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THE ON-LINE SATELLITE/CENTRAL COMPUTER FACILITY OF THE MULTIPARTICLE ARGO SPECTROMETER SYSTEM*

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ABSTRACT

An on-line satellite/central computer facility has been developed at Brookhaven National Laboratory as part of the Multiparticle Argo Spectrometer System (MASS). This facility consisting of a PDP-9 and a CDC-6600, has been successfully used in a study of proton-proton interactions at 28.5 GeV/c.

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1. Introduction

Many high energy theorists and experimentalists are currently directing their attention to the study of highly inelastic interactions, which typically produce many particles in the final state. The requirement of high statistics for low cross section topologies has placed such investigations beyond the capabilities of bubble chambers. While traditional electronic spectrometers have been employed, they too have had limitations, notably that of single particle detection.

In order to explore more comprehensively the nature of highly inelastic interactions, we have designed, constructed and used a system we call MASS,[1] the Multiparticle Argo Spectrometer System, which is the first of a new generation of all-electronic multiparticle spectrometer systems now coming into operation in high energy physics. The monitoring and data acquisition requirements for such complex systems go well beyond those of the single-arm spectrometers developed over a decade ago.[2]

Figure 1 shows the major components of MASS. A 28.5 GeV proton beam from the AGS was incident on a liquid hydrogen target, which was surrounded by cylindrical wire spark chambers located in a 10 kg magnetic field. This assembly, called the Vertex Spectrometer (VS),[3] with its nearly 4π geometry was designed to record all charged secondary particles from the interaction. Four hundred digitizing scalers were associated with the magnetostrictive readout of these spark chambers. External to the Vertex Spectrometer were two high resolution spectrometers; the Low Momentum Spectrometer (LMS) which required an additional 100 scalers for its spark chambers, and the High Momentum Spectrometer (HMS) with ferite core readout of 300 memory groups of 32 wires each.

The maximum intrinsic data rate of these three spectrometers was 80 K-18 bit words per second. When an interaction of interest occurred, the entire system was triggered, and the event recorded. One event typically generated 800-18 bit words, and required 100 ms of CDC-6600 CPU time to process. Here we present our solution to the problem of on-line monitoring and processing of the data from this complex spectrometer system.

2. Requirements

During 600 ms beam spills occurring every 2.6 seconds, data were generated and were immediately read into a buffer memory of 8000-18 bit words. At the maximum data rate this memory was filled during each beam spill. Computer service was required to transfer the contents of the buffer memory to magnetic tape, perform all required data checks, and build intermediate data files within the 2 second interval between beam spills.

Within this time structure, there were several data analysis objectives. First, it was essential to confirm that the spectrometer hardware was, to first order, functioning properly for each beam spill. Second, we required the option of requesting, on demand, relatively complete physics calculations to answer specific and changing questions. Third, as not all quantities of interest could, for time or statistics reasons, be calculated within the allotted time interval, provision for generating a data file for later analysis was necessary. Fourth, the system had to be easily divisible so that a smaller, yet self-contained portion of the hardware and software would be available to experimenters for use in development and testing prior to the actual experiment.

The above requirements cover a very broad spectrum of computer service, from first-order monitoring to heavy "number-crunching." A simple, direct solution, of course, is to provide the computer hardware for the maximum service required; even though this may represent only a 10% average utilization of the computer hardware capabilities. Such an approach is, however, prohibitively costly, particularly when more than one such user requires service simultaneously. The first practical approach to providing multi-user on-line computer service was the implementation of time sharing operating systems. The expectation was that now each user would have access to the full power of the computer when needed, and would relinquish such service to others during less demanding periods. In a previous experiment we have used such a time shared system on a DEC PDP-6, and it indeed provided us with a very powerful and versatile repetoire of resources.

However, it is clear that users synchronized in their requirements to an accelerator beam spill violate one of the premises on which time sharing is based; that is, temporally randomized service requests. The consequent degradation of system performance depends on many factors, such as accelerator duty cycle, number of users, user data rates, etc. The trend in experimental requirements has been such as to further exasperate rather than relieve this limitation of time sharing.

In our search for an alternative to on-line time sharing on a large computer, we were also influenced by several precepts formed from experience. First, direct control over local resources is the most trouble-free mode of operation. In addition, such control allows the modification of these resources to optimize the service provided. Second, it is frequently more economical to utilize established services for that portion of monitoring which has minimal real-time requirements. For example, "number crunching" is best performed by computer centers.

