ESD-TDR-65-175

(FINAL REPORT)

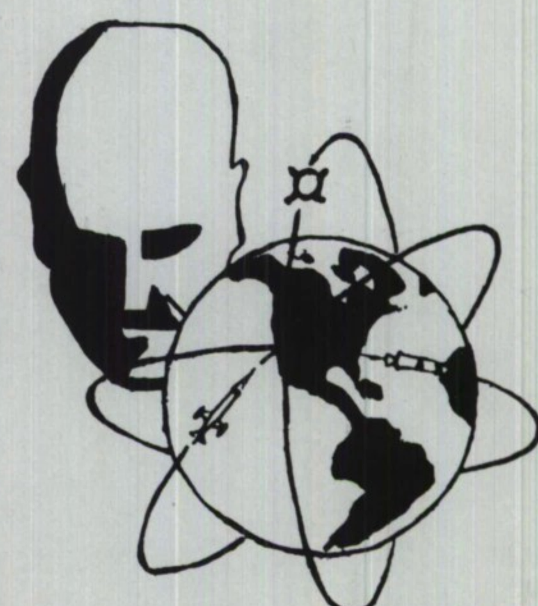
DEVELOPMENT OF TECHNIQUES FOR THE AUTOMATIC CONTROL OF EXPERIMENTS IN A PSYCHOLOGY LABORATORY

TECHNICAL DOCUMENTARY REPORT NO. ESD-TDR-65-175

FEBRUARY 1965

ESRH

DECISION SCIENCES LABORATORY
ELECTRONIC SYSTEMS DIVISION
AIR FORCE SYSTEMS COMMAND
UNITED STATES AIR FORCE
L. G. Hanscom Field, Bedford, Massachusetts



(Prepared under Contract No. AF 19 (628)-296 by Bolt Beranek and Newman, Incorporated, Cambridge, Massachusetts.)

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FOREWORD

This report was prepared by Bolt Beranek and Newman Inc, Cambridge, Massachusetts under Air Force Contract AF19(628)296 in support of Task No. 469002 of Project No. 4690. It is the final report and concludes work on this contract. This report has also been issued as Bolt Beranek and Newman Inc Report No. 1221. The work was administered by the Display Division, Decision Sciences Laboratory, Deputy for Engineering and Technology of the Electronic System Division. Dr. J. Richard Hayes and Dr. Charles R. Brown served as contract monitors.

ABSTRACT

This report details the development of methods for using a digital computer (the Digital Equipment Corporation PDP-1) to control apparatus and experimental procedures in psychological experiments. It describes the design of equipment for a multi-subject display system and a psychoacoustic laboratory system. An experiment illustrating the use of the system is included.

This Technical Report has been reviewed and is approved.

FOR THE COMMANDER

Donald W. Connolly

DONALD W. CONNOLLY
Chief, Display Division
Decision Sciences Laboratory

for James S. Duva

ROY MORGAN
Colonel, USAF
Director, Decision Sciences Laboratory

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DEVELOPMENT OF TECHNIQUES FOR THE AUTOMATIC CONTROL OF EXPERIMENTS IN A PSYCHOLOGY LABORATORY

I. INTRODUCTION

The objective of the work that we report upon here was the development of methods for using a digital computer to control the apparatus and procedures employed in psychological experiments. Experiments of two types were considered: (1) those having to do with the human cognitive processes of decision making, problem solving, and pattern recognition in which visual display of material is important; and (2) psychoacoustic experiments in which audio signals must be generated, processed, and transmitted. For both of these types of experiments, the major focus of our work was development of techniques for generation and presentation of stimulus materials. For the cognitive experiments these took the form of multi-subject display consoles. For the psychoacoustic experiments we designed and constructed special equipment for controlling standard audio signal processing apparatus.

In the case of the multi-subject stations for cognitive experiments, we concentrated on engineering analysis and preliminary design. This work led to the specification of the multi-subject station configuration developed jointly by us and the personnel of the Decision Sciences Laboratory and the Digital Equipment Corporation. The subject station consists of an oscilloscope display, a light-pen, a keyboard device, and a few computer controlled relays. The display and relays are used primarily for the presentation of stimuli. The light-pen and keyboard are used by the subject for making responses which can be interpreted by the computer. The subject stations were fabricated by the Digital Equipment Corporation under separate contract with the Decision Sciences Laboratory, and are composed of standard commercially available components. Four subject stations have been provided. They can be operated simultaneously and independently in the sense that different displays can be presented to each of the four subjects who can respond independently. A programming system to simplify the writing of display programs in the DECAL-BBN (Ref. 1) computer language is now being written under a separate contract.

Our work on the automation of psychoacoustic experiments has been devoted to extending the capabilities of the PDP-1 computer by providing it with actuators and sensors for controlling standard psychoacoustic laboratory equipment. The apparatus used in psychoacoustic experiments is highly developed and specialized. Rather than attempt to duplicate the functions of this apparatus, we have chosen to use the computer to operate, adjust, and calibrate existing standard laboratory apparatus. In this way, we can take advantage of the special features of psychoacoustic instrumentation. We have designed and constructed special equipment consisting primarily of switchgear, actuators, and sensors. The switchgear allows the computer to control the routing of audio signals among the subjects, the laboratory equipment, and the computer. The actuators allow the computer to adjust settings of the laboratory apparatus used in experiments both for calibration of the apparatus and for generation of stimulus signals. The sensors are used to make measurements of the signals for both calibration and control purposes. Programs have been written in the DECAL-BBN language to operate this apparatus, and through it to control psychoacoustic laboratory apparatus and procedures. These programs and this equipment have been used in some demonstration experiments having to do with methods for training people to recognize complex sounds. These experiments, which we performed to try out the system, were patterned after the sound learning experiments of Swets et al (Ref. 2).

The computer used as the central component in this development of automatic processes of experimentation was a Digital Equipment Corporation PDP-1. The PDP-1 computer, which had been installed at the Decision Sciences Laboratory prior to the beginning of this contract, was a good choice for a controller of experimental processes. It is a relatively high-speed machine, has extensive input-output capability, and is relatively inexpensive. For these reasons it is well-suited for use on-line in which it must be connected to a variety of analog apparatus, keyboard devices, and electronic displays. It has been used extensively by personnel of the Decision Sciences Laboratory in their own research program to execute experiments and analyze the results obtained (Ref. 3).

In this report, we first describe briefly the multi-subject display system designed for use in cognitive experiments. We then discuss the psychoacoustic laboratory system. We describe the hardware and software, the operation of the system, and give an example of its use in a typical experiment. In appendices we give a detailed description of the system including program write-ups and circuit diagrams of the apparatus.

II. MULTI-SUBJECT DISPLAY SYSTEM

The major portion of our work on the design of subject stations for cognitive experiments consisted of investigations of methods of connecting readily available equipments to the PDP-1 computer to provide both visual display and hard copy output from the computer; and keyboard and light-pen input to the computer. During the course of this investigation Digital Equipment Corporation introduced the preliminary specifications of a new and more suitable display oscilloscope system, the Model 340 incremental display. Subsequent studies led to the recommendation that this new system, plus certain options that facilitate the real-time operation of multiple stations, be purchased. It was also recommended that a teletypewriter, Teletype Corporation Model 33, with special control features be installed at each subject station to be used in conjunction with the display scopes. Both segments of the station are therefore standard, commercially available equipment. Detailed descriptions of both equipments are available from the manufacturers (Refs. 4 and 5). A brief discussion of each unit, however, is given below to show how these equipments operate and how they have been combined to provide a very flexible subject station for use in experiments involving decision making, problem solving, and pattern recognition.

A. DISPLAY

Digital Equipment Corporation's Model 340 Incremental Display is essentially the live registers of a small special purpose computer.

By means of an appropriate data channel these live registers are connected to the main computer memory which contains a stored program for the manipulation of the display. Thus, the display system operates as a semi-independent, special purpose, stored program computer which shares the main computer memory. The computer's main memory thus houses two semi-independent stored programs, the display program and the central program that calls the display.

However, unlike the central computer, the display computer does not complete each instruction within a memory cycle time and thus does not make continuous demands on memory. Having received a new instruction, the display computer will not fetch another instruction until the execution is terminated. During the time that the display computer is performing an instruction, the central computer has access to the memory and can continue executing its stored program. The amount of time "stolen" from the central program depends upon the type of instructions being performed by the display computer, but in most cases will be a small percentage of the total available time.

The internal operation of the display system is controlled by eight operating modes which determine how words received from main memory are interpreted. The modes of the display system are as follows:

1. Parameter Mode

When the display has been set to the parameter mode, it interprets the next word as containing information that may change its present mode, the scale of the display, the intensity, light-pen control, and interruption control parameters.

2. Point Mode

When the display has been set to the point mode, it interprets the next word as containing coordinate location and information that may change its present mode, light-pen, and intensity control parameters.

3. Vector Mode

When the display has been set to the vector mode, it interprets each succeeding word as containing the vector size and angle information, as well as intensity control and escape information. The display will remain in the vector mode until the escape bit is set, or until it reaches the raster edge, at which time it reverts to the parameter mode.

4. Vector Continue Mode

When the display has been set to the vector continue mode, it interprets each succeeding word as containing size and angle information, as well as intensity control and escape information. In this respect, it is the same as the vector mode. However, the vector will be continued until it goes off the edge of the rastor. The display will remain in the vector continue mode until the escape bit is set, at which time it reverts to the parameter mode.

5. Increment Mode

When the display has been set to the increment mode, it interprets each succeeding word as containing information to move the spot to four successive locations, each adjacent to the preceding spot. The spot can be placed into any one of the eight adjacent locations at each movement. The word also contains intensity control and escape information. The display will remain in the increment mode until the escape bit is set, at which time it reverts to the parameter mode.

6. Character Mode

When the display has been set to the character mode, it interprets each succeeding word as containing three alphanumeric characters or other symbols, each specified by six bits. The display remains in the character mode until a special code is encountered, at which time, it reverts to the parameter mode.

7. Subroutine Mode

When the display has been set to the subroutine mode, it interprets the next word as a jump, jump and save, or deposit instruction to some different location in the computer's memory. The subroutine word also sets the mode for the next word to be transferred.

8. Slave Mode

When the display has been set to the slave mode, it interprets the next word as a control word for up to four individual slave monitor displays. This word turns on or off the designated slave's electron beam and light-pen. The four slaves can be used to present all, or any part of, the main display's presentation. The slave word also sets the mode for the next word to be transferred.

Interaction between the central computer's program and the display computer's program is handled primarily through the interrupt system of the central machine. Although the main program may at any time monitor or modify the display operations, in most applications once a display is generated it is desirable to allow the same display program to remain looping indefinitely, or at least until a subject makes a response.

Each subject station display has associated with it a light-pen. As the display is posted on the face of the CRT, the subject may point his light-pen to any portion of the display. If the display program has enabled operation of the light-pen, as the point under the pen is intensified, the operation of the display computer is stopped, an interrupt to the main computer program is initiated, and a status bit is set to identify the station at which the interrupt was initiated. The main computer, by examination of the status of the display program when it was interrupted, can determine what action or modification should be made in that program. Then it can resume its operation.

B. TELETYPE

In addition to light-pen response, a subject may use the keyboard of the Model 33 teletypewriters to communicate with the main computer program. Similarly, the main program may type out instructions to the subject and provide certain stimuli that can be controlled by a relay closure, such as the ringing of a bell. The Model 33 is a relatively new, inexpensive teletypewriter and has been equipped with a paper tape reader and punch, as well as with specific code-actuated contact closures. It operates with an eight bit start-stop code and is capable of sending and receiving at a 100-word-per-minute (10 characters/sec) rate over a single pair of wires to the computer room. When the subject initiates a response by typing on the teletype, a sequence break is initiated and a status bit is set to identify the teletype being used.

Eight contact closures have been installed on each unit which are activated by specific codes received from the computer. It is intended that these contact closures will be used to provide program control of specialized equipments which may be needed in particular experiments.

III. PSYCHOACOUSTIC LABORATORY SYSTEM

A. SYSTEM DESCRIPTION

The psychoacoustic laboratory system is a hierarchical, multi-variable, feedback control system in which all the controller functions are performed by the PDP-1 Digital Computer. The system is multivariable in the sense that a relatively large number of parameters of standard laboratory apparatus can be controlled to achieve specified operating characteristics of the apparatus connected to the system. The system is hierarchical in the sense that control functions at several levels are performed in the process of setting a parameter.

The basic control loop in the system is that concerned with the adjustment of the parameters of a piece of apparatus so that it, or its output, has the characteristics that are desired. In order to perform this primary control function, the system is equipped with actuators for manipulating the controls of standard laboratory devices; with signal sources and sensors that allow the system to measure the characteristics of a device or of the signals appearing at its terminals; with programs that perform the decision making and command functions required to control the device; and with appropriate interfaces between the digital computer and the actuators and sensors. Since many primary control loops have to be controlled by the same computer, a set of selector switches is provided to permit the computer to actuate and measure the behavior of first one and then another piece of apparatus. Finally, a signal patch board is provided to which are brought all of the terminals of the apparatus connected to the laboratory so that interconnections can be made simply by connecting different points of the patch panel. Of course, associated with the system is an inventory of standard experimental laboratory equipment such as oscillators, amplifiers, attenuators, standard signal sources, meters and recorders from which the apparatus required for an experiment is assembled. These components are connected as shown in Fig. 1.

1. System Components

a. Equipment Inventory

The apparatus connected to the laboratory system is used for three purposes: (1) to generate and to process signals for use in an experiment; (2) to perform functions required for the operation of the laboratory system, and (3) to provide a readout, that is, a record or a display of signals obtained in an experiment. Certain pieces of apparatus may at one time serve as signal devices, and at another time serve as function devices. An oscillator is a signal device when it is generating the stimulus in an experiment, and it is a function device when it is used as a reference input to an amplifier when that amplifier is being calibrated. Other devices serve only single purposes. A standard load resistor is only a function device, an attenuator is only a signal device. Equipments such as voltmeters and plotters are only readout devices and do not generate signals or perform functions in the system.

b. Signal Patch Panel

The signal patch panel provides convenient access to the signal leads required to connect apparatus for an experiment and to

SIGNAL FLOW

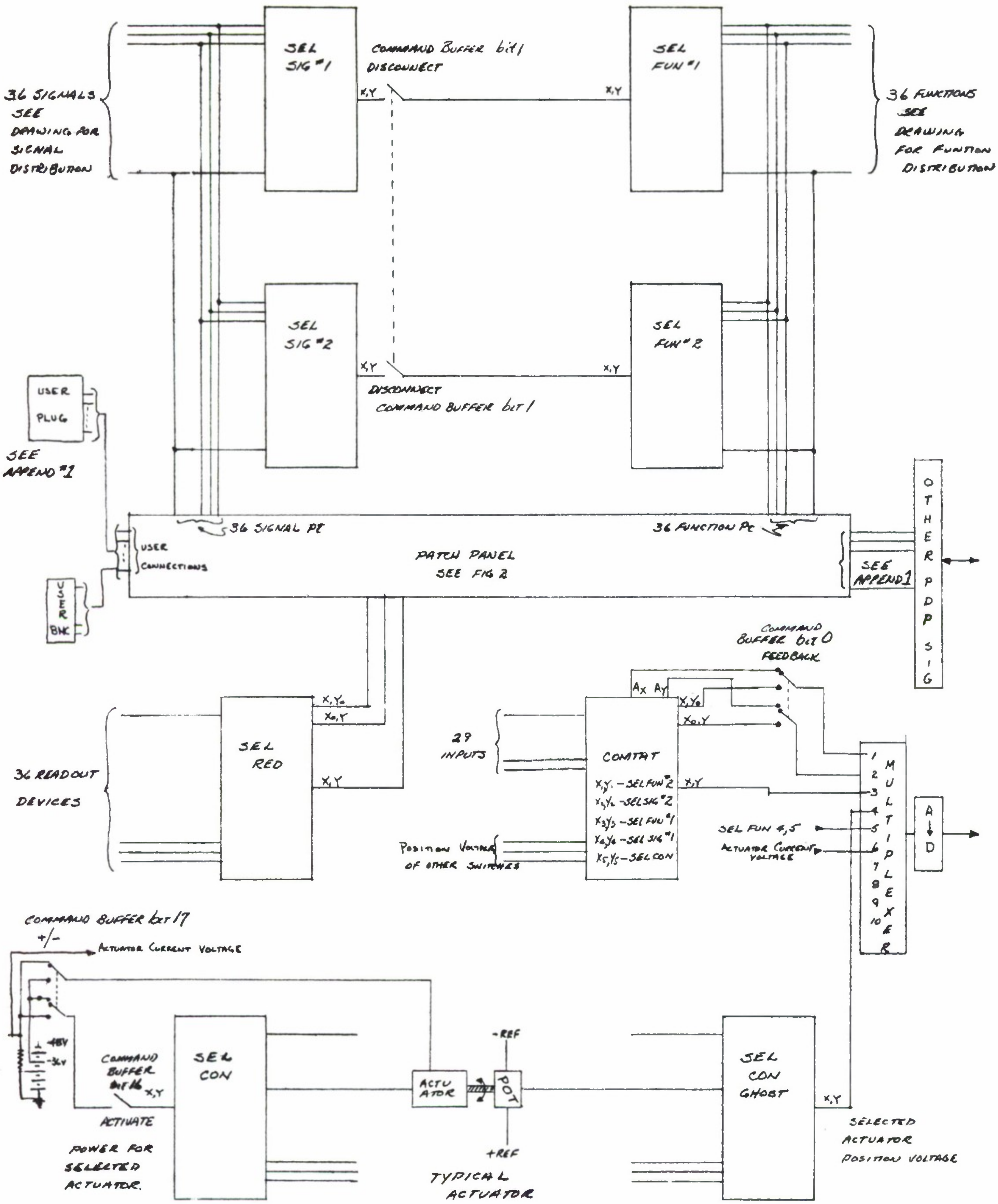


FIGURE 1

operate and monitor the operation of the laboratory systems. The terminals of signal, function, and readout devices are brought to the signal patch panel. In addition, the input-output buffer of the computer, the contacts of the computer-operated relay buffer, some of the sequence break inputs and inputs to the program flags, the contacts of the selector switches, and the terminals of the actuators are brought to the patch panel. The signals are arranged on the patch panel in functional groups, as shown in Fig. 2, so that, for example, all the terminals of the signal devices are located in one section of the patch panel, and all the terminals of the function devices are located in another. In those cases where a single device serves both as a signal and a function device, its terminals are brought to both the signal section and the function section of the patch panel.

The patch panel is used by the experimenter to interconnect the various terminals of the laboratory's equipment, as well as to monitor the performance of the system. It is removable, and in effect constitutes a removable program board containing the interconnections required for an experiment. To change from one experiment to another, one need only change patch panels. This permits rapid conversion from one apparatus configuration to another.

c. Mechanical Actuators

Most laboratory devices have controls on their front panel whose angular position determines the operating characteristics of the device. An oscillator, for example, typically has three such controls, one each for the amplitude, the frequency, and the frequency range of device. Two types of mechanical actuators which may be attached to the front panel controls are provided for computer control of apparatus. These are "digimotors," stepping motors for

PATCH PANEL
(FRONT VIEW)

TOP

	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16
1	SIG 0,5					SIG 5,5	SIG 1 "X" OUTPUT	bit 0 ARM	bit 0 NO	bit 0 NC	COMT "X"	COMT 1,5				COMT 5,5
2							SIG 1 "Y" OUTPUT				COMT "Y"					
3			S	I	G		SIG 1 "X,Y"		R		COMT "X,Y"		C	O	M	T
4			1	&	2		SIG 2 "X"		E		RED "X"	1,2				
5							SIG 2 "Y"		L		RED "Y"	COMT 0,0	COMT 2,1			COMT 5,1
6	SIG 0,0					SIG 5,0	SIG 2 "X,Y"		A		RED "XY"	1	2	3	4	5
7	FUN 0,5					FUN 5,5	FUN 1 "X"		Y		CON "X"	6	U	S	E	R
8							FUN 1 "Y"		S		CON "Y"	11	P	L	U	G
9			F	U	N		FUN 1 "X,Y"	bit 8 ARM	bit 8 NO	bit 8 NC	CON "X,Y"	16	17	18	19	20
10			1	&	2		FUN 2 "X"					CON 0,0	CON 1,0	CON 2,0		CON RETURN
11							FUN 2 "Y"					CON 4,0	CON 5,0	CON 0,1		
12	FUN 0,0					FUN 5,0	FUN 2 "X,Y" OUT					GHOST 0,0	GHOST 1,0	GHOST 2,0		(-) REF
13	RED 0,1	RED 1,0	RED 1,1	RED 0,2	RED 2,0	RED 2,2		bit 9 ARM	bit 9 NO	bit 9 NC		GHOST 4,0	GHOST 5,0	GHOST 0,1		(+) REF
14	RED 0,3	RED 3,0	RED 3,3			1 B										
15	IO BIT-0	IN BIT-9	IO BIT-0	OUT BIT 9	CHAN 3 S	2 N										
16	BIT-1	BIT-10	BIT 1	BIT 10	CHAN 4 B	3 C										
17	BIT-2	BIT-11	BIT 2	BIT 11	CHAN 5 S	4 U										
18	BIT-3	BIT-12	BIT 3	BIT 12	PF-4	5 S										
19	BIT-4	BIT-13	BIT 4	BIT 13	PF-5	6 E										
20	BIT-5	BIT-14	BIT 5	BIT 14	PF-6	7 R										
21	BIT-6	BIT-15	BIT 6	BIT 15	CLEAR PULSE	8 P		bit 17 ARM	bit 17 NO	bit 17 NC						
22	BIT-7	BIT-16	BIT 7	BIT 16	READ PULSE	9 N								GROUNDS		
23	BIT-8	BIT-17	BIT 8	BIT 17		10 L										

AMP 595039-1

FIGURE 2

making a discrete motion of detented control such as are found on attenuators and range switches and continuous servo motors for adjusting continuous controls such as the amplitude and frequency controls of oscillators. In addition, a 10:1 reduction gear is provided, which may be inserted between the actuator and the control, to operate heavily loaded controls which require high torque. The actuators are provided with feedback potentiometers which give a voltage proportional to the actuator position and therefore to the control position. This position feedback allows the computer to make a rapid approximate adjustment of the control without the necessity for measuring the characteristics of the signal obtained from the device being controlled. If very accurate setting of a device is required, final adjustment of the control is based upon measurements made on the signal.

d. Selection Switches

The selection switches enable the computer to select the equipment terminals on which the signal to be measured appears, or through which the actuators to be operated are energized. Each switch is constructed from a pair of rotary stepping switches arranged to give a 6x6 matrix (expandable to 24x24) of contacts as described in Appendix I. Each of the switches may be used either as a single-pole, 36-position switch, or as two single-pole, 6-position switches. Eight such switches, which are interchangeable, are used in the system.

Two switches, called SELFUN1 and SELFUN2, are used to select terminals of the function devices in the system. Two switches, called SELSIG1 and SELSIG2, are used to select terminals of the signal devices in the system. As shown in Fig. 1, the armature of SELSIG1 is connected to that of SELFUN1, and similarly for

SELSIG2 and SELFUN2. These two pair of switches permit one to calibrate devices having two terminals, such as an amplifier, which require that a signal obtained from some function device be connected to its input terminal and that a load resistor, which is a second function device, be connected across its output terminal. The amplifier itself is a signal device. A fifth switch called SELRED is used to select readout devices. The armatures of the stepping switches used for SELRED are brought to the patch panel and may be connected as desired.

Two switches, slaved together, called SELCON and SELCON GHOST, are used to operate the actuators. SELCON selects an actuator motor and connects it to the actuating voltage that operates it. SELCON GHOST selects the wiper arm of the feedback potentiometer of that actuator and connects it to one of the analog inputs to the computer.

The eighth switch, called COMTAT, is used as a low-speed commutator whose primary purpose is to provide a means of measuring the positions of the other seven switches. Each of the other seven switches (and COMTAT itself) provide a pair of feedback voltages which indicate the X and Y position to which the switch is set. These signals are brought to the terminals of the COMTAT switch and by moving COMTAT a pair of these signals is selected and connected to a pair of analog inputs to the computer.

e. Computer Interface

The interface between the computer and the rest of the system consists of several components. An 18-bit command buffer, loaded from the computer's I/O bus, operates solenoid drivers and controls the actuators and selector switches of the laboratory system. This buffer is the principal control output of the system. A 10-channel analog-to-digital multiplexer/converter incorporated within the computer is used for all analog inputs. A number of general purpose computer signals are connected to the signal patch panel and may be used within an experiment setup. These signals consist of: (1) the I/O bus output (18-bits), (2) the I/O bus input (18-bits), (3) the contacts of computer's relay output, (4) three inputs to program flags, and (5) three inputs to sequence break system.

