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Transient Data Acquisition Techniques Under EDS

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Abstract

This paper is the first of a series which describes the Enrichment Diagnostic System (EDS) developed for the MARS project at Lawrence Livermore National Laboratory. Although EDS was developed for use on AVLIS, the functional requirements, overall design, and specific techniques are applicable to any experimental data acquisition system involving large quantities of transient data. In particular this paper will discuss the techniques and equipment used to do the data acquisition. Included are what types of hardware are used and how that hardware (CAMAC, digital oscilloscopes) is interfaced to the HP computers. In this discussion I will address the problems encountered and the solutions used, as well as the performance of the instrument/computer interfaces. The second topic I will discuss is how the acquired data is associated to graphics and analysis portions of EDS through efficient real time data bases. This discussion will include how the acquired data is folded into the overall structure of EDS providing the user immediate access to raw and analyzed data. By example you will see how easily a new diagnostic can be added to the EDS structure without modifying the other parts of the system.

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1. Introduction

The Experimental Diagnostic System (EDS) developed for the MARS project is used to support Atomic Vapor Laser Isotope Separation (AVLIS) experiments at Lawrence Livermore National Laboratory. The AVLIS process uses finely tuned frequencies of laser light to photoionize, or electrically charge, atoms of a particular isotope of uranium. The photoionized atoms are collected on charged plates. Reactor grade uranium can be produced by separating uranium-235 atoms from other naturally occuring isotopes. The purpose of developing the AVLIS process is to produce reactor fuel at a lower energy consumption and at lower capital and operating costs than other processes (gaseous diffusion or centrifugation). An experimental facility (Figure 1) was constructed at LLNL to study the AVLIS process. The project is divided into two areas: the laser facility and the separator facility. EDS was written to support the separator protion of the process.

The general philosophy behind EDS is to create a diagnostic to study specific aspects of the process. From this philosophy EDS has evolved into a general purpose diagnostic system which provides the user a means of acquiring large quantities of transient data, viewing the raw data as it is taken, and analyzing that data in real time. EDS also interfaces to our process control system, PMC/1000, and to our in house process modeling and analysis system. EDS consists of over 100 programs written primarily in FORTRAN and currently manages four diagnostics and eight users. The four diagnostics are:

- Vapor characterization by absorption spectroscopy
- Gas analysis by mass spectrometry
- Extractor Performance using transient recorders
- Process Laser Characterization

This paper will discuss the front end hardware used to do the data acquisition as well as the diagnostic control programs and data structures used to interface the front end hardware to the rest of EDS. Figure 2 is a general block diagram of the Experimental Diagnostic System.

EDS has been implemented on an HP/1000-A700 computer with 4 Mbytes of memory, 94 Mbytes of disc, and a 1600 BPI tape drive. Front end hardware is made up of CAMAC (IEEE Std. 583-1982) data acquisition and control modules and Tektronix digital oscilloscopes. Graphics output is made available on HP 26xx terminals and Raster Technologies color graphics systems.

2. EDS Design Elements

In order to develop a diagnostic system that we could readily adapt to the changing requirements of a very dynamic experiment, the following principle design elements were identified:

- The front end hardware configuration had to be very flexible

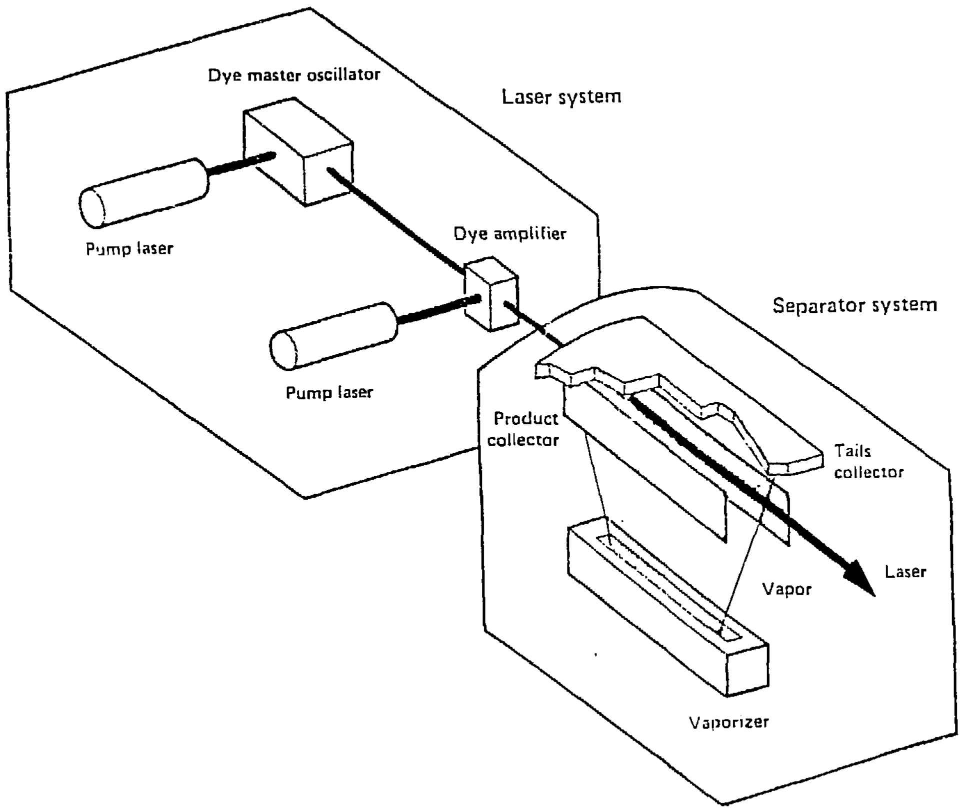

Figure 1. Atomic Vapor Laser Isotope Separation Diagram.

