STATE-OF-THE-ART ASSESMENT
OF
IN SITU CALIBRATION EQUIPMENT

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ABSTRACT

Automated Calibration Systems (ACS) represent the state-of-the-art in calibration of test measurement and diagnostic of equipment (TMDE). The features and capabilities of two systems in use by the U.S. Navy are discussed in this paper. The Centrally Operated System for Metrology Information Control (COSMIC) and the Metrology Equipment Calibration and Control Analysis (MECCA) system are being developed to greatly reduce the cost of calibrating a very large inventory of test equipment at sites around the world. The benefits of an in situ calibration capability has been demonstrated at the Naval Calibration Laboratory, Tustin, California, where these calibration systems have been integrated with online databases. Future advances are anticipated through simpler human interfaces and higher throughput rates. The in situ systems now coming into use offer significant material, calibration and repair cost savings. Improved calibration support will benefit most telemetry, communication, and weapon systems.

INTRODUCTION

Improvements in techniques to improve calibration of test measurement and diagnostic equipment (TMDE) have been realized through in situ methods. These permit the owner/user to retain the equipment versus shipping it to a depot for calibration. Approaches such as the Metrology Equipment Calibration and Control Analysis (MECCA) system developed by SAI for the U.S. Navy will play a role in the analysis effort. MECCA is a portable, microprocessor controlled, calibration system based for calibrating voltmeters and oscilloscoped in situ. It is also used in the SAI-developed, Centrally Operated System for Metrology Information Control (COSMIC) which is now under development by SAI for the Navy’s Metrology System for Uniform Recall of Equipment (MEASURE). These systems in themselves represent the state-of-the-art in in situ calibration and recall strategies used by the government. Thus the study offers the opportunity to expose these unique systems throughout the Federal community.

Inherent in the need for advanced concepts for in situ calibration is also the need for portability of the calibration devices themselves. MECCA, for example, was configured as a two suitcase, microprocessor controlled system which literally replaces over two hundred pounds of calibration equipment. This type of technology can and should be applied to many situations within the Federal Government. COSMIC, MEASURE, and MECCA are discussed below in order to point out their unique design capabilities and applicability to the telemeter, communication and weapon systems.

COSMIC Automated Calibration Station

The COSMIC Automated Calibration Station (ACS) combines minicomputer technology, calibration technology, and plasma panel development--into a single, state-of-the-art end product. The COSMIC ACS design is also an extension of work begun by the U.S. Navy's MECCA program at the Metrology Engineering Center in Pomona, California. To date, SAI has developed an Automated Calibration Station that has achieved the important milestone of being on-line and interface. The test station has also shown the capability of integration with the MECCA calibration system. Figure 1 presents an overall block diagram of the COSMIC Automated Calibration Station as configured for the U.S. Navy. Figure 2 presents a photograph of the COSMIC System which is now located at the Naval Calibration Laboratory Annex, Tustin, California. The size and configuration lends itself to the possibility of mobile implementations for various in situ calibration strategies.

The ACS is in the prototype testing stage and is designed to calibrate eight different models of RF signal generators. Certain tests like a frequency drift test can be performed completely by the ACS after the initial adjustment of the signal generator. Most tests require operator adjustments at the beginning of each test, but subsequent functions are aided or performed by the ACS in the following ways:

1. The ACS displays each adjustment value as it is needed by the technician.

2. The ACS can simplify some test measurements because it uses auto-ranging electronic voltmeter and automatic attenuators.

3. In most tests the ACS performs the following: reads test results verifies if result is within acceptable tolerance, records results, tallies out-of-tolerance occurences.

4. In one case that the ACS does not automatically read the test results, it aids the technician by performing the computations necessary to that test. In the Modulation Meter Accuracy Test, the technician enters the scale values measured from oscilloscope screen; the ACS computes automatically the percentage of modulation error and records the result.

