AN INTEGRATED DISPLAY AND CONTROL SYSTEM FOR MAN-MACHINE COMMUNICATION

CURTIS G. LAWSON

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by

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Captain, United States Marine Corps

Submitted in partial fulfillment of
the requirements for the degree of

MASTER OF SCIENCE
IN
ENGINEERING ELECTRONICS

United States Naval Postgraduate School
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ABSTRACT

Computer oriented systems have created the need for a closer interaction between men and computers. This thesis is an evaluation of, and the resulting system design of one such system. The main portion of the design is that of the operator's display and control console for this system. Included as a portion of the design problem is a computer program for the mechanization of wiring data for constructing the digital equipment.

The operator's display and control console is presently being constructed by Data Display, Incorporated of Saint Paul, Minnesota.

The author wishes to express his appreciation to Professor Mitchell L. Cotton of the U. S. Naval Postgraduate School, and to Mr. G. N. Grashorn of Data Display, Incorporated for their many helpful suggestions.

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1. Man-Machine Communications in a Digital System

The present use of computers in most applications can be classified as one of two categories:

a. Off-line operations in which a preformulated problem and precoded groups of data are fed to the computer along with the programs for processing the information. The computation then proceeds according to the preplanned program, if all data and programs are correct. Upon completion of a successful program, the desired results are then dumped from the computer memory to an output media for printing and evaluation at some later time. The extension of this technique has led to the "closed shop" computing center with their various "auto-monitor" programs in which the individual who wants the problem solved never sees the computer. This technique was prompted by the expense of large digital computers. The major drawback to such a scheme is that in writing new programs or trying to formulate new techniques for solving problems, there is a good chance for errors which will not allow the program to run to completion and may not give any indication of the reasons for stoppage. The cost of off-line formulation and "de-bugging" may be considerable in some circumstances.

b. On-line operations in which the operator is working in real time with the computer on a real time physical problem. This type of operation traditionally employs programs which are necessarily complex to take every possible situation into consideration. The role of the man in this system has been to make simple "yes-no" or similar decisions and to provide a means of accomplishing tasks

which are not automated or programmed whether by reason of difficulty or just oversight. Examples of on-line operations are the military systems (i.e., SAGE, NTDS, etc.) and industrial process controls. The cost of such systems are large as the computer is usually in full time use by the system due to the special purpose nature of the equipments.

There has been a recent trend to explore the possibilities of utilizing the best points of both techniques in systems linking man and computer more closely /1, 2/. In order to accomplish this, the basic class of operation must tend toward on-line operation. By having a closer link with the computer, the operator can make decisions at various points in the process based on real time feedbacks; examine changes in results due to varying inputs or parameters in real time; program and check blocks of codings easily before integration into a more complex program; and call up and inspect large blocks of information randomly from a large memory.

In order to accomplish this interaction between man and computer while keeping the overall system flexible and relatively inexpensive, certain requirements must be met: (a) A method of time sharing of the central computer must be implemented whether by programming or hardware techniques. (b) Display and control equipments must be designed to allow the operator to effectively communicate complex ideas to the computer and to allow the computer (through proper programming) to make requests on or display data to the operator. The first requirement is dictated by the desire to perform on-line and off-line computations interlaced in

time, while the second is essential to any closely coordinated man-computer system. The specifications of time sharing systems have been developed in recent literature [28, 29]. It is the purpose of this thesis to develop design criteria and to carry out the design of a display and control console which can be applied to many different type problems.

In a computer oriented system the flow of information is as shown in Figure 1-1.

The man-computer interface consists of two unique parts. There must be a provision for the operator to communicate his desires to the computer, and the computer should have the provision to display results or ask for further instructions. Specific techniques for accomplishing these functions will be discussed in Chapter 2.

In order to intelligently use any or all of the possible information available in a complex system, the display must be able to select various portions of information readily and easily. This means that the display console itself should be a complex buffer and should be able to control the computer's memory and programs. The main control programs in the central computer should be tailored to the display which in turn should be tailored to the human requirements for ease of operation along with flexibility.

Display updating may be done on any of the following criteria:

a. Upon receipt of new data by the computer

b. Upon a real time interval

c. Upon request from the display console

Priority considerations in the case of radar or automatic inputs

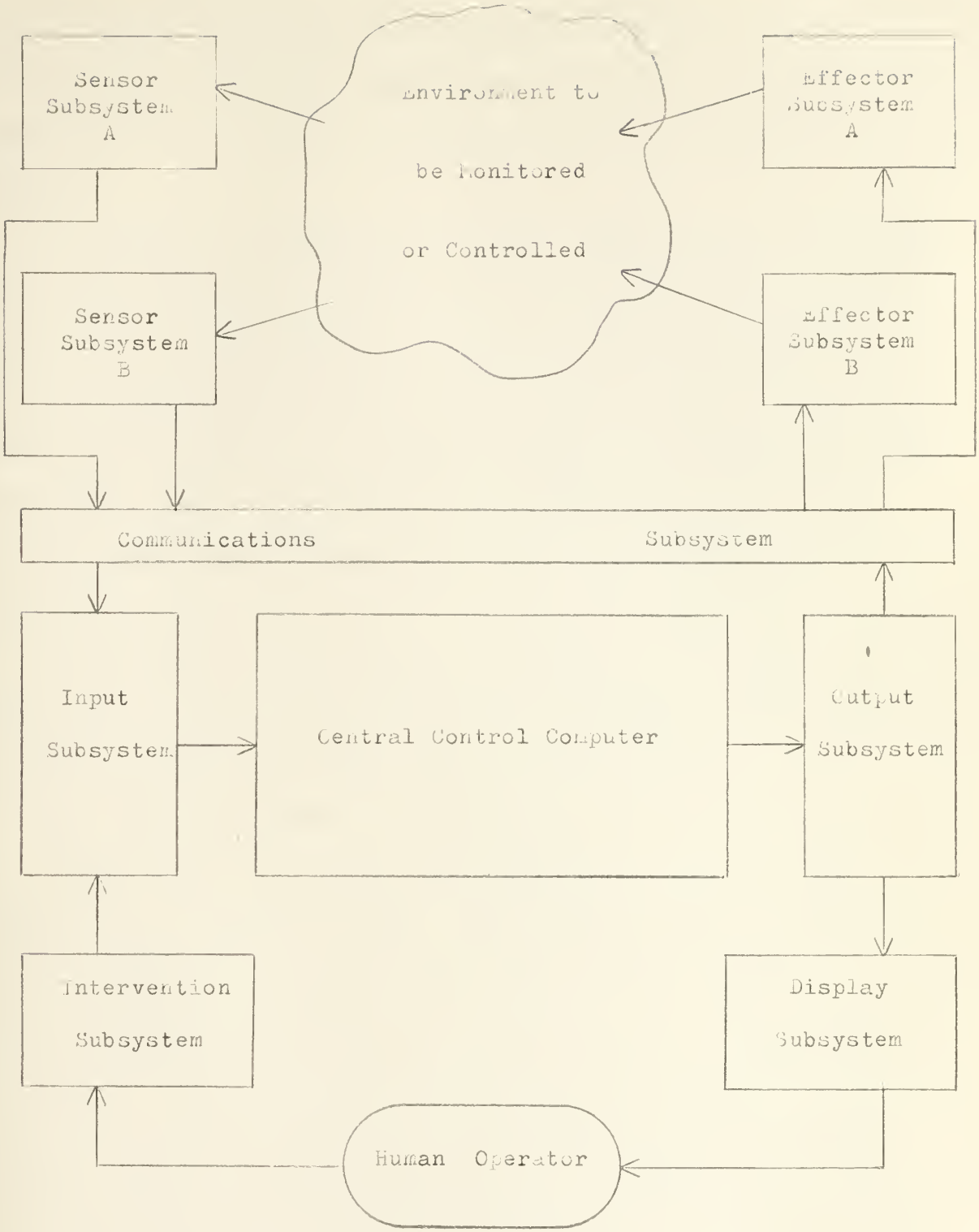


Figure 1-1
Flow of Information in a Man-Computer System

versus manual inputs should also be given consideration in the design of a given equipment. There should be a method for overriding any preselected priority sequence without changing the whole sequence.

The amount of information on a given display must be selectable by the human operator. If there is too much information or unwanted information mixed with the desired information, he must be able to remove some portions of the overall display or be able to expand a part of the display on a secondary display. He should also have control over selective portions of the display in order to view tabular or other information at the same time a graphical display is being produced.

All of these factors should be considered in the design of a given man-computer system with the main guide lines of the actual computer characteristics with which it is to operate.

The broad requirement for an input device is that an operator can readily adapt to it and can communicate his desires to the computer in an efficient manner. This requires that the device be designed using a minimum of controls, but with each control uniquely labeled and preferably able to call in a sequence of subroutines. The general purpose (stored program) computer is well suited for this type approach. By inserting an executive program into the memory, the control keys can be uniquely labeled to call out and execute desired portions of the program. Then, by changing the executive program, the functions of the controls can be changed. So by changing the labeling of the controls with an "overlay", many

special purpose control consoles may be simulated. An additional method for specifying information to a computer is that of allowing the operator to draw lines or symbols on a display surface or some input "sketch pad". An interpretive routine in the computer would then have to perform a pattern recognition, curve fitting, or other similar operation before taking action. One other desired control is closely linked to the display or output device. There must be a method for interrogating the computer about a point, a symbol, or an area on a display for the purpose of obtaining amplifying information about the interrogated portion.

The requirements for a display device are imposed by the user. Some of these are physical requirements based on the constraints of human reaction time and visual resolution, while others are based on clarity or recognition of information /3/. These have been listed with a brief explanation of each.

a. Selective display capability:

The computer can generate and hold in its memory a large amount of display information. The operator can intelligently use only a limited portion of the total supply of data at one time. For example, an aircraft controller may only be interested in traffic within a certain block of altitudes; so, he should be able to call in to the display only the representation of those aircraft within his volume of control.

b. Fast response to commands:

When asking for a new piece of information on a display or when dropping some outdated display, the response to the

command should be fast enough to allow continuity of thought for the operator. He should not have to wait for the command to be executed and the display changed.

c. Number and size of the display devices should fit the usage requirements:

In a large system several individual operators may be needed for specific tasks. This function may best be implemented by using a group of individual operator consoles working on data from a central computer and display generator. In some systems, a group of specialists may want to arrive at an optimum decision based on information on a central display. For this purpose, a large screen display is necessary with a possibility of inputting commands from one or more input devices.

d. The display should not flicker:

The retention of images by the eye is such that if a display is refreshed at a rate of about 30 frames per second, no flicker will result. The flicker of a display will be dependent on the storage time of the display elements. For example, if a long persistence phosphor is used in a cathode ray tube display, the refresh rate requirement is reduced, but the time required to change the position of any point on the display or the whole display is determined by the decay time of the phosphor. This decay time is dependent on the initial intensity of the display.

e. Resolution of the display should be greater than the resolving power of the eye:

The eye can discriminate parallel lines separated by

intervals equal to the line width to a value of 60 lines per degree. So for a single operator console, if the display surface is considered to be the base of an isosceles triangle and the eye to be the apex of this triangle (actually an isosceles cone), approximately 50% of viewing angle is included. This dictates that the display should have at least 2,000 "bins" for unique storage in each direction. To place this into a digital representation for computer generation the resolution should be at least 11 bits.

f. The contrast and brightness should be such that under ambient light conditions, the operator will not be subject to eye strain:

The intensity difference between background and information should be on the order of thirty to one for normal usage. If the ambient light is high, reflections from the display surface tend to "wash out" this contrast. A cathode ray tube display console that is designed to operate in normal room lighting needs to incorporate a fast phosphor that can be raised to a high intensity level without producing an extended decay time.

g. Accuracy and distortion should be reduced to an acceptable level:

In any display system, the ideal resulting display would have perfect registration and focus at all points of the display. This goal is rarely, if ever, attained due to hardware considerations. For example, in a cathode ray tube display there is definite defocusing effect at the edges of the tube as the path length of the electron beam is longer. Also, the voltages to pro-

duce the desired deflections in an electrostatic deflection tube (or conversely the current to produce deflections in an electromagnetic deflection tube) do not vary linearly with the distance from the center of the tube /4/. This leads to the use of compensation circuits in the control circuitry which can reduce these conditions to an acceptable level.

h. The coding should allow for a variety of presentations:

The requirements for flexibility encompass such ideas as color, size, shape, intensity, position and orientation. and blink rate as a means of attracting attention. Most displays require a set of symbols for normal usage. These would be numbers, the alphabet, and any frequently used symbols. In addition, a method of generating lines should be included for forming special symbols or line drawings. These "vectors" should allow for blanking portions of the length while proceeding along a given direction to enable the further coding of lines into dashed lines.

i. The format for the display should suit the usage requirements:

Some examples of formats are textual, tabular, graphical, situation or overlay map plus defining symbols, line drawings and diagrams, patterns of symbols to show complex situations, and pictorial symbols to show the status and condition of remote elements. The general classification can be termed either fixed or free. The fixed format is considered to be a textual or tabular type where automatic incrementing and positioning of symbols is accomplished on a set of constraints mechanized into the hardware.

The free format is usually implemented through a program control feature which must be generated in the computer.

The number of operators and/or viewers of a man-computer console has a direct bearing on the requirements as has been previously noted. For group displays, optical projection and electroluminescent panels have come into usage as the size of direct view cathode ray tubes are limited by deflection techniques. Examples of group displays have been discussed in recent publications /5, 6/. This thesis will discuss only single operator, direct view, non-colored cathode ray tube displays.

2. Techniques for Man-Computer Communication

The methods available for producing commands to a computer are largely dependent on the type computer being used in the system. For normal communications the computer is in control of the data lines, and the executive program must sample the possible inputs at "programmed" time intervals. For priority communications, the operator should have the ability to interrupt the computer and insert the necessary commands. The nature of any input to the computer is one of a digitally coded bit pattern dependent on the setting of switches or digital encoders, and the initiation of a command switch. A good example of this type communication is the console typewriter which can be used for input and output. An exception to this straightforward input technique is that of employing a 'sketch pad' in which the input takes the form of movement of a probe over a display or an analog surface. In these cases, the computer must sample the allowable surface at a rate fast enough so that normal motion of the probe by the operator generates a smooth input of coded positional values corresponding to the desired lines being traced by the probe. In the case of a direct view cathode ray tube, the probe is a light sensitive photo-diode, and the computer program must display a raster of points about the last recorded position of the probe. The new point is recorded as a feedback of information of the position in the raster which coincides with the probe.

In order to produce a visual display on a cathode ray tube surface from a computer output, a certain amount of decoding and

processing must accompany each computer word. Principle requirements by the display device for each piece of information displayed are: (a) positional information, i.e., X and Y or ρ and θ with respect to some reference point; (b) coded information specifying character or line type, intensity, and size of symbol or length of line. The display circuitry must be able to decode this information and convert its meaning into the necessary deflection and intensity signals to produce the desired symbol at the specified location.

The symbol formation signals must be superimposed upon the positional deflection signals. This can be accomplished by voltage or current summers in the analog deflection circuitry. Five methods of categorizing the various techniques for symbol generators have been listed in recent publications /7, 8, 9/. These are dot pattern, scanning raster, waveforms or strokes, and shaped beams.

In the dot pattern method, the symbols are made by positioning the beam to a sequence of positions defining the symbol. At each point in the sequence the beam is unblanked. The result is a group of dots oriented to form the desired symbol. The formation may use a cell of computer memory for each point displayed as in the PDP-1 console display /10/. This method is limited in speed to the speed of each memory cycle. An analog method for generating the dot pattern has been devised which makes use of resistor networks /11/.

A combination of scanning and the dot method are used by the Laboratory for Electronics in their SM-4 symbol generator. For this method each symbol in the set is represented by a selectable

matrix of magnetic cores. Each core is located at a position where a dot is to appear in the character. The matrix is scanned by rows while the beam in unblanked as a function of the cores.

A variation on the core scanning system is the VIDIAC /12/. Each symbol is again represented by a selectable matrix of magnetic cores. In this generator, the cores are positioned so that they make a double outline of the desired character. The selected matrix is then scanned by rows, and alternate cores turn the beam on and off. This causes the figure to be made up of a group of parallel line segments.

The scanning method of forming characters can be implemented by using flying spot scanner techniques /13/. In this method a fixed size scanning raster is moved to a spot on the generator tube which coincides with the desired character on a symbol mask. The portion of the beam that goes through the mask is focused on a photomultiplier, and this signal is amplified to control the intensity grid of the display tube. The scan pattern must be superimposed on the positional information for deflection signals. The combination of intensity and deflection produces the desired symbol on the display.

The stroke method has been used with much success in the "Calliscope" of Lincoln Laboratories /14, 15/, the symbol generator of Strand Engineering Laboratory, and the symbol generator of Data Display, Incorporated. The methods of deriving the deflection and intensity signals for each of these techniques vary considerably, but the results achieved are the same. The symbols are formed by

unblanking the beam at a starting point for each character and then moving the beam while it is unblanked. Some complex symbols require multiple unblanking and blanking during the formation period.

The shaped beam method is used extensively in the military display systems (SAGE and NTDS). The basis of the system is the "Charactron" tube /16/. The tube has a character matrix within the tube envelope. The character desired must be selected by positioning the beam to the associated figure in the mask by a small electrostatic deflection system. The beam is purposefully defocused to obtain a large cross-sectional area, and the shaped beam that gets through the mask is in the outline of the selected symbol. This shaped beam is then magnetically deflected to the desired position on the display surface.

A comparative analysis of these systems has been accomplished by Lowe, Sisson and Horowitz /7/. Two systems not included in this analysis are the "Strand" generator and the "DDI" generator. The respective times for generating a symbol with these systems are 40 and 6.6 microseconds. These rates of 25,000 and 150,000 characters per second compare very favorably with the other systems.

In addition to computer generated displays on cathode ray tubes, a common method for the computer to convey information to an operator is through coded and labeled lights. These are extremely easy for a computer to initiate, and providing the meaning is clear, can be an economical and efficient way for the computer to alert the operator. The main drawback for this technique is the relative inflexibility of the feedback and the possibility of

operator confusion if there are an excessive number of lights on the control console.

3. Design Specifications

The technical requirements for an advanced design digital control display console for the Digital Control and Automation Laboratory were stated as follows:

> This unit will provide character and symbol display facilities together with provision for direct display of radar video signals. In addition, it will function to provide for communications between an operator and a central computer.[1]

A research and development contract[2] was subsequently awarded to Data Display, Incorporated for the design and construction of the unit which has since been designated as the DD-05. The author worked in conjunction with Mr. Gene Grashorn of Data Display, Incorporated to specify and design this equipment. The remainder of this thesis will be devoted to the actual design of the DD-05.

The system requirements are dictated by the equipments that are to be controlled by or input to the DD-05. There are three distinct modes of operation inferred by the requirements:

a. To input radar information and to provide for (1) display of the video in a PPI format and (2) digitizing of any video return which may be determined to be a target by a detection unit so that the computer may act upon the information.

b. To allow the operator to enter information into the computer.

c. To allow the computer to present data to the operator in the form of symbols on a cathode ray tube or by drawing attention to certain input keys by a system of lights.

[1] J. I. Cotton, Technical Requirements Summary, Digital Control and Automation Laboratory, pp. 1, Feb., 1960

[2] Navy Contract NObsr 59578

The following radar units currently installed are to act as inputs to the system:

AN/SPS 5

AN/SPS 8

AN/SPS 12

AN/SPS 26

These radars are installed in the main radar laboratory, and the following information must be made available for use in the DP-65.

a. Azimuth information

b. "Main bang" or time of pulse transmission

c. Video return signal which will have any targets along with noise introduced in the process.

d. Height information in the case of the SPS 5 and SPS 26. This analog information must be converted to digital information for display and further transfer to the digital processors.

The digital computers incorporated in the system are a large scale scientific computer, the Control Data Corporation 1604 /17/ and a small data processor, the Control Data Corporation 160 /18/. These computers communicate with external equipment by parallel data transfer lines which are controlled by a sequence of control signals. Also, an essential part of the system is the Control Data Corporation 1607 magnetic tape system which contains circuits for a "Satellite" operation between the 160 and the 1604 /19/.

In order to perform an output from the computers to one of a number of peripheral equipments, the following sequence must be performed:

a. Communications established with the desired equipment (exclusive of all others) by a coded select signal proceeded by a sense signal to determine if equipment is available.

b. Data transferred to output lines, and a signal output ready is sent to all peripheral equipment.

c. The selected equipment (only) recognizes the ready and accepts the data, and at the same time sends an output resume signal back to the computer.

d. The computer, upon receipt of the resume signal, then drops the data and ready signals and prepares for the next word transfer, if any, or merely continues on the internal program.

In order to perform an input to a computer from an external equipment, the computer program must be written so that it looks to see if any equipment has data ready for input. This must be done by coded sense responses which must be built into the peripheral equipments. The computer, upon recognizing the source and the presence of an input word, then sends an input request signal which signifies that it has accepted the data and allows the equipment to drop the signals for its data lines. This sequence must be repeated for each data word entry.

In the 1604 an additional input mode has been utilized. This is the interrupt mode. This interrupt mode must be preselected by a select code in the program. If the selected interrupt occurs during the program, the program sequence is halted at that point. The address at the time of the halt is inserted into the address portion of the upper half of word number seven of the computer mem-

ory, and a jump is made to execute the lower half command of word number seven (note that the 1604 is a single address, two command per word computer /17/). The memory cell number seven should be set up previously to process the interrupt. This coding should place unconditional jump commands in both halves of the word and the address of a protected subroutine in the address portion of the lower half of the word. This subroutine must be written so that it ends with an unconditional jump to cell number seven. Thus, after having been interrupted, the subroutine is entered, and after processing the interrupt, the control can return to the program step which was being processed at the time of the interrupt.

These then are the physical rules by which the DD-5 was designed to perform its functions of control and display.

Certain other considerations in the realm of flexibility, usefulness and realizability then served to dictate the method of using the basic criteria in the actual system design. These will be listed as a collection of engineering decisions and the reasoning behind them.

<u>The display will have a self-contained memory unit</u>. This requirement was set for the purpose of freeing the computers from constant usage in refreshing the displays. The requirement that the display be refreshed every 50 milliseconds in order to obtain a "flicker free" display is one that is set by the response time of the eye. This dictates that if the display were to display text of 5,000 characters at six bits per character, then the bit rate

would be 900,000 bits per second. The 1604, if only one channel is active, has a maximum transfer rate of about 50,000 forty-eight bit words per second or about 2,400,000 buffered bits per second. The 160 has a transfer rate of about 80,000 twelve-bit words per second or about 960,000 bits per second (unbuffered). Thus, it is seen that the 160 can just barely do the static display at the necessary rate, and if any change is needed in the display, as would be the normal case for moving radar targets, it could not maintain a steady display. The 1604 is not as critical as it has a buffered output, but it still would be taxed in its buffering capabilities if more than a single channel is being used.

The use of a self-contained memory also frees the 1604 from the control subroutines which must be returned to in order to restart a display cycle. This allows more program time for computations. (In a real time air traffic control system with mach one aircraft, the computation times are critical.)

The memory package chosen was a 1024 x 24 bit ferrite core memory, licensed from Control Data Corporation. The size was chosen to compromise between the 12-bit 160 and the 48-bit 1604. The cycle time of the memory is 6.4 microseconds which is less than the 6.6 microseconds required to display a character. This allows a new memory cycle to be completed while the last character of the previous word is being displayed. Thus, for all characters to be painted, the total time involved is:

(6.6 microseconds per character) (4 characters per word) (1024 words per cycle) $\cong$ 28 milliseconds

The difference between the [illegible] milliseconds required and the 20 milliseconds required for an uninterrupted cycle allows five milliseconds for updating the data each cycle without inducing a flicker.

The intercomputer operation must be selective. In the physical layout of units the Control Data Corporation 1607 and the Control Data Corporation 1607 magnetic tape system are located in the U. S. Naval Postgraduate School computing center on the first floor of the Engineering Building. The Digital Control and Automation Laboratory is located on the fifth floor directly above the computing center. The DD-65 and the Control Data Corporation 160 of this system are to be located in that laboratory. Usage requirements dictate that the 1604 will not be available for use at certain times (pending the incorporation of a parallel processing monitor program). This requires a lockout be available for the 1604. Also, the 160 may be required to do full time processing of radar data for the 1604, and the data flow should be via the 1607 satellite system (13) independent of the DD-65 system. So a 160 lockout is required. The result is the incorporation of a selective mode for using the system.

a. 1604 only (160 locked out)

b. both (both computers may establish communications with the DD-65.)

c. 160 only (1604 locked out)

This is realized by a mode switch on the logic console.

The basic format for display information should be sequential and the display should include vectors as well as characters. The

requirements of a display to designate "where" and "what" for each piece of information displayed would at first seem that a format should be as follows:

X position	Y position	information

The normal usage of information, however, shows that there is usually a relationship between adjacent pieces of information. In the normal typed text or a drawn line that has been broken up into segments, the location of the next piece of information is incrementally connected to the previous one in some manner. The special case would then be taken as the carriage return for the typed text or the end of a line segment in the above examples. So only at these positions would an absolute location be required.

In the case of characters, the normal mode is to increment from left to right. This mode, along with an incrementing from up to down, has been included in the design.

In the case of vectors, several methods were examined. The generation of the vectors is to be under computer control so that any format using simple computations could be used. The following were the three possibilities:

a. Given a starting position, let the computer specify a completely variable ΔX and ΔY.

b. Given a starting position, let the computer specify a limited number of ΔX and ΔY in a coded format.

c. Given a starting position, let the computer specify ΔX and ΔY in 45 degree increments in coded format for a limited number of lengths.

Methods a. and b. both require dividers or variable length incremental counters in their construction. Also, method a. needs a completely variable intensity compensation over the line length variations. Method c. needs incremental up and down counters only, but needs counting rate changes and intensity compensation for each length of line to be drawn.

The accuracies of methods a. and b. are greater, but they sacrifice packing density, and they require a greater amount of hardware to construct.

Using this criteria (also keeping a six-bit coded vector package to be compatible with the character coding size), the design incorporated was that of method c., but allowing for an extremely short vector so that the error could be minimized if the accuracy was needed. The use of incremental counters also makes easier the sequential designation of vectors for forming continuous lines.

The requirement for both characters and vectors dictated that a bit be set aside in each string designator word for "mode". The details of display coding will be covered in detail in Chapter 6.

<u>There should be two display tubes, only one of which is a direct slave to the radar inputs.</u> Inasmuch as this system is in part being designed to allow investigation on various digital processing techniques in radar detection, the use for comparative displays is desirable. One display tube must be available to display video information at any time between the "main bang" and the maximum range time (if radar input has been selected). During this time, all display information from the internal memory must be

Blocked out [illegible] a [illegible] target. This limits the amount of [illegible] that may be done on this tube. The amount is proportional to the amount of time between the [illegible] and the [illegible] of the next [illegible].

The second tube is independent of the radar inputs and can be used to display processed radar with background maps and amplifying information (such as weight, type [illegible], etc.). This tube is always available to the memory cycle and can be used in conjunction with the direct radar display.

Future displays could perhaps be built utilizing dual beam electrostatic tubes[1] to remove the restrictions on time sharing of radar signals and computer displays.

<u>The manual inputs should allow flexibility</u>. The system is designed to be used with a stored program computer, so that a measure of flexibility is accomplished through the use of stored subroutines. The method of calling in a set of subroutines from a magnetic tape library must allow for different sections of the library to be called in for different uses of the console. This is best handled by an overlay [illegible], in addition to [illegible] switches to designate an overlay, can change the switch function [illegible] by having the function associated with each switch be engraved on the overlay board.

[1] Electronic Tube & Instrument Div. of General Electric Co., [illegible] - 12 ½ Inch Diameter, Dual Beam, Electrostatic Focus and Deflection Cathode Ray Tube, Sep., [illegible]

In addition to the [illegible] switches, there are a few functions common to all uses of the console. These are located on a subset of the special overlay function switches, and together they are referred to as keyboard two.

The character keyboard is referred to as keyboard one. This keyboard is made up of all the standard numerals and alphabet, along with special characters to complete the keyboard. These keyboards and their coding will be given full treatment in Chapter 7.

Other manual inputs required are a range switch to control the displayed radar presentation and some method for locating and identifying points on the display. There are two common methods for accomplishing this function digitally:

a. Track ball

b. Photo electric light gun

In the track ball method, two shaft position encoders are placed at right angles, and a ball in contact with both encoders allows the operator (by rolling the ball) to position the encoders very accurately. A symbol will have to be displayed under program control whose center is located at the X, Y position given by the encoders. Thus, by calling for the program to display track ball, the symbol may be centered over any point of interest, and then by a second subroutine this information may be used to enter new information or find a memory cell which contains this point for purposes of changing the display.

The method of the light gun accomplishes the same purpose, but it is positioned by hand over a display, and then the light sensi-

tive circuit is energized and the portion of the tube face under the light gun is illuminated, a circuit can be made to extract the contents of that memory cell or find the position.

The light gun is faster, and its use is a more natural reaction, but for closely spaced points the track ball with its accuracy is easier to use. Based upon this reasoning, a track ball was used in the DD-65.