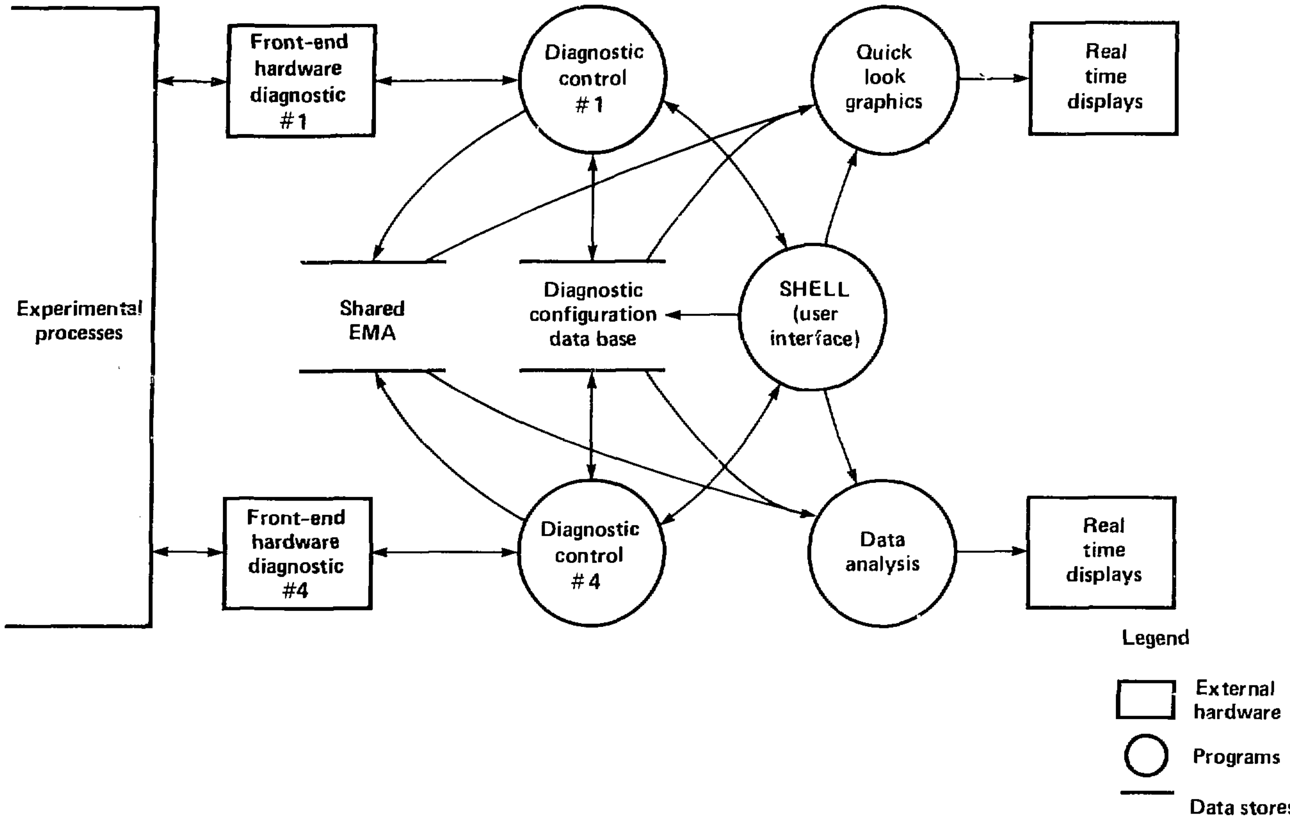

Fig. 2. EDS configuration.

- A method of logically connecting that hardware to the experiment was required (configuration data base)
- Large quantities of data had to be shared among many programs (data acquistion, graphics, analysis)
- Codes should be table driven
- Need a fast system
- Need a standard user interface
- Need a general graphics package

Figure 2 is a general overview of EDS showing all the major components of the system.

2.1 Front End Hardware Design Elements

In order to acquire large quantities of transient data the front end hardware must be capable of digitizing and storing that data without intervention or control from the computer. In the EDS system, control of front end hardware consists of set up, triggering, and unloading of the data. When and how often the data is sampled is controlled by the front end hardware after that hardware has been set up by the EDS system. All front end hardware used in EDS has local storage capabilities. By using front end hardware with local storage the communication to that equipment can be limited to small blocks (< 100 bytes) of programatic I/O for set up and control, and DMA I/O for all large blocks of data (>100 bytes).

By using front end hardware with these characteristics the constraints on the CPU I/O performance can be relaxed. The DMA speed between the computer and front end storage device must be capable of moving all data acquired by the front end hardware very quickly. In the EDS system we have found that an end to end transfer speed of 50 Kbytes per second is the minimum we can tolerate. From our experience we have found that the instrument we are using for a particular diagnostic is the limiting factor on the data transfer speed, not the CPU. The GPIB interface (IEEE Std. 488-1978) offered by HP, for the A-series computers is well within our performance constraints and is a reliable means of interfacing front end equipment. All four of the diagnostics that we use in the EDS system interface to the front end hardware via HPIB.