3. Hardware

The selection of specific hardware was predicated on the observation that the on-line response and computational power we required were inversely correlated. The on-line data processing performed between beam spills generally involved logical operations, for which a small computer is as efficient as a larger, more powerful central processor. On the other hand, we felt the detailed physics calculations which required floating point arithmetic could have a delayed turn-around.

Consequently a small, satellite computer linked to a large, central computer over high speed data lines was the obvious solution. In order that the satellite and central computer might run asynchronously, high speed mass storage devices were required at both ends. Further, a sufficient complement of satellite peripheral equipment was necessary for efficient and complete interface with the experimenter.

Our particular choice for the satellite computer (Figure 2) was a Digital Equipment Corporation PDP-9 with 16 K-18 bit word memory, automatic priority interrupt, extended arithmetic element, and memory protect. For local high speed mass storage we selected a Vermont Research Drum of 500 K word capacity connected to a direct memory access port of the PDP-9. The average access time for this drum was 17 ms and it could transfer data at the rate of 4.5 μs/word. Connected to the I/O bus of the PDP-9 were a KSR-35 teletype, 300 lines/m line printer, Tektronix 611 storage scope, and a paper tape reader and punch. The data channel of the PDP-9 serviced two DEC tape drives and an interface to a Data Box.

The Data Box contained hardwired logic to scan the wire chambers and several other data registers, and the buffer memory. The Data Box also contained an interface and driver for a magnetic tape drive which was used for primary raw data storage. In parallel, the data were accessible for transmission to the PDP-9 computer.

The central computer, to which the satellite PDP-9 was linked, was Brookhaven National Laboratory's (BNL) CDC-6600. Connection to the PDP-9 was via a second PDP-9 direct memory access port, with a data transfer rate of 250 kc, although a 1 mc rate was possible. The interconnecting data link, known locally as BROOKNET,[4] was capable of multiplexing 64 users. While BROOKNET has been in service for quite some time linked to remote batch processing terminals, our application was the first attempt to use BROOKNET for on-line monitoring of an experiment. Basically the BROOKNET link software permits any user to 1) transmit and build named data files at the CDC-6600, 2) place jobs into the input queue which act on these named data files, and 3) receive named output files at the satellite computer generated from the execution of these jobs. BROOKNET is an on-line service for the transmission of data files, but a batch mode terminal with regard to the execution of jobs operating on these data files.

4. Satellite Software

The system monitor, SCOSS,[5] in the PDP-9 was an interrupt driven, multi-task, foreground-background monitor. The monitor was responsible for scheduling six foreground tasks: 1) Data Box service, 2) BROOKNET transmissions, 3) Histogram generation, 4) File management and data transfers to and from the drum, 5) Display scope service, and 6) Teletype service package to initiate system operations. The remainder of the time was devoted to user jobs in the background mode. Each foreground task was divided into a resident and non-resident portion of code. The resident code for each task plus a buffer region occupied the lower 8 K of memory and was protected from the upper 8 K, user program area, with the memory protect feature. The resident task code was entered upon hardware interrupts from the appropriate peripheral device, or from software interrupts when program initiated. In the case of software interrupts, a clock routine was an effective 7th resident task to insure that the task scheduler scanned all task request switches at least every 100 ms to determine their software interrupt status. Using task 6, the Teletype service package, any one of several background user tasks could be requested as load modules and placed in execution.

In order to describe the interaction among user program, SCOSS monitor, BROOKNET software, and CDC-6600 user analysis program, it is important to understand the data flow. The Data Box delivered its data in 1,600 word blocks to the PDP-9, which were combined to form 12,800 word records on the drum. There were eight such drum records arranged in circular fashion. After a record had been filled by the Data Box service routine it became available on a read-only basis to the local user analysis program, and to the system BROOKNET service routine for transmission to the central CDC-6600.

After 20 minutes, approximately 250 record transmissions over BROOKNET would have been made, at which point the file at the central CDC-6600 was closed. A job file was then sent over BROOKNET to enter the job queue to analyze the current data file. We continued to take data and perform hardware checks at the local computer for another 30 to 40 minutes, while the central job was in execution. The results of the central job were then retrieved over BROOKNET for local printing and display.