<u>The display should allow for an auxilliary output channel to dump radar data.</u> In order to obtain best utilization of the computers, i.e., to let them perform computations at a speed limited by the programs (without interruptions for storing data), an auxilliary channel to accept the digitized X, Y (and Z component with minor modifications) has been provided. A buffer memory unit and associated control circuits should be provided between the radar data, and the computer assigned to do the processing. The radar processing computer can then call for targets at its own rate. The buffer memory unit must have a fast access time in order to accept targets at the rate they are received from the radars. The access time needs to be on the order of 100 microseconds if no targets are to be missed. This requirement can be met by designing the buffer unit from standard flip-flop circuits. This is economically feasible as the word size is only 12 bits, and the number of storage words needed should be small.

4. Hardware Consideration and Mechanization of Design Procedure

In order to design digital equipments to have high component packing density and at the same time to allow for easy maintainance, the computer industry has developed the following technique. The circuits to be used are specified in terms of type (pulse or level signal) and speed of response desired. From these requirements, a family of circuits can be designed which are compatible and which, by interconnection, can perform the logical functions AND, OR, or NOT. These circuits are then placed on printed circuit cards either singlely or in small groups. The system designer then need only know the parameters and limitations of the family of logic cards in order to specify the interconnections necessary to design a particular equipment. The construction is then completed by wiring the interconnections on a chassis made up of logic card sockets. In this way all active elements are on the removeable cards to allow for easy replacement of a faulty circuit.

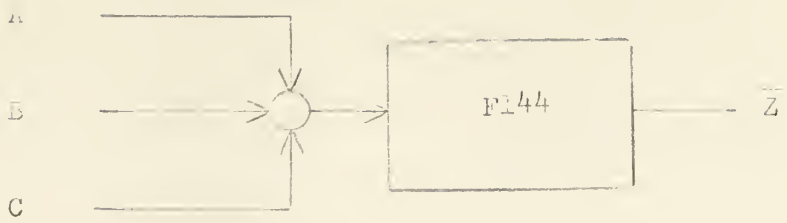
The logic card family used in the design of the DR-5 is mainly the Control Data Corporation type as described in their manuals /17, 18/ and reported on by J. F. Farrell /20/. These cards are designed to operate at clock rates up to five megacycles as level signal inverters. The switching delay is between 50 and 100 nanoseconds per card. Additional cards have been developed by Data Display, Incorporated for the special uses needed in displays. These are in two main categories: (a) Digital to analog conversion cards for driving the display beams and (b) a fast set of cards to work at about 20 mc for the display of digitized radar information.

[illegible] be [illegible] to [illegible] [illegible] [illegible] [illegible] compatible with the basic notions of [illegible] [illegible] except for some [illegible] details [illegible]

The logic circuitry used in [illegible] circuit is an inverter with [illegible] in such a way that (a) [illegible] together at a single input of another card, a logical [illegible] or (b) by connecting the outputs of more than one card to a card with multiple inputs a logical [illegible] is produced. Figure [illegible] shows the two basic configurations for the symbology used to denote logic functions. These basic functions may be combined to enable the designer to realize any complex logical condition desired.

This type of logical building block lends itself to system design using an initial input of [illegible] tions which are to be implemented.[1] For reason [illegible] that the three level logic ([illegible]) shift [illegible] logic [illegible] not easy to reduce [illegible] The method used is to specify the functions [illegible] In this way conditions [illegible] built up without carrying along the [illegible] tions that would be required. The technique used is equivalent [illegible] naming each inverter [illegible] the design [illegible], an equation file can be written in terms of inputs to each inverter.

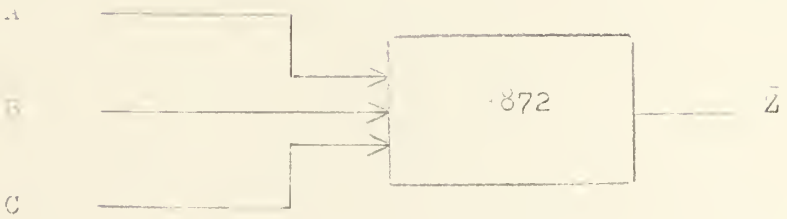
[1] A comparative system which can be implied technically is the "Sheffer stroke" system.



$$Z = A \cdot B \cdot C$$

$$\overline{Z} = \overline{A \cdot B \cdot C} = \overline{A} + \overline{B} + \overline{C}$$

LOGICAL "AND"



$$Z = A + B + C$$

$$\overline{Z} + \overline{A + B + C} = \overline{A} \cdot \overline{B} \cdot \overline{C}$$

LOGICAL "OR"

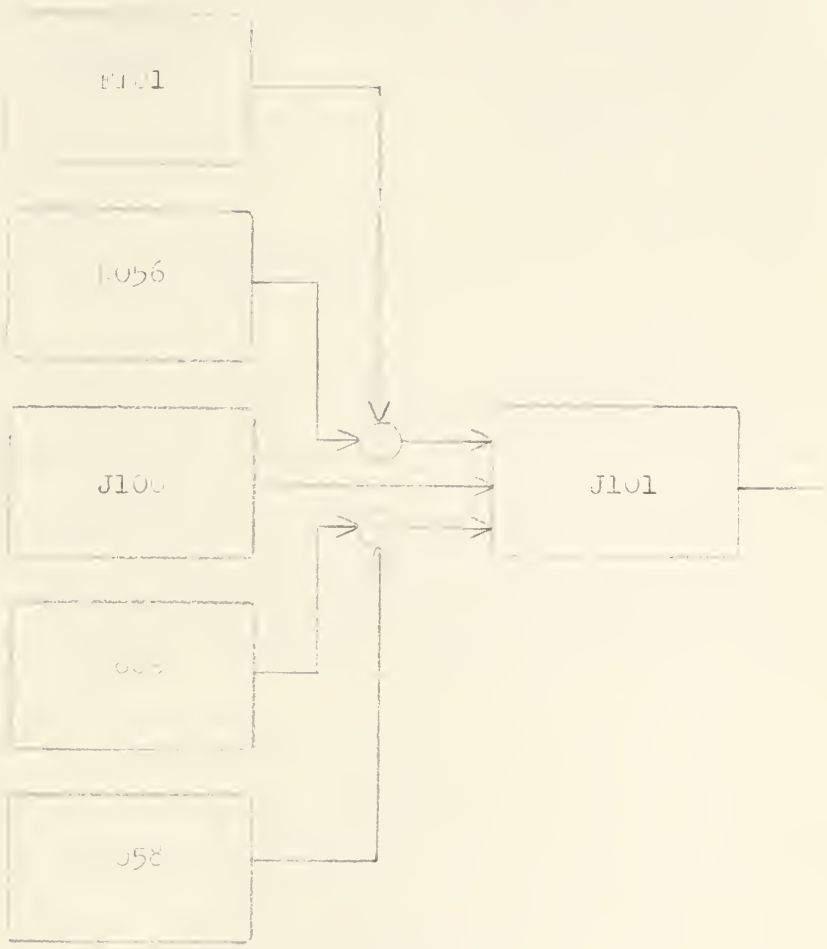
Figure 4-1
Logic Diagrams in Control Data Corporation Notation

This is shown in Figure 4-2. As the equations are written in terms of inputs, no explicit statement of the inversion is used. When the design diagrams have been completed the individual card types may be assigned based on the number of inputs and outputs. Once the card types have been assigned, the total number of cards needed are uniquely known, and a chassis size may be chosen. In this line of cards there are up to three inverter sections on each card. The chassis layout can then be specified by assigning each card section a place on the chassis. This is done by assigning a row, a column, and a section to each inverter. The assignment is usually a compromise between obtaining the minimum lengths of interconnecting wire and keeping sections of the chassis grouped into areas of logical functions.

The last step in committing a logical design to hardware is the actual assignment and completion of the interconnecting wiring. The wiring constraints are set by the fact that each card socket has only two terminals per pin. This means that multiple ...D signals have to be distributed along the wiring 'tree'.[1] (See Figure 4-3). The task of assigning pin connectors in a manner to minimize wire length is very tedious, and the tedium of it tends to cause errors in the production of a wiring tabulation.

The desire to minimize the number of errors induced in the process between the design diagram and the wiring tabulation re-

[1] a 'tree" is a graph having only one path between every two nodes.

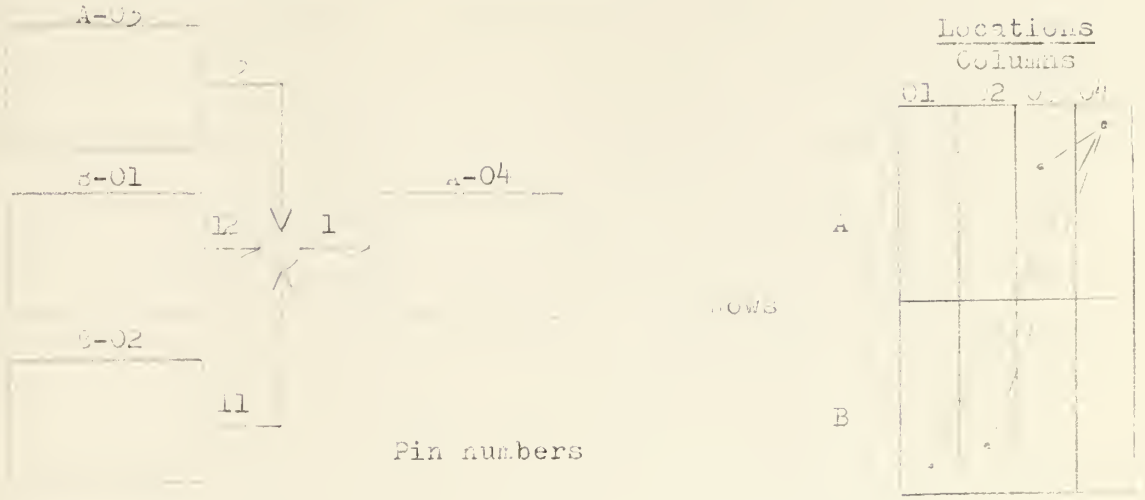


J101 = J100 + B069 · R056 + F100 · R05

Figure 4-2

Example of an equation written from a Logic Diagram

In order to wire an "n" gate of more than two inputs, the following considerations are necessary:



Each connector has only connection terminals for two wires so that the interconnection similar to the depiction in the logic diagram is not possible. The resulting method is to build up a complete wiring "tree" by first accepting the smallest interconnecting wire and then building on this base until all "nodes" have been added to the tree.

Figure 4-3
Constraints on Chassis Wiring

suited for programming, effort was made to automate some of the functions on the Control Data Corporation 1604 computer. The computer has been assigned the tasks of forming and printing out the completed file of equations and the final minimum wire length wire tabulations. Also, the program will assign card types, call attention to illegal equations, and give a tabular total of the number of cards by types required to implement the design. The necessary inputs are a set of "punched cards" which each such contain the equation for a single logic card section and a location for that logic card. The detailed report on usage of the program and an assembly listing of the program is included as appendix [illegible] of this thesis. A sample of the input and outputs are shown in figures 4-[illegible], 4-5, 4-6, and 4-7.

The method for computing the minimum length wiring to connect a group of nodes is based on an algorithm by Loberman and Weinberger./31/

This program was used in the production of the initial wiring data for the [illegible]-5. The total card count for the design is over 1500 cards. There are two separate chassis which made separate program runs necessary. The time required to compute the complete output listing was less than 20 minutes (exclusive of printing the magnetic tape off-line).

```
                    CHASSIS 1     DD 65
A000 = A001 + A002 V205 + A101 N009 + A201 N109                    J1 J05A
A001 = A000 J842 + A003 V205 + N108 + GNDE                         J1 J06A
A002 = A003 + A001 N800                                            J1 L04A
A003 = A002 + A000 N800 + GNDE + GNDE                              J1 J07A
A010 = A011 + A012 A003 V205 + A111 N009 + A211 N109               J1 J05C
A011 = A010 + A013 A003 V205 + N108 + GNDE                         J1 J03A
A012 = A013 + A011 N800                                            J1 K03C
A013 = A012 + A010 N800                                            J1 K03A
A020 = A021 + A022 A013 A003 V205 + A121 N009 + A221 N109          J1 L08A
A021 = A020 + A023 A013 A003 V205 + N108 + GNDE                    J1 L07A
A022 = A023 + A021 N802                                            J1 L06A
A023 = A022 + A020 N800                                            J1 L06C
A030 = A031 + A032 V215 + A131 N009 + A231 N109                    J1 L08C
A031 = A030 + A033 V215 + N108 + GNDE                              J1 L09A
A032 = A033 + A031 N802                                            J1 L10C
A033 = A032 + A030 N802                                            J1 L10A
A040 = A041 + A042 A033 V215 + A141 N009 + A241 N109               J1 N08A
A041 = A040 + A043 A033 V215 + N108 + GNDE                         J1 M08A
A042 = A043 + A040 N804                                            J1 M09A
A043 = A042 + A041 N802                                            J1 M09C
A050 = A051 + A052 V225 + A151 N019 + A251 N119                    J1 N08C
A051 = A050 + A053 V215 + N118 + GNDE                              J1 N09A
A052 = A053 + A051 N804                                            J1 N07C
```

Figure 4-4
Sample of Input to Mechanization Program

```
                    CHASSIS 1     DD 65

A000 = A001 + A002 V205 + A101 N009 + A201 N109
 J1 J05A   24    A005,    A001,

A001 = A000 J842 + A003 V205 + N108 + GNDE
 J1 J06A   14    T011,    H215,    A200,    A100,    A002,    A000,

A002 = A003 + A001 N800
 J1 L04A   22    T012,    T010,    A003,    A000,

A003 = A002 + A000 N800 + GNDE + GNDE
 J1 J07A   14    T013,    A021,    A020,    A011,    A010,    A002,    A001,

A010 = A011 + A012 A003 V205 + A111 N009 + A211 N109
 J1 J05C   24    A013,    A011,

A011 = A010 + A013 A003 V205 + N108 + GNDE
 J1 J03A   14    T013,    T012,    H215,    A210,    A110,    A012,    A010,

A012 = A013 + A011 N800
 J1 K03C   22    T011,    T010,    A013,    A010,

A013 = A012 + A010 N800
 J1 K03A   22    A021,    A020,    A012,    A011,

A020 = A021 + A022 A013 A003 V205 + A121 N009 + A221 N109
 J1 L08A   24    A023,    A021,

A021 = A020 + A023 A013 A003 V205 + N108 + GNDE
 J1 L07A   14    H215,    A220,    A120,    A022,    A020,

A022 = A023 + A021 N802
 J1 L06A   22    T001,    A023,    A020,

A023 = A022 + A020 N800
 J1 L06C   22    T000,    A022,    A021,

A030 = A031 + A032 V215 + A131 N009 + A231 N109
 J1 L08C   24    A033,    A031,

A031 = A030 + A033 V215 + N108 + GNDE
 J1 L09A   14    T002,    H225,    A230,    A130,    A032,    A030,

A032 = A033 + A031 N802
 J1 L10C   22    T003,    A033,    A030,
```

Figure [illegible]
Sample of output of file of equations

U S NAVAL POST GRADUATE SCHOOL DATA PROCESSING LABORATORY

COMPILATION OF CARD ASSIGNMENTS

CARD TYPE	NUMBER OF CARDS
11	1
12	NONE
13	NONE
14	210
15	1
16	36
31	NONE
32	NONE
33	NONE
21	81
22	204 1/2
23	17
24	29
01	21
61	NONE
62	NONE
S36	3 2/3
S04	NONE

Figure 4-3
Sample of Card Compilation

U S NAVAL POST GRADUATE SCHOOL DATA PROCESSING LABORATORY

INTER CARD WIRING TABULATION

	ORIGIN	DESTINATION	DESIGNATIONS	WIRE LENGTH
*	J05-01	J06-12	A000 TO A001	3 INCHES
*	L04-06	J09-12	A002 TO V205	6 1/2 INCHES
	J05-02	J09-12	A000 TO V205	3 1/2 INCHES
*	J05-03	I03-12	A000 TO N009	3 INCHES
	I02-12	I03-12	A101 TO N009	1 1/2 INCHES
*	J05-04	H05-06	A000 TO A201	7 INCHES
	H05-06	H12-06	A201 TO N109	4 INCHES
*	J06-01	J842	A001 TO J842	31 1/2 INCHES
	J06-01	J05-06	A001 TO A000	2 INCHES
*	J06-02	J07-12	A001 TO A003	3 INCHES
	J07-12	J09-11	A003 TO V205	2 INCHES
*	J06-03	L01-06	A001 TO N108	8 INCHES
*	J06-04	GNDE	A001 TO GNDE	32 INCHES
*	L04-01	J07-11	A002 TO A003	6 INCHES
*	L04-02	J06-11	A002 TO A001	6 INCHES
	J06-11	J08-12	A001 TO N300	2 INCHES
*	J07-01	L04-05	A003 TO A002	8 INCHES
*	J07-02	J08-11	A003 TO N300	2 1/2 INCHES
	J07-02	J05-05	A003 TO A000	2 INCHES
*	J07-03	GNDE	A003 TO GNDE	32 INCHES

Figure B-7
Sample of Wiring Tabulation

5. Radar Conversion Unit

The system must perform the two separate functions previously described in Chapter 3, i.e., (a) that of direct display of unprocessed video on a digital raster on a display tube, and (b) that of making available to the computer the digital information on a radar return if it is a possible target.

The requirement of a real time radar display places a restriction on the use of the display for computer generated information. The portion of time between start of sweep and the maximum range to be displayed must generate a signal to lock out any memory references to the display. As a result of this restriction, the system has been designed to include two separate display tubes so that one is always available for computer generated display information. The normal display information in the memory is directed to the designated display tube. The tubes are designated "0" for left and "1" for right for purposes of coding commands. The choice of which tube is to present the display is controlled by the use of the tube designator bit in the coding structure which will be discussed later. This "tube bit" controls the intensity grid of the designated tube by enabling the "unblank circuitry" to turn on the electron beam. Also, it sets the condition which [illegible] the display deflection signals to the designated tube. When radar video information is desired, the range switch is placed to the appropriate range. The receipt of a "main bang" from the radar set [illegible] a flip-flop whose output is used to remove control of the [illegible] the internally generated display information (see Figure [illegible]). The

"set" output of the flip flop "enabled" the X and Y digital radar counters to input to the position registers of the digital to analog converters. The "set" output also "disabled" the output of the computer generated display information, even though tube "0" may be designated to display some information while in the radar mode. When the designated maximum range has been reached, a signal is generated which "resets" the flip-flop. Thus, the internal display information can now be displayed on tube "0" until the next "main bang".

The range switch settings are shown in Figure 5-1 along with the time required by the radar to display each beam. This is based on the propagation rate of radar signals being 12.35 microseconds per range mile. The radar characteristics of the unclassified radars to be used with the system are shown in Figure [illegible]-2. The remainder of the table in Figure 5-1 is a listing of the proportion of time remaining for inserting computer generated displays to the total amount of time possible. This information should be used when writing system programs to superimpose target information over a radar display. For example, if using the SPS-8 with the pulse repetition frequency set to [illegible] cycles per second and the range switch set to 64 miles, the availability of tube "0" to the generated display is 60.4% of the time. This indicates that the information should be written into the memory at two places to insure that it will be displayed. This technique of time sharing limits the amount of information that can be superimposed on the longer ranges. The SPS-26 places a slightly more stringent set of re-

Range Switch Setting in Miles	Radar Display Time Requirements in Micro-seconds	Ratio of Time Available for Display			
		S P S - 8		[illegible]	[illegible]
		[illegible]	[illegible]	[illegible]	[illegible]
[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]
[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]
16	196	[illegible]	[illegible]	[illegible]	[illegible]
32	196	[illegible]	[illegible]	[illegible]	[illegible]
64	[illegible]	.308	[illegible]	[illegible]	[illegible]
128	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]
256	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]

Figure 5-1

Comparison Table of Time Available for Display [illegible]

	[illegible]	[illegible]	[illegible]
Horizontal Beam Width (in degrees)	.5	3	.5
Horizontal Rotation Rate of Antenna (in revolutions per minute)	5 to 1	[illegible] to [illegible]	1 to 10
Vertical Beam Width (in degrees)	[illegible]	[illegible]	1.1
Azimuth Information Available	1:1 Speed Synchro	1:1 Speed Synchro	1:[illegible] Speed Synchro
Peak Power (in kilowatts)	50	500	[illegible]
Pulse Width (in microseconds)	4	4	[illegible]
Pulse Repetition Frequency (in cycles per second)	150	[illegible]00	150 or [illegible]
Expected Range (in miles for 1 square meter target)	[illegible]	52	[illegible]

Figure [illegible]-2
Characteristics of Radars to be Used in the System

quirements on the display for time sharing than any of the unclassified radars.

The method of generating the radar sweep requires accurate azimuth information in the form of a shaft position from the radar. This shaft motion drives a digital shaft position encoder whose outputs are sine ϕ and cosine ϕ. The outputs have an accuracy of ten magnitude bits plus a sign bit. These quadrature values are then "multiplied" by a series of range pulses in such a manner that counters being driven by the multipliers hold the results R(sine ϕ) = Y, and R(cosine ϕ) = X. When the range counter reaches its maximum value as determined by the range switch, the range counter is cleared, and the X and Y counters are then disconnected from the digital analog converters by the "end of radar" flip-flop previously described.

This technique then describes a radar display raster of the form shown in Figure 5-3. There are 2,048 separate "bits" in X and in Y corresponding to the 11 bits. This gives a possible accuracy of $\pm$ 1/4 nautical mile on the 256 mile range with possible accuracies increasing to $\pm$ 7.9 yards on the four mile range. The actual accuracy of the video display without a video processor incorporated to use only the centroid of the radar return is mainly limited by the pulse width of the radar used. The pulse widths range from one to four microseconds (see Figure 5-2) with a resulting possible error of approximately $\pm$ 1/12 mile to $\pm$ 1/3 mile.

The heart of this system is the range counter and the oscillator driving the counter. The clock frequency required to obtain

the accuracies needed is 20.72 μs. The range switch then enables different bit positions of the counter to trigger the rate multiplier which results in full scale deflections for the chosen range. The radar section of the logic is the unit that determined the need for the new series of fast cards discussed in Chapter 4. The switching times of these logic cards were required to be much faster to reduce spikes in the radar video raster caused by the carry pulse in the counters when the most significant bit changes. (See Figure 5-4) These spikes (or "blivets") should be reduced in width enough to be insignificant by the fast cards.

The requirement of 11 bits of accuracy for the azimuth information requires accuracy to 0.175 degrees. The azimuth information available from the radars is in the form of 60 cycles per second synchro signals. The SPS-8 and SPS-26 have two-speed synchro systems which have an accuracy well within the 11 bits specified by the encoder. The SPS-6 and SPS-12 have only a one-speed synchro system which could have a maximum accuracy of about 0.3 degrees from the components. It is evident then that the available accuracy of bearing information is not quite precise enough for the system requirements. One other problem in this system is that the torque and inertia loads of the shaft position encoder require a high gain servo-system to drive the encoder. In order to furnish the maximum accuracy at suitable power levels to the encoder for each of the radar inputs, it was necessary to convert the individual radar synchro outputs to a single speed, high accuracy synchro output from the radar switch panel. The converter to be used for

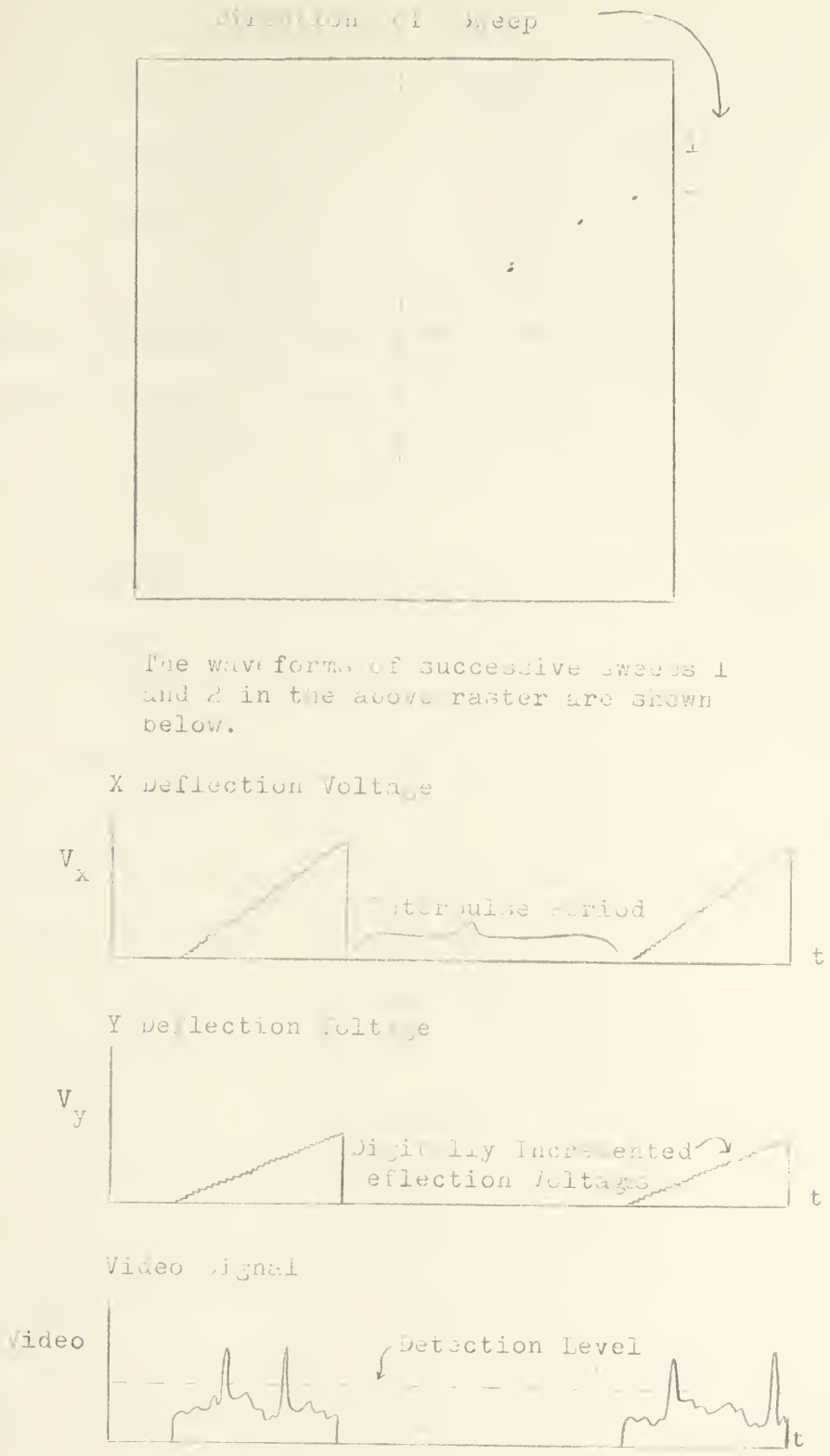
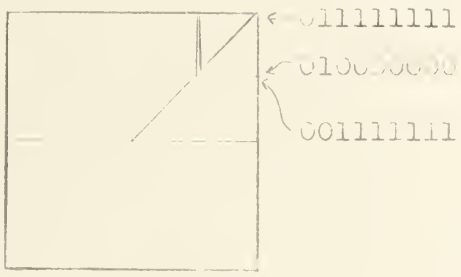


Figure 5-5 Example of the Digital Raster Produced by the Radar Scan

The condition exists when a digital increase of one increment in the lowest order bit position causes a carry bit in the higher order bit positions. For example: For a change of the Y counter from 001111111 to 010000000, two possibilities may occur if the circuits concerned have a large difference in rise times.

