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STUDY AND DEVELOPMENT OF A SELECTIVE MONITORING SYSTEM

TECHNICAL DOCUMENTARY REPORT NO. AMRL-TDR-62-144

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Biomedical Laboratory
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[Prepared Under Contract No. AF 33(616)-8370
by
George W. Morton
Allen I. Ligorner
Airborne Instruments Laboratory
A Division of Cutler-Hammer, Inc.
Deer Park, New York]

NOTICES

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FOREWORD

This report covers work conducted from June 1961 to July 1962. Mr. Charles A. Steinberg of the Department of Medical and Biological Physics, Airborne Instruments Laboratory, A Division of Cutler-Hammer, Inc., Deer Park, New York, was the principal investigator. Mr. Miles A. McLennan of the Medical Electronics Section, Biomedical Laboratory, served as project engineer under Contract No. AF 33(616)-8370, Project No. 7222, "Biophysics of Flight," Task No. 722203, "Specialized Instrumentation."

Special acknowledgment is made to Mr. David Smith of the EDP Corporation, Orlando, Florida; Mr. Sweeney of AMP, Inc., Harrisburg, Pennsylvania; and Mr. Gordon Bachand, Automated Data Systems Division, Sandia Corporation, Albuquerque, New Mexico.

ABSTRACT

To reduce the load on data transmitting and processing equipment--and thereby reduce the size and power requirements of such equipment in space vehicles--methods of selecting only the significant portions of data from transducers were investigated, and a six-channel laboratory model of a selective monitoring system was built and tested. Two principles of data selection were studied: (1) selection based on departure of a process variable from the steady state, and (2) excursion of a process variable beyond predetermined limits. Selection data while in the analog state--as taken directly from the transducers--and selection data after conversion to digital code were studied. The laboratory model demonstrates selective monitoring of analog data after conversion to digital code and uses as a selection criterion either departure from the steady state or excursion beyond limits. A program for applying the knowledge gained by the study and the principles demonstrated by the model to space-vehicle equipment is described.

PUBLICATION REVIEW

This technical documentary report has been reviewed and is approved.

Jos M Quashnock

Jos. M. Quashnock
Colonel, USAF, MC
Chief, Biomedical Laboratory

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I. INTRODUCTION

In many data-logging and monitoring applications, only a small percentage of the input data from the transducers is actually significant; logging the rest of the data imposes an unnecessary burden on the recording and analyzing facilities. When insignificant data is transmitted over long-range communication links, power and bandwidth are being used needlessly.

Power can be conserved and data-logging facilities used at maximum efficiency through selective monitoring. Selective monitoring is a term applied to automatic data selection techniques in which data input signals are selected for processing only when they vary significantly from their predetermined norms. Selective monitoring techniques can be particularly valuable in space-vehicle data logging, where the capacity of the telemetering link directly affects the dead weight at the launching pad.

The purpose of this work was (1) to study selective monitoring techniques based on the present and expected state of the art, (2) to design and construct a laboratory model selective monitoring system that exemplifies the principles of selective monitoring, and (3) to test and evaluate the selective monitoring principles as exemplified in the laboratory model under simulated operational conditions.

Throughout this study and development, primary emphasis was placed on the use of level-change (or departure from steady state) as a selection criterion; tentatively, a minimum level-change of 1 percent of full scale was defined as the condition for selection. A second condition for selection was the relationship between the level of the variable being monitored and predetermined normal limits of the level for that variable. The variables to be monitored were assumed to contain frequency components of 1 cps or lower for a full-scale deflection. Detailed performance specifications formulated at the end of the design study phase are listed in the Appendix.

This report summarizes the work performed in each of the three phases of the program. Design details and operating and maintenance instructions for the laboratory model selective monitoring system are contained in an operating and instruction manual (ref. 1). A program of further development, aimed at practical application of selective monitoring principles, has been presented in a proposal to the 6570th Aerospace Medical Research Laboratories.

II. STUDY OF SELECTIVE MONITORING TECHNIQUES

The first 3 months of the program were devoted to a survey of selective monitoring techniques and the design of a preferred system for development as a laboratory model. A number of basic components and techniques were investigated, and various alternative methods of implementing the data-selection process were studied.

Figure 1 is a block diagram of a typical monitored data selective monitoring system that uses principles of selective monitoring. Coupled to the process being monitored are various transducers that convert the process variables to a voltage or other common form suitable for further manipulation. A multiplexer permits major components in the system to be time-shared and reduces the number of components and circuits needed. The components may include:

1. A signal processor to convert the output voltages of the transducers into a form suitable for recording, transmission, and display

2. Signal-storage, display, and transmission facilities

3. A format control unit to record or transmit data (along with a real-time reference) in an orderly fashion for subsequent recovery and display

4. A data selection unit to determine what portions of the incoming data are of such significance that further processing is warranted

It is primarily the data selection unit with which this report deals, although consideration has been given throughout to the interfaces between the data selection unit and other components in the system.

The selection of certain portions of incoming data for further processing (recording or transmitting) will generally be based on one or more of the following:

1. OPERATOR COMMAND: It should be possible at any time for an operator to arbitrarily select portions of data for processing.

2. PASSAGE OF TIME: Data processing can be automatically initiated at periodic intervals, regardless of the characteristics of the data, to provide a baseline for reference.

3. LEVEL-CHANGE: The occurrence of a previously designated change in level from a starting value--departure from steady state--can be used to initiate selection. An alternative and more refined selection technique (actually used in the laboratory model) bases data selection on the difference between the maximum and minimum values of the variable during the monitoring interval.

4. RATE OF CHANGE OF LEVEL: The rate of change of level can serve to initiate selection. (This is a special case of level-change.)

5. LIMIT-CROSSING SELECTION: Normal limits can be specified for each variable; and selection can be programmed to occur whenever the variable falls outside a predetermined range.

Selection by operator command or by passage of time are not characteristics that are unique to a selective monitoring system, but they are desirable features in any monitoring system. Selection by level-change, by rate of change of level, and by limit-crossing are illustrated in figure 2.

It is helpful in discussing methods of implementing selection techniques to distinguish between analog and digital techniques. When analog techniques are discussed, the analog variables received from the transducers are assumed to be preserved as analog variables and the selection made as a result of exclusively analog manipulations; when digital techniques are discussed, it is assumed that the analog variables received from the transducers are converted into digital code by an analog-to-digital converter and that the operations involved in selecting data or in processing selected data are performed through manipulations of digitally coded quantities. Between the two extremes lies a variety of possible hybrid approaches.

A. SELECTION BASED ON LEVEL-CHANGE

1. ANALOG TECHNIQUES

Detection of level-change in a variable implies, for the general case, storage of a predetermined level for comparison with the level of the variable at an indefinite future time. There are a number of techniques for the storage of analog voltage levels. To meet the specifications for selection on the basis of level-change, a minimum change of 1 percent of full scale, a stability of better than 1 percent over a storage time of indefinite duration is required.

