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TITLE: AN OVERVIEW OF CTR-DIVISION CONTROL AND DATA ACQUISITION USAGE AT THE LOS ALAMOS SCIENTIFIC LABORATORY

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ABSTRACT

Computers have become an integral part of the control and data acquisition systems of several different fusion experiments in the CTR Division. These systems must 1) monitor and/or control approximately 200-1000 signals, 2) process from 40 to 250 diagnostic channels with a maximum plasma discharge repetition rate of once every five minutes, and 3) operate in an electrically noisy environment. Small to medium scale minicomputers interfaced to the experiment through CAMAC modules have been used to meet these requirements. System shielding and grounding have been given special consideration. These systems are also used for on-line data analysis and are linked to the local CTR network User Service Center where additional off-line analysis can be performed.

INTRODUCTION

This paper is an overview of the use of computers for data acquisition and control within the Controlled Thermonuclear Research (CTR) Division at the Los Alamos Scientific Laboratory (LASL). It will cover the basic local requirements and general design philosophy, and then trace the expansion of computer usage and evolution of technique over the years and several devices since computers were first used with CTR experiments. Finally, it will describe the design of the ZT-40 control and data acquisition system, which is the latest system and is currently under construction.

The charter of LASL's CTR Division is to explore alternative concepts in the quest to build a magnetically confined plasma fusion device. Work began with the toroidal Z-pinch in the early 1950's and has evolved to the present research on the Reverse Field Pinch (RFP)(1) configuration. The RFP configuration has an axisymmetric toroidal magnetic field geometry consisting of a poloidal field, produced by a toroidal current in the plasma, and a toroidal field whose direction is reversed outside the plasma column. The theta pinch(2), with a magnetic field geometry which is orthogonal to that of the Z-pinch, has been extensively investigated in both linear and toroidal configurations. Plasma ion temperatures up to 50 million degrees Kelvin and densities of several times 10^{16} cm^{-3} have been produced in the theta-pinch devices. The experiments use the same type of hardware and pose similar control and data acquisition problems. Table I contains a list of parameters relevant to CTR control system design. The experiments are carried out on large pulsed devices, which use spark-gap switched capacitor banks storing up to 10

TABLE I LASL CTR COMPUTER ENVIRONMENT

Capacitor banks	10^5-10^7	Joules
	10^4-10^5	Volts
	10^6-10^8	Amps
Plasma Lifetime	10^{-5}-10^{-3}	Seconds
Control System	10^2-10^3	Functions
	10^{-1}	Second time scale
Bank Repetition Rate	1-10	Per hour
Electrical Noise	Lots	Damage to control components and interference with data acquisition
People	Physicists	

megajoules of energy at tens of kilovolts, and which produce currents up to 100 megamps. The plasma lifetime is typically in the range of 10 to 1000 microseconds, requiring data acquisition devices which have internal data storage. The control systems must control and/or monitor up to a thousand variables, and cycle several times a second. The devices have repetition rates of 1 to 10 times an hour and are characterized by high electrical noise levels during the plasma discharges. Ground currents and radiated electro-magnetic interference are serious problems. The control system, which may ignore noisy signals for a cycle or two, need only be protected from physical damage. The data acquisition equipment, on the other hand, must be protected from interference which could cause spurious data. Another part of the systems is the people who operate them. Operators vary widely in their expertise with computer software, and the system designer must take this fact into account. The "mal" in operator malfunction is redundant. 71

DESIGN PHILOSOPHY

Software

The goal of software design is to produce programs which are easy to use and easy to maintain. The required operator input should be minimized, and the interaction with the operator should occur in the most natural way possible. For example, on the systems described here, most input is entered through switch panels and thumbwheel switches, and visual displays are used extensively. Software maintenance is made easier by modular design and the use of a high level language such as FORTRAN. For the last two large systems a control language has been developed. This language generates a file of command description blocks which are executed by a FORTRAN coded processor. With this approach, the operation of the system may be modified simply by editing the command list: no reprogramming in FORTRAN is required.

Hardware

Hardware has featured top-down[3] modular design techniques. A standard interface, the CAMAC[4],[5],[6] standard, was chosen to allow for easy expansion and transfer of equipment among experiments controlled by different makes of computers, and to take advantage of the wide range of functions readily available in the CAMAC format.

