

SECOND ANNUAL REPORT  
ON  
THE AUTOMATION OF A STELLAR PROPER MOTION MEASURING SYSTEM

BY

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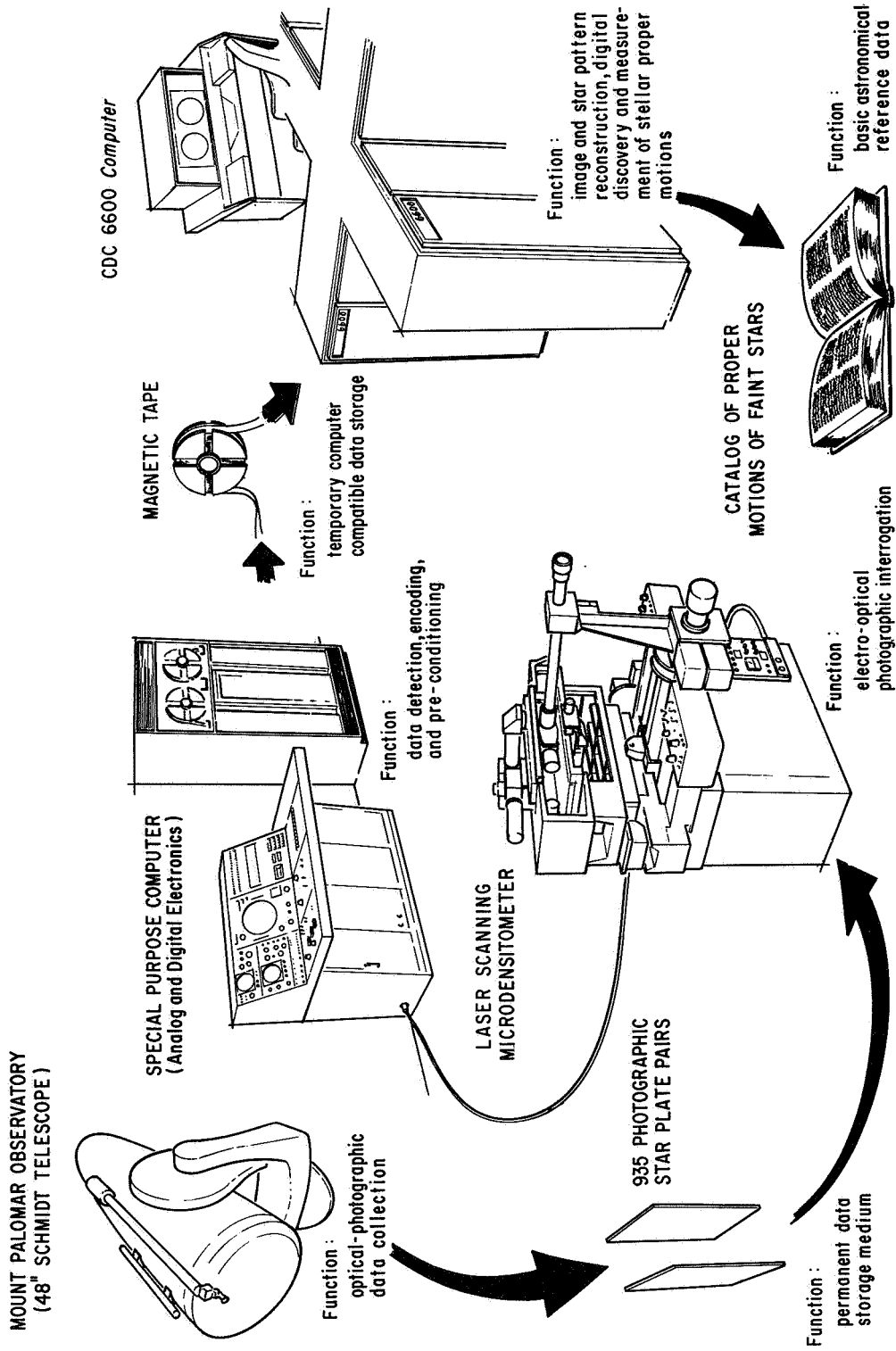
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# AUTOMATED STELLAR PROPER MOTION STUDY



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## SUMMARY

This, the second annual report, presents the mechanical design, the design of the operator aids and the displays, and the design of the data acquisition and control logic for the Automated Stellar Proper Motion Measuring System. These subsystems form the controlling and connecting link between the microdensitometer which scans the photographic star plate and the digital magnetic tape which receives the measurements for subsequent analysis by a super-scale high speed computer. Instruments described in the operator aids include CRT display of the star images being scanned, CRT presentation of image detection threshold levels, and motor controllers which are free of RFI. The logic section describes the control and paths of data flow through a small semiconductor very high speed memory and through a high speed core memory which together form a data buffer between the microdensitometer and the magnetic tape. The arrangement of data in a format making efficient use of the buffer, tape, and computer capabilities is described, as well as the spot position interpolator from a 25 megacycle clock.