2.2 Configuration Data Base Design Elements

The front end hardware used for data acquisition and diagnostic control is connected to the process being monitored through a configuration data base. The information in this data base provides a complete history of the front end hardware configuration for a particular experiment. The elements of this data base include:

- Which channels are active
- Engineering unit conversion algorithms and coefficients for all channels
- Short and long labels for each channel
- Relationships between the various data channels

- Where the data from each diagnostic event is stored
- The state of the front end hardware for each event

The data base not only holds the current diagnostic configuration but also the configuration of the hardware for the duration of the experiment. This feature is necessary because often times what we are trying to accomplish changes in the middle of an experiment and therefore the diagnostic configuration must also change to meet the new goals. To meet these design criteria, a fast and reliable data base management system was needed. A third party data base management product, Berkeley Software System Database, written explicitly for HP 1000's, is used for all EDS data bases. This data base is used to keep the entire diagnostic configuration for an experiment. To ensure the best possible performance for EDS, key parameters from the data base are kept in Extended Memory Access (EMA) and only updated when the data base is changed. With this scheme we have been able to make EDS a very fast data driven system.

2.3 Shared EMA Design Elements

The shared EMA in our system is designed to make both raw and analyzed data from each diagnostic available to the entire EDS system. Because of the way HP has implemented EMA, only one shared EMA partition per program, all EMA for EDS had to be lumped together. Currently our EMA partition is just under 800 pages(1024 words = 1 page). For each diagnostic the raw data is read directly into EMA via the VMAIO call to the front end hardware. Once the data has been read in by the respective diagnostic control program it is immediately written to disc by the diagnostic control program. Here the data is read out of EMA into local program memory, identifying information is attached, and then written to disc. EMA provides a means of handling large quantities of data on the HP machines but has the disadvantages of 1) only one EMA partition per program, 2) no shared VMA, and 3) access time for a variable in EMA is tripple that for a variable in local memory.

Another design philosophy of EDS required that the data acquisition, quick-look graphics, and real-time analysis portions of EDS be as independent as possible. In order to accomplish this the graphics and analysis phases of EDS always work from their own copies of the data. Once data is put into EMA by a diagnostic control program copies of that data are made by each program that wishes to operate on that data. This design allows each process to operate asynchronously from all other processes in the system. This also ensures that the performance of one process does not affect the performance of other processes and that the best possible system performance can be attained. The disadvantage of this method is that large amounts of memory are required to store multiple copies of all the data in the system (~ 800 pages).

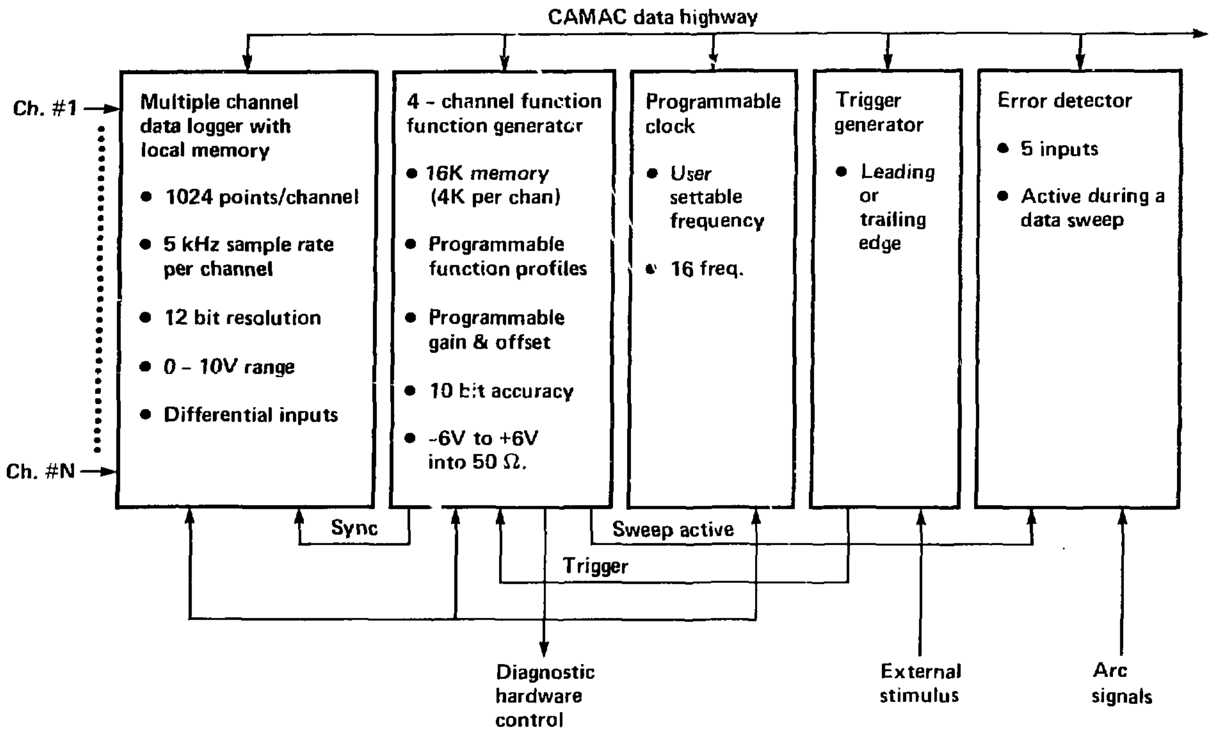

Fig. 3. CAMAC hardware configuration.

