A New
DIGITAL DATA PROCESSOR

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A physical and operational description of a new digital data processor (DIDAP) is given. This highly versatile processor handles both digital and analog data simultaneously and accepts various types of parallel or serial data. These data are processed at rates up to 32 times the real-time recording rate. The new processor shapes and conditions the data it receives, translates them into digital form, if not already in digital form, correlates the data with an accuracy better than one millisecond, and writes the data on digital tape in IBM 7094 computer format. Critical information is monitored on visual displays, and high-speed time-history plots of more than 80 selected functions can be produced simultaneously under the fully automatic control of a stored program.

A new digital data processor (DIDAP) developed by the Instrumentation and Development Group of the Applied Physics Laboratory has replaced an earlier model which had become outmoded and inefficient. The new DIDAP was designed to satisfy the need for a machine that would effectively and expeditiously handle the increased and varied data-processing load at APL. Retaining proven features of other data-processing equipment and incorporating many new characteristics, the DIDAP is unique in its wide range of capabilities and in the variety of ways it can be programmed to handle data.

Exceptionally versatile, the new design can satisfy almost any data-processing requirement, making it even more effective than originally planned. The new DIDAP can process rapidly and accurately large volumes of input data in a fully automatic operation. It can simultaneously handle both analog and digital data formatted in a variety of ways, write them on digital tape in computer entry format, display critical information, and produce, under the control of a variable stored program, high-speed time-history plots of selected functions.

Input data may be in parallel or in serial form. The DIDAP can accept parallel digital input data as recorded either on 7-track tape in IBM computer format or on 16-track digital tape. It can accept the digital output of a high-speed analog-to-digital converter. It can accept analog data and various types of telemetry data (including predetection data) recorded on analog tape. The new processor accepts either binary-coded decimal (BCD) range time in parallel form or any of the standard serial range time codes. At its output, the DIDAP can write IBM tapes of any record length up to 340 IBM words at densities of either 200, 556, or 800 bytes (one byte is 7 bits) per inch.

Design Approach

The design objective of the new DIDAP was to provide a highly versatile general-purpose processor that could rapidly and accurately handle virtually all types of serial or parallel input data. To achieve such a capability, emphasis was placed on conversion flexibility, programming simplicity, and operational reliability.

Conversion flexibility was achieved by including a small memory unit in which special programs to control the DIDAP's operation can be stored and by interfacing key inputs and outputs of various subsystems through a single digital patchboard. Programming simplicity was achieved by using a paper-tape system for loading the control memory and by simplifying patchboard programming. Operational reliability was achieved by using components at less than their rated values, by using convervative design techniques, and by practicing good human engineering.

Since high-speed processing was an essential feature of the design, stress was placed on achieving high playback-to-record ratios for the input tapes and fully automatic operation. Generally, the processing speed of the new DIDAP is limited only by the speed of the input-output equipment. Serial input rates for digital data are limited only by the speed of the existing logic. At present, serial digital data can be inserted at rates up to 120 kHz, and this rate could be increased to 500 kHz if necessary. Analog-to-digital conversions may be performed at any rates up to 40 kHz. Other types of parallel digital data input can be processed at somewhat higher instantaneous rates. However, for producing IBM tapes and multistylus plots, the output recorders limit the 18-bit character input rates to 20 kHz. Methods of programming the processor for specific problems also influence the maximum processing speed.

Mechanical Layout

The new DIDAP installation, shown in Figs. 1 and 2, is composed of an analog section and a digital section. It is housed in 20 racks including the input and output tape recorders and peripheral equipment.

The digital section of the installation is shown in Fig. 1. These ten racks contain approximately 1350 digital logic cards, the operator's console, the

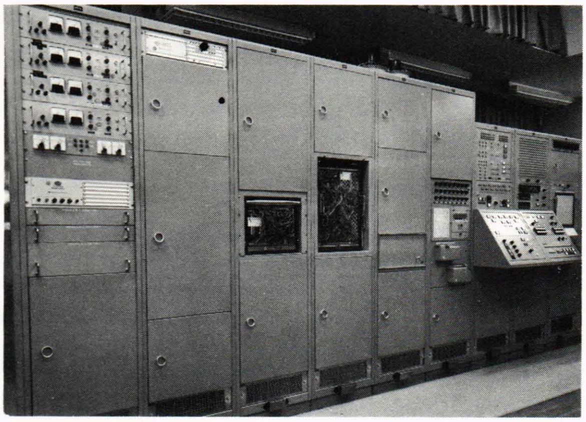

Fig. 1—Digital section of DIDAP installation.

