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**HIGH-SPEED AUTO-DATA SYSTEM
FOR BLAST STUDIES**

by

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JULY 1960

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Presented at: 1960 CONFERENCE PROCEEDINGS OF THE 4th NATIONAL
CONVENTION ON MILITARY ELECTRONICS
Unclassified Session 5.5, Data Handling

Issued by Sandia Corporation, a prime contractor
to the
United States Atomic Energy Commission

HIGH-SPEED AUTO-DATA SYSTEM FOR BLAST STUDIES
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Introduction

Recognizing that an automatic data handling system would greatly shorten delays between the collection of raw data and final reduction of these data to a form suitable for analysis, Sandia Laboratory has developed a multichannel, high-speed, automated data system for recording digitally the outputs of the analog transducers used in the study of blast effects from small high explosive charges (about 10,000 pounds of TNT. See Fig. 1). Test phenomena associated with these studies are of short duration (10 to 40 milliseconds).

To satisfy the requirements peculiar to blast-study work, a system was needed that would:

- 1) Provide automatic data reduction in the field
- 2) Deliver recorded information, for more detailed analysis, to conventional computers in a form compatible with their input requirements
- 3) Respond over a frequency range from DC to 5 kc or more, with a rise-time capability of 0.1 millisecond
- 4) Have an accuracy of 1 per cent of full scale.

The system developed to meet these requirements provides for the sampling of each of 32 analog inputs at a 12.5-kc rate and for the recording of sample amplitudes in the form of a serial, seven-digit, binary number on magnetic tape. This means that the information handling capacity of the recording system must therefore be 2.8 megabits per second. Allowing an additional 400 kilobits for internal synchronization and channel identification, the total recording capacity of the system must be 3.2 megabits per second.

After recording, the magnetic tape is played back at a rate slow enough to permit retranscription of the information to seven-level paper tape. The paper tapes are then read by auxiliary equipment, and the information is decoded and plotted on standard graph paper in a form suitable for "at the site" examination. Altern-

tively or concurrently the information can be translated to binary decimal excess-3 format suitable for input to an Elecom 125 computer for more detailed analysis.

System Organization

A simplified block schematic of the complete system is shown in Figs. 2 and 3. The recording section (Fig. 2) is straightforward and illustrates the sequence of sampling-coding-recording operations previously described. The playback section (Fig. 3) summarizes the operations required to provide a secondary transcription of the data to punched paper tape.

Functional details, as well as descriptions of the various major components, will be presented in the following sections. They will be grouped according to their relevance to data coding-recording, playback, or processing.

Recording

Commutator -- As shown in Fig. 2, blast-induced transients in analog form, detected by transducers located in the immediate blast environment, are transmitted by wire links to a commutator which assembles samples of the inputs in a time division multiplex to a high-speed analog-to-digital converter.

Individual channel switches, using solid-state devices and printed circuit techniques, are packaged in groups of eight and are activated at a 12.5-kc rate by control pulses from the program control unit. In the interest of maintaining modular flexibility, provision was made for switching eight channel groups at rates of either 6.25 kc or 25 kc through the use of a patch panel. In principle, commutation could be accomplished at still lower rates, thereby increasing the number of channels. However, the particular requirements of the blast studies group were satisfied by the 32-channel, 12.5-kc sampling-rate arrangement.

Forward resistance of the individual switches in the "closed" position is 50 ohms maximum to a common load of 1000 ohms. Back resistance of the switch in the "open"

Figure 1

Functional block diagram AUTO-BLAST-DATA-SYSTEM (recording)

Figure 2

Functional block diagram AUTO-BLAST DATA-SYSTEM (Playback)

Figure 3

condition is 4 megohms. Maximum signal input level is 1 volt.

Analog-to-Digital Converter -- In view of the short period (i.e., $2.5 \mu\text{sec}$) available for digitizing, the "flashcoding" cathode-ray tube techniques developed by R. W. Sears and associates at the Bell Telephone Laboratories were utilized to obtain analog-to-digital conversion. Tubes of this type have accomplished conversion at rates as high as 10 mc.¹

Because the converter is the heart of the recording system, it deserves further consideration here. The essential feature of the coding tube is a perforated plate, the holes of which represent an ordered array of the 2^n amplitude levels characterized by an n-digit binary code. A ribbon electron beam is deflected vertically by the output of the commutator.

Separate collector plates are placed behind the code plate. A pulse is produced only if the beam goes through a hole in the plate. Since the ribbon beam covers the full width of the code plate, the code is registered simultaneously on a plurality of digit collectors, one for each digit of the code. It should be noted that the digital outputs are in parallel here and that the code employed is the Gray code.