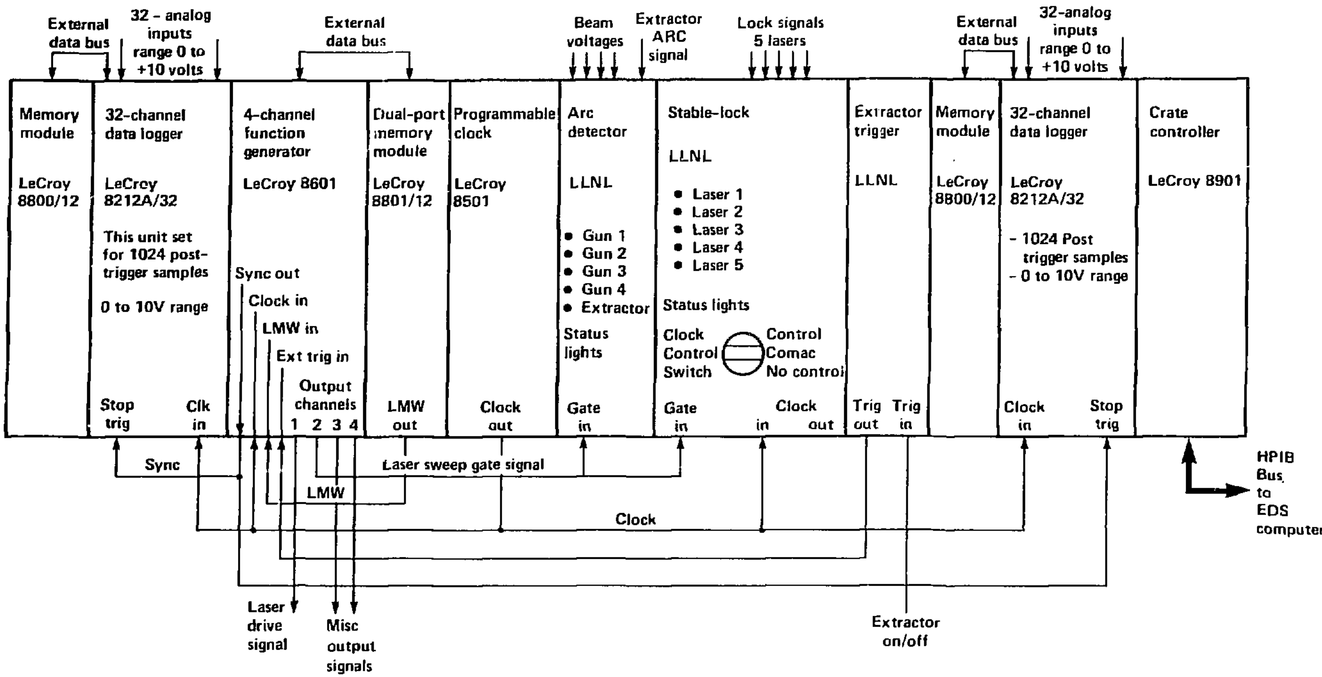

Fig. 4. Vapor characterization front end hardware.

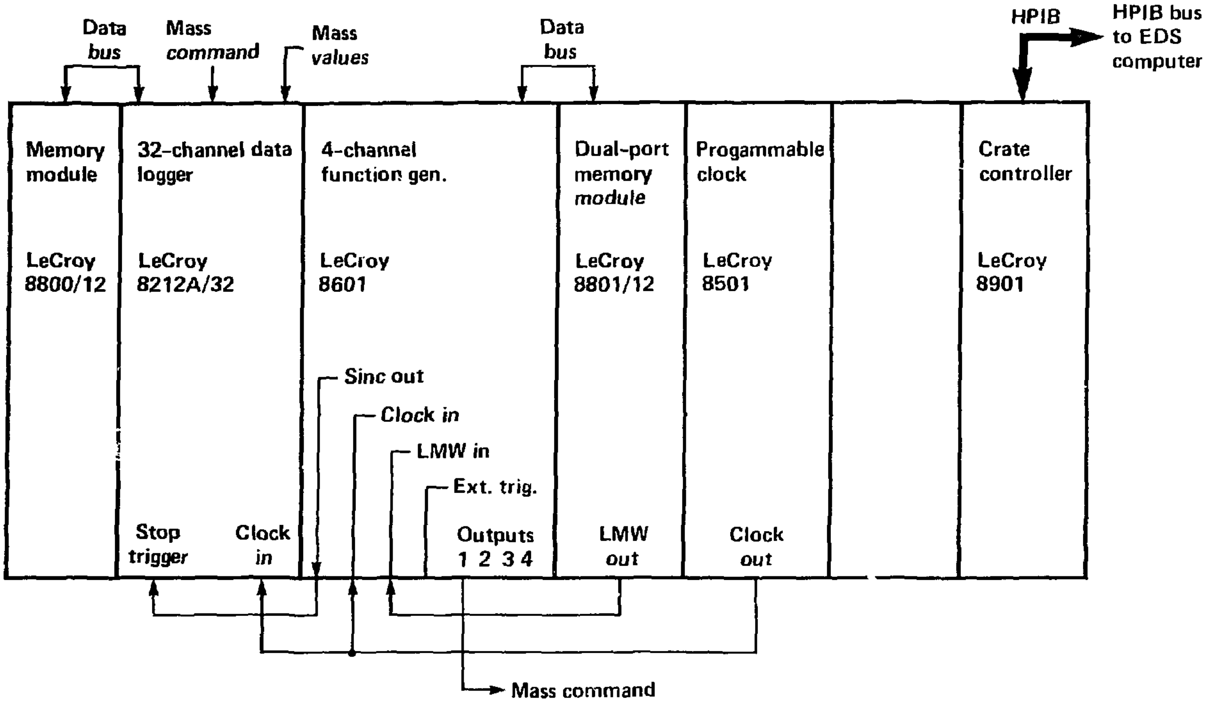

Fig. 5 Gas analysis front end hardware.