1. The carry bits may be too fast resulting in the value of 011111111 for an instant.



2. The carry bits may be too slow resulting in the value of 000000000 for an instant.

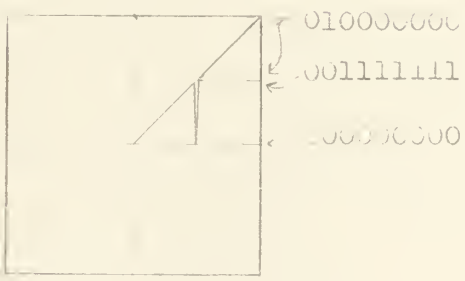


Figure 5-4

Formation of "blivets"

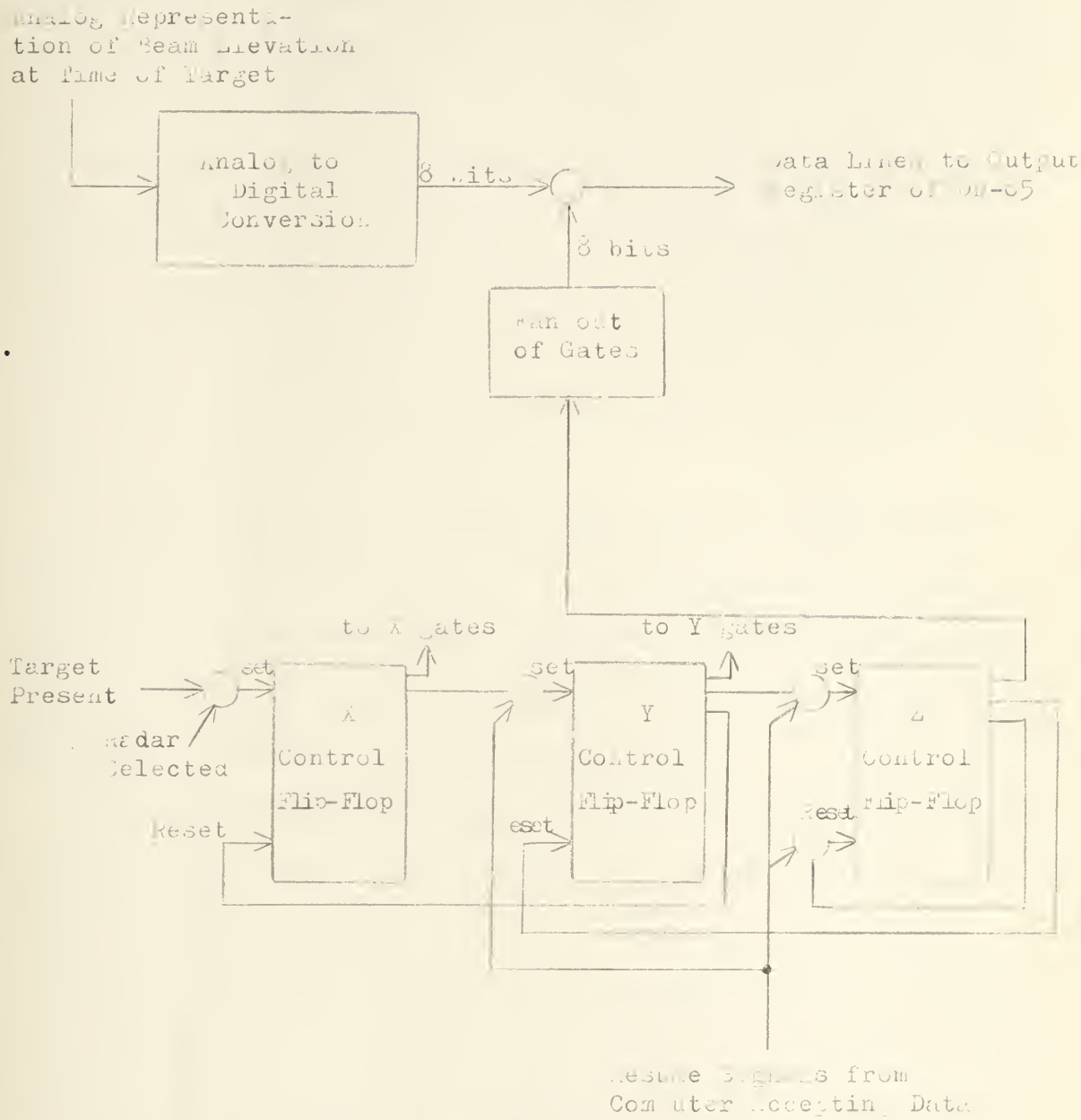
this is a "synchro amplifier". The unit is a standard Navy Supply servo system which accepts one or two speed synchro information and furnishes an accurate one speed synchro output. The output is specified to be a 400 cycle synchro signal for the long cable run from the Radar Laboratory to the Digital Control and Automation Laboratory. A commercial high gain servo system is to be purchased for driving the encoder unit in the DD-65.

The remaining requirement that the digital radar information be made available to the computer has been implemented by gating the 11 bits of X and 11 bits of Y to storage registers upon receipt of a signal signifying the presence of a possible target. This signal will be generated from raw video by an automatic detector which is designed to trigger when certain conditions are met, such as amplitude, slope of signal envelope, or combinations of time and amplitude. The study of optimum auto-detection units is to be one of the primary uses of this system. The detection units are to be fabricated on standard computer cards and locations for these circuits have been left in the operator's console of the DD-65. One type of detector has been designed and build by D. R. Briggs. It is a threshold detector with a voltage variable false alarm rate. This unit will be used on initial tests and is documented in a separate report /21/.

In the system design it was assumed that either the 160 or 1604 could be called on to process the radar data; so the X and Y registers were designed to be callable separately by the computers instead of packing them into a 22-bit word. This allows the 1604

with its 16-bit word structure to handle the processing job without excessive shifting of bits. The request by the computer for radar information sets a step counter which will sequence the X and then the Y information in a two-word group. The computer program must be tailored to this grouping by using a standard block input coding.

Provision has been left for extending the step counter to a three-word radar sequence. This was done to allow a third word, containing some measure of elevation angle or height information, to be sent to the computer for processing when using the SPS-26 or SPS-6. The output register of the DD-85 has eight bits set aside for this purpose. The implementation of this will entail an analog to digital conversion of the raw data into eight bits of digital information and provide a gate controlled by the third count of the step counter to enable the lines to the output register (see Figure 5-5).



Present logic includes only the X and Y control flip-flops.

NOTE: Set side of flip-flop is upper side; reset side of flip-flop is lower side.

Figure 5-5
Necessary Logic for Addition of Height Information

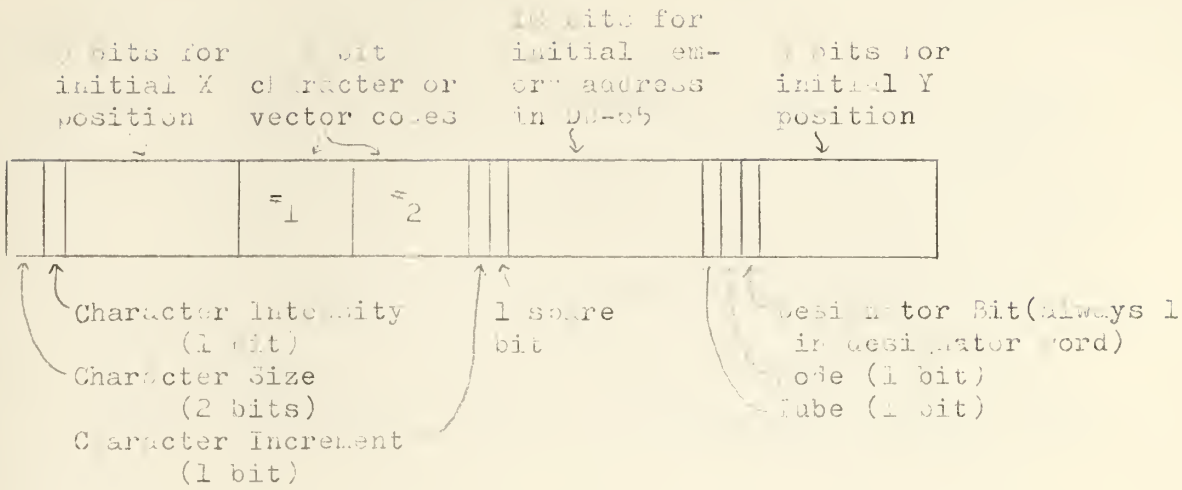
b. Design of Character and Vector Generators

The display of the actual characters and vectors is performed by cycling through the self-contained memory in the DD-65. This memory size is 1024 x 24. Therefore, in order to fill the memory with information, 512 words of 48 bits each would be required from the Control Data Corporation 1604 or 2, 48 words of 12 bits each would be required from the Control Data Corporation 160. Any updating of information from the computers to the DD-65 breaks the display cycle, but saves the address of the next display word, and continues from the break address after the new information is read into the memory.

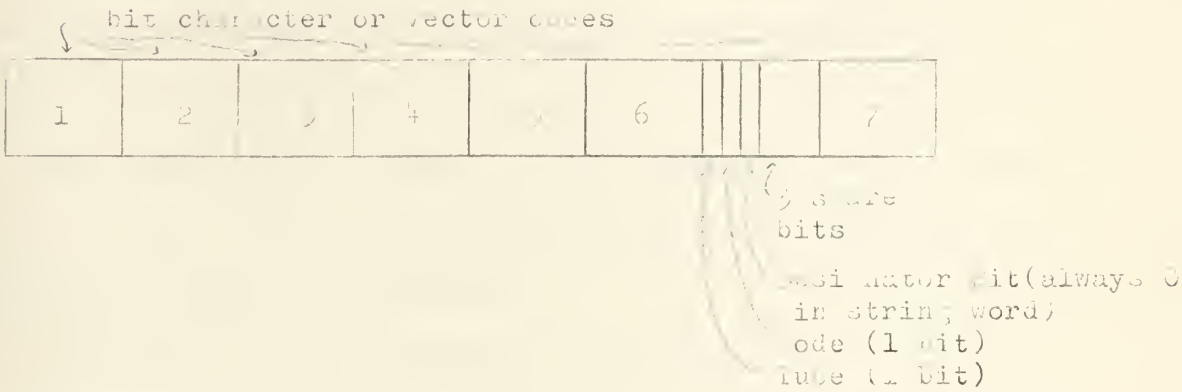
The basic length of the words needed by the decoding logic is 48 bits. This requirement is dictated by the fact that the number of bits needed for control information, position, and address are more than the 24 bits of the memory word. This then limits the total possible number of display words to 512.

As was mentioned previously, the formation of the characters or vectors are grouped into "strings". The first word of each string is called a "designator word". (see Figure 4-1) This furnishes the control information to the decoding logic to prepare for displaying the information. Two characters or vectors can also be packed into the "designator word" to provide fast updating of a moving symbol. All following words up to the next "designator word" are considered to be string words. They can have up to seven characters or vectors packed into each word. The reason for using only seven of the eight possible symbols is the need to be able to

DESIGNATOR WORD (1-1[illegible] word or [illegible]-1[illegible] words)



STRING WORDS



CONTROL CODES:

Mode: 0 - character (enables logic to decode the character information codes)

1 - Vector mode (enables logic to decode the vector information)

Tube: 0 - Display the stored information on left tube

1 - Display the stored information on right tube

X and Y positional information is formed by an eight-bit "absolute" magnitude code with a sign bit added to indicate direction from the center of the tube (0 sign bit is positive and 1 is negative). Initial memory address of DD-05 must be specified for each string by a 10-bit address code. The storage of consecutive words is incremented within the logic.

Figure 6-1 Programming Information for String Words

uniquely recognize the designator bit "D". Thus, the "D" bit must remain "0" in all string words.

In order to make corrections or update any part of a string, the whole corrected string must be read into the display memory. This is due to the incremental mechanization of the address counter. Only the designator word contains an address reference for the memory. Once a string of display words has been set up to read into the memory, the address counter is incremented as each 24 bits is accepted.

The designator word also contains the initial positioning information for the string. The initial position of the string is specified by nine bits of X and nine bits of Y. This allows a position to be selected to within 1/512 of the usable scope face. The usable portion of a 12-inch diameter tube is a square raster of about 8.5 inches. This allows the position of any symbols to be designated to within 0.0165 inches.

The choice of tube to display the information and the mode (i.e., choice of whether the information is a character or vector string) must be repeated in each word of the string. The appropriate coding for these are shown in Figure 6-1.

The vector mode and the character incrementing portion of the character mode use the same logical packages. These are a pair of nine bit position counters. The X and Y position counters are initially set to the position specified in the designator word for a string. The outputs of these counters drive the position registers of the digital-analog converters for the display tubes (see Fig-

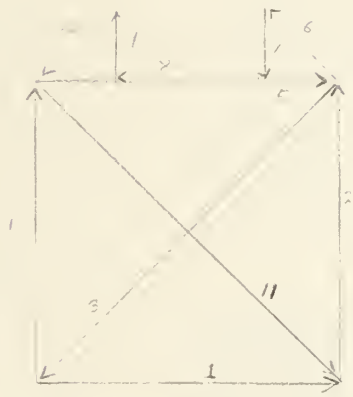
ure 6-1). The counters are designed so that the contents may be counted up or down or not incremented depending on the control signals generated in the decoding logic. Thus, the amount and direction of beam movement is determined by the individual mode decoding circuits.

The vector mode requires only initial position information from the designator word. The formation of a line is started by unblanking the beam and then moving it in direction and distance as specified by a six-bit vector code. The beam is then "blanked" while the next six-bit vector code is brought into the decode logic. The sequence is then repeated until the next designator word is encountered. This technique produces a line by starting each new segment from the end point of the last (see Figure 6-2). The blank words between the end of any information and the next designator word causes no problem as the "0" code in either the vector or character mode does not unblank the beam even though the position counters may be incrementing.

The vector decode logic separates the six-bit code into a three-bit direction code, a two-bit size code, and an "unblank" bit. The direction code allows for eight possible directions which corresponds to 45° increments in direction. The size code allows for four possible segment lengths. The unblank bit can be used to form dashed lines by allowing the beam to be blanked while still following a prescribed vector path. The vector codes are shown in Figure 6-3. The direction code determines the operation of the X and Y position counters, i.e., whether to count up, count down or

In order to depict the location of an infantry battalion on a military map, the following symbol is used:

To include this symbol on a map generated by the DD-5, the following trace could be generated:



The sequence of necessary vector codes (see Figure 6-5) to form the above symbol is:

(1) 110000
(2) 110010
(3) 110101
(4) 110010
(5) 110000
(6) 000011
(7) 100100
(8) 000100
(9) 100010
(10) 000101
(11) 110111

Note: The starting point location must be given in the designator word.

Figure 6-2 Example of the Trace Produced by Vectors

Vector format (5 bits per vector)

3 bits for direction
2 bits for size
1 bit for intensity

Intensity Information

Code	Interpretation
0	Deadening of the beam
1	Normal intensity

Size Information

Code	Interpretation
00	X and/or Y coordinate deflection is 1/128 of full scale deflection
01	X and/or Y coordinate deflection is 1/64 of full scale deflection
10	X and/or Y coordinate deflection is 1/32 of full scale deflection
11	X and/or Y coordinate deflection is 1/8 of full scale deflection

Direction Information

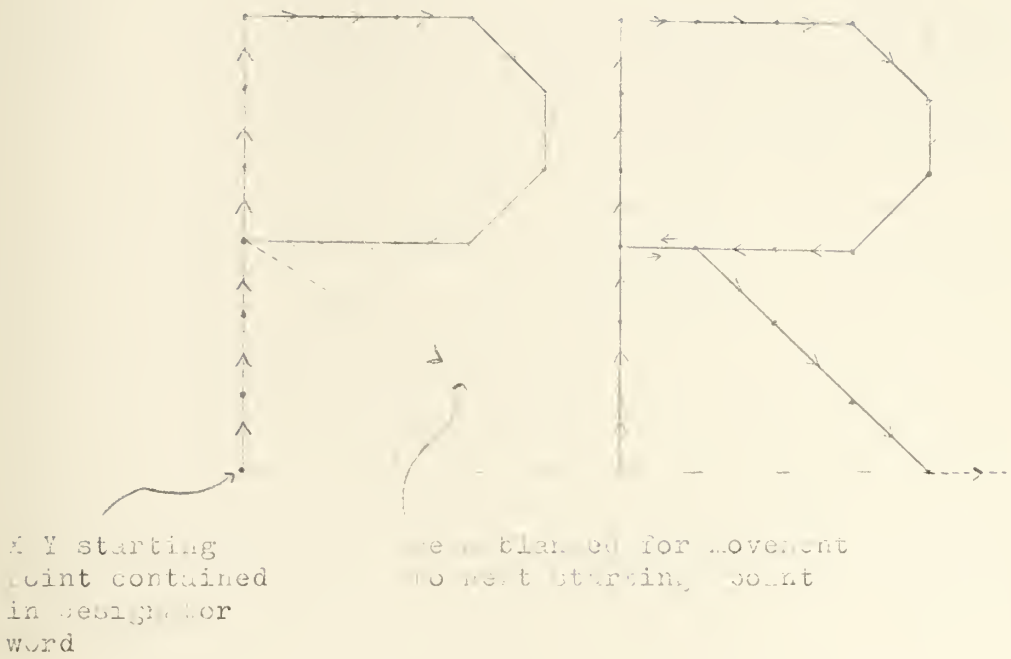
Code	Interpretation
000	Vector is drawn at an angle of 0° from starting point
001	Vector is drawn at an angle of 45° from starting point
010	Vector is drawn at an angle of 90° from starting point
011	Vector is drawn at an angle of 135° from starting point
100	Vector is drawn at an angle of 180° from starting point
101	Vector is drawn at an angle of -135° from starting point
110	Vector is drawn at an angle of -90° from starting point
111	Vector is drawn at an angle of -45° from starting point

Figure 6-3
Programmed Information for Coding Vectors

not count. The length code determines when to stop incrementing the counters. The incrementing rate is 0.4 microseconds per pulse, and the number of counts must increase in proportion with the line length. The longest line length was included for the purpose of economical drawing of ordinates. One line, the length of the digital raster, can be packed into a string of two words. It is felt that the smallest increment will allow special symbols to be made up from coded vector strings without being incompatible with the normal character sizes.

The character decode logic is considered to be proprietary information by Data Display, Incorporated. The general technique is one of micro-positioning the beam in relation to a reference X, Y position on a 5 x 7 matrix. The logic is entirely designed from the basic inverter logic cards. The characters are formed by moving the beam and turning it on and off under a clock control whose pulses occur every 0.2 microseconds. The character rate is determined by the number of increments needed to trace the most complex character. For the symbol selection of the DD-65 the number of increments required is 55 pulses. This sets the time for display of one character at 8.8 microseconds. This time includes the incrementing of the reference position to the next character location (see Figure 6-4).

In addition to the initializing information required in the designator word by both the vector and character modes, the character mode requires some additional information on size and incrementing. A convenience intensity control bit is included to



Formation is on a 5 x 7 matrix with spacing generated by the matrix size being slightly smaller than the incrementing deflection.

NOTE: The incrementing information is contained in the designator word.

Figure 3-4
Example of the Trace Produced by Characters

allow [illegible] normal display of characters for purposes of superimposing data over a background or radar display. The format is shown in Figure [illegible]-1. The bit pattern of these information bits sets flip-flops which control these functions throughout the current string. The size selection is limited to only three out of a possible four as no need is seen for the large character. The character size has a direct relation with the position increment length. As the vectors and characters use the same position counters, the character sizes were adapted to the increment lengths designated for vector lengths. The various codes for character control are shown in Figure [illegible]-3. The normal character sizes are the 32 or 64 per display width. The small size was incorporated to allow for possible future photography techniques which could allow large quantities of printed text to be differently recorded for later projection. The direction of incrementing characters within a string is normally to be left to right as in a printed page, but for possible plotting of graphs or points, a down increment has been included. This is easily incorporated as the [illegible] can be [illegible] into the minus side of the Y counter for [illegible] complexity than required for [illegible] only into the plus side of the X counter.

Size Information (2 bits)

Code	Interpretation
00	Character size is 1/128 of full scale deflection
01	Character size is 1/64 of full scale deflection
10	Character size is 1/32 of full scale deflection

Incrementing Information (1 bit)

Code	Interpretation
0	Successive characters are incremented to the right
1	Successive characters are incremented vertically downward

Intensity Information (1 bit)

Code	Interpretation
0	Normal intensity
1	Brighter than normal intensity

NOTE: The usage of these character control codes is shown in Figure 3-1.

Figure 3-5
Character Control Codes

7. Design of the Input, Output and Control Functions

In order to commit the requirements of Chapter [illegible] to hardware, a suitable set of rules in the form of logical circuitry must be designed to allow for the establishment of communications between the various units of the system, and the collection and transfer of data between these units.

The establishment of communications with the computers is accomplished within the standard structure of sense and select commands of the Control Data Corporation 160 and 1604. These commands and the control signals have been documented in the company manuals /17, 18/ and have been included as Appendix 2 to this thesis. All reference to command structures will be made in "octal" notation instead of the actual binary notation. The requirement that the computers can be selectively locked out of the system places an additional restriction on the decode functions. It was decided that in the individual computer operation modes (i.e., 160 only or 1604 only), the select codes for the other computer would be uniquely locked out. In the combined operation mode ("both"), the restrictions were lifted, and the computers can cross select to control the flow of information. For example, it is possible for the 160 to select an interrupt condition for the 1604 in this mode. The only arbitrary decision concerns the flow of manual input (i.e., keyboards, track ball and range switch). In the "both" mode all manual input selects are gated so that the data is input to the 1604.

The request for information or action by a computer is indicated by a 12-bit external function code being transmitted to all

peripheral equipment along with any control signals over their separate lines. From a study of all codes assigned to actual or proposed peripheral equipment for the computers, it was found that the 7XXX series of codes was not designated. This 7XXX series was chosen as the unique code series of the DD-65.

In order to continue further into the design of the control structure of the DD-65, it next became necessary to precisely define the various inputs and outputs and their inter-relationships.

The structure of the display words to be transferred from the computers to the DD-65 has been described in Chapter 6. These are the only data channel inputs to the system from the computers. The transfer of the "strings" of display information is to be by normal computer output blocks. The DD-65 must, then, have the provision for recognizing commands from the computers, to select this transfer, and to set up a "ready - resume" system of signals to control the input of the block of information. These two transfer channels have no restrictions set on them by other data modes of the system, but they should be mutually exclusive.

The digitized radar information is a sequence of words from the radar channel to one of three possible terminal equipments, i.e., the 1004, the 160 or the auxiliary channel. The sequence is controlled by a counter which successively gates in the 11 bits of X and the 11 bits of Y, and has provision for extending this to gate in eight bits of height information. These eight bits of elevation allow an angular resolution of about 1/4 degree. This sequence is triggered by an externally produced target pulse which

be manufactured from the video of the detection circuit. This input entails two levels of selection to be made by the select code used. These are: (a) the choice of one out of three possible terminations for the information and (b) the selection of accepting the radar information exclusive of all other inputs to the DD-65 except from the computers.

The group of manual inputs from the operator's console can only be directed to the computer assigned by the mode switch (as described in this section). This places the requirement for only a single input selection on the select code. The selection is to be exclusive of all other normal input selects.

There is one other unique input necessary from the DD-65 to the Control Data Corporation 160. This is the response to a "status request". This response should be selectable to the exclusion of all other inputs when the program on the 160 is checking for the occurrence of conditions at the DD-65. The response is coded into a one out of twelve response. In this way, if more than one recognizable condition has occurred, the response will include them, and it is up to the 160 program to check for the conditions. The "status response" selection is disabled when in the "1604 only" mode. Note that the 1604 operates the sensing of conditions of the peripheral equipment in a different manner. It uses a separate control signal to denote that the condition has been met.

To expand on the manual inputs, the following separate pieces of information are generated:

a. X track ball 9 bits

b. Y track ball [illegible] bits

c. overlay [illegible] bits

d. Range switch 2 bits

e. Symbol keyboard (number 1) [illegible] bits

f. Control keyboard (number 2) [illegible] bits

The X and Y track ball information has been made separately selectable to keep the DD-65 output register to less than 12 bits so that the same output register and usage rules may be used by both the 160 and 1604. The overlay and the control keyboard have been combined into a nine-bit output, as the method of interpreting the commands of the control keyboard is dependent on the overlay which should control the program package. The range switch and the symbol keyboard are treated independently.

The use of light feedbacks to the console operator (in conjunction with the control keyboard) dictated the need for additional select code requirements. These select codes are used to turn on or off any of the lights associated with the control keyboard. There is no restriction on the use of these selects as they have no inter-action with the inputs or outputs.

One other mode of operation to be incorporated is that of using the interrupt feature available on the Control Data Corporation 1604. These selections need not be unique or exclusive as the portion of the program entered when an interrupt occurs can be made to sense which of the selected interrupts has occurred.

A general diagram of the control function circuits is shown in Figure 7-1. A more detailed breakdown is given in Figure 7-2.

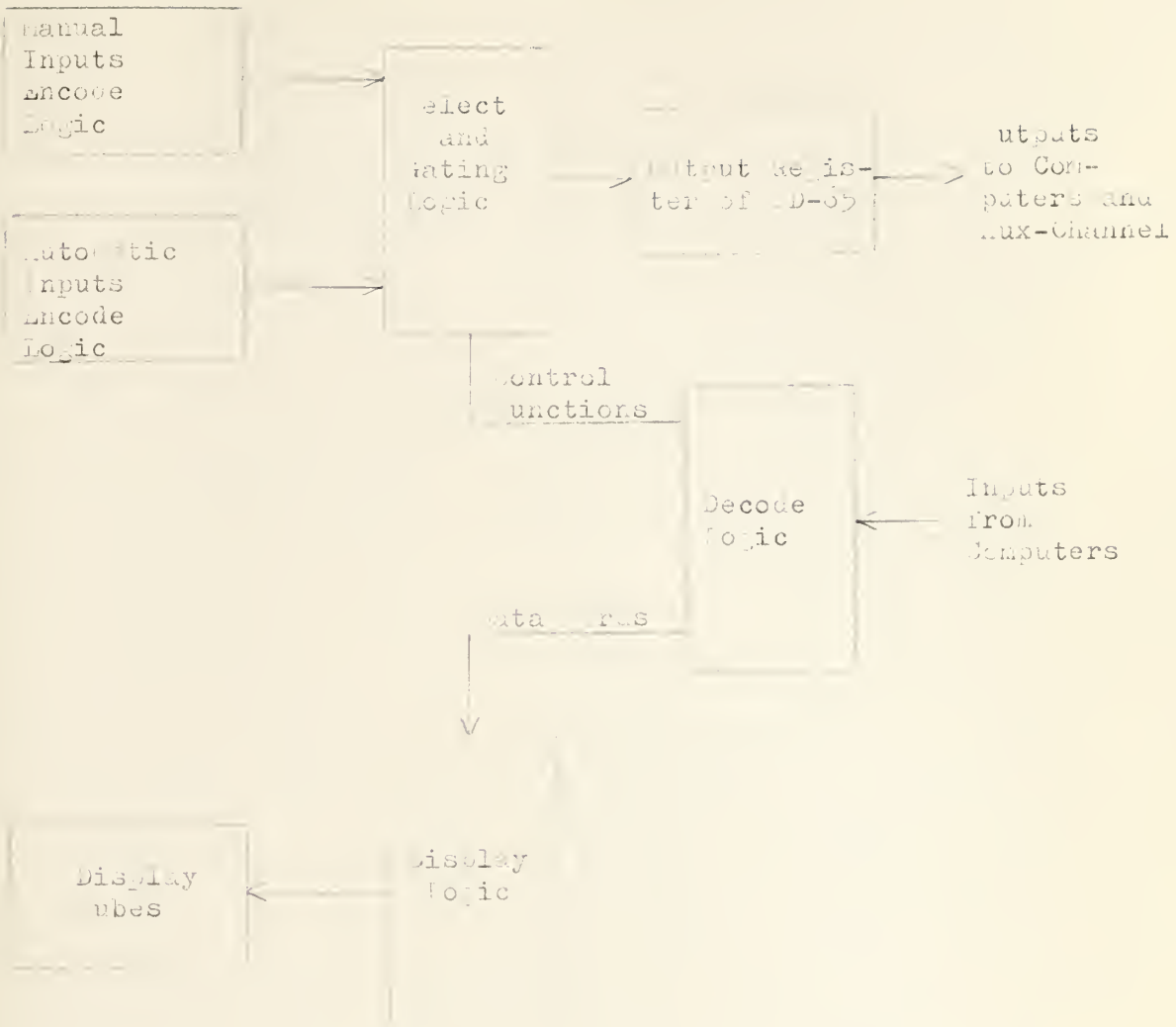


Figure 7-1
General Block Diagram of Control Functions

[illegible] to precisely define the necessary commands. The [illegible] a maximum of 64 possible [illegible]. This is specified by the allowed six bits in the keyboard code. In order to determine the necessary number of symbols needed for keyboard number one (the symbol keyboard), a comparison was made of the symbol sets required for various programming languages. The comparison included the assembly programs AP-2 [illegible] and [illegible] /23/, the business oriented compiler COBOL /24/, and the algebraic compilers [illegible] /25/, ALGOL /26/, and JOVIAL /27/. In addition to the [illegible] set, it was also necessary to include certain few editing keys. These are "carriage return", "tab", and "space". The choice of coding for the symbols was made using the criteria that standardization of the code would be desirable. The coding that evolved is an expansion of the basic "Binary Coded Decimal" (BCD) which is standard in most input and output equipments not having a provision for upper and lower case. The code "00" was not assigned an input symbol, but the key was included on the keyboard so it can act as an alternate space code. This allowed 60 symbols to be assigned to the remaining codes. The final assignment is shown in Figure 7-2. The physical layout of the keyboard was designed to separate the two major functions of its use. A standard typewriter keyboard and a tabular type numeric keyboard were formed by making the key covers of a different color than the special keys around them. This should allow easier identification of these areas of the keyboard for more efficient usage. The 64-key keyboard was bought as a com-

Symbol	Octal Code	Symbol	Octal Code	Symbol	Octal Code
∅	12	C	4	.	73
1	01	P	47	↑	55
2	02	[illegible]	50	,	[illegible]
3	03	R	51	→	35
4	04	[illegible]	22	<	72
5	05	T	23	≥	37
6	06	U	24	≠	14
7	07	V	25	=	13
8	10	[illegible]	26	/	21
9	11	X	27	x	[illegible]
A	61	Y	30	+	[illegible]
B	62	Z	31	-	45
C	63	CR	70	'	16
D	64	Tab	[illegible]	[illegible]	[illegible]
E	65	Space	20	Space	30
F	66	}	52	∧	57
G	67	{	75		
H	70	[	17		
I	71	]	32		
J	41	[illegible]	34		
K	42	)	74		
L	43	:	15		
M	44	//	53		
N	45	;	77		

Figure 7-2 Symbol Character Codes

[illegible]ete [illegible]ac[illegible]ge. Additional [illegible]ic [illegible]s in[illegible]rorate[illegible] [illegible]e the unit compatible wit[illegible] t e "ready - resume" [illegible]ls of t is syste[illegible]. The keyboard layout is shown in [illegible]ure 6-5.

