



A Real-Time/Time-Share Computer in a Research and Development Environment

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A centralized computer with high speed peripherals, mass storage and very flexible input/output ports provides eighteen remote laboratory terminals with real-time/time-share computer service. The EMR 6130 Computer with Sandia designed interfacing provides real-time response in research and development activities involving on-line data acquisition, analysis and display, and includes features which allow process control and equipment programming activities. The system supports a variety of component development activities and materials research and supplies the technical staff (scientists and component designers) with immediate response to data as it is acquired from experiment apparatus or test equipment. Such response allows experimenter interaction as the experiment progresses and provides timely acceptance or rejection with analog or statistical display of the data.

KEY WORDS AND PHRASES: real-time computer service, remote laboratory terminals, centralized computer, remote time-share service, data acquisition/display, experimenter data interaction, real-time monitor, computer interfaces, data transmission,

equipment programming, experiment interface

CR CATEGORIES: 3.25, 3.89, 6.35

INTRODUCTION

The computer system was installed to provide real-time response in research and development activities involving on-line data acquisition, analysis and display, and includes features which allow process control and equipment programming activities. The system, which uses a centralized computer (EMR 6130), is in a development and research laboratory environment among a variety of component development activities and materials research.

The system is intended to supply the technical staff (scientists and component designers) with immediate response to data as it is acquired from experiment apparatus or test equipment. Such immediate data analysis and display allows experimenter interaction as the experiment progresses. The response for component testing is in the form of acceptance, rejection, or statistical distributions of attributes and eliminates previously

long turnaround times involving off-line data handling and batch processing. Long turnaround time is very undesirable because of relatively long setup times involved at experiment and test locations. Immediate response at the completion of an operation saves much delay and repeated setup efforts when data analysis dictates the necessity of a test operation re-run.

It would be difficult to justify minicomputers with the necessary peripherals except at a few stations which experience high usage and acquire large amounts of data. The approach taken provides a centralized computer more powerful and with higher speed peripherals than would be practical with a minicomputer approach. Remote stations are equipped for direct access to the computer providing the more powerful system to each user. Efficient use of the larger computer is then possible by the accumulated utilization by many users. The background batch capability with a FORTRAN IV Compiler and a machine language (ASIST) assembler support a host of users from microwave and communication theory groups to materials research groups as well as checkout of real-time user programs. The magnetic tape units also provide data storage which is directly compatible to many similar or larger computer systems.

A patch-panel connecting scheme is used to connect remote data acquisition and control equipment to the computer input/output data ports. This hardware patch-panel arrangement is desirable since many of the experiment activities require very long setup times compared to the actual experiment run time. The patch-panel is arranged such that a user may be connected to any available computer port that he requires. In this manner, a small number of computer input/output ports may be shared by a large number of users. The computer provides time sharing among those data ports active at any given time.

Since a wide variety of experiment and test equipment will be interfaced to the computer at remote locations, a scheme is required that will allow simple hardware/software interface design. This scheme for connecting remote activities to the

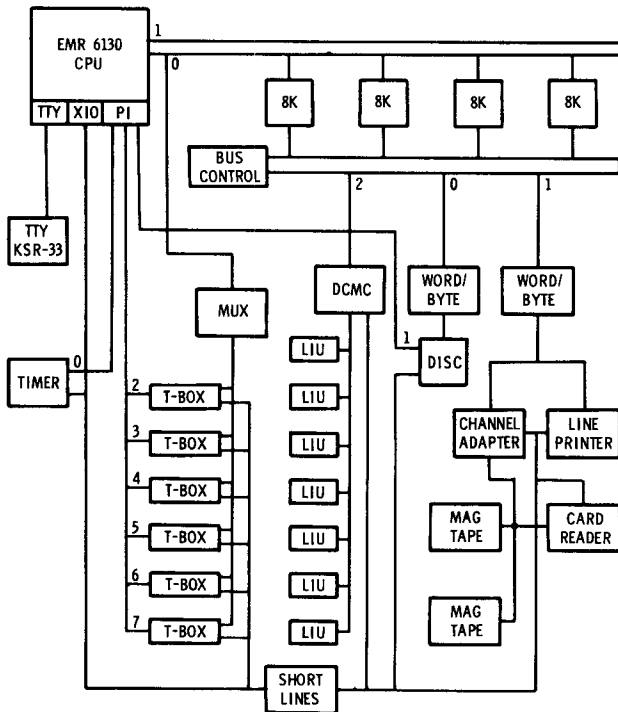
computer will be described.

