A HIGH ACCURACY INSTRUMENTATION SYSTEM WITH ON-LINE DATA PROCESSING FOR STATIC ROCKET TEST FIRING.

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Introduction and Application

The goal of landing men on the moon and the subsequent safe return to earth, requires extensive preliminary ground tests of all types of equipment. This paper describes two Digital Data Systems which will help in achieving manned lunar landing. The system will check the first stage rocket engines used on Project Apollo.

The Test Laboratory of the NASA Marshall Space Flight Center at Huntsville, Alabama is installing the two Digital Data Acquisition Systems as part of a rocket test facility expansion. The systems were designed and built by Beckman Systems Division under subcontract to Lear Siegler, Inc., prime contractor for installation of all instrumentation in the expansion.

The systems are ~~to be~~ used for NASA acceptance tests of the Rocketdyne H-1 engines and for pre-flight testing of the Saturn S1B first-stage rockets, which use eight of the H-1 engines: Six of the Saturn S1B's have already been built and tested by Marshall Space Flight Center and flown. The data systems will be required for the increased testing load when the Michoud facility near New Orleans, Louisiana, reaches full production and the S1B stages (serial numbers eleven through twenty) must be tested in rapid succession.

The Huntsville Test Laboratory receives the H-1 engines from Rocketdyne, performs acceptance tests, and then ships them down to Chrysler at Michoud for assembly into the S1B vehicles. Barges take the completed S1B stages up the Mississippi and Tennessee Rivers to within a few miles of Huntsville. The trip from dock to test stand is over a specially constructed highway. After testing, the S1B stages move back over part of the same route and then by water to Cape Kennedy for launching.

Nature of Tests

A typical S1B test uses both data acquisition systems, each capable of measuring, recording, and processing data from 192 transducers. Using two systems, each having one-half of the total required channel capability, increases the scanning speed, and adds to the reliability of the system. For further added reliability, fifty or more of the 192 channels in each data system measure, record, and process data from the same group of transducers, which measure key performance data. Key performance parameters include:

Combustion chamber pressure
(two transducers for each engine)
Combustion chamber temperature
Fuel inlet pressure
LOX inlet pressure
Fuel flow rate
LOX flow rate

These measurements are taken on each of the eight engines. In addition, a number of load cells in the supporting structure measure forces produced by the rocket thrust.

The remaining 284 channels monitor temperatures and pressures throughout the Saturn stage during these acceptance or pre-flight tests to determine if the many sub-systems are functioning properly and if temperatures and stresses throughout the stage remain within safe limits. Each-system also measures the output of 24 counters, the input of 90 event signals and records test run number, date and time information.

Uses of Output Data

During preparation €or test runs, the systems display the measured output of selected channels to assist the test engineering personnel in checking out the hook-up of the transducers and the wiring and settings of the signal conditioning equipment. To facilitate calibration, the system assists the operator in gathering calibration data and in preparing this data for use during testing and playback operations.

During the test the system performs three primary functions.

1. It records all channels on digital magnetic tape for later processing.
2. It compares the readings from selected channels against high and low alarm limits and gives an indication by means of an alarm signal whenever these limits are exceeded. By this means the system has the capability to initiate automatic test shut-down.
3. The system selects and outputs whatever data may be of interest to the test engineers during the test.

After the test, the system performs two main functions.

1. The system plays back the tape recorded during the test and, using the stored calibration coefficients, corrects all the recorded data and writes another tape in computer format which goes to the computation center for detailed performance evaluation.
2. The system can play back either the primary or secondary tape and output selected channels. From

these data the test engineers determine if the test objectives were met and decide whether the rocket should be removed from the test stand or prepared for another test.

System Description

There are two identical 192-channel, analog-to-digital data acquisition and processing systems. Each system has 192 amplifiers connected through one common, high-level analog patchboard so that amplifier outputs may be exchanged or shared between systems. High level outputs of the amplifiers are sampled by each system at a rate of 5,000 samples per second in a sequence determined by a logical patchboard. The data are then digitized and recorded directly on magnetic tape and also transferred into the memory of a Beckman Model 420 System Computer.