2. System Configuration

A block diagram of the signal flow paths of the system is shown in Fig. 1. Apparatus is attached to the system either through the distribution taper pin panels in the rear of the cabinet or through a user plug located in the front of the cabinet. Although most of the equipment is attached by means of the distribution taper pin panels and remains a permanent component of the system, the user plug provides a convenient means of attaching specialized equipment which is easily removed at the termination of the experiment. This plug allows for twenty connections to any point located on the patch panel and thus can provide signals, functions, computer control signals, actuator drive lines, etc., to equipments unique to the given equipment.

When a piece of apparatus is connected to the system, each of its terminals is assigned to a particular position of SELSIG1 and 2, SELFUN1 and 2, SELRED, or SELCON and SELCON GHOST, depending upon its class. The armature of SELSIG1 is tied to the armature of SELFUN1 through a disconnect relay, and thus any signal terminal may be connected to any function terminal. SELSIG2 is connected in a similar manner to SELFUN2. The purpose of the disconnect relay is to break these two connections when the switches are in motion since some combination of signals and functions are not allowable (i.e., amplifier output and oscillator output).

Actuators are connected in a similar manner. The actuator motor terminals are attached to SELCON while their associated potentiometer arm is attached to the corresponding position on SELCON GHOST. The single armature of SELCON GHOST is connected to Channel 4 of the A-D multiplexer of the computer, and thus the feedback position voltage can be read by the computer. The armature of SELCON is connected to a high current power source which is controlled by the command buffer register to apply no power voltage, a positive, or negative power voltage to operate the selected actuator. A 10-ohm resistor has been inserted in the power input lead to provide a means for measuring the current drawn by the actuator. The voltage across this resistor is connected to Channel 6 of the A-D multiplexer and can, therefore, be read.

In normal operation each SELSIG and SELFUN switch is used to select a single terminal of the 6x6 array of terminals connected to it. When used in this way we designate the output of the switch as the XY output to indicate that a particular X,Y position in the 6x6 array has been selected by the switch. As was pointed out earlier, the switching matrices can also be used as two independent 6-position, single-pole switches. In this mode it is possible to select any terminal in the first column of the array of terminals and, at the same time, any terminal in the first row of the array. When used in this mode, two outputs are obtained from the switch which are designated the XY_o and the X_oY output. The XY_o output is connected to the element of the first row of the matrix that has been selected, the X_oY output to the element of the first column of the array that has been selected.

This feature is used in the operation of SELRED when more than one signal is to be recorded simultaneously, or when one signal is to be recorded as a function of another. Readout devices requiring more than one input are assigned positions on the SELRED switch in the first column and first row of the switch array. The X_oY and the XY_o inputs of SELRED are brought to the patch panel and can be connected to desired signal points by patching, and, with appropriate control by the computer, the readout device will be activated at the correct time.

The X_oY and XY_o outputs are also used for the COMTAT switching unit. Although COMTAT is used as a general purpose slow-speed commutator to bring signals to the computer's analog-to-digital converter and multiplexer, its main purpose is to provide a convenient means of measuring the position of the seven other switching units. Associated with the X and Y positions of each selector switch is a set of contacts that connect to points on a resistive ladder network driven by a reference voltage. This ladder network provides a voltage proportional to the switch position. Each switch has two position feedback signals called A_X and A_Y, which denote the X position and the Y position of the switch. These two positional feedback voltages are permanently connected to positions in the first column and first row of the COMTAT switching array. The pair of voltages can, therefore, be selected simultaneously and connected to COMTAT's XY_o and X_oY outputs. The position of COMTAT itself is measured directly by its own A_X and A_Y feedback signals. A DPDT relay, operated by the command buffer, connects either COMTAT's A_X and A_Y signals, or COMTAT's XY_o and X_oY signals directly to the multiplexer channels 1 and 2.

Two other inputs to the analog multiplexer are permanently assigned in the system. Channel 3 is connected to the XY output of COMTAT allowing it to act as a general purpose slow-speed commutator for any signal which may be patched to its terminals. Channel 5 of the multiplexer is connected to the SELFUN switches (position 4,5) so that the multiplexer can be considered and treated as just another function available to the system.

All control of the system actuators and switches is accomplished by the 18-bit command buffer mentioned above. This register is loaded by a computer instruction from the I/O bus of the computer. In Table I are shown the functions performed by each of the bits of the command buffer.

By manipulating the value of this buffer as a function of time and measuring the appropriate feedback voltages with the analog multiplexer, complete control of the laboratory system is maintained. Computer programs can be written to move any switching unit to any position and to verify that the proper connections have been made. Similarly, computer programs can be written to move any actuator in either direction to any position and to measure the actuator's position by using the voltage from the feedback potentiometer.

3. System Programs

The programs which run on the PDP-1 computer to operate the laboratory system are categorized into three groups according to their function. They form a hierarchy, each program in the higher class requires the use of some of those in the class below. The three classes of programs are: (1) experiment control, (2) equipment control and measurement, and (3) system control. Class 1 programs, experiment control, are written by the experimenter since they

TABLE I

COMMAND BUFFER

Bit	Name	If 0	If 1
0	Feedback Relay	Connect COMTAT's XY_o and X_oY to Multiplexer	Connect COMTAT's A_X and A_Y Multiplexer
1	Disconnect Relay	Connect SELSIG and SELFUN	Disconnect SELSIG and SELFUN
2 3 4 5 6 7 8 9 10 11 12 13 14 15	COMTAT X COMTAT Y SELRED X SELRED Y SELFUN2 X SELFUN2 Y SELSIG2 X SELSIG2 Y SELFUN1 X SELFUN1 Y SELSIG1 X SELSIG1 Y SELCON X SELCON Y	Bits 2 through 15 are used to supply current to the coil of the appropriate rotary switch in each of the switching units. If the bit is "0" current is not supplied. When current is drawn by the coil, the rotary switch does not step forward, but instead "cocks" so that removal of the current causes the rotary to step forward one position. For proper operation a coil should be "cocked" for 50 msecs before released and not "cocked" again for 50 msecs to allow the rotary time to step forward. NOTE: SELCON GHOST is not directly activated by the buffer register since it is electrically slaved to SELCON.	
16	Activate Relay	Do Not Excite Actuators	Excite Actuators
17	Direction Relay	Use Positive Voltage On Actuators	Use Negative Voltage On Actuators

perform a particular experiment or function of his own design. Programs of this type are not provided with the system, but an example of such a set of programs is presented and discussed in Section IIID.

Class 2 programs, equipment control and measurement, control particular pieces of equipment such as oscillators, the computer relay buffer, and decade attenuators, and they make particular measurements such as frequency, peak voltage, and D-C voltage. Whenever a new piece of equipment is incorporated in the system, this group of programs must be augmented.

Class 3 programs, system control, includes all programs necessary to manipulate the mechanisms that constitute the laboratory system. They are used to set the selector switches of the system to a particular configuration so that programs in Class 2 can command the actuators to set equipment parameters to values desired by programs in Class 1.

In addition, a typewriter control program is provided. This program allows the operator to use an on-line typewriter to command the system switches and actuators to assume any desired configuration and to measure parameters (mainly voltages) of components of the laboratory system, and of apparatus connected to the system. The typewriter control program is useful for calibrating and debugging the laboratory system itself, for calibrating and debugging new Class 2 (equipment control and measurement) programs, and for debugging Class 1 (experiment control) programs.

In the following discussion we give a functional description of these programs. A detailed discussion of them, in the form of program write-ups and flow charts is in Appendix II. The Class

3 (system control) programs are the most basic, being lowest on the hierarchy, and will be discussed first. The reader is expected to be familiar with the basic configuration of the laboratory system described in the previous section and with the signal flow diagram of Fig. 1. In quick review, the system control facilities consist of seven selector switch groups: SELSIG1 and 2, SELFUN1 and 2, SELCON (with SELCON GHOST slaved), COMTAT, and SELRED; plus the four relays, DISCONNECT, FEEDBACK (input to multiplexer 1 and 2), ACTIVATE, and DIRECTION; and an 18-bit command buffer to control these devices. Fourteen bits of the command buffer operate the switches in X and Y, and four bits operate the relays.

a. Class 3 Programs - System Control

The programs in this group operate by causing the command buffer bits to assume particular configurations in a precise temporal pattern to effect the desired movements of the switches or relays. In the case of the switches, movement to a desired position is verified by readings taken on multiplexer channels 1 and 2. Programs to properly interpret voltage readings on these channels are included in this group.

The very basic programs in this group are those to facilitate manipulation of the bits in the command buffer. All programs are written as procedures in DECAL-BBN. Several tables are also included. One of these is the command buffer table which associates the bits required by the command buffer with the names of the functions performed by those bits. This table is composed of appropriately named registers, each of which contains a word with all zeroes except for a 1 in the bit position corresponding to the bit position of the command buffer that performs the named function. Thus, the register named "selsig2x" contains a 1 in bit position 8 which is the correct position in the command buffer for advancing the X arm of SELSIG2. This table contains the transformation from function to command buffer bit position. All subsequent programs use the contents of the registers in this table to assemble bit patterns for particular commands, thereby assuring that the correct bit is always used for a desired function. In addition, the use of the bit table makes it possible to modify the command-bit-to-function assignment by simple changing the contents of one memory word should such a change be necessary at some future time.

A second table contains a list of timing constants. These timing constants include such quantities (expressed in milliseconds) as: the maximum time for a relay to actuate or release, the minimum pulse-on time for a stepping switch, the minimum time between pulses for a stepping switch, the minimum pulse-on time for a digimotor, and the minimum time between pulses for a digimotor.

A third table contains feedback voltage constants and their allowable variance for different stepping switch positions and digimotor shaft positions. These values are used to determine whether a switch or digimotor is correctly positioned. A fourth table contains the multiplexer channel assignments.

In addition to the information contained in the tables just listed, additional information necessary for controlling the laboratory system is included in the charts of Appendix III. There are seven <u>switch feedback voltage charts</u> containing the A-D multiplexer reading obtained when measuring the feedback voltage at each selector switch position in both X and Y for each switch in the system. Seven <u>switch connection charts</u> show the apparatus and actuator terminals that are connected to the 36-positions available on each switch and a number of <u>actuator position voltage</u>

charts show the voltage reading available through SELCON GHOST for all pertinent positions of the actuators presently connected to the system. Additional actuator position voltage charts would have to be prepared when new actuators are connected to the system. The information contained in these three sets of charts is used to construct part of the arguments to the system control programs when these are called to cause the system to assume a particular configuration.

The programs in Class 3 are listed below with a short explanation. A complete write-up is given in Appendix II for each program.

(1) delay -- This program causes a delay equal to the number of milliseconds of its single argument.

(2) relaydelay -- This program is like delay, but it checks the argument to insure that it is not less than the minimum relay movement time.

(3) closebuf -- This program receives a bit pattern and a delay time as arguments. The bit pattern is inclusive or'ed to the command buffer and the program relaydelay is used to delay the time stated.

(4) openbuf -- Receives the same arguments as closebuf. The negation of the bit pattern is and'ed with the command buffer and the delay handled the same as with closebuf.

(5) pulsebuf -- Receives a bit pattern only. Uses constants from the timing table to send one properly formed pulse for stepping a selector switch.

(6) cyclebuf -- Same as pulsebuf, except that a second argument is the number of pulses to be issued.

(7) huntbuf -- This program receives four arguments; a bit pattern, a desired voltage reading, an allowable voltage variance, and a multiplexer channel to be used to read the voltage. These arguments are used to pulse the command buffer successively using pulsebuf until the desired voltage is obtained.

(8) huntswitch -- This program receives two bit patterns and two desired voltages. They are used with huntbuf to step a switch to a desired X and Y position.

(9) huntcomtat -- This program receives two voltage values. They are used with huntswitch to set COMTAT to a desired X and Y position.

(10) direction -- This program from its one argument (1 or 0) sets the direction bit in the command buffer to allow subsequent calls to energize (see below) to move actuators in the plus (clockwise) or minus (counterclockwise) direction.

(11) energize -- This program causes an actuator voltage to be applied for the duration equal to the number of milliseconds in its argument.

(12) fbvolts -- This program reads the voltage value on the multiplexer channel whose number is the argument. It insures that it returns a representative value for the D-C voltage being read by filtering out spikes and noise.

(13) stoplab -- This program clears the command buffer and halts.

The thirteen programs just listed and briefly explained, along with the tables discussed previously, comprise the entire set of system control programs. With them, and the appropriate information from the charts in Appendix III, it is possible to write a program to cause the system to assume any desired configuration and to apply appropriate commands to any equipment that has actuators attached to it.

b. Class 2 Programs - Equipment Control and Measurement

The programs in this group consist of basic actuator programs, basic measurement programs, and specific equipment control programs. The programs in Class 2 are listed below with a short explanation of each. Complete write-ups are in Appendix II.

Basic Actuator Programs:

(1) digistep -- Causes a connected digimotor to step the number of steps denoted by its single argument. Steps clockwise if argument positive, and counterclockwise if argument is negative. This program uses direction and energize.

(2) positiondigi -- Causes a connected digimotor to be moved until its feedback voltage (through SELCON GHOST) is equal to the voltage contained in the argument within the variance also in the argument.

(3) position -- Causes a connected servo motor to run until its feedback voltage (through SELCON GHOST) is equal to the

voltage in the argument within the variance in the argument.

(4) setphys -- Causes a connected servo motor to run until a specified measurement program reads a specified value (i. e., frequency equals 512 cps).

(5) pkvolts -- Reads the peak voltage of the A-C signal on multiplexer channel 5.

(6) freq -- Determines the frequency of the A-C signal on multiplexer channel 5.

Specific Equipment Control Programs:

(1) attenuate -- Sequentially selects the units and tens digimotors on attenuator No. 1 with SELCON and sets each to the correct value with positiondigi to give the signal attenuation commanded.

(2) setosc -- Sequentially selects the range, frequency, and amplitude knobs of oscillator No. 1 with SELCON and sets each with position and setphys to give the frequency and amplitude (peak) requested.

These specific equipment control programs can be used to set an oscillator and an attenuator to any value that might be desired by a Class 1 program using those pieces of equipment. In particular, they were the ones used by the programs written to run the sound learning experiment described in Section IIIC of this report. As new equipment is added to the automated laboratory, new specific equipment control programs must be written, but it is likely that the basic actuator and measurement programs will be sufficient.

B. SYSTEM OPERATION

The purpose of this section is to describe the various procedures an experimenter would follow in using the laboratory system. We discuss first the equipment components of the system, concentrating on the equipment layout and the procedures for making connections to the system. Then we discuss the computer programs, their operation and the use of the typewriter control program for debugging.

1. Hardware Operation

a. Panel Layout

A front view of the laboratory system is shown in Fig. 3. The equipment is housed in three standard 19-inch relay racks bolted together and mounted on casters. The right-hand rack contains four selector switching units (SELSIG1,2 and SELFUN 1,2), a battery compartment which houses the four 12-volt storage batteries which are the primary power source of the system, and a chassis containing a trickle charger for the batteries and certain control relays. The left-hand rack contains two more of the switching units (SELCON and SELCON GHOST) and a small amount of standard laboratory apparatus; three 2-decade attenuators, and a standard audio-frequency oscillator.

The center rack contains the command buff chassis, the signal patch panel, the user plug panel, the BNC panel, and the two remaining switching units (SELRED and COMTAT). On the front panel of each selector switch is a grid that represents the matrix of contacts of the switch. Indicator lights placed on the axes of the grid light to indicate the X and Y co-ordinate of the position

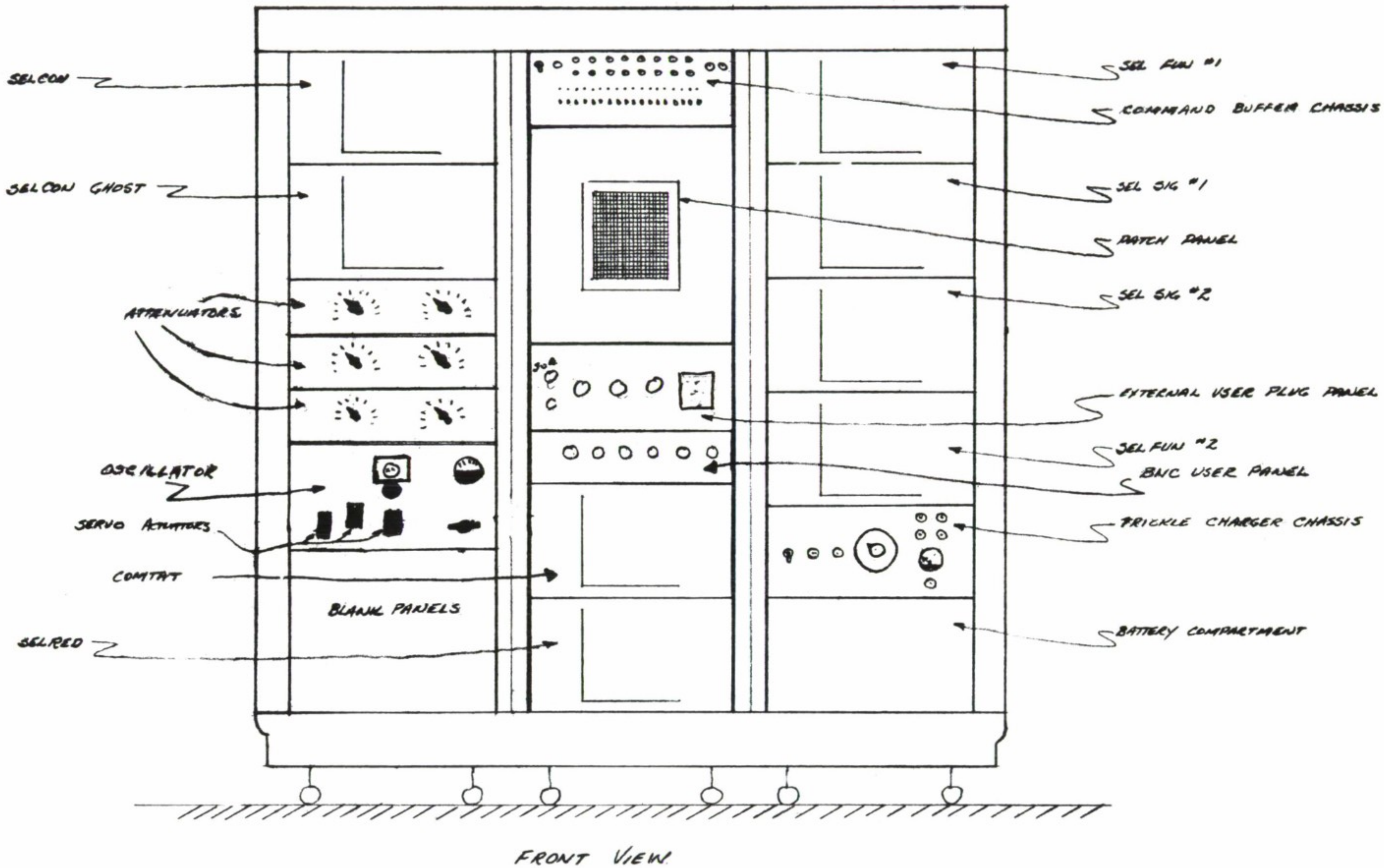

SELCON
SELCON GHOST
ATTENUATORS
OSCILLATOR
SERVO ACTUATORS
COMTAT
BLANK PANELS
SELRED
SEL FUN #1
COMMAND BUFFER CHASSIS
SEL SIG #1
PATCH PANEL
SEL SIG #2
EXTERNAL USER PLUG PANEL
SEL FUN #2
BNC USER PANEL
TRICKLE CHARGER CHASSIS
BATTERY COMPARTMENT
FRONT VIEW

FIGURE 3

to which the armature is set. The front panel of the trickle charger chassis has a toggle switch, pilot light, five fuses, a trickle rate control, and charging current meter. The trickle rate control should be set to allow approximately one ampere of charging current. The toggle switch turns the trickle charger on and should always be left in the ON position.

The apparatus in the left-hand rack has been wired to the system. Digimotor actuators have been attached to the tens and unit controls of the attenuators. These are mounted behind the front panels and have been assigned locations on SELCON and SELCON GHOST as in Fig. 10. Servo actuators have been attached to the frequency range, frequency and amplitude control knobs of the oscillator, and likewise have been assigned locations on SELCON and SELCON GHOST. A reduction gear is used with the actuator on the frequency range control.

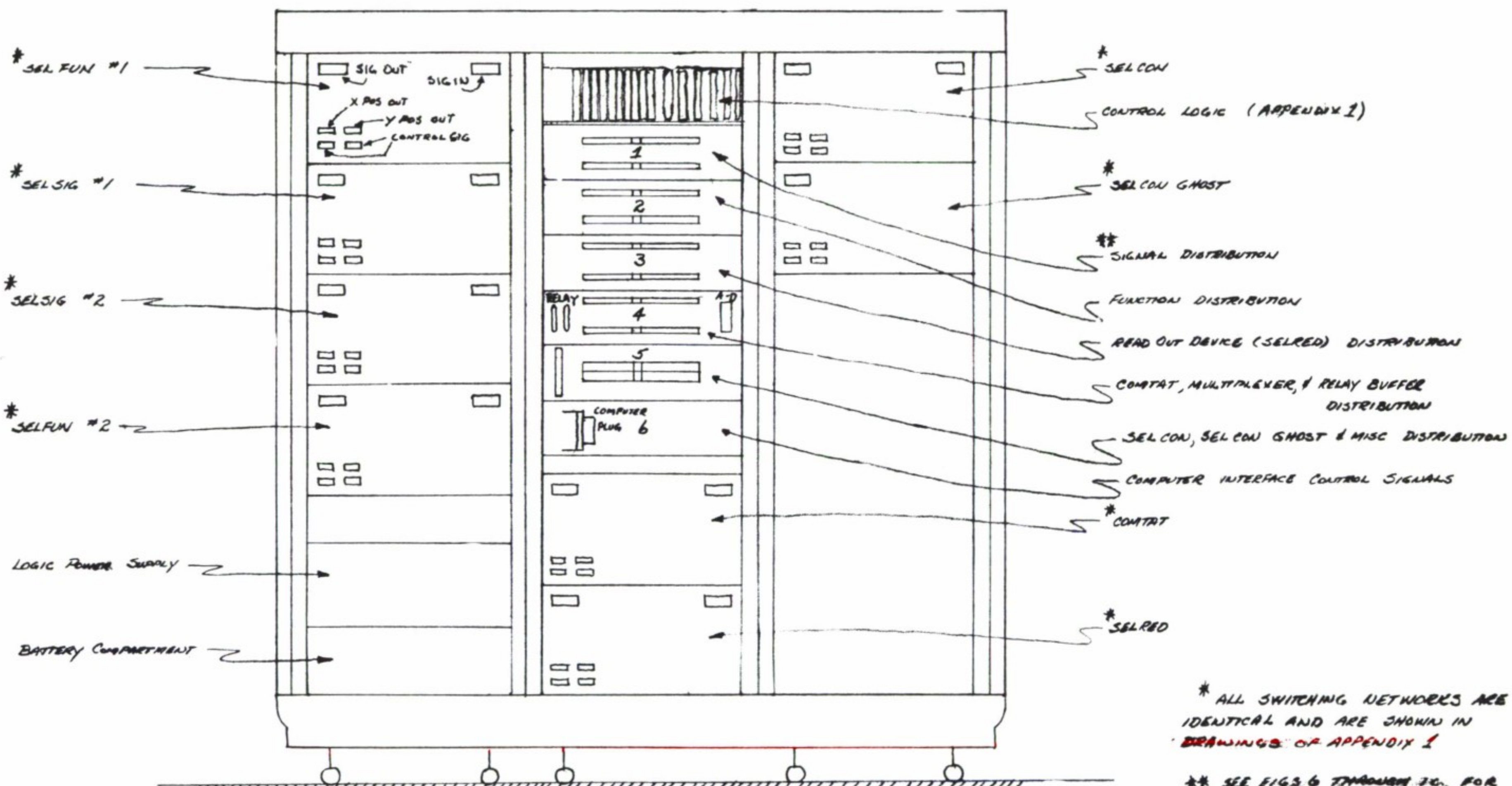
The layout of the signal patch panel is in Fig. 2. Reproducible copies of this patch panel drawing have been supplied with the equipment and should be kept up-to-date as new equipment is added or modifications are made.