SYSTEM HARDWARE CONFIGURATION

The block diagram of the EMR 6130 computer configuration is shown in Figure 1. The computer has the usual peripheral configuration with programmable input/output (XIO) and memory bus connections; however, it has additional buffered channels which operate with a variety of input/output ports for non-standard equipment interfacing. The buffered channels provide direct memory access for the input/output ports.

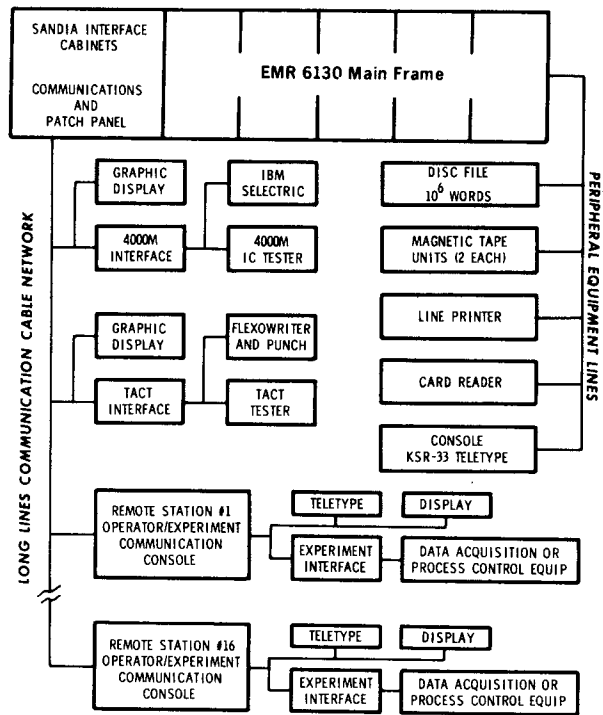
The EMR 6130 features an asynchronous bus organization which allows asynchronous devices to share the same memory module and memory modules of different speeds may be connected to the same bus. The bus system provides for simultaneous communication and control of multiple input/output (I/O) channels and/or multiple memory modules. The Sandia system is a two bus system. A bus can accommodate up to seven devices which share the access to the same memory modules. Each device connected to the memory bus can directly access memory which then frees the control processor from the routine tasks of handling all I/O activity. Each memory module therefore may connect with up to seven devices on each of two independent memory buses associated with each memory module. All I/O channels (except XIO) are buffered and connect directly to the memory and are assigned a priority relative to each of the other channels on the same memory bus. Memory service is on a first-come, first-served basis when two users are not requesting memory simultaneously. The additional bus will allow simultaneous access, by two different users, to different memory modules. One device may gain access through each memory bus. The memory module is 8K of 16-bit words plus parity and protect bits. The Sandia system has four such modules for a total of 32K words of core-memory while for mass storage there is a one-million word disc and two magnetic tape units.

The LIU's (Line Interface Units) and T-Boxes comprise the input/output ports of the computer for connection to outside activities.