The control keyboard (keyboard number two) is a collection of function designators. The propo[illegible]ed usage for them is for calling routines and subroutines for aid in console usage. This keyboard is also closely associated with the overlay and the light feedback features. There are three groupings of switc es in this control keyboard (see [illegible]igure [illegible]-5). The first group is a 20-s itc[illegible] matrix which is used in conjunction with the overlay[illegible]. The functions performed by each s itch are engraved on the plastic overlay panel which fits around the switc es. The co puter can illuminate selectively any switch or switches under program control to present a "guided" choice to the operator for his actions. The eight overlays available give a choice of system programs callable from a single library tape. The second group is a ten-switch unit which is also under computer control for light feedback. These are not associated with changeable overlays and are intended to perform functions which are common to all overl ys. or instance, one of these keys could be labeled "display trac ball symbol on left tube". The last group is a diamond of four switc es [illegible] are intended to be used in editing symbols. They ca be used to activate routines to move a marker over the face of t e displays. This marker can be used to indicate the position for writing or erasing the next character. The movement co nded by these switches is intended to be incre ental in nature as opposed to t e "continuous"

nature of the two c[illegible]. These [illegible]r keys are not associated with the computer controlled light feedback feature.

The coding of keyboard number two is made up from a diode matrix which was designed to use the minimum number of diodes. The coding of these keys is shown in Figure 7- . The depression of a key in keyboard two sets up a ready condition which is held until the computer samples the lines and releases the register. The overlay code is transmitted along with the control keyboard code when the input from keyboard number two is sampled. The overlay code is generated by the presence or absence of a contact post in the three bit positions of each overlay panel. This allows for changing the overlay code with a change of the overlay, and hence, to be able to change the labels associated with each of the 20 switches in the matrix.

The X and Y trackball generators are nine-bit shaft position encoders whose outputs are in "Gray Code" /[illegible]/. The outputs are converted to binary code for use in the computer. This coordinate information is always available and need only be selected by the computer to sample the value.

The radar display range switch is an eight-position switch. There are seven selectable ranges and an off position. The codes are shown in Figure 7-4. The switch has the dual function of controlling the radar video presentation and providing the computer with a measure of range correlation for making computations on target position. The entire operator's console is shown in Figure 8-5.

SWITCH POSITION	OCTAL CODE	SWITCH POSITION	OCTAL CODE	SWITCH POSITION	OCTAL CODE
1-A	01	4-A	31	5-1	61
1-B	02	4-B	32	5-2	62
1-C	03	4-C	33	5-3	63
1-D	04	4-D	34	5-4	64
1-E	05	4-E	35		
2-A	11	5-A	41		
2-B	12	5-B	42		
2-C	13	5-C	43		
2-D	14	5-D	44		
2-E	15	5-E	45		
3-A	21	6-A	51		
3-B	22	6-B	52		
3-C	23	6-C	53		
3-D	24	6-D	54		
3-E	25	6-E	55		

Keyboard 3 - Function Switch Designation

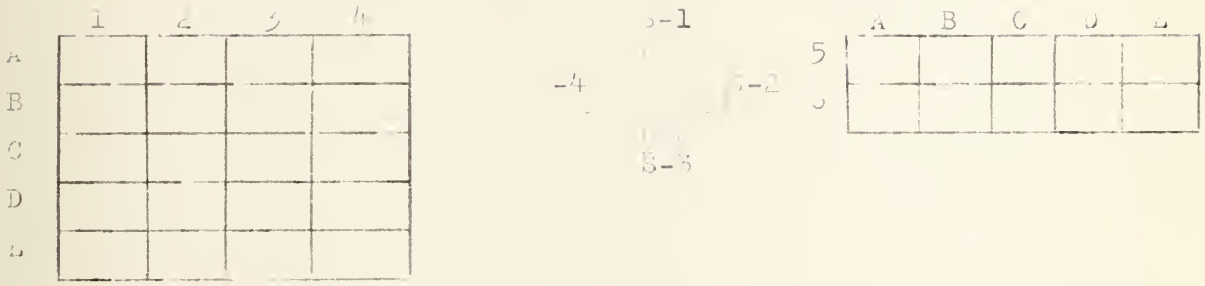


Figure 7-3
Function Switch Codes

[illegible] TRC [illegible]	[illegible] CODE
Off	0
[illegible] miles	1
[illegible] miles	2
1[illegible] miles	[illegible]
[illegible] miles	4
[illegible]4 miles	5
12[illegible] miles	[illegible]
25[illegible] miles	7

Figure 7-4
Range Switch Codes

Now that all inputs and outputs are defined, it is possible to assign select and sense codes, and design the logic. Two editing functions were added to the sense and interrupt functions. These were the keys 'carriage return' and "tab" of keyboard one. These were included as special cases of keyboard one for the possibility of processing a word or a group of words on a functional command instead of processing single characters. The sense codes are listed in Figure 7-5. The select codes are listed in Figures 7-6 and 7-7.

All the function codes are in the 7XXX series. The primary decode is done by checking for the coincidence of a 7XXX and one of the external function signals from the computers. In the "both" mode of operation a time shared check is made of the external function lines from the 160 and 1604. The checking rate is rapid enough to return to sample each computer wit in the eight microseconds that the function pulse is present. Once the initial 7XXX is recognized, a pulse is formed which samples the lower nine bits of the code and sets the selected flip-flop (or in the case of a sense code for the 1604, allows an output pulse to be formed conditioned on the sense).

The ability to clear all the select flip-flops has been incorporated using the external clear lines of the computer in control (as selected by the mode switch). In addition to these possibilities, the "clear/start" control for the DD-15 memory will clear all select flip-flops. The overall diagram of the control logic is shown in Figure 6-2.

Sense Condition	1604 Sense Command Codes	160 Sense Response Codes
Keyboard no. 2 hit	7108	xxx1
Keyboard no. 1 hit	7104	xxx2
Carriage Return hit	7110	xx4
Tab hit	7110	xx1x
Radar target present	7140	x2x
Keyboard no. 2 not hit	7109	
Keyboard no. 1 not hit	7105	
Carriage Return not hit	7111	
Tab not hit	7121	
No radar target	7141	
Keyboard no. 1 selected	7002	xx4x
Radar to AUX selected	7001	x1xx
Radar to 1604 selected	7002	x2xx
Radar to 160 selected	7004	x4xx
DD-65 from 1604 selected	7010	1xxx
DD-65 from 160 selected	7020	2xxx
Keyboard no. 2 selected	7040	4xxx

Figure 7-5
Sense Function Codes

Function [illegible]	[illegible]	[illegible]	[illegible]
Select Track Ball X	7102	7102	[illegible]
Select Track Ball Y	7104	7104	[illegible]
Select Range Switch	7110	7110	[illegible]
Select Keyboard 2 plus Overlay	7120	7120	[illegible]
Select Keyboard 1	7140	7140	[illegible]
Select Keyboard 2 plus Overlay with Interrupt on Key-hit	7105	7105*	[illegible]
Select Keyboard 1 with Interrupt with Interrupt on Key-hit	7105	7105*	[illegible]
Select Keyboard 1 with Interrupt on Carriage Return	7111	7111*	[illegible] code)
Select Keyboard 1 with Interrupt on Tab	7121	7121*	[illegible] code)
Select Radar Info to 1604 with Interrupt on Receipt of Target Pulse	7141	7141*	[illegible] (0[illegible]00) Future
Select Radar Info to Auxiliary on Receipt of a Target Pulse	7001	7001	Same
Select Radar Info to 1604 on Receipt of a Target Pulse	7002	7002*	Same
Select Radar Info to 160 on Receipt of a Target Pulse	7004*	7004	Same
Select 160 Status Response	7[illegible]0*	7[illegible]0	See Figure 7-5 for 160 Status Responses
Select n-word Memory Update from 160	7[illegible]	7[illegible]	None-see Figure 7-1 for Coding Info.
Select n-word Memory Update from 160	7020*	7020	None-see Figure 7-1 for Coding Info.

On 160 only - all manual inputs to the 160 on 1604 only or both - all manual inputs to the 1604.

* Disables selectively on 160 only or 1604 only - Code switch position

Figure - Select Function Codes for Control Functions

[illegible]	[illegible]	[illegible]
	1504	1[illegible]0
Select Light 1A-On	7202	[illegible]
Select Light 1A-Off	[illegible]	7203
Select Light 1B On	[illegible]	7204
Select Light 1B Off	[illegible]	7205
Select Light 1C-On	7210	7210
Select Light 1C-Off	7211	7211
Select Light 1D-On	7220	7220
Select Light 1D-Off	7221	7221
Select Light 1E-On	7240	7240
Select Light 1E-Off	7241	7241
Select Light 2A-On	7302	7302
Select Light 2A-Off	7303	7303
↯	↯	↯
Select Light [illegible]E-Off	7741	7741

Keyboard 2-Light Designation--

	1	2	3	4
A	*	*	*	*
B	*	*	*	*
C	*	*	*	*
D	*	*	*	*
E	*	*	*	*

	A	B	C	D	E
[illegible]	*	*	*	*	*
6	*	*	*	*	*

Figure 7-7
Select Function Codes for Light Dedock

8. System Implementation and Conclusions

The preceeding chapters described the design details of the functions to be performed by the DD-65. The complete block diagrams for the DD-56 are shown in Figures 8-1 and 8-2. The physical design of the unit requires over 1,500 logic circuit cards. In addition to these components, a number of power supplies and the deflection circuits for the display tubes are required. This large number of components, a number of power supplies and the deflection circuits for the display tubes are required. This large number of components prohibited a single cabinet design for the equipment. The digital logic has been placed in a separate cabinet which also contains all the low voltage power supplies for the digital circuits and the data line terminations from the computers. The operator's console contains the manual inputs and the display tubes as well as the high voltage power supplies to control the display tubes. Also incorporated in the operator's console are the digital to analog conversion circuits and the radar video circuits.

The entire system block diagram is shown in Figure 8-3. The pulse amplifier, video amplifier, and video quantizer are designed for implementation on the same size printed circuit cards as are used in the digital circuits. This allows these circuits to be contained within the logic cabinet of the DD-65. The final configuration of the DD-65 led to the proposed placement of the equipment in the Digital Automation and Control Laboratory as shown in Figure 8-4. The installation should be completed by August 1962.

The system, as designed, allows a great deal of programming flexibility and, therefore, a similar flexibility in respect to use of the operator's console. No attempt will be made here to flow-chart or dictate the type of system programs to be used with the DB-55, but a broad overview of possible functions will be undertaken. The discussion will be slanted toward specification of labels for the various overlays and operator keys. See Figure 8-5 for a diagram of entire operator's console.

The basic set of eight overlays could be specified as follows:

a. Air surveilence and flight following

b. Air intercept and control

c. Program composition and de-bugging

d. Servomechanism design

e. Network synthesis

f. Library information retrieval and update

g. Linear programming package

h. Statistical analysis package

Additional sets of overlays could be used by merely changing the system library tape in the computing center. These overlays have twenty unique function keys available for use which have the labels associated with them changed each time the overlay is changed. These labels and, hence, the programmed functions should include only those functions which are not common to all usage overlays.

The individual labels and associated programs can be determined only by actually outlining each overlay program in considerable detail. A few possible functions that could be associated with the

"programming" overlay are the selection of the various languages to be used for coding. These language select keys would set up a format subroutine for accepting "symbol keyboard" information. For instance, the "tab" key would produce character spacing which would be compatible with the format normally used to input the language to the computer. Further "step process" keys could be labeled for the storing of a completed program on a magnetic tape library or for a "trace" mode of running for de-bugging purposes.

Those functions which are common to all overlays are to be controlled by the ten function keys which are associated with light feedbacks, but whose labels are not changed with the overlay change. The possible set of functions to be programmed with these keys are:

a. Tube "0" display

b. Tube "1" display

c. "Display" track ball

d. "Hook" track ball

e. "Drop" track ball

f. Enter data

g. Delete data

h. Start process

i. Stop process

j. Load library

These functions are tentative, but the set of functions described are common to all the proposed overlays, and the subroutines involved should not take many cells of the memory to implement. The track ball sequence, as proposed, will entail calling for the dis-

play of the track ball on a particular tube, and then the operator can move the displayed "TB" symbol to the desired position by movement of the track ball. The "hook" track ball can then be executed which can have various meanings depending on the usage overlay. Possible uses of "hook" would be to insert a point or symbol at the designated spot on the display or the process could be reversed, and information concerning the point which is designated by the "TB" symbol could be displayed. The "drop" track ball could be executed after either a "display" or "hook". This function command could mean to delete a symbol or point from the display or drop the "TB" symbol and/or the amplifying information called up by the hook. The "Load", "Start", and "Stop" functions are proposed to be associated with the handling of display data within the computer. For instance, to enter a line of data could mean to place it into permanent storage location for processing after the temporary (for display purposes) information has been verified as correct.

The remaining four function keys are to be marked with direction arrows and are proposed to be used to move an editing symbol over the chosen display tube for purposes of locating the position for typing in or erasing information.

The actual operation of a system as proposed would require an overlay to be inserted and a library load executed. The computer, when ready to commence, would light the "start" process light. The operator, upon depressing the "start" process button, causes the computer to drop the selected light and start through the executive program. Upon reaching various points in the programs where infor-

mation is needed from the operator, various lights or groups of lights are selected "on" by the computer. The function labels associated with the lights outline the required action or inputs to be initiated by the operator. In this manner of reply-request-display, the man can thread through the programs in close association with the computer until the operator chooses to stop the process by depressing the "stop" function key.

It is felt that the flexibility in usage of the command console and the speed and packing density of the display information will provide an experimental device for man-computer systems which will not rapidly become obsolescent.

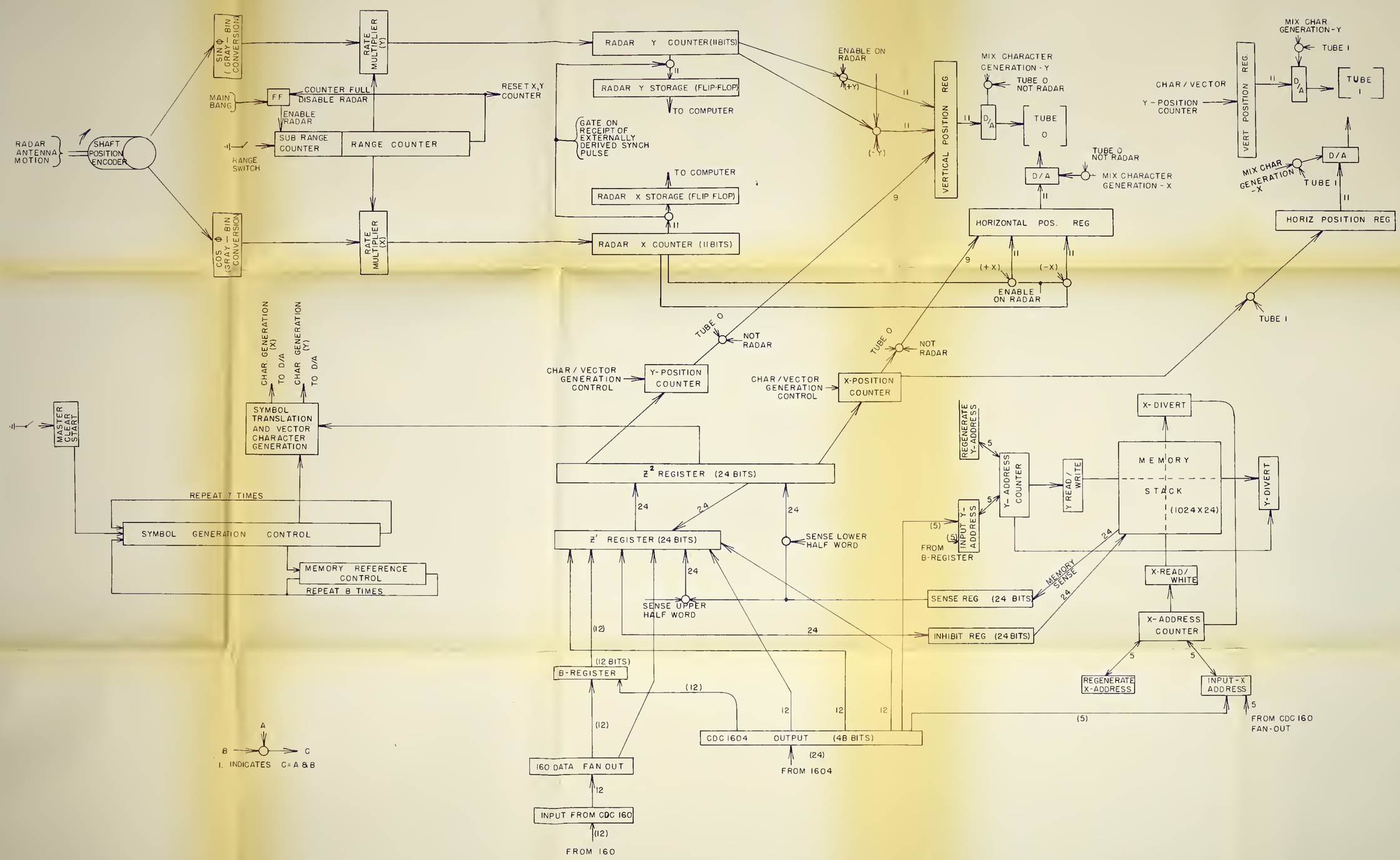


FIG. B-1 BLOCK DIAGRAM OF THE SYMBOL & RADAR GENERATORS & THE MEMORY

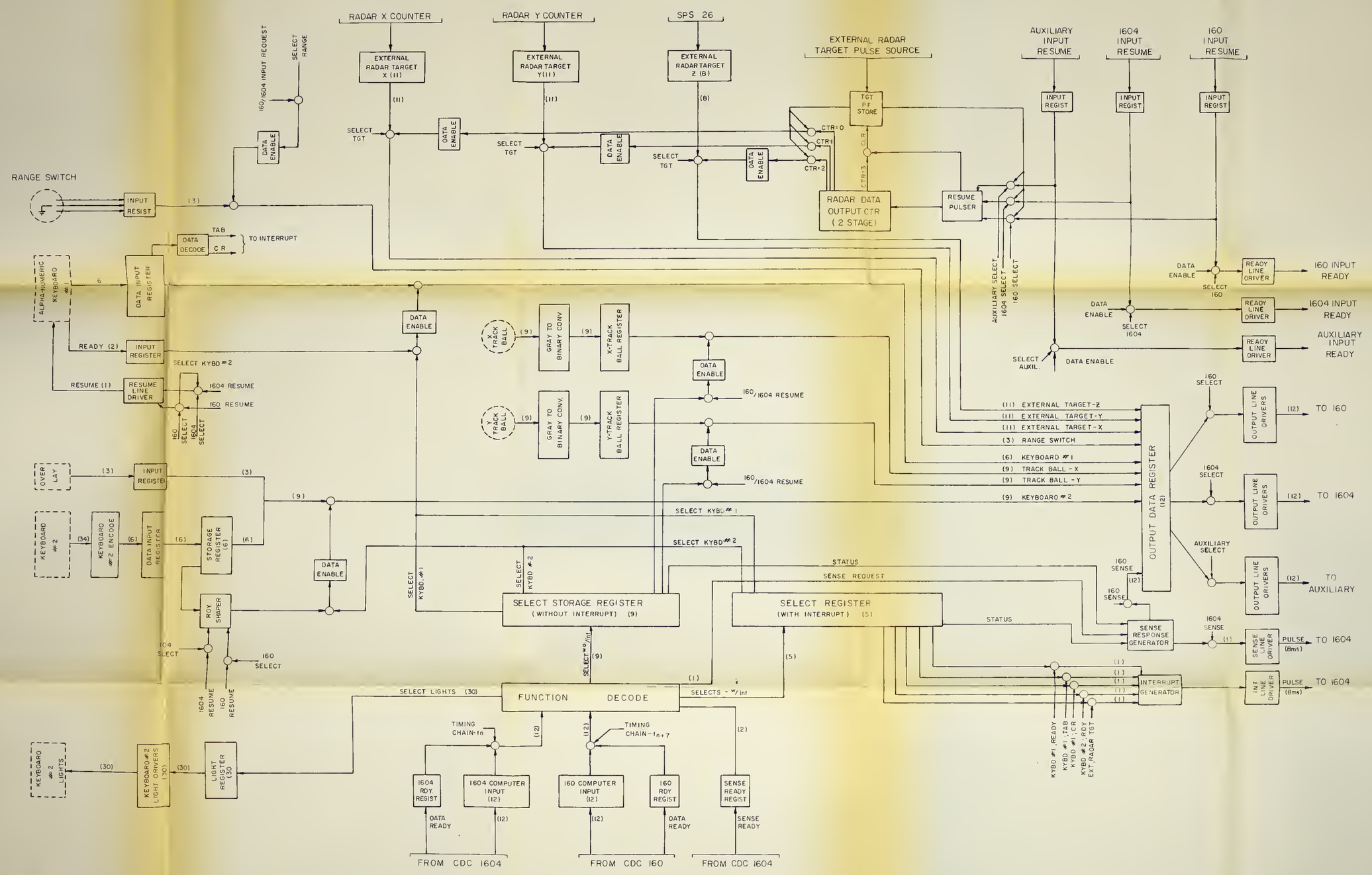
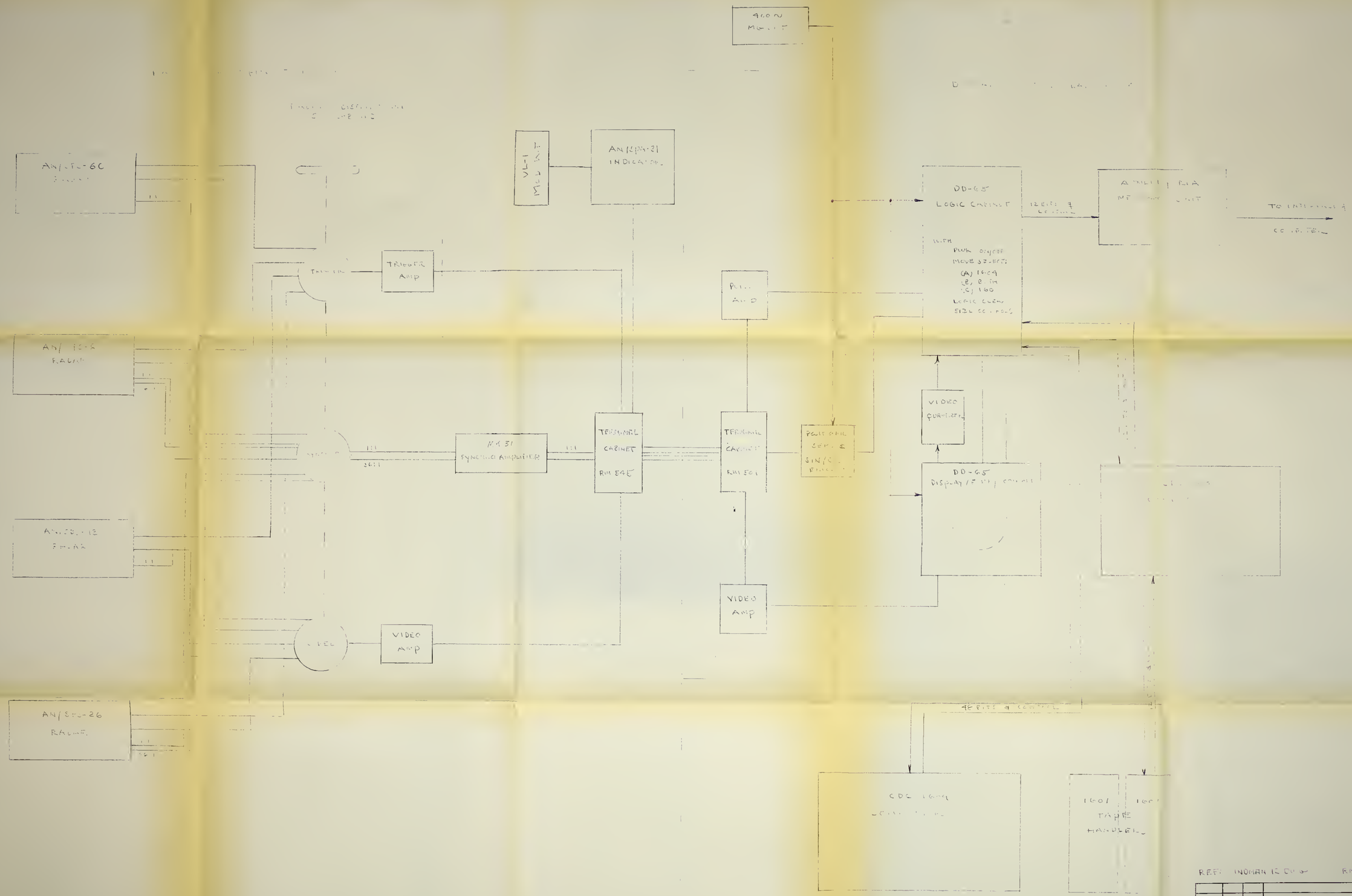


FIG. 8-2 BLOCK DIAGRAM OF THE CONTROL CIRCUITS



REF: INDMAN 12 DW 3 RM-65-5-43

REVISION	DATE	APPD	DESCRIPTION	BY

DES.
DWN.
CHK.
PROJ. ENG.
BRANCH HD.
DIVISION HD.
SCALE:
SHEET 1 OF 2
DATE APRIL 6

Industrial Manager, USN, 12th Naval District
ELECTRONICS DEPARTMENT

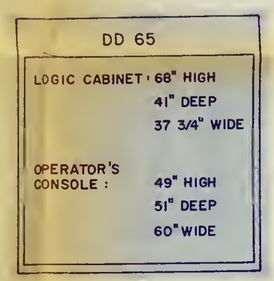
U.S. NAVAL [illegible]
DIGITAL CONTROL LABORATORY;
COMPUTER COORDINATED DISPLAY SYSTEM

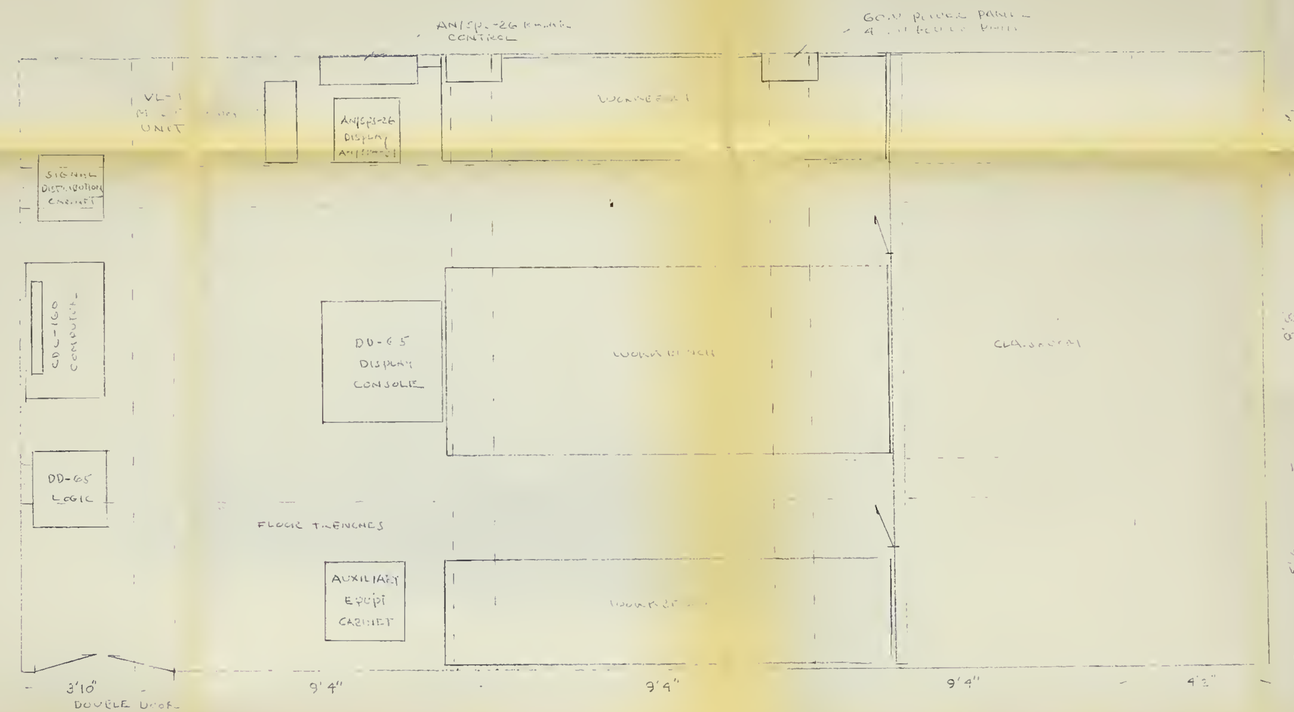
APPROVED
ELECTRONICS ASST.
FOR INDMAN 12ND

SATISFACTORY TO
USN
FOR
DATE

INDMAN 12ND SKETCH NO.