All thirty-six signal contacts of the SELSIG and SELFUN have been brought to the panel. Selected contacts of COMTAT, SELCON, SELCON GHOST and SELRED have been brought to the panel. The three armature terminals of each of the switches also appear on the panel. The contacts of the 18 relays that are energized by the computer's relay buffer are on the panel as is the computer I/O bus, three sequence break channels, and three program flags. The BNC panel has 10 BNC connectors which have been assigned position on the patch panel and provides a convenient means of connecting external equipment into the system. The 50 pin users plug has 20 pins that are assigned positions on the patch panel and thus may be connected to any point in the system. The panel of the command buffer chassis provides a means for an experimenter to control the system when it is not connected to the computer. It also gives the operator a visual indication of the various control signals issued by the computer. This panel contains an 18-bit toggle switch register which serves to simulate the computer's I/O bus, 18 indicator lights to display the state of each bit of the command buffer, a push button to clear the buffer, a second push button to load the buffer from the toggle switch register, the main power ON-OFF switch and associated pilot light, and power fuses for each of the eight switching units.

A rear view of the laboratory system is shown in Fig. 4. Except for the power supply located in the left-hand rack near the bottom, which supplies the digital logic elements, the left- and right-hand racks merely expose the rear of the equipments mounted from the front. The center rack, however, contains a series of taper pin distribution panels in addition to the digital logic associated with the command buffer.

Figure 5 is a block diagram of the digital logic used in the command buffer circuit to control the operation of the system. This logic was constructed from Digital Equipment Corporation standard logic modules and standard Digital Equipment Corporation techniques were used. The logic is basically a standard 18-bit flip-flop register with solenoid and indicator driver outputs.

As is the practice for computer drawings, the heavy line rectangles in Fig. 5 indicate logic circuit boards and the numbers within the rectangle refer to the position of the circuit board within the mounting frame. Circuit board No. 14, Model 1562, reference

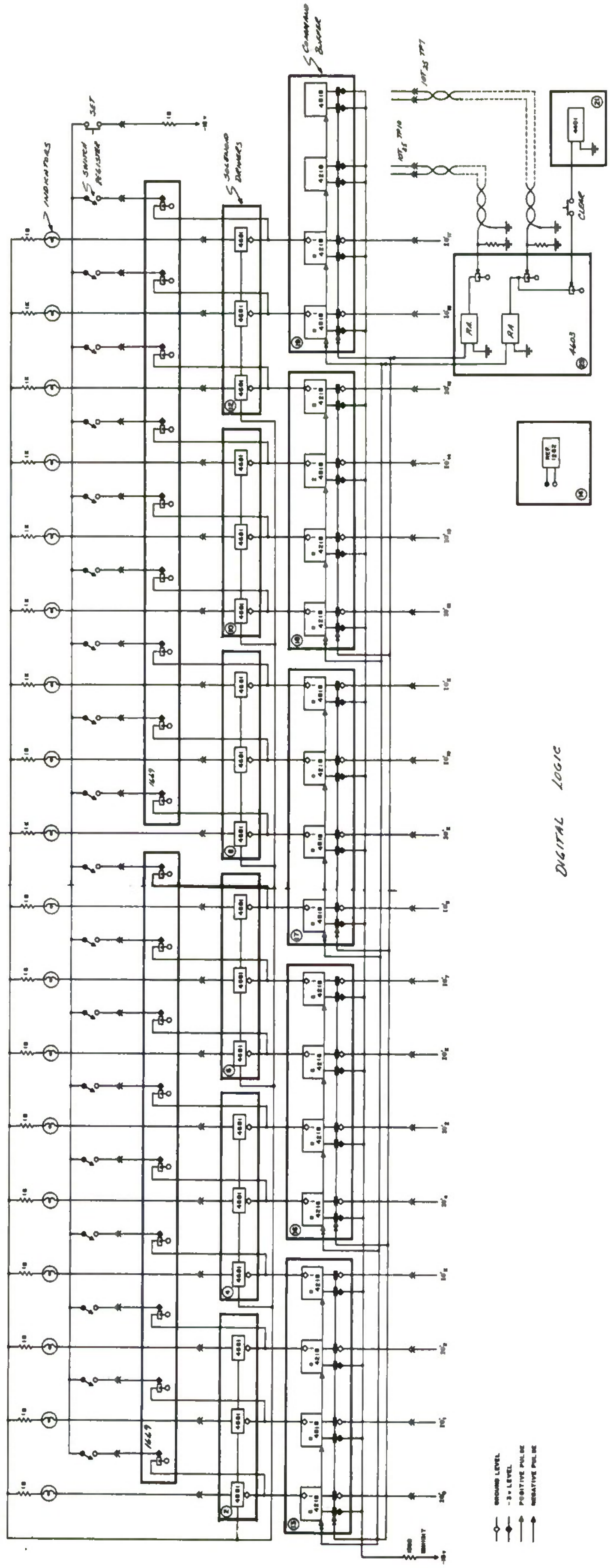


REAR VIEW (DOORS REMOVED)

* ALL SWITCHING NETWORKS ARE IDENTICAL AND ARE SHOWN IN DRAWINGS OF APPENDIX I

** SEE FIGS 6 THROUGH 12 FOR DISTRIBUTION PANEL LAYOUT

FIGURE 4



DIGITAL LOGIC

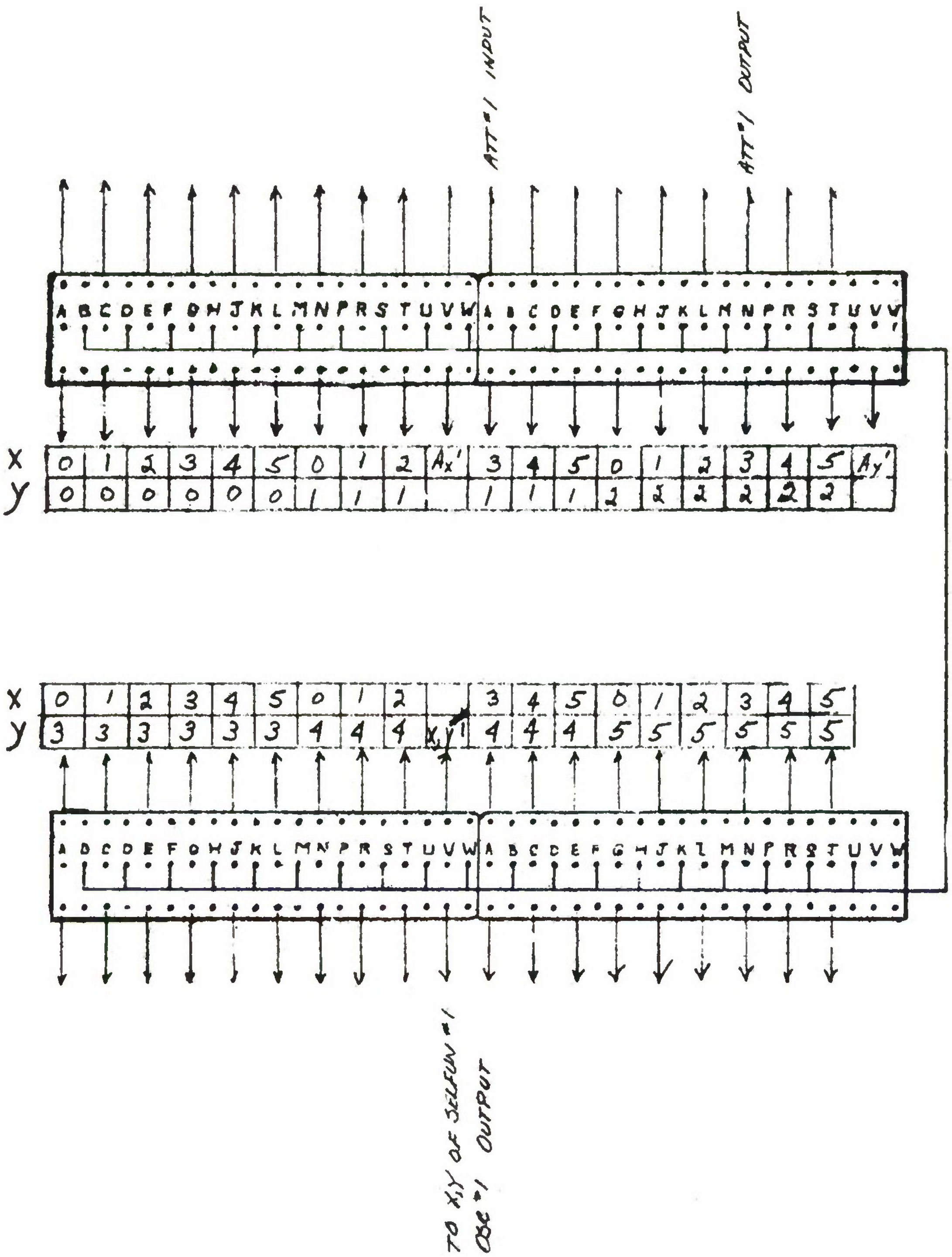
FIGURE 5

supply, is shown with no connections to its output since it is not directly connected to other logic elements. This circuit serves as a voltage reference for the entire system and drives all feedback potentiometers.

The five distribution panels in the rear of the center rack are used to connect equipment that is to remain a permanent part of the system to the selector switches and patch panel. All connections to these distribution panels are made with the same standard kind of taper pins that are used throughout the computer. These distribution panels provide connections to the selector switch terminals and to the signal patch panel. The first distribution panel is for apparatus of the signal type and connects to SELSIG1 and 2. The second panel is for apparatus of the function type and connects to SELFUN1 and 2. Panel 3 is for readout devices and connects to SELRED. Panel 4 connects to COMTAT and also provides plugs for cables to the analog multiplexer and the computer operated relays. Panel 5 provides connection between actuators and SELCON and SELCON GHOST. Panel 6 is the plug that provides the main connection to the computer.

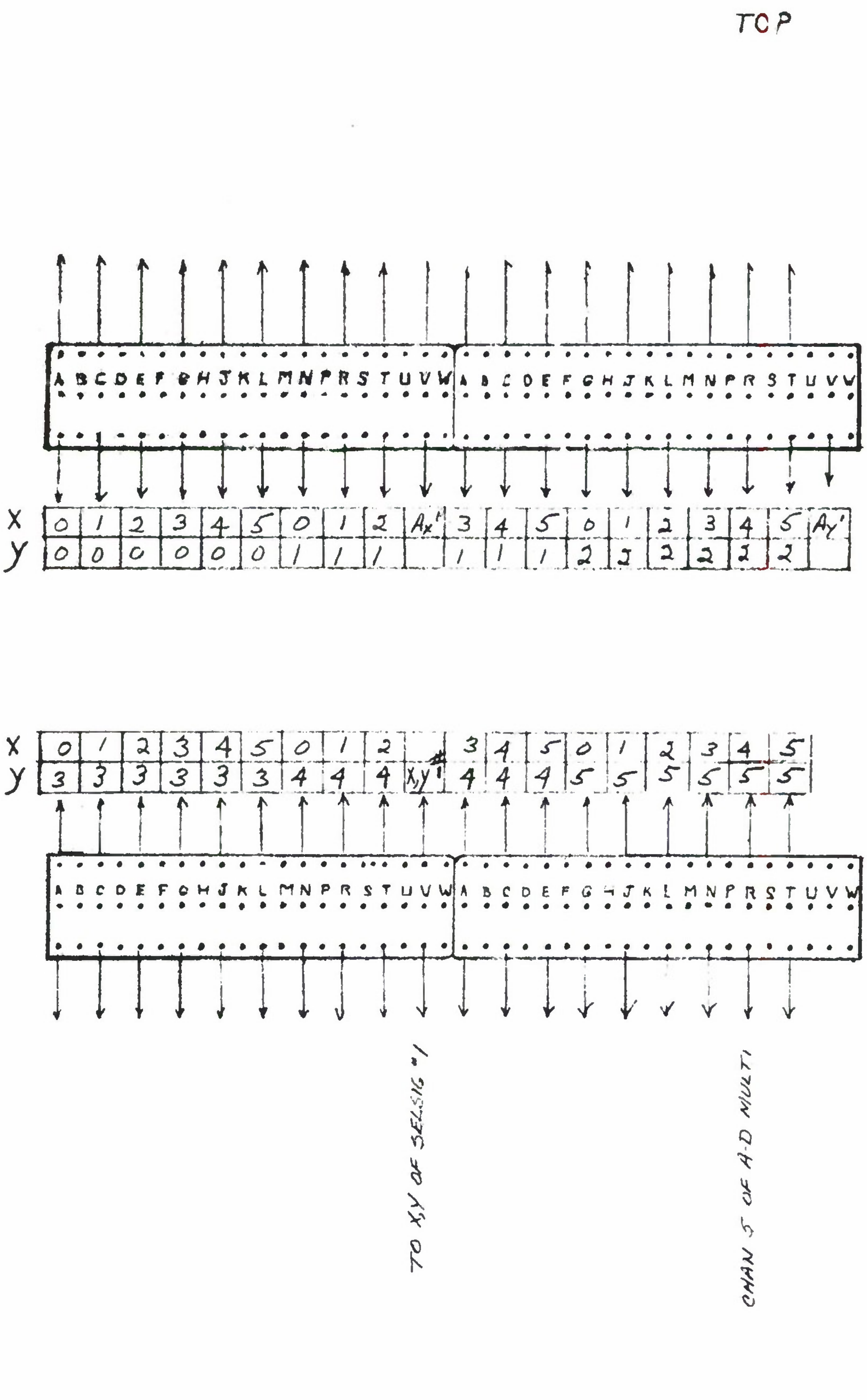
In Figs. 6, 7, and 8 are drawings of distribution panels 1, 2, and 3, respectively. All connections to external apparatus that were made at the time of delivery of the laboratory system are shown in these figures. These three panels are identical in construction. The taper pin blocks used on the signal distribution panel are the type that have their columns shorted together. Therefore, it does not matter into which row a signal and its ground is inserted. Every second column, starting with Column A is for signal inputs. The alternate columns are for the associated ground. Unused ground terminals should be tied together as indicated in the figure. Each column pair is marked to indicate the location in X

TOP



SEL SIG DISTRIBUTION PANEL

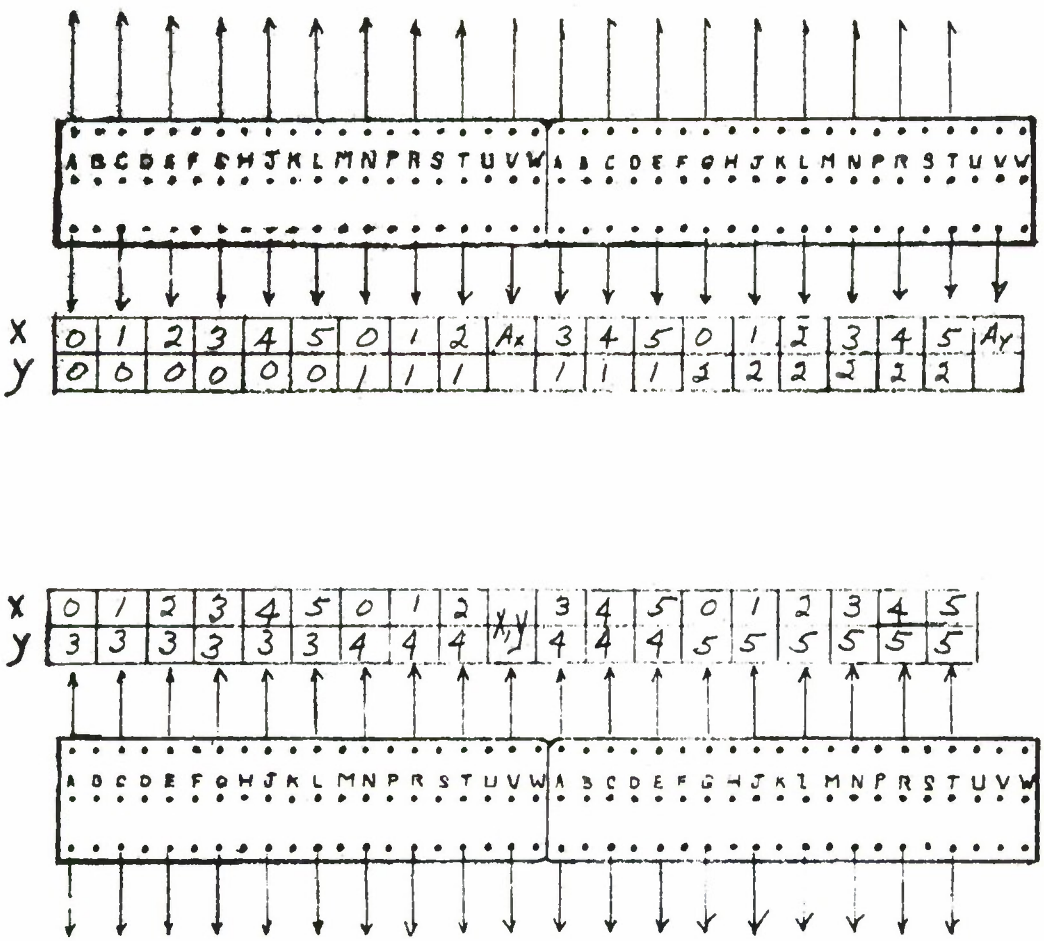
FIGURE 6



SEL FUN DISTRIBUTION PANEL

FIGURE 7

TOP



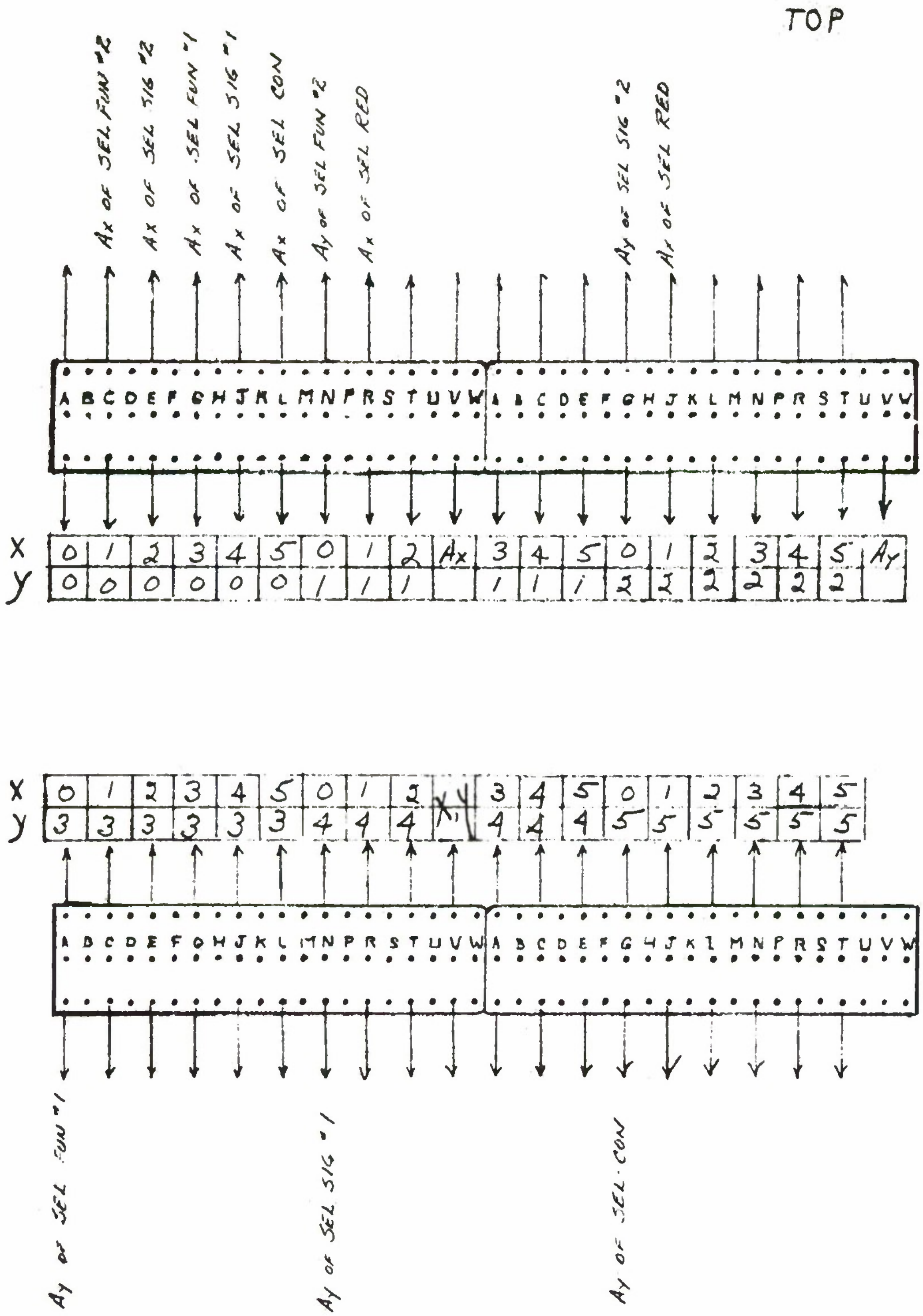
SEL RED DISTRIBUTION PANEL

FIGURE 8

and Y of the switching units to which the column refers. The three switch outputs XY, X_oY and XY_o are also brought to the distribution panels where connections to other switches or terminals are made. If a piece of apparatus serves both as a signal device and as a function device, a jumper lead connecting panels 1 and 2 should be inserted in the proper locations. All connections to apparatus and all interconnects among distribution panels existing at the time of delivery of the laboratory system are indicated in the figures. Reproducible drawings of these panels have been supplied with the equipment and as new apparatus is added to the system, the panel drawings should be updated.

Distribution panel 4 is wired to serve three functions: distribution of signals to COMTAT, connection to the analog multiplexer, and connections to the relay contacts of the computer's relay output. Fig. 9 is a drawing of this panel. With one exception, distribution of inputs to COMTAT is accomplished in the same manner as for the other panels. All inputs located along both the X and Y axis of COMTAT are internally connected to the A_X and A_Y feedback signals of the other switching units. When adding new signals to COMTAT, the input points on the axes should not be used since it would result in shorting the A_X and A_Y signals. The analog multiplexer plug and the two relay contact plugs (not shown in Fig. 9) are used to receive the cables from the multiplexer relay buffer on computer main frame.

Connection of new actuators to SELCON and SELCON GHOST is accomplished using distribution panel 5. Figure 10 is a drawing of this panel. Unlike the other distribution panels, the taper pin blocks used on this panel do not have their columns shorted, but instead have their two outer rows shorted. Row 1 is tied to the positive terminal of the reference voltage supply (card 14 in the



NOTE: RELAY AND MULTIPLEX PLUGS NOT SHOWN

CONTACT DISTRIBUTION PANEL

FIGURE 9

SELCON AND SELCON GHOST
DISTRIBUTION PANEL

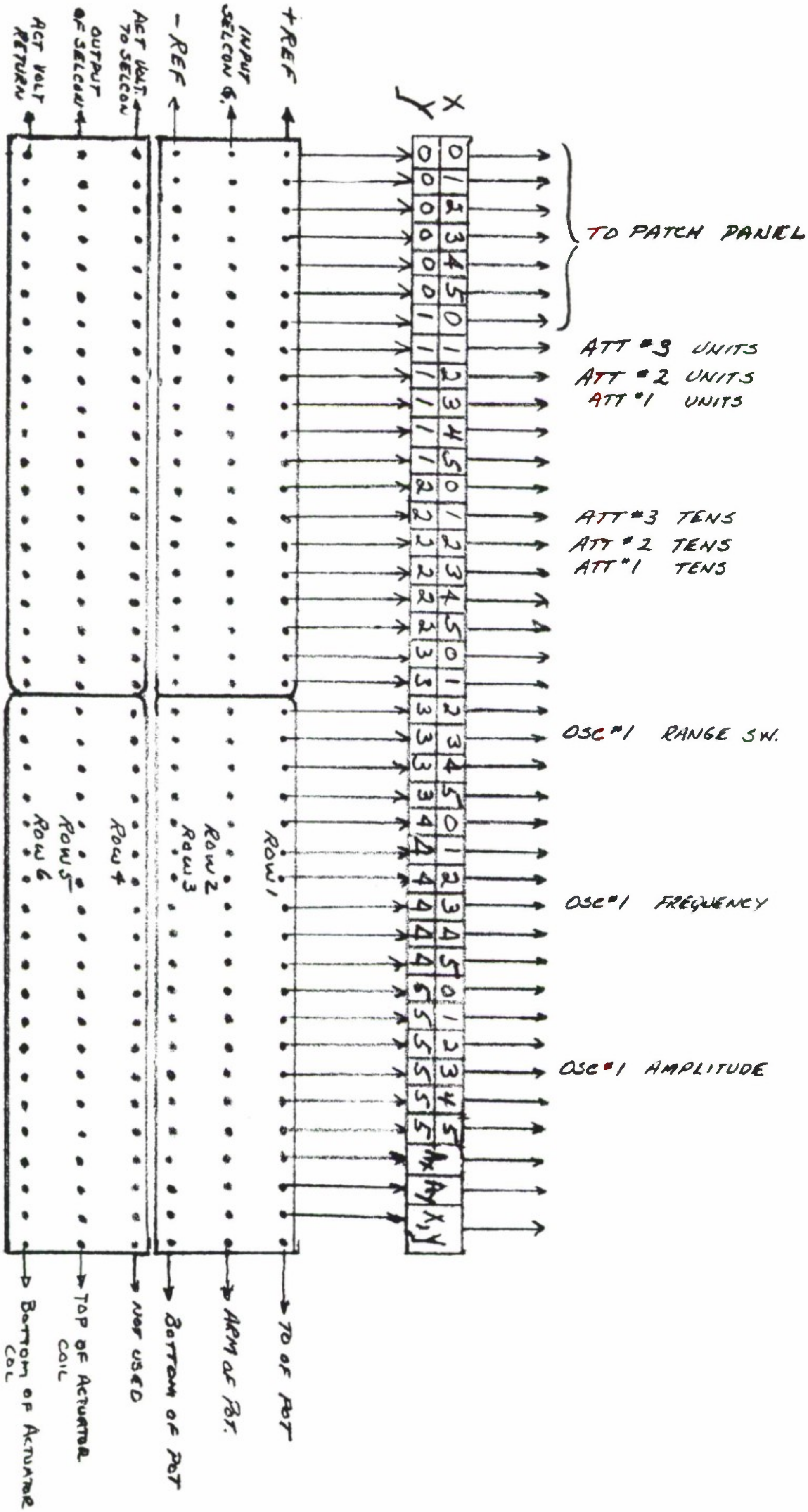


FIGURE 10

command buffer chassis), and row 3 to the negative terminal. Row 2 terminals connect to the appropriate terminals of SELCON GHOST. Similarly, row 4 connects to the actuating power voltage leading to SELCON, row 5 to the output of SELCON, and row 6 to the opposite side of the actuating power voltage. When adding a new actuator to the system, the following connections should be made: Row 1 to the top of the feedback potentiometer; row 2 to the arm of the feedback potentiometer; row 3 to the bottom of the feedback potentiometer; row 5 to the top of actuating coil winding; and row 6 to the bottom of actuating coil winding. No connection should be made to row 4.