The function of the user program, residing in the upper half of core, was to continuously verify that the hardware was functioning properly, as well as perform other service functions on demand. The user program was structured as a series of overlays, which were called by a permanently resident driver. Overlays could be grouped and executed as a chained sequence. In addition, some overlays, notably those which actually processed the data, were able to yield control temporarily back to the driver which scanned software switches for any requested special service. At the completion of the special service, control would be returned to the specific overlay which had allowed a yield. Figure 3 shows a block diagram of the on-line user program driver which called the user overlays. Other user programs were also constructed for particular needs.

5. Central Software

The central computing facility at Brookhaven consists of two CDC-6600 computers. Each CDC-6600 has 64 K-60 bit words of fast core memory, 131 K words of directly addressable extended core storage, and access to 10 M words of disk storage. As noted above, the function of the on-line BROOKNET transmission task in the satellite PDP-9 computer was to assemble a data file on the disk storage of the CDC-6600. Consequently, once the satellite computer had placed a job file in the input queue to process this data file, all subsequent operations were as if the central job and data had been submitted in the normal batch mode.

The 6600 analysis program, ONLINE, was written in FORTRAN for ease in its modification. Its results were available at the CDC-6600 and the PDP-9. Because ONLINE was run in near-real time, the code had to be error free, fast, and produce output that was both intelligible and economical. ONLINE was also used as the first program in the off-line analysis chain. The program was written as the individual components of the MASS were built, tested, and modified so its monitoring functions changed in time as the operating characteristics of the components were discovered. Thus, the ONLINE code has evolved through many cycles of growth and development.

To execute ONLINE without high priority charges, its length was limited to 32 K words. By dividing it into four sequential programs which communicated through mass storage files, this size was achieved. The overall flow diagram with field length requirements appears as Fig. 4. The times indicated are average clock time for the analysis of 2,500 events.

To make the best use of BROOKNET hardware, large data blocks were shipped. The SETUP program arranged the data into blocks of a size which corresponded to those written on magnetic tape at the experiment site. Thus, the read/unpack ONLINE routines were independant of the data source.

The second program, INIT, initialized scalars, histogram vectors, and scatter plot fields; read in the control parameters; and calculated geometrical survey constants of the spectrometers. Execution of ONLINE from the PDP-9 permitted control parameters and the source code to be changed remotely for any run. In practice only about 20 of a possible 300 parameters were altered frequently. A precise line-up of individual spectrometer components was then obtained when a portion of the data was read, unpacked, and partially analyzed.

The third program, ACC, read, unpacked, and analyzed the data event by event. After reading and unpacking, the accumulation of statistics proceeded in four distinct phases: one for each of the three spectrometars and one for the event identification words.

After the last event was processed the initialization constants, counters, histograms, and plots were written onto a data file for the final program, PRINT. A second output file was written to provide a display of individual events on a memory scope at the experiment site. This file contained VS track coordinates and was useful in obtaining a quick estimate of how well that complex deivce was operating.

At the conclusion of the data taking we had available in the ONLINE program a substantial part of the code necessary for our final off-line analysis of the data. Not only did this represent a considerable saving in manpower, but we could begin our off-line analysis that much sooner.

6. Evaluation

The development of MASS has extended over a period of four years and incorporates many state-of-the art technological developments. We have now completed an experiment of over 3 million proton-proton interactions, which has been a demanding test of the satellite/central computing facility.

The satellite PDP-9 computer has enabled us to maintain a very close examination of the system from beam deflection magnet currents to spark chamber efficiencies. Even slight changes were instantly detected and corrected. Without such on-line response a great deal of data would have been lost as the number of hardware components to be monitored exceeded by several orders of magnitude that which the experimenter alone could manually record. While the PDP-9 computer sampled only 30% of the recorded data during maximum data rates, it was never processing data more than 10 seconds old. After the satellite software was debugged, we experienced virtually no hardware or software downtime.

The instantaneous data rates during transmission over BROOKNET to the central CDC-6600 facility corresponded to 12,800-18 bit words sent in 100 ms. The average rate corresponded to an actual duty cycle of $\sim 1/6$, so that the load was not near the design maximum, but neither was it trivial. The reliability of the BROOKNET operations were adequate for our needs, and have continued to improve. The central computer would drop two or three times per day, but come up again promptly. On 90% of these drops, the data already transmitted were still intact after recovery. In general, the hardware was solid when unperturbed.