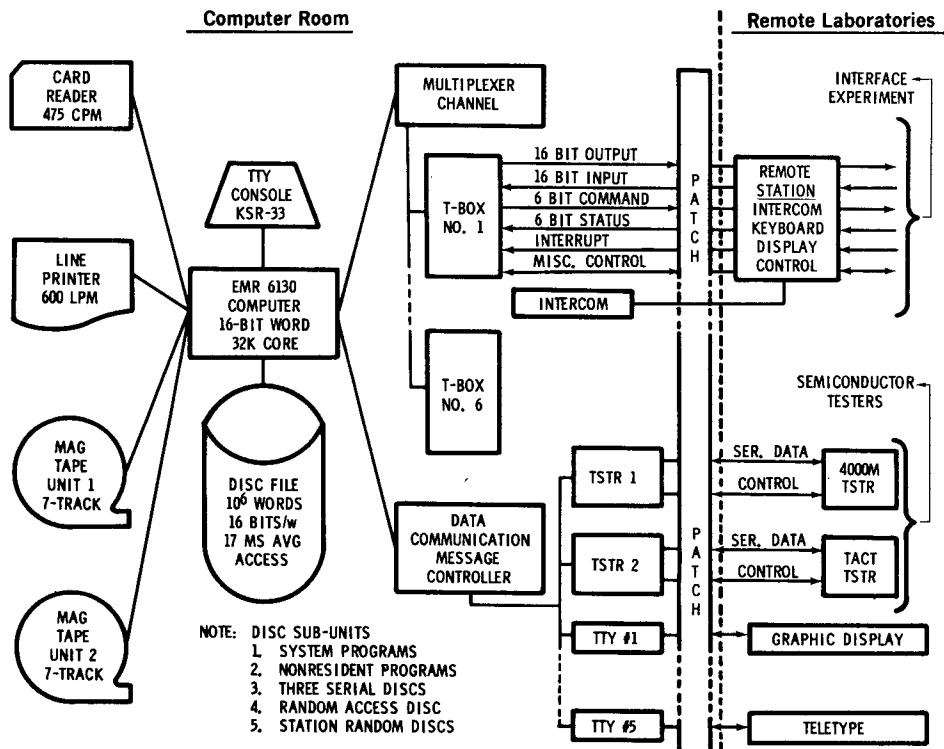
COMPUTER CONFIGURATION

Figure 1



REMOTE TERMINALS

Figure 3



SYSTEM INTERFACING

Figure 2

The general interfacing scheme is shown in Figure 2 and indicates how the input/output ports on the computer can be patched to a variety of users such as laboratory experiments, component testers, teletypes, or graphical display terminals.

The Multiplex Channel (MUX) is the buffered channel through which the T-Box ports obtain access to memory. The MUX scans the six T-Boxes and services those that are active and require attention. The Data Communication Message Controller (DCMC) provides a similar service to the LIU's.

The T-Box and LIU differ significantly in their operation. The T-Box, as shown in Figure 2, is a full-duplex/bit-parallel interface capable of high speed data transfer (10,000 to 50,000 words per second) with the transfer command being supplied by the remote station. The LIU is a half-duplex/bit-serial interface capable of data rates ranging from teletype keyboard operation up to the highest speed modems.

The diagram in Figure 3 shows the general configuration of the remote terminals. The present system can patch any one of eighteen remote laboratory terminals to any one of the six T-Boxes, two tester interfaces, and five teletype interfaces. Each terminal has the capability of being patched simultaneously to one T-Box or both tester interfaces and up to three teletype interfaces.

A typical remote terminal might consist of the following:

Remote Station Console. The RS console allows operator and experiment communication with the computer (priority interrupts, station assignment, program requests, octal data entries by keyboard, station sign-off, data and station status transfer and display).

Experiment Interface. The experiment interface marries the experiment equipment or tester to the remote station console.

Teletypewriter. The teletypewriter provides for alphanumeric input or output messages and summary data hard copy.

Graphic Display Terminal. The display terminal displays analog, discrete, or alphanumeric data resulting from experiment or tester input data (in some cases the display terminal might double for input/

output message or data transfers).

TRANSMISSION SCHEME

The cable network is made up of 18 separate cable sets, each providing the required signal lines for connection of a remote station console. The 18 cable sets fan out from the computer room and terminate at 18 different laboratory locations on two floors of the building. The length of a cable set ranges from 100 to 350 feet.

The cable set contains several shielded twisted-pair signal lines to allow high speed data transfer for the full-duplex interfaces as well as high speed half-duplex display terminals and the slower speed teletype terminals.

The transmission scheme for the remote stations uses isolated line drivers and receivers at the ends of a shielded twisted-pair. The transmit/receive circuits for full-duplex transmission are shown schematically in Figure 4. The scheme provides excellent isolation eliminating the need for a common ground between the computer and remote stations. The circuit has been free of cross-talk and exhibits good insensitivity to outside noise sources. The devices may be paralleled at each end of a twisted-pair line to allow half-duplex transmission (such a circuit is used for the Tester Interface type LIU).

REMOTE STATION TERMINAL

The purpose of the remote station (RS) console (see Figure 3) is to provide the computer port at the location of the experiment or test station in each laboratory. In addition, it provides a well-defined hardware/software interface to which each station activity is married. The console provides a method of operator communication with the centralized computer and allows control of the station activity by the computer. Operator communications and computer/station status are displayed on the console display panel. The principal parts of the remote station console provide the following features:

Intercom. The intercom provides a direct line of communication between computer and remote station