The vertical taper pin block located to the left on the SELCON GHOST distribution panel (not shown on Fig. 10) is used to send certain signals to the patch panel. It is not used to connect new signals and need never be modified or used by an operator. A description of its wiring is given in Appendix I. On panel 6 is located the main computer interface control signal plug. This 50 pin plug contains all the signals from the computer necessary to operate the laboratory system. A cable schedule for this plug is given in Appendix I.

b. Operation of Equipment

When an operator wishes to run an experiment, he should use the following procedure:

(1) Connect the large (50-wire) cable between the cutput plug (Bay3, rowF, plug2) on the computer to the interface control signal plug in the rear of the laboratory system.

(2) Connect the loosely grouped coaxial cable between the analog

multiplexer plug in the rear of the center rack and the input BNC connectors on the analog multiplexer panel (Bay0, rowE).

Line A	Chan 1 input
Line B	Chan 2 input
Line C	Chan 3 input
Line D	Chan 4 input
Line E	Chan 5 input
Line F	Chan 6 input.

The remaining lines are spares for expansion.

(3) Turn multiplexer on to "EXT."

(4) If the relay buffer is a part of the equipment connect the relay cable between the two relay input plugs located on the Distribution panel 4 in the rear of the center rack and the two output plugs located on the computer's relay buffer panel (Bay0, rowD).

(5) Connect auxiliary equipment by means of a cable to the user plug and the BNC plugs in the front panel of the center rack.

(6) Insert the pre-patched patch panel into its guide on the front of the laboratory system and engage it.

(7) Push the power-ON switch on the manual control panel to its most upward position and hold it there momentarily. When power is first turned on, the command buffer may assume any arbitrary state which, in turn, may activate any, or all, components of the laboratory system, and the command buffer register should be cleared as power is applied. The power-ON

switch is a three-position switch, the uppermost position providing only momentary contact. In its most upward position, power is turned on and the buffer is cleared.

All necessary connections have now been made, the laboratory system is now active and the operator may return to the computer console to start his procedure for program entry.

2. Program Operation

Operation of the programs supplied with the laboratory system is similar to the operation of any PDP-1 program. A complete set of paper tapes, listings and program write-ups are included with this report and form the basis for writing programs for particular applications. The principal debugging and calibration aid supplied with the laboratory system is a typewriter control program known as LABTYC. Experiment control programs, other than the one programmed as an example and discussed in Section IIIC, are to be generated by users of the laboratory system. A running version of LABTYC is supplied and can be run by itself to check or experiment with the laboratory system equipment.

a. Running Programs

When a program is to be run, the laboratory system must first be connected to the PDP-1 computer as described in the previous section. Failure to connect the equipment carefully and completely will result in faulty operation, or no operation at all, when the program to be run is started. If difficulty is encountered when trying to run a program, the equipment connection procedure should be reviewed carefully to see that no essential steps have been omitted.

The exact procedures to follow to initiate operation of a program depend on the particular program. For example, the procedure for starting and running the sound learning experiment program is as follows:

(1) PDP-1 computer on and running.

(2) On-line typewriter on and running.

(3) Subject earphones connected to laboratory system patch board and patch board wired as shown in Fig. 11.

(4) Load the binary (EXBIN1) paper tape of "Complete Sound Learning" (C1ALL) into the PDP-1 paper tape reader.

(5) Engage the reader, set all sense switches down, and depress read-in key.

(6) The program will commence operation by stepping the laboratory system switches to the position necessary for measurement and control of oscillator No. 1. It will then present stimuli to the subject through the earphones while typing suitable comments out on the typewriter and reacting to subject responses on the typewriter.

The running version of LABTYC is started in a similar manner. The EXBIN1 paper tape of LABTYC should be read in and the laboratory system patch board should be disengaged. Control of the laboratory apparatus and equipment is then available to the experimenter through the on-line typewriter as described in the program write-up (Appendix II).

b. Debugging and Calibrating Programs

Debugging and calibrating will be easier when the DECAL linking loader tape of LABTYC is included in the new program. When it is not, it will be necessary to leave room in the memory for loading in the binary tape of LABTYC (EXBIN1) in order to debug and calibrate. LABTYC will almost always be needed during this phase and it will occupy much less room if it is integrated with the programming system being debugged and calibrated, than if it is loaded separately.

When the new programs and LABTYC are in memory, debugging and calibrating may begin. If calibration of new actuators is necessary, LABTYC should be started first and used to determine the necessary feedback voltage values and other unknown parameters required for the particular apparatus being controlled. The facilities of LABTYC make this a fairly straightforward process. The values determined should be inserted into memory in the places required by the program being debugged, and then operation of the program should be attempted. If trouble is encountered, LABTYC should be used to debug the program. A possible source of difficulty is that actuator feedback calibration values have changed indicating either mechanical slip somewhere in the actuator connection (which must be corrected before proceeding) or an error in ascertaining and storing the calibration values. If neither of these has occurred, the program logic being used to control the device may be faulty, or the capabilities of the equipment may be exceeded. Eventually, the program will commence to run, at which time a copy of memory should be made for future use, or an updated version of the program should be produced which corrects major errors.

c. Production

All the programs supplied with the laboratory system are written in the DECAL-BBN language and it is assumed that new programs will be written in the same language. The reader is referred to the DECAL-BBN Operating Manual (Ref. 1) for detailed instructions for producing programs on the PDP-1 computer using the DECAL-BBN system.

The programming material provided with the laboratory system, which will be used, or referenced, during this phase, consists of the following items:

(1) DECAL Symbolic and DECAL Linking paper tapes of the laboratory control programs (3 tapes).

(2) DECAL Symbolic and DECAL Linking paper tapes for the basic control, basic measurement, and specific equipment control programs (7 tapes).

(3) DECAL Symbolic and DECAL Linking paper tapes for the LABTYC program. (2 tapes).

(4) DECAL Symbolic listings and DECAL maps for all programs supplied.

C. AN EXAMPLE OF THE USE OF THE LABORATORY SYSTEM

The psychoacoustics laboratory system extends the capabilities of the PDP-1 computer by allowing it to control and monitor many external devices. The range of uses to which it might be put is large. To illustrate one use of the equipment and to obtain information on the reliability of the laboratory system itself, a particular experiment was programmed and run. In this section we describe the experiment, the programming that was necessary to perform it with the aid of the PDP-1 and psychoacoustic laboratory, and the equipment reliability experienced.

In a previous research effort at BBN, undertaken by Swets et al, (Ref. 2) an investigation was conducted to determine the effects of training methods on the ability of observers to learn to identify complex sounds. Because it was necessary to try many different training methods, it was decided to use the PDP-1 computer to run the experiment. A considerable effort went into the production of several programs to generate the stimuli used in the experiment. The fact that these programs could be replaced by some very simple programs and the psychoacoustic laboratory system led to the decision to reprogram one phase of this experimental work as a test of that system.

1. The Experiment

The stimuli to be presented to the subjects for identification were sounds which were varied in five ways: frequency, amplitude, duty cycle, repetition rate, and length. Frequency, amplitude and length are self-explanatory. Each stimulus consisted of a series of tones. The rate of repetition of these tones was varied to give the parameter "repetition rate." The percentage of time that the tone was on while it was being presented was the "duty cycle." Thus, a particular stimulus might be a 400 cps tone at 82 db turned on during 100 milliseconds of each 200 millisecond period for 1 second.

Each of the five parameters of the stimulus could independently assume one of five values. Thus, the entire ensemble of stimuli consisted of 3125 (5^5) items.

The subjects were trained to identify each stimulus by assigning to it a five-digit number (each digit from 1 to 5) corresponding to their estimate of the value of each of the five parameters of the signal. One training method was to present sequentially and identify for the subject random samples from the set of possible stimuli. The only response required of the subject was a signal to indicate when he was ready to receive each new stimulus. This particular "training" method was programmed using the laboratory system.

2. Programming

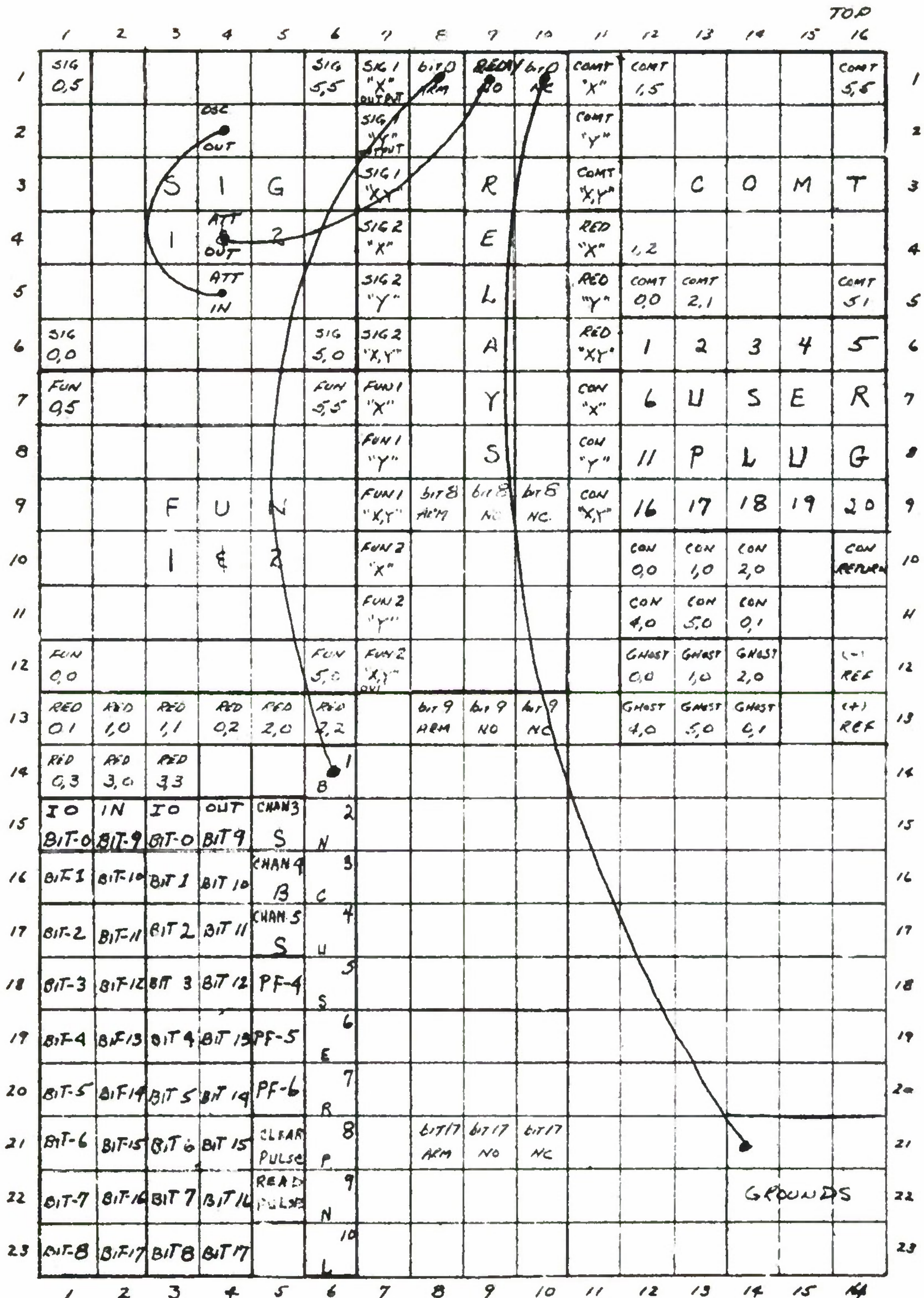
The entire programming effort to run this experiment with the laboratory system took approximately two days with about two more days spent in check out and debugging. The programs consist of: (1) programs to generate a table of stimuli; (2) programs to generate and present the sounds; (3) programs to conduct the experiment and (4) programs to initialize the laboratory system.

The patch board was used so that one of the computer operated relays could be used to turn the sound source ON and OFF. The patch board connections in Fig. 11 cause the arrangement shown schematically in Fig. 12 to exist. The initializing program set SELSIG1 to position 3,4 so that the output of oscillator No. 1 could be measured. It also positioned SELFUN1 to position 4,5 so that the multiplexer channel No. 5 was connected for the measurement and set COMTAT in position for monitoring the position of SELCON.

The generation of the sound consisted of a call to the "Setosc" program to set the oscillator to a specified frequency followed by a call to the "attenuate" program to give the desired attenuation. During this operation the relay used to connect the subjects' earphones to the signal is in the OFF position so the subject hears nothing. Presentation of the stimulus is accomplished by opening and closing the relay in the proper sequence to construct the desired signal.

PATCH PANEL
(FRONT VIEW)

LAYOUT FOR SOUND LEARNING



AMP 595039-1

FIGURE 11

SCHEMATIC FOR
SOUND LEARNING

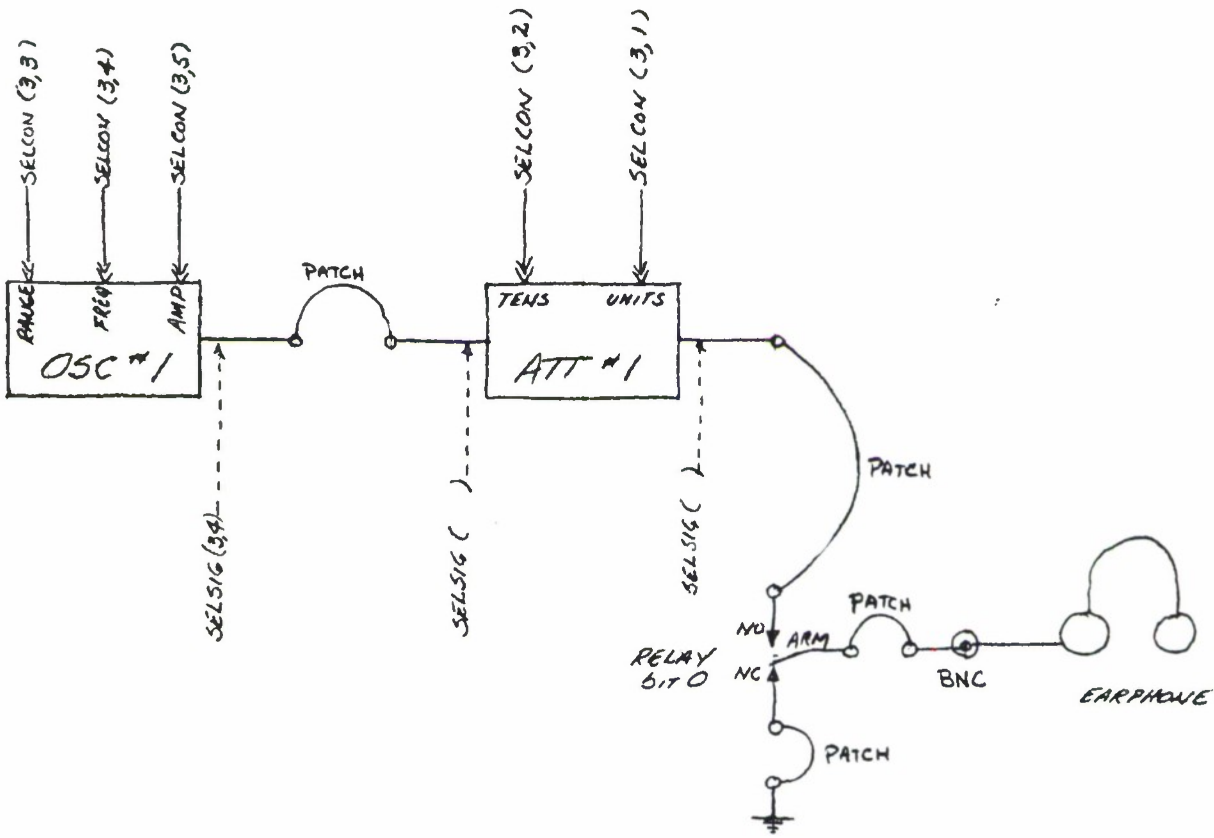


FIGURE 12

The experiment was conducted by running a program which selected sequentially the items from the stimulus table, generated the required signal, typed out a key to the subjects, waited for a response to go ahead, presented the signal and then repeated the procedure until all table entries were exhausted.

3. Operating Experience

This experiment was first run utilizing the laboratory system in June, 1964. The authors were used as subjects and the program was run sufficiently to verify that all the equipment was working. The stimuli generated were satisfactory and the equipment performed as expected. With the exception of one factor mentioned below, the experiment ran exactly as had Swets' earlier version, and had taken considerably less time to program. The one factor that was different was the amount of time between stimuli. In the original version of the experiment a stimulus could be generated and presentation begun almost instantaneously. Our version required from 5 to 15 secs to generate each new stimulus. This is the time necessary to set the oscillator and attenuator. This difference is probably not significant in this experiment since the subject requires some time to digest one stimulus before asking for the next one. While he is thinking, the next stimulus is being prepared.

After several months in which work on the laboratory system equipment was finished and delivery and installation of the equipment at DSL was made, the program was run again -- this time on the DSL PDP-1. It operated as before, indicating that the feedback voltages from the laboratory system devices and the mechanical and electronic parts of the laboratory had a high degree of stability.

IV. CONCLUSIONS

The facilities for automatic control of experimental procedures described in this report provide very flexible tools for conducting experiments in psychology. The multi-subject stations make it possible to present visual stimuli of considerable complexity and to elicit responses from up to four subjects simultaneously. The psychoacoustic system provides the facilities required to couple the PDP-1 computer to standard laboratory audio apparatus for control and calibration purposes. The usefulness of these facilities depends, of course, upon the computer programs that are written to operate them. Basic programs for the psychoacoustics system have been written. Programs for the multi-subject stations are being written under another contract. These should provide the experimenter with relatively simple access to these facilities.

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4. "Type 340 Precision Incremental CRT Display," Technical Manual H-340, Digital Equipment Corporation, Maynard, Mass., February, 1965.

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APPENDIX I
EQUIPMENT CONSTRUCTION AND MAINTENANCE

In this appendix it is assumed that the reader is familiar with the system's organization, its operation and the terms to describe it. The purpose of this appendix is to give a detailed description of the switching units, trickle charger chassis, wiring, actuators, and maintenance procedures.

A. SELECTION SWITCHES

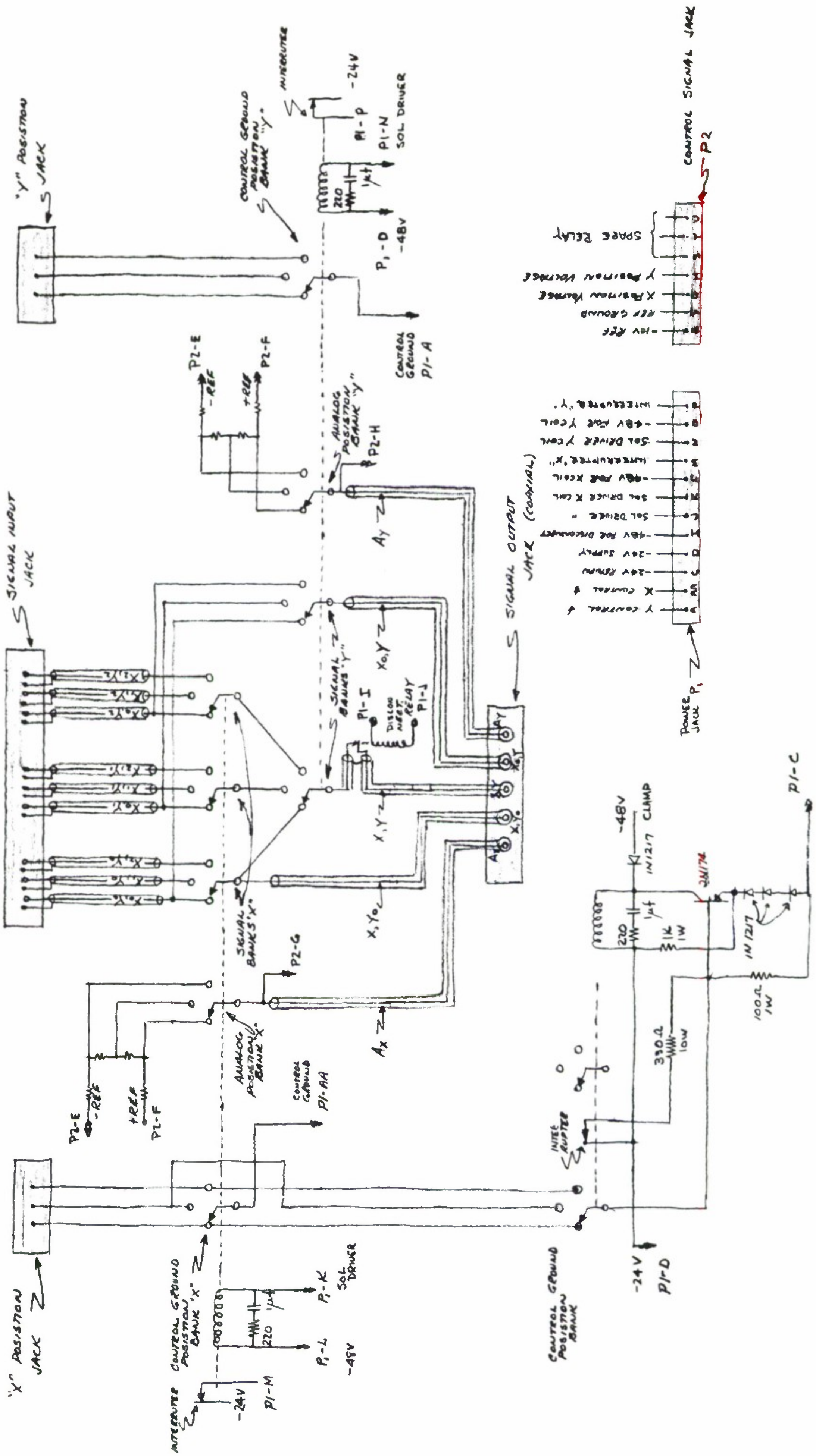
All switching units are similar and can be interchanged. Each contains an X and Y rotary stepping switch of 25-positions. The X rotary stepping switch logically has 24 separate signal banks. All input signals are connected to these signal banks which are designated banks Y0 through bank Y23. The armature of each signal bank on the X rotary bank is connected to a single bank (designated the signal bank) on the Y rotary switch such that the armature of bank Y0 is connected to the first position on the Y rotary switch and armature Y23 to the 24th position. The armature of this bank of the Y rotary switch, therefore, can be connected to any armature of the X rotary switch, which, in turn, can be connected to any input signal on its associated bank. Thus 24x24 possible connection points are provided. This armature of the signal bank of the Y switch is the XY output of the switch. It connects to the disconnect relay and then goes to the signal output plug of the switching unit.