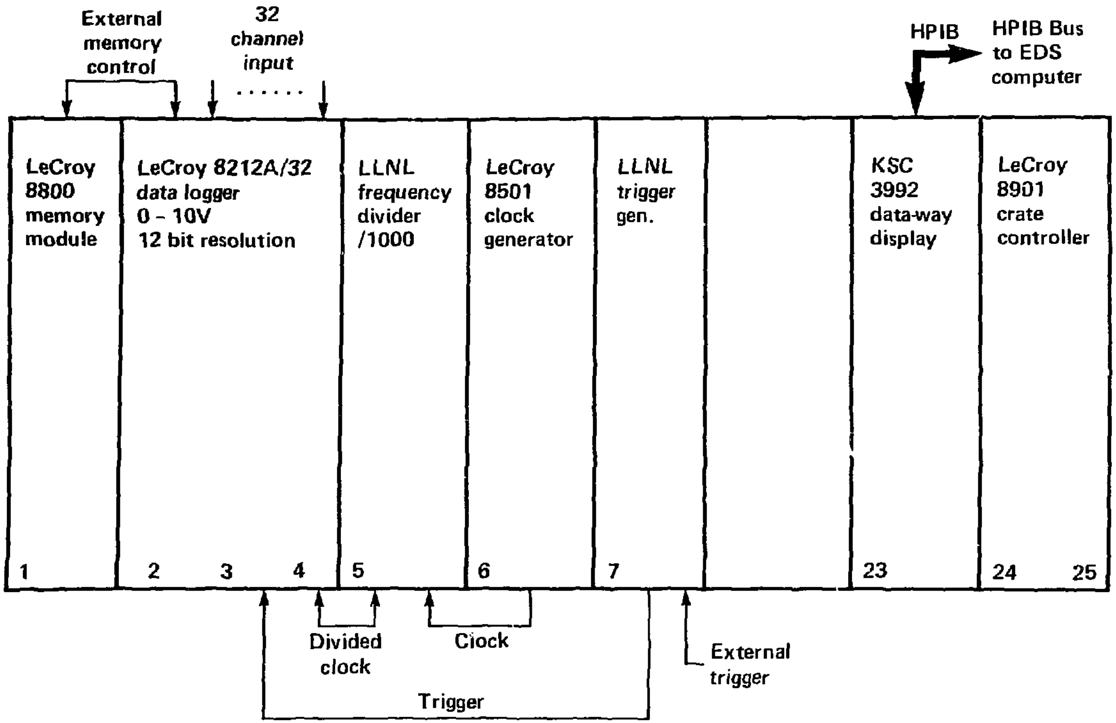

Fig. 6. Hardware configuration for process laser characterization.

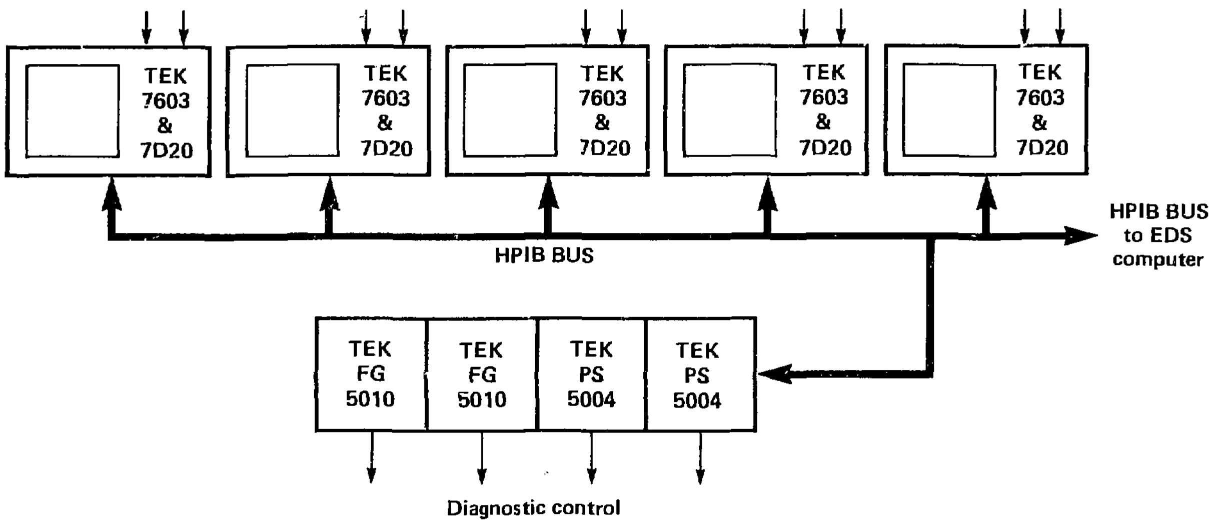

Fig. 7. Extractor performance diagnostic front end hardware.