A standard signal nomenclature has been devised and is used for both hardware and software. The use of standard nomenclature enhances communication between people of diverse backgrounds.

The electrical noise problems are treated systematically. The devices are characterized as signal sources, the control and data acquisition equipment as receivers, and the attenuation required to achieve a desired low noise level determined. Various techniques--isolation, shielding and transient suppression--are used to achieve the design goal.

EVOLUTION

Scyllac

The first CTR experiment to use a computer was Scyllac. A Sigma 2 was acquired in 1969 and installed after the device had been designed and was already under construction. The computer was originally used only for data acquisition but later assumed some monitoring and scram/abort functions.

The Scyllac Sigma 2 configuration is shown in Figure 1. Plasma data were stored in fast transient digitizers. Slow data such as bank voltages were acquired by a 128-channel analog-to-digital converter (ADC). The operator could control the computer through the numerical input panel. After each plasma discharge the transient recorders were read and the data stored on disk. The operator could call up various data analysis programs and view the results on a multi-channel video display. Additional detailed analysis was done on the User Service Center's DEC-10. The operating system used was the Xerox Real-time Batch Monitor (RBM).

Second Sigma 2

In 1971 a surplus Sigma 2 was acquired. This serves as a data acquisition computer for 4 small experiments. The configuration of this system is shown in Figure 2. Originally all devices were interfaced using Xerox standard interface units. These direct interfaces have been replaced with CAMAC standard interfaces. This computer uses the same Xerox RBM operating system as the Scyllac computer.

Scylla IV-P

The construction of Scylla IV-P, a 5-meter linear theta pinch,[6] was begun in 1975. This was the first computer-based control and data acquisition system designed as an integral part of a plasma physics device at LASL using top-down techniques. The computer chosen was a Prime 300. Figure 3 diagrams its configuration. All the interfaces are through the CAMAC standard. This system runs under Prime's real-time operating system (RTOS) which is a multi-foreground, single background user system. The control language approach was developed on this system. All of the control and data acquisition tasks operate in the foreground. The background, which has a 64K word virtual address space, is used for on-line data analysis.

LATEST DESIGN

ZT-40, a large reversed field Z-pinch, is currently under construction. It is the most complex device built in CTR at LASL in terms of the number of control functions which must be implemented, and the sensitivity to electrical noise of the data acquisition equipment. A Prime 400 with the Primos IV segmented virtual memory operating system was chosen as the control and data acquisition computer. This system's configuration is shown in Figure 4. All interfaces to the device are through the CAMAC standard. The data acquisition equipment is on a parallel highway, while the control system operates via a byte-serial highway.

The PRIMOS IV time-sharing operating system supports up to 16 or 64 users depending on the version. The standard system supports user priority levels, system clock calls for delays or periodic execution, and WAIT/NOTIFY semaphores. The standard system has been modified at LASL to support additional real-time functions. A CAMAC driver has been developed. Modules may be temporarily assigned to a specific user on a crate-station basis. A system call which locks/unlocks user memory has been implemented. This routine is used by the control programs to guarantee that time-critical code is memory resident when the device is in operation. A set of software queues which use shared memory have been installed for inter-process communication. The priority structure has been modified to allow some user processes to operate at a priority higher than that of the supervisor.

The control software is modeled after that of Scylla IV-P although the implementation is quite different because of the difference in operating systems. Four processes are involved: 1) a monitor process which carries out all I/O operations with ZT-40 and provides current status information, 2) a CAMAC interrupt handler, 3) a control process which is the control language processor and operator interface, and 4) a sequential processor for data acquisition programs. Since PRIMOS IV is a time-sharing system, program development, data analysis and diagnostic development can be carried out concurrently with device operation.

Figure 5 shows the layout of the area in which ZT-40 is being built. The torus in the center is the plasma vessel with its associated conductors and iron cores. Diagnostic equipment will be located on the platform around the torus. The shield room containing the computer, data acquisition equipment and timing-pulse generators is located at one end of the area. A control center, containing the serial crates and interface circuitry is located in relay racks at the opposite end of the area. The charging system power supplies are in a room below the control center. The main capacitor banks are built in twelve pie-shaped sections around the torus. Several auxiliary banks are located in odd corners of the area.

