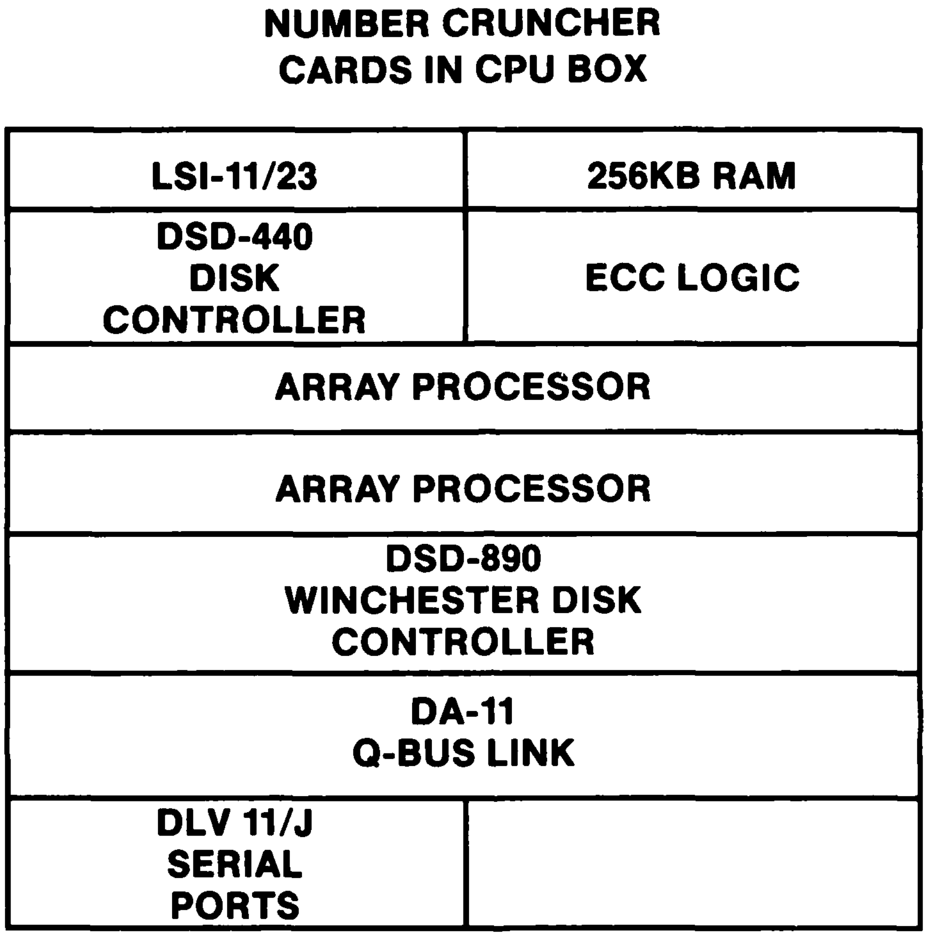

Figure 7 — Number Cruncher, Cards in CPU Box

Figure 8 represents the hardware abstraction of normal operations. Data generally flows in and out from the left. Commands also flow in from the left, and the mass storage devices are on the right. The CPU sits on top controlling the bus, arbitrating between its own requirements and DMA requests. The array processor is actually a co-processor functioning as a DMA device, operating with the permission of the main processor. RAM is essential to all operations and thus anchors the bus.

Figure 9 is a time slice view of the number cruncher software; the number associated with a task is its priority. As in the master, tasks move between various states depending on their priority and ability to run. The differing states occur in the same way as they do for the master.

The "SYSSAVED.CMD" file that defines this operating system is almost identical to the file that created the master, except the processor is an LSI 11/23. However, in order to function correctly with the array processor some of the device drivers must be "unloaded." This method is preferable to generating a separate system because it gives us a readily available backup if the LSI 11/73 fails.

