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L. Martin
T. Gadd
T. Baker

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L. Martin, T. Gadd, and T. Baker
Lawrence Livermore Laboratory, University of California
Livermore, California

Introduction

A large amount of nuclear test and simulation data is in the form of single-transients which might be in the picosecond to microsecond range and which ordinarily are recorded with an oscilloscope[1] and high-speed film system. The requirement to analyze large quantities of film, the desire to remove the human factor in the data analysis process, as well as to experiment with image processors in an interactive or remote time-shared computer environment, have prompted the approach to a computer-controlled image-digitizing system that is described in this paper. The system is based on a photo-matrix controlled by a small DEC PDP-8 computer. Only selected portions of the system and its principal components are described in the following.

The Photo-Matrix Head

The "eye" of this system is a photo-conductive solid-state thin-film device made by RCA.[2-5] This device is formed on a glass substrate with matrix strips for addressing each photoconductive element. Each element behaves electrically as a photoconductor in series with a diode and thus each point in the matrix is interrogated by applying a forward bias pulse sequentially to each diode element via the address strips. This is done sequentially, in a scan fashion, point-by-point over the entire 100 x 128 array. Each point is represented in the output as a binary level only. Ordinary discrete component transistor circuit technology supplemented with special low capacitance insulated gate field effect transistors is used in the amplifier-driver and decode functions. These circuits are all combined compactly into the matrix drive-decode unit shown in Fig. 1. The photoconductive array is shown in the foreground mounted to the four-connector two-sided printed circuit board. A 30 mm square fiber optics section is also shown. In operation, the image transmits through this section to the matrix. Not shown is the projector-optics assembly into which this entire matrix drive-decode unit is mounted and a support electronics unit which contains the scanning logic and control circuits.

Computer System Arrangement

The digitizing system was originally planned to interface conveniently with a PDP-8 computer and yet provide for the likelihood of remoteness of operation, both from the controlling PDP-8 and from a central CDC 6600 computer. Consequently, the matrix and support electronics are connected to the PDP-8 only by a couple of twisted pair lines. The general arrangement is shown in Fig. 2. The primary components of the image-digitizing system are thus as follows:

1. Photo-matrix sensing unit
2. PDP-8 digital computer with teletypewriter
3. Kennedy 1600 magnetic tape transport
4. Matrix scan and control unit and interface
5. PDP-8 and LLL Octopus system control interface
6. Several computer programs for control and processing
7. Display oscilloscope
8. The central computer

The thin-film matrix sensing unit and the matrix scan and control unit which make up the matrix electronics are interconnected by short cables or printed circuitry. The operation of this part of the system is described next.

Matrix Electronics System

The matrix electronics system shown in Block diagram form in Fig. 3 consists primarily of reading, scanning, input-output logic, and display circuitry. There are two main pairs of control lines from the PDP-8 computer to the matrix unit. Over one pair a clock or scan pulse is supplied from the PDP-8, under program control, to cause the scan electronics to advance one point on the matrix array each time a pulse is received. In return, binary data is sent to the computer, indicating the on-off light state of the associated point in the matrix.

Additional binary data sent to the computer at the end of one line of scan furnishes the line number and also an identification number as set by front panel dial switches. The entire data is a serial bit stream with a format of 128 bits of matrix data, followed by 9 bits (in 3-bit words) of dial number setting, by 7 bits (a word) of matrix line number, and by 32 zero bits. The scanning unit contains both the scan and input-output logic circuitry. The input-out logic switches from an internal clock to an external computer supplied clock or scan pulse and mixes the data described above. This unit also distributes clock pulses to the address register and scan control logic cards, and supplies vertical

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and horizontal synchronization for the display oscilloscope.

The scan control logic synchronizes the address register, the horizontal (matrix line) shift register, and the vertical (matrix bit) shift register. Under proper conditions, it generates a master reset signal which effectively sets all registers to point (0,0) on the matrix. The first clock pulse then generates a parallel entry signal which sets all registers to (1,1), the next pulse steps to (1,2), etc., and continues to scan the matrix one point at a time.

The horizontal and vertical shift registers are identical, the vertical one operating at the lower rate, with 1 shift per 176 shifts of the horizontal. In each register there are actually two shift registers, a 16-bit one and an 8-bit one, with outputs logically intersected in the reading unit to form the equivalent of a 128-bit shift register.