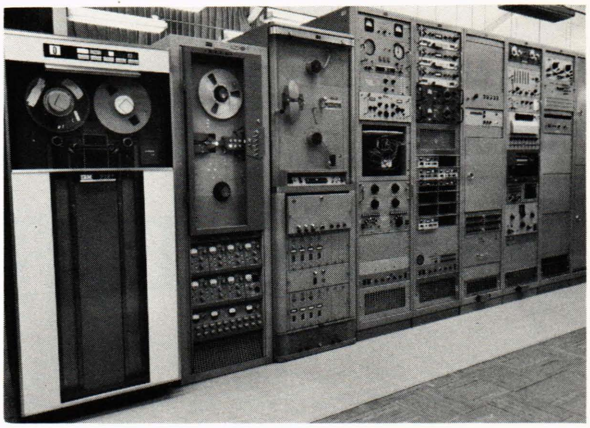

Fig. 2—Analog section of DIDAP installation.

DC power distribution system, a digital printer, a paper tape punch and reader, two magnetic core memories, a programming patchboard, an auxiliary logic patchboard, a multistylus recorder, and 551 styli keyer circuits. A typical logic card is shown in Fig. 3.

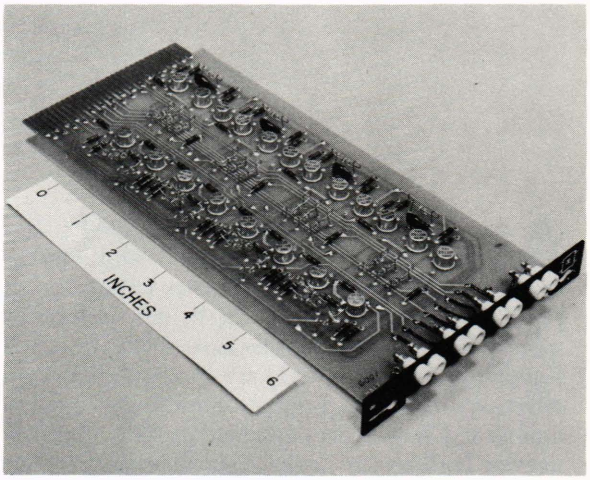

Fig. 3—Typical logic card.

The analog section of the installation is shown in Fig. 2. These ten racks contain the input digital and analog tape recorders; the output tape recorder; analog-to-digital conversion equipment; an analog patchboard that serves to interconnect the peripheral input discriminators, a bit synchronizer, an array of signal-conditioning circuitry; and peripheral test equipment. One rack houses the Data Processing Facility central patchboard.

System Description

A simplified block diagram of the new DIDAP is presented in Fig. 4. All inputs to the system are connected through the analog and digital patchboard assemblies. The input data are generally obtained either from digital tape or from one or more tracks of analog tape. Telemetry data may be frequency-division or time-division multiplexed or both. Usually, the data are accompanied by serial range time information coded in one of the standard coding formats. The range time recorded on digital tape may be in either serial or parallel form.

The input data may be operated upon by data recovery circuits consisting of discriminators, filters, operational amplifiers, a bit synchronizer, an analog-to-digital converter, and other circuits, all of which are interconnected through the analog patchboard assembly. After recovery, the data are connected through the digital patchboard assembly to the digital section of the processor. Range time is connected directly to a range time converter for processing.

The digital patchboard assembly is used to program the processor in a variety of ways, to interconnect conversion logic, and to arrange the format of the input/output data. The programmed conversion logic translates the recovered raw input data to a digital form that can be handled by the remainder of the DIDAP. When processing input data, all operations are automatic. The operations depend both on the manner in which the input signals are patched and on the manner in which the subsystems are programmed. Some of the operations are controlled by a stored program which can be varied to suit the needs of each particular job. As the data and range time are processed, they are correlated with an accuracy approaching one millisecond.

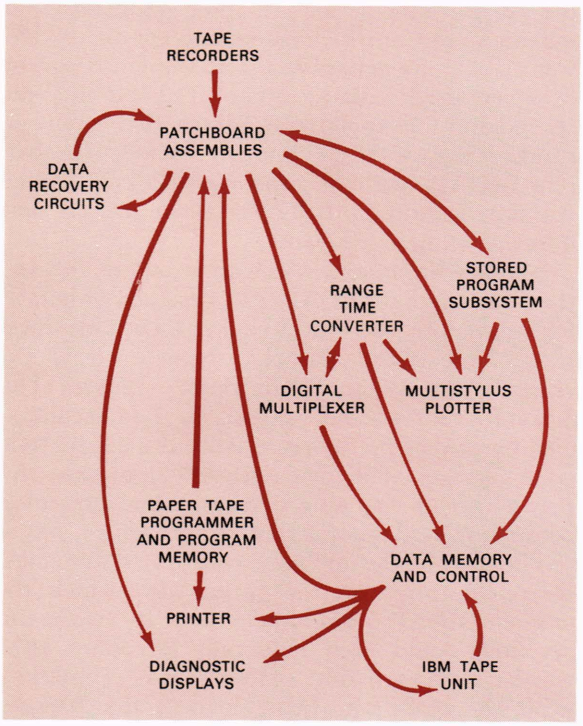

Fig. 4—Simplified DIDAP flow diagram.