Decommutator -- The primary function of the decommutator is to serialize the output of the coding tube. Then the seven-digit number characterizing the amplitude of a sample from a given channel is interlaced with the seven-digit number representing the amplitude of a sample from a second channel to form the two-channel serial multiplex depicted in Fig. 4. That is, digital representations of channels 1 and 3 are contained in an $80\text{-}\mu\text{sec}$ frame corresponding to the 12.5-kc sampling rate. (The term "frame" is used here to refer to the particular array of digit pulses associated with a given sample. The term "framing pulse" refers to the timing index or fiducial pulse used to mark the instant of sampling and to order the array.) In this way 32 channels of data are recorded on 16 magnetic tape channels.

It should be noted (Fig. 4) that the channel-3 framing pulse is redundant since channel 3 is sampled $5 \mu\text{sec}$ after channel 1. The space which would otherwise be assigned to the channel-3 framing pulse is reserved for a playback program-control

pulse used as an event mark. This pulse can also be made to activate the paper-tape punch in playback, thereby providing a search-mode operation.

The decommutator provides one other function, that of inserting a recognition signal consisting of all zeros in the frame except for the framing and playback program-control pulses. This unique value is reserved to show that calibration information will follow on the channels.

The first step in the decommutation process is to feed the seven-digit outputs of the analog-to-digital converter to magnetostrictive sonic delay lines which provide delays varying from 10 to $70 \mu\text{sec}$ in $10\text{-}\mu\text{sec}$ steps. After amplification and regeneration, the digital pulses (delayed for longer periods as their significance decreases) are fed to a solid-state logic complex where they are combined with the previously described program signals to make up the format of Fig. 4.

Finally, after power amplification, the 16-channel output of the decommutator is fed to the magnetic tape recorder.

Program Control Unit -- Obviously, the success of the timing and gating operations described above depends upon accurate time alignments of control pulses from the program control unit. These are obtained from a set of 12 basic control pulses which are fed to various units where they are combined in diode matrices to form control pulses for commutation, decommutation, etc. For convenience, a standard printed, diode, plug-in package consisting of eight 3-leg AND gates was adopted for this purpose.

For the most part, individual circuits are conventional. A few of the more unconventional circuits have been described by Meacham and Peterson.²

Recorder

Serial-type magnetic tape recording was adopted in preference to parallel tape recording. The playback circuitry required by the serial type is not as extensive but is more functionally complex than the parallel type, since interlaced frame and data pulses must be separated electronically. The complexity arises in reclocking the pulses at the playback rate. Although this electronic discrimination is

WORD FORMAT
32-CHANNEL BLAST DATA RECORDER

Figure 4

avoided in parallel recording in which data and framing pulses are recorded on separate magnetic channels, pulse amplification and regeneration equipment must there be duplicated.

An additional justification for the adoption of serial recording stems from a consideration of the mechanical problems associated with parallel recording. In particular, registration difficulties from variable differential tape stretching at high recording speeds were anticipated. These difficulties become even more acute in field use where tape handling and storage facilities are far from ideal and where both tape and recorder will be subject to extremes of temperature, humidity, and dust (see Fig. 1).

The tape transport employed was developed for this particular application by Clevite-Brush. Sixteen channels are recorded on 3/4-inch Mylar-base magnetic tape fed from a basket providing storage for 800 feet. The recording speed is 350 inches per second with a recording pulse density of 570 pulses per inch, which corresponds to the 200-kc pulse recording rate.

Once serial-type recording was adopted, it was decided for simplicity to differentiate the framing and data pulses by recording at two amplitude levels (see Fig. 4). Since the framing pulse appears only once for each frame, it was assigned maximum amplitude. The limitation on the amplitude of the framing pulse is fixed by saturation of the tape magnetization. Of course, while the code pulses must have lower amplitudes to distinguish them from the framing pulse, their amplitudes must be high enough to maintain a favorable signal-to-noise ratio on the comparatively slow-speed playback.

Playback

The primary function of the playback system is to transfer the data recorded on the primary storage medium (magnetic tape) to permanent storage in the form of punch paper tape (see Fig. 3). To do this, the magnetic tape is examined channel by channel; in a 32-channel set-up, 32 magnetic tape passes are required to punch 32 paper tapes, one for each of the original analog input channels.

The first step in this process is

amplification and regeneration of the recorded pulses. The playback circuitry provides pulses of constant width and amplitude and also separates out the framing pulse on the basis of amplitude discrimination. The framing pulse drives a clock-pulse generator which produces two sets of eight clock pulses corresponding to the positions of digits indicated on Fig. 4 for channels 1 and 3. A "fly-wheel" effect is included in this circuit so that loss of an occasional framing pulse will not cause loss of synchronization.