The reading unit alone contains buffers, AND-gates, switches, the photo-matrix itself, and a discriminator-amplifier. Input logic signals from the scanning unit are buffered from TTL levels to various levels required by each set of switches. Representative matrix read unit circuitry is shown in Fig. 4. The anode switches are bipolar transistors with AND-gate action on emitter and base inputs. The collector is connected directly to an anode line of the matrix. A diode-resistor AND-gate is used with an FET to switch the cathode lines of the matrix. This FET is an HEH566, p-channel enhancement-mode device with a source-drain capacitance of about 0.08pF and a gate-drain capacitance of about 0.3pF. The drains of all of the FET switches are common and connect to the emitter of a common base amplifier. The collector output of this amplifier is amplified by the Model 702 operational amplifier with a variable threshold control on its other input. The output of this amplifier is matrix data which is then gated by the input-output logic in the scanning unit for reading by the computer or for video display or for both.

The Control Program

This software package constitutes a controlling main program with interaction among the major elements of the system. The on-line teletypewriter provides operator command to the PDP-8. This interaction gives an operator a certain amount of flexibility in determining which part of the digitizing operation to start (or repeat).

The controlling program sends a message to the teletypewriter and awaits an appropriate response from the operator. It will continue and produce a read of the matrix unless a wrong command is given which then immediately causes a return to start. In fact, if the response is not correct at any given point in the communication, a diagnostic is sent to the operator advising him of an error and a return to start is given. A complete list of steps as each occurs during one complete matrix scan and read operation from start to finish is listed next:

PDP-8 to Teletypewriter	Response from Operator
1	M = scan, read, and store matrix data
	E = end program, complete digitizing
2	Four digit identification
3	D = display matrix read
4	O = transmit
5	Auxiliary
6	R = write digitized information on magnetic tape

Thus, existing software features provide the capability of restarting the matrix scan and read process at any point in the operation. Each digitization scan has its own unique four digit numerical identification. The operator may elect to display the data as stored by the PDP-8 immediately on a Tektronix Display Oscilloscope Model RM602. This provides visual indication of the overall digitization as compared to the video display mentioned above. Provision is also made for transmitting over the LLL Octopus system from a remote terminal, but this part of the system has not been used. After the operator decides to continue and desires to record the information from one matrix read for further processing on a larger computer, the data is written with a Kennedy Model 1600 magnetic tape unit onto an eight inch diameter seven track magnetic tape. This tape provides a permanent store at the PDP-8, since succeeding "reads" continue to use the same core space in memory, and consequently this main storage area is cleared after each run to prevent duplication. Data from a single run is packed conveniently into about 2000 words with associated line and bit counts being stored. The program itself occupies a like amount of core, with approximately 3000_8 words taken.

Processing Computer Program

After the respective images have been digitized and, through the preceding PDP-8 set of programs, have been transferred to a media of permanent storage, such as magnetic tape or disk, the data itself is readied for further processing.

At LLL this further processing is accomplished by a large general purpose computer, such as the CDC 6600. Here, for example, each one-half inch seven track tape used would contain several digitized images in the pre-established BCD packed format. Processing of this raw output data may be considered as a two-pass operation. The first pass converts the raw binary BCD data into a disk file with the specific format of twelve octal control words followed immediately by the established file data points. The second pass results in further processing of the created file so as to establish a new format suitable for printing, presenting the data for view on a graphics monitor display, or to CRT output for hard copy paper plots

Only a description of the first pass operation is given here.

Initially, the raw binary data from the magnetic tape is buffered into the CDC 6600 record by record. For each record a unique name is created by prefixing the alphanumeric character R to the unique code number previously established for each digitization run on the PDP-8. This new name is assigned to the 6600 disk file and referenced for further processing. Next, control words are established. These are created merely to satisfy other existing code requirements. They are as follows:

WORD	DESCRIPTION
0	Number of pairs
1	Blank
2	Blank
3	Blank
4	Disk file name
5	Blank
6	Blank
7	Blank
10	Blank
11	1.0
12	First data point

For example, the x,y coordinates representing the data points are placed in their proper storage locations. The resulting disk file is finally created and all the data is buffered out into a manageable form for further processing or analysis at later times. This pass or stage of the program is completed when the program has sensed an end-of-file mark. All of these newly created or "pre-processed" files can now be exited to magnetic tape or mass photo storage.