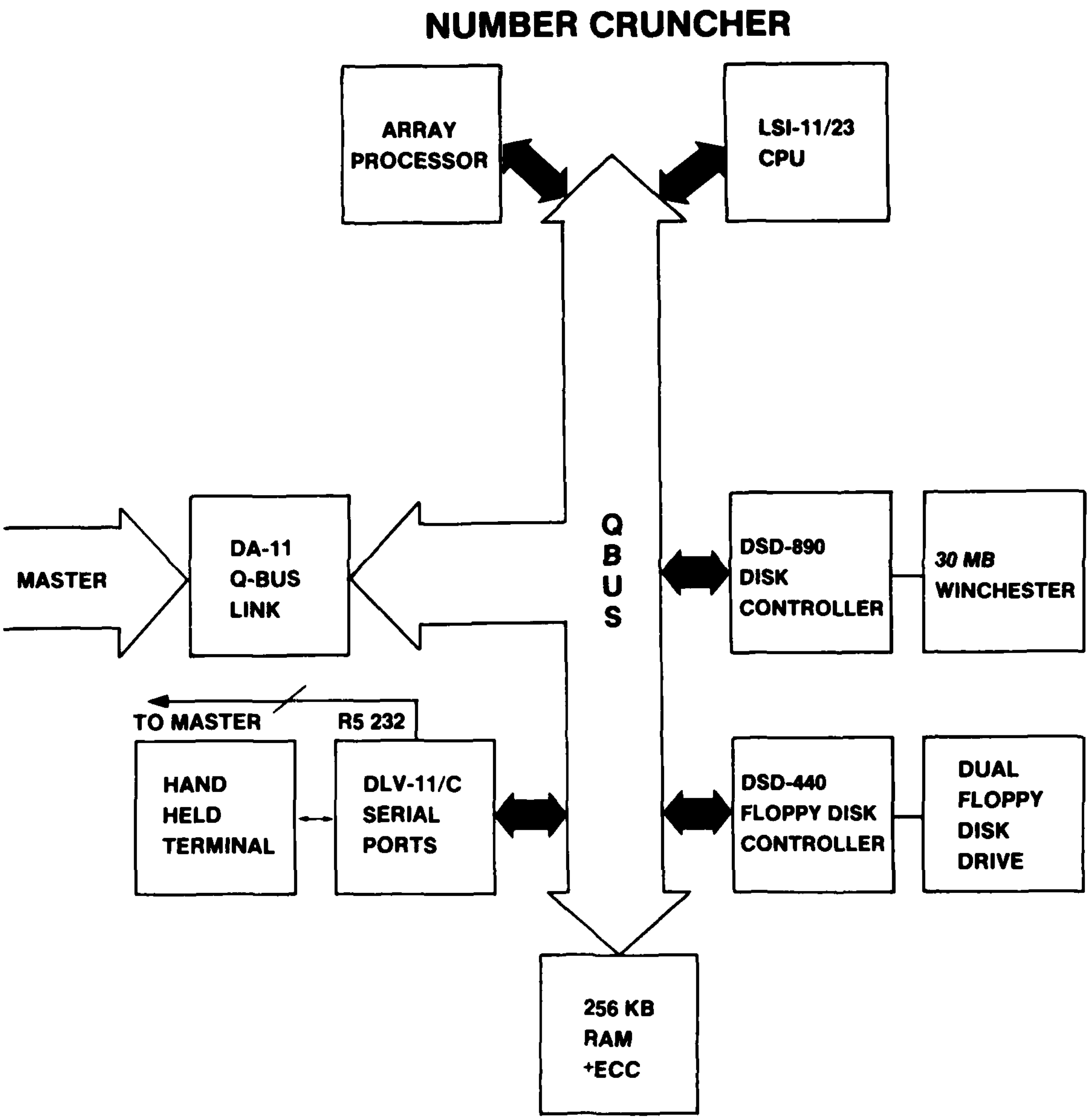

Figure 8 — Number Cruncher, A Functional View of the Hardware

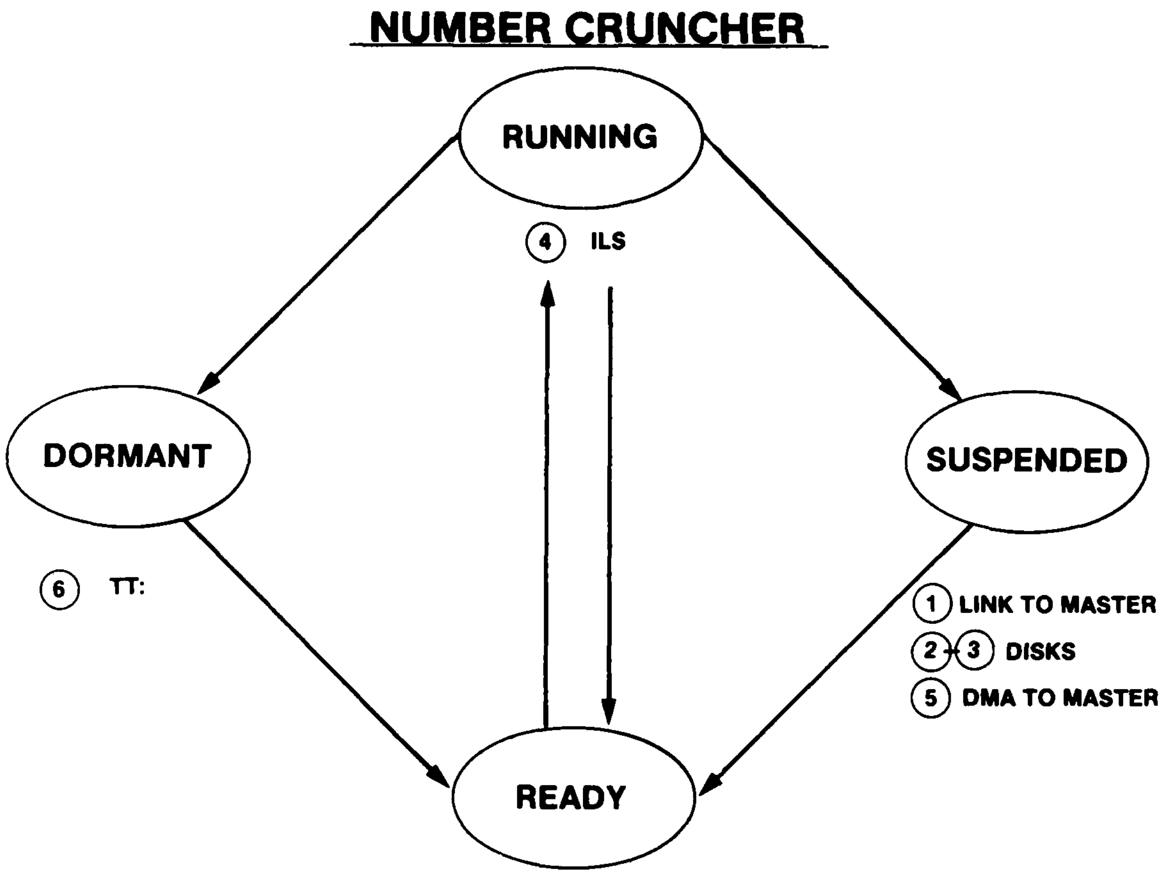

Figure 9 — Number Cruncher, A Functional View of the Software

2.3.1 THE ARRAY PROCESSOR. The array processor is a pipelined vector processor manufactured by Sky Computers, capable of one million operations per second. A portion of the speed is derived from the pipeline effect, in which instructions are fetched and executed in an overlap fashion. The vector concept executes the identical instruction on a vector of data instead of the scalar components that make up the vector. These engineering efforts combine to produce the greatest benefit in work like digital signal processing and simulation.

2.3.2 THE DSP SOFTWARE. We are using an interactive Digital Signal Processing software package made to run on the Sky array processor. It can, for example, compute a Fourier transform of a time series, display both on a color graphics terminal, and then by calling other functions, the operator can use the cross hairs to select a range, expand the display, filter it, or modify it. The software, in combination with the operating system will support multiple users or tasks, or through indirect command files, enable unattended operation.

2.4 Nodes 3 thru 7, The Slaves

The slaves perform two roles: (1) intelligent data acquisition systems; and (2) communication links back to the master. The brain of each slave is a Digital Equipment Corporation LSI 11/23 micro-processor. It manages four distinct information flows through the slave:

(1) Commands generated from within the slave, directed to the analog-to-digital converter (ADC), the analog filters, or the various components in the slave's sensor tree;

(2) Command and status messages between the slave and the master. These could be relayed by both, for example, the operator at the master might change the gain of one channel;

(3) Data from the slave's ADC into the slave's memory;

(4) Data from the slave's memory back to the master.

The analog characteristics of the slaves are alterable, many in software requiring only fractions of a second, and others requiring wires to be jumpered taking possibly several hours. Each slave can handle 16 sensors, and with five slaves the system capacity is 80 channels.