FIG. 8-3 BLOCK DIAGRAM OF THE ENTIRE SYSTEM





PLAN - BOTTOM BUILDING

REF: INDMAN 12 DWG RM-GF-3773

REVISION	DATE	APPD	DESCRIPTION	BY

DES. C. G. LUNN
DWN.
CHK.
PROJ. ENG.
BRANCH HD.
DIVISION HD.
SCALE: NO SCALE
SHEET 2 OF 2
DATE APR. 16 '6

Industrial Manager, USN, 12th Naval District
ELECTRONICS DEPARTMENT

U.S. NAVAL POSTGRADUATE SCHOOL
DIGITAL CONTROL LAB
FLOOR PLAN
EQUIPMENT LAYOUT

APPROVED
ELECTRONICS ASST.
FOR INDMAN 12ND

SATISFACTORY TO
USN
FOR
DATE

INDMAN 12ND SKETCH NO.

FIG 8-4 PROPOSED EQUIPMENT LAYOUT FOR THE DIGITAL
PAGE 82 CONTROL & AUTOMATION LABORATORY

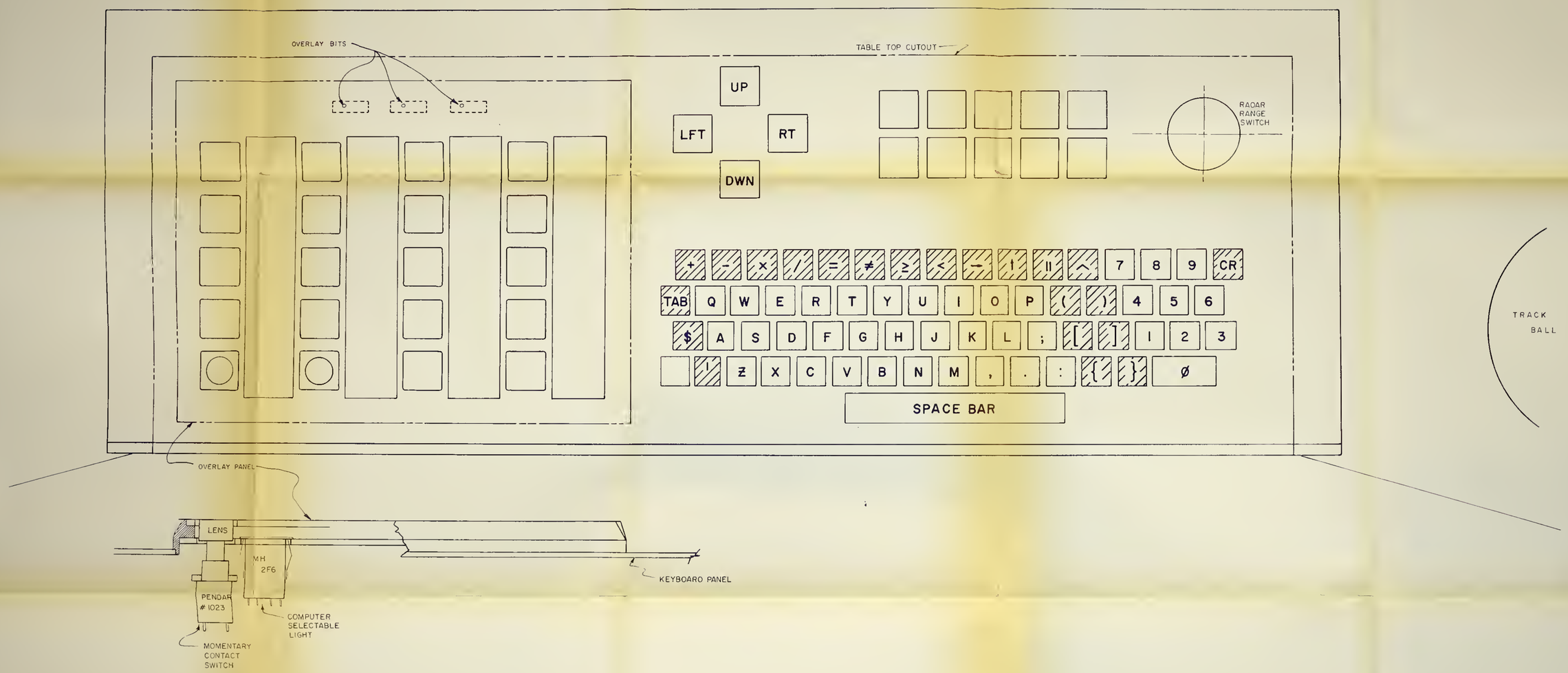


FIG. 8-5 LAYOUT OF THE OPERATORS CONSOLE

3. J. C. R. Licklider, Man-Computer Symbiosis, IRE Transactions on Human Factors in Electronics, HFE-1, pp. 4-11, March, 1960.

4. J. C. R. Licklider and W. E. Clark, On-Line Man-Computer Communications, Proceedings Spring Joint Computer Conference, 21, pp. 113-128, National Press, 1962.

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5. E. A. Sack, P. M. Wolfe, and J. A. Asars, Construction and Performance of an ELF Display System, Proceedings of the IRE, 50, pp. 401-426, April, 1962.

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8. R. A. Barker, Techniques of Dynamic Display - Part 1, Control Engineering, 7, pp. 100-105, February, 1960.

9. R. A. Barker, Techniques of Dynamic Display - Part 3, Control Engineering, 7, pp. 97-102, June, 1960.

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14. A. E. Perry, E. J. Aho, Generating Characters for Cathode Ray Readout, Electronics, 31, pp. 72-75, January 1, 1958.

15. A. E. Perry and E. J. Aho, Radar Computer Display Traces Alphanumeric Characters, Electronics, 4, pp. 75-79, June 30, 1961.

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APPENDIX I

DESIGN MECHANIZATION PROGRAM

Description, use and coding of a Control Data Corporation 1604 program for mechanizing portions of the design of digital equipments using Control Data Corporation type logic cards and format.

This appendix is written in standard "Co-op"[1] program description form.

Examples of sample outputs and inputs are shown in Figures 4-4 through 4-7 of this thesis.

[1] "Co-op" is the Control Data Corporation 1604 user group organization.

A. IDENTIFICATION

Title: Card Assignment and Wiring List Assembler for Control Data Corporation Input file of Equations

Category: Logical Design Aid

Programmer: C. G. Lawson

Date: 30 January 1962

B. PURPOSE

This routine is a composite of two separate functions:

1. It completes a file of equations and assigns card types to each equation for a given set of input equations.
2. It also computes and lists a wiring table if chassis locations for each section are designated.

In order to accomplish the first function, a magnetic tape containing punched card images of the input equations are processed by compiling an input table for the entire set of equations. This table is then searched to make up a list of outputs for each card. The number of inputs and outputs are then counted and logic cards are assigned, based upon the constraints of the family of cards. Certain special card types may be designated in the equation statements by special symbols. The number of cards required are counted during this process, and any erroneous equations are noted. The output at this point is a magnetic tape having the original input equations, each followed by a line containing the card type and a list of output destinations. Also, for any erroneous equations a star is placed in the left column adjacent to the equations. Following the equation file on the tape is a list of the card types

and the total number of each required for the design.

The second part of the program adds to the output tape a wiring tabulation of the intercard wires. In order to make up "wire tabs" the location of each section must be designated. This is done by adding the location information to the punched card for each equation. The program is then run with jump key one set and with an input of a magnetic tape containing the punched card images of the equations and locations. When there is a choice of wiring between points, the program compares lengths and assigns the shortest interconnection possible. The output is now a magnetic tape which contains all of the output lists.

The purpose for separating the program outputs is due to consideration of design proceedures. In most cases the file of equations are written from logic diagrams which do not necessarily show all the output wires. The clarity of the diagrams is improved if fewer interconnection lines need be shown. Therefore, the type card cannot always be assigned before finding how many outputs are needed. Also, if the total number of outputs required are more than the legal possible number of outputs, paralleling of signals is necessary. These considerations dictate that the completion of a design be done in two parts. The first part is to find out the card types necessary and to point out any errors in the equations. The location for the sections may now be assigned based upon the knowledge of card types and, also, any corrections may be entered into the input equations by changing the erroneous punched cards. The new inputs will now allow the output of all the desired lists

For Wiring the Consis.

L. USIL

1. Calling Sequence:

a. On bioctal tape at present time

b. Start location =500

c. Successful completion leaves 10000 in U

2. Arguments: none

3. Space required: 1500 cells

4. Temporary storage requirements: 1500 + 18X (number of input equations)

5. Alarms: none

6. Error returns: none

7. Error stops: 5456 in L if output criteria not satisfied (may be restarted if desired as errors will be indicated on printout)

1653 in L if inconsistancies in designation are encountered

8. Input and output tape mountings:

a. Input:

(1) Source tape: [illegible] 202

b. Output:

(1) Output tape A: [illegible] 4 [illegible]

9. Input and output formats:

a. Input: [illegible] 80 character card image of input equations. Input equations written in standard [illegible] format (see references).

(1) Input for card assignment only (jump key 1 not set):

(a) Each term must consist of four alphanumeric characters.

(b) The function must be the first term of the equation.

(c) The only restrictions on spacing or locations on the card is that columns 75 through 80 be set aside for insertion of location when assigned.

(d) The following characters are defined as operators when used in a logical equation:

space + - * / ( ) _ , > .

(e) All entries following . / , * , ( ) are treated as remarks.

(f) A maximum of 16 input terms may be used in an equation

(g) A maximum of 100 output uses will be compiled for a function

(h) When inserted anywhere <u>following the equation</u>, these symbols define unique types of cards:

. or <u>space only</u>	inverters (series 10 and 20)
*	flip-flops (series 50) (one flip-flop per card)
,	input cards (01) (three inverters per card)
/	output cards (02) (three inverters per card)
,	clock cards (01) (two oscillators per card)

(single inverter (336) (three inverters per card)

) diode fanout (804) (three sets of three diodes each per card)

(i) If flip-flops (series 30) designated, the pair input equations should be adjacent, and the implicit input should be the first OR term.

(2) Input for complete program (jump key one set): In addition to (a) through (i) above, the location must be typed into columns 77 through 80 and should have the following format:

Input card column	77	78 and 79	80
Meaning	ROW	COLUMN	SECTION
Allowable contents	A thru R	01 thru 99	A for 10 series A or C or 20 and 30 series or clock 804 A, B or C for 60 series or 336

Columns 73 through 76 can be used to identify chassis.

b. Outputs: 120 character line image in program control format for listing on output tape A.

(1) Outputs for card assignment only (jump key 1 not set):

(a) comments lines where applicable

(b) input equation lines as read in

(c) output lines with card type followed by list of output locations (following each input line)

(d) tabulation of the number of cards necessary to

implement the design.

(e) If any errors occur, such as too many inputs or outputs, no assignment is made and an error symbol is placed in the output line (along with an error stop).

(2) Outputs for complete program (jump key one set):

(a) as above

(b) input equation lines minus the location information

(c) output lines with location and card type followed by list of output locations (following each input line)

(d) as above

(e) tabulation of wiring data containing the following:

(e-1) origin and destination by row, column and pin number, if an internal card or by designation if external input

(e-2) designations of the above origin and destinations

(e-3) wire length in inches

(e-4) separation of AND groups by symbol * in left column

10. <u>Selective jump and stop settings</u>:

a. First run: none - to obtain card types

b. Second run: jump key one set - to allow processing of

location information

11. Timing: depends on number of input equations

12. Accuracy: not applicable

13. Cautions to user: No tape errors are checked in the routine.

14. Equipment configuration: 1604 with two 1607 units; 1607 tape mountings to include a "scratch tape" on Ch4 FU4

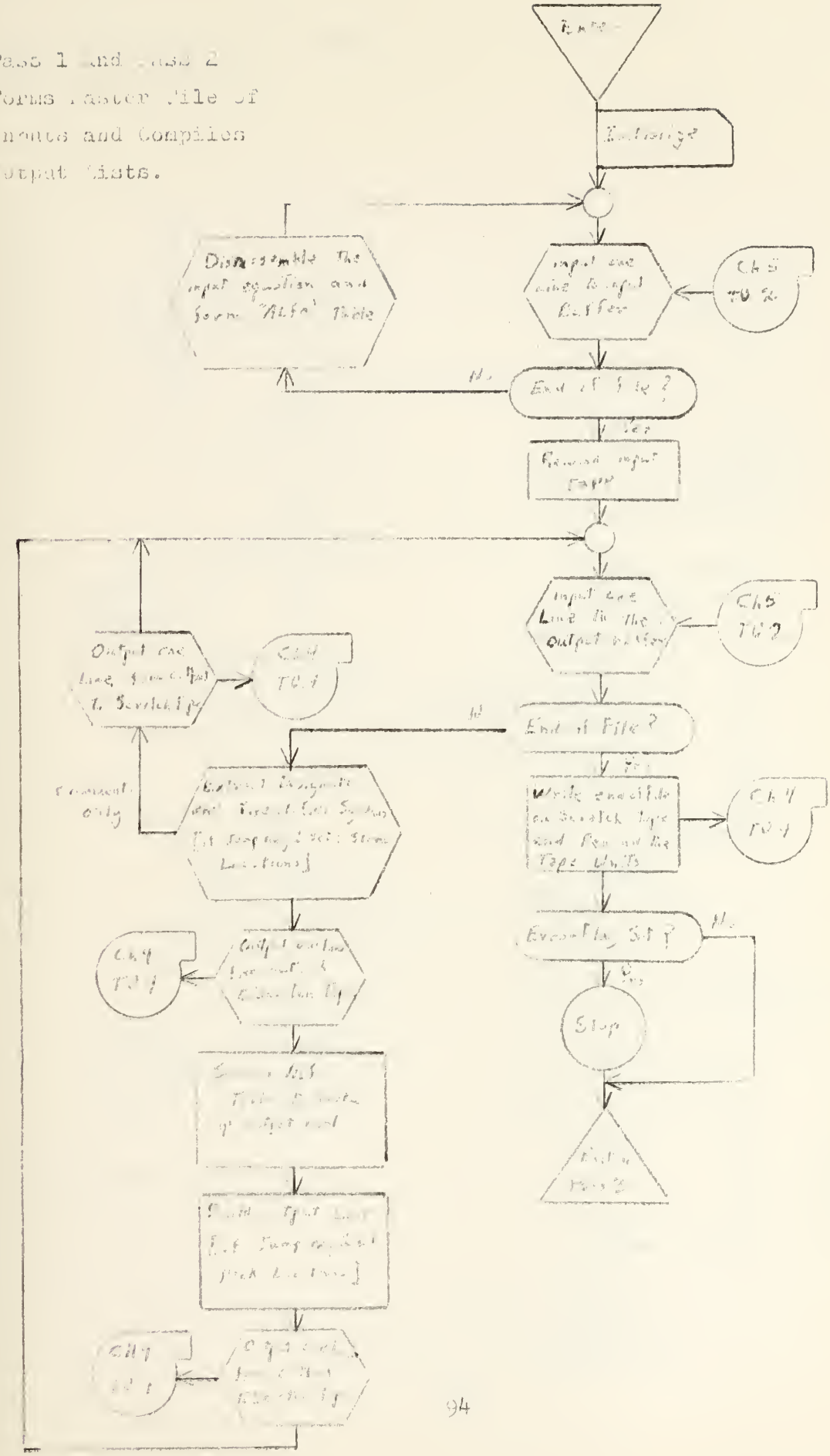
15. References:

a. 1604 Computer Instruction Book, Vol. 1, Description and Operations, Control Data Corporation

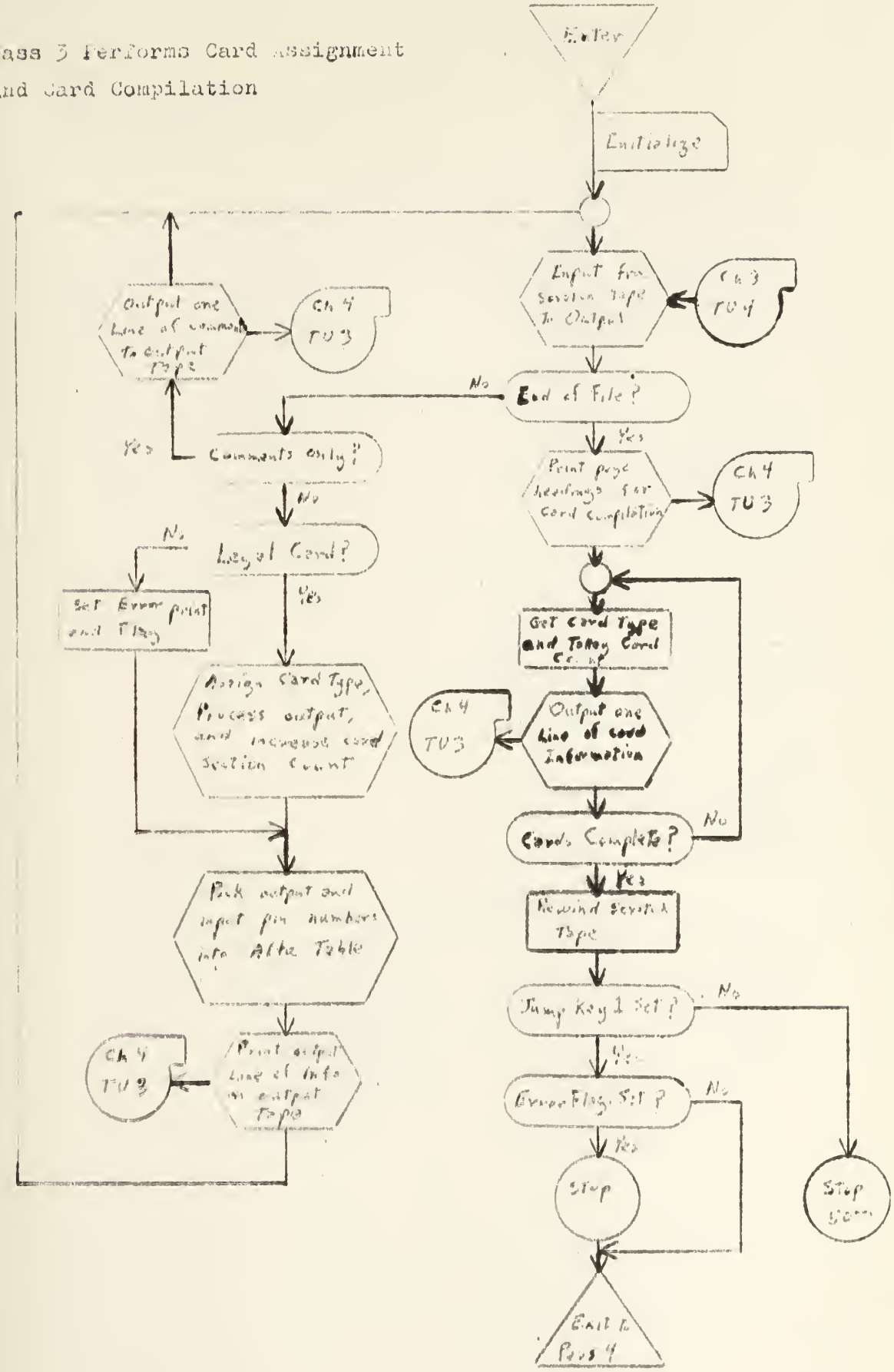
b. 1604 Computer Instruction Book, Vol. 2, Principals of Operations, Control Data Corporation

c. H. Loberman and A. Weinberger, Formal Procedures for Connecting Terminals with a Minimum Total Wire Length, J. Assoc. Computing Machinery, Vol. 4, no. 4, pp. 428-447, October, 1957

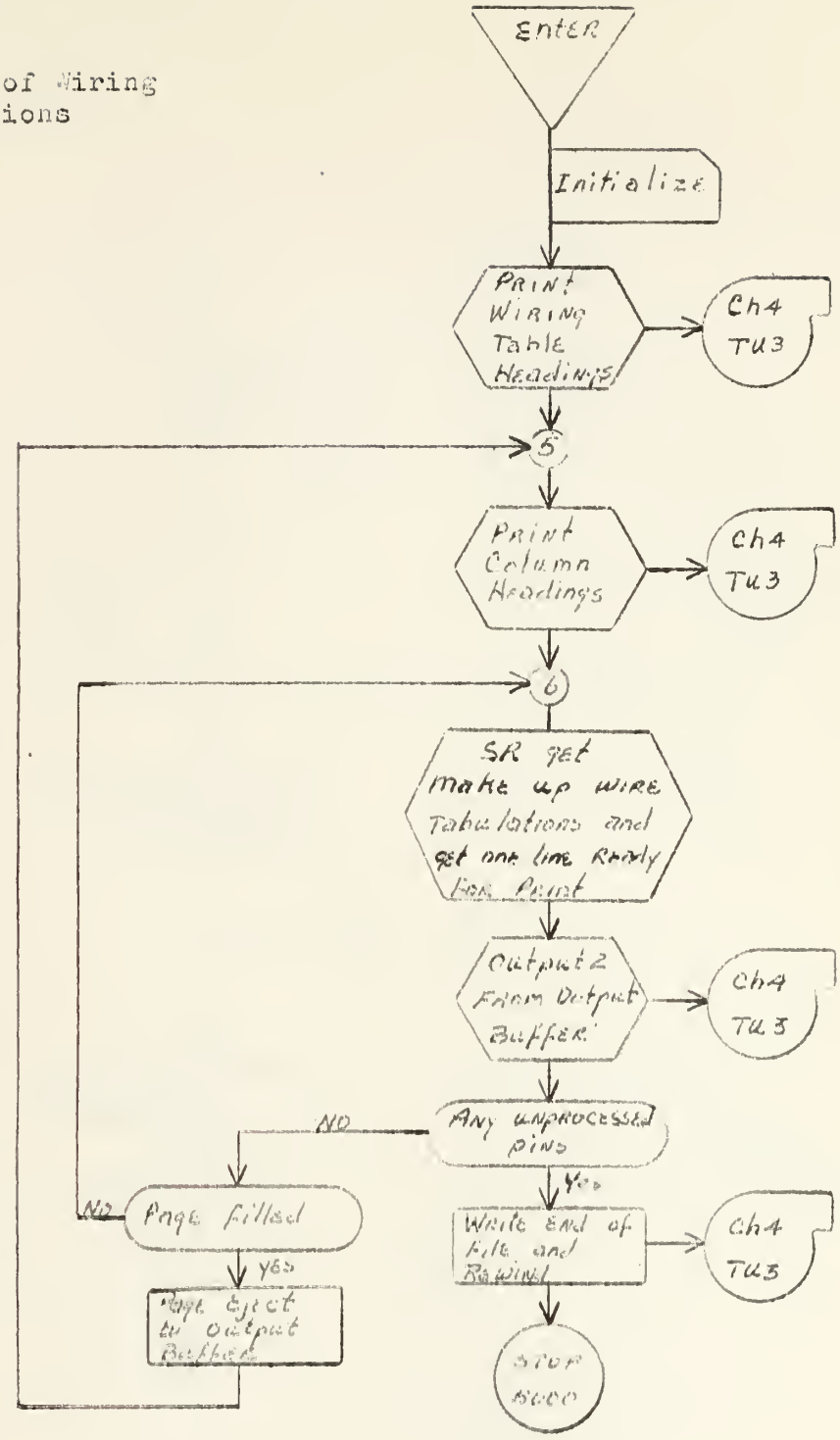
Pass 1 and Pass 2
Forms Master File of
Inputs and Compiles
Output Lists.



Pass 3 Performs Card Assignment and Card Compilation



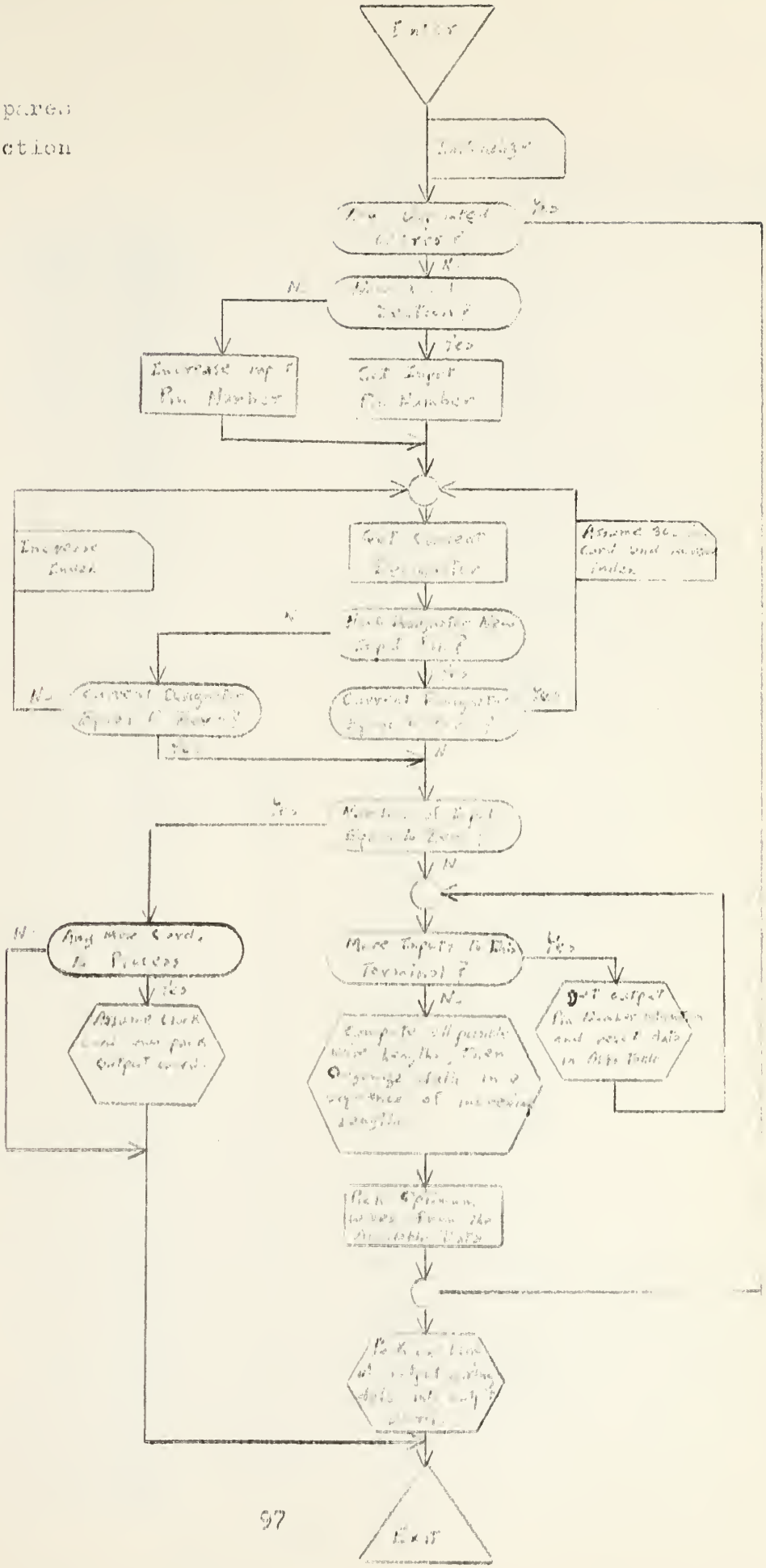
Pass 4
Makeup of Wiring
Tabulations



Subroutine [illegible]