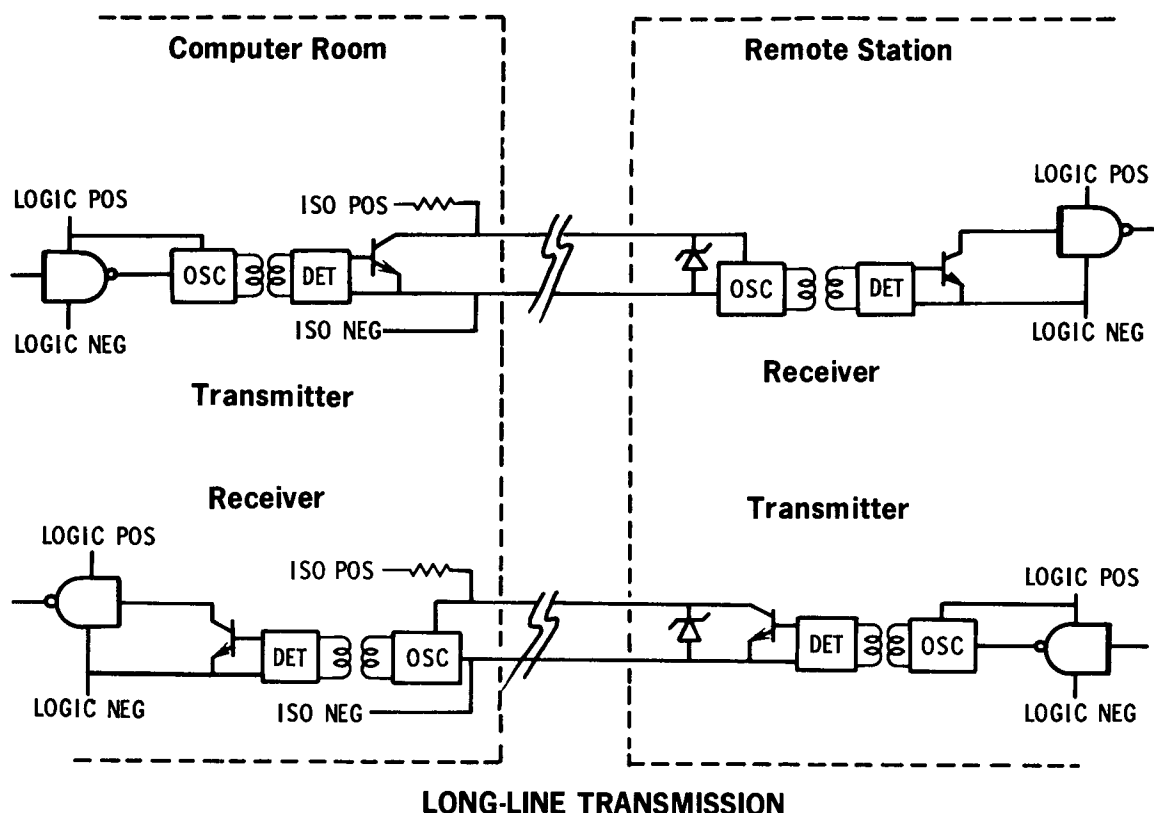


Figure 4

operators. The intercom is used for station connect and disconnect requests and allows automatic station hold if the master station is busy, hands-off communication for remote station operators, and direct communication for prolonged checkout and maintenance procedures.

Operator Keyboard. The keyboard is used for selecting a specific program from the computer program library. The selected program may assume control of an automatic tester or interact with the RS operator who responds on the keyboard. The keyboard also allows the RS operator to interrupt an activity at any time.

Display Panel. The RS display panel indicates program and operational status to the RS operator. The display panel also indicates requests made to the RS operator by the program and allows the operator to view his keyboard entries prior to transmission to the computer.

Control Chassis. The control chassis automatically provides the signal conditioning, control and a portion of the timing for the interaction of the computer program, experiment equipment, keyboard and display. The control chassis also provides the input/output data lines with certain control and status lines for connection to the experiment interface.

Other Support Equipment. The remote station equipment cabinet which contains the above items also contains long-line cable transmitters and receivers, power supplies, cooling equipment, AC control panel, work surface, and space for the laboratory equipment interface.

The above hardware allows design of a standard and optimized system software package which simplifies application programming and minimizes software overhead. All features common to all remote stations are consolidated in a single

design to provide the advantages of standardization and its effect on initial fabrication costs and maintenance support activities.

EXPERIMENT INTERFACE

The remote station console provides space for the experiment interface hardware if required, although in some cases it may be desirable to house the interface with the experiment or test equipment. The experiment interface (see Figure 3) amounts to a single instrument chassis which provides the final interface unique to a specific laboratory experiment or class of experiments. The experiment interface chassis provides the following as required by a specific laboratory activity: (1) Signal conditioning between the RS and the experiment or test equipment; (2) Analog-to-digital converters, digital-to-analog converters, analog multiplexers, and sample-and-hold circuits; (3) Data storage and shift registers; (4) Data encoders and decoders; (5) Data word multiplexers to sequentially connect storage registers to computer data lines via the RS (the system software and RS hardware allow direct random addressing of such storage registers, if desired, similar to an input/output bus arrangement); and (6) Power supply modules as required to make it a self-contained chassis.

Sandia design of computer room interfacing, remote stations and the experiment interfaces makes use of a commercial line of standard integrated circuit logic and computer services for layout and fabrication support.

The following paragraphs will describe in some detail a test station and two experiment stations receiving on-line service from the EMR 6130 Centralized Computer. These are laboratory stations which make use of the general purpose remote station console and the full-duplex T-Box interface at the computer.