Figure 13 is a simplified drawing of a switching unit. It has been simplified only in that it shows the wiring as if the X and Y rotary switch had only three, as opposed to 25-positions, and it shows one of the amplifiers used for slaving switches. In all other respects, the drawing is analogous to the actual switching units. The five output plugs shown are those actually used and can serve as a wiring schedule.

A second bank on the Y rotary has been employed to obtain the X_oY output which can be connected to the first position of each signal bank on the X rotary switch. The armature of this second bank, X_oY, is brought out to the signal output plug. In addition, the armature of the Y_o bank of the X rotary switch has been connected to the signal output plug to provide the XY_o output.

An additional bank on each rotary has been wired with 1k resistors between each position, and another 1k resistor at each end to form a resistor ladder which is connected to the system's reference voltage source. The armatures of these two banks provide a voltage which is proportional to the armature position. These A_X and A_Y lines are also brought to the signal output plug.

The contacts of the one remaining bank (the control position bank) on each rotary switch has been wired directly to the X position plug and Y position plug, respectively. The armatures of these banks are connected to power ground through the power plug. By connecting the armature of the control position bank of a second switch to a power amplifier, it is possible to make the second switch follow the first. This technique of "slaving" switches is used for slaving SELCON GHOST to SELCON and is used within a switching unit. Internal slaving is required because the X rotary switch is constructed from three separate stepping switches to



SELECTION SWITCH

FIGURE 13

provide the 26 banks required. The first, or master switch, has eight banks. Two eleven bank switches are slaved to the master in the following manner.

A control position bank on each of the slaves is tied in parallel with X position plug described above. The armature of each of these banks is connected to the base input of a transistor amplifier whose output drives the solenoid coil of the slaved stepping switch. The base of this transistor amplifier is connected to the main 24-volt power supply through the slave switch's interrupt contact and is driven to conduction when the circuit is completed. The amplifier's output activates the drive solenoid and cocks the stepper. After the stepper has been cocked, the interrupt contact opens, removing the input drive to the amplifier and thus allowing the stepper to step one position forward. After moving forward one position, the interrupt contact closes again supplying drive for the amplifier which "cocks" the stepper for another step, and so forth.

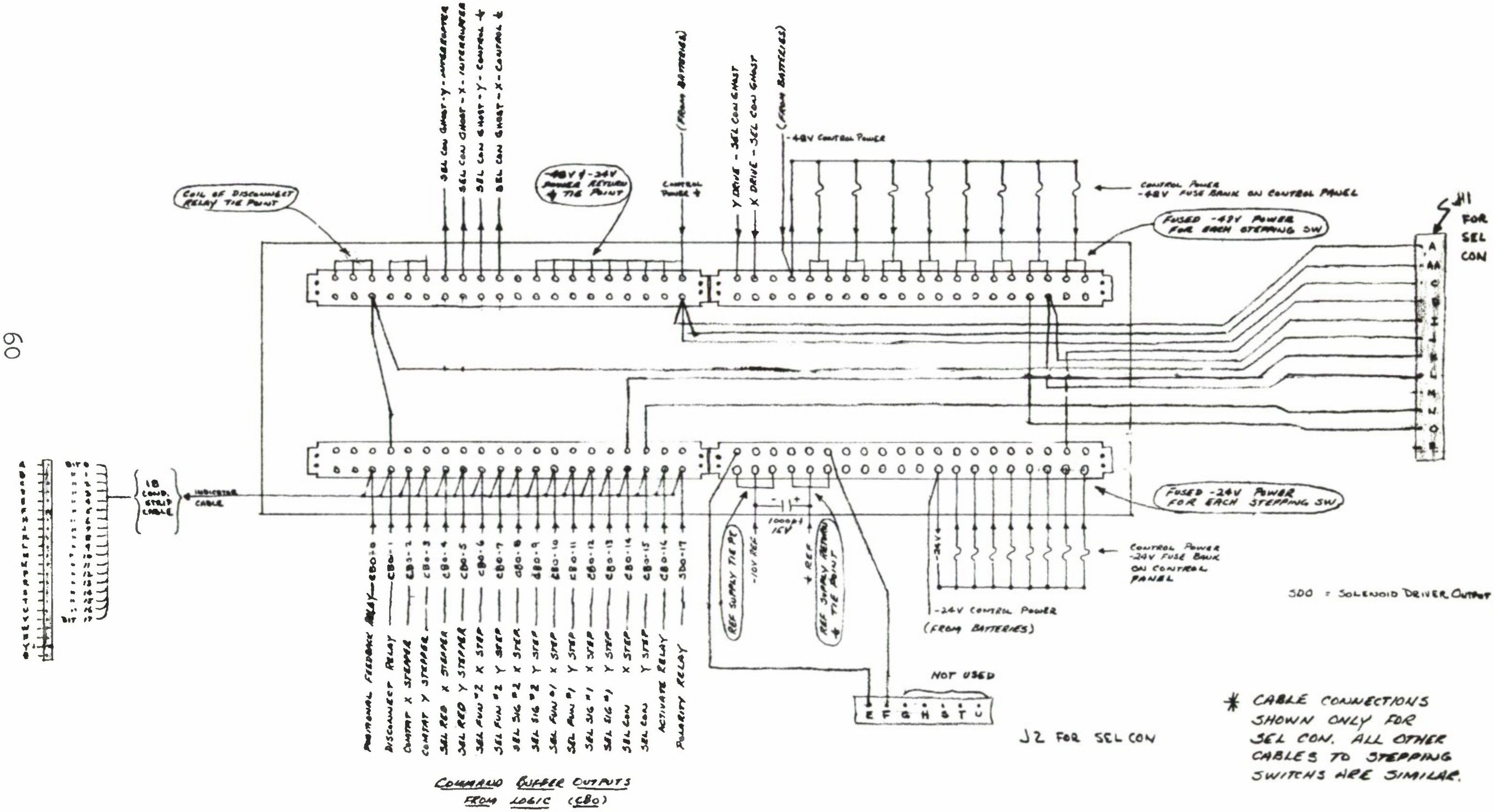
The slave stepping switch will continue stepping around until the base input to the transistor amplifier is shorted to power ground by the armature of slave's control position bank when it reaches the position which corresponds to the position of the "master" stepper. In this position, the drive current for the amplifier is shorted, and the slave rotary switch will stop. When the "master" stepper is advanced and its control ground moves to the next position, the short to ground is removed from the slave amplifier and the slave will advance, find the control ground, and then stop. In this way the slave switch steppers follow the master. The X slaving amplifiers are located within the switching unit housing and are shown in Fig. 13.

Each switching unit is identical. The function a given unit fulfills in the laboratory system is determined only by the set of cables that connects to the unit in the rear. Located in the center rack directly below the cooling fan is the Control Signal Distribution Panel. All control cables to the various switching units originate from this panel. Figure 14 is a pictorial drawing of this panel.

For clarity, only one pair of cables, those for SELCON, are shown in Fig. 14, but each cable pair to the remaining switching units are essentially the same. They vary only in which solenoid drive output and which fused power line is used. The single exception being the cables to SELCON GHOST. Since the SELCON GHOST switching unit should at all times follow the SELCON switching unit, it has been permanently slaved to it in a manner similar to that used to slave the two X rotary switches within a switching unit. The control cable to SELCON GHOST, therefore, is slightly different from the other cables. Instead of receiving its drive signals from solenoid drivers, it receives them from two slaving amplifiers located on the trickle charger chassis. The appropriate terminal points for the SELCON GHOST cable on the Control Signal Distribution Panel are marked in Fig. 14.

For reference purposes, a partial list of parts of the components used in the construction of the switching units is in Table AI.

*CONTROL SIGNALS DISTRIBUTION PANEL



* CABLE CONNECTIONS SHOWN ONLY FOR SEL CON. ALL OTHER CABLES TO STEPPING SWITCHS ARE SIMILAR.

FIGURE 14

TABLE AI

PARTIAL PARTS LIST FOR SWITCHES

Component	Function	Description
Connector	Signal Input Plug	AMP201310-1 (75-pin)
Connector	Signal Input Plug Mate	AMP2013-11-1 (75-pin)
Connector	Power Plug (P_1)	AMP201298-1 (14-pin)
Connector	Control Signal Plug (P_2)	AMP201298-1 (14-pin)
Connector	X Position Plug	AMP200512-2 (26-pin)
Connector	Y Position Plug	AMP200512-2 (26-pin)
Connector	Signal Output Plug	AMP20114-41 (20-pin, co-axicon)
Cable	Wiring	Amphenol RG-174/V
Rotary Switch	Y Rotary	GEC UN1400, 6 banks, 25-positions, 4 shorting 2 non-shorting, 48-volt coil
Rotary Switch	X Master Rotary	GEC, 8 banks, 25-position 4 shorting, 48-volt coil 2 non-shorting
Rotary Switch	Y Slave Rotary	GEC UN1400, 11 banks, 25-positions, 1 shorting, 10 non-shorting, 24-volt coil
Relay	Disconnect Relay	Clare, HQS1009
Transistor	Slave Amplifier	RCA 2N174
Diode	Slave Amplifier	GE 1N217
Mount	Shock Mount	Barry 275-4

B. TRICKLE CHARGER CHASSIS

Figure 15 is a schematic diagram of the various components located on the trickle charger chassis, and has been broken down into six separate sub-groupings. Figure 16 is a pictorial layout of the components on this chassis.

K1, the direction relay, in conjunction with K2, the activate relay, are used to supply voltage to the input XY of the SELCON switching unit which, in turn, activates the actuators. Command buffer bits 17 and 16, respectively, drive these relays. Terminal connections on the terminal boards used in this chassis are as shown.

K3, the feedback relay, is driven from command buffer bit 0 and places either COMTAT's A_X and A_Y position voltages, or COMTAT's XY_o and X_oY output lines (A_X and A_Y of selected switching unit) to channels 1 and 2 of the analog multiplexer plug. All connections to this DPDT relay are from the terminal board position TB2 as shown.

The power control and trickle charger position of this chassis are standard in design as are the two slaving transistor amplifiers for SELCON GHOST. The inputs and outputs of these amplifiers are cabled to the Control Signal Distribution Panel and are shown in Fig. 14.

For reference purposes, a partial list of parts of the components used in the construction of the Trickle Charger Chassis is in Table AII.

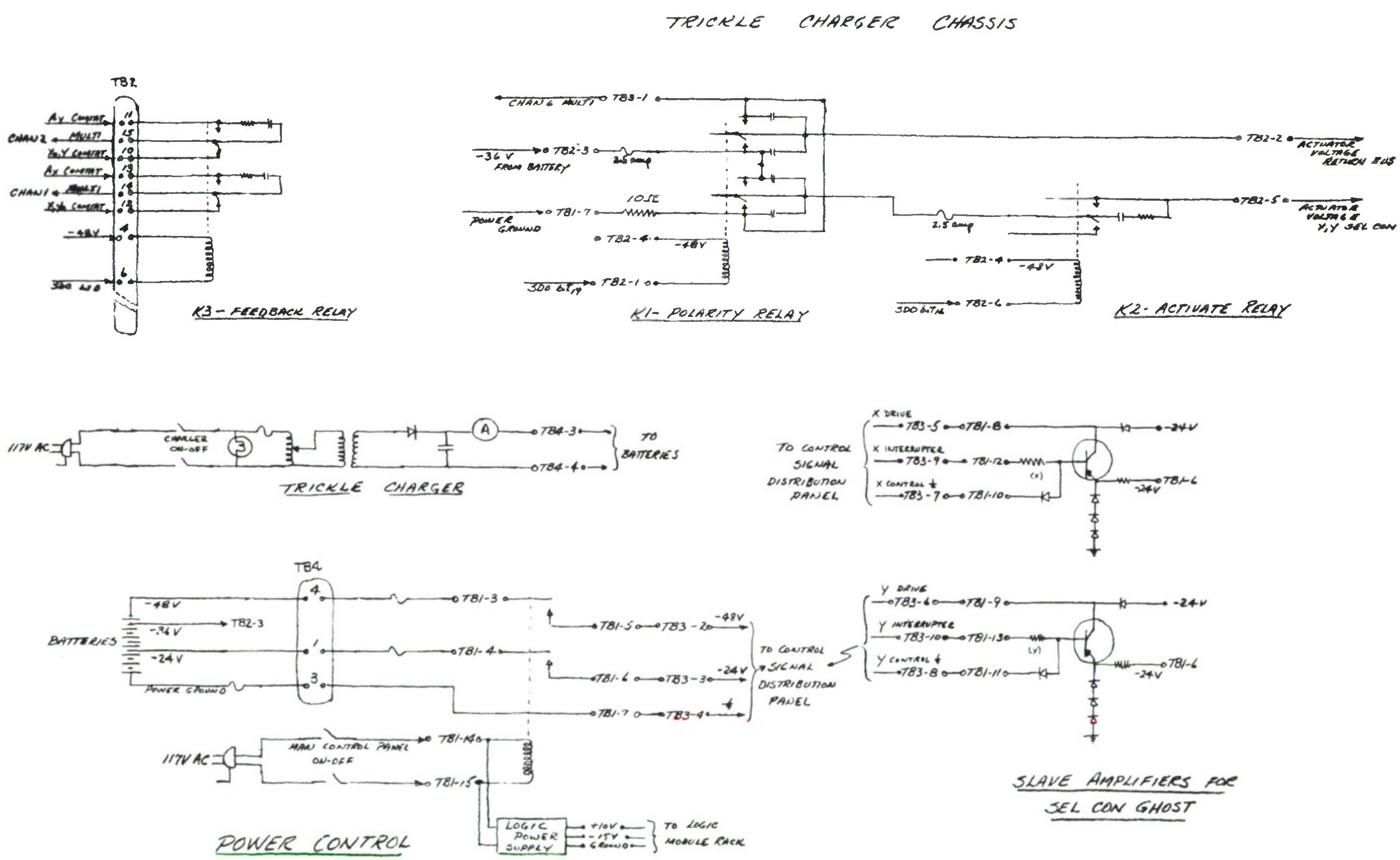
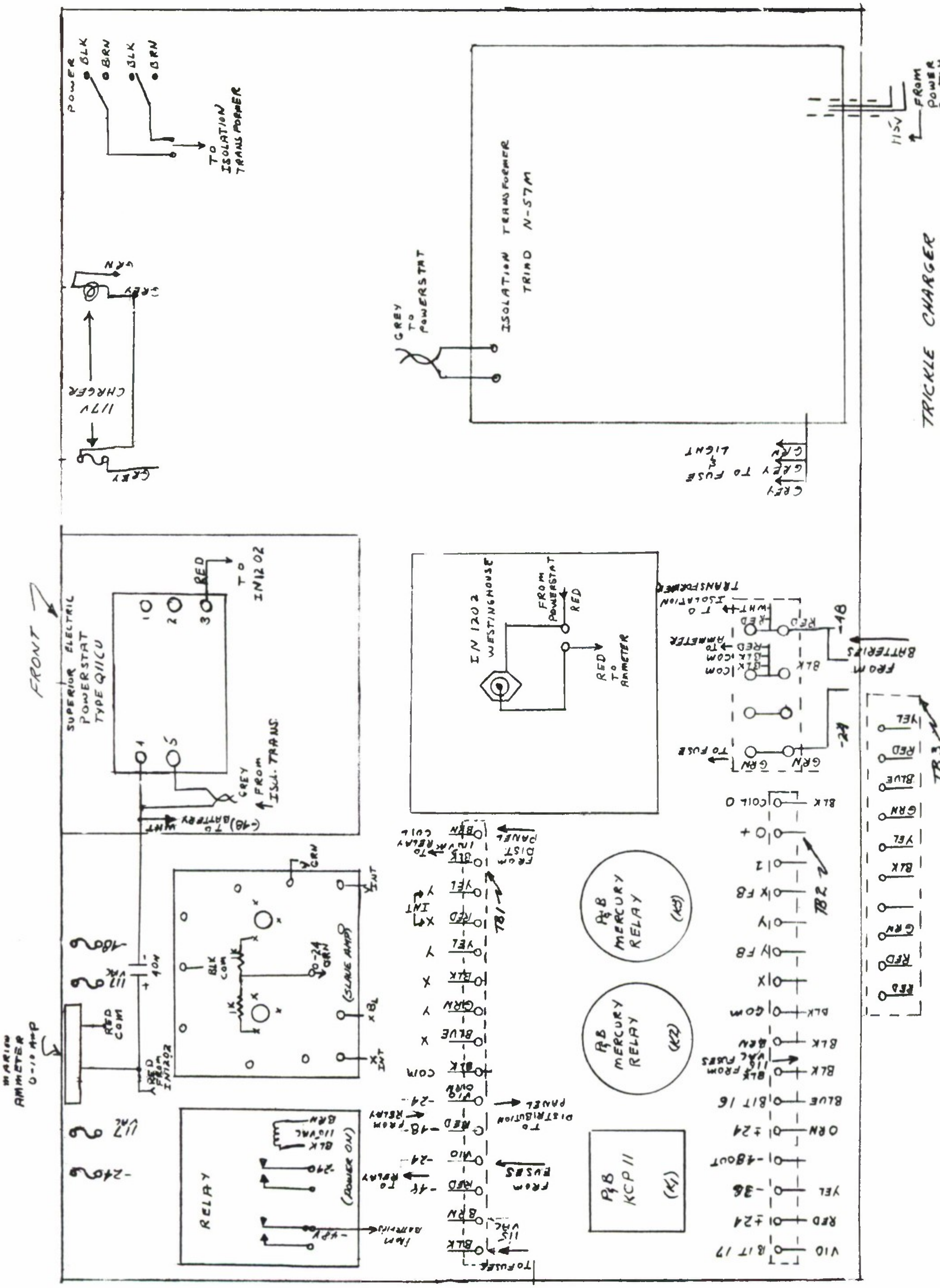

TRICKLE CHARGER CHASSIS
TB2
K3 - FEEDBACK RELAY
K1- POLARITY RELAY
K2- ACTIVATE RELAY
CHAN 6 MULTI
TB3-1
-36 V FROM BATTERY
TB2-3
POWER GROUND
TB1-7
TB2-4
-48V
TB2-1
TB2-2
ACTUATOR VOLTAGE RETURN BUS
TB2-5
ACTUATOR VOLTAGE X,Y SEL CON
TB2-6
117V AC
CHARGER ON-OFF
TB4-3
TB4-4
TO BATTERIES
TRICKLE CHARGER
X DRIVE
X INTERRUPTER
X CONTROL
TO CONTROL SIGNAL DISTRIBUTION PANEL
Y DRIVE
Y INTERRUPTER
Y CONTROL
-24V
TB4
BATTERIES
POWER GROUND
MAIN CONTROL PANEL ON-OFF
LOGIC POWER SUPPLY
+10V
-15V
GROUND
TO LOGIC MODULE RACK
POWER CONTROL
SLAVE AMPLIFIERS FOR SEL CON GHOST

FIGURE 15



TRICKLE CHARGER CHASSIS LAYOUT

FIGURE 16

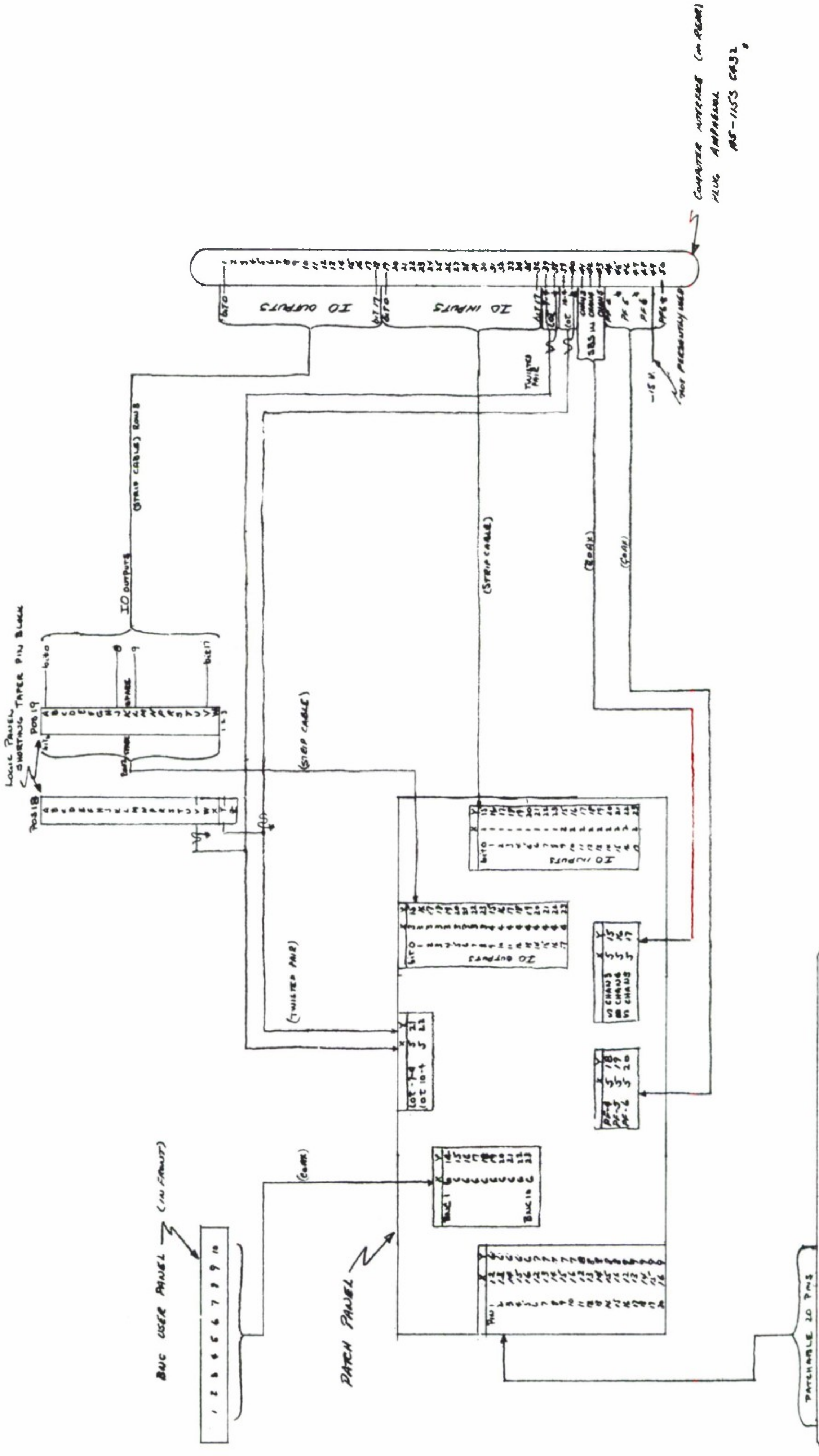
TABLE AII

PARTIAL LIST OF PARTS OF COMPONENTS USED IN CONSTRUCTION OF TRICKLE CHARGER CHASSIS

Component	Function	Description
Transformer	Isolation	Triad N-57M
Variac	Charge Current Control	Superior Electric Type Q116U
Ammeter	Charge Monitor	Marion 0-10A up
Relay	Power Turn On	Guardian 2200U-DPDT 115V
Relay	Feedback Relay	PandB Mercury
Relay	Actuate Relay	PandB Mercury
Relay	Polarity Relay	PandB KCP-11
Diode	Rectifier	Westinghouse 1N1202
Capacitor	Filter	Sprague TVA
Power Supply	Logic Power Supply	DEC 728
Transistor	Slave Amplifier	2N174
Diode	Slave Amplifier	1N1217

C. INTERFACE WIRING

Figure 17 is a wiring diagram for the user plug, BNC panel and computer interface plug. All of these signals are routed to the patch panel and have been permanently assigned locations as shown. Although many of these signals, such as the 18-line input to the computer's I/O register, are not used directly within the laboratory system, they have been made available on the patch panel so that a user would have a convenient means of attaching equipments in general to the computer.