Significant Features

Clearly, the system operations revolve around the objective of getting the digitized information for further analysis. "Further analysis" can mean almost any manipulation performed on raw digitized data. This system is a developmental one which employs only a 100 x 128 matrix. This modest array limits the amount of detail which could be digitized without an extreme amount of sequential time or space tying. In some data involving oscilloscope traces,[6] as few as 50 digitized points might be considered adequate.

Thus far, film digitization trials here have been limited to sections of 35 mm transparencies contacted directly with the fiber optics plate surface. A representative digitized output appears in Fig. 5. Here, a triangular pattern is presented to the matrix which provides the scattering of points shown. A situation of preferred directions of sensitivity is apparent along certain vertical lines as evidenced in the expanded view section. A consistent or symmetrical line pattern of this type could always be averaged for the case of digitization of known single-valued function inputs to the matrix. Possible additional complications, such as contrast limitations, have not yet been explored.

Conclusions

In conclusion, this system can be considered a modest one that employs only a rather specialized type of construction, a 100 x 128 matrix that is not presently commercially available. The overall approach, however, could possibly be applied to other forms[7] of solid state image sensors now being reported.

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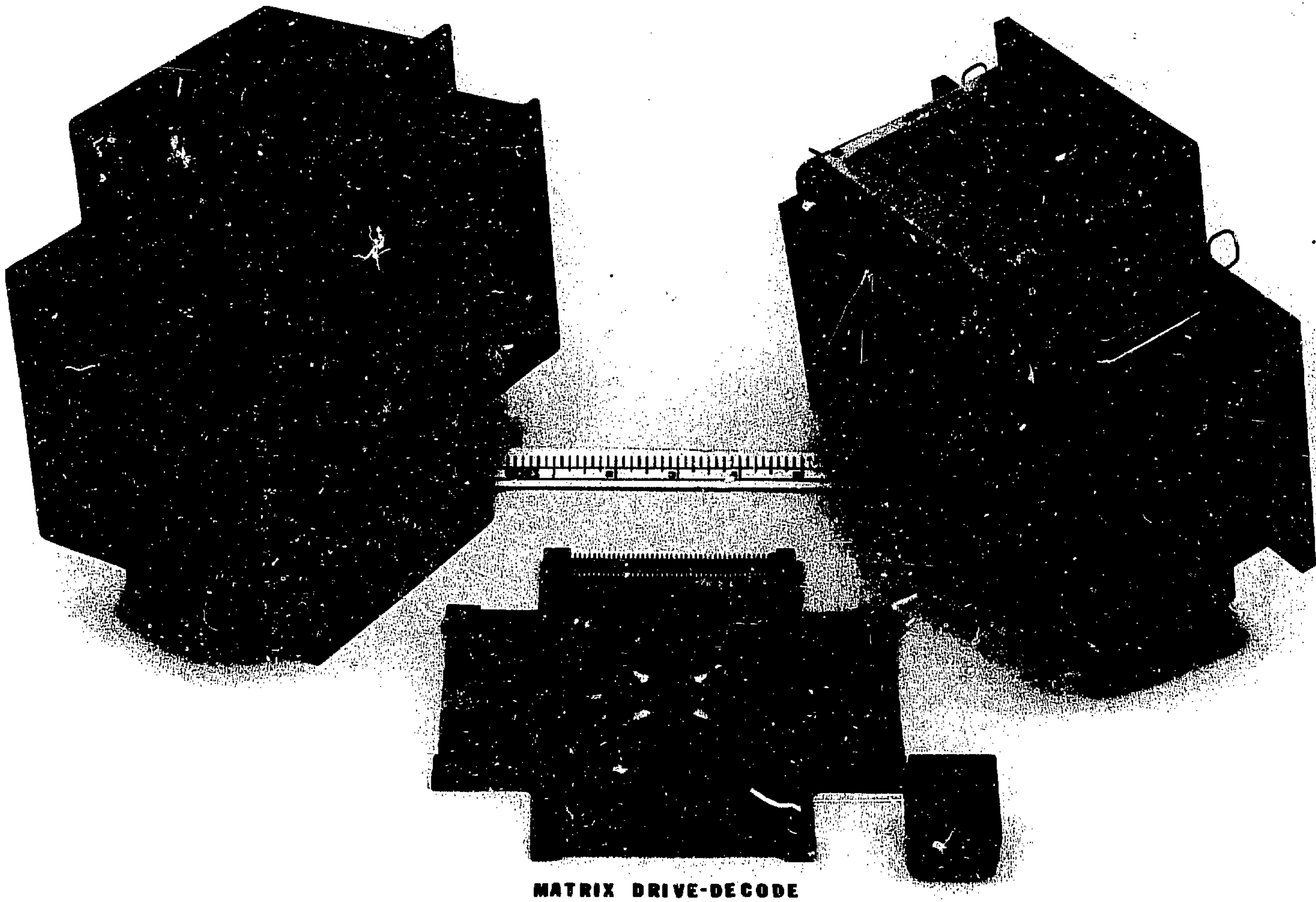