The fireset tester makes use of the Sandia designed remote station console and a single drawer chassis which contains the electronics to connect the special fireset tester to the standard remote station console. The fireset tester performs evaluation testing on multichannel units which function to provide specified dc-to-dc conversions under a variety of signal input and environmental conditions. The tester

may be programmed to apply specified signals on a specified time schedule and measure input and output parameters (up to 33 measurement channels may be programmed). The tester controller may be programmed manually or by computer. For the computer control mode of operation, the tester operator has a direct intercom line with the centralized computer operator for computer patch-panel service. The tester operator requests to be patched on-line to the necessary computer input/output port. Once connected, the tester operator is in full control except for priority and equipment assignment decisions reserved for the computer operator in order to coordinate all computer service.

The operation of a single keyboard button by the tester operator causes the computer real-time monitor to automatically read the remote station console ID. The station ID is associated with all activity at this station and is used by the computer software executive. If the ID is acceptable, a message is typed out on the computer room console requesting the computer operator to assign a base priority for all operation by this station. This allows priorities to be assigned based on current computer facility activity. Once the computer operator responds with a base priority, the system monitor causes a display at the remote station console asking the tester operator what he wishes to do. The tester operator answers by entering an operation code and a nonresident program number and depressing the keyboard reply button. This causes the requested program to be queued on the memory allocation queue and loaded into core when memory is available. Execution of the program is initiated as the program is loaded into memory. The tester operator is now under his own program control, a program in which he may have included many options through tester operator interaction with the program. The alternate choice left to the tester operator, in response to the above mentioned monitor display, is a stop request which provides the tester operator with a method of terminating operation at his discretion. Up to this point, the remote station operation for all stations is the same. The flexibility now lies in the combined capability of the user program and the remote laboratory hardware.

The basic fireset user program provides essentially three options to the test operator; however, its first

act is to request a teletype for use at the remote station for tester operator communications with the user program. After the computer operator patches the teletype to an available teletype (LIU) input/output port on the computer, he then makes the assignment on the computer room console teletype and the fireset user program execution continues. The three modes of operation within the fireset user program are program, test and idle. In the program mode, the tester operator may build a test from a library of basic commands and assign the test routine a program number. Several such tests are constructed by the tester operator through use of the teletype keyboard. This group of tests (number programs) is modeled to the test requirements of the specific fireset to be tested. These programs are stored on the mass storage disc in the dedicated station random disc area for the fireset station. The tester operator may now go to the test mode of operation (all tester operator communication with the user program is accomplished with the teletype located at the fireset tester). In the test mode, the user program requests a test program number from the operator and upon receipt of this program number, loads the test program and executes it. The test program specifies the input variable values and those measurements to be saved on the station random disc and/or typed out as hard copy on the station teletype. This is repeated for each test selected by the tester operator until all fireset channels and input combinations are completed for the specific fireset being tested. Another fireset is then connected to the tester and the test process is repeated until all firesets have been tested and the data stored on the station random disc in the computer room. The entire operation is usually repeated at three temperatures prior to and after each environmental test (vibration, mechanical shock, thermal shock, etc.). The acquired data is periodically transferred by another user program from the station random disc to magnetic tape in a special format compatible to many sort, analyze and output routines which is a standard software package on an IBM 7090. This standard package is used by a variety of data acquisition centers throughout Sandia for data analysis.

A radiation effects group also makes use of the remote station console

terminal. This station studies semiconductor junction capacitance as related to semiconductor process techniques, semiconductor geometries, and radiation environments. A programmable capacitance bridge has been interfaced to the computer through the remote station console. Programs have been developed for bridge programming data acquisition and a variety of analyses and display routines exist for immediate response.

The test station operator interacts with the data acquisition program through the use of the graphic display terminal keyboard (after the initial connection and sign-on procedure through the remote station terminal as discussed in the fireset tester application). The station operator enters the desired component and test identification and specifies the voltage range and incremental values of the voltage variable to be applied to the device. In the test mode, the computer outputs the sequence of voltage values to be applied and accepts from the station the measured values for each voltage level. The experiment interface contains a DAC to convert the digital value from the computer to an analog value and applies the voltage to the device as it signals the capacitance bridge to take a measurement. The capacitance bridge provides digital values for capacitance and dissipation or conductance and includes range multiplier, decimal point and units for both values. Each bridge measurement is multiplexed by the experiment interface into three computer words and transmitted to the computer through the remote station console. Upon completion of the data acquisition process, the station operator may request graphic displays of C (capacitance) VS voltage, $1/C^2$ VS voltage, $1/C^3$ VS voltage, and impurity concentration VS distance.

The station is now studying diffused and ion implanted junctions for silicon and gallium arsenide semiconductors including radiation effects on such devices.