The noise susceptibility of the plasma diagnostic equipment led to the design of an elaborate star-type ground system depicted schematically in Figure 6. The star is centered on a point near the center of the torus, which is designated "Mecca," and all subsystems are interconnected via ground plane "highways" which radiate from this point. Every section of the machine is carefully isolated from the steel structure and from building ground so that ground loops are eliminated. Problems with ground loops and shield penetrations in some areas, especially the control wiring and timing tables, have been eliminated by the use of fiber optics.[8]

The byte serial CAMAC highway is carried between the control center and the shielded computer room on 18 optical fibers. This link was designed and built in-house. A second, identical byte serial link connects an auxiliary screen room to the computer room. The circuitry in the control center is not as sensitive to noise as the plasma diagnostics equipment, but still needs to be protected from physical damage by voltage transients, which may be as high as several hundred volts, on the lines extending into the machine. Each line is terminated at the CAMAC end in a transient suppression network and has an optical link built into it. The optical links consist of photon-coupled TTL gates in eight pin DIP's for digital signals, and photon-coupled analog amplifiers on hybrid substrates for analog signals. At the machine end, the digital outputs operate air solenoids, the digital inputs are derived from dielectrically actuated microswitches, and the analog outputs are operated into photon-coupled devices, so that all these signal lines are doubly protected. The analog inputs monitor voltage dividers which are referenced to machine ground, and balanced lines and differential amplifiers with a high common mode rejection ratio are used.

The diagnostics cabling into the shielded computer room was very carefully designed. These are the only wires which penetrate the shield, except for the power lines which are heavily filtered. Coaxial cables are carried in 20 2-inch copper pipes from the diagnostics area to the screen room. The pipes are enclosed in a steel box over their entire length. This arrangement provides skin-effect shielding(9) of the cables from currents induced in the capacitively coupled ground loop which follows the torus, diagnostic boxes and cables, shielded room, steel structure and ground plane back to the torus. The copper pipes form a low impedance ground path for their cables reducing crosstalk. Crosstalk is further reduced by wrapping each cable many times around a large ferrite toroid where it enters the shielded room.(10)

Figure 7 is a schematic diagram of the layout of equipment in the shielded room. The computer, control terminal, and peripherals are located in the center of the room. Relay racks are placed around the walls. Signal cables are routed between the computer, equipment racks, and patch panels via a wireway which is in contact with a copper ground plane. Ground loops are minimized by isolating the racks and providing each with a single connection to the ground plane. Power is distributed throughout the room by a separate wireway system. Twisted pair wire is used to reduce the 60 Hz magnetic flux in the room, and isolated transformers are used at each rack to maintain isolation. These transformers are mounted in 3-layer magnetic shields to reduce the high leakage flux common in this type of transformer.

The shielded enclosure is a Lindgren 4-shield room, 22 feet by 25 feet. The original design was modified by replacing two layers of copper with two layers of silicon transformer steel to extend the low frequency attenuation to cover a peak expected in the power spectrum of ZT-40 at 300 Hz.(11)

CONCLUSION

The use of top-down, modular design techniques for both software and hardware increases system reliability and reduces system maintenance effort. The adoption of an industry standard interface is highly desirable. The time and effort spent on designing a system in a structured fashion with careful consideration of power and ground distribution systems, prior to the construction of a device, has paid handsome dividends. This approach has allowed easy expansion of existing systems and the transfer of technology between computers of different manufacture.