The data and range time are arranged in proper format for computer entry and are loaded aperiodically into an 8-by-2048 buffer memory through either a digital multiplexer or a format register. If the digital multiplexer is used, it not only steers the digitized data into the memory input register but also performs other functions including correlating the data with range time, generating identifiers for the data, and generating memory load commands. If the format register and its associated logic are used, they align parallel input data, convert serial data to parallel form, and transfer the parallel output data both to the buffer memory and to the stored-program-assembly register and to the quick-look multistylus system. When the processor is started, the frame and clock signals derived from the input data control the stored-program operation, the load commands to the buffer memory, and the transfer of range time to the memory.

As output data become available, they are transferred along with identifying information into the memory input register. After odd parity is generated for each memory input character, the data and range time are loaded, in sequential order, into the memory. When the quantity of information in the memory is equal to an IBM record, loading operations are interlaced with periodic unload operations. Data which are unloaded from the memory are checked for parity, tape character parity is generated, and the data are written on digital tape in standard IBM tape format. Because the memory load and unload operations are not synchronous, the unload operations receive priority over the load operations. Therefore, to maintain a continuous flow of information through the buffer memory to the output tape unit without data loss, the processor must always be programmed so that the *average* load rate is less than the unload rate including the tape gapping time.

As information is transferred to the IBM output tapes, critical information is visually displayed, and all functions or selected functions in each input data frame may be recorded on the multistylus plotter. Selection of the functions, characteristics, and resolutions of the plots may be controlled either by a stored program or by switches on the operator's control console. Control of the plotter can be switched from the stored program to the control console and back during a processing run.

The first time a program is used it is inserted into the machine's 12-by-256 control memory by manual operation of a paper-tape programmer. After loading the memory, the program is transferred to punched paper tape for later use. Subsequently it is inserted into the memory automatically by the paper tape reader when needed. While the DIDAP is processing data, control programs may be manually inserted into the control memory if a stored program is not being used at the time.

A stored control program can be used either by the stored-program subsystem alone to control the multistylus plotter or by the analog-to-digital conversion subsystem to control both the conversion and the plotter simultaneously. Some control programs can exercise limited control over the entire DIDAP.

Generally, when DIDAP output tapes are produced for computer use, each file is annotated with certain identifying information which is needed by the programmer or analyst. This information is placed in the buffer memory manually by a file identification generator within the DIDAP system. If he wishes, the operator can verify this information by means of a digital printout before it is written on the final output tape.

The DIDAP makes it easy to check the quality of its output tapes before they are sent to the computer. The tapes may simply be checked for parity errors or the data may be verified by the DIDAP. If the latter procedure is used, the data on the tapes, or selected parts of it, may be printed out by a digital printer; critical units of information along with range time may be displayed visually for diagnostic checking; or any or all of the data functions may be plotted under the control of a stored program or under the control of the operator's console switches.

Various peripheral devices such as numeric displays, a data simulator, a small arithmetic unit, clock signal units, programmable delay units, counters, shift registers, operational amplifiers, a direct writing oscillograph, a bit synchronizer, filters, and several types of test equipment are included in the new DIDAP to aid in signal conditioning, in conversion, and in checking the quality of data during processing runs or during maintenance.

Comparison with Original DIDAP

The Laboratory's first digital data processor was designed in 1959 primarily to convert Polaris shakedown test data into a form that could be handled by the Univac 1103 computer. Soon after it was delivered, the Laboratory gave up its 1103 in favor of an IBM 7090 and then 7094 computer. The DIDAP was then modified to make it compatible with the new computing equipment. Within a few years it became quite evident that this data processor would have to undergo major redesign if APL's data processing capability was to keep pace with the newly developing data acquisition systems. The extent of this redesign is highlighted by the comparison shown in Table I. The old DIDAP referred to in the table is the Laboratory's original DIDAP after modification to make it compatible with IBM computers and after a few other minor modifications.