The initial implementation of COSMIC was accomplished by SAI under contract to the Naval Air System Command Representative, Pacific, NAS North Island in 1976. The effort called for the implementation of an automated calibration station and provided for the interfacing of this station with the existing MEASURE program. The instrumentation delivered to the Navy was based on an adaptation and expansion of the calibration technology orginally developed as part of Metrology Improvement Equipment Performance program. An overview of the MEASURE/ACS system is shown in Figure 3.

The MEASURE technology was extended to encompass a wider class of calibration equipment as well as further automation of the calibration procedures. The calibration procedures developed for the COSMIC system provide for instructions to the calibration technician on set-up procedures, automated stimuli to the instrument being tasked, analysis of the return signal for logging the received state of the gear, and setup procedures for additional calibration cycles.

In providing the automated calibration procedures, the system, as a side benefit, provides historical information on the instrumentation undergoing calibration, as well as inventory control information. This type of information is required in the existing MEASURE Program; hence the requirement for providing the ability to eventually interface the COSMIC system with the MEASURE Program.

The proposed technical approach which SAI followed in the development of COSMIC was designed to achieve the following goals:

1. The further development of an automated calibration system interfaced and controlled by the COSMIC system which is suitable for performing the TMDE calibration requirements of the NAVAIR Type IV labs.

2. Determine the feasibility of using optical scanning techniques for inventory control.

3. Provide in situ equipment maintenance.

4. Fully document all COSMIC operations.

5. Develop automated training procedures for calibration personnel.

The largest percentage of costs persently expended in acceptance testing or calibration of electronics equipment is for manpower. Much of the time consumed in these processes is for repetitive, often robot-like stimulate, monitor, respond activities. As equipment becomes more sophisticated, test time increases with some items taking as much as thirty-six man-hours of complex sequences. The technology now exists to automate the repetitive redundate functions, saving the highly skilled, well-trained technician or engineer for the actual calibration functions and the more unpredictable, non-repetitive requirements.

At present, calibration work is left undone due to the lack of personnel to perform the necessary but time-consuming and repetitive tasks. Many government agencies have the work to do, the requirement to do it, and the funds, but “ceiling” limitations on manpower prevent its accomplishment. Automation is the answer.

The COSMIC ACS has extended in several ways the initial MECCA concept of prompting a technician through the calibration steps in place and of providing the proper stimuli necessary for calibration of test instruments without removing the equipment from its regional environment.

1. Processor Control. The COSMIC ACS central processor has been given control of the complete calibration cycle as well as control of the measurement and evaluation of test instrument output.

2. On-Line Data Base. Through the COSMIC-MEASURE interface, a subset of the MEASURE date-base is on-line and interactive for inquiry, update, and inventory control.

3. Historical Data Retention, For archival value, the system retains historical information for each piece of equipment in the inventory.

4. New Procedures. Software drivers are generalized to the extent that new calibration procedures can be implemented in the field without the need of highly skilled programers.

5. On-Line Procedures. Calibration procedures are on-line for immediate use.

6. Multi-tasking. The processor allows several technicians to use a single COSMIC ACS simultaneously.

7. Plasmascope Touchpanel. The touchpanel eliminates the need for a keyboard, thereby greatly reducing training for the COSMIC ACS technician.

While developing the COSMIC ACS, SAI has maintained consistent guidelines to insure the utility of the final system. One of the major costs of manual calibration is the time consumed in repetitive operations. Technicians spend the majority of their time in a robot-like mode of stimulate, monitor, record, and respond actions. The COSMIC ACS has automated these repetitive tasks, freeing highly skilled technicians and engineers for the non-repetitive and more complex tasks associated with calibration, In addition, the following guidelines for development have been observed.

- Reliability. The COSMIC ACS uses field-proved equipment with readily available service and spare parts. All standards integrated into the station are off-the-shelf items from the Navy inventory of available test standards.

- Ease of Maintenance. The system is designed for the maximum capability of self-calibration. The system is referenced to three basic standards: one for resistance, one for voltage, and one for frequency.

- Modularity. The system designed allows subsystems to be removed without detrimental effects on the remaining system components. An individual test station can be configured to meet current needs and current needs and reconfigured at a later date to best meet new requirements. Also, modules are easily transferred from one test station to another, simplifying maintenance and repair.