Chooses and Prepares

Best Wire Connection



```
                                ORG     5000
                                REM     PART ONE OF THE LOCI
                                REM     SUBROUTINE WHICH COL
                                REM     LOGICAL EQUATIONS AN
                                REM     ON THE LINE IMMEDIAT
05000   50 1 00000              ENI   1 0
        10 0 00000              ENA   0 0
05001   20 1 10000              STA   1 ANBUF
        50 0 00000              ENI   0 0
05002   54 1 67700              ISK   1 67700
        75 0 05001              SLJ   0 /-1
05003   20 0 05253              STA   0 FLAG
        20 0 05310              STA   0 PAGE
05004   20 0 06067              STA   0 WAIT
        20 0 06064              STA   0 COUNT
05005   50 0 00000      INPUT   ENI   0 0
        74 7 52000              EXF   7 52000
05006   10 0 05267              ENA   0 INBUF+10D
        61 0 00005              SAL   0 5
05007   74 0 52022              EXF   0 52022
        74 7 52000              EXF   7 52000
05010   74 5 05255              EXF   5 INPUF
        74 7 52000              EXF   7 52000
05011   74 7 52006              EXF   7 52006
        75 0 05044              SLJ   0 DISASS
05012   74 5 05267              EXF   5 INBUF+10D
        50 0 00000              ENI   0 0
05013   74 0 52005              EXF   0 52005
        57 1 07226              SIL   1 GCFER
05014   12 0 07226              LDA   0 GCFER
        20 0 05242              STA   0 TEMP+1
05015   75 4 05202              SLJ   4 FILL
        50 0 00000              ENI   0 0
05016   50 0 00000      ELEV    ENI   0 0
        74 7 52000              EXF   7 52000
05017   10 0 05302              ENA   0 OUTPUF+11D
        61 0 00005              SAL   0 5
05020   74 0 52022              EXF   0 52022
        74 7 52000              EXF   7 52000
05021   74 5 05270              EXF   5 OUTBUF+1
        74 7 52000              EXF   7 52000
05022   74 7 52006              EXF   7 52006
        75 0 05037              SLJ   0 TWELVE
05023   74 5 05302              EXF   5 OUTBUF+11D
        74 7 42000              EXF   7 42000
05024   74 0 42042              EXF   0 42042
        74 0 42003              EXF   0 42003
05025   74 7 42000              EXF   7 42000
        74 0 42005              EXF   0 42005
05026   74 0 52005              EXF   0 52005
        12 0 05253              LDA   0 FLAG
05027   22 0 05456              AJP   0 PASS3
        10 0 00000              ENA   0 0
05030   20 0 05253              STA   0 FLAG
        76 0 05456              SLS   0 PASS3
05031   75 0 00000      OUTPUT  SLJ   0 0
        74 7 42000              EXF   7 42000
05032   20 0 05246              STA   0 TEMP+5
        72 0 05310              RAO   0 PAGE
05033   10 0 05306              ENA   0 OUTBUF+15D
        61 0 00004              SAL   0 4
05034   74 0 42042              EXF   0 42042
        74 7 42000              EXF   7 42000
05035   74 4 05267              EXF   4 OUTBUF
        74 7 42000              EXF   7 42000
05036   12 0 05246              LDA   0 TEMP+5
        75 0 05031              SLJ   0 OUTPUT
05037   75 4 05077      TWELVE  SLJ   4 EXTRACT
        50 0 00000              ENI   0 0
05040   75 4 05031              SLJ   4 OUTPUT
        50 0 00000              ENI   0 0
```

```
05041   12 0 05252                LDA  0 SPACE
        20 0 05267                STA  0 OUTBUF
05042   20 0 05305                STA  0 OUTBUF+140
        12 0 05241                LDA  0 TEMP
05043   50 0 00000                ENI  0 0
        75 0 05125                SLJ  0 SEARCH
05044   50 2 00000   DISASS      ENI  2 0
        50 3 00000                ENI  3 0
05045   50 4 00000                ENI  4 0
        50 5 00000                ENI  5 0
05046   50 0 00000                ENI  0 0
        10 0 00000                ENA  0 0
05047   16 2 05255   ONE          LDQ  2 INBUF
        50 0 00000                ENI  0 0
05050   05 0 00006   TWO          ALS  0 6
        20 0 05241                STA  0 TEMP
05051   10 0 00000                ENA  0 0
        07 0 00006                LLS  0 6
05052   50 6 00013                ENI  6 11D
        50 0 00000                ENI  0 0
05053   64 6 05206                EQS  6 LIST
        75 0 05063                SLJ  0 THREE
05054   10 6 00000                ENA  6 0
        22 1 05056                AJP  1 /+2
05055   10 5 00000                ENA  5 0
        22 0 05072                AJP  0 FIVE+2
05056   10 6 00000                ENA  6 0
        15 0 05254                SUB  0 UNITS
05057   22 3 05071                AJP  3 FIVE+1
        51 6 77770                INI  6 -7
05060   55 6 05061                IJP  6 /+1
        75 0 05075                SLJ  0 OR
05061   55 6 05062                IJP  6 /+1
        75 0 05075                SLJ  0 OR
05062   10 0 00000                ENA  0 0
        75 0 05067                SLJ  0 FOUR
05063   70 0 05241   THREE        RAD  0 TEMP
        50 0 00000                ENI  0 0
05064   54 3 00003                ISK  3 3
        75 0 05067                SLJ  0 FOUR
05065   70 1 16000                RAD  1 ALFA
        51 5 00001                INI  5 1
05066   51 1 00001                INI  1 1
        10 0 00000                ENA  0 0
05067   54 4 00007   FOUR         ISK  4 7
        75 0 05050                SLJ  0 TWO
05070   54 2 00010   FIVE         ISK  2 10
        75 0 05047                SLJ  0 ONE
05071   54 5 00022                ISK  5 22
        75 0 05073                SLJ  0 /+2
05072   75 0 05005                SLJ  0 INPUT
        50 0 00000                ENI  0 0
05073   10 0 00000                ENA  0 0
        20 1 16000                STA  1 ALFA
05074   51 1 00001                INI  1 1
        75 0 05071                SLJ  0 /-3
05075   12 0 05455   OR           LDA  0 BIT48
        20 1 16000                STA  1 ALFA
05076   10 0 00000                ENA  0 0
        75 0 05067                SLJ  0 FOUR
05077   75 6 00000   EXTRACT      SLJ  0 0
        10 0 00000                ENA  0 0
05100   50 5 00000                ENI  5 0
        16 0 05270                LDQ  0 OUTBUF+1
05101   05 0 00006                ALS  0 6
        20 0 05241                STA  0 TEMP
05102   10 0 00000                ENA  0 0
        50 0 00000                ENI  0 0
05103   07 0 00006                LLS  0 6
        50 6 00013                ENI  6 11D
05104   64 6 05206                EQS  6 LIST
        75 0 05107                SLJ  0 /+3
05105   10 6 00000                ENA  6 0
```

```
        22 0 05172                  AJP  0 TENA-1
05106   75 0 05102                  SLJ  0 /-4
        50 0 00000                  ENI  0 0
05107   70 0 05241                  RAD  0 TEMP
        50 0 00000                  ENI  0 0
05110   54 5 00003                  ISK  5 3
        75 0 05101                  SLJ  0 /-7
05111   50 3 00000                  ENI  3 0
        50 2 00000                  ENI  2 0
05112   75 5 05173                  SLJ  5 MAKEX
        50 0 00000                  ENI  0 0
05113   16 2 05270                  LDQ  2 OUTBUF+1
        50 0 00000                  ENI  0 0
05114   10 0 00000                  ENA  0 0
        50 0 00000                  ENI  0 0
05115   07 0 00006                  LLS  0 6
        50 6 00007                  ENI  6 7
05116   64 6 05206                  EQS  6 LIST
        75 0 05120                  SLJ  0 /+2
05117   75 0 05122                  SLJ  0 /+3
        50 0 00000                  ENI  0 0
05120   54 3 00007                  ISK  3 7
        75 0 05114                  SLJ  0 /-4
05121   54 2 00010                  ISK  2 8D
        75 0 05113                  SLJ  0 /-6
05122   12 6 05232                  LDA  6 CARD21
        20 0 05205                  STA  0 OUTBUF+14D
05123   12 6 05221                  LDA  6 CHECK
        61 0 05247                  SAL  0 EIGHT
05124   75 0 05077                  SLJ  0 EXTRACT
        50 0 00000                  ENI  0 0
05125   53 1 05242    SEARCH        LIL  1 TEMP+1
        50 3 00000                  ENI  3 0
05126   16 0 06113    SIX           LDQ  0 LCMASK
        50 0 00000                  ENI  0 0
05127   66 1 16000                  MEQ  1 ALFA
        75 0 05141                  SLJ  0 BUILD
05130   57 1 07226                  SIL  1 GOFER
        12 0 07226                  LDA  0 GOFER
05131   04 0 00000                  ENQ  0 0
        22 0 05141                  AJP  0 BUILD
05132   25 0 05230                  DVI  0 INCRM
        23 0 05140                  QJP  0 SEVEN
05133   57 1 07226                  SIL  1 GOFER
        12 0 07226                  LDA  0 GOFER
05134   21 0 05231                  STQ  0 DECRM
        15 0 05231                  SUB  0 DECRM
05135   20 0 05231                  STA  0 DECRM
        53 2 05231                  LIL  2 DECRM
05136   16 0 06113                  LDQ  0 LCMASK
        44 2 16000                  LIL  2 ALFA
05137   20 3 05311                  STA  3 BETA
        51 3 00001                  INI  3 1
05140   12 0 05241    SEVEN         LDA  0 TEMP
        75 0 05126                  SLJ  0 SIX
05141   75 4 05202    BUILD         SLJ  4 FILL
        50 0 00000                  ENI  0 0
05142   75 1 05143                  SLJ  1 /+1
        75 0 05144                  SLJ  0 /+2
05143   12 0 06066                  LDA  0 HOLD
        20 0 05270                  STA  0 OUTBUF+1
05144   55 3 05145                  IJP  3 /+1
        75 0 05167                  SLJ  0 PRNONE
05145   10 3 00000                  ENA  3 0
        15 0 05247                  SUB  0 EIGHT
05146   22 3 05150                  AJP  3 /+2
        12 0 05251                  LDA  0 STAR
05147   20 0 05267                  STA  0 OUTBUF
        72 0 05253                  RAD  0 FLAG
05150   75 0 05152                  SLJ  0 /+2
        50 0 00000                  ENI  0 0
05151   75 4 05202                  SLJ  4 FILL
        50 0 00000                  ENI  0 0
```

```
05152    50 4 00002                ENI  4 2
         10 3 00000                ENA  3 0
05153    60 0 05162                SAU  0 NINE+5
         60 0 05171                SAU  0 TEN
05154    50 3 00000                ENI  3 0
         50 0 00000                ENI  0 0
05155    16 0 05250     NINE       LDQ  0 COMMA
         12 3 05311                LDA  3 BETA
05156    07 0 00030                LLS  0 24D
         50 0 00000                ENI  0 0
05157    20 4 05270                STA  4 OUTBUF+1
         50 0 00000                ENI  0 0
05160    54 4 00015                ISK  4 13D
         75 0 05171                SLJ  0 TEN
05161    75 4 05031                SLJ  4 OUTPUT
         50 0 00000                ENI  0 0
05162    54 3 00000                ISK  3 0
         75 0 05164                SLJ  0 /+2
05163    75 0 05173                SLJ  0 TENA
         50 0 00000                ENI  0 0
05164    75 4 05202                SLJ  4 FILL
         50 0 00000                ENI  0 0
05165    12 0 05232                LDA  0 CARD21
         20 0 05270                STA  0 OUTBUF+1
05166    50 4 00002                ENI  4 2
         75 0 05155                SLJ  0 NINE
05167    12 0 05306     PRNONE     LDA  0 NONE
         20 0 05272                STA  0 OUTBUF+3
05170    75 0 05172                SLJ  0 TEN+1
         50 0 00000                ENI  0 0
05171    54 3 00000     TEN        ISK  3 0
         75 0 05155                SLJ  0 NINE
05172    75 4 05031                SLJ  4 OUTPUT
         50 0 00000                ENI  0 0
05173    75 4 05202     TENA       SLJ  4 FILL
         50 0 00000                ENI  0 0
05174    75 4 05031                SLJ  4 OUTPUT
         50 0 00000                ENI  0 0
05175    20 0 05246                STA  0 TEMP+5
         10 0 00110                ENA  0 72D
05176    65 0 05310                TRS  0 PAGE
         75 0 05016                SLJ  0 ELEV
05177    10 0 00000                ENA  0 0
         20 0 05310                STA  0 PAGE
05200    12 0 05307                LDA  0 FJECT
         20 0 05267                STA  0 OUTBUF
05201    12 0 05246                LDA  0 TEMP+5
         75 0 05016                SLJ  0 ELEV
05202    75 0 00000     FILL       SLJ  0 0
         50 5 00000                ENI  5 0
05203    12 0 05252                LDA  0 SPACE
         20 5 05267                STA  5 OUTBUF
05204    54 5 00016                ISK  5 14D
         75 0 05203                SLJ  0 /-1
05205    75 0 05202                SLJ  0 FILL
         50 0 00000                ENI  0 0
05206    00 0 00000     LIST       OCT     73
         00 0 00073
05207    00 0 00000                OCT     54
         00 0 00054
05210    00 0 00000                OCT     53
         00 0 00053
05211    00 0 00000                OCT     21
         00 0 00021
05212    00 0 00000                OCT     33
         00 0 00033
05213    00 0 00000                OCT     34
         00 0 00034
05214    00 0 00000                OCT     74
         00 0 00074
05215    00 0 00000                OCT     60
         00 0 00060
05216    00 0 00000                OCT     13
```

```
        00 0 00013
05217   00 0 00000              OCT     14
        00 0 00014
05220   00 0 00000              OCT     20
        00 0 00020
05221   00 0 00000   CHECK      OCT     10
        00 0 00010
05222   00 0 00000              OCT     5
        00 0 00005
05223   00 0 00000              OCT     2
        00 0 00002
05224   00 0 00000              OCT     1
        00 0 00001
05225   00 0 00000              OCT     5
        00 0 00005
05226   00 0 00000              OCT     1
        00 0 00001
05227   00 0 00000              OCT     3
        00 0 00003
05230   00 0 00000   INCRM      OCT     22
        00 0 00022
05231   00 0 00000   DECRM      BSS     1
        00 0 00000
05232   20 2 02020   CARD21     BCD     /        .
        20 2 02073
05233   20 2 02020   CARD31     BCD     /        *
        20 2 02054
05234   20 2 02020   CARD61     BCD     /        $
        20 2 02053
05235   20 2 02020   CARD62     BCD     /        /
        20 2 02021
05236   20 2 02020   CARD01     BCD     /        ,
        20 2 02033
05237   20 2 02020   CARDS56    BCD     /        (
        20 2 02034
05240   20 2 02020   CARDS04    BCD     /        )
        20 2 02074
05241   00 0 00000   TEMP       BSS     6
        00 0 00000
05247   00 0 00000   EIGHT      OCT     10
        00 0 00010
05250   33 2 02020   COMMA      BCD     /,
        20 2 02020
05251   20 2 02020   STAR       BCD     /        *
        20 5 42020
05252   20 2 02020   SPACE      BCD     /
        20 2 02020
05253   00 0 00000   FLAG       BSS     1
        00 0 00000
05254   00 0 00000   UNITS      OCT     7
        00 0 00007
05255   00 0 00000   INBUF      BSS     10D
        00 0 00000
05267   00 0 00000   OUTBUF     BSS     15D
        00 0 00000
05306   45 4 64565   NONE       BCD     /NONE
        20 2 02020
05307   01 2 02020   EJECT      BCD     /1
        20 2 02020
05310   00 0 00000   PAGE       BSS     1
        00 0 00000
05311   00 0 00000   BETA       BSS     100D
        00 0 00000
05455   60 0 00000   BIT48      OCT     6000000000000000
        00 0 00000
                                REM     CARD ASSIGNMENT ROUTINE
05456   50 1 00032   PASS3      ENI   1 26D
        10 0 00000              LNA   0 0
05457   20 1 06027              STA   1 ICOUNT
        55 1 05457              IJP   1 /
05460   75 4 05700   PASS3A     SLJ   4 INPUT2
        50 0 00000              ENI   0 0
05461   74 7 32006              EXF   7 32006
```

```
          75 0 05552                SLJ  0 TEST
05462     74 3 05306                EXF  3 OUTBUF+150
          75 4 05202                SLJ  4 FILL
05463     12 0 06010                LDA  0 PAGEJ
          20 0 05267                STA  0 OUTBUF
05464     75 4 05705                SLJ  4 OUTPUT2
          50 0 00000                ENI  0 0
05465     75 4 05717                SLJ  4 CLRBUF
          50 0 00000                ENI  0 0
05466     10 0 06140                ENA  0 HEAD1
          60 0 05713                SAU  0 MSG+1
05467     12 0 06012                LDA  0 LNGTH1
          60 0 05714                SAU  0 MSG+2
05470     75 4 05712                SLJ  4 MSG
          50 0 00000                ENI  0 0
05471     75 4 05717                SLJ  4 CLRBUF
          50 0 00000                ENI  0 0
05472     10 0 06150                ENA  0 HEAD2
          60 0 05713                SAU  0 MSG+1
05473     12 0 06013                LDA  0 LNGTH2
          60 0 05714                SAU  0 MSG+2
05474     75 4 05712                SLJ  4 MSG
          50 0 00000                ENI  0 0
05475     75 4 05717                SLJ  4 CLRBUF
          50 0 00000                ENI  0 0
05476     10 0 06155                ENA  0 HEAD3
          60 0 05713                SAU  0 MSG+1
05477     12 0 06014                LDA  0 LNGTH3
          60 0 05714                SAU  0 MSG+2
05500     75 4 05712                SLJ  4 MSG
          50 0 00000                ENI  0 0
05501     50 5 00000                ENI  5 0
          75 4 05717                SLJ  4 CLRBUF
05502     12 0 05252                LDA  0 SPACE
          20 0 05274                STA  0 OUTBUF+5
05503     20 0 05275                STA  0 OUTBUF+6
          50 0 00000                ENI  0 0
05504     12 5 06116                LDA  5 CARD
          20 0 05271                STA  0 OUTBUF+2
05505     12 5 06027                LDA  5 ICOUNT
          75 4 05512                SLJ  4 OCTBCD
05506     54 5 00021                ISK  5 17D
          75 0 05502                SLJ  0 /-4
05507     74 0 32005                EXF  0 32005
          12 0 05253                LDA  0 FLAG
05510     75 1 05511                SLJ  1 /+1
          76 0 05000                SLS  0 5000
05511     22 0 06163                AJP  0 PASS4
          76 0 06163                SLS  0 PASS4
05512     75 0 00000    OCTBCD      SLJ  0 0
          50 6 00000                ENI  6 0
05513     65 0 06020                THS  0 RFR03
          51 6 00001                INI  6 1
05514     65 0 06017                THS  0 RFR02
          51 6 00001                INI  6 1
05515     65 0 06016                THS  0 RFR01
          51 6 00001                INI  6 1
05516     65 0 06015                THS  0 RFR00
          51 6 00001                INI  6 1
05517     55 6 05520                IJP  6 /+1
          75 0 05532                SLJ  0 FRACT
05520     16 6 06021                LDQ  6 MASK
          21 0 05243                STQ  0 TEMP+2
05521     04 0 00000                LNQ  0 0
          21 0 05241                STQ  0 TEMP
05522     04 0 00000                ENQ  0 0
          25 6 06015                DVI  6 RFR00
05523     22 1 05524                AJP  1 /+1
          12 0 06107                LDA  0 ZERO
05524     20 0 05244                STA  0 TEMP+3
          12 0 05241                LDA  0 TEMP
05525     05 0 00006                ALS  0 6
          14 0 05244                ADD  0 TEMP+3
```

```
05526    20 0 05241                STA  0 TEMP
         21 0 05244                STQ  0 TEMP+3
05527    12 0 05244                LDA  0 TEMP+3
         55 6 05522                IJP  6 /-5
05530    12 0 05241                LDA  0 TEMP
         14 0 05243                ADD  0 TEMP+2
05531    20 0 05274                STA  0 OUTBUF+5
         50 0 00000                ENI  0 0
05532    10 5 00000    FRACT       ENA  5 0
         15 0 06026                SUB  0 TRIP
05533    22 2 05542                AJP  2 THIRD
         10 5 00000                ENA  5 0
05534    15 0 06025                SUB  0 DOUB
         22 2 05547                AJP  2 HALF
05535    12 0 05274    ITEST       LDA  0 OUTBUF+5
         15 0 05252                SUB  0 SPACE
05536    22 1 05540                AJP  1 OUTLINE
         12 0 05306                LDA  0 NONE
05537    20 0 05274                STA  0 OUTBUF+5
         50 0 00000                ENI  0 0
05540    75 4 05705    OUTLINE     SLJ  4 OUTPUT2
         50 0 00000                ENI  0 0
05541    75 0 05512                SLJ  0 OCTBCD
         50 0 00000                ENI  0 0
05542    12 5 06040    THIRD       LDA  5 FCOUNT-9D
         22 0 05535                AJP  0 ITEST
05543    64 0 06015                EQS  0 REROO
         75 0 05545                SLJ  0 /+2
05544    12 0 06072                LDA  0 ATHIRD
         75 0 05546                SLJ  0 /+2
05545    12 0 06073                LDA  0 BTHIRD
         50 0 00000                ENI  0 0
05546    20 0 05275                STA  0 OUTBUF+6
         75 0 05540                SLJ  0 OUTLINE
05547    12 5 06040    HALF        LDA  5 FCOUNT-9D
         22 0 05535                AJP  0 ITEST
05550    12 0 06074                LDA  0 AHALF
         20 0 05275                STA  0 OUTBUF+6
05551    75 0 05540                SLJ  0 OUTLINE
         50 0 00000                ENI  0 0
05552    12 0 05305    TEST        LDA  0 OUTBUF+14D
         50 1 00000                ENI  1 0
05553    64 0 05252                EQS  0 SPACE
         75 0 05560                SLJ  0 TEST2
05554    75 0 05556                SLJ  0 /+2
         50 0 00000                ENI  0 0
05555    75 5 05734    TEST1       SLJ  5 OUTPIN
         50 0 00000                ENI  0 0
05556    75 4 05705                SLJ  4 OUTPUT2
         50 0 00000                ENI  0 0
05557    75 0 05460                SLJ  0 PASS3A
         50 0 00000                ENI  0 0
05560    64 0 05234    TEST2       EQS  0 CARD61
         75 0 05570                SLJ  0 NEXT1
05561    75 4 05705    ICCD        SLJ  4 OUTPUT2
         50 0 00000                ENI  0 0
05562    75 4 05700                SLJ  4 INPUT2
         50 0 00000                ENI  0 0
05563    12 1 06134                LDA  1 CARD+14D
         20 0 05271                STA  0 OUTBUF+2
05564    72 1 06056                RAO  1 FCOUNT+5
         15 0 06077                SUB  0 TRIO
05565    22 0 05566                AJP  0 /+1
         75 0 05555                SLJ  0 TEST1
05566    10 0 00000                ENA  0 0
         20 1 06056                STA  1 FCOUNT+5
05567    72 1 06045                RAO  1 ICCOUNT+14D
         75 0 05555                SLJ  0 TEST1
05570    64 0 05235    NEXT1       EQS  0 CARD62
         75 0 05655                SLJ  0 NEXT2
05571    50 1 00001                ENI  1 1
         75 0 05561                SLJ  0 ICCD
05572    64 0 05233    TEST3       EQS  0 CARD51
```

```
         75 0 05616                SLJ  0 TEST4
05573    50 6 00012                ENI  6 100
         75 4 05723                SLJ  4 ORCOUNT
05574    75 4 05705                SLJ  4 OUTPUT2
         50 0 00000                ENI  0 0
05575    75 4 05700                SLJ  4 INPUT2
         50 0 00000                ENI  0 0
05576    12 0 06063                LDA  0 ORCNT
         50 0 00000                ENI  0 0
05577    64 0 06100                EQS  0 DUO
         75 0 05612                SLJ  0 TRY2
05600    12 1 06124     FFCD       LDA  1 CARD+6
         20 0 05271                STA  0 OUTBUF+2
05601    10 0 00001                ENA  0 1
         20 0 06070                STA  0 FFFLG
05602    72 1 06035                RAO  1 ICOUNT+6
         75 5 05734                SLJ  5 OUTPIN
05603    75 4 05705                SLJ  4 OUTPUT2
         50 0 00000                ENI  0 0
05604    75 4 05700                SLJ  4 INPUT2
         50 0 00000                ENI  0 0
05605    75 4 05705                SLJ  4 OUTPUT2
         50 0 00000                ENI  0 0
05606    75 4 05700                SLJ  4 INPUT2
         50 0 00000                ENI  0 0
05607    12 1 06124                LDA  1 CARD+6
         20 0 05271                STA  0 OUTBUF+2
05610    12 0 05455                LDA  0 BI148
         20 2 16001                STA  2 ALFA+1
05611    75 0 05555                SLJ  0 TEST1
         50 0 00000                ENI  0 0
05612    64 0 06077     TRY2       EQS  0 TRIO
         75 0 05614                SLJ  0 TRY3
05613    50 1 00001                ENI  1 1
         75 0 05600                SLJ  0 FFCD
05614    64 0 06076     TRY3       EQS  0 QUAD
         75 0 05665                SLJ  0 ERROR1
05615    50 1 00002                ENI  1 2
         75 0 05600                SLJ  0 FFCD
05616    64 0 05232     TEST4      EQS  0 CARD21
         75 0 05661                SLJ  0 TEST5
05617    50 6 00012                ENI  6 100
         75 4 05723                SLJ  4 ORCOUNT
05620    75 4 05705                SLJ  4 OUTPUT2
         50 0 00000                ENI  0 0
05621    75 4 05700                SLJ  4 INPUT2
         50 0 00000                ENI  0 0
05622    75 4 05672                SLJ  4 OUTCOUNT
         50 0 00000                ENI  0 0
05623    12 0 06063                LDA  0 ORCNT
         50 0 00000                ENI  0 0
05624    64 0 06075                EQS  0 QUINT
         75 0 05632                SLJ  0 TRY6
05625    12 1 06101     UNCD       LDA  1 OUTEND
         50 0 00000                ENI  0 0
05626    65 0 06062                THS  0 OUTCNT
         75 0 05630                SLJ  0 /+2
05627    75 0 05670                SLJ  0 ERROR2
         50 0 00000                ENI  0 0
05630    12 1 06122                LDA  1 CARD+4
         20 0 05271                STA  0 OUTBUF+2
05631    72 1 06033                RAO  1 ICOUNT+4
         75 0 05555                SLJ  0 TEST1
05632    64 0 06102     TRY6       EQS  0 SEXT
         75 0 05634                SLJ  0 INV1
05633    50 1 00001                ENI  1 1
         75 0 05625                SLJ  0 UNCD
05634    64 0 06015     INV1       EQS  0 REROO
         75 0 05647                SLJ  0 INV2
05635    12 1 06075     INCD       LDA  1 QUINT
         50 0 00000                ENI  0 0
05636    65 0 06062                THS  0 OUTCNT
         75 0 05641                SLJ  0 SER20
```

```
05637    12 1 06116                LDA  1 CARD
         20 0 05271                STA  0 OUTBUF+2
05640    72 1 06027                RAC  1 ICOUNT
         75 0 05555                SLJ  0 TEST1
05641    51 1 00011    SER20       INI  1 9D
         12 1 06116                LDA  1 CARD
05642    20 0 05271                STA  0 OUTBUF+2
         72 1 06040                RAC  1 ICOUNT+9D
05643    15 0 06100                SUB  0 DUO
         22 0 05645                AJP  0 /+2
05644    75 0 05555                SLJ  0 TEST1
         50 0 00000                ENI  0 0
05645    10 0 00000                ENA  0 0
         20 1 06040                STA  1 ICOUNT+9D
05646    72 1 06027                RAC  1 ICOUNT
         75 0 05555                SLJ  0 TEST1
05647    64 0 06100    INV2        EQS  0 DUO
         75 0 05651                SLJ  0 INV3
05650    50 1 00001                ENI  1 1
         75 0 05635                SLJ  0 INCD
05651    64 0 06077    INV3        EQS  0 TRIO
         75 0 05653                SLJ  0 INV4
05652    50 1 00002                ENI  1 2
         75 0 05635                SLJ  0 INCD
05653    64 0 06076    INV4        EQS  0 QUAD
         75 0 05671                SLJ  0 ERROR3
05654    50 1 00003                ENI  1 3
         75 0 05635                SLJ  0 INCD
05655    64 0 05237    NEXT2       EQS  0 CARDS36
         75 0 05657                SLJ  0 NEXT3
05656    50 1 00002                ENI  1 2
         75 0 05561                SLJ  0 ICCD
05657    64 0 05240    NEXT3       EQS  0 CARDS04
         75 0 05572                SLJ  0 TEST3
05660    50 1 00003                ENI  1 3
         75 0 05561                SLJ  0 ICCD
05661    64 0 05236    TEST5       EQS  0 CARD01
         75 0 05665                SLJ  0 ERROR1
05662    50 1 00004                ENI  1 4
         75 4 05705                SLJ  4 OUTPUT2
05663    75 4 05700                SLJ  4 INPUT2
         50 0 00000                ENI  0 0
05664    75 0 05641                SLJ  0 SER20
         50 0 00000                ENI  0 0
05665    12 0 06103    ERROR1      LDA  0 TAGE
         50 0 00000                ENI  0 0
05666    20 0 05271                STA  0 OUTBUF+2
         72 0 05253                RAC  0 FLAG
05667    75 0 05555                SLJ  0 TEST1
         50 0 00000                ENI  0 0
05670    12 0 06104    ERROR2      LDA  0 OUTE
         75 0 05666                SLJ  0 /-2
05671    12 0 06105    ERROR3      LDA  0 INE
         75 0 05666                SLJ  0 /-3
05672    75 0 00000    OUTCOUNT    SLJ  0 0
         50 6 00013                ENI  6 11D
05673    10 0 00000                ENA  0 0
         20 0 06062                STA  0 OUTCNT
05674    12 0 06110                LDA  0 CMASK
         16 0 06110                LDQ  0 CMASK
05675    46 6 05272                SBL  6 OUTBUF+3
         22 1 05677                AJP  1 /+2
05676    72 0 06062                RAC  0 OUTCNT
         50 0 00000                ENI  0 0
05677    55 6 05674                IJP  6 /-3
         75 0 05672                SLJ  0 OUTCOUNT
05700    75 0 00000    INPUT2      SLJ  0 0
         74 7 32000                EXF  7 32000
05701    10 0 05306                ENA  0 OUTBUF+15D
         61 0 00003                SAL  0 3
05702    74 0 32042                EXF  0 32042
         74 7 32000                EXF  7 32000
05703    74 3 05267                EXF  3 OUTBUF
```

```
        74 7 32000                EXF  7 32000
05704   75 0 05700                SLJ  0 INPUT2
        50 0 00000                ENI  0 0
05705   75 0 00000   OUTPUT2      SLJ  0 0
        74 7 42000                EXF  7 42000
05706   10 0 05306                ENA  0 OUTBUF+15D
        61 0 00004                SAL  0 4
05707   74 0 42032                EXF  0 42032
        74 7 42000                EXF  7 42000
05710   74 4 05267                EXF  4 OUTBUF
        74 7 42000                EXF  7 42000
05711   75 0 05705                SLJ  0 OUTPUT2
        50 0 00000                ENI  0 0
05712   75 0 00000   MSG          SLJ  0 0
        50 5 00000                ENI  5 0
05713   12 5 00000                LDA  5 0
        20 5 05270                STA  5 OUTBUF+1
05714   54 5 00000                ISK  5 0
        75 0 05713                SLJ  0 /-1
05715   75 4 05705                SLJ  4 OUTPUT2
        50 0 00000                ENI  0 0
05716   75 0 05712                SLJ  0 MSG
        50 0 00000                ENI  0 0
05717   75 0 00000   CLRBUF       SLJ  0 0
        12 0 06011                LDA  0 DBSP
05720   20 0 05267                STA  0 OUTBUF
        50 5 00015                ENI  5 13D
05721   12 0 05252                LDA  0 SPACE
        20 5 05270                STA  5 OUTBUF+1
05722   55 5 05721                IJP  5 /-1
        75 0 05717                SLJ  0 CLRBUF
05723   75 0 00000   ORCOUNT      SLJ  0 0
        10 0 00000                ENA  0 0
05724   20 0 06063                STA  0 ORCNT
        04 0 00000                ENQ  0 0
05725   16 6 05267                LDQ  6 OUTBUF
        50 4 00007                ENI  4 7
05726   07 0 00006                LLS  0 6
        50 0 00000                ENI  0 0
05727   64 0 06106                EQS  0 PLUS
        75 0 05731                SLJ  0 /+2
05730   72 0 06063                RAQ  0 ORCNT
        50 0 00000                ENI  0 0
05731   10 0 00000                ENA  0 0
        55 4 05726                IJP  4 /-3
05732   55 6 05725                IJP  6 /-5
        72 0 06063                RAQ  0 ORCNT
05733   75 0 05723                SLJ  0 ORCOUNT
        50 0 00000                ENI  0 0
05734   75 0 00000   OUTPIN       SLJ  0 0
        53 2 06067                LIL  2 WAIT
05735   16 0 06071                LDQ  0 SMASK
        44 0 05271                LDL  0 OUTBUF+2
05736   15 0 06071                SUB  0 SMASK
        22 0 05752                AJP  0 TYP3
05737   16 0 06111                LDQ  0 TMASK
        44 0 05271                LDL  0 OUTBUF+2
05740   22 1 05752                AJP  1 TYP3
        02 0 00001                ORS  0 1
05741   44 0 05271                LDL  0 OUTBUF+2
        22 1 05763                AJP  1 TYP2
05742   10 0 00001                ENA  0 1
        75 4 05771                SLJ  4 INPIN
05743   10 0 00014                ENA  0 12D
        50 0 00000                ENI  0 0
05744   05 0 00030   MID          ALS  0 24D
        70 2 16000                RAD  2 ALFA
05745   12 0 06070                LDA  0 FFFLG
        22 0 05750                AJP  0 /+3
05746   12 0 05455                LDA  0 BIT48
        20 2 16001                STA  2 ALFA+1
05747   10 0 00000                ENA  0 0
        20 0 06070                STA  0 FFFLG
```

```
05750    51 2 00022                 INI   2 22
         57 2 06067                 SIL   2 WAIT
05751    75 0 05734                 SLJ   0 OUTPIN
         50 0 00000                 ENI   0 0
05752    04 0 00077    TYP3         ENQ   0 77
         44 0 05270                 LDL   0 OUTBUF+1
05753    64 0 06114                 EQS   0 PTA
         75 0 05756                 SLJ   0 /+3
05754    10 0 00001                 ENA   0 1
         75 4 05771                 SLJ   4 INPIN
05755    10 0 00004                 ENA   0 4D
         75 0 05744                 SLJ   0 MID
05756    64 0 06115                 EQS   0 PTB
         75 0 05761                 SLJ   0 /+3
05757    10 0 00005                 ENA   0 5
         75 4 05771                 SLJ   4 INPIN
05760    10 0 00010                 ENA   0 8D
         75 0 05744                 SLJ   0 MID
05761    10 0 00011                 ENA   0 9D
         75 4 05771                 SLJ   4 INPIN
05762    75 0 05743                 SLJ   0 MID-1
         50 0 00000                 ENI   0 0
05763    04 0 00077    TYP2         ENQ   0 77
         44 0 05270                 LDL   0 OUTBUF+1
05764    64 0 06114                 EQS   0 PTA
         75 0 05767                 SLJ   0 /+3
05765    10 0 00001                 ENA   0 1
         75 4 05771                 SLJ   4 INPIN
05766    10 0 00006                 ENA   0 6
         75 0 05744                 SLJ   0 MID
05767    10 0 00007                 ENA   0 7
         75 4 05771                 SLJ   4 INPIN
05770    75 0 05743                 SLJ   0 MID-1
         50 0 00000                 ENI   0 0
05771    75 0 00000    INPIN        SLJ   0 0
         05 0 00036                 ALS   0 30D
05772    70 2 16000                 RAD   2 ALFA
         75 0 05771                 SLJ   0 INPIN
05773    75 0 00000    MAKEX        SLJ   0 0
         12 0 05301                 LDA   0 OUTBUF+10D
05774    20 0 06066                 STA   0 BCD
         41 0 06112                 SCL   0 HIMASK
05775    07 0 00060                 LLS   0 48D
         12 0 05241                 LDA   0 TEMP
05776    75 4 06001                 SLJ   4 ENTER
         50 0 00000                 ENI   0 0