In summary, we feel that the satellite/central computer configuration for on-line use is a very powerful and efficient resource. For devices such as MASS, and even less complex ones as well, this system represents an optimum match of CPU power, computational requirements, and on-line response at each phase of the data processing.

Acknowledgments

The success of this project was dependent on the availability of many technical services at BNL. The system monitor for the PDP-9, SCOSS, was written by the Computer Group of the Instrumentation Division. The several interfaces required were constructed and maintained by both the Instrumentation Division and the Applied Mathematics Department. We also wish to acknowledge the advice of our collaborators and colleagues throughout this period.

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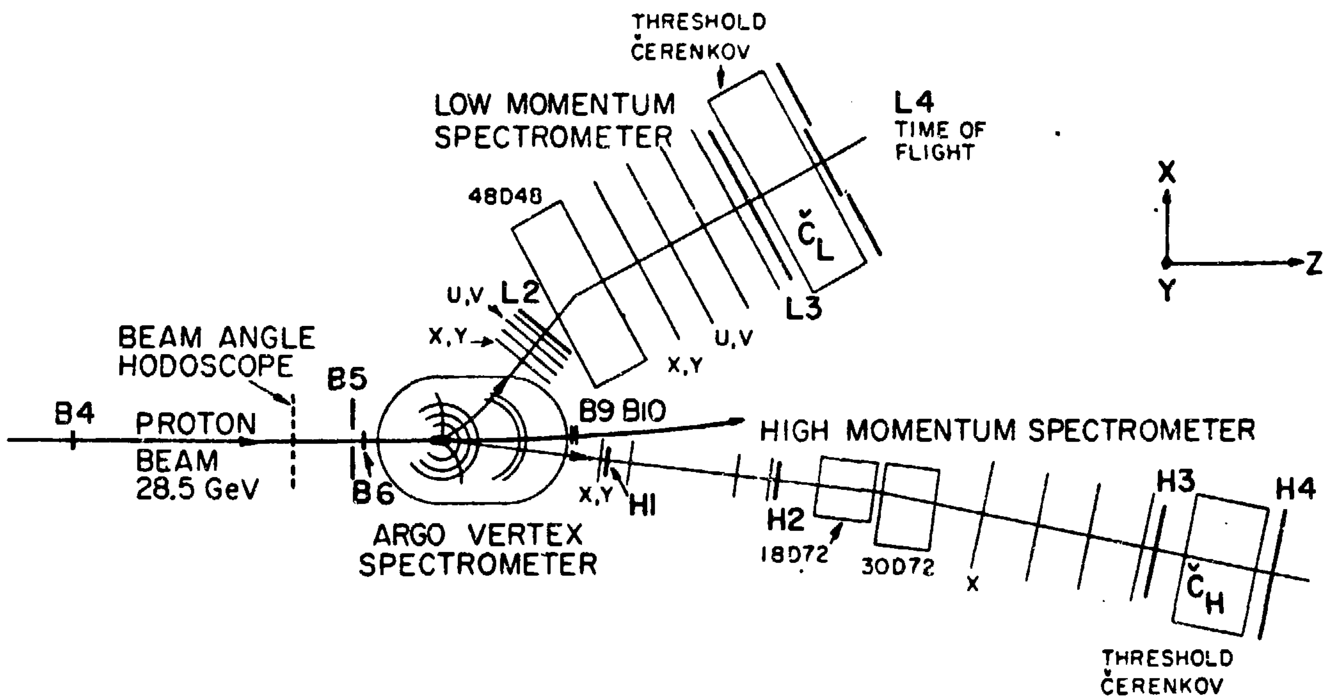
FIGURE CAPTIONS

Figure 1 A schematic of MASS showing the three spectrometers. B4, B5 and B6 are defining counters for the incident beam, while L2, L3, L4, and H1, H2, H3, H4 define respectively scattered particles in the LMS and HMS. The three sets of counters B, L, and H form the trigger for the entire system. The X and Y chambers have their wires vertical and horizontal, while the U and V chambers have wires oriented at $\pm 27^{o}$ to the vertical.