- Upward Compatibility and Expandability. The test station is designed with a bus structure that allows easy implementation of new calibration standards and techniques without affecting the operation of previously installed modules. The control bus of the test station is designed to be independent of the processor bus so that the station can be utilized in installations where a different type of processor may already exist, and the acquisition of another processor solely for the test stations would be uneconomical.

- Ease of Operation. Human engineering is a very important consideration in the design of any system where the end user may need to either modify or expand upon system capabilities. The current system has automated calibration techniques to the fullest extent of the test standards available. System connections and reconnections are at a minimum, system set-up is as automated as test standards will allow; results are analyzed according to predefined tolerances; and reports are generated automatically.

- Simultaneous Multiple Operations. The system design allows more than one user to utilize a rack of test standards. Multiple operations allow the most efficient and cost-effective operation of the test stations.

- Accuracy. The standards used by the COSMIC ACS are the same as those used when manual calibration is performed. However, the ACS is ultimately more accurate because the test are more thorough and the data recorded is not subject to human error.

In order to accomplish the objectives of increased production, job enrichment, as well as thorough testing, a totally automated test laboratory was proposed. The automated test laboratory was proposed. The automated test laboratory must have several characteristics:

- Reliability
- Maintainability
- Modularity of equipment
- Upward compatibility
- Expandability
- Cross compatibility
- Ease of operation
- Provision for simultaneous multiple operations
- Accuracy and throughness of testing
- Automatic generation of reports

In addition to all of these requirements, a further overall consideration was made. Military activities and government activities supporting the military for test equipment calibration or servicing must often be mobile. This requirement is made more apparent as world political situations fluctuate and as new commitments arise. As a result, the optimized facility should be housed in specially designed transportable enclosures with all components designed into a unitized system. This will allow the automated calibration functions to support the primary goal of military and operational readiness.

As a result of the foregoing overviews of the problems and requirements of test and calibration facilities, we saw a need to prototype for the Department of Defense an optimized automated calibration system.

This system would have, as minimum requirements, the following characteristics:

- Multiple function calibration stations at a single facility, the number of functions primarily limited by the control capacity of the calibration function processor and/or the physical and operational capacity of the facility, The initial prototype was to be a three-function facility, capable of simultaneous function operation.

- Calibration station hardware was to be of processor-independent design.

- Calibration stations were designed to be reconfigured in terms of calibration equipment.

This accomodates a wide range of PMTE. Where possible, commonly used or GFE calibration equipment was to be installed at each station.

It is essential to preserve latitude in the selection and arrangement of calibration equipment, not only to accommodate the variations in workload encountered, but also to allow for the progressive upgrading of the labs as new calibration techniques evolve and as new PMTE items are introduced into the field.

The design is such as to partition the calibration equipment among the work stations in a way that for any particular instrument to be calibrated. There will normally be a single work station where the calibration and repair can be carried out in its entirety. Because of the number of ranges and diversity of capabilities of some test instruments, this will not prove to be possible for the entire inventory. Two solutions are available which are reasonable. One is to take advantage of the design flexibility of the work station to another on an ad hoc basis. The other alternative simply involves carrying out the calibration at more than one work station on those infrequent occurrences where this might occur. It was planned that both means be developed depending on the number of individual calibrations and considerations for cost-effectiveness.

The need for reconfigurable work positions is indicated in the preceding discussion. This need arises partly from the variations in instrument populations at various sites, and partly due to changing instrument inventories and emerging measurement capabilities. Fortunately, design concepts for ATE systems are available which permit this need to be met in a reasonable way. This involves the use of modularly designed calibration equipment with standardized interfacing and driving facilities, whereby individual items can be readily interchanged or replaced.

To date, Science Applications, Inc. has designed and is constructing a prototype Automated Calibration Station (ACS) for screening certain VHF Signal Generators for compliance to publish "I" level tolerances. This station incorporates state-of-the-art Plasmascope and Touchpanel technology to simplify communication between the ACS and the calibration technician. Initially the software language used was BASIC. Subsequently, FORTRAN was used to improve the multitasking capabilities of the system and to facilitate the communication of calibration data to the MEASURE program.