ACKNOWLEDGEMENT

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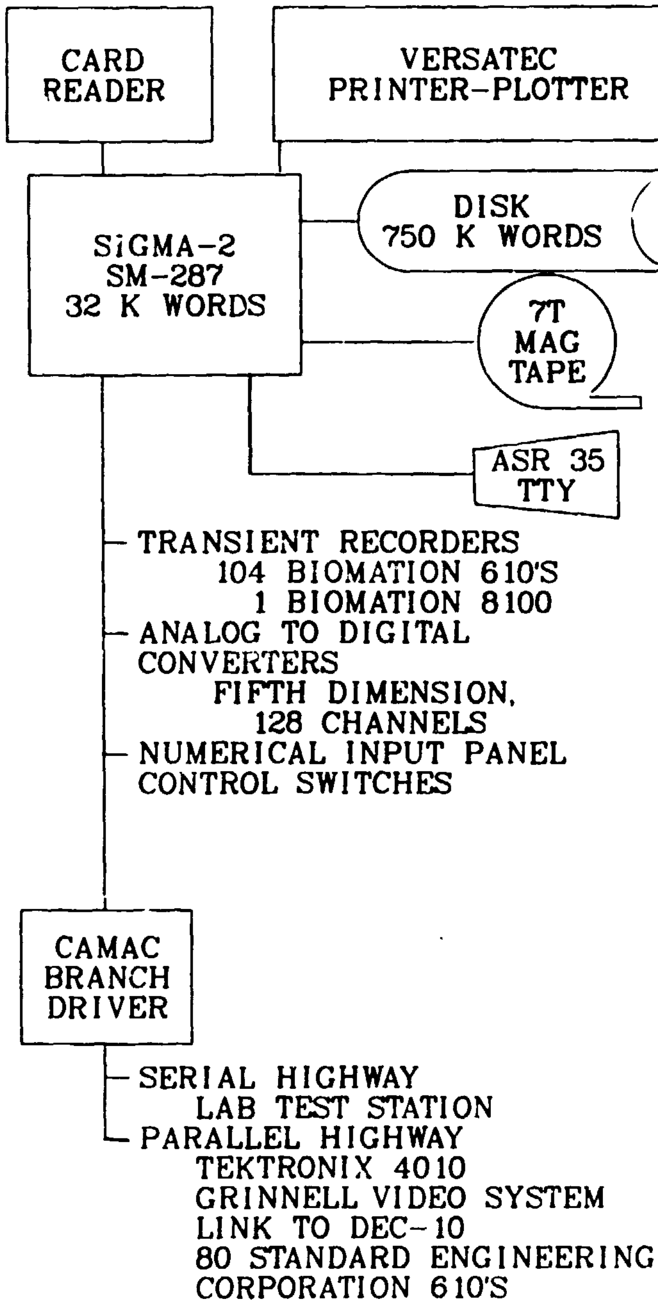
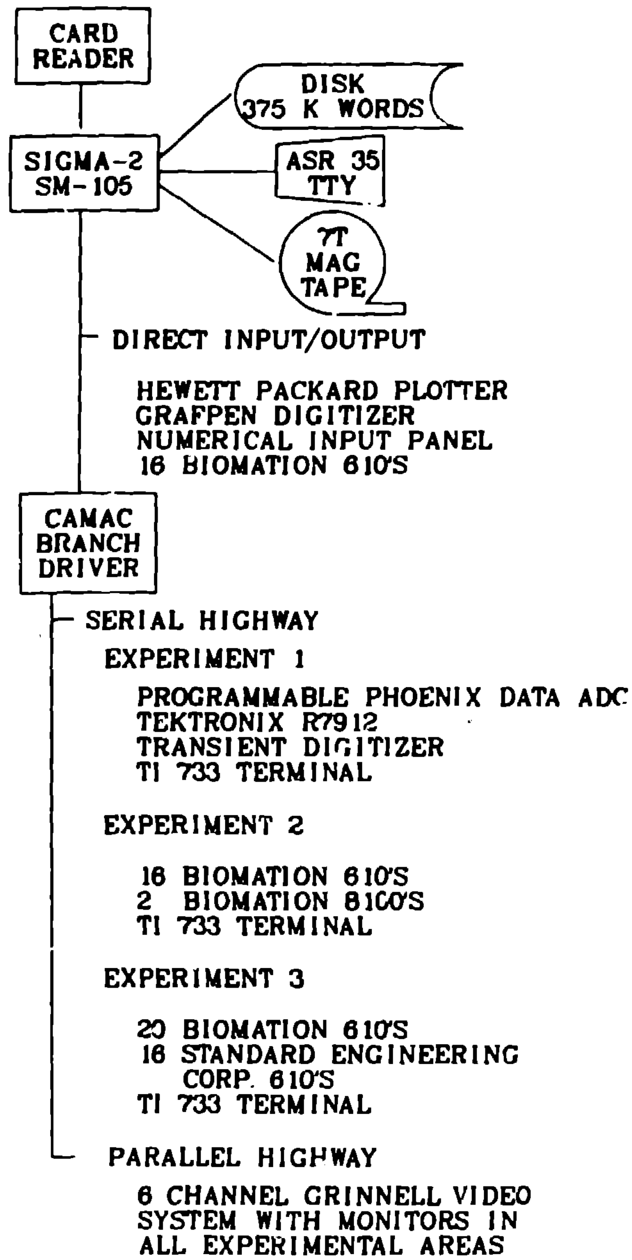