Figure 1. Photo-Matrix Head Assembly

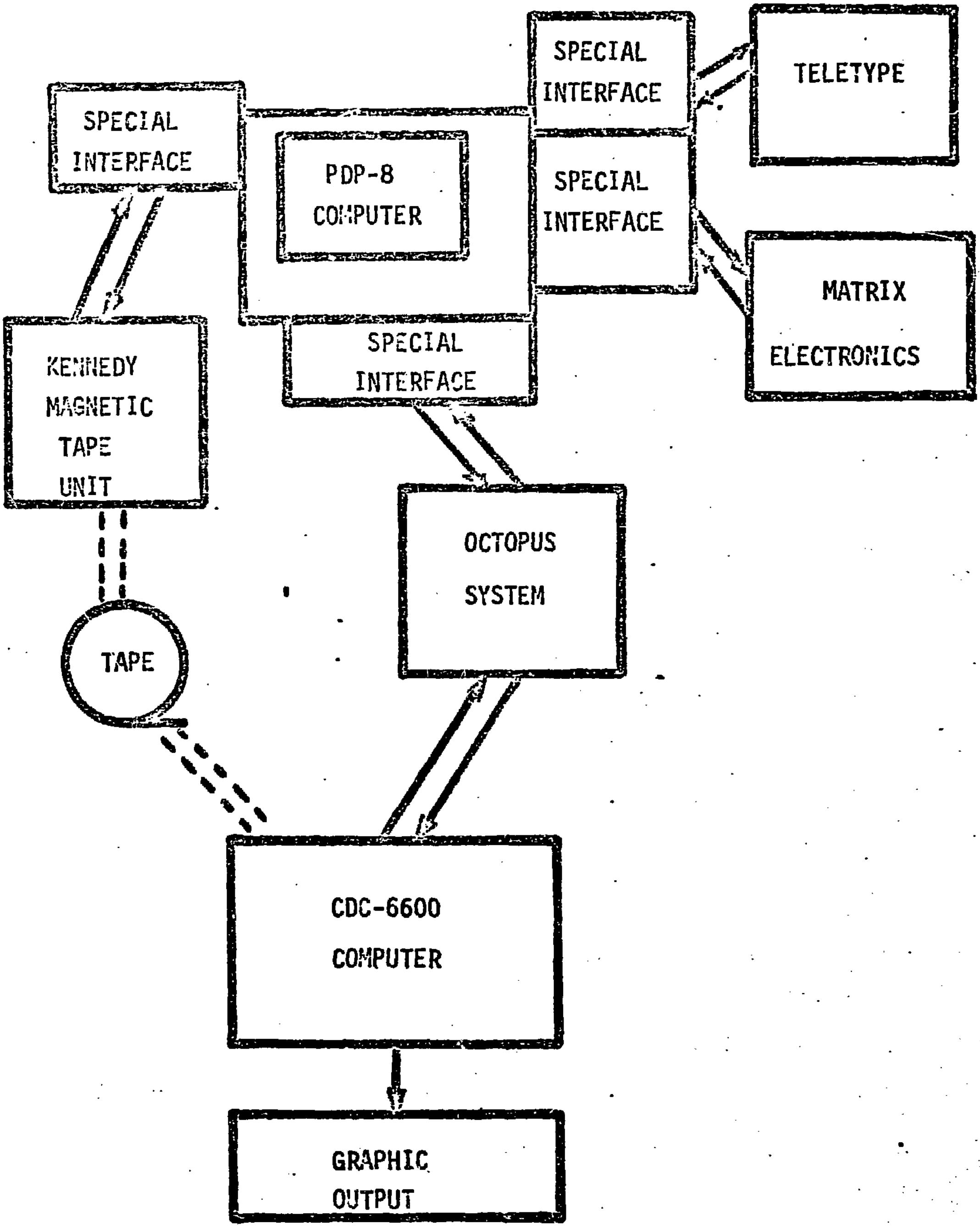