The storage elements must further provide periodic nondestructive readout during the storage period at intervals sufficiently short to detect a level-change of 1 percent in a 1 cps, full-scale signal. Hence, hundreds or even thousands of readout operations may be called for in the course of selection.

Finally, the storage elements must be capable of being up-dated immediately to a current value of the input variable when called for by the program control unit. (Such a requirement will exist, for example, if automatic reset of the select condition is to be provided.)

A functional block diagram of a multichannel analog level-change selector is shown in figure 3. Initially, the value of each analog input voltage is entered in the appropriate analog memory element. During subsequent cycles of the input multiplexer, the new sampled value of each input is compared with the stored value in a pair of differential amplifiers.

Two banks of analog storage elements are used: one to store the maximum values of the monitored variables, the other to store the minimum values. These values are continuously up-dated by comparison with the new data samples. A comparison between maximum and minimum levels in each channel is periodically made in a third differential amplifier whose output is applied to an absolute-level trigger that initiates the select operation.

Table I lists information on a number of types of analog storage devices whose characteristics approach those needed for the detection of the specified 1 percent level-change. Study of these characteristics led to the conclusion that the integrating amplifier (item 4, table I) and the transfluxor magnetic-core storage unit (item 5) most nearly met the requirements of the selective monitoring application.

Laboratory tests made with a commercially available, solid-state integrating amplifier and a number of high-quality, low-leakage, storage capacitors indicated that reference voltages could be stored over periods of many minutes with a decay in level of only a small fraction of 1 percent. The problem in using the integrating amplifier in a multichannel system arises in the method by which a number of such amplifiers can be commutated into the common comparison and selection circuits.

As indicated in figure 3, the storage elements are effectively shunted by the multiplexer. The integrator storage times listed in table I depend on leakage resistances of the order of 10^{11} ohms, a value that virtually excludes the use of solid-state electronic commutators. Thus, the use of integrating amplifiers as storage units appears to be limited to those applications in which electromechanical or, possibly, vacuum-tube electronic commutation is acceptable.

TABLE I

SURVEY OF ANALOG STORAGE COMPONENTS

	Type of Storage Device	Useful Dynamic Range	Storage Time	Type of Readout	Useful Life	Advantages	Limitations
1.	Magnetic drum	40-50 db (FM Recording)	Indefinite	Non-destructive	Thousands of hours (mechanical-wear limit)	Can be self-clocked	Weight, mechanical wear, power consumption
2.	Electrostatic storage tube	20 db	Hours	Non-destructive	--	--	Insufficient dynamic range; fragility; requires high-voltage supply and much auxiliary deflection circuitry; inefficient for storage of small amounts of data
3.	Acoustic delay lines	20 db	Milli/seconds	Destructive (signal must be regenerated)	--	--	Insufficient dynamic range and storage time; recirculation not practical for analog storage
4.	Integrating amplifiers	50-60 db	30-50 hours	Non-destructive	Estimated mean time between failures: 10^4 hours for six-channel system	Good dynamic range and storage time. Low power consumption	High impedance makes switching or commutation difficult without degradation of signal

TABLE I (cont'd)

SURVEY OF ANALOG STORAGE COMPONENTS

	Type of Storage Device	Useful Dynamic Range	Storage Time	Type of Readout	Useful Life	Advantages	Limitations
5.	Magnetic storage in ferrite cores (transfluxors)						
	a.	20 db	Indefinite	Non-destructive	Similar to that of integrating amplifiers	Can be switched	Limited dynamic range; in early development
	b.	20 db	Indefinite	Non-destructive	Similar to that of integrating amplifiers	Can be switched	Limited dynamic range
	c.	40 db	Indefinite	Destructive	Similar to that of integrating amplifiers	Can be switched	Destructive readout; slow response
	d.	40 db	Indefinite	Non-Destructive	Similar to that of integrating amplifiers	Can be switched	Not yet commercially available

Development of magnetic transfluxors (magnetic storage in ferrite cores) for the storage of analog quantities is at present less advanced and less fully documented than that of the integrating amplifier. Tentative information from 4 sources is quoted in table I. Of these, item 5d appears to best meet the requirements for accurately detecting a change of 1 percent in voltage level over long periods of time.

This transfluxor, the result of unclassified, Government-sponsored development, appears to merit further investigation as a long-range possibility for operational use in selective monitoring systems. Its major advantage is its potentially low impedance and, hence, high degree of immunity to leakage. In spite of their long-range potential, it did not appear that analog transfluxors were sufficiently far advanced for use in the construction of the laboratory model selective monitoring system.

2. DIGITAL TECHNIQUE

As already suggested, the digital technique for level-change selection is based on the use of an analog-to-digital converter. In a practical system, the resolution of the converter is so adjusted that 1 percent of full-scale change in the level of the input variable from the transducer will be equal to three of the minimum resolution elements (quantiles) of the analog-to-digital converter. (This resolution is readily achievable for the specified 5.0-volt signal span.) A logic tree, operating on the output of the two least significant bits from the converter, then establishes a cyclically repeating four-level sequence across the entire input range of the converter. This pattern is illustrated in figure 4.

If the condition for selection be that the converted signal value occupy all four of the possible levels at some time during the sampling period (as shown in figure 4), there will exist a 100 percent probability of detecting signals with a level change in excess of 3 quantile widths. This follows because the select condition is satisfied, regardless of the absolute level of the monitored variable.

Because of the nature of the select logic, there will also exist a finite but decreasing probability of selecting data whose level changes lie between 2 and 3 quantile widths. This condition is illustrated in figure 5, which assumes a random distribution of absolute level for the selected variable. Level changes of less than 2 quantile widths will not be selected, however, so the selection logic will be effective even in the presence of a relatively high noise level on the incoming variable.

Figure 6 shows a functional block diagram of a digital level-change selector using the principles outlined above. In this arrangement, the 0 and 1 outputs from the last two bits in the converter enter a logic net that has four output leads, one for each of the four cyclically repeated input ranges. The output from each of these leads is entered in one channel of a four-channel, circulating shift register.

The stepping of the shift register is synchronized with that of the input multiplexer so that the previously entered data for each step of the multiplexer is in the read/enter location of the shift register just as the data from the new samples become available. On each consecutive sample, new data (if present) are entered in the appropriate shift-register position by changing a 0 to a 1 whenever the input signal enters a new level for the first time.

When all four levels have been occupied by the signal in a given channel, the select condition is satisfied, and a select pulse is generated at the output of the level-change-selector matrix. Provision must be made to reset all of the level indications for a channel immediately after selection has occurred to assure the continued operation of the selection logic. A typical time sequence of operation showing selection appears in figure 4.