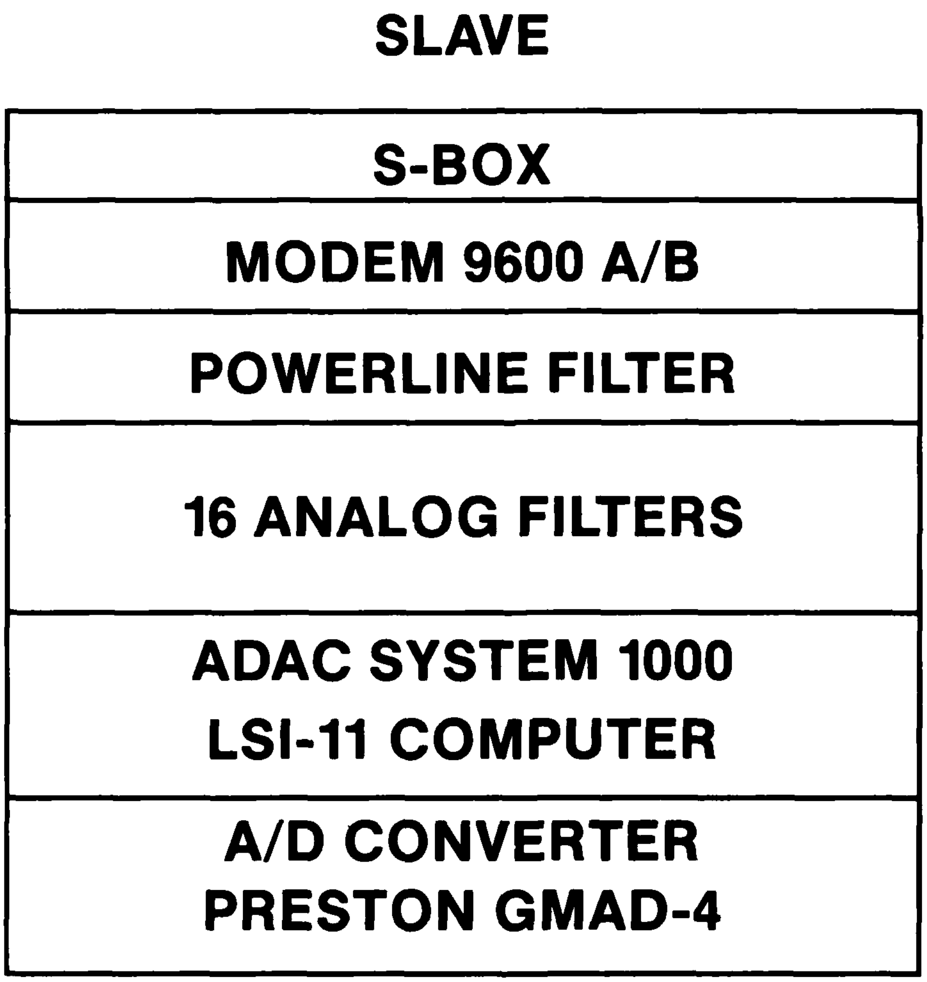

Figure 10 — Slave, Layout of Components

The physical layout of the components in a slave is shown in Figure 10, and, as in the other nodes represents a compromise between cooling needs of the equipment and operator convenience. Figure 11 is the arrangement of cards in the ADAC 1000 backplane. As in nodes 1 and 2, boards would be ideally placed in the daisy-chain sequence leading from the processor in the upper left, to the right, then down, then left, then down, etc. corresponding to the interrupt priority desired. Once again, this ideal must be altered so that no space is left vacant and hardware quirks are accommodated.

SLAVE
CARDS IN CPU BOX

LSI-11/23	256KB RAM
QBC 11/02 MBM CONTROLLER	ECC LOGIC FOR RAM
DRV-11B DMA INTERFACE	
Q MONITOR	DLU-11J
1632 TTL	
QBI 11/512 .5 MB MBM	QBI 11/512 .5 MB MBM
QBI 11/512 .5 MB MBM	QBI 11/512 .5 MB MBM

Figure 11 — Slave, Cards in CPU Box

Figure 12 represents the hardware abstraction of normal operations. Data generally flows from left to right, that is from the ADC to the MBM or modem, and commands flow from right to left. All of this, whether a DMA transaction or under program control, passes through the RAM. RAM is essential to all operations and thus anchors the bus. The CPU sits on top controlling the bus, arbitrating between its own requirement and DMA requests.

SLAVE

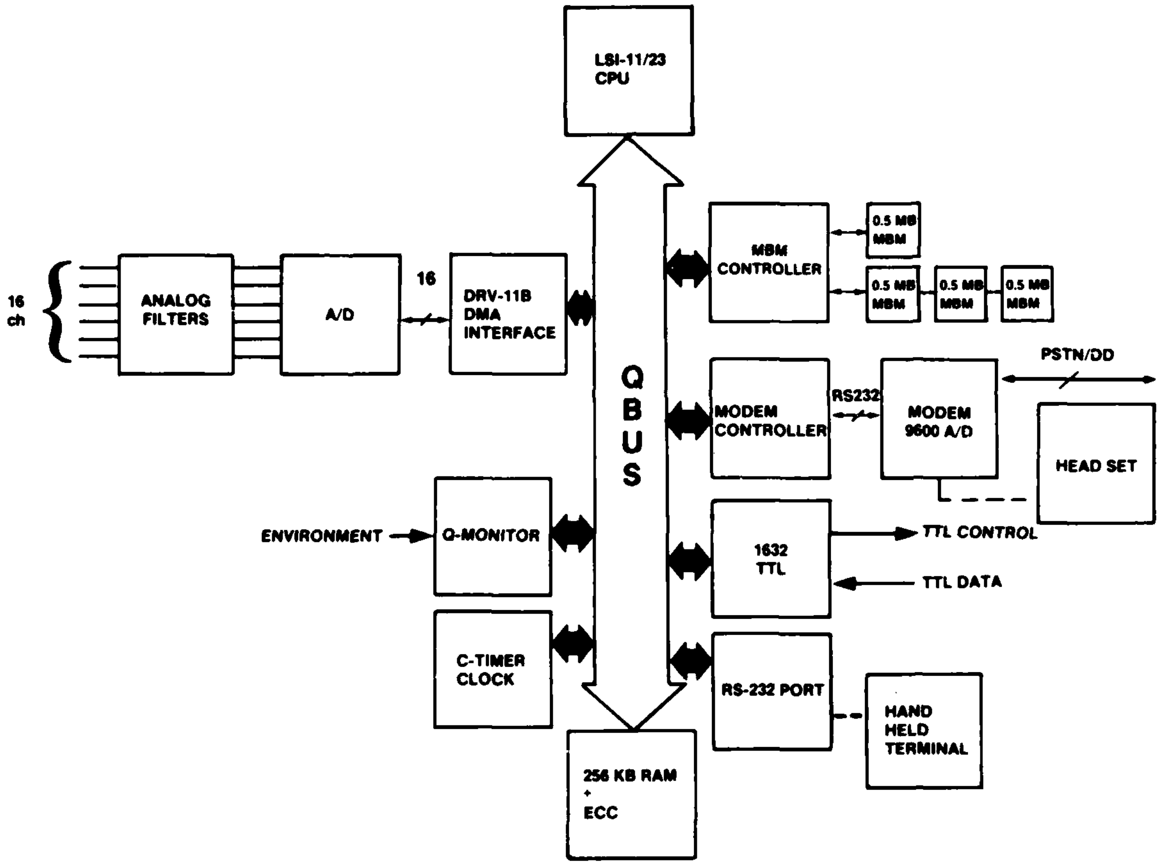

Figure 12 — Slave, A Functional View of the Hardware

Appendix C is a copy of the "SYSSAVED.CMD" file used during the "system generation" procedure. A close examination of this file reveals the software options selected as well as the hardware supported. The slave is a very simple system, designed to occupy as little MBM space as possible.