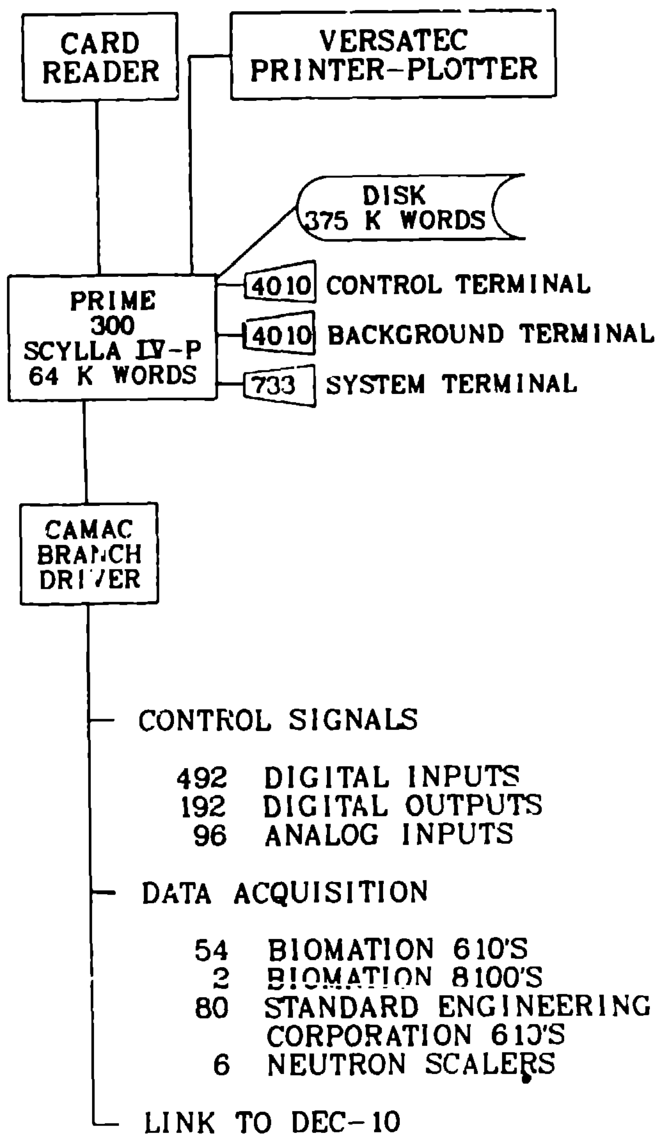
SM-287 SIGMA-2 CONFIGURATION

Figure 1.