B. SELECTION BASED ON RATE OF CHANGE OF LEVEL

The techniques discussed in the preceding paragraphs are theoretically independent of rate of change of level up to a maximum limit imposed by the sampling period of the multiplexer. Actually, a limit on the minimum detectable rate of change is imposed by the stability of the signal processing circuits, if by no other factor. A control on the minimum rate of change of level required for selection by the level-change detector could be imposed by inserting a high-pass filter ahead of the selection circuits. This would differentiate the signal components falling below cutoff of the input circuit.

A second limitation imposed, in a practical system, on the minimum rate of change of level is that resulting from a periodic programming of the select sequence for routine monitoring. It may be normal practice, for example, to monitor all data channels at specified intervals regardless of their activity. After such a programmed monitoring cycle, the level-change detectors could logically be cleared so that level changes will be measured from the most recently monitored value. With this arrangement, the minimum detectable rate of change is determined in part by the interval between programmed select sequences.

C. SELECTION BASED ON LIMIT-CROSSING

1. ANALOG TECHNIQUES

An analog circuit well-suited for limit-crossing selection is the Schmitt trigger circuit. A solid-state application of this circuit is shown in figure 7. When the analog input variable crosses the preset threshold, the output voltage changes from -10 volts to 0 volts. In a laboratory environment, the hysteresis and stability of this circuit is sufficient to afford a precision of 1 percent of full scale in trigger-level adjustment. In a system involving a small number of channels such as the laboratory model, the use of individual triggers to establish minimum and maximum limits appeared to offer the most flexible and straightforward solution.

For a multichannel system with a large number of channels, the use of only one pair of trigger circuits, with the necessary analog commutation circuitry, would be preferable. Such a system is illustrated in figure 8. It will be noted that this arrangement closely resembles the analog level change selection system depicted in figure 3, the principal difference being the substitution of adjustable voltage levels for the analog storage elements. This arrangement affords continuous limit adjustments over the entire range of each variable. Such an arrangement would be particularly advantageous if it were incorporated in an analog-level-change selection system, such as that shown in figure 3, to permit time-sharing of common components.

2. DIGITAL TECHNIQUE

By appropriate logic connections to the anlog-to-digital converter, any desired threshold within the resolution limits of the converter can be chosen as a threshold of selection. The number of elements in each such logic network will depend on the precision with which the threshold is to be specified. Where threshold values can be preassigned, the recognition logic can be installed as part of the permanent circuit, and little difficulty will be encountered in achieving the highest precision of which the converter is capable.

When continuously adjustable limits are required on each variable, the system becomes more complex. A precise all-digital system, for example, might require a matrix with a separate output lead for each resolution element of the converter. A possible compromise solution would be an all-digital system based on the use of a limited number of equal subranges uniformly distributed throughout the full range of the converter. Figure 9 shows a scheme based on 16 subranges. In this case, the upper and lower limit settings for each channel can be varied in steps of 6-1/4 percent of full scale.

III. DEVELOPMENT OF LABORATORY MODEL SELECTIVE MONITORING SYSTEM

The purpose of the laboratory model was to demonstrate the performance of the more promising selective monitoring techniques for processing typical input data. This goal was to be achieved within the present state of the art and without imposing special environmental or other physical limitations on the laboratory model beyond those sufficient to assure reliable performance in the usual laboratory environment.

At the same time, the eventual application of selective monitoring systems in extreme environments and the possible need for low power consumption and high-density packaging were anticipated; techniques and components incorporated in the laboratory model included only those that could be further developed to meet the more stringent requirements with a reasonable expenditure of engineering effort. To this end, the use of solid-state circuitry has taken precedence over circuitry involving electromechanical or thermionic components.

Figure 10 shows the laboratory model selective monitoring system, which incorporated both level-change and limit-crossing selection of data. It was completed and first tested in January 1962. All specifications listed in the Appendix were met. As originally constructed, however, the equipment required manual reset after selection. Early tests indicated the desirability of including automatic reset upon removal of the select condition, and this feature was added before proceeding with additional tests.

IV. PERFORMANCE TESTING OF THE LABORATORY MODEL SELECTIVE MONITORING SYSTEM

Figure 11 presents a number of chart-recordings of the performance of the laboratory model selective monitoring system. The input signals used for test purposes were obtained from a Hewlett-Packard Model 212A low-frequency function generator.

In figure 11A, a 0.02-cps sine wave (upper trace) is applied to the input of one channel of the laboratory model, and the selected output is displayed on the lower trace. Level-change was the criterion of selection in this case. The level-change selection was adjusted to automatically reset approximately 0.6 second after each selection event. It will be noted that the frequency of selection events is proportional to the slope of the sinusoidally varying input voltage.

Figure 11B shows limit-crossing as a basis for selection, and figure 11C shows the combination of level-change and limit-crossing as selection criteria.

It was originally expected that actual recordings of physiological data could be used in testing the laboratory model selective monitoring system. Suitable data did not become available before completion of the program. The laboratory model was delivered to the 6570th Aerospace Medical Research Laboratories in June 1962 for further testing, evaluation, and demonstration.

V. APPLICATIONS FOR SELECTIVE MONITORING TECHNIQUES

During development of the laboratory model, the application of the selective monitoring system to pretransmission processing of telemetered data from a space vehicle was a long-range objective. The transition to a space-vehicle environment would involve:

1. Determination of input/output characteristics and operational requirements for a specific application, and further development of techniques and components to meet such requirements

2. Development of methods of organizing and processing data that will permit selected data to be transmitted and/or interpreted and acted on with maximum efficiency

3. Investigation and application of techniques for repackaging the system in rugged, high-density, solid-state components for minimum power consumption and maximum reliability in a space-vehicle environment.

A detailed program of future activity in each of the above 3 areas has been submitted in a proposal to the 6570th Aerospace Medical Research Laboratories. The principal features of this proposal are:

1. Development and construction of a companion data-conversion unit that will convert various physiological inputs to a form compatible with the input requirements of the laboratory model selective monitoring system

2. The addition of adaptive monitoring and data-format features to the laboratory model to make its operation compatible with conventional methods of storage, transmission, and display of data collected by space-vehicle instruments

3. Preliminary design of vital functional units of the selective monitoring system for high-density packaging and low power drain based on available thin-film or molecular electronic modular components.

VI. SUMMARY AND CONCLUSIONS

Basic principles of selective monitoring have been reduced to practice in a six-channel laboratory model selective monitoring system that meets all of the original contract specifications. Further steps in the application of these principles toward increasing the efficiency of data transmission, storage, and display components are summarized.

Design of the programming and level-change selection portions of the selective monitoring system has been based on the use of available digital modules of proven performance and reliability. The limit-crossing selection is based on use of trigger circuits compatible in performance with the digital modules. The latter form of selection is accomplished without time-sharing in the laboratory model because of the small number of channels involved, and because it provides a maximum flexibility of adjustment. In an operational model for space-vehicle application, one of the commutation techniques would be equally feasible.

REFERENCES

1. Operation and Maintenace Manual for Type 1158 Demonstration Model Selective Monitoring System, Publication No. 1158-H-1, Airborne Instruments Laboratory, Division of Cutler-Hammer, Inc., Deer Park, N. Y., June 1962.