Figure 13 is a time slice view of the slave software. Tasks move between various states depending on their priority and ability to run, just as in the number cruncher and the master.

2.4.1 POSSIBLE PROBLEMS. If the network crashes, the slaves are capable of performing the data acquisition and storage as previously programmed, independent of outside conditions. Note, however, that local data storage capacity is limited to the capacity of the magnetic bubble memory.

The slaves are also capable of running on battery power for up to 60 minutes. Moreover, alternate power conserving modes of operation during power failure could be directed from the master. In the event of power and network failure, the slave could hibernate until an internal timer signals an upcoming scheduled event. A lighter sleep might possibly sample inputs, looking for conditions before becoming fully operational. These options should extend battery powered system life to hours or days.

2.4.2 MAGNETIC BUBBLE MEMORY. Crucial to the concept of the slave is its magnetic bubble memory (MBM). Since MBM is nonvolatile, data written into it will remain, with or without power, until deliberately erased. Each slave has two Mbytes of MBM on four 0.5 Mbyte cards, with one controller capable of implementing up to sixteen Mbytes of MBM as eight separate emulated floppy disk drives, or one hard disk drive.

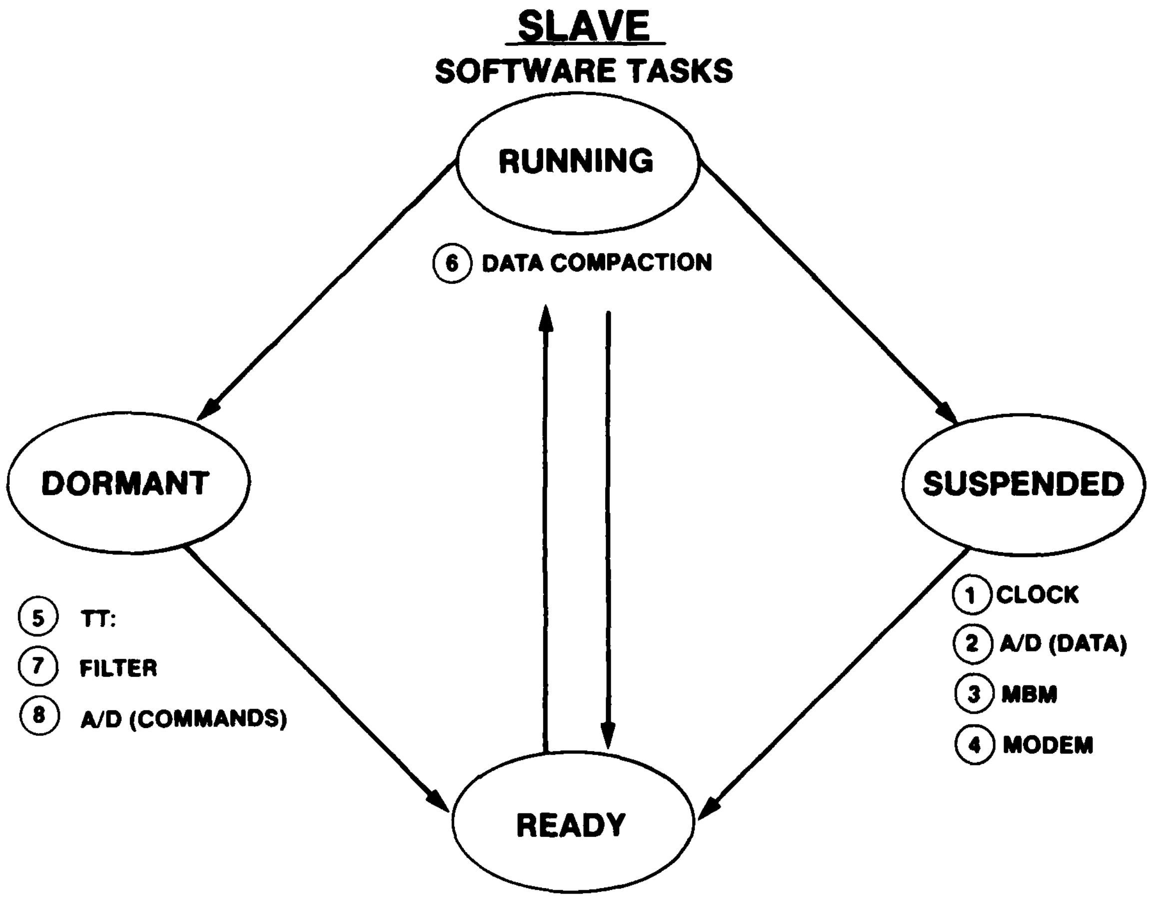

Figure 13 — Slave, A Functional View of the Software

With 0.5 Mbytes set aside for the operating system and applications programs, each slave is therefore completely self-contained. Additionally, the 1.5 Mbytes of MBM allocated to data storage will provide a safe buffer in the event that the network crashes, or room for several minutes of data in a "stand-alone" mode if the network is undesirable or impossible to implement.

The exact capacity of the MBM is a function of data bandwidth, data accuracy, and number of channels. The data bandwidth is related to the signal bandwidth by the quality of the anti-aliasing filter. Currently, at each slave, we can store approximately 16 minutes of 30 Hz data at 0.5 percent accuracy, but only four minutes of 60 Hz data at maximum accuracy.

Use of modular MBM permits flexibility. For example, if less than five slaves are desired, the MBM can be swapped into the remaining slaves thus increasing their capacity. If the entire system is to be expanded, the MBM can be easily increased. However, MBM is expensive.

2.5 The Analog Front End

The analog front end consists of: all the sensors, pre-amplifiers, cables, junction boxes, and switch boxes which together comprise the sensor tree; the anti-aliasing filters; and the analog to digital converter. Closest to the computer is the analog-to-digital converter (ADC). We are currently using 16 channel units capable of sampling all channels simultaneously.