USER PLUG, USER BNC PANEL, & COMPUTER INTERFACE PLUG WIRING DIAGRAM

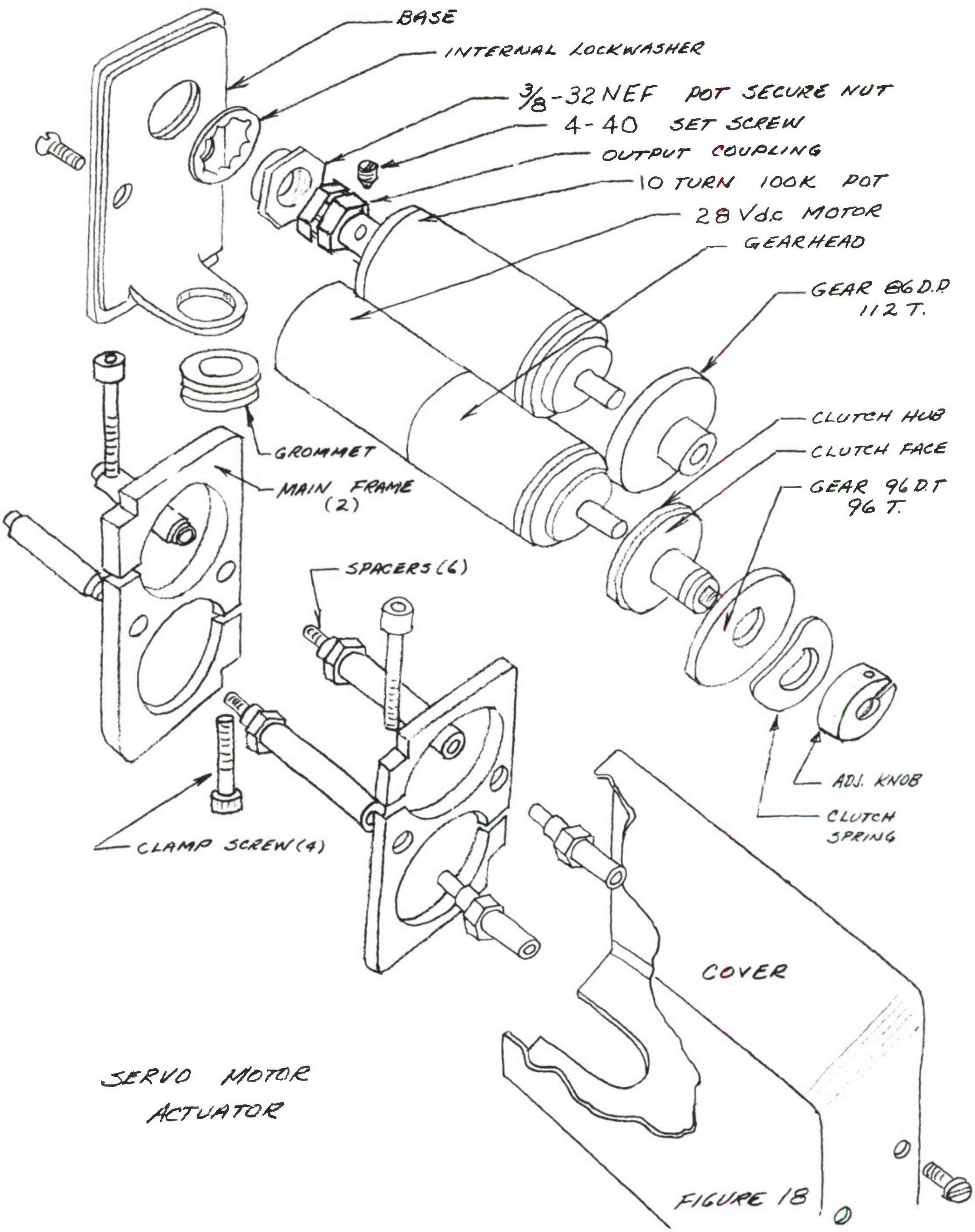
FIGURE 17

D. ACTUATORS

Two types of actuators have been supplied with the laboratory system; discrete motion Ledex "digimotors" and a continuous D-C motor potentiometer combination designed specifically for the laboratory system by the William M. Volna Company of Minneapolis. The Ledex is a size 5, bi-directional, 12-position, 550-turn, Model 215248-026 and is operated from the standard 36-volt actuator power supply. Such a configuration leads to intermittent stepping rate approximately 25 steps/sec. These "digimotors" have been permanently attached to the attenuator frame and coupled to a standard 12-position rotary switch and the input shaft of the attenuators. One 1k resistor placed around the rotary serves as a discrete potentiometer similar to the rotaries in the switching units. The armature of this 12-position rotary, therefore, gives an analog voltage proportional to the shaft position, or attenuator setting. Electrical connection of the "digimotors" are made on the SELCON Distribution panel as described above.

Unlike the "digimotors" the continuous D-C motor actuators in most cases do not require any modification or sheet metal work to install on a new piece of equipment. Figure 18 is an exploded pictorial view of this type of actuator. The 3/8-32 NEF Pot Secure Nut shown near the base is the standard nut commonly used to mount control potentiometers of equipment to their face plate. By removing the knob and securing the nut of a potentiometer, the actuator may be slipped over the protruding shaft and again securely refastened to the face plate by means of the nut within the actuator.

The basic components of this actuator are the 28-volt, D-C motor, 10-turn, 100K, potentiometer, clutch and gear train. Operation



SERVO MOTOR
ACTUATOR

FIGURE 18

of the actuator is similar to the discrete type in that the motor coil is driven from SELCON as is the digimotor coil, and the potentiometer leads provide an analog signal proportional to the output shaft position. The major difference, aside from allowing continuous control, is that the potentiometer allows a full ten turns of revolution. The nominal output torque of the actuator is 5-oz/in, but can be adjusted downward by means of the slip clutch shown. In addition to these actuators four 10:1 gear boxes have been supplied with the system to allow operation of devices requiring up to 50-oz/in of torque.

E. MAINTENANCE

Very little routine maintenance is required to keep the laboratory system in operating condition. The switching units are totally enclosed to protect the contacts from dirt and need not be opened at regular intervals. It is recommended, furthermore, that the switching units not be opened unless a failure develops. Lubrication of the rotary switches is not required for 10^6 closures. In case trouble with the units does not develop, a complete adjustment procedure is described in Maintenance Instruction Manual 1A.109 (Uniselectors) available from Imtra Corporation of Cambridge, Massachusetts 02138. One copy of this manual is supplied with the equipment.

Any malfunction of the equipment within the equipment inventory should be corrected by following the procedures specified by the manufacturer of the particular equipment. The command buffer logic is constructed from standard modules from the Digital Equipment Corporation. Replacement modules are available off-the-shelf and an inventory of spare modules is probably not necessary. The one component of the system which will require routine maintenance is the supply batteries. These batteries are standard automobile batteries and require replacement approximately once every two years. Approximately once every two weeks the water level should be checked and re-established if necessary.

To verify that the system is working properly, it is recommended that once every month a technician exercise all switching units and actuators. The LABTYC program described in Appendix II is an ideal program for this purpose and the maintenance man should become faimiliar with its operation.

APPENDIX II

PROGRAM WRITE-UPS AND LISTINGS

PROGRAM WRITE-UPS (continued)

*The items listed are supplied separately

FLOW CHART

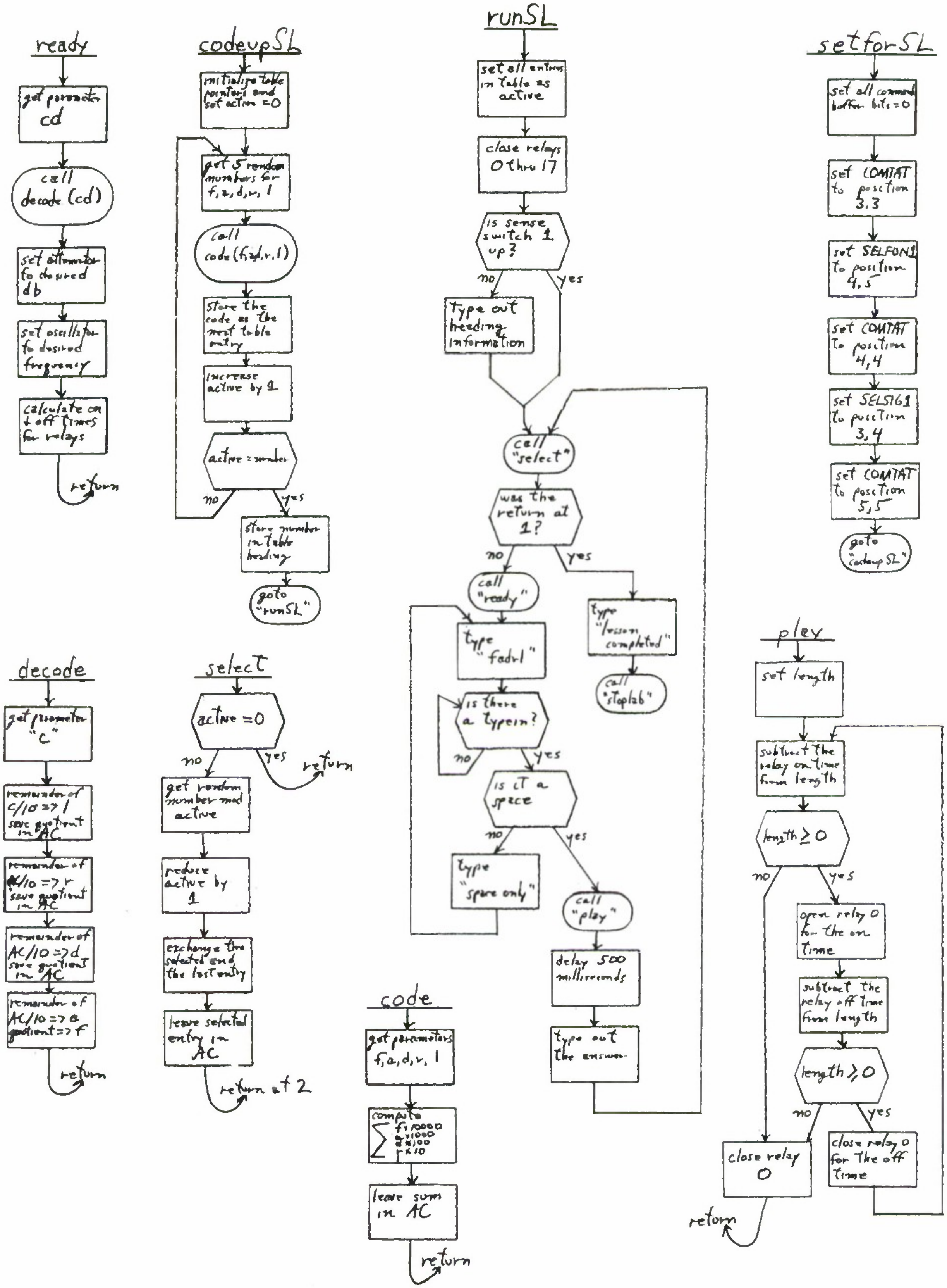


Figure 19 Class 1 — Experiment Control

FLOW CHART

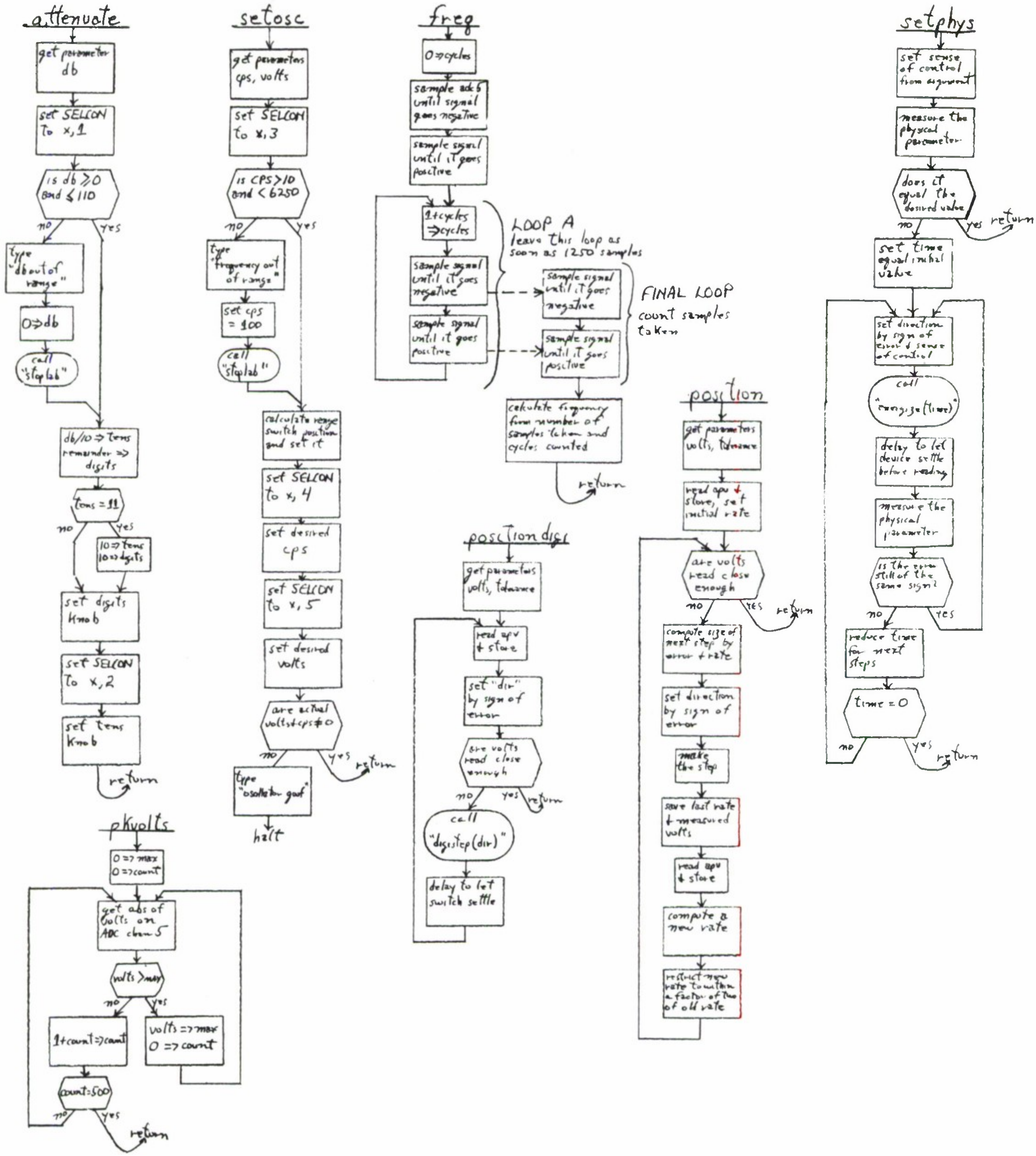


Figure 20 Class 2 - Equipment Control

FLOW CHART

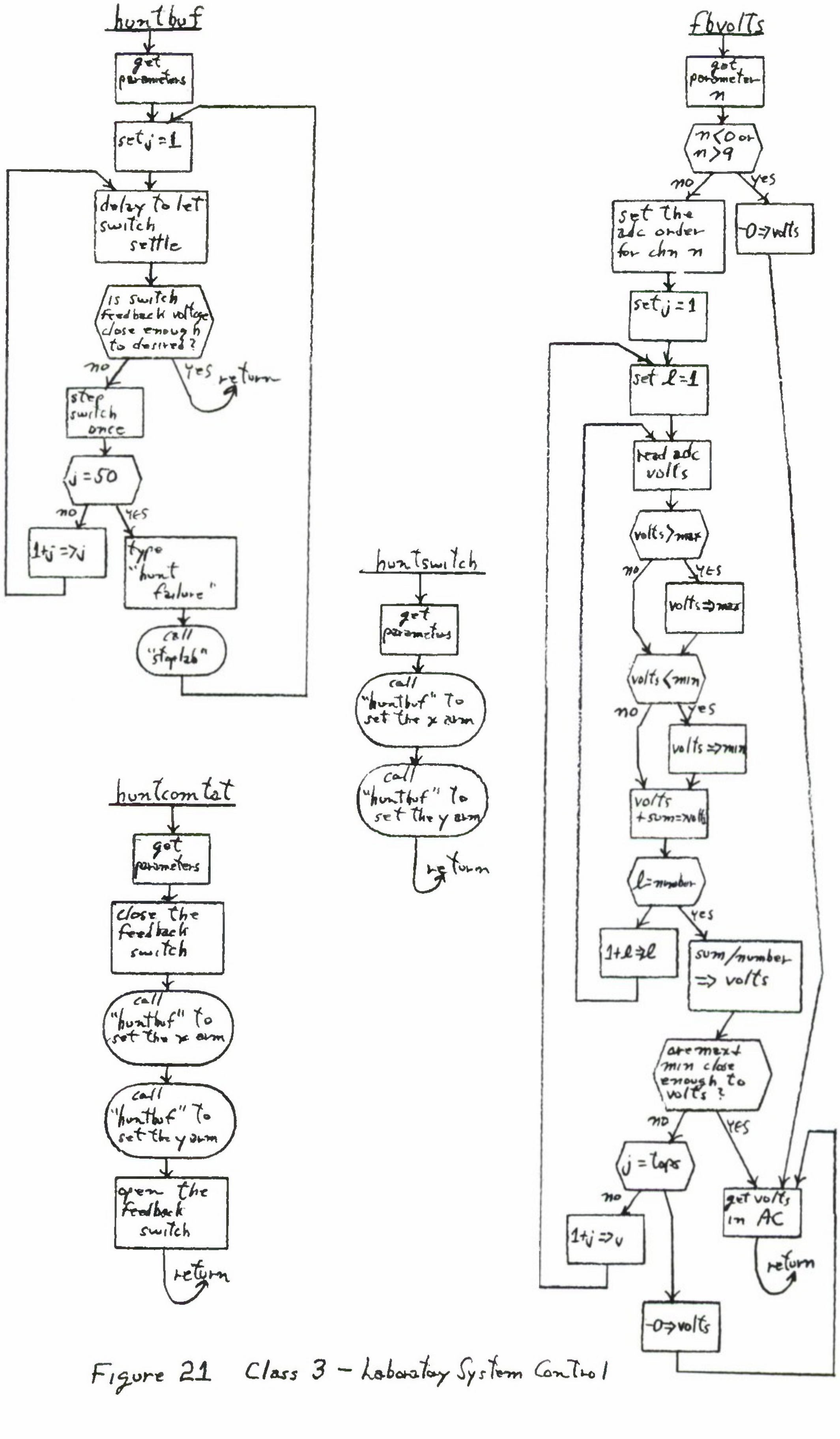


Figure 21 Class 3 – Laboratory System Control

PROGRAM WRITE-UP FOR PSYCHOACOUSTIC LABORATORY SYSTEM

MNEMONIC: runSL
FULL NAME: RUN THE SOUND LEARNING EXPERIMENT
TAPES: DS, DL) PART OF C1SL1
LISTINGS: DS, DM)
CLASS: 1

The program "runSL" is written as a section of coding to carry on the Sound Learning experiment. It assumes that the coded designators for the individual stimuli to be presented during the lesson have previously been put in the table area. First, the table is set to indicate that all coded designators are active and the 18 computer-operated relays are closed. Sense switch 6 on the console controls whether or not a small heading and instruction section is initially typed out on the on-line typewriter. Placing the sense switch up suppresses this type-out. The sequence of events for running the lesson are:

1. Select a code from the table with the program "select."

2. Prepare this designated stimulus for presentation with a call to the program "ready."

3. Type out a key on the on-line typewriter ("fadrl"), and position the typewriter at the left margin to await a "space" from the subject.

4. When the "space" is received, indicating that the subject desires to hear the stimulus, present the stimulus with a call to "play."

5. Delay 1/2 second after the stimulus has been completely presented.

6. Type out underneath the key the number designating the particular values of the 5 parameters which existed for the stimulus just presented.

7. Cycle back to No. 1 and present the next stimulus.

When all the stimuli have been presented the message "lesson completed" is typed out to the subject and "stoplab" executed to halt the computer and laboratory system equipment. At this time the lesson may be repeated by depressing the console switch CONTINUE.

PROGRAM WRITE-UP FOR PSYCHOACOUSTIC LABORATORY SYSTEM

MNEMONIC: code

FULL NAME: CODE A STIMULUS DESIGNATION

TAPES: DS, DL) PART OF C1SL2

LISTINGS: DS, DM)

CLASS: 1

The program "code" is written as a procedure with five arguments. The arguments are each a number from 1 through 5 inclusive designating the frequency, amplitude, duty cycle, repetition rate and length of the stimulus being coded. The purpose of the procedure is to produce a single binary word containing the 5 parameters in such a way that they can subsequently be decoded. This is accomplished by producing the sum of the frequency X 10,000, the amplitude X 1,000, the duty cycle X 100, the repetition time X 10, and the length. The coded number is returned in the accumulator.

Example of calling sequence:

```
cod (1,2,3,4,5)
```

The binary number equivalent to 12345_{10} will be returned in the accumulator.

PROGRAM WRITE-UP FOR PSYCHOACOUSTIC LABORATORY SYSTEM

MNEMONIC: codeupSL

FULL NAME: PRODUCE THE SOUND LEARNING CODE STIMULUS TABLE

TAPES: DS, DL) PART OF C1SL2

LISTINGS: DS, DM)

CLASS: 1

The program "codeupSL" is written as a section of coding headed by the system symbol "codeupSL" and terminated by a jump to "runSL" (which see). The function of this section of coding is to produce a number of random selections from the set of 3125 possible stimuli for the Sound Learning experiment, code the designators for these stimuli into single words by using the program "code" and store these coded stimulus designators in a table to be used subsequently during the running of the Sound Learning experiment. The procedure "ranmodn" is used to randomly select values between 1 and 5 for the several parameters of each stimulus. The table will contain the number of randomly generated coded stimulus designations indicated by the contents of the register "number."

Example of calling sequence:

```
goto codeupSL
```

The stimulus table will be generated and control transferred to "runSL."

PROGRAM WRITE-UP FOR PSYCHOACOUSTIC LABORATORY SYSTEM

MNEMONIC: decode
FULL NAME: DECODE A STIMULUS DESIGNATOR WORD
TAPES: DS, DL) PART OF C1SL2
LISTINGS: DS, DM)
CLASS: 1

The program "decode" is written as a procedure with one argument. The argument is the binary word designating a stimulus which has been coded by the program "code" (which see). This program successively divides the argument by 10 thereby recovering the original numbers from 1 to 5 designating each of the parameters of the stimulus. The individual parameter values are stored in the system symbol registers "frq," "amp," "duty," "rep," and "length."

Example of calling sequence:

decode (12345)

The numbers 1,2,3,4,5 will be stored in the 5 system symbol registers mentioned above.

PROGRAM WRITE-UP FOR PSYCHOACOUSTIC LABORATORY SYSTEM

MNEMONIC: play
FULL NAME: PRESENT A STIMULUS
TAPES: DS, DL) PART OF C1SL2
LISTINGS: DS, DM)
CLASS: 1

The program "play" is written as a procedure with no arguments. Its purpose is to open and close a relay in the proper temporal sequence to present a stimulus to the subject. The frequency and amplitude setting of the oscillator are assumed previously accomplished through a call to the program "ready." Also, the number of milliseconds to open and close the relay and the total length of time during which to open and close the relay is assumed previously calculated by the call to"ready." This program opens the relay for the period of time calculated then closes it for the period calculated and repeats this procedure until the total length of time calculated is expended. The programs "open" and "close" (which see) are used to manipulate the relay.

Example of calling sequence:

```
play ()
```

The stimulus previously set by "ready" will be presented to the subject.

PROGRAM WRITE-UP FOR PSYCHOACOUSTIC LABORATORY SYSTEM

MNEMONIC: ready

FULL NAME: PREPARE A STIMULUS FOR PRESENTATION

TAPES: DS, DL) PART OF C1SL2

LISTINGS: DS, DM)

CLASS: 1

The program "ready" is written as a procedure with one argument. The argument is the coded stimulus designator for the next stimulus desired. The program "decode" is used to produce the numbers from 1 to 5 designating the particular values of the signal parameters to be used. Five tables are provided giving the physical value for each parameter for each of its possible values from 1 to 5. With the decoded value of amplitude, the attenuation desired is determined from the table provided and the program "attenuate" (which see) used to set the laboratory system attenuator to the desired value. The decoded value for frequency is used with the table provided to determine the cycles per second desired and the program "setosc" (which see) used to set the laboratory system oscillator to this desired frequency. The tables for duty cycle, repetition time, and length are used to determine the values for these parameters and calculations made to convert these values to the three quantities for manipulating a relay to present a stimulus (number of milliseconds on, number of milliseconds off, total number of milliseconds to present the signal). The result of the operation of this program is that the stimulus designated by the code is available for immediate presentation to the subject by subsequent calls to the program "play."

Example of calling sequence:

ready (12345)

The attenuator will be set to give the attenuation required for amplitude number 2, the oscillator will be set to give the frequency number 1, and relay on-time, off-time and total length of values in milliseconds calculated so that the program "play" will create the required repetition time, duty cycle, and length.