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SECOND ANNUAL REPORT  
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I. INTRODUCTION

This report summarizes the design and fabrication efforts for the second year of the Automated Stellar Proper Motion Measuring System sub-contract to the University of Minnesota (Purchase Order F8711) under NASA Contract NSR24-005-062 from July 1966 through September 1967.

The major directions in which the year's efforts were channeled are:

- (1) Fabrication of the final mechanical design of the scanner on the Moore Measuring Machine with suitable electromechanical drives and controls.
- (2) Fabrication, including the necessary design, of the control console. This includes the video display module, the image position display module, the data acquisition module, and the core memory-power supply module.
- (3) Fabrication, including the necessary design, of the scanner control electronics in the separate cabinet physically and electrically connected to the scanner.
- (4) Design and fabrication of the data acquisition system.
- (5) Design and fabrication of the special tape synchronizer needed to connect the buffer output to the magnetic tape.
- (6) Design and fabrication of the data display system for the console.

The basic design concepts of the scanning system from which these specific instruments came are set forth in the first annual report of the contract <sup>(1)</sup> to which the attention of the reader is directed for further information if needed. This, the second annual report, will present information about the second year's effort.

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(1) "Design of an Automated Stellar Proper Motion Measuring System," J. S. Newcomb, G. E. Zenk, and A. E. LaBonte; Control Data Corporation, Minneapolis, Minnesota, July 1966. NASA Document No. N66-33399.

## II. THE STAR PLATE SCANNING MACHINE

### A. General Configuration

The star plate scanning machine is a scanning microdensitometer mounted on the orthogonal ways of a Moore Measuring Machine #3. The pair of star plates move together along the X axis during scanning. Actual star image densities are measured as the relative decrease in the amount of light from a helium-neon continuous gas laser passing through each star plate as the spot crosses the star image. The spot of laser light moves 16 mm in the Y direction each time the plates move five microns in the X direction, producing a scanned "stripe" 356 mm long and 16 mm wide. After the completion of a stripe, the plates are moved 16 mm along the Y axis and the scanning process repeated until the pair of plates is completely scanned.

Measurement of the X position of the star plates with respect to the scanner is reported by a pulse generator, or incremental angle encoder, directly coupled to the X axis lead screw. This generator delivers one pulse per micron of star plate movement. An identical angle encoder is connected to the Y axis lead screw and reports the position of the lower edge of the stripe being scanned. The instantaneous Y axis position of the moving laser beam spot is measured by the position of a third or reference spot split off the laser beam and passing across 16 microns wide alternate clear and opaque stripes 64 microns center to center. The electronic report of this density variation is interpolated by a factor of 64 using a fast oscillator with a digital output. The instantaneous Y axis position of the spot in microns obtained from the reference beam and the interpolation counter is added to the initial position of the stripe as reported by the angle encoder to obtain the complete instantaneous Y axis position of the spot. The scanning machine reports to the data acquisition logic the X and Y positions on the star plates of the beginning and end of the scan of each star image to the nearest micron.

The location of the major components on the scanning machine is shown in Figures 1 and 2 in front and side view, respectively. Photographs of the completed scanner are shown in Figures 3, 4, and 5. The scanner is 54 inches high, 54 inches wide, and 64 inches long. Attached to the rear of the scanner is a cabinet containing the motor and actuator controls. This cabinet is 30 inches high, 26 inches long, and 24 inches wide. The scanner and cabinet weigh approximately one ton. The electric cables of the scanner exit the rear opening of the cast iron base and are connected to terminal strips in the cabinet. The 208 volt, three phase and 120 volt, single phase AC power input receptacles are located at the rear of the cabinet. All other necessary AC and DC voltages are developed within the cabinet and distributed to the scanner. Two control panels and a star number entry panel located at the front of the scanner provide the operator with the necessary controls to load or remove the star plates, align the two plates with respect to each other, test the outputs, and run sample scans.