The computer performs a wide variety of operations using programs written specifically for this application. Computer output devices include magnetic tape transports, a line printer, alarm limit relay contact closures, data logging typewriters and digital-to-analog converters for output into X-Y plotters, galvanometers, and chart recorders.

Amplifiers

A separate amplifier for each incoming analog signal is necessary to provide the accuracy and reliability required by this system. High quality carrier amplifiers employing massive loop gain and transformer isolation of the input circuits provide frequency response up to 300 Hz, high accuracy, and insensitivity to external disturbances such as common-mode voltages. The over-all accuracy of the system is largely determined by input amplifier performance in an amplifier-per-channel system of this type.

Each amplifier has ten gain settings between 2.5 and 500 millivolts full scale. Plug-in filters supplied with the system may be inserted to filter the signal before it enters the amplifier or as it leaves the amplifier. Plug-in filters are typically two-pole RLC, low-pass filters, with attenuation of 12 db per octave beyond the corner frequency. Filters with corner frequencies from 2 to 50 Hz are used with the systems

Commutator

Solid-state commutating switches sample the five-volt, full scale, low impedance outputs of the data amplifiers. A sample and hold circuit tracks the commutator output and holds the uncertainty of time of sampling down to less than ±1/4 microsecond. This permits a more accurate measurement of the high frequency components.

Analog-Digital Converter

A successive approximation type analog-to-digital converter converts each amplifier transducer signal to a 14-bit binary number with sign.

Flowmeter Inputs

Twenty-four channels accept frequency analog signals from turbine type flowmeters and magnetic pick-up tachometers. Each frequency analog signal is sampled twenty-five times per second. Each flowmeter or tachometer input signal operates a binary counter which runs continuously. Each time a counter is sampled, its value is transferred to the system buffer register.

Contact Closure Inputs

The system also has the capability to sample a total of 90 digital contact closure inputs. These inputs come from switches or valves and various other controls to indicate their "on" or "off" state. When these inputs are sampled, 90 bits corresponding to the state of 90 contact closures are loaded into the system buffer register.

Control of Sampling Sequence

For each sample, the sequencer patchboard specifies the source of information (analog channels, flow channels, or contact closures). The patchboard has 192 pairs of hubs which emit signals in a sequence from one to 192 at the rate of 5,000 per second. The patchboard also has a set of hubs connected to the analog commutator switches and to the digital gates which enter data into the buffer register. Connecting one of the emitting hubs to one of the sampling hubs causes the selected channel to be sampled at that position in the sequence. One cycle of the sequencer is called a frame. If it is desired to sample a given channel more than once per frame, this is accomplished by paralleling on the patchboard the outputs of several of the emitting sequencer hubs.

Time Accumulator

One of the data sources is a digital time accumulator operating from the system clock. Under control of the sequencer patchboard the time of day may be sampled and recorded in any desired sequence position. The time accumulator counts milliseconds, seconds, minutes, and hours in binary coded decimal form.

Magnetic Tape Units

Each system has two magnetic tape units. These operate with one-half inch digital tape in seven-track IBM compatible format and character spacing of 200/inch. The system writes raw data from the ADC in gapless format at a tape speed of 75 inches per second. Playback of the raw data tape for calibration corrections and conversion to engineering units and writing of a gapped computer compatible tape occurs at 37.5 inches per second. The 420 Computer writes the corrected and converted data in gapped format at 75 inches per second, stopping the tape between racords.

Computer

The 420 System Computer operates on-line as an integral. part of the system. It receives data from the ADC during the data acquisition modes or from the playback of one of the magnetic tape transports in the data processing modes. It performs calibration corrections, conversion to engineering units, alarm limit comparisons, averages, and computes performance parameters. The computer outputs these data to a variety of output devices which include:

1. A 300-line per second line printer with a line length of 120 characters.
2. Four typewriters, which type information in engineering units.
3. Six Digital-to-Analog Converters which drive three $X-Y$ recorders, or galvanometers and strip chart recorders.
4. Forty-eight relays which provide contact closures for operating annunciator lights, audible signals, or test control circuits.
5. Sixteen remote digital numerical displays distributed throughout the data complex. These displays indicate both sequence-position and data.