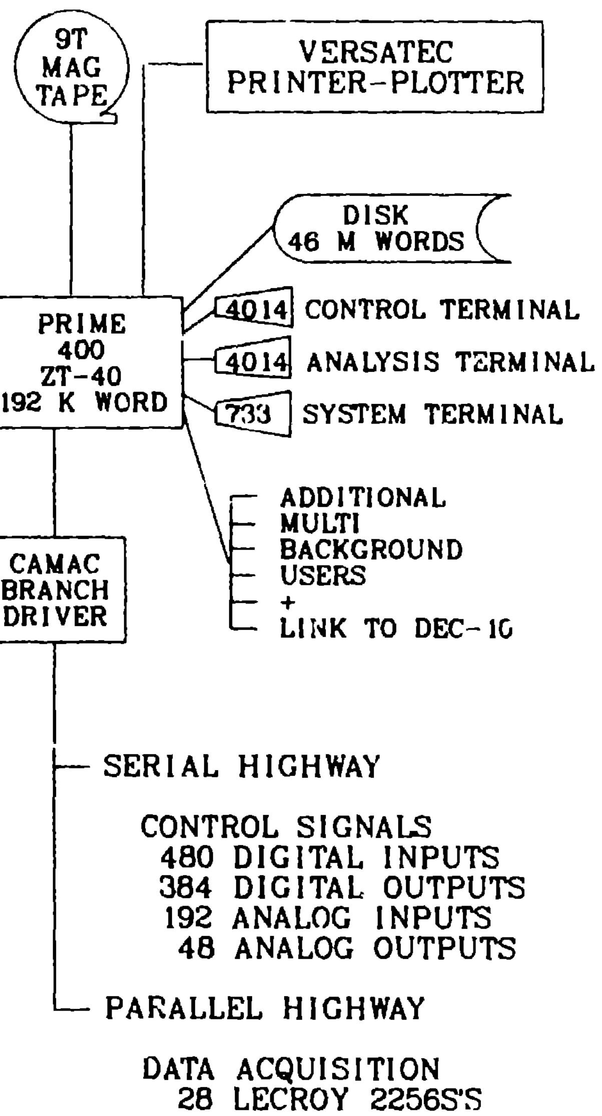
SM-105 SIGMA-2 CONFIGURATION

Figure 2.