FIGURE 2. GENERAL ARRANGEMENT

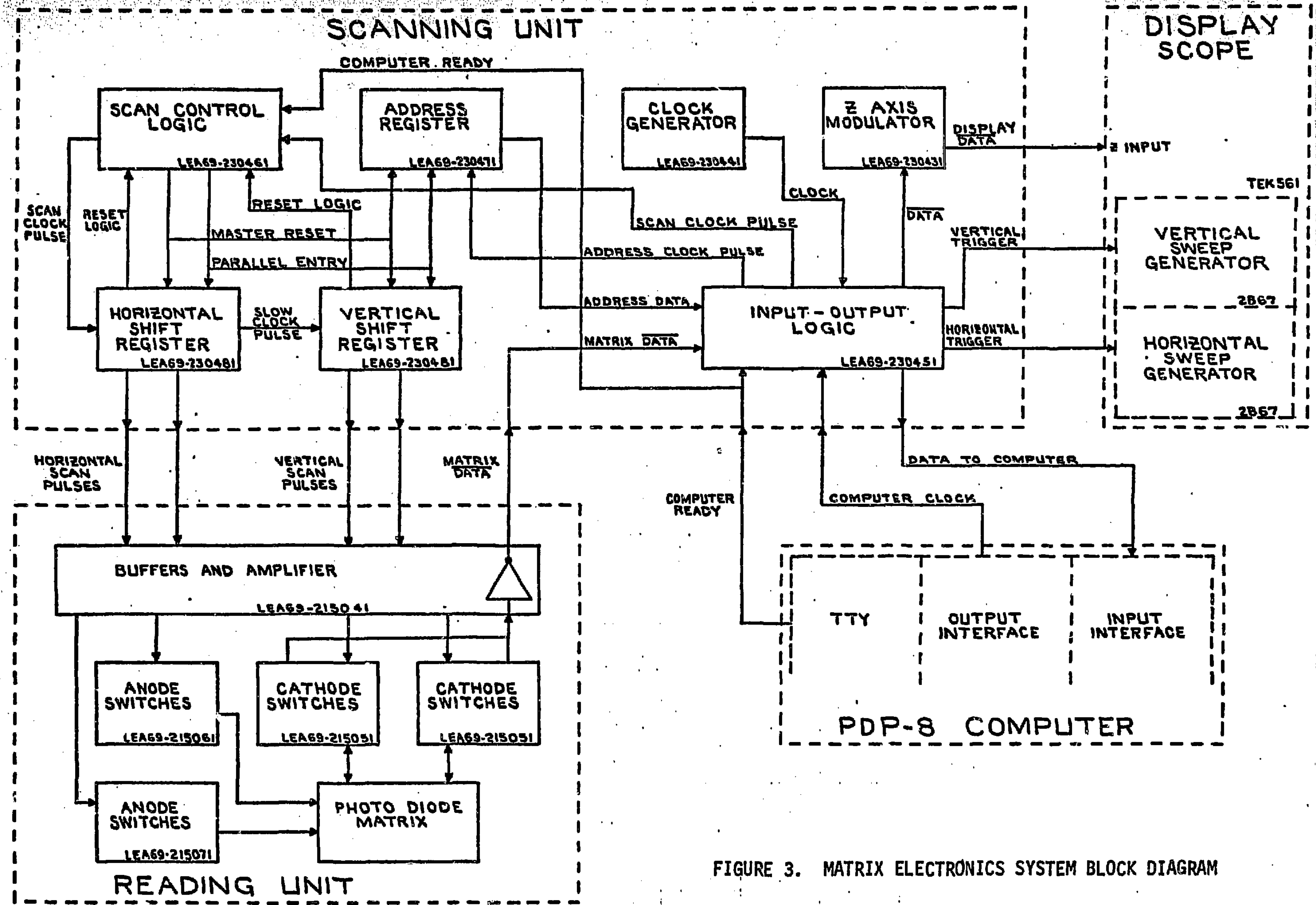

FIGURE 3. MATRIX