3. Front End Hardware Configuration

On the MARS project we are using two general purpose hardware configurations for the four diagnostics in EDS. One configuration is based on a set of CAMAC modules and the other is based on high speed digital oscilloscopes.

3.1 CAMAC Front End Hardware

Figure 3 is a block diagram of the CAMAC hardware we use to interface three of our diagnostics. Figures 4, 5, & 6 are the detailed drawings of how the CAMAC equipment is configured for the Vapor, Gas Analysis, and Process Laser Characterization diagnostics. A four channel function generator is used to control any hardware associated with the particular diagnostic. The 32 channel data loggers are used to monitor all the signals associated with the diagnostic. As many 32 channel data loggers as neccesary can be used for each configuration. Each data logger is capable of taking 5000 samples per second per channel and up to 1024 samples per channel can be held in local memory at each data logger. We have found this configuration to be very versatile. In order to pre-filter the data acquired by EDS we developed a general purpose error detection module that can be used to eliminate bad data before it is read into the computer. This module is active only when the front end hardware is acquiring data. At the end of a data scan, before the data is read into the computer, the status of the error detector is checked and if a problem occured the front end hardware is immediately retriggerd. Another module developed at Livermore is the trigger generator. This module allows us to trigger a data sweep in one of three ways: 1) operator command from the keyboard, 2) rising edge of an external stimulus, and 3) falling edge of an external stimulus. As shown in Figures 3 through 6 all the components described above are tied together through a common clock. This hardware configuration has the characteristics required to do a wide range of medium speed transient data acquisition: 1) Experimental hardware can be controlled by the diagnostic, 2) data acquistion equipment is able to acquire multiple channels of vector data simultaneously, and 3) the experimental configuration can be linked to this hardware via the configuration data base within EDS.

3.2 Digital Oscilloscopes

The second type of general purpose front end hardware that we use for diagnostics in EDS are digital oscilloscopes and programmable instrumentation built by Tektronix. This equipment allows us to control diagnostic hardware as well as acquire diagnostic data on multiple channels at a rate of 40Mhz per channel. Figure 5 is a typical hardware configuration using digital scopes as the main data acquisition device. As with the CAMAC equipment described above this hardware can be logically linked to the experiment through a real time data base. In addition to the increased sampling speed, these scopes offer the following advantages: 1) data can be previewed on the scope prior to being read in by the computer, 2) all scope settings are read and stored with the data, 3) These oscilloscopes have a wide input range, and 4) satistical functions can be performed on the data in the scope itself (i.e. signal averaging).

4. EDS Diagnostics

The following paragraphs will describe, in more detail, the four diagnostics that we have implemented under EDS on the MARS project. Each diagnostic consists of front end hardware taylored specifically for that diagnostic and a diagnostic control program which interfaces the front end hardware to the rest of EDS as well as to the real time data bases. In each case the real time data bases serve at least three basic functions: 1) they allow the experimenter to assign names and calibration factors to the input channels, 2) allow the experimenter to define relationships between the input signals, and 3) the data base is used to record exactly the state of the diagnostic each time data is acquired.

The diagnostic control programs associated with each diagnostic must meet the following guidelines in order to obtain the maximum performance and flexibility from each diagnostic: 1) CPU utilization by the control program must be kept to a minimum, 2) I/O must be as fast as possible due to the large quantities of data, 3) the user must be able to control all phases of the diagnostic from his terminal, 4) all pertinent information concerning the experiment must be saved in a data base as the experiment progresses, and 5) the control program must operate independent of the real time graphics and analysis. By meeting these criteria the diagnostic control programs are capable of controlling equipment and acquiring large amounts of data without putting undo strain on the CPU.

4.1 Vapor Characterization by Absorption Spectroscopy

Vapor diagnostics is designed to provide the user with the characteristics of the uranium vapor being created in the MARS facility. This diagnostic is based on absorption spectroscopy in a doppler broadened medium. Figure 8 is a block diagram of a typical configuration used to do absorption spectroscopy work on a uranium vapor source. Figure 4 is a diagram of the front end CAMAC hardware used to interface the absorption spectroscopy equipment to the EDS system. In order to support absorption spectroscopy experiments the front end hardwre configuration must be able to accurately control CW dye lasers, acquire multiple channels of transient data simultaneously, and be logically connected to the experiment through a data base.

The four channel function generator is used to control the frequency of the dye lasers and the 64 channel data logger is used to monitor the intensity of the diagnostic laser light as well as other associated information about the experiment. The arc detector is used to monitor the status of the electron beam guns generating the vapor. The arc detector is only active during a laser sweep and can be queried at the end of each sweep before the data is read into the