05777    12 0 05252                 LDA   0 SPACE
         20 0 05301                 STA   0 OUTBUF+10D
06000    75 0 05773                 SLJ   0 MAKEX
         50 0 00000                 ENI   0 0
06001    75 0 00000    ENTER        SLJ   0 0
         57 6 06065                 SIL   6 STORE
06002    53 6 06064                 LIL   6 COUNT
         20 6 10000                 STA   6 ARGUE
06003    21 6 13000                 STQ   6 VALUE
         50 0 00000                 ENI   0 0
06004    54 6 02777                 ISK   6 2777
         75 0 06006                 SLJ   0 /+2
06005    04 0 00000                 ENQ   0 0
         75 0 06007                 SLJ   0 /+2
06006    50 0 00000                 ENI   0 0
         57 6 06064                 SIL   6 COUNT
06007    53 6 06065                 LIL   6 STORE
         75 0 06001                 SLJ   0 ENTER
06010    01 2 02020    PAGEJ        BCD     /1
         20 2 02020
06011    12 2 02020    DBSP         BCD     /0
         20 2 02020
06012    00 0 00000    LNGTH1       DEC     7
         00 0 00007
06013    00 0 00000    LNGTH2       DEC     4
         00 0 00004
06014    00 0 00000    LNGTH3       DEC     5
```

```
                00 0 00005
06015           00 0 00000   RF300     OCT     1
                00 0 00001
06016           00 0 00000   RF301     OCT     12
                00 0 00012
06017           00 0 00000   RF302     OCT     144
                00 0 00144
06020           00 0 00000   RF303     OCT     1750
                00 0 01750
06021           20 2 02020   MASK      OCT     2020202020202000
                20 2 02000
06022           20 2 02020               OCT     2020202020200000
                20 2 00000
06023           20 2 02020               OCT     2020202020000000
                20 0 00000
06024           20 2 02020               OCT     2020202000000000
                00 0 00000
06025           00 0 00000   DOUB      DEC     9
                00 0 00011
06026           00 0 00000   TRIP      DEC     14
                00 0 00016
06027           00 0 00000   ICOUNT    BSS     18D
                00 0 00000
06051           00 0 00000   FCOUNT    BSS     9D
                00 0 00000
06062           00 0 00000   OUTCNT    BSS     1
                00 0 00000
06063           00 0 00000   ORCNT     BSS     1
                00 0 00000
06064           00 0 00000   COUNT     BSS     1
                00 0 00000
06065           00 0 00000   STORE     BSS     1
                00 0 00000
06066           00 0 00000   HOLD      BSS     1
                00 0 00000
06067           00 0 00000   WAIT      BSS     1
                00 0 00000
06070           00 0 00000   FFFLG     BSS     1
                00 0 00000
06071           00 0 02200   SMASK     OCT     220000000000
                00 0 00000
06072           20 2 00121   ATHIRD    OCT     2020012103202020
                03 2 02020
06073           20 2 00221   BTHIRD    OCT     2020022103202020
                03 2 02020
06074           20 2 00121   AHALF     OCT     2020012102202020
                02 2 02020
06075           00 0 00000   QUINT     OCT     5
                00 0 00005
06076           00 0 00000   QUAD      OCT     4
                00 0 00004
06077           00 0 00000   TRIO      OCT     3
                00 0 00003
06100           00 0 00000   DUO       OCT     2
                00 0 00002
06101           00 0 00000   OUTEND    OCT     7
                00 0 00007
06102           00 0 00000   SEXT      OCT     6
                00 0 00006
06103           00 0 00000   TAGE      OCT     54542020
                54 5 42020
06104           00 0 00054   OUTE      OCT     5454542020
                54 5 42020
06105           00 0 05454   INE       OCT     54545454542020
                54 5 42020
06106           00 0 00000   PLUS      OCT     60
                00 0 00060
06107           00 0 00000   ZERO      OCT     12
                00 0 00012
06110           00 0 00000   CMASK     OCT     33000000
                33 0 00000
06111           00 0 00004   TMASK     OCT     400000000
                00 0 00000
```

```
06112    77 7 77777   HIMASK   OCT    7777777700000000
         00 0 00000
06113    00 0 00000   LOMASK   OCT    77777777
         77 7 77777
06114    00 0 00000   PTA      OCT    61
         00 0 00061
06115    00 0 00000   PTE      OCT    62
         00 0 00062
06116    20 2 02001   CARD     BCD    /    11
         01 2 02020
06117    20 2 02001            BCD    /    12
         02 2 02020
06120    20 2 02001            BCD    /    13
         03 2 02020
06121    20 2 02001            BCD    /    14
         04 2 02020
06122    20 2 02001            BCD    /    15
         05 2 02020
06123    20 2 02001            BCD    /    16
         06 2 02020
06124    20 2 02003            BCD    /    31
         01 2 02020
06125    20 2 02003            BCD    /    32
         02 2 02020
06126    20 2 02003            BCD    /    33
         03 2 02020
06127    20 2 02002            BCD    /    21
         01 2 02020
06130    20 2 02002            BCD    /    22
         02 2 02020
06131    20 2 02002            BCD    /    23
         03 2 02020
06132    20 2 02002            BCD    /    24
         04 2 02020
06133    20 2 02012            BCD    /    01
         01 2 02020
06134    20 2 02006            BCD    /    61
         01 2 02020
06135    20 2 02006            BCD    /    62
         02 2 02020
06136    20 2 02203            BCD    /   S36
         06 2 02020
06137    20 2 02212            BCD    /   S04
         04 2 02020
06140    24 2 02220   HEAD1    BCD    /U S NAVA
         45 6 12561
06141    43 2 04746            BCD    /L POST G
         22 2 32067
06142    51 6 16424            BCD    /RADUATE
         61 2 36520
06143    22 6 37046            BCD    /SCHOOL
         46 4 32020
06144    20 2 06461            BCD    /  DATA P
         23 6 12047
06145    51 4 66365            BCD    /RCCESSIN
         22 2 27145
06146    67 2 04361            BCD    /G LABORA
         62 4 65161
06147    23 4 65130            BCD    /TCRY
         20 2 02020
06150    20 2 02020   HEAD2    BCD    /
         20 2 02020
06151    63 4 64447            BCD    /CCMPILAT
         71 4 36123
06152    71 4 64520            BCD    /ICN OF C
         46 6 62063
06153    61 5 16420            BCD    /ARD ASSI
         61 2 22271
06154    67 4 54465            BCD    /GNMENTS
         45 2 32220
06155    20 2 02020   HEAD3    BCD    /
         20 2 02020
06156    63 6 15164            BCD    /CARD TYP
```

```
        20 2 33047
06157   65 2 02020          BCD     /F
        20 2 02020
06160   20 2 02020          BCD     /
        20 2 02020
06161   45 2 44462          BCD     /NUMBER O
        65 5 12046
06162   66 2 06361          BCD     /F CARDS
        51 6 42220
06163   50 1 00000  PASS4   ENI   1 0
        50 2 00000          ENI   2 0
06164   50 3 00000          ENI   3 0
        50 4 00000          ENI   4 0
06165   50 6 00002          ENI   6 2
        10 0 00000          ENA   0 0
06166   20 0 06027          STA   0 ICCUNT
        20 0 06067          STA   0 WAIT
06167   20 0 06066          STA   0 HOLD
        75 4 05202          SLJ   4 FILL
06170   12 0 06010          LDA   0 PAGEJ
        20 0 05267          STA   0 OUTBUF
06171   75 4 05705          SLJ   4 OUTPUT2
        50 0 00000          ENI   0 0
06172   75 4 05717          SLJ   4 CLRBUF
        50 0 00000          ENI   0 0
06173   10 0 06140          ENA   0 HEAD1
        60 0 05713          SAU   0 MSG+1
06174   12 0 06012          LDA   0 LNGTH1
        60 0 05714          SAU   0 MSG+2
06175   75 4 05712          SLJ   4 MSG
        50 0 00000          ENI   0 0
06176   75 4 05717          SLJ   4 CLRBUF
        50 0 00000          ENI   0 0
06177   10 0 06560          ENA   0 HEAD4
        60 0 05713          SAU   0 MSG+1
06200   12 0 06556          LDA   0 LNGTH4
        60 0 05714          SAU   0 MSG+2
06201   75 4 05712          SLJ   4 MSG
        50 0 00000          ENI   0 0
06202   75 0 06206          SLJ   0 ONLY
        50 0 00000          ENI   0 0
06203   75 4 05202  NXTP    SLJ   4 FILL
        50 0 00000          ENI   0 0
06204   12 0 06010          LDA   0 PAGEJ
        20 0 05267          STA   0 OUTBUF
06205   75 4 05705          SLJ   4 OUTPUT2
        50 0 00000          ENI   0 0
06206   75 4 05717  ONLY    SLJ   4 CLRBUF
        50 0 00000          ENI   0 0
06207   10 0 06565          ENA   0 HEAD5
        60 0 05713          SAU   0 MSG+1
06210   12 0 06557          LDA   0 LNGTH5
        60 0 05714          SAU   0 MSG+2
06211   75 4 05712          SLJ   4 MSG
        50 0 00000          ENI   0 0
06212   75 4 05717  WLINE   SLJ   4 CLRBUF
        50 0 00000          ENI   0 0
06213   75 4 06223          SLJ   4 GET
        50 0 00000          ENI   0 0
06214   75 4 05705          SLJ   4 OUTPUT2
        50 0 00000          ENI   0 0
06215   12 0 05277          LDA   0 OUTBUF+80
        41 0 05252          SCL   0 SPACE
06216   22 1 06221          AJP   1 /+3
        50 0 00000          ENI   0 0
06217   74 0 42003          EXF   0 42003
        74 7 42000          EXF   7 42000
06220   74 0 42005          EXF   0 42005
        76 0 05000          SLS   0 5000
06221   54 6 00043          ISK   6 35D
        75 0 06212          SLJ   0 WLINE
06222   75 0 06203          SLJ   0 NXTP
        50 0 00000          ENI   0 0
```

```
06223    75 0 00000   GET     SLJ  0 0
         10 2 00000           ENA  2 0
06224    22 1 06264           AJP  1 PREP
         12 0 06027           LDA  0 ICOUNT
06225    22 1 06321           AJP  1 UDAT
         12 3 16000           LDA  3 ALFA
06226    01 0 00036           ARS  0 30D
         20 0 06611           STA  0 PINNI
06227    10 0 00001           ENA  0 1
         20 0 06027           STA  0 ICOUNT
06230    51 1 00001   GOT     INI  1 1
         16 0 06113           LDQ  0 LCMASK
06231    44 1 16000           LDL  1 ALFA
         20 2 06603           STA  2 AND
06232    36 1 16001           SSK  1 ALFA+1
         75 0 06235           SLJ  0 PICK
06233    22 0 06230           AJP  0 GOT
         51 2 00001           INI  2 1
06234    75 0 06240           SLJ  0 COMPUT
         50 0 00000           ENI  0 0
06235    22 0 06237   PICK    AJP  0 /+2
         51 2 00001           INI  2 1
06236    75 0 06230           SLJ  0 GOT
         50 0 00000           ENI  0 0
06237    10 0 00000           ENA  0 0
         20 0 06027           STA  0 ICOUNT
06240    57 2 06066   COMPUT  SIL  2 HOLD
         10 2 00000           ENA  2 0
06241    22 0 06322           AJP  0 LOOK
         16 0 06113           LDQ  0 LCMASK
06242    44 3 16000           LDL  3 ALFA
         20 0 06602           STA  0 IAND
06243    55 2 06244           IJP  2 /+1
         75 0 06250           SLJ  0 BAT
06244    12 2 06603           LDA  2 AND
         75 4 06504           SLJ  4 SEARCHI
06245    50 0 00000           ENI  0 0
         02 0 00006           ARS  0 6
06246    21 2 06621           STQ  2 LOCAT
         75 4 06511           SLJ  4 DECOUT
06247    20 2 06612           STA  2 PINNO
         75 0 06243           SLJ  0 /-4
06250    16 0 06113   BAT     LDQ  0 LCMASK
         44 3 16000           LDL  3 ALFA
06251    75 4 06504           SLJ  4 SEARCHI
         50 0 00000           ENI  0 0
06252    02 0 00006           ARS  0 6
         21 0 06620           STQ  0 OLOC
06253    12 0 06611           LDA  0 PINNI
         11 0 00001           INA  0 1
06254    05 0 00036           ALS  0 30D
         17 0 06743           LRC  0 IMASK
06255    43 3 16000           SSU  3 ALFA
         20 3 16000           STA  3 ALFA
06256    50 0 00000           ENI  0 0
         04 0 00000           ENQ  0 0
06257    12 0 06747           LDA  0 INDIC
         20 0 05270           STA  0 OUTPUT+1
06260    53 2 06066           LIL  2 HOLD
         75 4 06327           SLJ  4 BEST
06261    12 0 06027           LDA  0 ICOUNT
         22 1 06264           AJP  1 PREP
06262    51 3 00022           INI  3 22
         56 3 06263           SIU  3 /+1
06263    50 1 00000           ENI  1 0
         50 0 00000           ENI  0 0
06264    51 2 77776   PREP    INI  2 -1
         57 6 05311           SIL  6 BETA
06265    04 0 00000           ENQ  0 0
         12 2 06717           LDA  2 TABLE
06266    07 0 00006           LLS  0 6
         20 0 05246           STA  0 TEMP+5
06267    21 0 05245           STQ  0 TEMP+4
```

```
        53 6 05245          LIL  6 TEMP+4
06270   12 6 06611          LDA  6 PINNI
        22 0 06275          AJP  0 /+5
06271   75 4 06526          SLJ  4 CNVT
        50 0 00000          ENI  0 0
06272   03 0 00022          LRS  0 18D
        12 6 06620          LDA  6 OLOC
06273   14 0 06737          ADD  0 PRMSK
        07 0 00022          LLS  0 18D
06274   75 0 06276          SLJ  0 /+2
        50 0 00000          ENI  0 0
06275   12 6 06602          LDA  6 IAND
        14 0 06740          ADD  0 UPSPA
06276   20 0 05273          STA  0 OUTBUF+4
        50 0 00000          ENI  0 0
06277   12 6 06602          LDA  6 IAND
        14 0 06741          ADD  0 TOSPA
06300   20 0 05277          STA  0 OUTBUF+8D
        12 0 05246          LDA  0 TEMP+5
06301   04 0 00000          ENQ  0 0
        07 0 00006          LLS  0 6
06302   21 0 05245          STQ  0 TEMP+4
        53 6 05245          LIL  6 TEMP+4
06303   12 6 06611          LDA  6 PINNI
        22 0 06310          AJP  0 /+5
06304   75 4 06526          SLJ  4 CNVT
        50 0 00000          ENI  0 0
06305   03 0 00022          LRS  0 18D
        12 6 06620          LDA  6 OLOC
06306   14 0 06737          ADD  0 PRMSK
        07 0 00022          LLS  0 18D
06307   75 0 06311          SLJ  0 /+2
        50 0 00000          ENI  0 0
06310   12 6 06602          LDA  6 IAND
        14 0 06740          ADD  0 UPSPA
06311   20 0 05271          STA  0 OUTBUF+2
        50 0 00000          ENI  0 0
06312   12 6 06602          LDA  6 IAND
        14 0 06740          ADD  0 UPSPA
06313   05 0 00014          ALS  0 12D
        20 0 05276          STA  0 OUTBUF+7
06314   16 0 06113          LDQ  0 LOMASK
        44 2 06717          LDL  2 TABLE
06315   75 4 06476          SLJ  4 WIRE
        50 0 00000          ENI  0 0
06316   20 0 05302          STA  0 OUTBUF+11D
        12 0 06601          LDA  0 INCHES
06317   20 0 05303          STA  0 OUTBUF+12D
        53 6 05311          LIL  6 BETA
06320   75 0 06223          SLJ  0 GET
        50 0 00000          ENI  0 0
06321   72 0 06611  UDAT    RAO  0 PINNI
        75 0 06230          SLJ  0 GOT
06322   12 3 16000  LOOK    LDA  3 ALFA
        22 0 06223          AJP  0 GET
06323   12 3 16001          LDA  3 ALFA+1
        22 1 06325          AJP  1 /+2
06324   12 0 07227          LDA  0 CLOCK
        20 0 05277          STA  0 OUTBUF+8D
06325   51 3 00022          INI  3 22
        56 3 06326          SIU  3 /+1
06326   50 1 00000          ENI  1 0
        75 0 06223          SLJ  0 GET
06327   75 0 00000  BEST    SLJ  0 0
        57 6 06065          SIL  6 STORE
06330   10 0 00000          ENA  0 0
        50 6 00107          ENI  6 71D
06331   20 6 06627          STA  6 SINK
        55 6 06331          IJP  6 /
06332   20 0 05253          STA  0 FLAG
        75 4 06401          SLJ  4 POSITS
06333   55 2 06332          IJP  2 /-1
        12 0 06066          LDA  0 HOLD
```

```
06334   60 0 06451                SAU  0 DIAG+11D
        11 0 77776                INA  0 -1
06335   60 0 06452                SAU  0 DIAG+12D
        75 4 06436                SLJ  4 DIAG
06336   12 0 06066                LDA  0 HOLD
        57 2 05245                SIL  2 TEMP+4
06337   11 0 77776                INA  0 -1
        60 0 06376                SAU  0 ACCEPT+3
06340   16 0 07224   MAINL       LDQ  0 BLOT
        11 2 77776                INA  2 -1
06341   50 0 00000                ENI  0 0
        44 2 06654                LDL  2 CHAIR
06342   22 1 06343                AJP  1 /+1
        55 2 06341                IJP  2 /-1
06343   04 6 00000                ENQ  6 0
        23 1 06351                QJP  1 EARLY
06344   07 0 00006                LLS  0 6
        05 0 00006                ALS  0 6
06345   20 0 06735                STA  0 END1
        20 0 06726                STA  0 SUBTRE
06346   21 0 06736                STQ  0 END1+1
        21 0 06727                STQ  0 SUBTRE+1
06347   50 4 00002                ENI  4 2
        57 4 06067                SIL  4 WAIT
06350   75 0 06373                SLJ  0 ACCEPT
        50 0 00000                ENI  0 0
06351   04 0 00000   EARLY        ENQ  0 0
        07 0 00006                LLS  0 6
06352   05 0 00006                ALS  0 6
        50 0 00000                ENI  0 0
06353   64 4 06735   DOG          EQS  4 END1
        75 0 06361                SLJ  0 RAT
06354   57 4 05247                SIL  4 TEMP+6
        50 0 00000                ENI  0 0
06355   07 0 00060                LLS  0 48D
        53 4 06067                LIL  4 WAIT
06356   64 4 06726                EQS  4 SUBTRE
        75 0 06367                SLJ  0 WEDO
06357   10 0 00000                ENA  0 0
        20 2 06654                STA  2 CHAIR
06360   20 0 05253                STA  0 FLAG
        75 0 06340                SLJ  0 MAINL
06361   53 4 05253   RAT          LIL  4 FLAG
        55 4 06365                IJP  4 SKIP
06362   07 0 00060                LLS  0 48D
        50 4 00001                ENI  4 1
06363   57 4 05253                SIL  4 FLAG
        50 4 00002                ENI  4 2
06364   75 0 06353                SLJ  0 DOG
        50 0 00000                ENI  0 0
06365   57 4 05253   SKIP         SIL  4 FLAG
        50 4 00002                ENI  4 2
06366   75 0 06340                SLJ  0 MAINL
        50 0 00000                ENI  0 0
06367   53 4 06067   WEDO         LIL  4 WAIT
        20 4 06726                STA  4 SUBTRE
06370   53 4 05247                LIL  4 TEMP+6
        20 4 06735                STA  4 END1
06371   72 0 06067                RAQ  0 WAIT
        10 0 00000                ENA  0 0
06372   20 0 05253                STA  0 FLAG
        50 0 00000                ENI  0 0
06373   12 2 06654   ACCEPT       LDA  2 CHAIR
        20 6 06717                STA  6 TABLE
06374   10 0 00000                ENA  0 0
        20 2 06654                STA  2 CHAIR
06375   50 4 00002                ENI  4 2
        53 2 05245                LIL  2 TEMP+4
06376   54 6 00000                ISK  6 0
        75 0 06340                SLJ  0 MAINL
06377   53 2 06066                LIL  2 HOLD
        53 6 06065                LIL  6 STORE
06400   75 0 06327                SLJ  0 BEST
```

```
        50 0 00000                  ENI  0 0
06401   75 0 00000   POSITS         SLJ  0 0
        04 0 00077                  ENQ  0 77
06402   44 2 06620                  LDL  2 OLOC
        22 0 06434                  AJP  0 NULOT
06403   64 0 06107                  EOS  0 ZERO
        75 0 06405                  SLJ  0 /+2
06404   10 0 00000                  ENA  0 0
        50 0 00000                  ENI  0 0
06405   20 0 05246                  STA  0 TEMP+5
        06 0 00006                  CLS  0 6
06406   44 2 06620                  LDL  2 OLOC
        01 0 00006                  ARS  0 6
06407   64 0 06107                  EOS  0 ZERO
        75 0 06411                  SLJ  0 /+2
06410   10 0 00000                  ENA  0 0
        50 0 00000                  ENI  0 0
06411   24 0 06107                  MUI  0 ZERO
        70 0 05246                  RAD  0 TEMP+5
06412   24 0 06746                  MUI  0 DCOL
        20 2 06701                  STA  2 HOR
06413   16 0 07221                  LDQ  0 GLOP
        44 2 06620                  LDL  2 OLOC
06414   22 1 06416                  AJP  1 /+2
        10 0 00011                  ENA  0 9D
06415   20 0 05246                  STA  0 TEMP+5
        75 0 06417                  SLJ  0 /+2
06416   10 0 00000                  ENA  0 0
        20 0 05246                  STA  0 TEMP+5
06417   16 0 07222                  LDQ  0 GLUM
        44 2 06620                  LDL  2 OLOC
06420   22 0 06425                  AJP  0 /+5
        10 0 00007                  ENA  0 7
06421   70 0 05246                  RAD  0 TEMP+5
        04 0 10000                  ENQ  0 10000
06422   44 2 06620                  LDL  2 OLOC
        22 0 06424                  AJP  0 /+2
06423   10 0 00002                  ENA  0 2
        75 0 06427                  SLJ  0 /+4
06424   10 0 00001                  ENA  0 1
        75 0 06427                  SLJ  0 /+3
06425   16 0 07225                  LDQ  0 BLOB
        44 2 06620                  LDL  2 OLOC
06426   01 0 00014                  ARS  0 12D
        50 0 00000                  ENI  0 0
06427   70 0 05246                  RAD  0 TEMP+5
        24 0 06744                  MUI  0 DROW
06430   20 0 05246                  STA  0 TEMP+5
        12 2 06611                  LDA  2 PINNI
06431   24 0 06745                  MUI  0 DPIN
        14 0 05246                  ADD  0 TEMP+5
06432   20 2 06710                  STA  2 VER
        10 0 00000                  ENA  0 0
06433   75 0 06401                  SLJ  0 POSITS
        50 0 00000                  ENI  0 0
06434   20 2 06701   NULOT          STA  2 HOR
        20 2 06710                  STA  2 VER
06435   10 0 00000                  ENA  0 0
        75 0 06401                  SLJ  0 POSITS
06436   75 0 00000   DIAG           SLJ  0 0
        57 3 05246                  SIL  3 TEMP+5
06437   50 3 00000                  ENI  3 0
        50 6 00001                  ENI  6 1
06440   12 6 06701                  LDA  6 HOR
        15 2 06701                  SUB  2 HOR
06441   20 0 05245                  STA  0 TEMP+4
        24 0 05245                  MUI  0 TEMP+4
06442   20 0 05245                  STA  0 TEMP+4
        12 6 06710                  LDA  6 VER
06443   15 2 06710                  SUB  2 VER
        20 0 05247                  STA  0 TEMP+6
06444   24 0 05247                  MUI  0 TEMP+6
        70 0 05245                  RAD  0 TEMP+4
```

```
06445    10 6 00000              ENA  6 0
         05 0 00006              ALS  0 6
06446    11 2 00000              INA  2 0
         05 0 00044              ALS  0 36D
06447    14 0 05245              ADD  0 TEMP+4
         20 3 06627              STA  3 SINK
06450    51 3 00001              INI  3 1
         50 0 00000              ENI  0 0
06451    54 6 00000              ISK  6 0
         75 0 06440              SLJ  0 DIAG+2
06452    54 2 00000              ISK  2 0
         75 0 06454              SLJ  0 /+2
06453    51 3 77776              INI  3 -1
         75 0 06456              SLJ  0 ORDER
06454    57 2 05245              SIL  2 TEMP+4
         53 6 05245              LIL  6 TEMP+4
06455    51 6 00001              INI  6 1
         75 0 06440              SLJ  0 DIAG+2
06456    57 3 05245    ORDER     SIL  3 TEMP+4
         72 0 05245              RAO  0 TEMP+4
06457    16 0 07223              LDQ  0 BLAM
         10 3 00000              ENA  3 0
06460    11 0 06627              INA  0 SINK
         61 0 06462              SAL  0 /+2
06461    60 0 06471              SAU  0 VARI
         50 0 00000              ENI  0 0
06462    53 6 05245              LIL  6 TEMP+4
         44 0 00000              LDL  0 0
06463    67 6 06627              MTH  6 SINK
         75 0 06467              SLJ  0 /+4
06464    57 6 07226              SIL  6 GOFER
         10 0 06627              ENA  0 SINK
06465    14 0 07226              ADD  0 GOFER
         60 0 06471              SAU  0 VARI
06466    44 6 06627              LDL  6 SINK
         75 0 06463              SLJ  0 /-3
06467    52 5 06471              LIU  5 VARI
         12 5 00000              LDA  5 0
06470    20 2 06654              STA  2 CHAIR
         10 0 00000              ENA  0 0
06471    20 0 00000    VARI      STA  0 0
         51 2 00001              INI  2 1
06472    55 3 06474              IJP  3 LAMP
         53 3 05246              LIL  3 TEMP+5
06473    75 0 06436              SLJ  0 DIAG
         50 0 00000              ENI  0 0
06474    53 5 06462    LAMP      LIL  5 ORDER+4
         56 5 06471              SIU  5 VARI
06475    75 0 06462              SLJ  0 ORDER+4
         50 0 00000              ENI  0 0
06476    75 0 00000    WIRE      SLJ  0 0
         50 0 00000              ENI  0 0
06477    57 6 06065              SIL  6 STORE
         50 6 00124              ENI  6 84D
06500    65 6 07074              IBS  6 APPX
         75 0 06502              SLJ  0 /+2
06501    12 6 06750              LDA  6 TYPE
         75 0 06503              SLJ  0 /+2
06502    12 0 07220              LDA  0 MAX
         50 0 00000              ENI  0 0
06503    53 6 06065              LIL  6 STORE
         75 0 06476              SLJ  0 WIRE
06504    75 0 00000    SEARCH1   SLJ  0 0
         04 0 00000              ENQ  0 0
06505    57 6 06065              SIL  6 STORE
         53 6 06064              LIL  6 COUNT
06506    64 6 10000              EQS  6 ARGUE
         75 0 06510              SLJ  0 /+2
06507    16 6 13000              LDQ  6 VALUE
         50 0 00000              ENI  0 0
06510    53 6 06065              LIL  6 STORE
         75 0 06504              SLJ  0 SEARCH1
06511    75 0 00000    DECOUT    SLJ  0 0
```

```
        57 6 06065                  SIL  6 STORE
06512   53 6 05242                  LIL  6 TEMP+1
        16 0 06113                  LDQ  0 LOMASK
06513   66 6 16000                  MEQ  6 ALFA
        75 0 06524                  SLJ  0 /+9D
06514   16 0 06742                  LDQ  0 OMASK
        44 6 16000                  LDL  6 ALFA
06515   22 1 06517                  AJP  1 /+2
        12 2 06603                  LDA  2 AND
06516   16 0 06113                  LDQ  0 LOMASK
        75 0 06513                  SLJ  0 /-3
06517   01 0 00030                  ARS  0 24D
        20 0 06067                  STA  0 WAIT
06520   11 0 77776                  INA  0 -1
        05 0 00030                  ALS  0 24D
06521   17 0 06742                  LQC  0 OMASK
        43 6 16000                  SSU  6 ALFA
06522   20 6 16000                  STA  6 ALFA
        12 0 06067                  LDA  0 WAIT
06523   75 0 06525                  SLJ  0 /+2
        50 0 00000                  ENI  0 0
06524   10 0 00000                  ENA  0 0
        50 0 00000                  ENI  0 0
06525   53 6 06065                  LIL  6 STORE
        75 0 06511                  SLJ  0 DECOUT
06526   75 0 00000     CNVT         SLJ  0 0
        57 6 06065                  SIL  6 STORE
06527   50 6 00011                  ENI  6 9D
        04 0 00077                  ENO  0 77
06530   66 6 06542                  MEQ  6 BACK
        75 0 06532                  SLJ  0 /+2
06531   75 0 06537                  SLJ  0 /+6
        50 0 00000                  ENI  0 0
06532   15 0 06541                  SUB  0 FORTN
        22 3 06534                  AJP  3 /+2
06533   12 0 06555                  LDA  0 BACK+11D
        75 0 06540                  SLJ  0 RAW
06534   11 0 00001                  INA  0 1
        22 3 06536                  AJP  3 /+2
06535   12 0 06554                  LDA  0 BACK+10D
        75 0 06540                  SLJ  0 RAW
06536   12 0 06553                  LDA  0 BACK+9D
        75 0 06540                  SLJ  0 RAW
06537   12 6 06542                  LDA  6 BACK
        50 0 00000                  ENI  0 0
06540   53 6 06065     RAW          LIL  6 STORE
        75 0 06526                  SLJ  0 CNVT
06541   00 0 00000     FORTN        OCT     14
        00 0 00014
06542   00 0 00000     BACK         OCT     401201
        00 4 01201
06543   00 0 00000                  OCT     401202
        00 4 01202
06544   00 0 00000                  OCT     401203
        00 4 01203
06545   00 0 00000                  OCT     401204.
        00 4 01204
06546   00 0 00000                  OCT     401205
        00 4 01205
06547   00 0 00000                  OCT     401206
        00 4 01206
06550   00 0 00000                  OCT     401207
        00 4 01207
06551   00 0 00000                  OCT     401210
        00 4 01210
06552   00 0 00000                  OCT     401211
        00 4 01211
06553   00 0 00000                  OCT     400112
        00 4 00112
06554   00 0 00000                  OCT     400101
        00 4 00101
06555   00 0 00000                  OCT     400102
        00 4 00102
```

```
06556    00 0 00000   LNGTH4   DEC    4
         00 0 00004
06557    00 0 00000   LNGTH5   DEC    11D
         00 0 00013
06560    20 2 02020   HEAD4    BCD    /
         20 2 02020
06561    71 4 52365            BCD    /INTER CA
         51 2 06361
06562    51 6 42026            BCD    /RD WIRIN
         71 5 17145
06563    67 2 02361            BCD    /G TABULA
         62 2 44361
06564    23 7 14645            BCD    /TION
         20 2 02020
06565    20 2 02020   HEAD5    BCD    /
         20 2 02020
06566    20 2 04651            BCD    /  ORIGIN
         71 6 77145
06567    20 2 02020            BCD    /
         20 2 02020
06570    64 6 52223            BCD    /DESTINAT
         71 4 56123
06571    71 4 64520            BCD    /ION
         20 2 02020
06572    20 2 02020            BCD    /
         20 2 02020
06573    20 2 02064            BCD    /   DESIG
         65 2 27167
06574    45 6 12371            BCD    /NATIONS
         46 4 52220
06575    20 2 02020            BCD    /
         20 2 02020
06576    20 2 02020            BCD    /
         20 2 02020
06577    26 7 15165            BCD    /WIRE LEN
         20 4 36545
06600    67 2 37020            BCD    /GTH
         20 2 02020
06601    71 4 56370   INCHES   BCD    /INCHES
         65 2 22020
06602    00 0 00000   IAND     BSS    1
         00 0 00000
06603    00 0 00000   AND      BSS    6
         00 0 00000
06611    00 0 00000   PINNI    BSS    1
         00 0 00000
06612    00 0 00000   PINNO    BSS    6
         00 0 00000
06620    00 0 00000   OLOC     BSS    1
         00 0 00000
06621    00 0 00000   LOCAT    BSS    6
         00 0 00000
06627    00 0 00000   SINK     BSS    21D
         00 0 00000
06654    00 0 00000   CHAIR    BSS    21D
         00 0 00000
06701    00 0 00000   HOR      BSS    7
         00 0 00000
06710    00 0 00000   VER      BSS    7
         00 0 00000
06717    00 0 00000   TABLE    BSS    7
         00 0 00000
06726    00 0 00000   SUBTRE   BSS    7
         00 0 00000
06735    00 0 00000   ENDT     BSS    2
         00 0 00000
06737    00 0 00020   PRMSK    OCT    2020000000
         20 0 00000
06740    20 2 02020   UPSPA    OCT    2020202000000000
         00 0 00000
06741    23 4 62020   TOSPA    OCT    2346202000000000
         00 0 00000
06742    00 0 00077   OMASK    OCT    7700000000
```

```
        00 0 00000
06743   00 0 07700   IMASK   OCT   770000000000
        00 0 00000
06744   00 0 00000   DROW    DEC   38
        00 0 00046
06745   00 0 00000   DPIN    DEC   2
        00 0 00002
06746   00 0 00000   DCOL    DEC   5
        00 0 00005
06747   20 2 02054   INDIG   BCD   /   4
        20 2 02020
06750   04 0 32020   TYPE    BCD   /43
        20 2 02020
06751   04 0 22001           BCD   /42 1/2
        21 0 22020
06752   04 0 22020           BCD   /42
        20 2 02020
06753   04 0 12001           BCD   /41 1/2
        21 0 22020
06754   04 0 12020           BCD   /41
        20 2 02020
06755   04 1 22001           BCD   /40 1/2
        21 0 22020
06756   04 1 22020           BCD   /40
        20 2 02020
06757   03 1 12001           BCD   /39 1/2
        21 0 22020
06760   03 1 12020           BCD   /39
        20 2 02020
06761   03 1 02001           BCD   /38 1/2
        21 0 22020
06762   03 1 02020           BCD   /38
        20 2 02020
06763   03 0 72001           BCD   /37 1/2
        21 0 22020
06764   03 0 72020           BCD   /37
        20 2 02020
06765   03 0 62001           BCD   /36 1/2
        21 0 22020
06766   03 0 62020           BCD   /36
        20 2 02020
06767   03 0 52001           BCD   /35 1/2
        21 0 22020
06770   03 0 52020           BCD   /35
        20 2 02020
06771   03 0 42001           BCD   /34 1/2
        21 0 22020
06772   03 0 42020           BCD   /34
        20 2 02020
06773   03 0 32001           BCD   /33 1/2
        21 0 22020
06774   03 0 32020           BCD   /33
        20 2 02020
06775   03 0 22001           BCD   /32 1/2
        21 0 22020
06776   03 0 22020           BCD   /32
        20 2 02020
06777   03 0 12001           BCD   /31 1/2
        21 0 22020
07000   03 0 12020           BCD   /31
        20 2 02020
07001   03 1 22001           BCD   /30 1/2
        21 0 22020
07002   03 1 22020           BCD   /30
        20 2 02020
07003   02 1 12001           BCD   /29 1/2
        21 0 22020
07004   02 1 12020           BCD   /29
        20 2 02020
07005   02 1 02001           BCD   /28 1/2
        21 0 22020
07006   02 1 02020           BCD   /28
        20 2 02020
```

```
07007    02 0 72001    BCD    /27 1/2
         21 0 22020
07010    02 0 72020    BCD    /27
         20 2 02020
07011    02 0 62001    BCD    /26 1/2
         21 0 22020
07012    02 0 62020    BCD    /26
         20 2 02020
07013    02 0 52001    BCD    /25 1/2
         21 0 22020
07014    02 0 52020    BCD    /25
         20 2 02020
07015    02 0 42001    BCD    /24 1/2
         21 0 22020
07016    02 0 42020    BCD    /24
         20 2 02020
07017    02 0 32001    BCD    /23 1/2
         21 0 22020
07020    02 0 32020    BCD    /23
         20 2 02020
07021    02 0 22001    BCD    /22 1/2
         21 0 22020
07022    02 0 22020    BCD    /22
         20 2 02020
07023    02 0 12001    BCD    /21 1/2
         21 0 22020
07024    02 0 12020    BCD    /21
         20 2 02020
07025    02 1 22001    BCD    /20 1/2
         21 0 22020
07026    02 1 22020    BCD    /20
         20 2 02020
07027    01 1 12001    BCD    /19 1/2
         21 0 22020
07030    01 1 12020    BCD    /19
         20 2 02020
07031    01 1 02001    BCD    /18 1/2
         21 0 22020
07032    01 1 02020    BCD    /18
         20 2 02020
07033    01 0 72001    BCD    /17 1/2
         21 0 22020
07034    01 0 72020    BCD    /17
         20 2 02020
07035    01 0 62001    BCD    /16 1/2
         21 0 22020
07036    01 0 62020    BCD    /16
         20 2 02020
07037    01 0 52001    BCD    /15 1/2
         21 0 22020
07040    01 0 52020    BCD    /15
         20 2 02020
07041    01 0 42001    BCD    /14 1/2
         21 0 22020
07042    01 0 42020    BCD    /14
         20 2 02020
07043    01 0 32001    BCD    /13 1/2
         21 0 22020
07044    01 0 32020    BCD    /13
         20 2 02020
07045    01 0 22001    BCD    /12 1/2
         21 0 22020
07046    01 0 22020    BCD    /12
         20 2 02020
07047    01 0 12001    BCD    /11 1/2
         21 0 22020
07050    01 0 12020    BCD    /11
         20 2 02020
07051    01 1 22001    BCD    /10 1/2
         21 0 22020
07052    01 1 22020    BCD    /10
         20 2 02020
07053    20 1 12001    BCD    / 9 1/2
```