2. V. A. Van Praag, W. Stanke, and D. Mindeno, "Magnetic Core Converts Voltage to Pulse Duration," Control Engineering, p 87, August 1961.

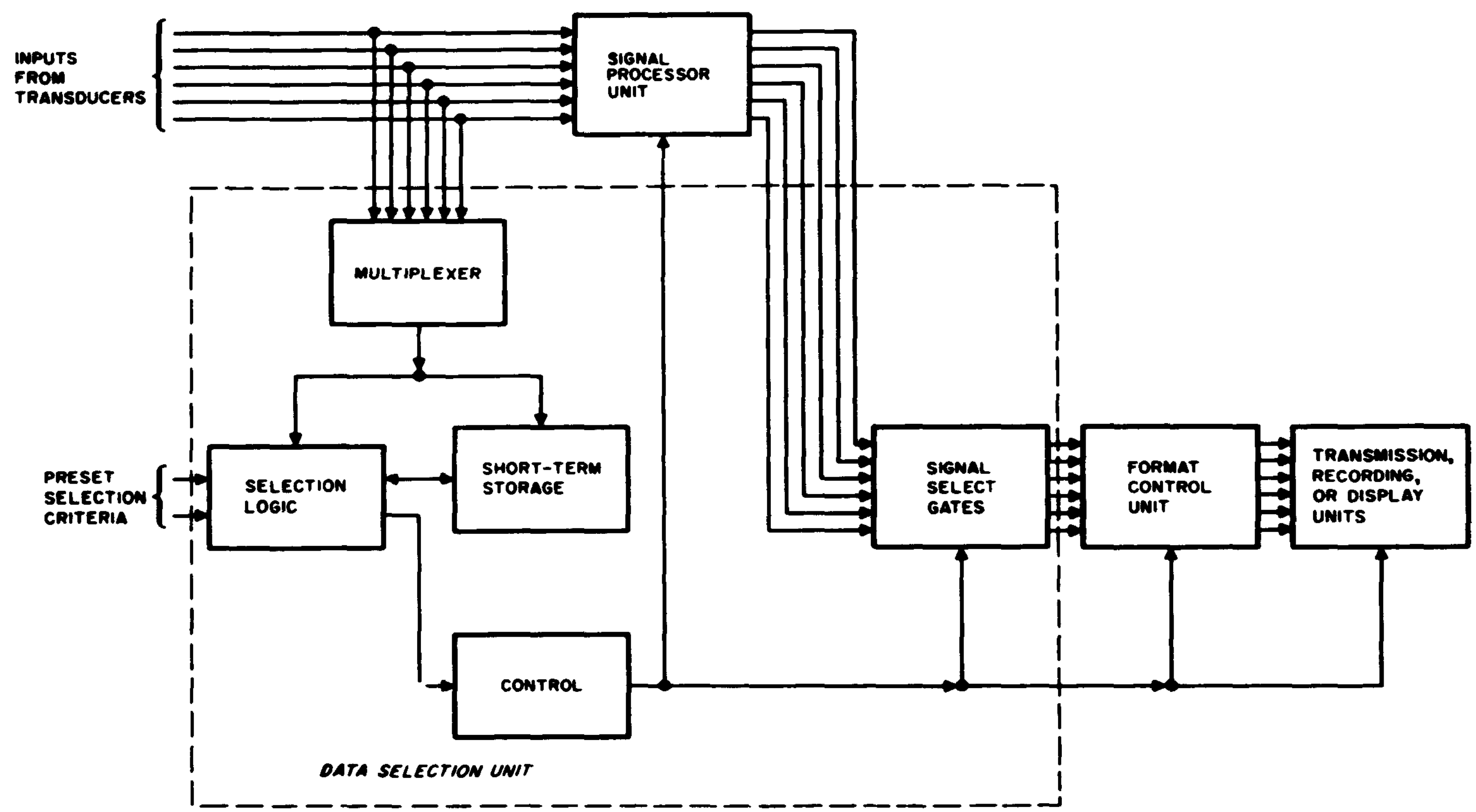

FIGURE 1. BLOCK DIAGRAM OF TYPICAL MONITORED DATA SYSTEM

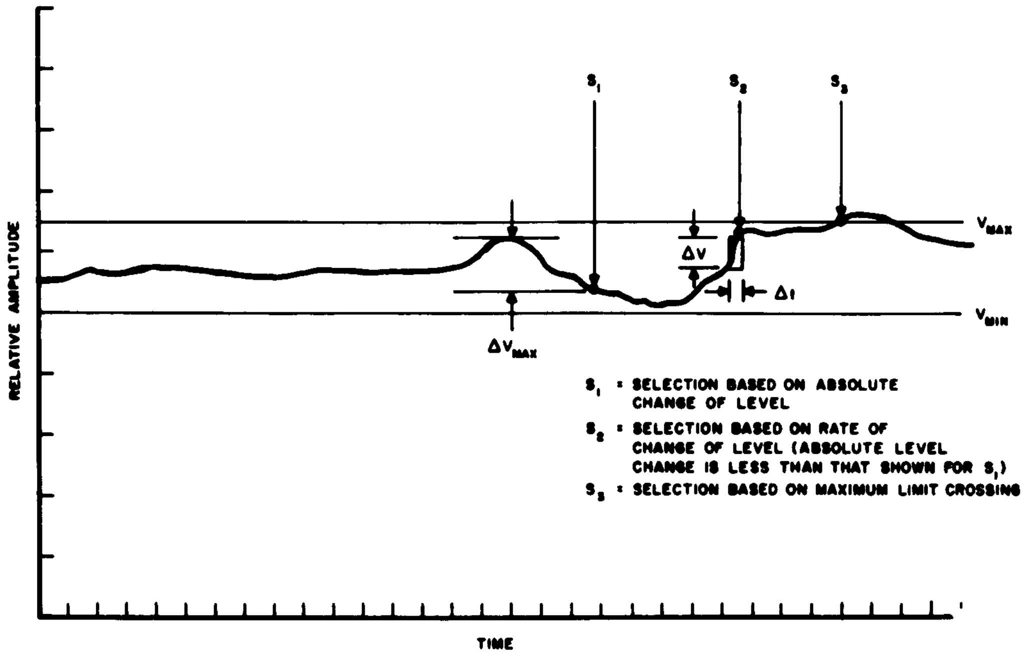

FIGURE 2. GRAPH OF ANALOG-DATA INPUT SHOWING SELECTIVE MONITORING CRITERIA

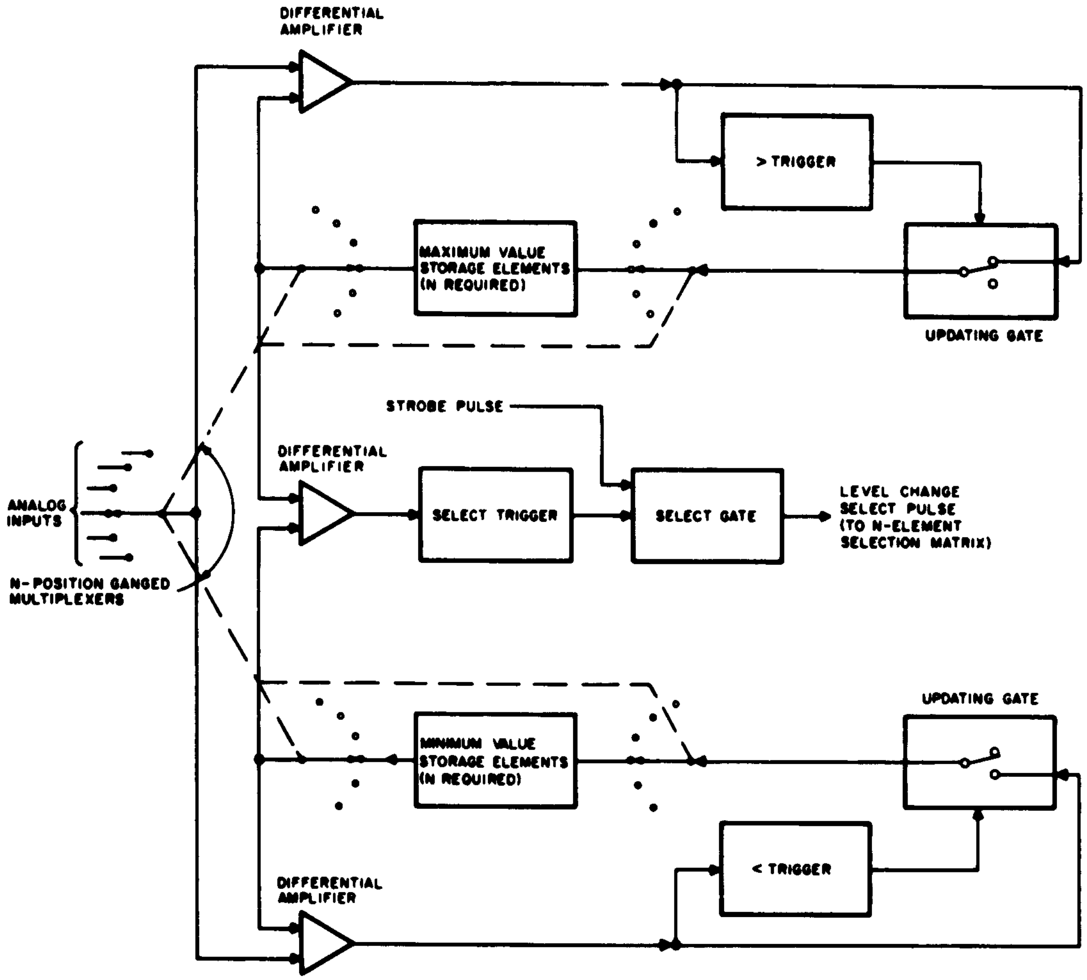

FIGURE 3. BLOCK DIAGRAM OF ANALOG MULTICHANNEL LEVEL-CHANGE SELECTOR

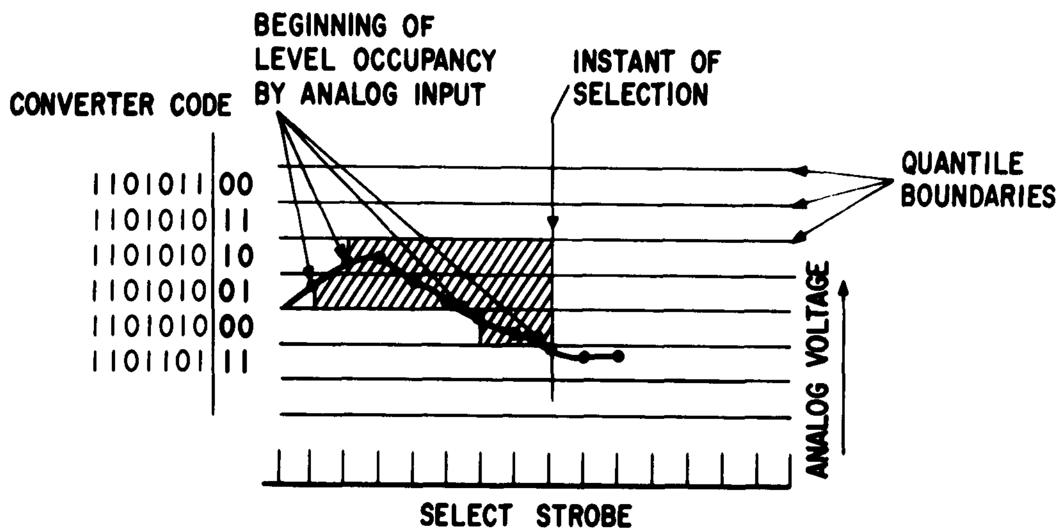

FIGURE 4. GRAPH SHOWING DIGITAL LEVEL-CHANGE SELECTION LOGIC

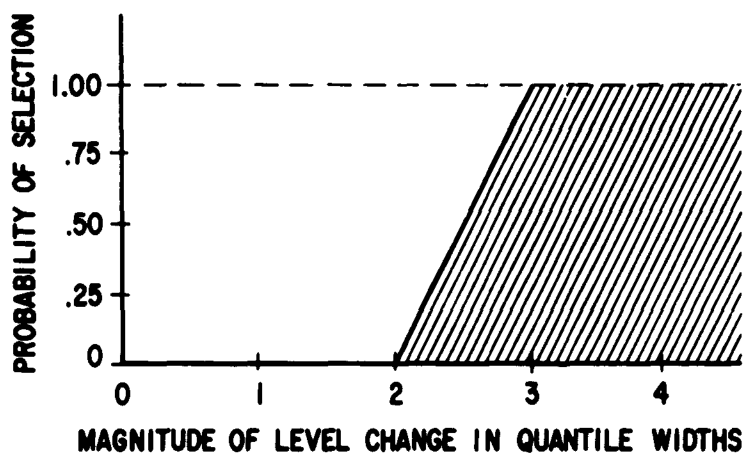

FIGURE 5. CHART SHOWING PROBABILITY OF DATA SELECTION VS MAGNITUDE OF LEVEL-CHANGE

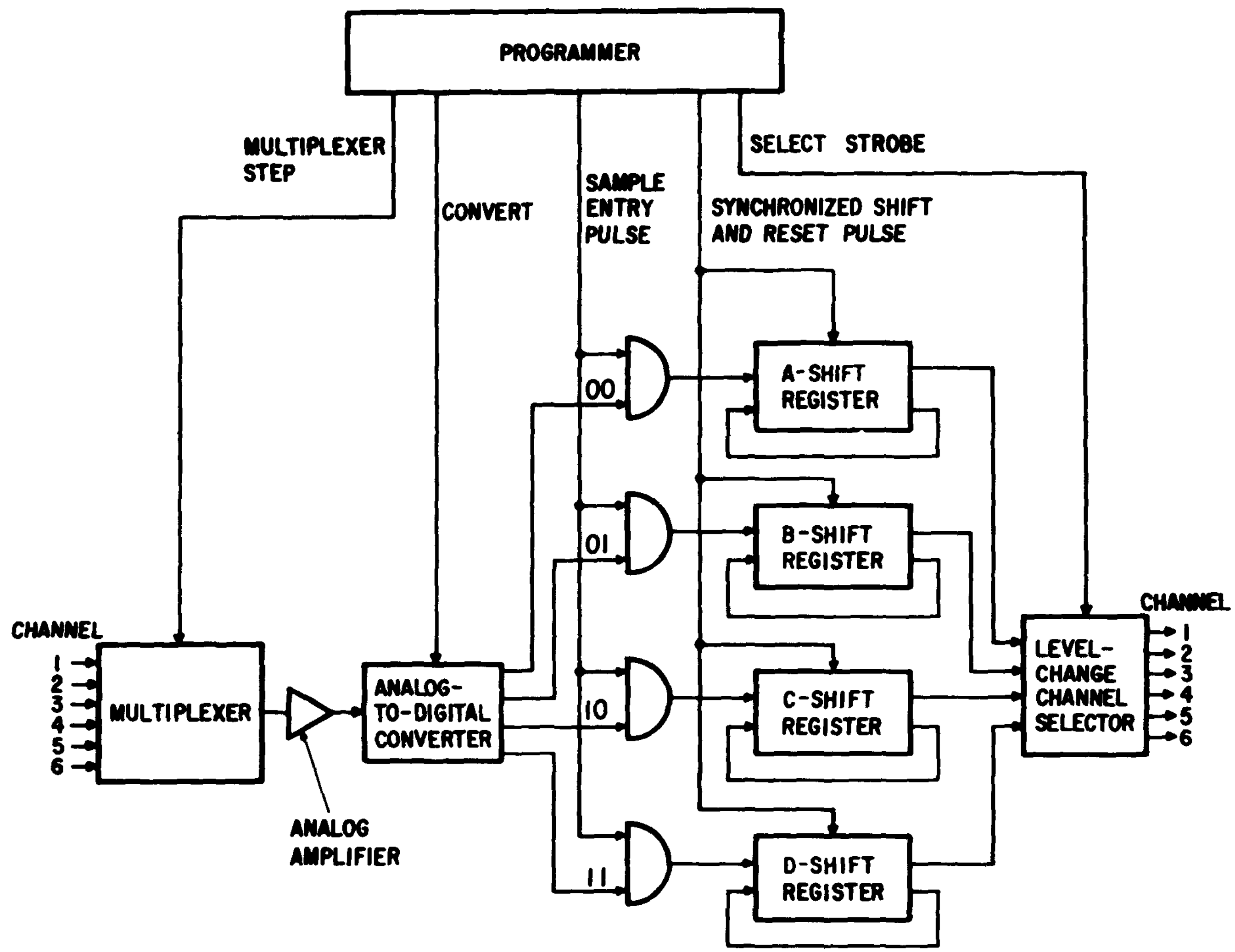

FIGURE 6. BLOCK DIAGRAM OF DIGITAL MULTICHANNEL LEVEL-CHANGE SELECTOR