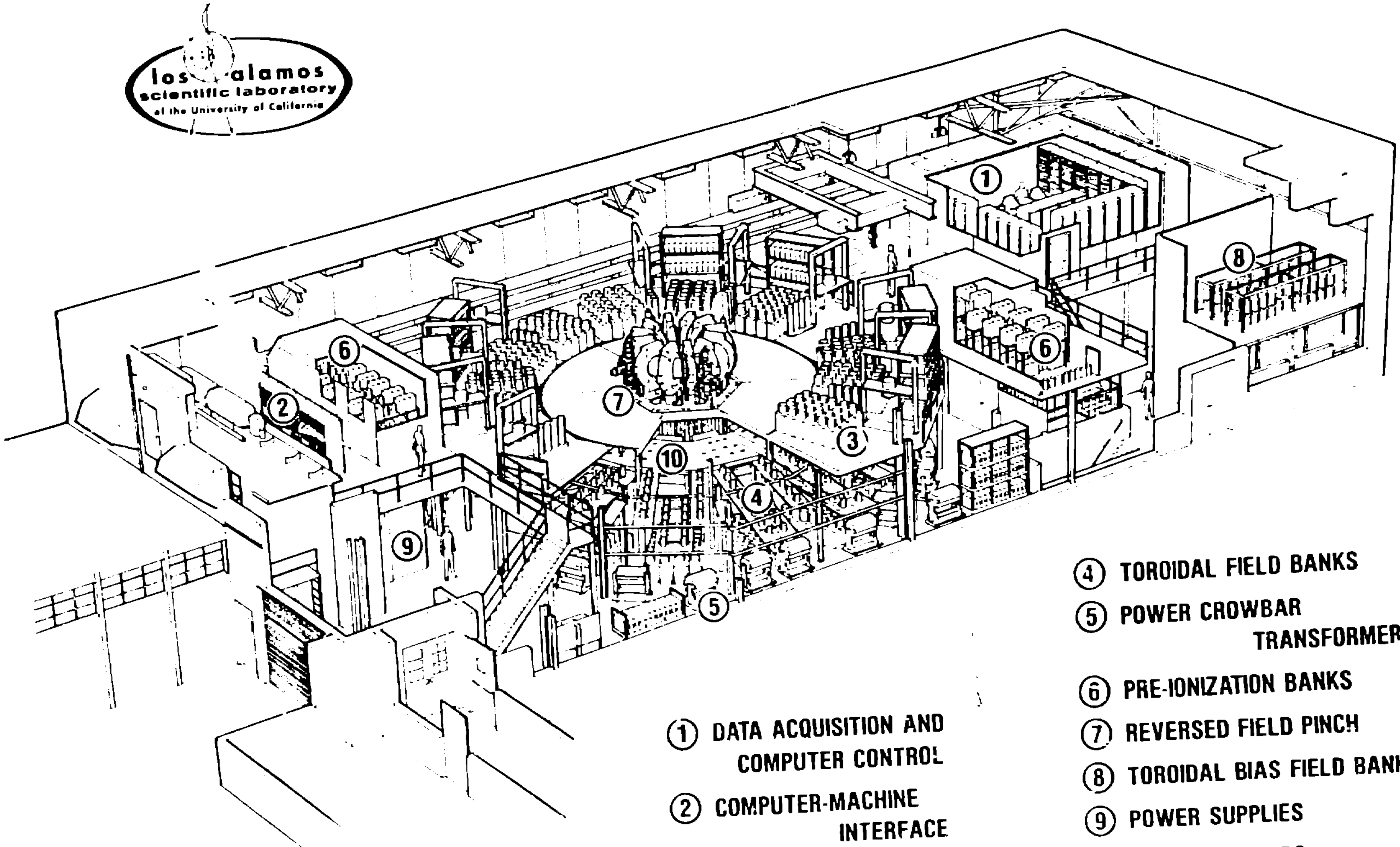
SCYLLA IV-P PRIME 300
CONFIGURATION

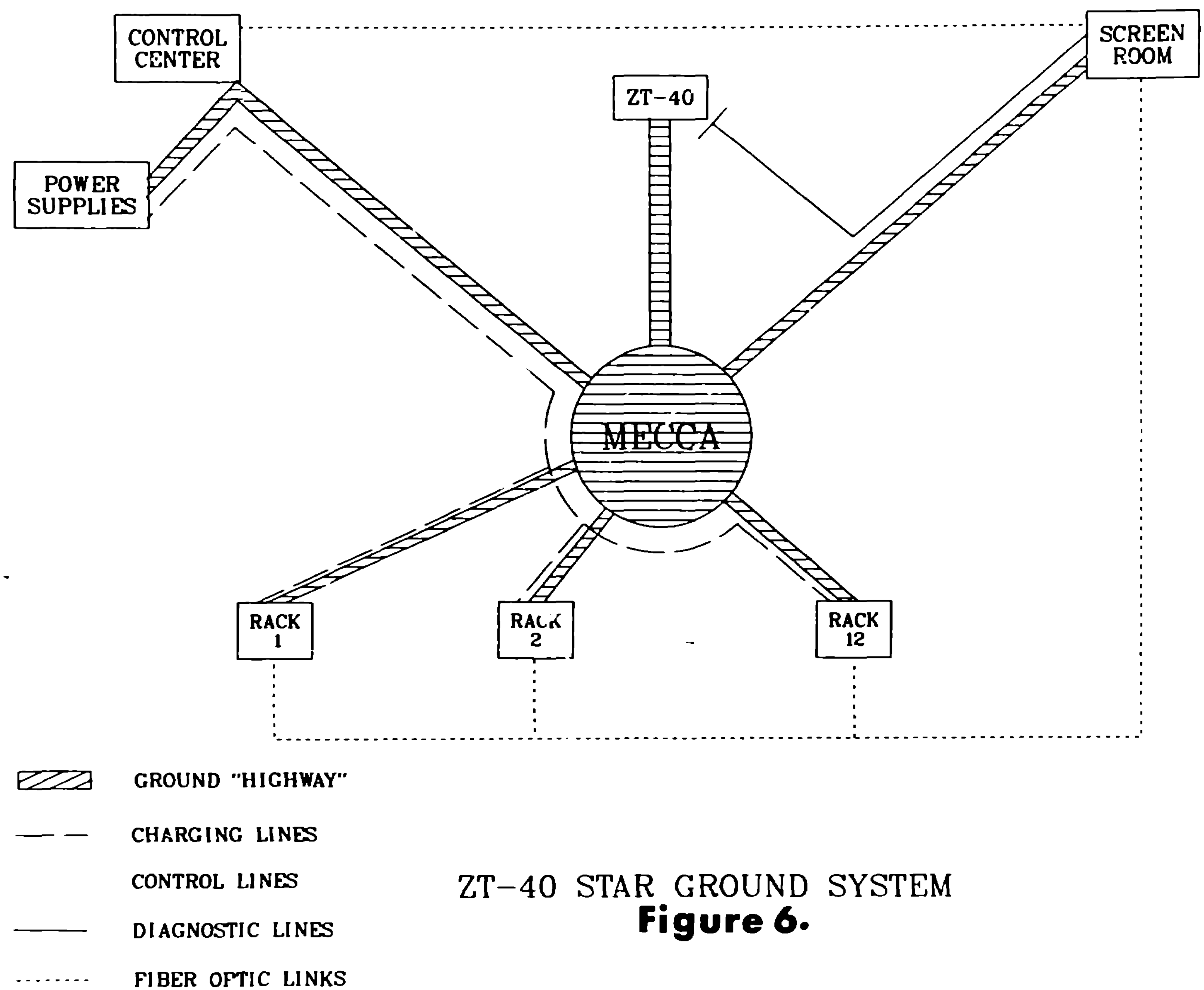
Figure 3.