PROGRAM WRITE-UP FOR PSYCHOACOUSTIC LABORATORY SYSTEM

MNEMONIC:	select	
FULL NAME:	SELECT A CODED STIMULUS DESIGNATOR FROM THE TABLE	
TAPES:	DS, DL)	PART OF C1SL1
LISTINGS:	DS, DM)	
CLASS:	1	

The program "select" is written as a subroutine with no arguments. It is called with a "jsp." Its purpose is to select at random a particular word from those remaining in the stimulus table, transfer it out of the active portion of the stimulus table, reduce the number of stimulus designators remaining in the table, and return in the accumulator the stimulus designator word just removed from the table.

Example of calling sequence:

```
jsp select
```

A random value will be selected from the stimulus table and returned in the accumulator.

PROGRAM WRITE-UP FOR PSYCHOACOUSTIC LABORATORY SYSTEM

MNEMONIC:	setforSL	
FULL NAME:	SET THE LAB SYSTEM FOR RUNNING THE SOUND LEARNING EXPERIMENT	
TAPES:	DS, DL)	PART OF C1SL2
LISTINGS:	DS, DM)	
CLASS:	1	

The program "setforSL" is written as a sequence for coding headed by the system symbol register labeled "setforSL" and terminated by a jump to "codeupSL" (which see). The purpose of this program is to position the laboratory system switches such that the measurements and control required for the Sound Learning experiment can take place. It accomplishes this in the following manner: COMTAT is moved to the X,Y position necessary to measure the feedback voltage from SELFUN1 with a call to "huntcomtat." Then SELFUN1 is positioned to 4,5 by a call to "huntswitch." SELFUN1 is thus positioned so that multiplexer channel 5 can subsequently be used for measuring physical parameters. Next COMTAT is moved to the position for reading the feedback voltage from SELSIG1 with another call to "huntcomtat." Then SELSIG1 is moved to position 3,4 with a call to "huntswitch." This position connects SELSIG1 to the output of oscillator number 1. Finally, COMTAT is moved to the position necessary for reading the feedback from SELCON by yet another call to "huntcomtat" and then SELCON is set to position 3,1 with a call to "huntswitch." The various arguments necessary for the calls to "huntcomtat" and "huntswitch" just mentioned are determined by reference to the charts in Appendix III and are included as a table with this program.

Example of calling sequence:

goto setforSL

The switches SELSIG1 and SELFUN1 will be positioned to 3,4 and 4,5, respectively, COMTAT to the position necessary to read SELCON's feedback, and SELCON itself to position 3,1.

PROGRAM WRITE-UP FOR PSYCHOACOUSTIC LABORATORY SYSTEM

MNEMONIC:	digistep	
FULL NAME:	STEP A DIGIMOTOR	
TAPES:	DS, DL)	PART OF C2BC
LISTINGS:	DS, DM)	
CLASS:	2	

The program "digistep" is written as a procedure with one argument. The single argument is the number of step pulses to be applied to the digimotor connected at SELCON's present position. If the number is positive clockwise steps will result, and if negative counter-clockwise steps will result. This program uses "direction" (which see) to set the direction of the step pulses to be issued, and then uses the program "energize" and "delay" (which see) to create the number of stepping pulses to the digimotor. First the system constant "digistepon" is used as an argument to "energize" to put actuating power to the digimotor and then the system constant "digistepoff" is used as an argument to "delay" to wait the required time before attempting another actuating pulse to the digimotor.

Example of calling sequence:

```
digistep (3)
```

The digimotor connected at SELCON's present position will be advanced clockwise 3 positions.

PROGRAM WRITE-UP FOR PSYCHOACOUSTIC LABORATORY SYSTEM

MNEMONIC: positiondigi

FULL NAME: POSITION A DIGIMOTOR

TAPES: DS, DL) PART OF C2BC

LISTINGS: DS, DM)

CLASS: 2

The program "positiondigi" is written as a procedure with two arguments. The first argument is the desired actuator position voltage, and the second argument is the amount above or below this value which will be tolerated. The purpose of this program is to set a digimotor to the position which gives a particular actuator position voltage through SELCON GHOST. The program "fbvolts" is used with "apvchn" as its one argument to measure the existing actuator position voltage. If this voltage is not within the prescribed limits of the desired voltage, the direction to step in order to reduce the discrepancy is computed and a step of 1 position in the correct direction is executed by calling the routine "digistep." After the step is accomplished, a delay is executed to allow time for the digimotor actuator position voltage to stabilize and then the actuator position voltage again measured and the whole procedure repeated until the desired position is attained.

Example of calling sequence:

```
positiondigi (-302, 10)
```

The digimotor connected at SELCON's present position will be stepped clockwise or counterclockwise as necessary until the actuator position voltage reading is between -292 and -312.

PROGRAM WRITE-UP FOR PSYCHOACOUSTIC LABORATORY SYSTEM

MNEMONIC: position

FULL NAME: POSITION A KNOB TURNER

TAPES: DS, DL) PART OF C2BC

LISTINGS: DS, DM)

CLASS: 2

The program "position" is written as a procedure with two arguments. The first argument is a desired actuator position voltage reading and the second is the amount above or below this reading that will be tolerated. The purpose of this program is to set a knob turner to a position giving a particular actuator position voltage. Since the actuator position voltage cannot be measured reliably while a knob turner is moving, it is necessary to measure the voltage while the knob turner is at rest, and then apply actuating voltage to the knob turner for a period of time calculated to bring it to, or close to, the desired position, then stop and again measure the actuator position voltage. If the voltage measured at the new position is not the desired actuator position voltage within the prescribed limits, then the procedure is repeated. The programs "fbvolts,"direrection," and "energize" are used to accomplish the above.

A comparison is made between the actuator position voltage measured at the current knob turner setting and the argued actuator position voltage. The relation of these two voltages determines the direction of the next move and the magnitude of the difference between these two voltages determines, in relation to a current assumed <u>rate</u>, the period of time that the knob turner will be next energized. Originally a rate is assumed and is dynamically changed during subsequent moves as a result of actual experience. However, the acceleration of the rate is limited to avoid instability.

Example of calling sequence:

```
position (-622, 3)
```

The knob turner connected at SELCON's present position will be driven in the appropriate direction until the actuator position voltage available through SELCON GHOST is between -619 and -625.

PROGRAM WRITE-UP FOR PSYCHOACOUSTIC LABORATORY SYSTEM

MNEMONIC: setphys
FULL NAME: SET A PHYSICAL PARAMETER
TAPES: DS, DL) PART OF C2BM
LISTINGS: DS, DM)
CLASS: 2

The program "setphys" is written as a subroutine with three arguments. The subroutine is called with a "jda" with arguments 1 and 2 in the accumulator and in-out register, respectively. The third argument is in the register following the "jda" to "setphys" and is executed by "setphys" during its operation. The purpose of this program is to control a knob turner in order to set a physical parameter to a particular value. The first argument to this routine is the value desired for the controlled physical parameter. The second argument is a word of all zeros, or all 1's, to indicate the sense of the controlled shaft. If the shaft is turned clockwise to increase the value of the controlled physical parameter, the sense word should contain all 1's and if the shaft should be turned counterclockwise to increase the value of the controlled physical parameter the sense word should contain all zeros. The third argument to this routine is a word which when executed will cause the measurement of the controlled physical parameter. This program uses the programs "direction," "energize," and "delay." The program accomplishes its function by measuring the physical parameter, comparing this value with the desired value and from the sign of the relation between these two values and the sense argued computing the direction of the movement to decrease the discrepancy. It then applies actuating voltage to the knob turner for a prescribed period. After this step, the physical parameter is again measured and if the sign of the error is the same, an equal step is made again. These steps are made until the sign of the error changes. Then the size of the steps is decreased and the smaller moves made in the opposite direction until the sign of the error changes once again. The step size is again decreased and direction changed. In this manner the desired knob setting is finally attained. Although this method of setting the physical parameter seems somewhat crude, it works surprisingly well and is, as might be expected, remarkably insensitive to extreme non-linearities in the relation between knob position and physical parameter value.

Example of calling sequence:

```
4000; lio = ..777777; jda setphys; freq()
```

The oscillator, whose frequency is controlled by the knob turner connected at SELCON's present position, will have its frequency set to 4000 cps.

PROGRAM WRITE-UP FOR PSYCHOACOUSTIC LABORATORY SYSTEM

MNEMONIC:	pkvolts	
FULL NAME:	PEAK VOLTS MEASUREMENT	
TAPES:	DS, DL)	PART OF C2BM
LISTINGS:	DS, DM)	
CLASS:	2	

The program "pkvolts" is written as a procedure with no arguments. The purpose of this program is to measure the peak voltage referenced to 0 of the A-C signal on multiplexer channel 5. The method used is to take 500 measurements of the signal, each at least 100 microseconds apart, and compute the maximum absolute value from the 500 samples. For signals with a frequency less than 10 cps the value returned will not be reliable.

Example of calling sequence:

pkvolts ()

The peak voltage of the signal on multiplexer channel 5 will be measured and returned as an integer value in the accumulator with a range from 0 to +1023.

PROGRAM WRITE-UP FOR PSYCHOACOUSTIC LABORATORY SYSTEM

MNEMONIC: freq

FULL NAME: FREQUENCY MEASUREMENT

TAPES: DS, DL) PART OF C2BM

LISTINGS: DS, DM)

CLASS: 2

The program "freq" is written as a procedure with no arguments. The purpose of this program is to determine the frequency of the signal on multiplexer channel 5 (SELFUN 4,5). The method used to determine the frequency of the signal is to find the amount of time required for a number of cycles of the unknown signal. The unknown signal is sampled with the analog-to-digital converter on multiplexer channel 5 once each 80 microseconds and the time between samples used to perform certain calculations. When the routine begins, the sign of each succeeding sample is compared with that of the preceding sample until a minus-to-plus change is noted. When that event occurs, the routine commences to time out a 100 millisecond period, and during this period continually compares each sample with the previous sample to note and count each minus-to-plus sign change. When the 100 milliseconds has elapsed the routine then counts the number of samples until the next and final minus-to-plus sign change is noted. In this way an exact integer number of cycles of the signal is counted. The time for these cycles is known as the amount of time necessary for the basic 100 millisecond period plus the time necessary for the subsequent 80 microsecond samples taken to find the final minus-to-plus sign change.

The uncertainty in this measurement of the time for a certain number of cycles for the signal is plus or minus 80 microseconds and since the minimum time over which signal cycles are counted is 100,000 microseconds, the error possibility due to this inaccuracy is less than plus or minus .08 percent. The calculation for cycles per second is truncated to an integer value so it may be almost 1 cps low in addition to the plus or minus .08 percent maximum error due to tracking. Therefore, the maximum error is 1 cps plus or minus .0008 cps, and as an example, the error range for a signal measured as 5,000 cps is 4996-5005 and for a signal at 100 cps is 99.92 to 101.08.

The frequency range allowable for the input signal is from 10 to 6250 cps. Signals of frequency higher than 6250 will give indefinite results and the answer returned for signals less than 10 cps will be minus zero.

Example of calling sequence:

```
freq ()
```

The frequency of the signal on multiplexer channel 5 will be returned as an integer value in the accumulator.

PROGRAM WRITE-UP FOR PSYCHOACOUSTIC LABORATORY SYSTEM

MNEMONIC:	attenuate	
FULL NAME:		
TAPES:	DS, DL)	PART OF C2SE
LISTINGS:	DS, DM)	
CLASS:	2	

The program "attenuate" is written as a procedure with one argument. The argument is the number of db attenuation desired $0 \leq db \leq 110$. This program computes the correct setting for the units and tens knob on attenuator No. 1 and sets them to these computed positions. It is assumed that the X arm of SELCON has already been set to position 3. This program will first position the Y arm of SELCON to position 1 (see the switch connection chart in Appendix III) to connect SELCON to control the digimotor connected to the units knob of attenuator 1 and then calls "positiondigi" to set the knob to the desired position. A table of actuator position voltage readings for each of the possible desired settings for the units knob of attenuator 1 is a part of this program. Next, the Y arm of SELCON is advanced to position 2 to connect the tens knob of the attenuator to SELCON and "positiondigi" is called to position the tens knob to the desired position. As before, a table of the actuator position voltage readings for each possible desired position of the tens knob is a part of this program. If a db attenuation is requested that is outside the range 0 to 110 inclusive, a message "db out of range" will be typed out on the on-line typewriter and "stoplab" executed to halt the proceedings. Depressing the console switch CONTINUE will resume operation in the "attenuate" program and set attenuator 1 to give 0 db attenuation.

Example of calling sequence:

attenuate (52)

The units knob of attenuator 1 will be set to 2 and then the tens knob to 5.

PROGRAM WRITE-UP FOR PSYCHOACOUSTIC LABORATORY SYSTEM

MNEMONIC: setosc

FULL NAME: SET OSCILLATOR NO. 1

TAPES: DS, DL) PART OF C2SE

LISTINGS: DS, DM)

CLASS: 2

The program "setosc" is written as a procedure with two arguments. The first argument is the frequency desired in cycles per second, and the second argument is the desired output voltage reading expressed as an analog-to-digital converter value. This program assumes that the X arm of SELCON has been previously positioned to position 3 (see switch connection chart in Appendix III). It first positions the Y arm of SELCON to position 3 in order to have control of the knob turner connected to the range switch of oscillator No. 1. The argued frequency, which must be between 10 and 6250 cps, is used to compute which setting of the range switch is necessary to provide the frequency desired. A table showing the actuator position voltage reading for the knob turner connected to the range switch for each different range setting is a part of this program. The program "position" is called with a value from this table in order to position the range switch to the proper setting. Next, the Y arm of SELCON is advanced to position 4 to connect SELCON to the knob turner controlling the frequency vernier control of oscillator No. 1. The frequency is initially checked by a call to the program "freq" and if it is sufficiently close to the desired frequency, it is left untouched. If, however, the frequency must be adjusted this is accomplished with a call to the program "setphys." After the frequency has been set, the output voltage is checked by a call to the program "pkvolts" and if it is sufficiently close to the desired value the final error check is made. If it is necessary to adjust the output voltage, the Y arm of SELCON is advanced to position 5 to connect to the knob turner controlling the amplitude knob on oscillator No. 1. Then the output voltage is adjusted to the desired value with a call to the program "setphys." Finally, an error check is made to see that neither the resulting frequency nor the resulting voltage equals -0 as would be the case if the program "setphys" were unable to correctly set the frequency or amplitude.

Example of calling sequence:

```
setosc (1042, 300)
```

Oscillator No. 1 will be set to the times 1000 range position, the frequency adjusted to give 1042 cps, and the amplitude control knob adjusted to give an output peak voltage relative to 0 of 300 as an analog-to-digital converter value.

PROGRAM WRITE-UP FOR PSYCHOACOUSTIC LABORATORY SYSTEM

MNEMONIC:	delay	
FULL NAME:		
TAPES:	DS, DL)	PART OF C3P, C3P-C3T
LISTINGS:	DS, DM, LM)	
CLASS:	3	

The "delay" program is written as a procedure with one argument. The argument is the number of milliseconds to delay. If the number is zero or negative about .07 milliseconds will be lost in discovering this and returning. For arguments of 1 or greater, the procedure will loop internally until the required number of milliseconds have elapsed and then return. Time is counted using the memory cycle time of the PDP-1 as a base. When this is 5 microseconds, as it should be, the routine will give exact delays.

Example of a calling sequence:

```
delay (10)
```

A delay of 10 milliseconds will occur.

PROGRAM WRITE-UP FOR PSYCHOACOUSTIC LABORATORY SYSTEM

MNEMONIC: close

FULL NAME: CLOSE A RELAY

TAPES: DS, DL) PART OF C3P, C3P-C3T

LISTINGS: DS, DM, LM)

CLASS: 3

The program "close" is written as a procedure with two arguments. The first argument is the number of the relay to be closed ($0 \leq n \leq 17_{10}$) and the second argument is the number of milliseconds to delay after closing the relay. The bit position in the relay buffer corresponding to the argued relay number is picked up from the system table "bt" and inclusive or'ed with the current setting of the relay buffer as recorded in the system register "relays." This word is then transferred to the computer relay buffer causing the relay specified by the first argument to close. A delay is then executed by calling the program "delay" with the second argument of this program or 5, whichever is larger, as its one argument.

Example of calling sequence:

```
close (3, 100)
```

Relay number 3 will be closed and then a delay of 100 milliseconds executed. No other relays will be affected.

PROGRAM WRITE-UP FOR PSYCHOACOUSTIC LABORATORY SYSTEM

MNEMONIC: open
FULL NAME: OPEN A RELAY
TAPES: DS, DL) PART OF C3P, C3P-C3T
LISTINGS: DS, DM, LM)
CLASS: 3

The program "open" is written as a procedure with two arguments. The first argument is the number of the relay to be opened ($0 \leq n \leq 17_{10}$) and the second argument is the number of milliseconds to delay after opening the relay. The bit position in the relay buffer corresponding to the argued relay number is picked up from the system table "bt" and the not of this word and'ed with the current setting of the relay buffer as recorded in the system register "relays." The resulting word is then transferred to the relay buffer causing the relay specified by the first argument to open. A delay is then executed by calling the program "delay" with the second argument of this program or 5 (whichever is larger) as its one argument.

Example of calling sequence:

```
open (3, 500)
```

Relay No. 3 will be opened and then a delay of 500 milliseconds executed. No other relays will be affected.

PROGRAM WRITE-UP FOR PSYCHOACOUSTIC LABORATORY SYSTEM

MNEMONIC:	cycle	
FULL NAME:	CYCLE A RELAY	
TAPES:	DS, DL,)	PART OF C3P, C3P-C3T
LISTINGS:	DS, DM, LM)	
CLASS:	3	

The program "cycle" is written as a procedure with four arguments. The first is a relay number as in "open" and "close" (which see). The second and third arguments are respectively the number of milliseconds to close the relay and the number of milliseconds to open the relay. The last argument is the number of times to go through the close-open cycle. The programs "close" and "open" are used to control the specified relay.

Example of calling sequence:

```
cycle (5, 100, 300, 5)
```

Relay 5 will be closed for 100 milliseconds and then opened for 300 milliseconds 5 times. After 2 seconds control will return to the calling program. No other relays will be affected.

PROGRAM WRITE-UP FOR PSYCHOACOUSTIC LABORATORY SYSTEM

MNEMONIC:	relaydelay	
FULL NAME:		
TAPES:	DS, DL)	PART OF C3P, C3P-C3T
LISTINGS:	DS, DM, LM)	
CLASS :	3	

The "relaydelay" program is written as a procedure with one argument. The argument is the number of milliseconds to delay. If the argument is less than "relaytime" (a system constant expressing in milliseconds the minimum time to reliably move a system relay) then "relaytime" is substituted for the argument. In either case, the argument is used in a call to "delay" (which see) to cause a delay for the appropriate number of milliseconds.

Example of calling sequence:

```
relaydelay (50)
```

A delay of at least 50 milliseconds will occur.

PROGRAM WRITE-UP FOR PSYCHOACOUSTIC LABORATORY SYSTEM

MNEMONIC:	closebuf	
FULL NAME:		
TAPES:	DS, DL)	PART OF C3P, C3P-C3T
LISTINGS:	DS, DM, LM)	
CLASS:	3	

The program "closebuf" is written as a procedure with two arguments. The first argument is a word containing a one in the bit position, or positions, in the command buffer that are to be closed, and the second argument is the number of milliseconds to delay after closing (setting to 1) the required bits. The current setting of the command buffer bits (held in system constant register "solbuf") is inclusive or'ed with the first argument and the command buffer set to this new configuration. Then the second argument is used in a call to "relaydelay" (which see).

Example of calling sequence:

```
closebuf (selconx, 100)
```

The solenoid actuating the X arm of the SELCON switch matrix will be energized and then a delay of 100 milliseconds executed. The solenoid is still energized when the routine returns.

PROGRAM WRITE-UP FOR PSYCHOACOUSTIC LABORATORY SYSTEM

MNEMONIC: openbuf

FULL NAME:

TAPES: DS, DL) PART OF C3P, C3P-C3T

LISTINGS: DS, DM, LM)

CLASS: 3

The program "openbuf" is written as a procedure with two arguments. The first argument is a word containing a one in the bit position, or positions, in the command buffer that are to be opened (set to 0), and the second argument is the number of milliseconds to delay after opening the required bits. The current setting of the command buffer bits (held in system constant register "solbuf") is and'ed with the negation of the first argument and the command buffer set to this new configuration. Then the second argument is used in a call to "relaydelay" (which see).

Example of calling sequence:

```
openbuf (selconx, 100)
```

The solenoid actuating the X arm of the SELCON switch matrix will be released and then a delay of 100 milliseconds executed.

PROGRAM WRITE-UP FOR PSYCHOACOUSTIC LABORATORY SYSTEM

MNEMONIC:	pulsebuf	
FULL NAME:		
TAPES:	DS, DL)	PART OF C3P, C3P-C3T
LISTINGS:	DS, DM, LM)	
CLASS:	3	

The program "pulsebuf" is written as a procedure with one argument. The argument is a word containing ones in the bit position, or positions, in the command buffer that are to be pulsed. Two system constants, "stepontime" and "stepofftime" define a pulse to the stepper switches. The constant "stepontime" is the minimum number of milliseconds that a resting stepping switch must be energized to insure that it will advance one position when released. The constant "stepofftime" is the minimum number of milliseconds that must be allowed for a stepper switch to resume a resting state after it has been energized and released. The program "pulsebuf" first calls "closebuf" (which see) with the one argument of "pulsebuf" and "stepontime" as arguments. Then it calls "openbuf" (which see) with the one argument of "pulsebuf" again and "stepofftime" as arguments. Thus, a single pulse is issued to the designated steppers and the proper time delayed so that this pulse could be followed immediately by another.

Example of calling sequence:

```
pulsebuf (selconx)
```

The X arm of the SELCON switch matrix will be advanced one position.

PROGRAM WRITE-UP FOR PSYCHOACOUSTIC LABORATORY SYSTEM

MNEMONIC: cyclebuf
FULL NAME:
TAPES: DS, DL)
LISTINGS: DS, DM, LM) PART OF C3P, C3P-C3T
CLASS: 3

The program "cyclebuf" is written as a procedure with two arguments. The first argument is a word containing ones in the bit position, or positions, in the command buffer that are to be pulsed and the second argument is the number of pulses desired. The procedure "pulsebuf" (which see) is called with the first argument of this procedure as its argument for the number of times indicated by the second argument of this procedure. Thus, the stepper switches designated by the command buffer bits noted in the first argument will be advanced the number of positions indicated in the second argument.

Example of calling sequence:

```
cyclebuf (selconx, 10)
```

The X arm of the SELCON switch matrix will be stepped (advanced) 10 times.

PROGRAM WRITE-UP FOR PSYCHOACOUSTIC LABORATORY SYSTEM

MNEMONIC:	huntbuf	
FULL NAME:		
TAPES:	DS, DL)	PART OF C3P, C3P-C3T
LISTINGS:	DS, DM, LM)	
CLASS:	3	

The program "huntbuf" is written as a procedure for four arguments. It is used to advance stepper switches until the feedback voltage available through a specified multiplexer channel reaches a prescribed value within prescribed limits. The first argument is a word containing a one in the bit position, or positions, in the command buffer that are to be pulsed. The second argument indicates the desired voltage. The third argument is the amount above and below that voltage that can be tolerated. The fourth argument is the multiplexer channel to be used to measure the voltage. The multiplexer channel specified is used as the argument to "fbvolts" (which see) to determine the voltage at the current position. If the voltage is near enough to the desired as specified by the second and third arguments, then "huntbuf" returns. Otherwise, a single call to "pulsebuf" (which see) is made with the first argument of this program as argument to "pulsebuf." The multiplexer channel is again measured after delaying for the time indicated in the system variable "afterpulsetime." This delay is necessary to allow time for the contacts of the stepper switch to fully close after a pulse and for the feedback voltage to stabilize. The cycle of pulse-wait-measure is continued until either the desired voltage is found, or 50 pulses have been given. If 50 pulses fail to achieve the desired voltage, the message "huntfailure" is typed out and the routine "stoplab" (which see) is called. After a failure depressing the console key "CONTINUE" will cycle this routine to try another 50 pulses ad infinitum.

Example of calling sequence:

```
huntbuf (selconx, -407, 10, xfbchn)
```

The X arm of the SELCON switch matrix will be stepped until the feedback voltage measured on the multiplexer channel noted in system constant register "xfbchn" is between -397 and -417, inclusive.

PROGRAM WRITE-UP FOR PSYCHOACOUSTIC LABORATORY SYSTEM

MNEMONIC:	huntswitch	
FULL NAME:		
TAPES:	DS, DL)	PART OF C3P, C3P-C3T
LISTINGS:	DS, DM, LM)	
CLASS:	3	

The program "huntswitch" is written as a procedure with four arguments. Its use is to set both arms of any particular matrix, except COMTAT, to a particular position. The first two arguments are words with a 1 in the bit position corresponding to the command buffer bit to set the X and Y arm, respectively, of the desired switch matrix. The second two words are, respectively, the feedback voltages at the desired X and Y positions. This program first calls "huntbuf" (which see) to set the X arm and then calls "huntbuf" again to set the Y arm system constant registers "xfbchn," "yfbchn," and "var" (which see) are used to complete the arguments to "huntbuf."