2.5.1 ACCURACY. Accuracy is 15 bits, or approximately 0.003 percent. This is far superior to any of the sensors we currently use, and we do not anticipate the ADC ever becoming the weak link in the VAMS. If accuracy to only 0.5 percent is desired, only one byte is needed to represent the data. Maximum input bandwidth is 40KHz but the bubble memory is currently capable of supporting only 150 samples per second at maximum accuracy for 16 channels. For a slight increase in system complexity this can be increased to 450 samples per second, but without additional MBM, this higher data rate would only expend MBM more quickly. Additionally, the network could not handle this higher data flow unless either the number of input channels or the data accuracy were reduced. Increasing the total data flow on the network is also not possible without substantially increasing the speed of the master.

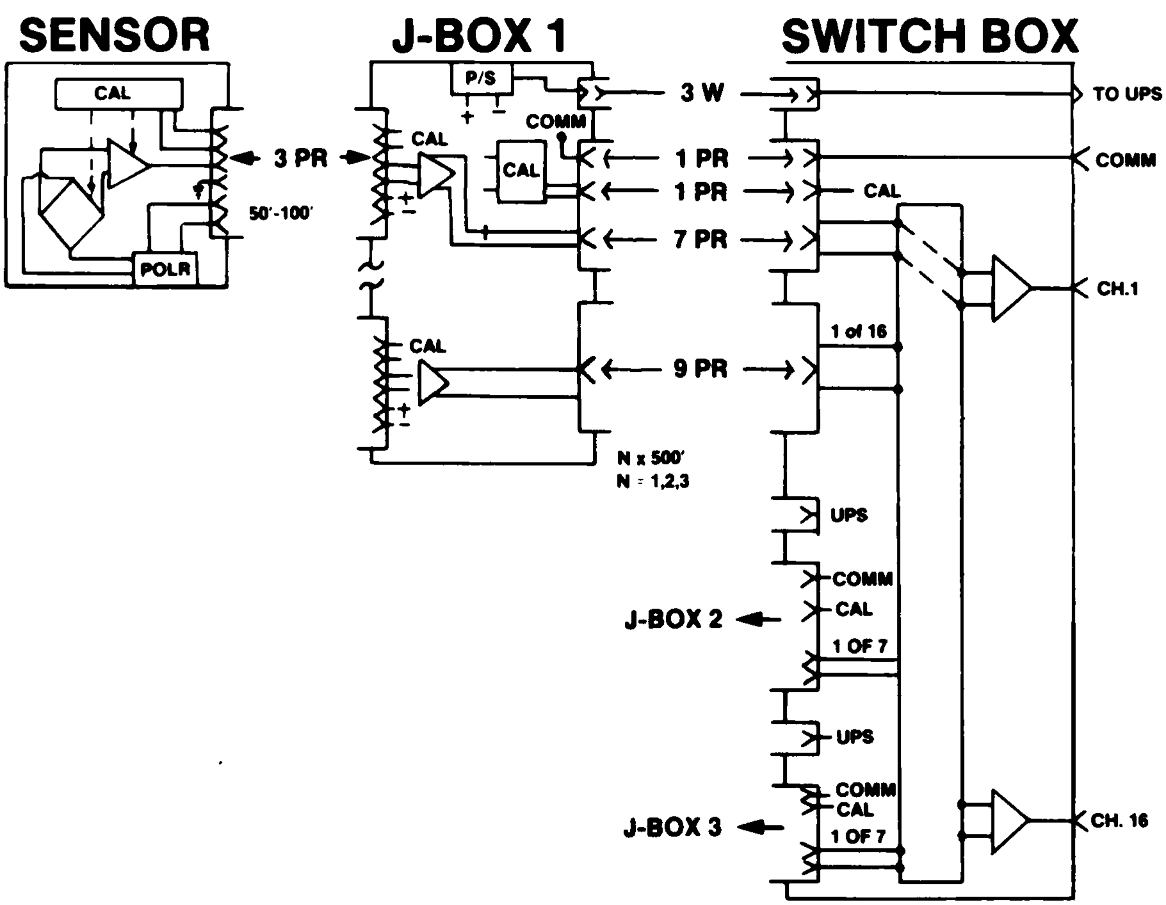

Figure 14 — The Sensor Tree

The input to the ADC is from the anti-aliasing analog filters. Soon to be implemented are software programmable, variable gain and variable cutoff, low pass filters. These filters determine the ratio of ADC sampling to the highest signal frequency desired. With 80dB/octave roll-off, our units enable us to obtain 15 bit accuracy by sampling at only 3.06 times the highest frequency desired, assuming a white noise environment. If the noise is red in the area of concern, or less accuracy is acceptable, this ratio can be improved. The switch box (S-box) portion of the sensor tree feeds the anti-aliasing filters.

2.5.2 THE SENSOR TREE. The arrangement of the sensors reminds one of tree trunks splitting into limbs, branches and leaves; hence, the name sensor tree. Each slave is capable of supporting a maximum of 16 sensors clustered around a maximum of three Junction boxes (J-boxes) in any possible configuration. Engineering efficiency dictated one J-box capable of handling sixteen sensors and two seven-channel J-boxes. The J-boxes feed the Switch box (S-box), which in turn feeds the anti-aliasing filters. See Figure 14, Sensor Tree.

The elements of the sensor tree provide the low level pre-amplification, signal conditioning, and line driving needed to insure signal integrity when it arrives at the slave, as well as the calibration and communication that must be maintained between the slave, the master, and the sensors.

Distance from the sensor to the J-box should be no more than 200 feet, and from each J-box to the S-box should be less than 2000 feet. The S-box is at the slave, and the distance from the slave to the master is limited only by available communication links.

2.5.3 SENSORS. The VAMS currently use seven types of sensors: absolute, gage, and differential pressure sensors; strain gages, seismometers, eddy field displacement, and accelerometers. All the sensors except the seismometer consist of a transducer and a pre-amplifier. The seismometers do not require this extra gain before reaching the J-box.

The J-box supplies $\pm$5V to the sensor, as well as a calibration pair, and the sensor has a return signal pair. If the sensor is capable of producing "volts" for its given physical sensitivity, the J-box can amplify this signal to $\pm$10V for the ADC. If, as in the case of our pressure transducer, the output is "micro-volts", we put a gain stage at the sensor. Any type transducer, with any physical range, that is capable of operating within these constraints is compatible with the VAMS, bearing in mind the overall low frequency (max of 50-150 Hz) nature of the VAMS.

3. CAPABILITIES AND LIMITATIONS

3.1 Capabilities

Currently, the VAMS is capable of recording and analyzing 80 channels of seismic and/or pressure signals with a maximum frequency of interest at 50 Hz.