Setup & Checkout Operations

During test setup, the systems are used to assist the Test Engineers in connecting the transducers and signal conditioning equipment to the system inputs and in making the necessary adjustments. Digital displays, located near the racks of signal conditioning equipment, display the readings of selected channels while adjustments for those channels are being made on the signal conditioning equipment.

The cathode ray tube displays the data value of 100 channels in terms of the vertical heights of 100 bars. A reverse polarity, a signal out-of-range, or the approximate reading of any signal are apparent from a glance at the cathode ray tube. Because the cathode ray tube display uses digitized readings from the ADC, it also serves as an excellent check on the performance of the instrumentation system from the transducer up to and including the ADC.

The system has two check-out modes, one allows it to stop on a single channel and repeatedly digitize and display the single value on that channel, the other to scan once through all the channels and then stop. These operating modes are useful during test setup and for checkout of the system itself.

Calibration Operations

After all the instrumentation has been set up and adjusted, the system has a histogram mode which assists the operator in determining system accuracy. In this mode of operation, the computer calculates the mean of a large number of readings from one or more selected channels. The line printer prints the mean and the distribution of all the readings around the mean. This provides the Instrumentation Engineer or Test Operator with an excellent statistical analysis of the readings and enables them to readily identify any excessive offset or noise.

The Test Laboratory at Huntsville calibrates the entire Data Acquisition System after the rocket is in place in the test stand and after all the instrumentation has been connected and adjusted. Wherever possible, known values of the primary stimuli are applied to transducers. These values and corresponding ADC readings of the data systems are used to generate calibration curves for each transducer. For instance, solenoid valves disconnect the pressure transducers from the pressure taps in the engines and connect them to calibration pressure sources of known value. Known voltages are substituted for thermocouple outputs and known frequencies are substituted for the outputs from turbine type flow meters or magnetic pickup tachometers.

The computer program for calibration is designed to facilitate the gathering of calibration data. By means of the typewriter, the computer conducts a dialogue with the operator which results in the entry of all necessary calibration data, and which serves as a check list to make sure that all calibration functions are performed. The computer requests the channel numbers to be calibrated, then asks the operator to type in the value of the primary stimulus being used. After receiving these data, the computer takes the ADC reading automatically, and repeats the process until a set of calibration points have been collected. After the calibration points have been collected, it calculates the coefficients of a set of equations which define the calibration curve and checks to make sure that the curve fits the original calibration points within a specified error tolerance. After all channels have been calibrated, the computer writes a paper tape, called the Coefficients Tape, which contains all the information necessary for the computer to perform calibration corrections and conversions to engineering units for all input channels.

Operations During the Test

During the test, the system records ADC readings directly on magnetic tape. The system provides for recording on both digital tape units in parallel for reliability or on a single tape with switchover to the other tape for maximum recording time.

ADC readings from all channels enter the magnetic core memory of the computer through one of the independent input-output channels. In the computer, data from channels previously designated by the operator are selected for further processing. The computer may perform any computations on the data, subject only to the limitation of the amount of time available,

One of the data processing functions performed by the on-line programs is the comparison of readings with high and low limit values stored in memory. When a data value passes the limit value, the computer program can initiate audible or visual alarm or automatic test shutdown, The program ean also provide overlimit indications which depend on a logical function of several limit comparisons.

For all data which is selected for output printing or display, the computer makes calibration corrections and converts from raw ADC readings to familiar engineering units. At the option of the operator, several readings from the same channel may be averaged together to smooth out short time variations of the measured signal. The computer program then converts the readings from binary to decimal. and prepares them in the required format for output to the various peripheral devices.

The organization of the computer is such that the inputting of ADC data and the outputting of converted data are completely buffered. They proceed concurrently with the execution of instructions in the main computer program and do not require the attention of the main computer program on a word-by-word basis.