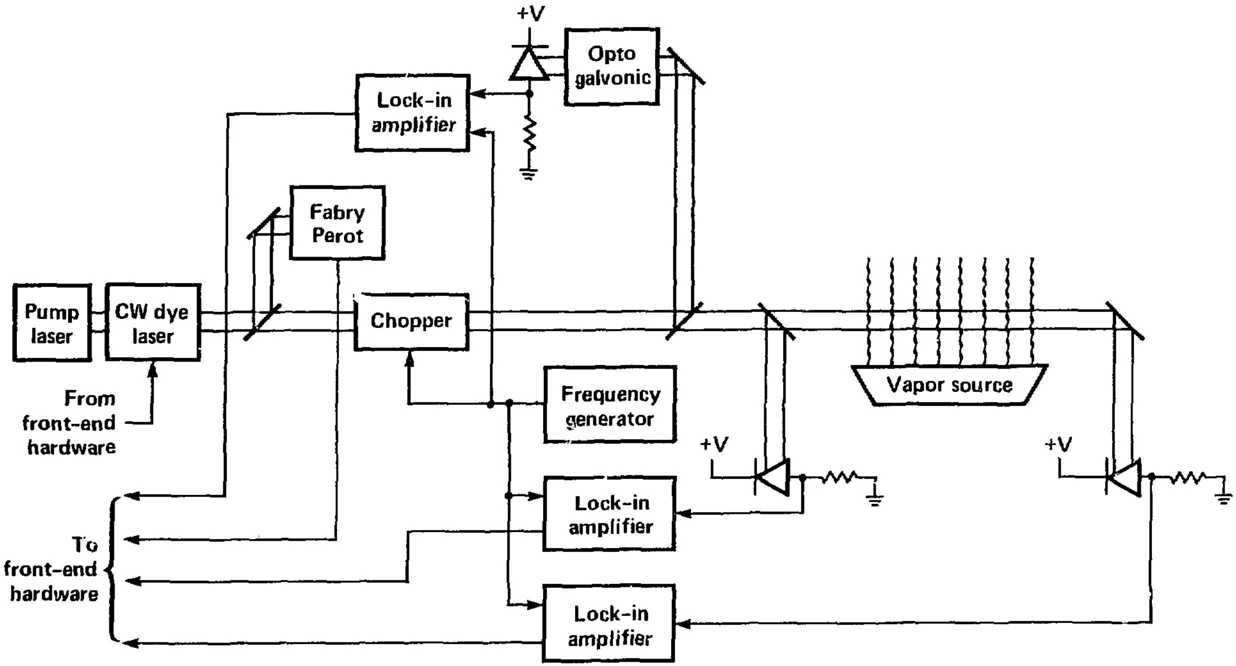

Fig. 8. Absorption spectroscopy hardware configuration.

computer. If one of the guns had an arc during the sweep the data is discarded and the lasers are reswept for new data. The trigger generator is used to start a sweep from external stimulus. A laser sweep can be started by the operator from the keyboard, by the leading edge of a trigger pulse or from the falling edge. All of this equipment is then tied together through a common clock with a variable frequency. The hardware configuration described here has the characteristics required to do vapor diagnostics in real time: 1) experimental hardware can be controlled, 2) multiple channels of vector data can be acquired simultaneously, and 3) the experimental configuration is linked to this hardware via a data base.

The diagnostic control program ,VCDL, is written to work explicitly with the front end hardware described above and meets the general guidelines for a diagnostic control program. This program allows the user to control all of the functions required to do vapor characterization, is responsible for archival of the data to disc, and keeps the real time data base current on each diagnostic laser sweep. Control of the diagnostic functions is communicated to VCDL through the EDS user interface, SHELL. Typical functions that the user can control thru SHELL are when to sweep the diagnostic laser, the profile of the laser sweep, the duration of the laser sweep, whether or not data is archived, and what conditions generate an automatic resweep of the lasers (arc mask).

When a laser sweep is initiated by the operator, VCDL sweeps the diagnostic lasers, waits for the sweep to complete, unloads the data loggers, archives the raw data to a disc file and places diagnostic status parameters into the real time data base for vapor diagnostics. When the data is read in by VCDL it is read into shared EMA partition so that the other pieces of EDS can get at the data. Once the data is read into shared EMA both quick-look graphics and real-time analysis make copies of the raw data to work from. Once the copies are completed the raw data can be written over with a new laser sweep. In this manner, as much independence as possible is maintained between the individual diagnostic and the graphics and analysis packages in EDS. This independence is maintained without sacrificing speed.

The combination of the front end hardware described above, the diagnostic control program, VCDL, and the real time data base create an environment which can be controlled by the user, changes with the experiment being performed, and does real-time vapor diagnostics.

4.2 Gas Analysis by Mass Spectrometry

The gas analysis diagnostic was designed to provide a real time indication of the relative amounts of different gases in our vacumn vessel. For this diagnostic the front end hardware and diagnostic control program must be able to control a UTI residual gas analyzer and monitor the output of that device. Input to the UTI consists of a DC voltage representing mass number and the output is a DC voltage reresenting the amount of gas sensed by the UTI. In order to get levels for a number of different gases the UTI is swept through mass numbers 0 to 50 using a function generator and mass values for those gases are monitored by data loggers.

The front end hardware used for this diagnostic is a subset of the hardware used for the vapor characterization diagnostic and is shown in Figure 5. The four channel function generator is used to drive the UTI through mass numbers 0 through 50 and two channels of the 32 channel data logger are used to monitor the drive signal sent to the UTI and the mass values returned. Both the function generator and the data logger are run from a common clock that has a programmable frequency. The hardware described here has the capabilities required to do real time residual gas analysis: 1) diagnostic hardware can be controlled, 2) multiple channels of vector data can be acquired simultaneously, and 3) the experimental configuration is logically connected to the front end hardware via a data base.