The early DIDAP had many limitations which either made it impossible to use on certain assignments or which made its use slow and inconvenient. For example, it had only one digital input channel. Thus, in processing telemetry data from the experimental 5E-1 satellite which are received in three different forms, pulse amplitude modulation (PAM), pulse code modulation (PCM), and pulse duration modulation (PDM), the old DIDAP had to make three runs using a separate patch panel to program the machine for each run. The new DIDAP, however, with its nine digital input channels, can accept all three types of data simultaneously and can, for example, process all the information received during a 5E-1 satellite pass in one operation.

Another serious limitation of the older DIDAP was the rate at which it could accept serial digital data. Since it was designed primarily for processing Polaris data at an 8:1 speed reduction, the maximum rate at which it could accept digital data was 10,200 bits per second. The Gemini program, however, used a data rate of 112,600 bits per second and the Apollo and Saturn IVB programs transmit data at 51,200 bits per second. The current DIDAP, with its capacity to accept digital PCM data at rates up to 120 kHz, can process data from any of these programs.

Another limitation, which grew out of the fact that the original DIDAP was designed primarily for Polaris use, was that it could accept only three range time codes, namely, those used at the Atlantic and White Sands missile ranges. This meant that it could not be used for data accompanied by any of the more recently developed time code formats. The new DIDAP eliminates this problem by being able to accept the nine most commonly used types of range time code.

The size of the memory constituted the most severe limitation on the speed with which the original DIDAP could handle data. Its two memory units could each hold only 20 36-bit IBM words. Although one memory was unloading while the other was being loaded, the 20-word capacity kept the original DIDAP from making full use of its inherent processing speed and

TABLE I

COMPARISON OF DIDAP CHARACTERISTICS

BEFORE AND AFTER REDESIGN

	Old	*New*
1. Analog Input Channels	32	32, expandable to 96
2. Digital Input Channels	1	9
3. Input Time Codes	3	9
4. Output Time Codes	3	1 (BCD only)
5. Coding Speed	5 kHz	40 kHz
6. Serial Data Rate	10 kHz	120 kHz
7. Record Length	20 IBM words only	1 to 340 IBM words
8. Bit Packing Density (Bytes/Inch)	200;556	200;556;800
9. Stored Program	No	Yes
10. Patch Panels	8	2
11. Data Diagnostics	None	Extensive
12. Digital Logic Cards	450	1350
13. Time History Plotting		
a. Input data frame length (functions)	1 to 32	1 to 512
b. Control	Switch selectable	Switch selectable or automatic by stored program
c. Function resolution	Fixed (same for all functions plotted during given run)	Variable (all functions plotted during a given run may be plotted with different resolution)
d. Max. no. of functions that can be simultaneously plotted	up to 32	> 80

generated IBM tapes containing three times as much gap space as data-record space. The present machine's 340-word memory effectively eliminates this problem. The use of a small, separate, control-program memory has enhanced the convenience of using the DIDAP immeasurably. When processing Polaris instrumentation data on the old DIDAP, for example, a separate patch panel had to be set up for each set of telemetry functions desired up to a maximum of 32. On the new DIDAP, comparable control programs can be inserted in the program memory by paper tape. Program tapes are written once for each set of functions desired and are retained for later use. All these taped programs may be used with the same patch-board set-up. Not only has the use of programs which can be stored in the special control memory made the DIDAP easier to use, but, in addition, the various terminals which require use of patchboards have been consolidated so that now only one patchboard is needed rather than the eight that were previously required.

While both DIDAPs used a multistylus plotter as one of their outputs, the usefulness of this device in the older version was somewhat limited. The plotter had to be programmed through a patch panel, and this meant, of course, that the program was fixed for the entire processing run. Furthermore, because of the machine's basic design, even with the patch panel, the selection of what could be plotted was quite limited, and only one function characteristic and one resolution value could be selected for a given run. Use of the patch panel also meant, of course, that all functions and function characteristics to be plotted had to be selected before one saw the data. In the new DIDAP, however, the multistylus plotter (see Fig. 5 for typical output) can be programmed through the control program in the small memory, and in case of need, this program can be overridden by the operator simply by selecting push-button switches on the control console. This means that the DIDAP now has the great advantage that one can change one's mind about what functions to plot, what aspects of the functions to plot, and in what degree of detail you want to see particular functions as you see the data emerge. A second, analogous advantage is that, in converting from analog to digital data, the parameters of conversion can be altered by either control console switches or program tapes rather than by repatching a patchboard.