Various magnetic-tape playback speeds were tried, and the results indicated that 1 inch per second was the minimum acceptable playback rate for a signal-to-noise ratio great enough to ensure reliable synchronization of the recording and playback circuitry. With a recording speed of 350 inches per second, the minimum acceptable playback rate is approximately 35 frames per second.

The final step in recovery of playback data consists in making a serial-to-parallel conversion. Regenerated data pulses corresponding to either channel 1 or 3 can be gated into a shift register composed of a linear array of two-core-per-bit magnetic storage elements. In response to shift signals from the clock pulse generator, the data pulses move along the array until the register is completely filled. At this point, the data in the shift register are transferred to a seven-level Teletype tape punch. Temporary parallel storage and interlocking electronics are required to synchronize perforation with the playback framing rate. Data characterizing amplitudes of successive samples of each of the analog inputs have now been transcribed to seven-level perforated tape and are available for processing.

Data Processing -- The computing-plotting facility developed for preliminary data evaluation consists of three principal units: a paper tape reader, a digital-to-analog converter, and an X-Y plotter. A fourth unit, an asynchronous program control, coordinates operations of the other units mentioned. Digital data from the punched tape are translated by a digital-to-analog converter into analog signals for automatic point-by-point plotting by the X-Y plotter.³ An asynchronous program control was devised so that the plotter would receive information from the reader only as fast as it could be plotted.

In general, successive plot transits are small enough to permit plotting at rates from 2 to 4 points per second. In cases in which more elaborate mathematical operations on the recorded data are desired, the outputs of the paper tape reader are fed to a converter which provides a binary decimal excess-3 retranscription of the same data in a format suitable for input to the Elecom 125 computer.

Installation

The complete automatic data system is installed in an underground shelter at Sandia Laboratory's Coyote Canyon Test Field. Regulated power supplies are mounted in the right end bay shown in Fig. 5. Playback equipment is located immediately to the left of the power supplies. The next bay contains the 16-channel magnetic tape transport (common to both recording and playback operation). Directly to the left of the tape basket are the flash coder (analog-to-digital converter) and the sonic delay lines. These chassis have been turned in their racks for the illustrative purpose. The commutator and high-speed program control unit are located above the delay lines.

Not shown is the control console which contains the teletype tape punch, reader, X-Y plotting equipment, and control panel.

Operation

In practice, the control console is supervised by a remotely located master program timer. In response to control signals from this unit, the recording equipment is automatically activated. Immediately before detonation of the explosive charge, the high-speed forward traverse of the tape transport is initiated. After zero-time signals and calibration information for individual channels are recorded, all input channels are cleared to record outputs of the analog transducers employed to detect the blast effects. After the shot, the high-speed forward traverse of the magnetic tape is halted, and control of the system is returned to the local operator by the master program timer.

At the discretion of the local operator, the playback circuits are then activated and the magnetic tape played back.

Recorded data, including zero time marks and calibration information, are retranscribed on paper tape. The paper tapes are then ready for processing.

Conclusion

Despite the high ratio of recording to playback speeds and the use of conventional recording-playback techniques, synchronization can be maintained between recording and playback equipment even under the environmental extremes encountered in blast study work.

The authors originally hoped that enough reliability could be designed into the system so that it could be maintained and operated by untrained personnel. Unfortunately this aim was not realized; one of them was always required to "mother" the system. It should be emphasized, however, that no attempt has been made to redesign the system for greater reliability; rather, any design expedient that seemed to promise earlier field operation was adopted.

As is often the case in blast study work, the equipment described here was hurriedly assembled for a particular test series of blast diffraction experiments and was utilized for the evaluation of test instrumentation. The details of the system are reported here, not only for their historical interest, but also because they illustrate the application of digital instrumentation techniques to a rather unusual area of endeavor.

Because of sentimental attachment to the system by the authors and their supervision, the device was not consigned to salvage--the usual practice--but has rather been retained almost intact on a standby basis. It is now used as a training aid to instruct new personnel in the principles of digital instrumentation.

Acknowledgements

The authors are grateful for the cooperation of the following Bell Telephone Laboratories personnel: Mr. R. W. Sears, for arranging the loan of a seven-digit flash coding tube, and Messrs. R. K. Potter and R. L. Carbrey, who supplied designs for associated circuitry.

Figure 5

This work was supported by AEC Contract No. AT-(29-1)-789.

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