Accuracy is better than 0.5 percent for pressure in the range of 0 to 1.5 PSID. Since all the sensors except the seismometers are average quality, off-the-shelf items, this is typical performance. Sensitivity of the seismometers to motion is better than 2×10^{-6} cm/sec; this is well below the average ground noise present. However, this degree of sensitivity is necessary for geophysical research.

3.2 Limitations

Altering the system to respond to different ranges of physical stimulus is simply a matter of defining the sensor. Stronger limitations are placed on the VAMS by its existing technology. Anticipated absolute maximums would be 200 Hz signals, at 15 bit (0.003 percent) accuracy for all 80 channels. The VAMS would operate at this speed for only minutes before overloading its buffering capability. Reducing any parameter above would enable the others to increase, but again, there are individual maximum limitations that have not been fully explored. Reducing all, for example, to the levels discussed previously would enable the system to operate stably for indefinite periods of time.

4. RESULTANT SYSTEM

The VAMS meets requirements that it be able to operate despite limited power and communications links to the outside and that it provide real time monitoring from mobile structures during STS launches.

The VAMS uses distributed computer techniques, as well as state-of-the-art hardware, including magnetic bubble memory and high speed synchronous modems.

Eighty channels can be locally recorded and then centrally displayed in near real time. Of these, 20 channels can be centrally recorded and displayed in real time.

The system consists of a master control unit to manage the network and continually record data, an array processor, and five slave units. The network will function using only one voice grade telephone line between the master and each slave.

APPENDIX A
Vandenberg AFB Instrumentation

Five Slaves, 13 junction boxes, and 76 sensors will be used by AFGL during the first STS launch from Vandenberg AFB.

A1 THE MOBILE SERVICE TOWER

A1.1 Instrumentation Slave Unit No. 1

S1 will be located on Level B, on the south side, east of the stairs near the west wall of the elevator between Columns G-3 and G-4. Electrical power, (110 VAC, 20 amp), and a dedicated telephone line, (having 3 kilohertz capacity), will be supplied to this unit. The supporting UPS unit will be installed adjacent to this ISU, located as necessary within a 6-ft. radius.

Junction Box and S1-JB1. S1-JB1 will be located on the roof, adjacent to the hatchway, mounted to the reverse side of the vertical bracket that has been installed just east of the hatch opening.

The sensors connected to S1-JB1 can be logically considered in three groups. Most cable runs will be predominantly 200 ft.

*Structural Sway.*There are two three component ± 5G accelerometer packages and two, two component ± 5G accelerometer packages covering the four corners.

West-Face Exterior Pressure Loading. There are two 0-20 PSIA sensors on the west wall, just below the roof.

South-Face Exterior Pressure Loading. There is one 0-20 PSIA sensor in the center of the south wall, just below the roof. This sensor is, in a data reduction sense, grouped with the pressure array in S2-JB3.

Junction Box No. S2-JB2. S1-JB2 will be located on Platform 20, on the south walkway, adjacent to the crane rail, near Column F-3. The sensors connected to S1-JB2 are logically considered one group.

MST Crane. One, three component ± 5G accelerometer package will be placed midway on the crane bridge.

Junction Box No. S1-JB3. S1-JB3 will not be used for first launch.

A1.2 Instrumentation Slave Unit No. S2

S2 will be located beside S1. Electrical power, (110 VAC, 20 amp) and a dedicated telephone line (having 3 kilohertz capability), will be supplied to this unit. The supporting UPS unit will be installed adjacent to this ISU, located as necessary within a 6-ft. radius.

Junction Box S2-JB1. Junction Box No. S2-JB1 will be located on Platform B, on the north side adjacent to the north wall, near Column A-3. The sensors connected to S2-JB1 can be logically considered in two groups measuring: (1) equipment vibration, and (2) hold down post strain. Cable runs will be 100 feet.

Selected Equipment Vibration. Three hydraulic units located on the second and third floors on the north side of the MST, will each be monitored by one ± 5G vertical accelerometer.

Hold Down Post Strain. One ± 2000 micro in/in strain base will be placed on a vertical member and a diagonal member in the northwest hold down post area.

Junction Box No. S2-JB2. S2-JB2 will be located on Level B, on the south side, near the west wall, near Column G-1. The sensors connected to S2-JB2 are approximately a mirror image of S2-JB1. They can be logically considered in two groups measuring: (1) equipment vibration and (2) hold down post strain. Cable runs will be 100 feet.

Selected Equipment Vibration. Two hydraulic units located on the second and third floors on the south side of the MST, will each be monitored by one ± 5G vertical accelerometer.

Hold Down Post Strain. One ± 2000 micro in/in strain base will be placed on a vertical member and a diagonal member in the southwest hold down post area.

Junction Box No. S2-JB3. S2-JB3 will be located on platform 18, near the south wall, between Columns G-2 and G-3. The sensors connected to S2-JB3 can be logically considered in two groups measuring: (1) south face pressure loading, and (2) west face pressure loading. This second group belongs, on a data reduction sense, with S1-JB1 — Group 2. Conversely, the sensor in S1-JB1 — Group 3 belongs with the first group here.

South Face Pressure Loading. Three groups of two 0-20 PSIA pressure sensors will be mounted, back-to-back (exterior interior pressures) on the south face between the 235 foot and 335 foot levels.

West Face Exterior Pressure. One 0-20 PSIA pressure sensor will be placed at the 300 foot level, facing west.

A2 THE SHUTTLE ASSEMBLY BUILDING

A2.1 (Instrumentation Slave Unit No. 3)

S3 will be located on the first level, on the north leg of the SAB, in the northeast end of the Mechanical Equipment Room No. 1, near Column A-6. Electrical power, (110 VAC, 20 amp), and a dedicated telephone line, (having 3 kilohertz capability), will be supplied to this unit. The supporting UPS unit will be installed adjacent to this ISU, located as necessary within a 6-ft. radius.

Junction Box No. S3-JB1. S3-JB1 will be located on the north leg of the SAB at the bridge crane level, on the walkway platform adjacent to the crane rail, near Column C-5, with the junction box mounted on its side to avoid causing congestion on the walkway. There are two logical groupings for these sensors.

Crane Bridge. One three component ± 5G accelerometer package will be placed on the crane bridge, midspan.

Crane Support. One ± 5G accelerometer will be placed midspan on the north crane rail. The south rail is physically covered in S3-JB3 — Group 3, but for data reduction, it will be grouped here.

Junction Box No. S3-JB2. Junction Box No. S3-JB2 will be located on the SAB roof, secured in place, on the north side of the ventilation structure, located approximately midway between the east and west ends of that structure. The three logical groups for these sensors measure: (1) structural sway, (2) east face pressure loading and (3) south face pressure loading.

Structural Sway. Two, two component ± 5G accelerometer packages will be placed to measure sway of the northeast and northwest corners.