Example of calling sequence:

huntswitch (selconx, selcony, -407, -514)

The X arm of the SELCON switch matrix will be set so that the feedback voltage measured on xfbchn" is equal to -407 ± "var." Then the Y arm will be set so that the feedback voltage measured on "yfbchn" is equal to -514 ± "var."

PROGRAM WRITE-UP FOR PSYCHOACOUSTIC LABORATORY SYSTEM

MNEMONIC: huntcomtat
FULL NAME:
TAPES: DS, DL)
LISTINGS: DS, DM, LM) PART OF C3P, C3P-C3T
CLASS: 3

The program "huntcomtat" is written as a procedure with two arguments. They are, respectively, the feedback voltages at the desired X and Y positions of the COMTAT switch matrix. The feedback voltage for COMTAT is measured with the same multiplexer channels as for any other switch, but first the system feedback relay must be energized to change the multiplexer channels from COMTAT's contacts to COMTAT itself. This is done with a call to "closebuf" (which see) with the system constant "fbsw" (which see) and zero delay as arguments. Then the system constants "comtatx," "var," and "xfbchn" (which see) together with the first argument of the program are used in a call to "huntbuf" (which see) to set the X arm of COMTAT. Next the system constants "comtaty," "var" and "yfbchn" (which see) together with the second argument of this routine are used in another call to "huntbuf" to set the Y arm of COMTAT. That done, a call is made to "openbuf" (which see) with "fbsw" and zero delay as arguments to release the relay set just before the two calls to "huntbuf." Thus, the system is back to its original state with COMTAT in a new position.

Example of calling sequence:

huntcomtat (-407, -514)

The X arm of the COMTAT switch matrix will be set to a position giving a feedback voltage equal to -407 ± "var" then the Y arm to -514 ± "var."

PROGRAM WRITE-UP FOR PSYCHOACOUSTIC LABORATORY SYSTEM

MNEMONIC:	direction	
FULL NAME:		
TAPES:	DS, DL)	PART OF C3P, C3P-C3T
LISTINGS:	DS, DM, LM)	
CLASS:	3	

The program "direction" is written as a procedure with one argument. The purpose of this program is to set the direction relay so that the "energize" program (which see) will cause actuators to move either clockwise or counterclockwise as desired. If the argument to "direction" is a 1, then the direction relay will be closed by a call to "closebuf" (which see) with the system constant "fbsw" and zero delay as arguments. This will result in clockwise movement of actuators during subsequent calls to "energize." However, if the argument to "direction" is not equal to 1 (i. e., anything else) the direction relay will be opened by a call to "openbuf" (which see) with the same arguments as "closebuf" above. This will result in counterclockwise movement of actuators during subsequent calls to "energize."

Example of calling sequence:

```
direction (1)
```

Subsequent calls to "energize" will cause clockwise movement of the connected actuator.

PROGRAM WRITE-UP FOR PSYCHOACOUSTIC LABORATORY SYSTEM

MNEMONIC: energize

FULL NAME:

TAPES: DS, DL) PART OF C3P, C3P-C3T

LISTINGS: DS, DM, LM)

CLASS: 3

The program "energize" is written as a procedure with one argument. The argument is the number of milliseconds to apply actuating voltage to the digimotor or knob turner that is connected to the SELCON switch matrix. The program "closebuf" (which see) is called with the system constant "actsw" (which see) and the number of milliseconds as arguments. The activate relay will close and be held closed for the desired time thereby applying voltage to the connected actuator for that period. Finally, the program "openbuf" is called with "actsw" and zero delay as arguments to release the activate relay and therefore the voltage to the actuator.

Example of calling sequence:

energize (100)

The actuator connected through SELCON will receive actuating voltage for 100 milliseconds.

PROGRAM WRITE-UP FOR PSYCHOACOUSTIC LABORATORY SYSTEM

MNEMONIC: fbvolts
FULL NAME: FEEDBACK VOLTS
TAPES: DS, DL) PART OF C3P, C3P-C3T
LISTINGS: DS, DM, LM)
CLASS: 3

The program "fbvolts" is written as a procedure with one argument. The one argument is the number of multiplexer channels to use ($0 \leq n \leq 9$). The purpose of this program is to get a reliable estimate of the D-C voltage on a channel when there is a possibility of noise spikes or that the desired signal has not yet settled to a stable value. The method used is to compute the maximum, minimum and average value of a number of analog-to-digital converter readings on the desired multiplexer channel taken some milliseconds apart. If the maximum and minimum do not vary from the average more than a prescribed amount, the average is returned in the accumulator as the desired value. Should the test just described fail, the whole procedure is repeated. If the procedure fails a certain number of times, the value -0 is returned. The system constant registers "dcnumber," "dcdelay," and "dcrepeat," contain, respectively, the number of samples to be used in an estimate, the number of milliseconds between samples during an estimate, and the number of times to repeat the whole procedure before giving up and returning the error value (-0). The system constant "dcvar" contains the maximum amount by which the computed maximum and minimum may vary from the computed average.

The voltage measured is returned as an analog-to-digital converter reading. It is an integer number in the A-C which may range from 1023_{10} to -1023_{10} representing measured voltages from 10 to -10 volts.

Example of calling sequence:

```
fbvolts (5)
```

Returns with the D-C voltage on channel 5 in the accumulator.

PROGRAM WRITE-UP FOR PSYCHOACOUSTIC LABORATORY SYSTEM

MNEMONIC:	stoplab	
FULL NAME:		
TAPES:	DS, DL)	PART OF C3P, C3P-C3T
LISTINGS:	DS, DM, LM)	
CLASS:	3	

The program "stoplab" is written as a procedure with one argument. The argument is the address to transfer control to after "stoplab" has performed its function. The purpose of "stoplab" is to clear the command buffer, thereby putting the laboratory system into a known configuration in which none of the equipment is energized. The program "openbuf" is called with ones in all bit positions and zero delay to cause all command buffer bits to become zero. Then "stoplab" halts. Operation may be resumed at the location noted by the argument of "stoplab" by depressing the console key "CONTINUE."

Example of calling sequence:

```
stoplab (1000)
```

The command buffer is cleared and the computer halts. If CONTINUE is depressed, control transfers to address 1000_{10}.

PROGRAM WRITE-UP FOR PSYCHOACOUSTIC LABORATORY SYSTEM

MNEMONIC:	LABTYC
FULL NAME:	TYPEWRITER CONTROL PROGRAM FOR THE PSYCHOACOUSTIC LABORATORY SYSTEM
TAPES:	DS, DL, EXBIN1
LISTINGS:	DS, DM, LM
CLASS:	Miscellaneous

LABTYC uses the on-line typewriter to allow control of the laboratory system and its connected equipment by employing the appropriate Class 2 and Class 3 programs to perform functions as directed. Commands are typed by the operator via the on-line typewriter and certain measured parameters are typed out.

The general format of commands to LABTYC is a major command denoted by a three-letter designator typed by the operator followed by one or more subcommands. One major command group includes commands to manipulate the seven laboratory system switch matrices and three commands to allow simultaneous movement of several switch matrices. The individual commands in this group are listed and described below:

cmt	major command to manipulate COMTAT
ss1	major command to manipulate SELSIG1
ss2	major command to manipulate SELSIG2
sf1	major command to manipulate SELFUN1
sf2	major command to manipulate SELFUN2
scn	major command to manipulate SELCON
srd	major command to manipulate SELRED
set	major command to set up a list of switches to be moved simultaneously

grp major command to move switches designated by "set"

all major command to move all switches.

The subcommands are usually signed decimal integers terminated by a letter, or just a letter. LABTYC indicates completion of a command by typing a slash, or the requested information.

The subcommands that may be used with cmt, ss1, ss2, sf1, sf2, scn, srd, grp, and all are:

αx if α is a positive number the X arm of the switch designated by the major command will be advanced α times. If α is a negative number, it will be taken as a feedback voltage. The X arm of the switch designated will be advanced until the X feedback voltage from COMTAT equals the requested value.

αy if α is a positive number the Y arm of the switch designated by the major command will be advanced α times. If α is a negative number, it will be taken as a feedback voltage. The Y arm of the switch designated will be advanced until the Y feedback voltage from COMTAT equals the requested value.

v types out the current X and Y feedback voltages from COMTAT.

αb if α is a positive number, both arms of the switch designated by the major command will be advanced α times. If π is a negative number, both arms of the designated switch will be advanced until the X feedback voltage from COMTAT equals the requested value.

c types out the voltage from the present COMTAT X,Y position.

NOTE:

X and Y feedback voltages which are sought due to a command will be either the voltages available through COMTAT, or COMTAT's own voltage, as appropriate. In particular, they will be COMTAT's own voltage when the major command is cmt, or all. They will also be COMTAT's own voltages for a "grp" command after a "set" command which specified COMTAT. In all other cases they will be the voltages through COMTAT's contacts.

The subcommands that may be used with "set" are the major commands cmt, ss1, ss2, sf1, sf2, scn, and srd. They are used to designate the particular switches to be moved as a group under the command "grp."

Four major commands for measurements have no subcommands. The commands are:

fre types out the frequency of the signal on multiplexer channel 5 (SELCON 4,5).

pkv types out the peak voltage re: 0 of the signal on multiplexer channel 5 (SELFUN 4,5).

dcv types out the value of the D-C voltage on multiplexer channel 5 (SELFUN 4,5). Filters out noise and spikes.

apv types out the actuator position voltage which is available on SELCON GHOST's armature.

The remaining major command is "act." It causes entrance to a group of subcommands for manipulating the digimotors and knob turners. The subcommands are:

αs if $-10 \leq \alpha \leq 10$ then α digimotor step pulses are applied to the actuator connected to SELCON's current position. A positive α gives clockwise steps, and a negative α gives counterclockwise steps. If $\alpha < -10$ then digimotor step pulses in the appropriate direction are given until the actuator position voltage equals α.

αh the knob turner assumed connected to SELCON is run in the appropriate direction until the actuator position voltage equals α.

αr the knob turner assumed connected to SELCON is run for $|\alpha|$ milliseconds. If α is positive then the knob turner is run clockwise, and if it is negative it is run counterclockwise.

v the current actuator position voltage is typed out (the same as major command "apv").

Typing carriage return at any time causes LABTYC to exit from the current subcommand group and position the typewriter to accept a new major command. Erroneous commands also cause this reaction. Non-terminating commands, such as asking a digimotor to move to an impossible actuator position voltage setting must be terminated by restarting the LABTYC program.

Summary Table of Major Commands and Subcommands

MAJOR COMMANDS	APPROPRIATE SUBCOMMANDS
ss1 ss2 sf1 sf2 scn cml srd grp all	αx αy v αb c
set	ss1, ss2, sf1, sf2, scn, cmt, srd
act	αs, αb, αr, v
fre, pkv, dcv, apv	none

APPENDIX II
LIST OF PROGRAM TAPES

Types:		
	EXBIN1	Core Image Tapes
	DS	Decal Symbolic Tapes
	DL	Decal Linking Tapes
	LIBTAPE	DECAL Library Tapes

Program Code Name	Description	Types of Tapes
LABTYC/..........	Typewriter control program for debugging and calibrating programs and equipment.	DS DL EXBIN1
C3P/control	Programs for control of the laboratory system equipment.	DS
C3T/System tables	Tables and constants for laboratory system equipment.	DS
C3P-C3T/.........	Programs and tables for the laboratory system equipment.	DL
C2BC/Basic control	Basic programs for the control of actuators connected to the laboratory system.	DS DL
C2BM/Basic measurement	Basic programs for the measurement of signal parameters, from equipment, controlled by the laboratory system.	DS DL

Program Code Name	Description	Types of Tapes
C2SE/Specific equipment control	Programs for the control of specific equipment connected to the laboratory system.	DS DL
C2ALL/All C2 programs	Library tape containing C2BC, C2BM, and C2SE Decal Linking tapes.	LIBTAPE
C1SL1/Sound Learning Main program	The main program to run the sound learning experiment.	DS DL
C1SL2/Sound Learning procedures and tables	Specific procedures and tables used for the sound learning experiment.	DS DL
C1ALL/Complete Sound Learning	The complete programs to run sound learning experiment. Contains all the programs supplied with the laboratory system.	EXBIN1
ALMISC (Miscellaneous programs for the laboratory system.)	Decimal number input and output via the typewriter and string typeout.	DS DL

APPENDIX II

PROGRAM LISTINGS AND COMPILATION TYPEOUTS

Types:	DS	Decal Symbolic listings
	DM	Decal Maps (typeout during compilation of DS tapes)
	LM	Linking-Map (typeout during linking of DL tapes)

See LIST OF PROGRAM TAPES for complete program names and brief descriptions -- only the mnemonics are used in this list.

Program Code	Type of Listings
LABTYC	DS
	DM
	LM
C3P	DS
C3T	DS
C3P-C3T	DM
C2BC	DS
	DM
C2BM	DS
	DM
C2SE	DS
	DM
C1S1	DS
	DM
C1SL2	DS
	DM
C1ALL	LM
ALMISC	DM

APPENDIX III
CALIBRATION AND CONNECTION CHARTS

Types of Charts

A. Actuator Position Voltage Charts

These charts show the feedback voltage readings for specific functional positions of the various actuators connected through SELCON.

B. Switch Connection Charts

These charts show the connections to each of the 36-positions available on the seven switch matrices.

C. Switch Feedback Voltage Charts

These charts show the feedback voltage associated with each X and each Y position on the seven switch matrices.

CONTENTS

ACTUATOR FEEDBACK VOLTAGE CHART

Actuator Name: ATTEN 1 UNITS

Type: DIGIMOTOR

Position	Voltage	Description
0	-1023	0 db
1	- 924	1 db
2	- 827	2 db
3	- 733	3 db
4	- 641	4 db
5	- 548	5 db
6	- 457	6 db
7	- 369	7 db
8	- 276	8 db
9	- 185	9 db
10	- 94	10 db
11		
12		

ACTUATOR FEEDBACK VOLTAGE CHART

Actuator Name: ATTEN 1 TENS

Type: DIGIMOTOR

Position	Voltage	Description
0	-1023	0 db
1	- 924	10 db
2	- 827	20 db
3	- 733	30 db
4	- 641	40 db
5	- 548	50 db
6	- 457	60 db
7	- 369	70 db
8	- 276	80 db
9	- 185	90 db
10	- 94	100 db
11		
12		

ACTUATOR FEEDBACK VOLTAGE CHART

Actuator Name: OSC 1 RANGE

Type: KNOB MOTOR

Position	Voltage	Description
0		
1		Times 10 (10-100)
2	-261	Times 100 (100-1000)
3	-378	Times 1K (1K-10K)
4	-590	Times 10K (10K-100K)
5		Times 100K (100K-1MC)
6		Times 1MC (1MC-10MC)
7		
8		
9		
10		
11		
12		

ACTUATOR FEEDBACK VOLTAGE CHART

Actuator Name: OSC 1 FREQ

Type: KNOB MOTOR

Position	Voltage	Description
0		
1		
2		
3		
4		
5		
6		
7		
8		
9		
10		
11		
12		

ACTUATOR FEEDBACK VOLTAGE CHART

Actuator Name: OSC1 AMP

Type: KNOB MOTOR

Position	Voltage	Description
0		
1		
2		
3		
4		
5		
6		
7		
8		
9		
10		
11		
12		

SWITCH CONNECTION CHART

SWITCH COMTAT

Y						
5	SELCON Y					
4	SELSIG1 Y					
3	SELFUN1 Y					
2	SELSIG2 Y	SELRED Y				
1	SELFUN2 Y	SELRED X				
0		SELFUN2 X	SELSIG2 X	SELFUN1 X	SELSIG1 X	SELCON X
	0	1	2	3	4	5

X

SWITCH CONNECTION CHART

SWITCH SELCON

Y						
5				OSC. 1 Amplitude Control		
4				OSC. 1 Freq. Vernier		
3				OSC. 1 Range Switch		
2				Atten. 1 Tens		
1				Atten. 1 Units		
0						
	0	1	2	3	4	5

X

SWITCH CONNECTION CHART

SWITCH SELSIG 1 and 2

Y						
5						
4				OSC. 1 Output		
3						
2						
1						
0						
	0	1	2	3	4	5
						X

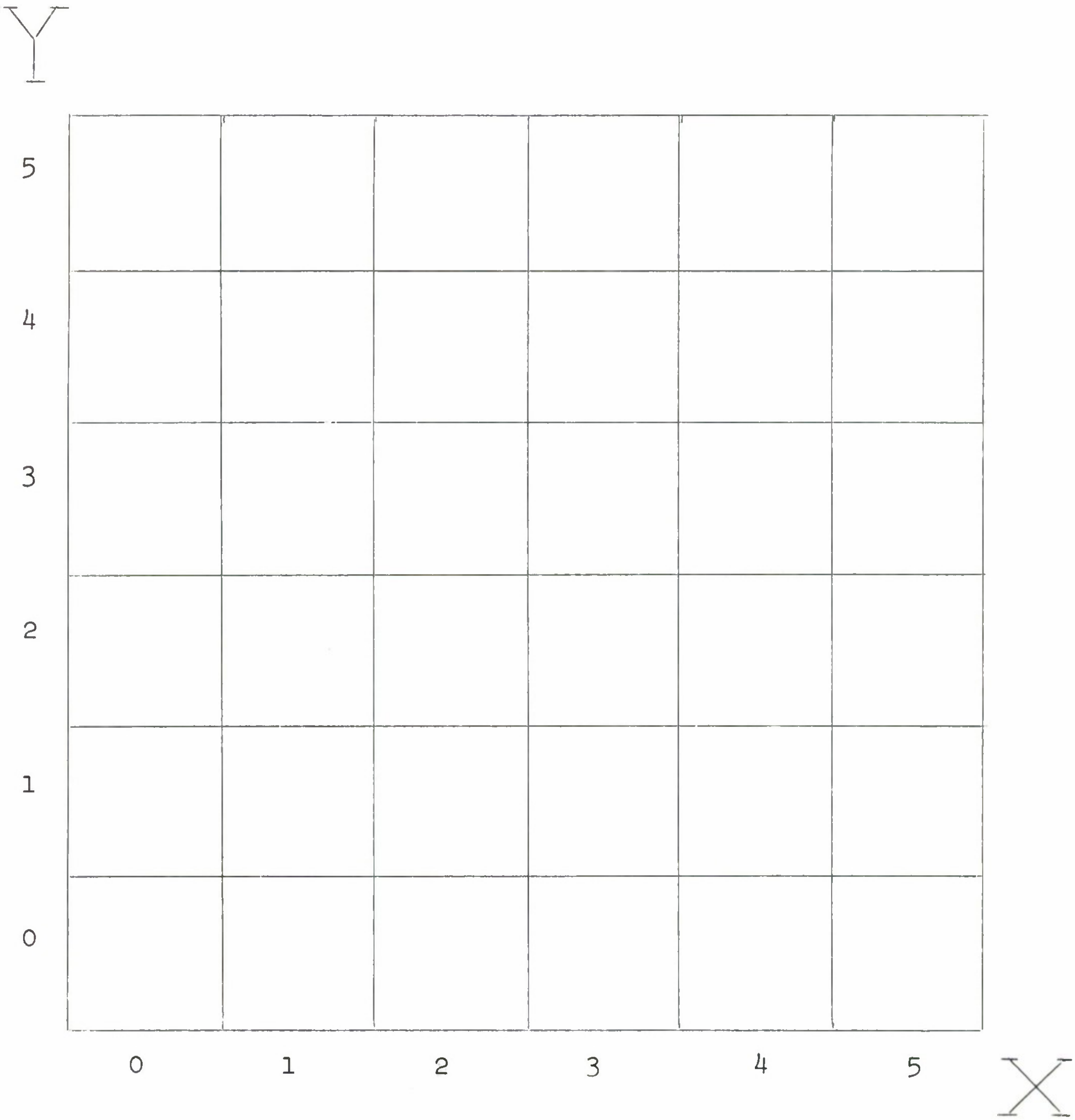
SWITCH CONNECTION CHART

SWITCH SELFUN 1 and 2

Y \ X	0	1	2	3	4	5
5					ADC Channel 5	
4						
3						
2						
1						
0						

SWITCH CONNECTION CHART

SWITCH SELRED



SWITCH FEEDBACK VOLTAGE CHART

SWITCH COMTAT

X

Position	Voltage
0	- 98
1	-195
2	-292
3	-392
4	-491
5	-590
6	
7	Not
8	
9	
10	
11	
12	
13	
14	
15	
16	
17	
18	
19	
20	
21	
22	Used
23	

Y

Position	Voltage
0	- 98
1	-198
2	-294
3	-391
4	-488
5	-587
6	
7	Not
8	
9	
10	
11	
12	
13	
14	
15	
16	
17	
18	
19	
20	
21	
22	Used
23	

SWITCH FEEDBACK VOLTAGE CHART

SWITCH SELCON

X

Position	Voltage
0	- 99
1	-195
2	-293
3	-390
4	-489
5	-588
6	
7	Not
8	
9	
10	
11	
12	
13	
14	
15	
16	
17	
18	
19	
20	
21	
22	Used
23	

Y

Position	Voltage
0	- 98
1	-196
2	-291
3	-386
4	-481
5	-577
6	
7	Not
8	
9	
10	
11	
12	
13	
14	
15	
16	
17	
18	
19	
20	
21	
22	Used
23	

SWITCH FEEDBACK VOLTAGE CHART

SWITCH SELSIG 1

X

Position	Voltage
0	- 97
1	-196
2	-294
3	-391
4	-488
5	-584
6	
7	Not
8	
9	
10	
11	
12	
13	
14	
15	
16	
17	
18	
19	
20	
21	
22	Used
23	

Y

Position	Voltage
0	-100
1	-196
2	-291
3	-384
4	-480
5	-575
6	
7	Not
8	
9	
10	
11	
12	
13	
14	
15	
16	
17	
18	
19	
20	
21	
33	Used
23	

SWITCH FEEDBACK VOLTAGE CHART

SWITCH SELFUN 1

X

Position	Voltage
0	- 99
1	-199
2	-298
3	-395
4	-492
5	-591
6	Not
7	
8	
9	
10	
11	
12	
13	
14	
15	
16	
17	
18	
19	
20	
21	
22	Used
23	

Y

Position	Voltage
0	- 94
1	-196
2	-289
3	-389
4	-487
5	-589
6	Not
7	
8	
9	
10	
11	
12	
13	
14	
15	
16	
17	
18	
19	
20	
21	
22	Used
23	

SWITCH FEEDBACK FOLTAGE CHART

SWITCH SELSIG 2

X

Position	Voltage
0	- 99
1	-194
2	-295
3	-391
4	-487
5	-586
6	
7	Not
8	
9	
10	
11	
12	
13	
14	
15	
16	
17	
18	
19	
20	
21	
22	Used
23	

Y

Position	Voltage
0	- 98
1	-195
2	-293
3	-392
4	-487
5	-585
6	
7	Not
8	
9	
10	
11	
12	
13	
14	
15	
16	
17	
18	
19	
20	
21	
22	Used
23	

SWITCH FEEDBACK VOLTAGE CHART

SWITCH SELFUN 2

X

Position	Voltage
0	-101
1	-200
2	-296
3	-392
4	-491
5	-583
6	
7	Not
8	
9	
10	
11	
12	
13	
14	
15	
16	
17	
18	
19	
20	
21	
22	Used
23	

Y

Position	Voltage
0	- 98
1	-197
2	-297
3	-393
4	-490
5	-585
6	
7	Not
8	
9	
10	
11	
12	
13	
14	
15	
16	
17	
18	
19	
20	
21	
22	Used
23	

SWITCH FEEDBACK VOLTAGE CHART

SWITCH SELRED

X

Position	Voltage
0	-101
1	-199
2	-301
3	-397
4	-492
5	-592
6	Not
7	
8	
9	
10	
11	
12	
13	
14	
15	
16	
17	
18	
19	
20	
21	
22	Used
23	

Y

Position	Voltage
0	- 99
1	-195
2	-292
3	-391
4	-491
5	-589
6	Not
7	
8	
9	
10	
11	
12	
13	
14	
15	
16	
17	
18	
19	
20	
21	
22	Used
23	

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13. ABSTRACT

This report details the development of methods for using a digital computer (the Digital Equipment Corporation PDP-1) to control apparatus and experimental procedures in psychological experiments. It describes the design of equipment for a multi-subject display system and a psychoacoustic laboratory system. An experiment illustrating the use of the system is included.

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