The system, controlled by a NOVA 830 processor, was moved from NASNI to the Naval Calibration Laboratory Annex at Tustin, California. This was done to enable further study and refinement of the application as well as to integrate other automated calibration standards into an ACL. The Signal Generator ACS program, now tailored for use on the NOVA 830 processor is in the final stages of integration, and will soon demonstrate the feasibility of the COSMIC Automated Calibration Station.

As the program progresses, it seems clear that manufacturers of test equipment and calibration standards are adopting a common instrument interface plan based on IEEE

Standard 488-1975 (identical to ANSI Standard MC1.1). By the beginning of 1978 some ninety-six companies were producing 281 devices capable of being interfaced on this system. Rather than continue to commit all development efforts to an existing control scheme that was unique and potentially obsolescent, parallel steps were taken to investigate the 488 bus and its applicability to the ACL. Thus far, the 488 bus remains a candidate for ACL-type work. Up to fourteen devices that are 488 compatible can be controlled by a computer. They include measurement, storage, switching, display, control and stimulus devices. These can be addressed and controlled by the NOVA-830 either individually or in specific configurations depending on the requirements of the TI being calibrated.

MECCA

SAI has had extensive experience with the MECCA system. First as designer and developer of the controller and plasma touch panel, and, now, with the implementation, evaluation, and expansion of the system to meet added goals and to function in new environments. The MECCA system is an excellent candidate with which to study the feasibility of making calibration systems and procedures more cost-effective. MECCA is one of the first systems which can truly investigate the utility of performing in situ calibration of a significant percentage of TMDE which will be part of any calibration activity's inventory. At the same time, the usefulness and cost effectiveness of portable calibration systems themselves can be investigated. Large numbers of in situ calibrations can be performed due to the compact calibration data storage capabilities of the MECCA's magnetic cassette tape systems. In additions to their efficiency as measured by the compactness of magnetic tape storage, the MECCA cassette tapes are also cost effective in at least two ways. First, the initial cost of the cassette is low compared to other modern forms of data storage, and the cassettes can be re-used many times.

Portability of the MECCA system has always been one of the most important aspects of the MECCA concept, and this feature will continue to be emphasized as the system is refined and adapted to new situations. This design goal is reflected in both the MECCA's LSI 8080 8-bit microprocessor, and in the utilization of a plasma touchpanel for both the display of information and for operator control of input to and output from the system. The configuration of the MECCA system is shown in Figure 4. Use of the plasma touch panel, eliminates the need for a keyboard to control and operate the system thereby making the system more compact and useful for in situ calibration. However, when MECCA is being used in a facility such as the Automated Calibration Laboratory (ACL) at Tustin, California, a standard ASCII keyboard can easily be interfaced to the MECCA system. This has the effect of making the system more versatile, and allowing more sophisticated techniques for transmitting calibration data from MECCA to a calibration data base management system. Using the MECCA in the ACL permits it to make use of disk resident calibration procedure which may not be available on cassette or which may have been modified. The ACL central processor is capable of editing MECCA cassette tapes, and of creating new ones.

In addition to the above, the MECCA system presently being evaluated retains the important human engineering features which have contributed substantially to the ease with which the system can be learned and used. Indeed, even an untrained technician can calibrate sophisticated TMDE in a matter of hours. This is another way in which MECCA, along with other automated calibration systems, can potentially be of enormous value in reducing the cost of calibration while maintaining the accuracy and integrity required on any calibration.

COSMIC-MEASURE Interface (CMI)

The COSMIC-MEASURE Interface was designed to support the development and operation of the Automated Calibration Stations and to match the anticipated speed and efficiency of equipment processing with speed and efficiency in data processing. The original design goals have been accomplished by a versatile and flexible combination and integration of several software modules. In concert, the modules of the CMI can support the ACS and a variety of peripheral studies. To perform this important work, the CMI was designed and became operational with the following capabilities.