The diagnostic control program, MCDL, was written to work explicitly with the front end hardware described above and meet the general guidlines for a diagnostic control program. This program allows the user to control the diagnostic via the user interface, SHELL, is responsible for archiving the data to disc, and maintains current diagnostic status in a real-time data base. Typical functions that the user can control through SHELL are when to do an RGA sweep, the duration of the sweep, whether or not the data is archived, and whether or not to do quick look graphics and real time analysis with each sweep. If the user has chosen to do graphics and analysis it is the responsibility of the diagnostic control program to schedule these tasks. If these tasks are scheduled they are done so without wait so that the diagnostic can proceed independently from the graphics and analysis.

The comnbination of front end hardware described above, the diagnostic control program, MCDL, quick-look graphics, real-time analysis, and a user interface combine to perform real-time gas analysis on the MARS experiment.

4.3 Process Laser Characterization

The process laser characterization diagnostic has been designed to monitor all the parameters in the MARS facility which determine the amount of separative work the facility is doing. This diagnostic is the simplest of the three described so far in that it is simply a slow speed data logger with real-time display and analysis of the data it is acquiring. Figure 6 is a diagram of the front end CAMAC hardware used to interface the signals of interest to the EDS system. Control of the diagnostic is done through the system wide user interface, SHELL, and plotting of the data is done through the quick-look graphics system. As with all other diagnostics in the system, status of the diagnostic is maintained in a real-time data base. In order to support the integrated separator diagnostics the system must be able to acquire multiple channels of slowly moving data and be logically connected to the front end hardware through a data base.

The hardware for this diagnostic includes only a 32 channel data logger and a programmable clock. As shown in Figure 6 the same clock is used here as for the other diagnostics but it is divided down by a factor of 1000 to better match the requirements.

The diagnostic control program for the integrated separator, ICDL, has many of the same capabilities as VCDL and MCDL described above. One additional command is avaliable to the user with this diagnostic; he is able to set the rate the data is archived independently from the sample rate. The sampling rate is detemined by how often one wishes the real-time plots to be updated and the archival rate determines how many points are plotted with each diagnostic scan as well as how many points are saved. The main function of the real-time data base for the integrated separator diagnostic is to attach name and conversion values to each signal comming into the data logger. The other function of the data base is to maintain the state of the diagnsotic.

This front end hardware along with the diagnostic control program combine to create an environment where the user can monitor all the parameters associated with isotope separation in one location.

4.4 Extractor Performance Using Transient Recorders

This diagnostic is designed to provide the user with a means of monitoring very high speed transients yet make the data being taken available to the entire EDS community. Figure 7 is a diagram of the front end hardware we have selected to do this diagnostic. As one can see this diagnostic has been implmented mainly with Tektronix 7D20 digital oscilloscopes. A diagnostic control program has been written to control these devices and a data base designed to logically connect the front end instrumentation to the data being acquired.

Tektronix digital scopes were chosen for this diagnostic for a number of reasons: 1) they have a wide dynamic input range, 2) all scope settings can be read in along with the data, 3) data can be previewed before it is read in, 4) signal averaging can be done in the scopes to reduce random noise, and 5) the equipment is very easy to work with and interface to the computer. As this diagnostic progresses control can be added by using Tektronix programmable instrumentation.

The diagnostic control program for this equipment is designed to simply pass user commands on to the front end equipment. This is the best way to communicate with this equipment because it already has a large set of English like commands that it understands. What the diagnostic control program does in addition to this is to allow the user to define an active set of scope channels and provide a small number of higher level commands which are strings of basic 7D20 commands. When a command is issued by the user, that command or string of commands is sent to all active scope channels as defined by the user. A diagnostic control data base is maintained and keeps track of the state of the diagnostic as well as where data is stored in the archive file for each data acquisition event. Once data has been read into the computer further viewing of it can be done through quick-look graphics.

5. I/O Performance of the Front End Equipment

I/O performance of the CAMAC front end equipment is governed by the crate controller used. On the MARS project we have been using the LeCroy 8901 GPIB crate controller. An evaluation of this has been reported to the HP 1000 users group in 1983 (UCRL-89129). Essentially this device will handle DMA I/O at rates up to 400 Kbytes per second. However in some instances the line level handshaking of the HPIB bus on the A-series computer is to fast for the 8901. In these instances the HPIB bus must be artificially delayed by placing a slower device on the bus. At Livermore, we have designed such a device into a CAMAC module that plugs into the same bus as the crate controller. This reduces the effective DMA speed to approximately 100Kbytes per second. In some cases where the CAMAC crate is placed more than 20 meters from the computer we have extended the HPIB bus with fiber optic bus extenders. The disadvantage of this method is that DMA speed is further reduced to 50Kbytes per second. But as I stated earlier we have found that an effective throughput rate of 50Kbtes per second is adequate.

When we implemented the Tektronix digital oscilloscopes we found that we were able to communicate with them from the HP computer immediately. The transfer time for a single waveform of 1024 points and all associated parameters is approximately one second. We have never actually measured the DMA speed of these devices but have not found them to be a problem. One of the best things that can be said about the Tektronix scopes is that they worked as promised the first time.

6. Conclusions

EDS has been a successful integration of work done by many people over several years. It is unique at LLNL in the amount of data acquired, the graphics displayed, and the analysis done in real-time. The EDS design has withstood the test of time. While continually incorporating new commands, diagnostics, and capabilities, it has been run at regular intervals, one to three times a month. At the present time, EDS has been used in twenty (20) experiments with a total operating time in excess of one thousand (1000) hours.