East Face Pressure Loading. One 0-20 PSIA pressure sensor will be put on the northeast corner at the 319 foot level during data reduction. This sensor will be considered part of S3-JB3 — Group 1.

South Face Pressure Loading. One ± 5 PSID pressure sensor will measure interior exterior pressure at the 319 foot level. Again, during data reduction, the sensor will be grouped with those on S3-JB3 — Group 2.

Junction Box No. S3-JB3. S3-JB3 will be located on the south leg of the SAB, on Stairway No. 2, above the platform on the interior of the SAB mounted east of the doorway, mounted on an I-Beam approximately 4 ft. above the platform deck. This junction box will also be mounted on its side, similar to S3-JB1. There are three logical groupings measuring: (1) east face pressure loading, (2) south face pressure differential, and (3) crane support vibration.

East Face Pressure Loading. Two 0-20 PSIA pressure sensors are located on the southeast corner at the 215 and 265 foot levels.

South Face Pressure Differential. Three ± PSID pressure sensors are located on the middle of the south wall between 165 foot level and the 265 foot level. The sensors in S3-JB3 — Group 3 are grouped here for data reduction.

Crane Support Vibration. One ± 5G accelerometer is placed midspan on the south crane rail. It is grouped with S3-JB1 — Group 1 for data reduction.

A3 THE PAYLOAD CHANGEOUT ROOM

A3.1 Instrumentation Slave Unit No. 4

S4 will be located on Level 5, on the north side of the PCR, northwest of the main traffic area between Columns I-1 and I-2. Electrical power (110 VAC, 20 amps), and a dedicated telephone line, (having 3 KHz capability), will be supplied to this unit. The supporting UPS unit will be installed adjacent to this ISU, located as necessary within a 6-ft. radius.

Junction Box No. S4-JB1. S4-JB1 will be located on Level 1, in the stairway No. 1 entry area, near Column H-1, in the northwest corner of the PCR.

Hold Down Post Strain. Two ± 2000 micro in/in strain gages will be mounted on the north side, one in the northwest corner and one in the northeast corner.

Junction Box No. S4-JB2. S4-JB2 will be located on the north side of the PCR, on Level 8, adjacent to the west wall, between Columns G-2 and H-2.

Equipment Vibration. Predominantly vertical, ± 5G accelerometers will be placed on the base of assorted equipment on platforms from the 132 foot level thru the 191 foot level.

Junction Box S4-JB3. S4-JB3 will be located on Level 1, in the stairway No. 2 entry area, near Column B-1, on the southwest corner of the PCR.

Hold Down Post Strain. This is a mirror image of S4-JB1 on the south side.

A3.2 Instrumentation Slave Unit No. 5

S5 will be located on Level 5, on the south side of the PCR, southwest of the main traffic area between Columns A-1 and A-2. Electrical power, (110 VAC, 20 amps), and a dedicated telephone line, (having 3 KHz capability), will be supplied to this unit. The supporting UPS unit will be installed adjacent to this ISU, located as necessary within a 6-ft. radius.

Junction Box No. S5-JB1. S5-JB1 will be located in the room adjacent to the stairway southwest corner, on platform 14, secured in place, between Columns D-1 and D-2. There are three logical groupings for these sensors measuring: (1) east facing pressure, (2) structural sway and (3) PCR/PPR displacement.

East Face Pressure. One 0-20 PSIA pressure sensor is located in the southeast corner at the 260 foot level.

Structural Sway. One, two component ± 5G accelerometer package is located in the northwest corner.

PCR/PPR Displacement. Four displacement sensors measure the PCR/PPR gap at the roof level.

Junction Box No. S5-JB2. S5-JB2 will be located on platform 12, on the south side, between Columns C-3.5 and C-4. There are four logical groupings for the J-box measuring: (1) PGHM rail vibration, (2) equipment vibration, (3) east exterior pressure and (4) south exterior pressure.

PGHM Rail Vibrations. One, three component ± 5G accelerometer package is placed on the PGHM rail.

Equipment Vibration. One ± 5G vertical accelerometer is used, but during data reduction, it will be grouped with S4-JB2 - Group 1.

East Exterior Pressure. One 0-20 PSIA pressure sensor is placed at the 206 foot level.

South Exterior Pressure. One 0-20 PSIA pressure sensor is placed at the 235 foot level.

Junction Box S5-JB3. Junction Box No. S5-JB3 will not be used for first launch.