Finally, it is a lot harder to make a mistake with the new DIDAP than it was before. The older equipment had no techniques for checking the accuracy of the data being recorded on the output IBM tape during a processing run. (You could, of course, run the tapes through the machine a

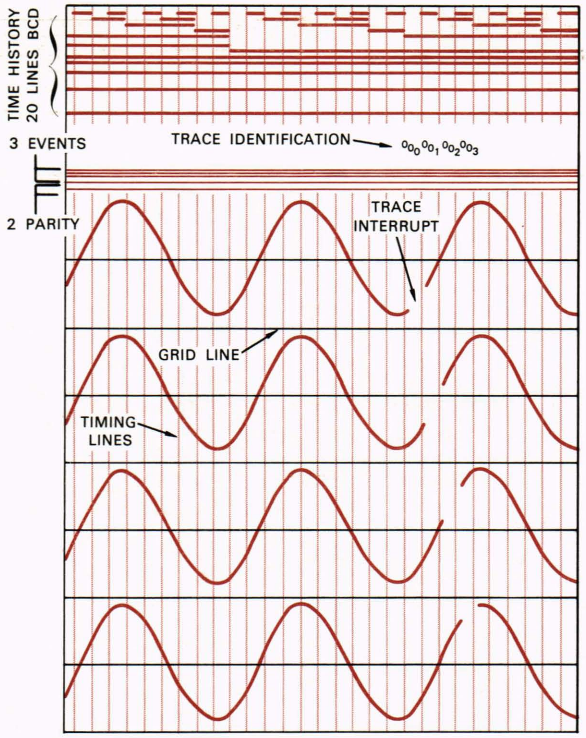

Fig. 5—Typical time-history plot made with the DIDAP multistylus plotter. This particular run was on a typical FM/FM input signal which had been digitized for processing.

second time to spot-check data accuracy.) With the new equipment, there are automatic parity checking devices, memory-error checks, visual diagnostics for the incoming data, and the data's calibrations can be displayed during the processing run so that the operator can be sure the DIDAP is operating as expected.

Conclusions

The development of the new Digital Data Processor represents a significant milestone in APL's continuing effort to improve the capability and efficiency of its data-processing center. The new DIDAP is probably one of the most versatile general purpose processors currently available for the large-volume conversion of a wide range of raw input data into a form which can be accepted by an IBM computer.

Since the new DIDAP was placed in operation, it has been programmed to process input data both from major Laboratory programs such as the space, missile, and Polaris programs and also for the analog-to-digital conversion of research data from the National Institutes of Health, The University of Texas, the Air Force's Cambridge Research Center, and a number of smaller APL programs. The DIDAP is in almost constant operation and has a relatively low maintenance and checkout down-time of about three percent. Because of its flexibility and reliability, the usefulness of the DIDAP will expand as more programs develop that require such data-processing services. It is already clear that it will take several years to exploit the full potentialities of this powerful equipment.

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ADDRESSES

The listing below comprises the principal recent addresses made by APL staff members to groups and organizations outside the Laboratory.

T. A. McCarty, "Location of Loran Grids by Aerial Photogrammetry," *Geodetic-Cartographic Air Target Material Conference, Sponsored by the Defense Intelligence Agency,* Alexandria, Va., Oct. 18–27, 1967.

I. Katz, "Clear Air Turbulence," *Mechanics Department Colloquium, The Johns Hopkins University,* Baltimore, Md., Mar. 1, 1968.

W. E. Buchanan and J. Dassoulas, "DODGE – Public Relations and the Technical Program," *Baltimore Public Relations Council,* Baltimore, Md., Mar. 12, 1968.

R. W. Hart and R. A. Farrell, "Medical Radioisotope Scanning I. Optimum Data Processing Considerations in Two Dimensions," *Symposium on Processing of Scanning Information, Central Chapter, Society of Nuclear Medicine,* Chicago, Ill., Mar. 15, 1968.

E. L. Cochran, B. C. Weatherley, V. A. Bowers, and F. J. Adrian, "ESR Spectrum and Structure of HCN at 4.2°K," *American Physical Society,* Berkeley, Calif., Mar. 18, 1968.

R. M. Fristrom, "Present Status of Chemical Kinetic Programs," *Thermochemical Panel Meeting,* Douglas Aircraft Co., Huntington Beach, Calif. Mar. 25, 1968.

R. E. Gibson, "Elements of Modern Culture," *Joint General Session, Association for the Education of Teachers in Science and National Science Supervisors Association, at the National Science Teachers Association Sixteenth Annual Convention,* Washington, D.C., Mar. 29, 1968.

The following two addresses were given at the *Second Communications Satellite Systems Conference,* San Francisco, Calif., Apr. 8–10, 1968:

F. F. Mobley, "Gravity-Gradient Stablization Results from the DODGE Satellite;"