The interface functions within a data processing network. It records data at the point of generation, and processes and formats the collected data into a compact form. At scheduled intervals, it transmits the data at a high rate to update the MEASURE data base. In its present configuration, the CMI functions as a Remote Control Center (RCC). Specifically, the CMI supports remote terminal operations, work-in-process functions, on-line data base inquiry, and transmission of data elements in addition to calibration requirements.

The CMI can collect data from a variety of sources and at a variety of rates. The primary data sources is the digital output from the ACS controller. It can also collect data from conventional manual data entry at a keyboard or from devices like the MECCA system. When loading a particular subset of the MEASURE data base, the CMI accepts highly compacted, preformatted data. The rate of data collection varies according to the source and can range from 110 characters per second to 9600 baud, The interface has the capability to create audit files that enable the re-creation of data transactions that might be inadvertently lost.

The Data Base Manager was created and implemented to permit the maximum response to changes in the data structures of the MEASURE data base and to be a flexible tool in the studies of automated calibration systems. The Data Base Manager creates or changes logical data structures to meet the specifications of different modules of applications software. However, in doing so, it does not change the compact physical structure and storage of the data itself. This feature makes the data base independent of the application software that it serves.

Another feature of the Data Base Manager is the reduced storage requirements. When compared to typical file structures (e.g., index-sequential) the Data Base Manager can store the same data in one-third the space. The three to one compaction ratio makes it possible to store the 300,000 item MEASURE data base on two 50 megabyte disks. The current configurations will support a 1.2M record inventory of PMTE.

Directions for Future Study of In Situ Calibration Equipment

The power and versatility of the CMI should enable it to serve the needs of the ACS and peripheral studies for some time. However, as new study results dictate, the CMI will undergo modification so that it will keep collection and processing of data on par with the advances in equipment processing,

In the near future, greater emphasis will be placed on converting the ACL interface to a configuration which holds the additional promise that one technician may calibrate a variety of equipment from his single terminal. In the longer term, invertigation of multitasking will increase to test the concept of more than one technician calibrating different types of equipment on a time-sharing basis.

The actual function of the ACS/ACL varies depending on certain factors including: (1) the complexity of the Test Instrument (TI), (2) the experience of the calibration technician. (3) the availablility of standards (both manual and automatic); and (4) the frequency with which a given type of TI is processed at the ACL. The ACL will have the capability of generating hardcopy reports for local use at the user’s discretion.

These ACS/ACL functions cover a spectrum from “Automatic Page Turners” at the simple extreme to fully automated stations at the other end of the concept. The “Automatic Page Turner” is, in fact, more than just that, i.e., it includes a library of continually updated calibration laboratory. It also gathers and disbributes METER card information locally and upwards as well as providing any required MEASURE formats.

The next level of complexity allows the ACS/ACL to perform as above plus automatically controlling certain standards as they function as stimuli and/or monitors. The manner in which the control and reporting of response data is accomplished is through use of standards compatible with the IEEE-488-1975 interface bus.

The third and highest level will see the ACS/ACL perform as above as well as control the TI which itself would be IEEE-488-1975 compatible, i.e., there will be an absolute minimum of technician intervention.

A typical sequence of calibration screening events is as follows; assume first of all that the TI is a Fluke Model 6010A Signal Generator with IEEE-488 interface option installed and the device is in the MEASURE Inventory. The operator enters the UNI number (a unique 10 digit number assigned to each piece of test equipment) at the ACS terminal. The terminal prompts for the METER Card Item Control No. which the operator then enters. Having identified the TI, the controller displays the beginning of the connect to the TI, make preliminary settings, and observe warmup requirements, When compliance is indicated by the operator, the controller configures the calibration standards and instructs the standards as well as the TI how to proceed. The controller monitors the resultant response data, checks for out-of-tolerance conditions and completes METER card information. The operator is informed of the disposition of the TI and takes appropriate action, either returning it to shipping or sending it for adjustment.

Current estimates based on industry experience are that overall throughput will be from two to three times greater than with a traditional laboratory and that a semi-skilled individual can operate the system in place of a more highly trained test technician. This means that the NCL Tustin ACL will aid in reducing the work load of MCC-3 and will act as a source of valuable training for personnel newly assigned to a calibration environment.