APPENDIX B

Master SYSSAVED.CMD

```
.IFT $SGN2 .ENABLE DATA $1
.ENABLE GLOBAL
.;
.; Phase I input saved answers
; created on 29-OCT-86 at 14:12:48
; by SYSGEN version 3.03
.;
.SETT $MAP
.; Target Configuration Section
.SETS $TPR "11/73"
.SETT $SWR
.SETN $TME 124.
.SETF $KSR
.SETT $FPP
.SETT $EIS
.SETN $PRO 0.
.SETS $LIN "A"
.SETF $WAT
.SETT $MPR
.SETT $CAH
.SETS $DEV "CO01DK01DL02DY02MS03"
.SETS $DV2 "LP01XB01XL04"
.SETS $DV3 "DU01YL09NL01"
.; Host Configuration Section
.SETT $LPR
.SETS $SPL "/-SP"
.SETT $FWI
.SETS $ALD "NL:"
.SETS $MPD "NL:"
.; Executive Options Section
.SETF $DBM
.SETT $F11
.SETT $RMS
.SETT $NRT
.SETT $LLR
.SETT $DRC
.SETT $MMD
.SETT $SRF
.SETT $GMC
.SETT $ACK
.SETT $IOR
.SETT $MUP
.SETT $ANM
.SETT $OUD
.SETT $LOD
.SETT $LLD
.SETT $AST
.SETT $CSM
.SETT $TKT
.SETT $PRF
.SETT $IRR
```

```
.SETT $20K
.SETT $LGD
.SETT $ERL
.SETF $ELC
.SETF $UWD
.SETT $WCH
.SETT $SWL
.SETT $XDT
.SETF $NET
.SETF $TSA
.SETT $DMA
.SETT $AMC
.SETT $PRN
.SETT $GGE
.SETS $DRR 'ABCDEFHIJKL'
.SETN $NPK 15.
.SETN $DTV 33.
.SETN $RRS 5.
.SETN $HIC 150.
.SETN $LOC 1.
.SETN $DKS 90.
.SETN $SWP 5.
.SETN $PNR 255.
.SETN $RSD 177564
.SETT $CHK
.SETT $DYN
.SETS $CRA 'B'
.SETN $NOT 177564
.SETS $MDD 'DY1:'
.SETN $MDC 177170
.SETT $RTE
.; Terminal Driver Options
.SETN $TMN 120.
.SETT $USC
.SETT $BWS
.SETT $CNR
.SETT $ESC
.SETT $MLC
.SETT $SMC
.SETT $GTD
.SETT $RAP
.SETT $RUB
.SETT $HRE
.SETT $DIC
.SETS $TTY 'C'
.; System Options
.SETF $IP11
.SETT $FRL
.SETS $FCP 'LARGE'
.SETT $PMD
.SETT $RMD
.SETT $DCL
.SETN $NUC 5.
.SETT $PMT
.SETS $NOD 'MASTER'
```

```
.SETF $SPM
.; Peripheral Configuration Section
.ENABLE GLOBAL
.SETS $$XB0 "274,774004"
.SETS $$XL0 "500,775700,H,6"
.SETS $$XL1 "510,775710,H,6"
.SETS $$XL2 "520,775720,F,6"
.SETS $$XL3 "530,775730,F,6"
.SETS $$LP0 "304,776504,LA180,0,300,160130"
.SETS $$DK0 "220,177404,1"
.SETS $$DL0 "160,174400,3"
.SETS $$DL1 "164,174600,1"
.SETS $0DL0 "RL02"
.SETS $1DL0 "RL02"
.SETS $2DL0 "RL02"
.SETS $0DL1 "RL01"
.SETS $$DU0 "254,172150,1"
.SETS $0DU0 "1"
.SETS $$DY0 "264,177170,2"
.SETS $$DY1 "270,777150,2"
.SETS $0DY0 "DOUBLE"
.SETS $1DY0 "DOUBLE"
.SETS $0DY1 "DOUBLE"
.SETS $1DY1 "DOUBLE"
.SETS $$MS0 "224,172522"
.SETS $$MS1 "230,772726"
.SETS $$MS2 "170,772532"
.SETS $$YL0 "60,177560,NO"
.SETS $$YL1 "310,776510,NO"
.SETS $$YL2 "320,776520,NO"
.SETS $$YL3 "340,776540,NO"
.SETS $$YL4 "350,776550,NO"
.SETS $$YL5 "360,776560,NO"
.SETS $$YL6 "370,776570,NO"
.SETS $$YL7 "430,775630,E"
.SETS $$YL8 "330,776530,NO"
.SETN $HIV 600
.SETF $EDX
.DISABLE DATA $1
.IFT $SGN1 .SETT $CS1
.IFT $SGN1 .ENABLE DATA
.ENABLE GLOBAL
.;
.; PHASE II input saved answers
; created on 29-OCT-86 at 14:59:23
; by SYSGEN version 2.11
.;
.SETF $LEM
.SETT $BAD
.SETS $PRM "NL:"
.SETF $EDF
.SETT $DFL
.SETF $ERV
.DISABLE DATA
.SETT $CS2
```

APPENDIX C
Slave SYSSAVED.CMD

```
.IFT $SGN2 .ENABLE DATA $1
.ENABLE GLOBAL
.;
.; Phase I input saved answers
; created on 30-OCT-86 at 16:33:51
; by SYSGEN version 3.03
.;
.SETT $MAP
.; Target Configuration Section
.SETS $TPR "11/23"
.SETF $SWR
.SETN $TME 124.
.SETF $KSR
.SETT $FPP
.SETT $EIS
.SETS $LIN "A"
.SETF $WAT
.SETT $MPR
.SETS $DEV "DL01DY01"
.SETS $DV2 ""
.SETS $DV3 "YL07NL01"
.; Host Configuration Section
.SETT $LPR
.SETS $SPL "/-SP"
.SETT $PWI
.SETS $ALD "NL:"
.SETS $MPD "DL:"
.; Executive Options Section
.SETF $DBM
.SETT $F11
.SETT $RMS
.SETT $NRT
.SETT $LLR
.SETF $DRC
.SETT $MMD
.SETF $SRR
.SETT $GMC
.SETT $ACK
.SETT $IOP
.SETF $MUP
.SETF $ANM
.SETF $OUD
.SETT $LOD
.SETF $LLD
.SETT $AST
.SETT $CSM
.SETT $TKT
.SETT $PRF
.SETF $IRR
.SETT $20K
.SETT $LGD
```

```
.SETF $ERL
.SETF $ELC
.SETF $UWD
.SETF $WCH
.SETF $SWL
.SETF $XDT
.SETF $NET
.SETF $TSA
.SETT $DMA
.SETF $AMC
.SETF $PRN
.SETT $GGE
.SETS $DRR 'ABCDFHIJKL'
.SETN $NPK 15.
.SETN $DTV 33.
.SETN $RRS 5.
.SETN $HIC 150.
.SETN $LOC 1.
.SETN $DKS 0.
.SETN $RSD 177564
.SETF $CHK
.SETF $DYN
.SETS $CRA 'C'
.SETF $RTE
.; Terminal Driver Options
.SETN $TMN 120.
.SETT $USC
.SETT $RWS
.SETT $CNR
.SETT $ESC
.SETT $MLC
.SETT $SMC
.SETT $GTD
.SETT $RAF
.SETT $RUB
.SETT $HRE
.SETT $DIC
.SETS $TTY 'C'
.; System Options
.SETF $BBF
.SETF $IP11
.SETT $FRL
.SETS $FCP 'LARGE'
.SETF $PMD
.SETF $RMD
.SETF $PRT
.SETF $PMT
.SETS $NOD 'SLAVE V2'
.SETF $SPM
.; Peripheral Configuration Section
.ENABLE GLOBAL
.SETS $$DLO '164,174600,1'
.SETS $ODLO 'RL01'
.SETS $$DYO '264,177170,2'
```

```
.SETS $0DYO 'DOUBLE'
.SETS $1DYO 'DOUBLE'
.SETS $$YLO '60,177560,NO'
.SETS $$YL1 '310,776510,NO'
.SETS $$YL2 '320,776520,NO'
.SETS $$YL3 '300,776500,NO'
.SETS $$YL4 '330,776530,NO'
.SETS $$YL5 '340,775610,E'
.SETS $$YL6 '350,775620,E'
.SETN $HIV 400
.SETF $EDX
.DISABLE DATA #1
.IFT $SGN1 .SETT $CS1
.IFT $SGN1 .ENABLE DATA
.ENABLE GLOBAL
.;
.; PHASE II input saved answers
; created on 30-OCT-86 at 17:14:26
; by SYSGEN version 2.11
.;
.SETT $LEM
.SETT $BAD
.SETS $PRM 'DL:'
.SETF $EDF
.SETT $DFL
.SETF $ERV
.DISABLE DATA
.SETT $CS2
>
```

END
DATE
FILMED
7-88
DTIC