ELECTRONICS SYSTEM BLOCK DIAGRAM

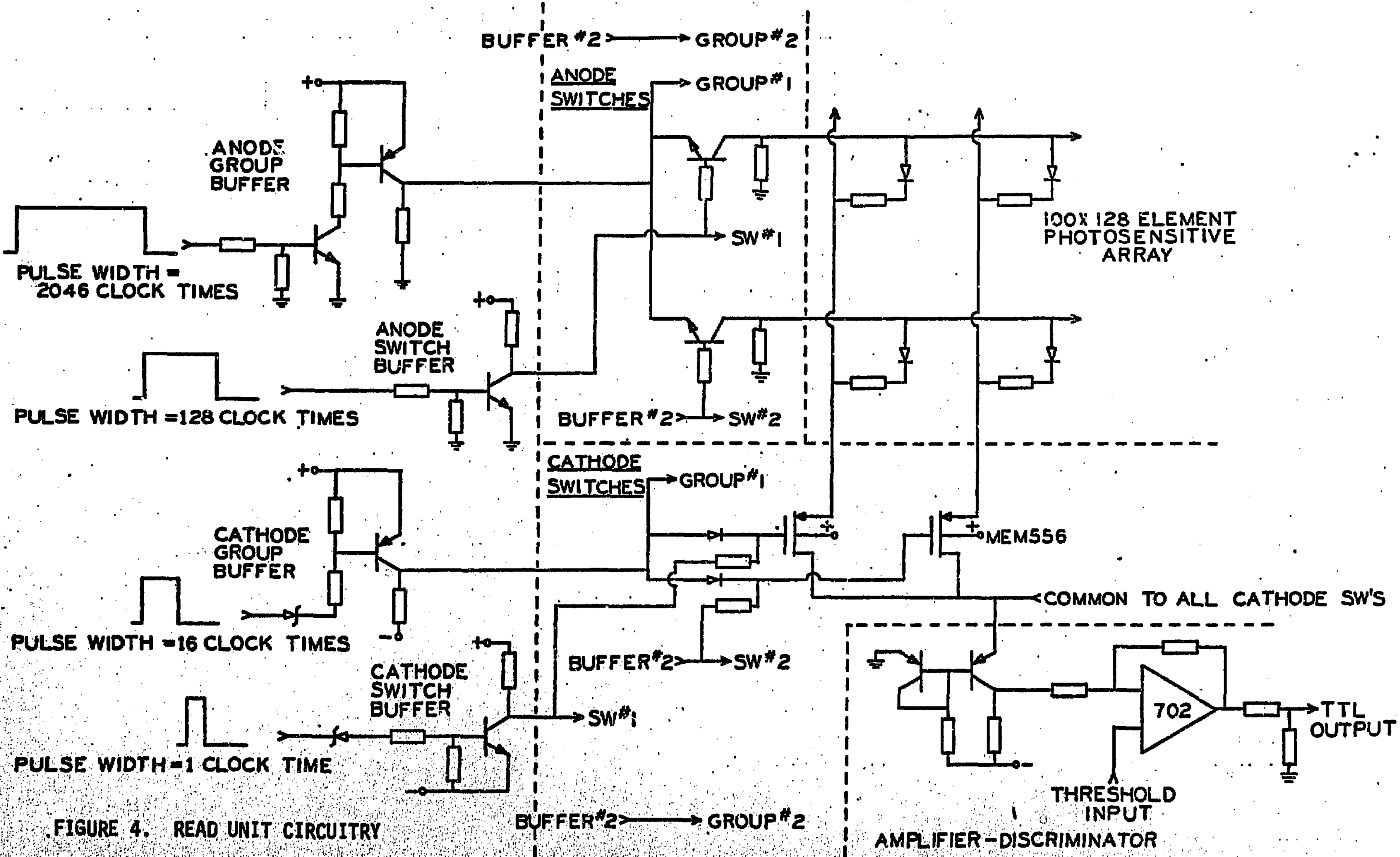