Figure 2 Hardware configuration of the satellite PDP-9 computer and its BROOKNET connection to the central CDC-6600 computer.

Figure 3 Simplified block diagram of the on-line user program driver. Each square box represents code that is loaded into core as an overlay and part of one of several chained sequences. The sequence N_1 through N_3 provides on-line analysis of the current data. The sequence E_1 through E_3 generates a job file for the CDC-6600. The sequence D_1 and D_2 provides data analysis on information from special devices which are infrequently scanned.

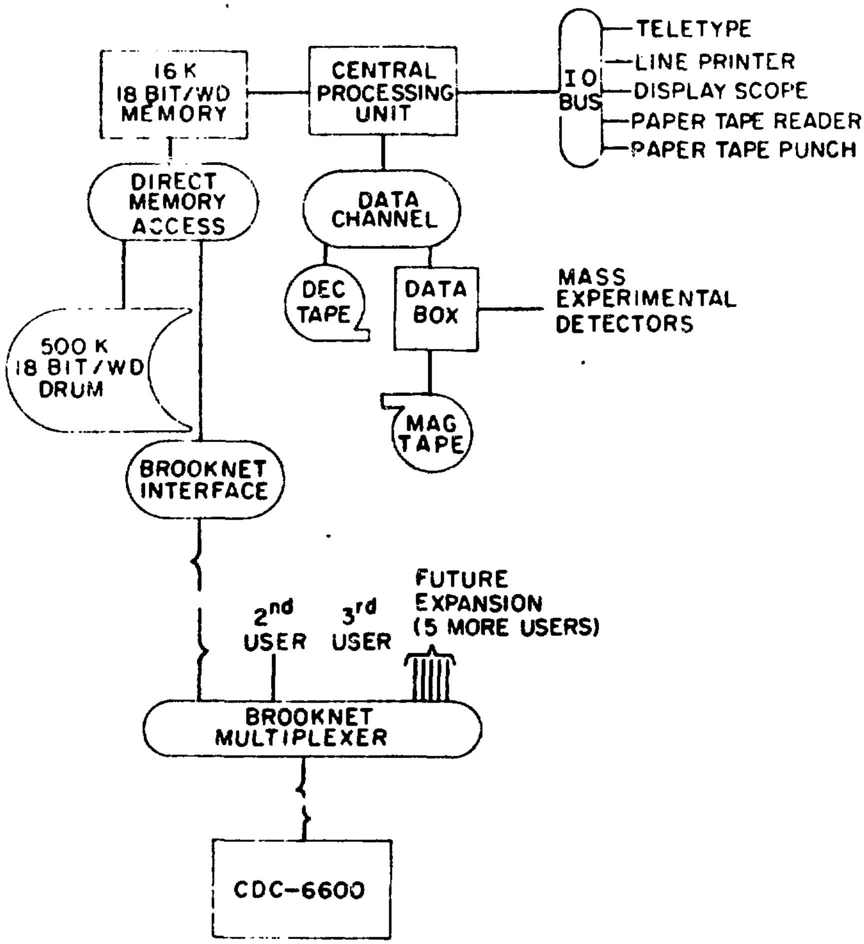
Figure 4 Flow chart of the CDC-6600 analysis program ONLINE.



MULTIPARTICLE ARGO SPECTROMETER SYSTEM
(MASS)