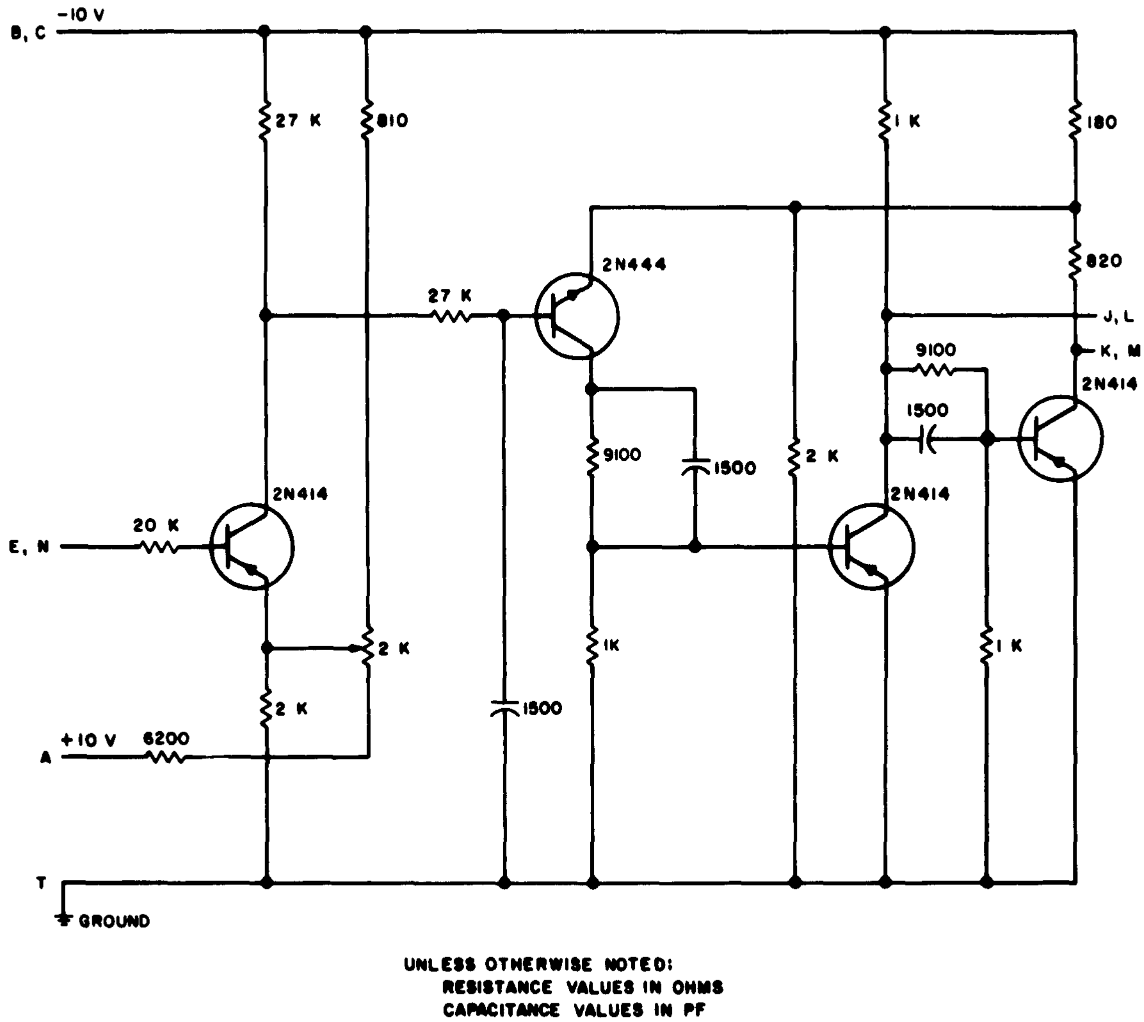

FIGURE 7. SCHEMATIC DIAGRAM OF TRIGGER CIRCUIT FOR LEVEL-CHANGE SELECTOR

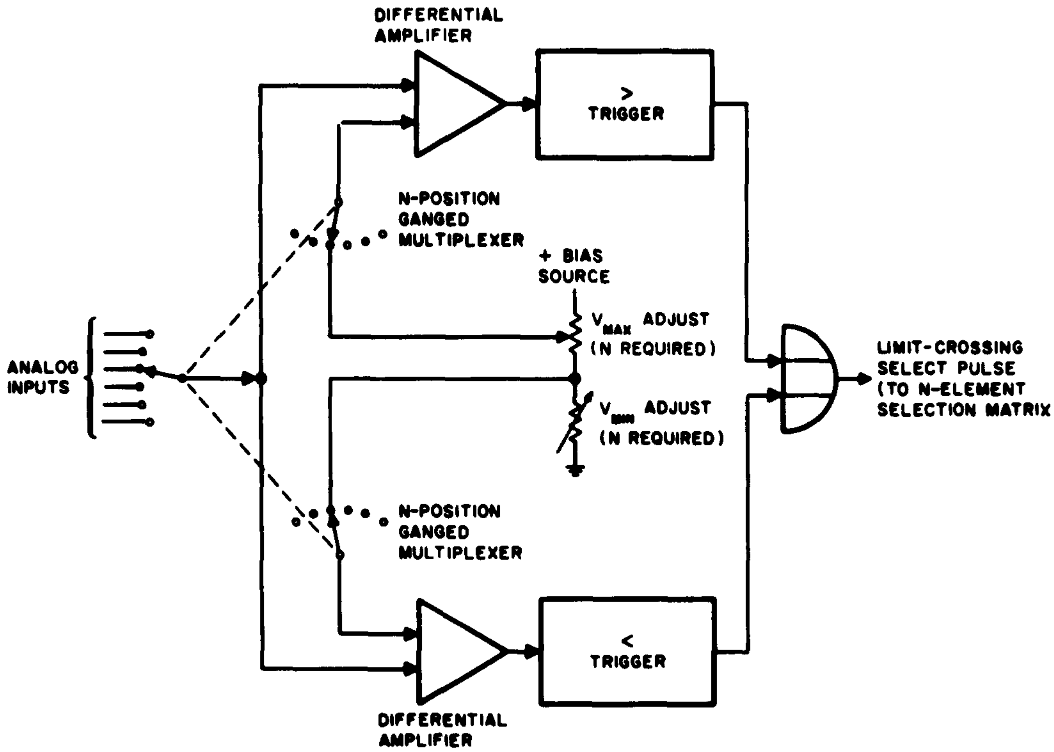

FIGURE 8. BLOCK DIAGRAM OF ANALOG MULTICHANNEL LIMIT-CROSSING SELECTOR

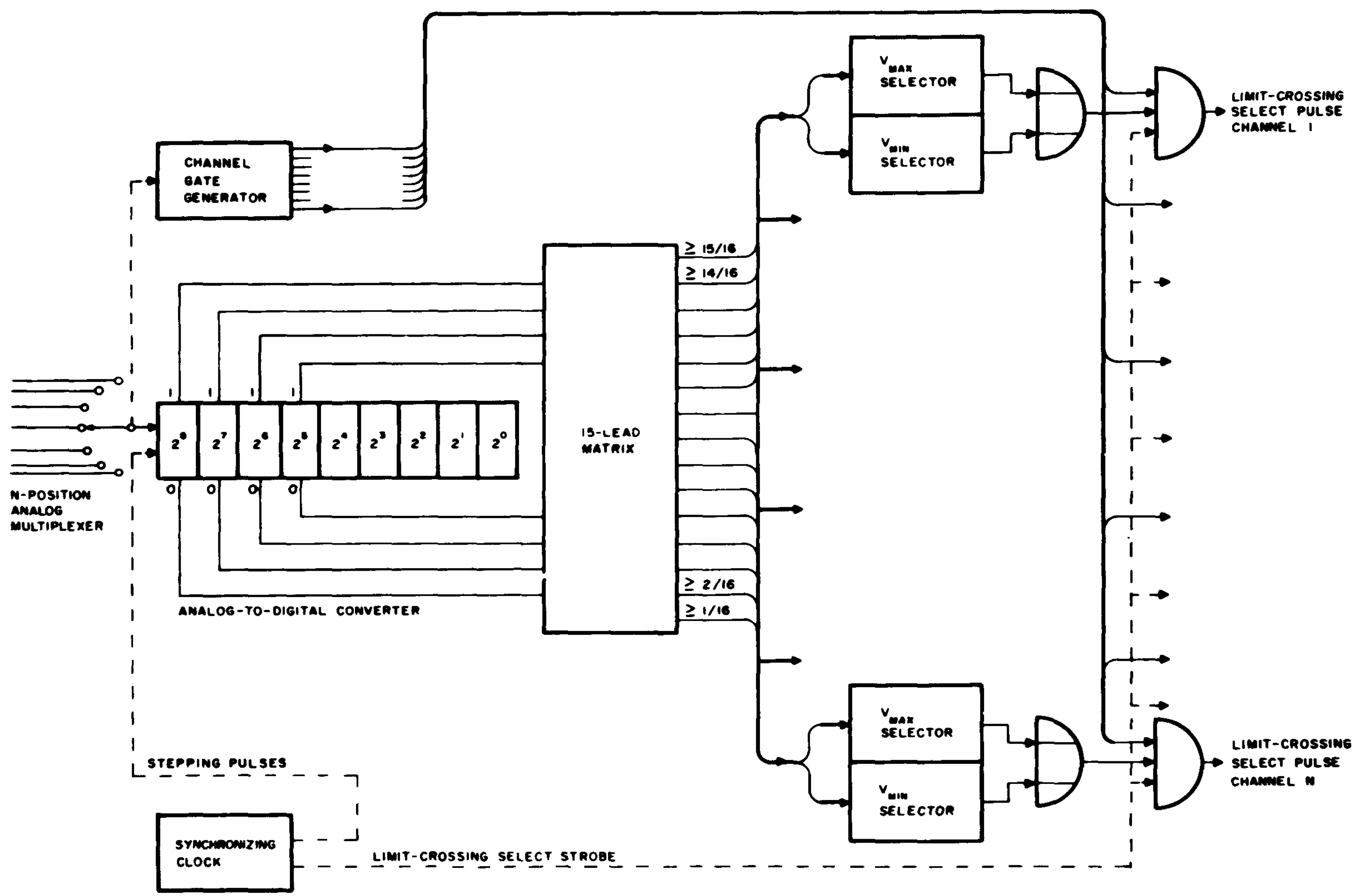

FIGURE 9. BLOCK DIAGRAM OF DIGITAL MULTICHANNEL LIMIT-CROSSING SELECTOR

FIGURE 10. LABORATORY MODEL SELECTIVE MONITORING SYSTEM

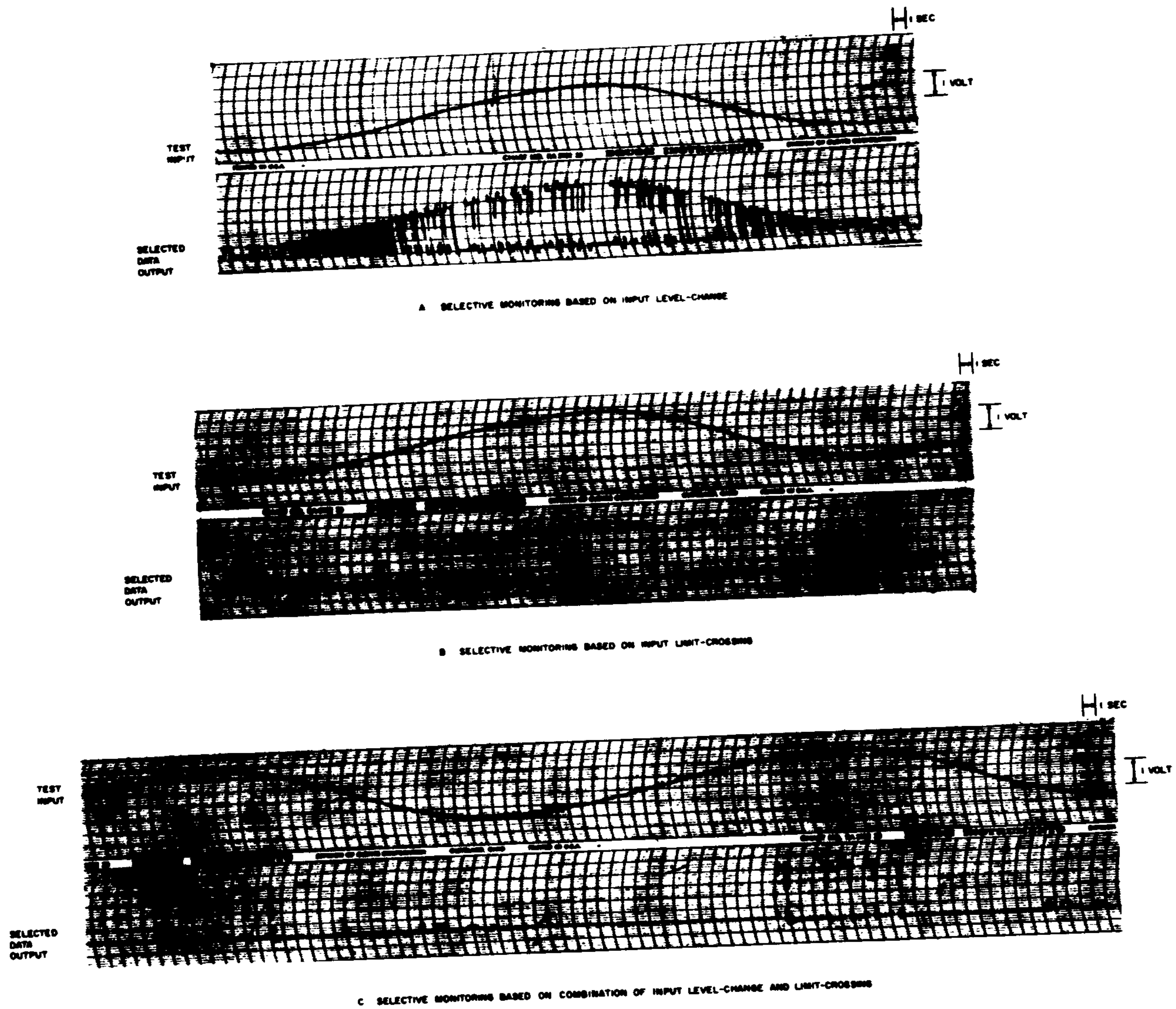

FIGURE 11. CHART-RECORDINGS OF PERFORMANCE OF LABORATORY MODEL SELECTIVE MONITORING SYSTEM

APPENDIX

SPECIFICATIONS OF LABORATORY MODEL SELECTIVE MONITORING SYSTEM

INPUTS

NUMBER OF CHANNELS:	6 maximum
VOLTAGE RANGE:	0-5 volts DC maximum
FREQUENCY RANGE:	0-1 cps at full sensitivity
CHANNEL SELECTION:	Automatic application of selection criteria to any number of channels from 1 to 6