FIGURE 4. READ UNIT CIRCUITRY

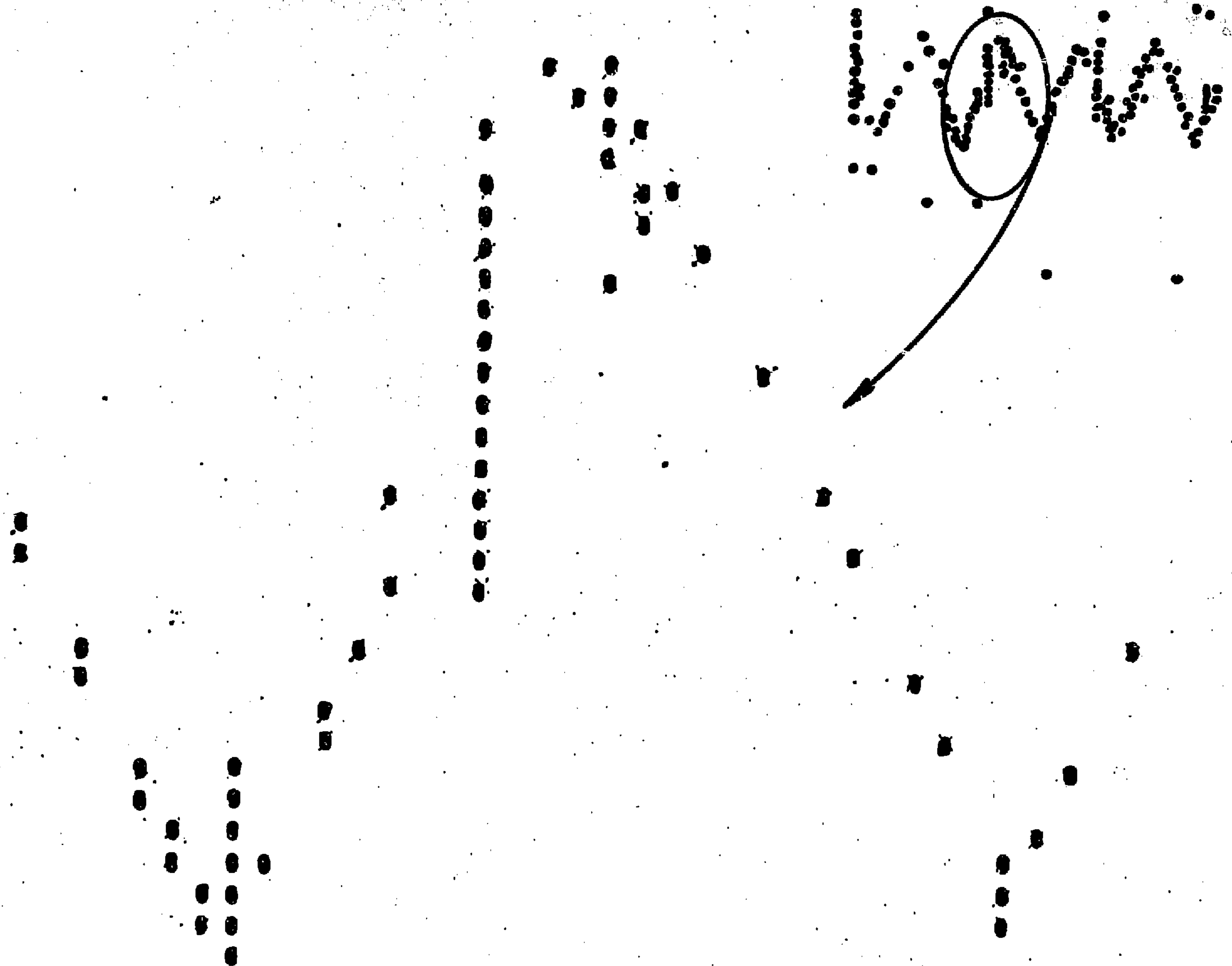

FIGURE 5. DIGITIZED OUTPUT