Post-Test Operations

The tape 'containing "raw" ADC readings in gapless format made during the test (called Tape I) is considered to be a primary test record and tape processing operations are organized to minimize the handling and playbacks of this tape. During the tape conversion mode of system operation, Tape I is played back at half the speed at which it was recorded, or 37.5 inches per second, without stopping. The System Computer applies calibration corrections, converts all data to engineering units and records them on another magnetic tape (called Tape II) in gapped IBM compatible format. Tape 11 is then used for all subsequent processing, both at the system and at the central computing facility.

One of the programs provides for reviewing either Tape I or Tape II. In this mode, the tape is played back and data from selected channels is displayed by the various computer peripheral devices. Engineers use this Review Mode information to determine if test objectives have been met and to scrutinize areas of performance not covered by the data printed or recorded during the test.

After a successful test of the rocket it is shipped to Cape Kennedy for launching.

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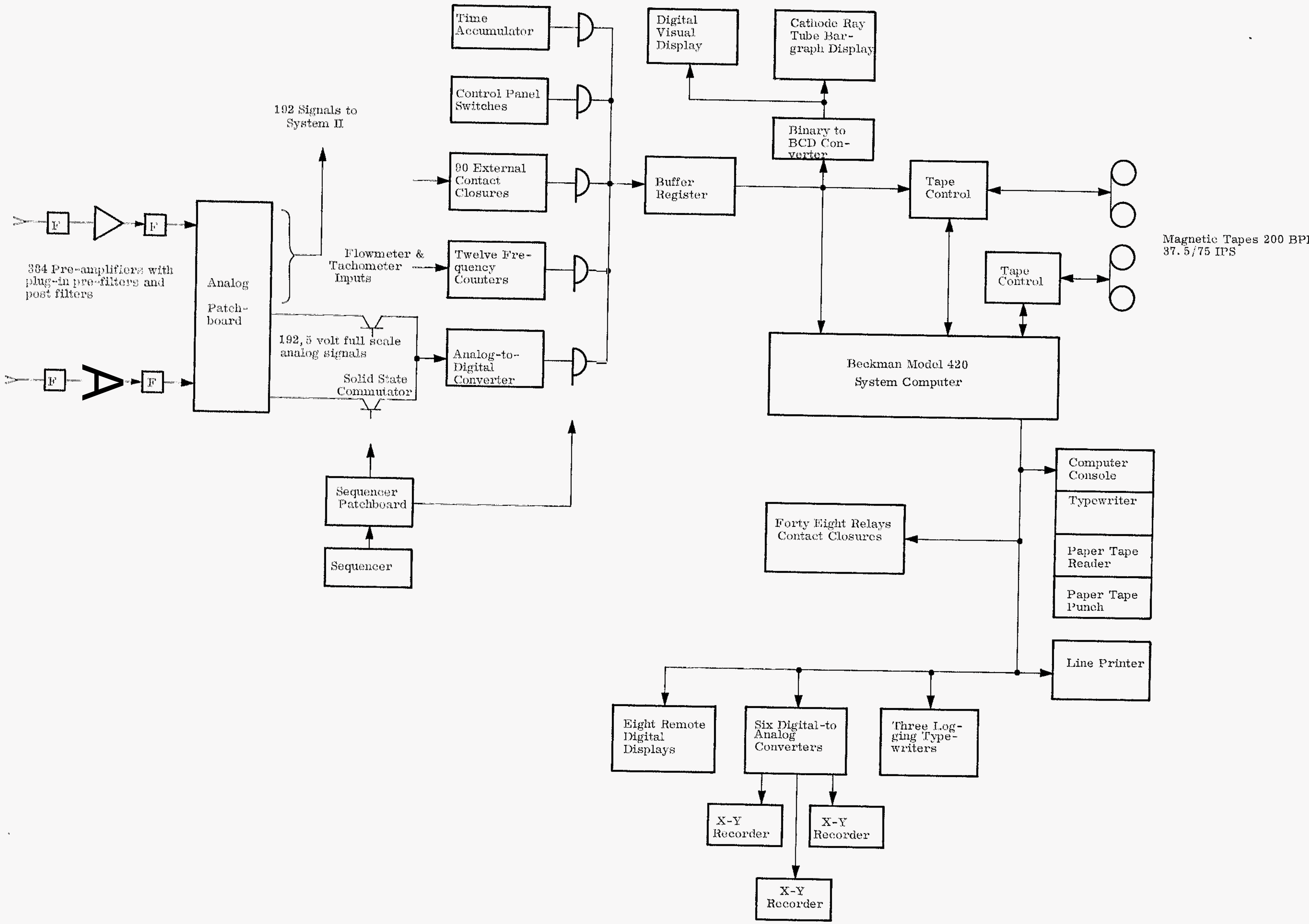
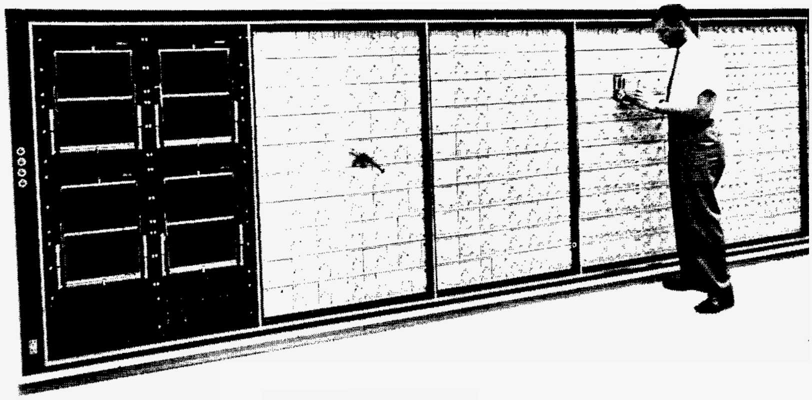
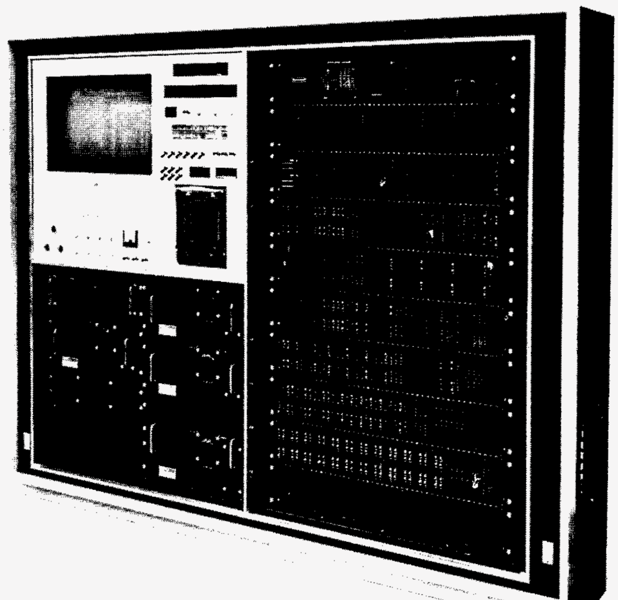