ZT-40 PRIME 400
CONFIGURATION
Figure 4.

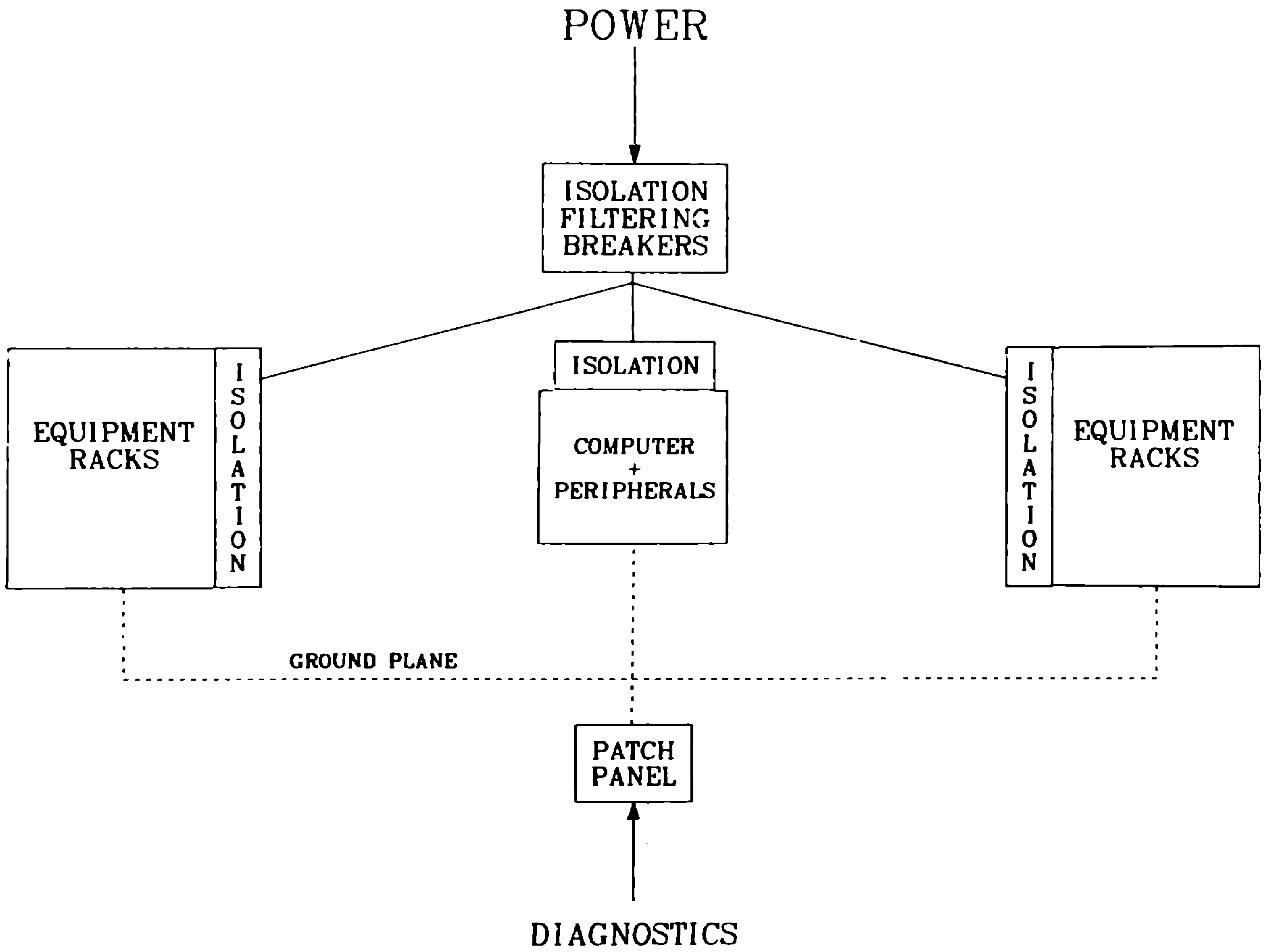
Figure 5.
ZT-40 FACILITY





ZT-40 STAR GROUND SYSTEM

Figure 6.



ZT-40 SHIELD ROOM
POWER DISTRIBUTION
Figure 7.