The remote station console is also used by a materials research and development group. Gas-material reactions are being measured and studied in association with interaction of materials and gas products within evacuated devices (caused by outgassing and leaks) and also in the development and study of gettering materials. The data is acquired through the use of a vacuum system, controlled gas leaks and

pressure measurements and analyzed on the computer to provide reaction rates and absorption information.

INTEGRATED CIRCUIT TESTER STATION

An example of a data acquisition and display station is the 4000M Integrated Circuit Tester as shown in Figure 3. The tester interface does not use a remote station console. A single chassis was designed to provide the interconnection of the 4000M IC Tester and output writer (an IBM 735 Selectric) to the EMR 6130 Computer. The chassis acts as a junction box and provides the necessary timing, control, code conversion and data transfer. A block diagram of the chassis is shown in Figure 5. The interface handles data transfers in four directions and provides the code conversion hardware for each direction as required: (1) 4000M Tester to IBM 735 (no code conversion); (2) 4000M Tester to EMR 6130 with IBM BCD-to-EBCDIC code conversion; (3) IBM 735 to EMR 6130 with a second (different from tester BCD code) code conversion from Selectric Input Code-to-EBCDIC; and (4) EMR 6130 to the IBM 735 with a third code conversion from EBCDIC-to-IBM BCD.

The interface was designed to make use of the existing IBM 735 I/O writer (as an integral part of the 4000M test station) for hard copy data output and as an input/output writer for operator communication with the computer. The interface chassis also provides serial-to-parallel and parallel-to-serial data conversion for data transfers between the test station and the computer. The 4000M test station is connected to the special high speed (5000 bps) LIU which is a half-duplex bit-serial computer interface (input/output port).

The 4000M tester is an automatic tester with a temperature chamber, a conveyor to sequence IC's under a test head, and a controller which sequences a program (stored on a magnetic disc within the tester) through several predetermined tests which are performed on each IC while it is under the test head. The test data is normally output on the output writer; but with the computer interface, the data is sent directly to the centralized computer for interpretation and subsequent analysis. Immediately after the last IC

is tested, a data analysis program may be requested by the tester operator. The information is displayed on a Computek graphical display terminal at the test station and allows the operator to interact with the data and the analysis program by: (1) Requesting a complete statistical analysis for any test performed on the IC's; (2) Overriding any data rejections made automatically by the statistical program; and (3) Rejecting from the distribution any device numbers he desires.

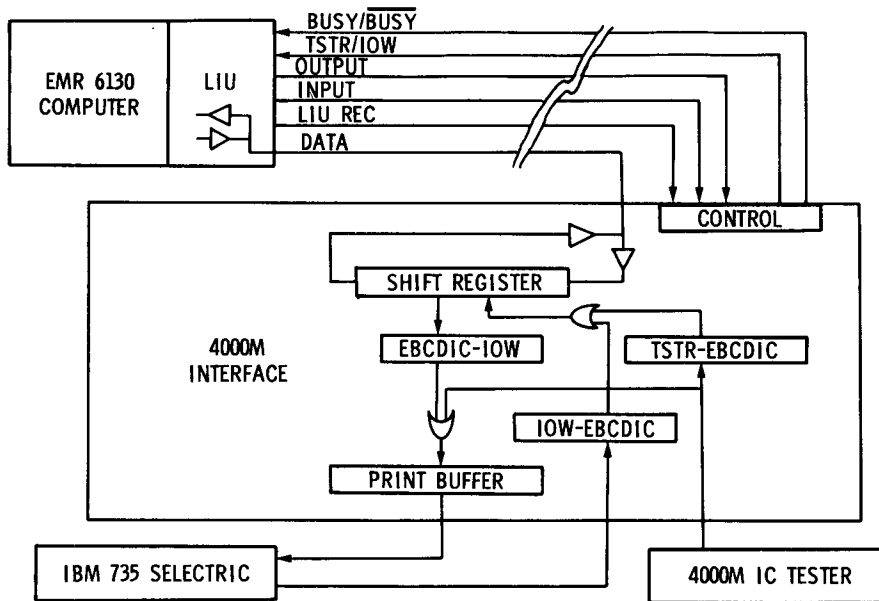
For each of the above operator options, the statistical information is recalculated and displayed on the CRT terminal. A hard copy may be made of any display with a Polaroid camera and hood accessory. Samples of the statistical display for the 4000M station are shown in Figures 6 and 7. Figures 8 and 9 are samples of graphical plots made on the CRT terminal of semiconductor doping profiles and reflect the curve plotting capability of the terminal.