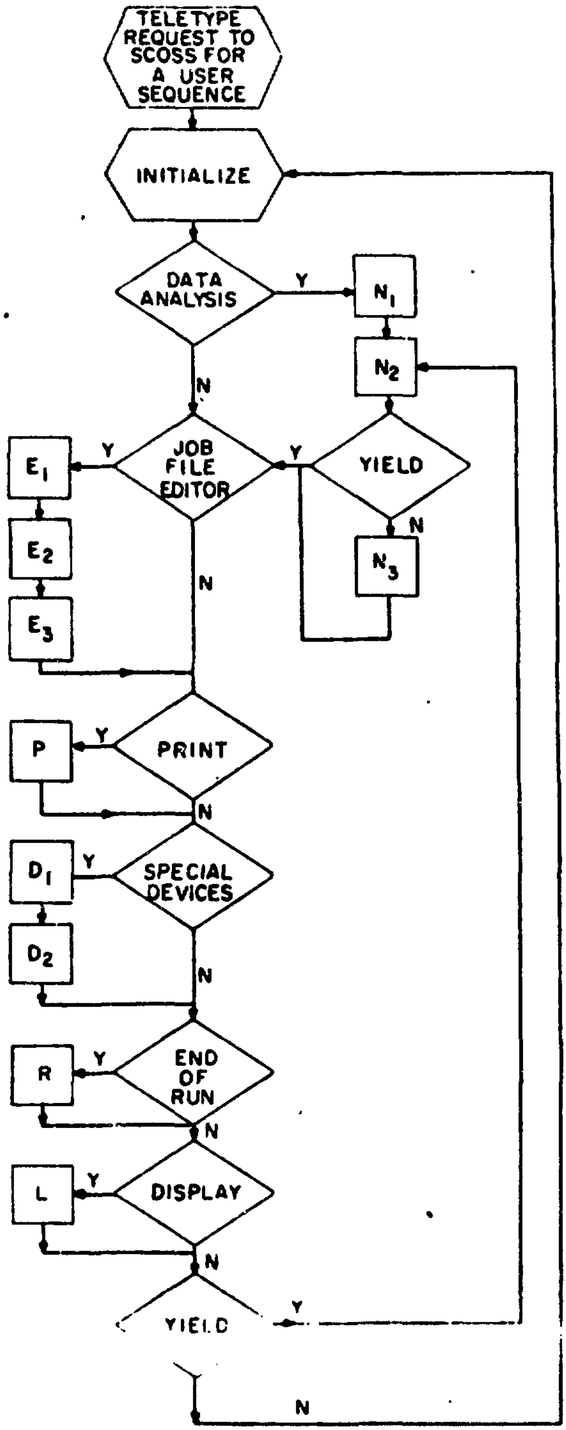
Fig. 1

Neg. # 8-5-74



Neg. # 8-964-74

Fig. 2



:ig. 3

Neg. # 8-963-74

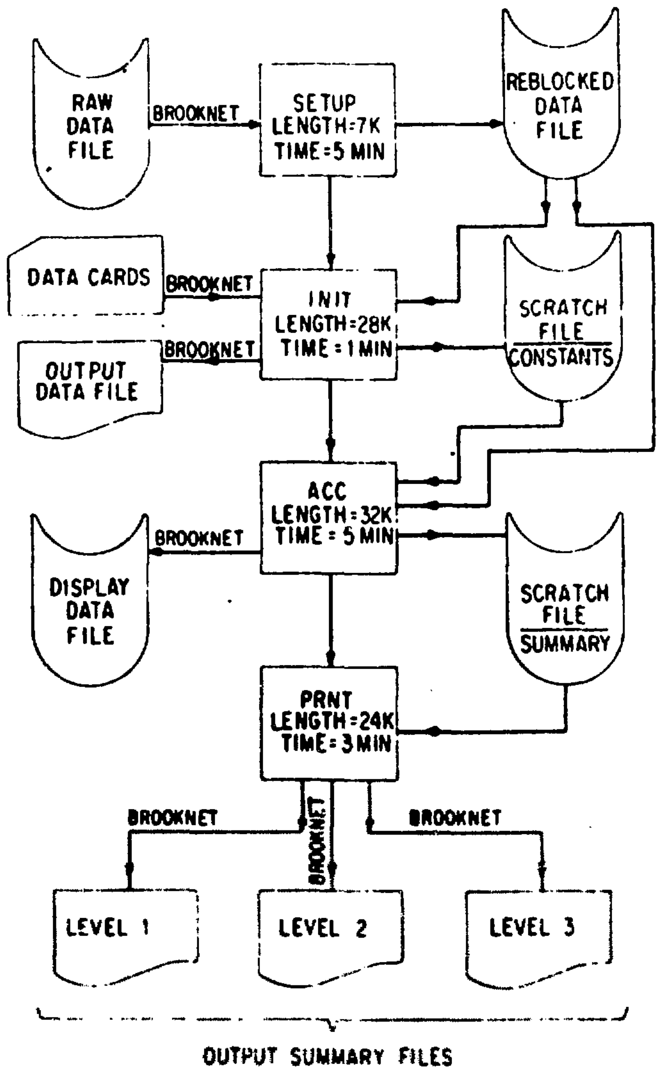


Fig. 4

Neg. # 8-962-74