	21 0 22020				
07054	20 1 12020		BCD	/ 9	
	20 2 02020				
07055	20 1 02001		BCD	/ 8 1/2	
	21 0 22020				
07056	20 1 02020		BCD	/ 8	
	20 2 02020				
07057	20 0 72001		BCD	/ 7 1/2	
	21 0 22020				
07060	20 0 72020		BCD	/ 7	
	20 2 02020				
07061	20 0 62001		BCD	/ 6 1/2	
	21 0 22020				
07062	20 0 62020		BCD	/ 6	
	20 2 02020				
07063	20 0 52001		BCD	/ 5 1/2	
	21 0 22020				
07064	20 0 52020		BCD	/ 5	
	20 2 02020				
07065	20 0 42001		BCD	/ 4 1/2	
	21 0 22020				
07066	20 0 42020		BCD	/ 4	
	20 2 02020				
07067	20 0 32001		BCD	/ 3 1/2	
	21 0 22020				
07070	20 0 32020		BCD	/ 3	
	20 2 02020				
07071	20 0 22001		BCD	/ 2 1/2	
	21 0 22020				
07072	20 0 22020		BCD	/ 2	
	20 2 02020				
07073	20 0 12001		BCD	/ 1 1/2	
	21 0 22020				
07074	00 0 00000	APPX	DEC	284516	
	01 0 53544				
07075	00 0 00000		DEC	277782	
	01 0 36426				
07076	00 0 00000		DEC	271128	
	01 0 21430				
07077	00 0 00000		DEC	264556	
	01 0 04554				
07100	00 0 00000		DEC	258064	
	00 7 70020				
07101	00 0 00000		DEC	251653	
	00 7 53405				
07102	00 0 00000		DEC	245322	
	00 7 37112				
07103	00 0 00000		DEC	239072	
	00 7 22740				
07104	00 0 00000		DEC	232902	
	00 7 06706				
07105	00 0 00000		DEC	226814	
	00 6 72776				
07106	00 0 00000		DEC	220806	
	00 6 57206				
07107	00 0 00000		DEC	214879	
	00 6 43537				
07110	00 0 00000		DEC	209032	
	00 6 30210				
07111	00 0 00000		DEC	203266	
	00 6 15002				
07112	00 0 00000		DEC	197580	
	00 6 01714				
07113	00 0 00000		DEC	191975	
	00 5 66747				
07114	00 0 00000		DEC	186451	
	00 5 54123				
07115	00 0 00000		DEC	181008	
	00 5 41420				
07116	00 0 00000		DEC	175645	
	00 5 27035				
07117	00 0 00000		DEC	170363	
	00 5 14573				

07120	00 0 00000 00 5 02451	DEC	165161
07121	00 0 00000 00 4 70450	DEC	160040
07122	00 0 00000 00 4 56570	DEC	155000
07123	00 0 00000 00 4 45030	DEC	150040
07124	00 0 00000 00 4 33411	DEC	145161
07125	00 0 00000 00 4 22113	DEC	140363
07126	00 0 00000 00 4 10735	DEC	135645
07127	00 0 00000 00 3 77700	DEC	131008
07130	00 0 00000 00 3 66771	DEC	126457
07131	00 0 00000 00 3 56170	DEC	121976
07132	00 0 00000 00 3 45514	DEC	117580
07133	00 0 00000 00 3 35162	DEC	113266
07134	00 0 00000 00 3 24750	DEC	109032
07135	00 0 00000 00 3 14657	DEC	104879
07136	00 0 00000 00 3 04706	DEC	100806
07137	00 0 00000 00 2 75056	DEC	96814
07140	00 0 00000 00 2 65347	DEC	92903
07141	00 0 00000 00 2 55760	DEC	89072
07142	00 0 00000 00 2 46512	DEC	85322
07143	00 0 00000 00 2 37365	DEC	81653
07144	00 0 00000 00 2 30360	DEC	78064
07145	00 0 00000 00 2 21474	DEC	74556
07146	00 0 00000 00 2 12731	DEC	71129
07147	00 0 00000 00 2 04306	DEC	67782
07150	00 0 00000 00 1 76004	DEC	64516
07151	00 0 00000 00 1 67623	DEC	61331
07152	00 0 00000 00 1 61563	DEC	58227
07153	00 0 00000 00 1 53642	DEC	55202
07154	00 0 00000 00 1 46042	DEC	52258
07155	00 0 00000 00 1 40363	DEC	49395
07156	00 0 00000 00 1 33025	DEC	46613
07157	00 0 00000 00 1 25607	DEC	43911
07160	00 0 00000 00 1 20512	DEC	41290
07161	00 0 00000 00 1 13536	DEC	38750
07162	00 0 00000 00 1 06702	DEC	36290
07163	00 0 00000 00 1 02167	DEC	33911
07164	00 0 00000	DEC	31613

```
          00 0 75575
07165     00 0 00000          DEC    29395
          00 0 71323
07166     00 0 00000          DEC    27258
          00 0 65172
07167     00 0 00000          DEC    25202
          00 0 61162
07170     00 0 00000          DEC    23226
          00 0 55272
07171     00 0 00000          DEC    21341
          00 0 51523
07172     00 0 00000          DEC    19516
          00 0 46074
07173     00 0 00000          DEC    17782
          00 0 42566
07174     00 0 00000          DEC    16129
          00 0 37401
07175     00 0 00000          DEC    14556
          00 0 34334
07176     00 0 00000          DEC    13064
          00 0 31410
07177     00 0 00000          DEC    11653
          00 0 26605
07200     00 0 00000          DEC    10323
          00 0 24123
07201     00 0 00000          DEC    9073
          00 0 21561
07202     00 0 00000          DEC    7903
          00 0 17337
07203     00 0 00000          DEC    6815
          00 0 15237
07204     00 0 00000          DEC    5806
          00 0 13256
07205     00 0 00000          DEC    4879
          00 0 11417
07206     00 0 00000          DEC    4032
          00 0 07700
07207     00 0 00000          DEC    3266
          00 0 06302
07210     00 0 00000          DEC    2581
          00 0 05025
07211     00 0 00000          DEC    1976
          00 0 03670
07212     00 0 00000          DEC    1452
          00 0 02654
07213     00 0 00000          DEC    1008
          00 0 01760
07214     00 0 00000          DEC    645
          00 0 01205
07215     00 0 00000          DEC    363
          00 0 00553
07216     00 0 00000          DEC    137
          00 0 00211
07217     00 0 00000          DEC    70
          00 0 00106
07220     04 0 36020  MAX     BCD    /43+
          20 2 02020
07221     00 0 00000  GLOP    OCT    200000
          00 2 00000
07222     00 0 00000  GLUM    OCT    100000
          00 1 00000
07223     00 0 07777  BLAM    OCT    0000777777777777
          77 7 77777
07224     77 7 70000  BLOT    OCT    7777000000000000
          00 0 00000
07225     00 0 00000  BLUB    OCT    70000
          00 0 70000
07226     00 0 00000  GOFER   OCT    0
          00 0 00000
07227     20 2 02063  CLOCK   BCD    /   CLOCK
          43 4 66342
                      ARGLE   EQU    10000
                      VALUE   EQU    13000
```

```
.ALFA      EQU     16000
           END
```

CHAPTER II

GENERAL DATA CONFIGURATION INPUT AND OUTPUT CODING AND CONTROL LINES

A. 1964

1. Coding

The external function instruction (74) acts in three different modes to give (a) activation of a channel; (b) sensing of a condition at an external equipment or (c) selecting an external equipment to communicate with the computer.

The channel activate sub-instructions 74.1 through 74.6 are interpreted as follows:

74	1 thru 6	Base Execution Address
6 bit operation code	3 bit index (channel) designator	15 bits which specifies the initial address for data storage in buffering operation

The sense sub-instruction 74.7 is interpreted as follows:

74	7	1 thru 7	1 thru 7	
sense		3 bit channel selection code	3 bits external equipment code	3 bits condition code which specifies operation being sensed

Note: If the sensed condition is met, a full exit from the word is performed. If the sensed condition is not met, a half exit from the word is performed.

The select sub-instruction 74.0 is interpreted as follows:

74	0	1 thru 7		
6 bit operation code	1 bit index	3 bits channel selection code	5 bits external equipment code	9 bits condition code which specifies operation being selected

Select

2. Data and Control Lines

Input equipment to computer

input data (48 lines)		Comprise two complete cables and two lines of a third cable of a buffer or transfer cable group
Input data ready (1 line)	Function:	Indicates equipment input register contains information which computer may sample.
	Operation:	Turned off by input data resume from computer. (Computer resync circuitry orients itself about leading edge of ready signal; auxiliary scanner is stopped and input word is passed to computer.)

Computer to Input Equipment

Input data resume (1 line)	Function:	Indicates to equipment that computer has accepted input word.
	Operation:	Turned off by input data ready; turned on when computer has accepted and stored input word.

Computer to Output Equipment

Output (48 lines)		Comprise two complete cables and two lines of a third cable of a buffer or transfer cable group.
Output data ready (1 line)	Function:	Accompanies output data from computer.
	Operation:	Turned on when computer has word of information ready for equipment; off by resume from equipment.

Output Equipment to Computer

Output data resume (1 line)	Function:	Indicates that equipment has accepted word.
	Operation:	Turned on when equipment has accepted word. (Computer resync circuitry orients itself about the trailing edge of resume; when signal drops auxiliary scanner stops and another word is exchanged. Computer prepares a word for exchange while output data resume signal is up.)

Computer to External Equipment

External function (12 lines)	Function:	Carries external function (EF) codes to select or sense a condition within the equipment
	Operation:	Lines continuously monitored by all equipment. Appropriate function or sense ready alerts equipment on a

		[illegible] channel to [illegible] LF code on lines.
External Master Clear (1 line)	Function:	Clears all equipment on all channels.
	Operation:	Occurs when clear switch at console is in [illegible] position.
External Equipment to Computer		
Sense response	Function:	Indicates equipment's reply to sense code.
	Operation:	ON indicates presence of condition specified by sense code; OFF indicates absence of condition.
Interrupt (1 line)	Operation:	External equipment or internal computer control sends signal when a condition arises that was previously selected by a 74.[illegible].
Computer to Input Equipment		
Input function ready (1 line)	Function:	Accompanies LF select code
	Operation:	Turned on by instruction 74.[illegible] causes input equipment to translate LF code.
Input sense ready (1 line)	Function:	Accompanies LF Sense Code
	Operation:	Turned on by instruction 74.7. causes input equipment to translate LF code and send response back to computer.
Input Buffer Active (1 line)	Function:	Indicates computer is prepared to receive a block of data.
	Operation:	Turned on when input buffer channel

is activated by instruction 74.1, 74.3 or 74.5. Remains on until final word of block is entered in storage.

Computer to Output Equipment

Output Function Ready (1 line)	Function:	Accompanies EF select code.
	Operation:	Turned on by instruction 74.0. Causes output equipment to translate EF code.
Output Sense Ready (1 line)	Function:	Accompanies EF sense code.
	Operation:	Turned on by instruction 74.7. Causes output equipment to translate EF code and send response back to computer.
Output Buffer Active (1 line)	Function:	Indicates computer is prepared to transmit a block of data.
	Operation:	Turned on when output buffer channel is activated by instructions 74.2, 74.4, or 74.6. Remains on until final word of block is transmitted to output equipment.

B. 160

1. Coding

The computer controls the operation of its external equipment by issuing 12 bit function codes. This process, initiated by the external function (75) instruction, places a designated 12-bit code on the output lines and activates the function ready signal. Each external equipment receives the data, but only the equipment recognizing it responds to it by sending back a function resume signal.

[illegible] computer built into the [illegible], not one of the [illegible] - it function [illegible] must [illegible] status [illegible] must from the external equipment. The equipment must be designed to place a 12-bit status response code on the input cable. The [illegible] must then process this response through an input instruction [illegible] (70) which will bring the 12 bits into the "A" register. The status response must be a one out of twelve response for each condition as more than one condition may exist. This allows for only twelve possible conditions for sensing to be designed into any external equipment.

Normal input and output are handled by the INT (74) and OUT (73) commands respectively. These operate on blocks of memory.

2. Data and Control Lines

INPUT Cable Lines	FUNCTION
Input Data and Input Status (12 lines)	Normal purpose: 1) As data lines they hold equipment input register contents which the computer may sample. 2) As input status lines they indicate equipment's response to status request interrogation.
Input Ready (1 line)	Indicates that the external equipment contains information which the computer may sample. (Computer resync circuits are oriented about the leading edge of the ready signal.)
Input Request	Indicates to external equipment that computer

([illegible] line)	[illegible] coupled input [illegible]. [illegible] to [illegible] off [illegible] input [illegible].
Input Disconnect (1 line)	Indicates to computer that input device has no more data to deliver. Computer is then free to resume main program with no further delay. (Generally the input instruction establishes a storage field block of greater capacity than the sufficient in it information block.)

OUTPUT CHANNEL LINES	FUNCTIONS
Output Data and Output Function (12 lines)	Continuously monitored by all equipment. Dual purpose: 1) As output data lines they hold output word which the external device may sample. 2) As output function lines they carry external function (EF) codes to select or sense a condition within the equipment. Function ready alerts the equipment to sample the EF code.
Function Ready (1 line)	Accompanies EF code. It is turned on by instruction 70 and causes the equipment to sample the EF code. It is turned off by output response from the external equipment.
Information Ready (1 line)	This signal accompanies the output data word from the computer and is turned on when the computer has a word of information ready for the

	external equipment. It is turned off by an output resume from the equipment.
Output Resume (1 line)	This signal is turned on when the external device has accepted the output word or LF code. (The computer resync circuitry orients itself about the trailing edge of the resume; when the signal drops the word is exchanged.) The computer prepares a word while the signal is up.
Master Clear (1 line)	This signal clears all external equipment. It occurs when the Load-Clear switch at the console is in the Clear (down) position.

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