CONCLUSION

We believe that the thorough exploration of the ACS capabilities for in situ calibration of other types of equipment will offer significant benefits to the many agencies of the Federal Government that use TMDE.

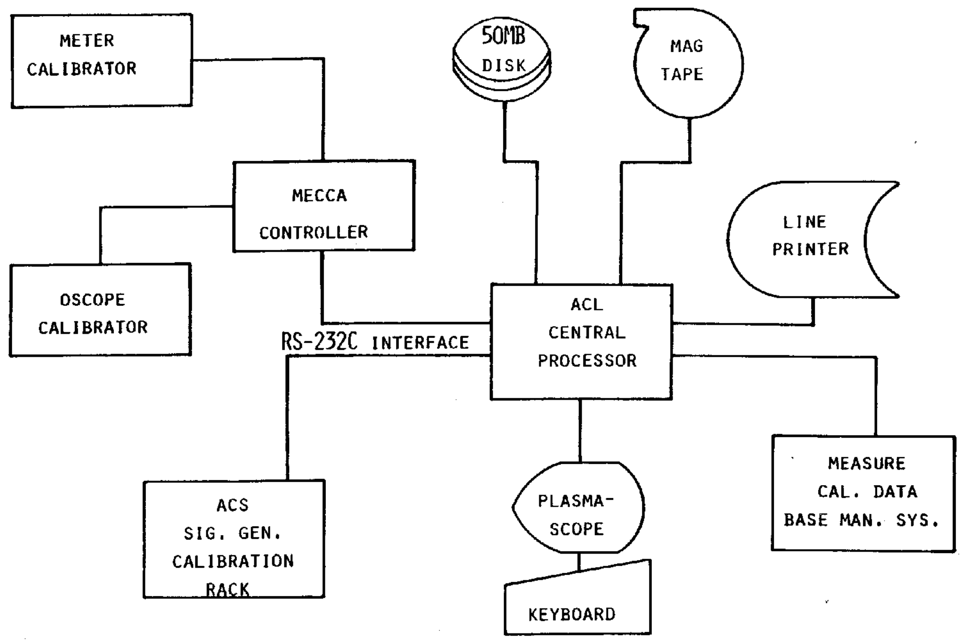