SYSTEM SOFTWARE ORGANIZATION

User programs are written for each remote station to handle data acquisition, analysis and display as well as process control and equipment programming. The user program can make use of the complete computer configuration for each remote station. It directs all activity among remote station, buffered data interfaces, core-memory and the peripherals (two magnetic tape units, card reader, line printer and magnetic disc). The user programs may be written in Fortran, compiled, then stored on the mass storage device (disc) as a non-resident routine. The non-resident user program is queued on the Memory Allocation Queue upon request from a remote station. When core-memory becomes available, the program is loaded and receives control from the Job Sequencer on a priority basis.

The system software organization is shown in a very general sense by Figure 10. The system contains a real-time monitor which allows multiple programs to run concurrently based on an interrupt and priority organization and includes a time scheduler.

The real-time monitor receives requests from Remote Stations, Timer and Input/Output Interrupts, User



INTEGRATED CIRCUIT TESTER INTERFACE

Figure 5

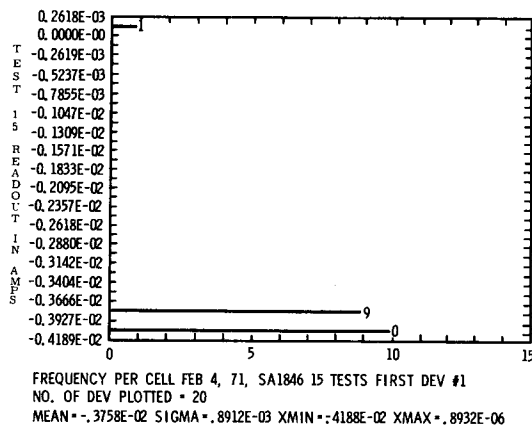


Figure 6

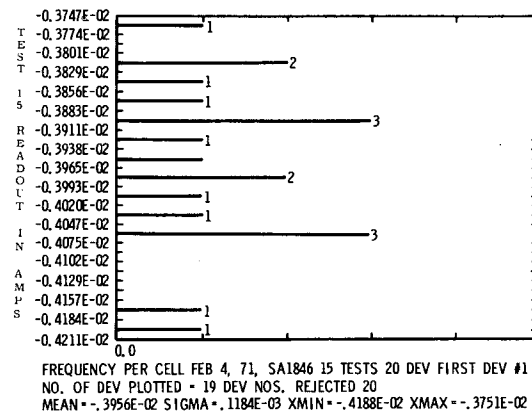


Figure 7

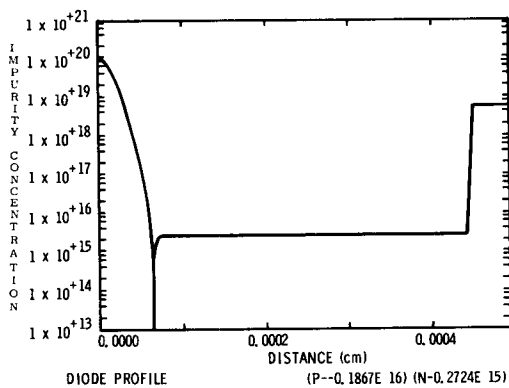


Figure 8

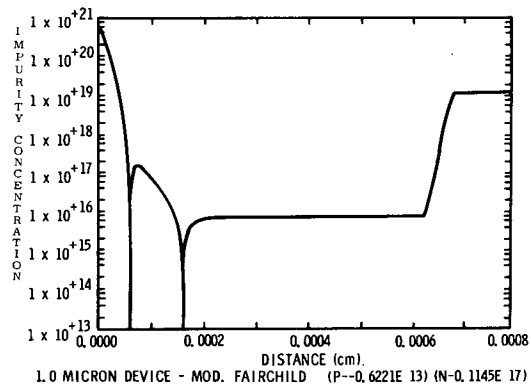
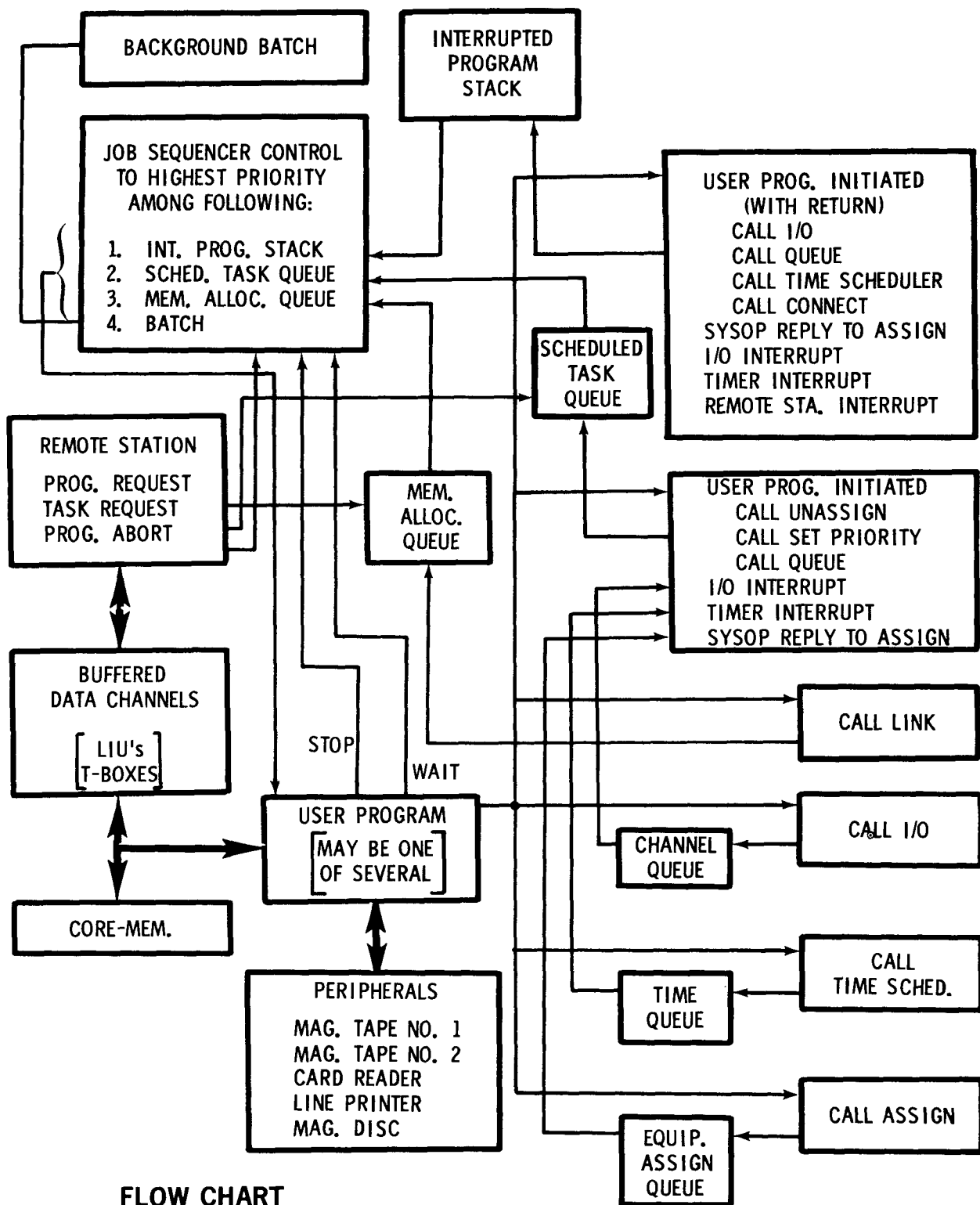


Figure 9



FLOW CHART

Figure 10

Programs and System Operator Interrupts. After the monitor has processed an interrupt or a request, control is given to the Job Sequencer routine which determines which program is to be given control. Control is given to the highest priority program among the programs on the Interrupted Program Stack, Scheduled Task Queue and Memory Allocation Queue. If two or more programs are tied for highest priority, they are selected from their source in the order listed above. If all three of these lists are empty, control is given to Background Batch (if active); otherwise, the computer enters an idle loop.

A program being executed is interrupted, and its status is put on the Interrupted Program Stack by each of the following events: user program return calls (CALL LINK, CALL I/O, CALL QUEUE, CALL TIME SCHEDULER, CALL CONNECT); station interrupts; input/output interrupts; timer interrupts; and system operator replies to user assign request, and a station request. Tasks are also scheduled indirectly from Channel Queues, Time Queue, and Equipment Assign Queue as a result of previous user program calls (CALL I/O, CALL TIME SCHEDULER, and CALL ASSIGN). The Memory Allocation Queue is loaded by a user program calling link or a program request from a remote station.

The Job Sequencer is the heart of the system and with the interrupt service routines supervises the Sandia real-time system.

SUMMARY

The centralized computer provides support to eighteen remote laboratory terminals on a real-time/time-share basis. The system is designed to provide the necessary support for the variety of component development and materials research activities of Sandia's Directorate of Electronic Component Development and has the advantages of expansion and flexibility in configuration and application. The many applications include: semiconductor device testers; semiconductor process development (doping profiles); partial pressure analysis and vacuum systems (gas analysis, leak detection, diffusion coefficient studies, etc.); vacuum bake-out stations associated with glove-box line and clean room

activities; and more complex component testers.

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