DIGITAL DATA ACQUISITION SYSTEM/BLOCK DIAGRAM

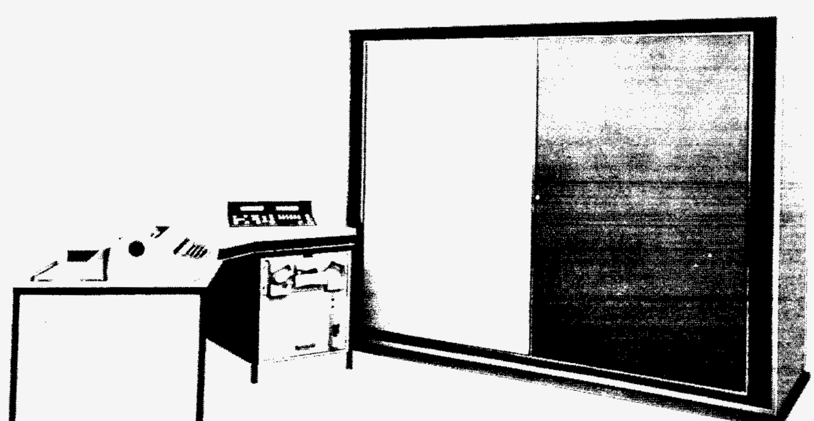


AMPLIFIER AND ANALOG PATCHBOARD CABINET

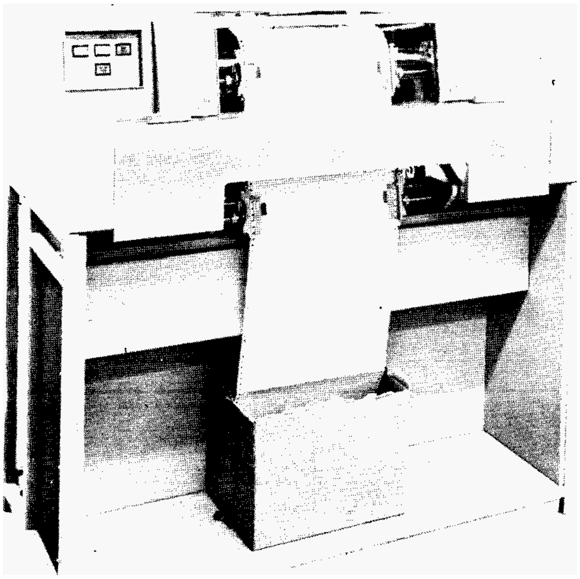


ANALOG CABINET WITH BAR GRAPH

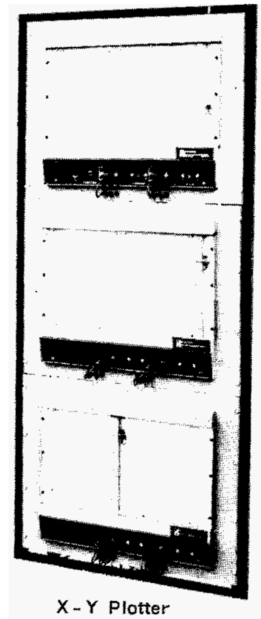
DIGITAL CABINET WITH DIGITAL TAPE UNITS



BECKMAN MODEL 420 SYSTEM COMPUTER

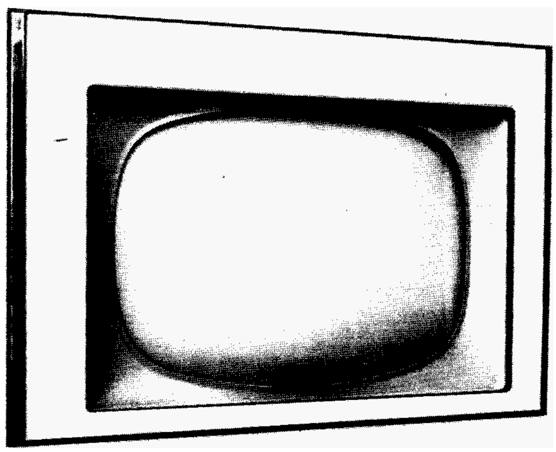


Line Printer

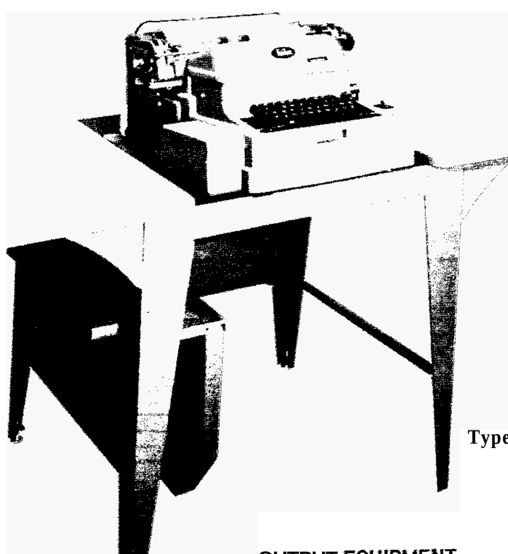


X - Y Plotter

OUTPUT EQUIPMENT



Cathode Ray Tube - Bur Graph Display



Typewriter

OUTPUT EQUIPMENT