FIGURE 1 AUTOMATED CALIFRATION FUNCTIONAL LAYOUT ACL LAYOUT

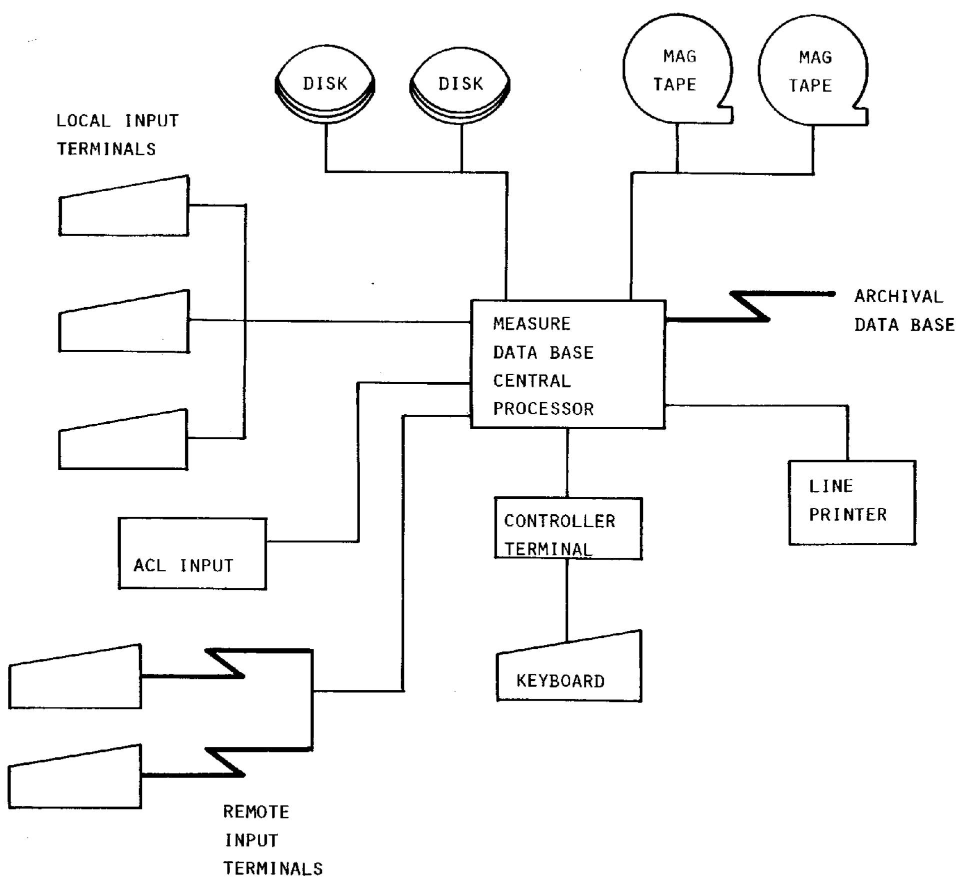

FIGURE 2 MEASURE/ACL INTERFACE CONFIGURATION

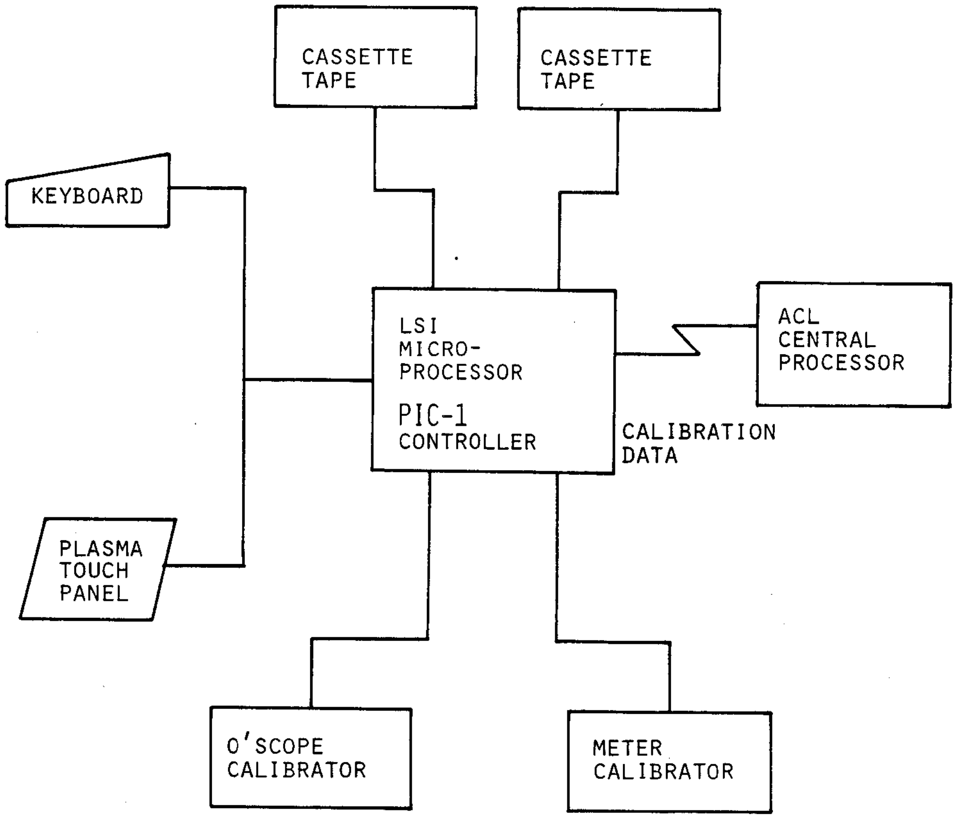

FIGURE 3   FUNCTIONAL SCHEMATIC OF THE MECCA SYSTEM

FIGURE 4