OUTPUTS

VISUAL INDICATORS:	Panel-light display of channel selected and mode of selection
SELECT SIGNAL:	Six-channel output with 5 volt DC step at time of selection
GATED SIGNAL:	Relay-contact closures to input signal initiated by select function

SELECTION LOGIC AND TIMING

LEVEL-CHANGE SELECTION:	Sensitivity continuously adjustable on each channel down to 1 percent of full scale or less
LIMIT-CROSSING SELECTION:	Upper and lower selection limits continuously adjustable on each channel over full-scale range
TIMING:	Selection and reset to be initiated periodically by a built-in timer, by an external signal, or by operator from control panel
SELECTION LOGIC CONTROL:	Selection based on level-change only, on limit-crossing only, or on both via front-panel control

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Unclassified report

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IV. Airborne Instrument Laboratory, Deer Park, New York

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and tested. Two principles of data selection were studied: (1) selection based on departure of a process variable from the steady state, and (2) excursion of a process variable beyond predetermined limits. Selection data while in the analog state—as taken directly from the transducers—and selection data after conversion to digital code were studied. The laboratory model demonstrates selective monitoring of analog data after conversion to digital code and uses as a selection criterion either departure from the steady state or excursion beyond limits. A program for applying the knowledge gained by the study and the principles demonstrated by the model to space-vehicle equipment is described.

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1. Monitors
2. Space Vehicles
3. Transducers
4. Space Flight
5. Data Processing Systems

I. AFSC Project 7222, Task 722203
II. Biomedical Laboratory
III. Contract AF 33(616)-8370
IV. Airborne Instrument Laboratory, Deer Park, New York

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Aerospace Medical Division, 6570th Aerospace Medical Research Laboratories, Wright-Patterson AFB, Ohio. Rpt. No. AMRL-TDR-62-144. STUDY AND DEVELOPMENT OF A SELECTIVE MONITORING SYSTEM. Final report, Dec 62, v + 25 pp. incl. illus., 1 table, and 2 refs.

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