The base structure and cross slides of the star plate machine shown in Figures 1, 2, and 3 are the lower portion of the Moore Measuring Machine, Model 3, manufactured by the Moore Special Tool Company, Inc., of Bridgeport, Connecticut. The upper structure was designed and built at Control Data Corporation, Minneapolis, Minnesota.

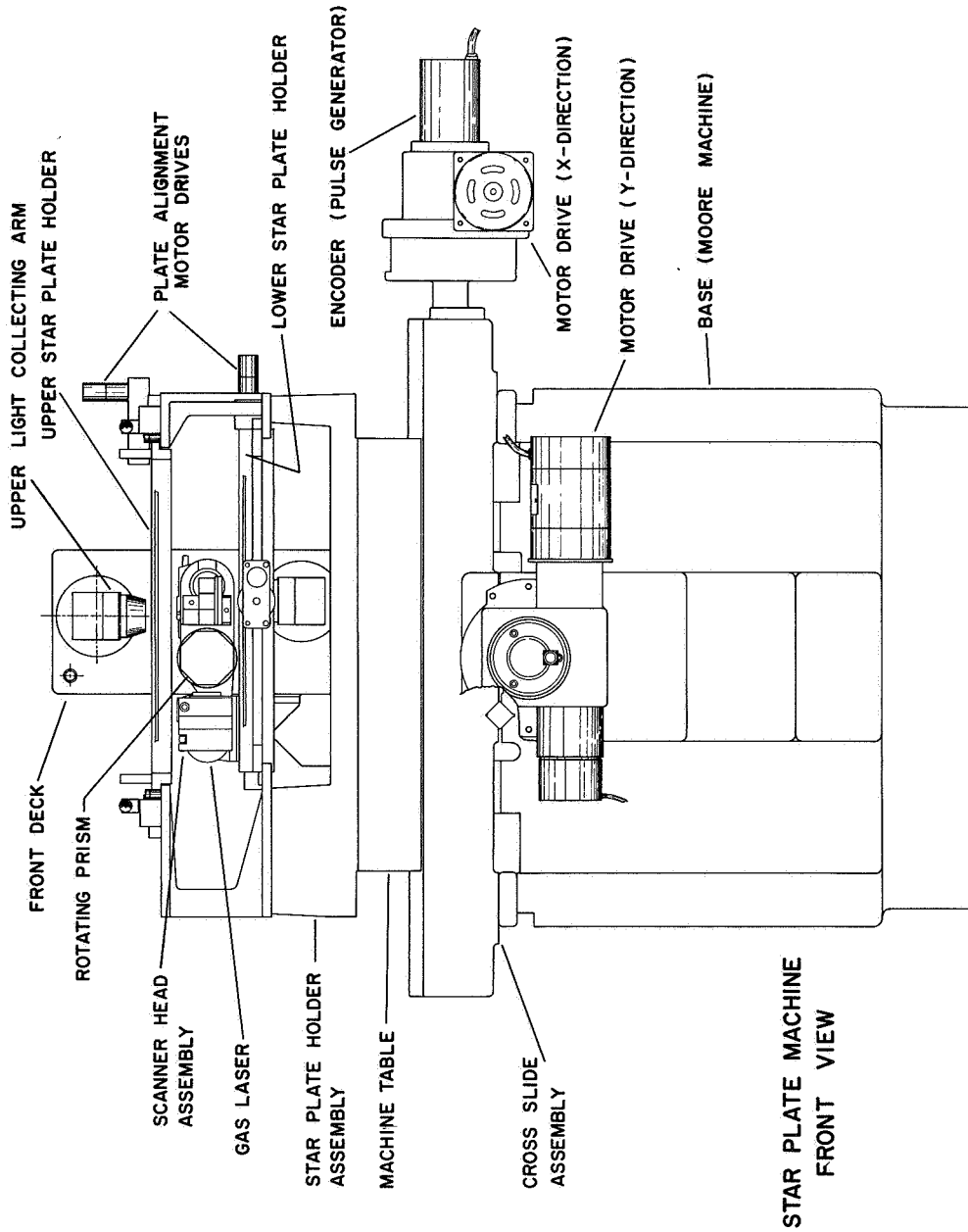
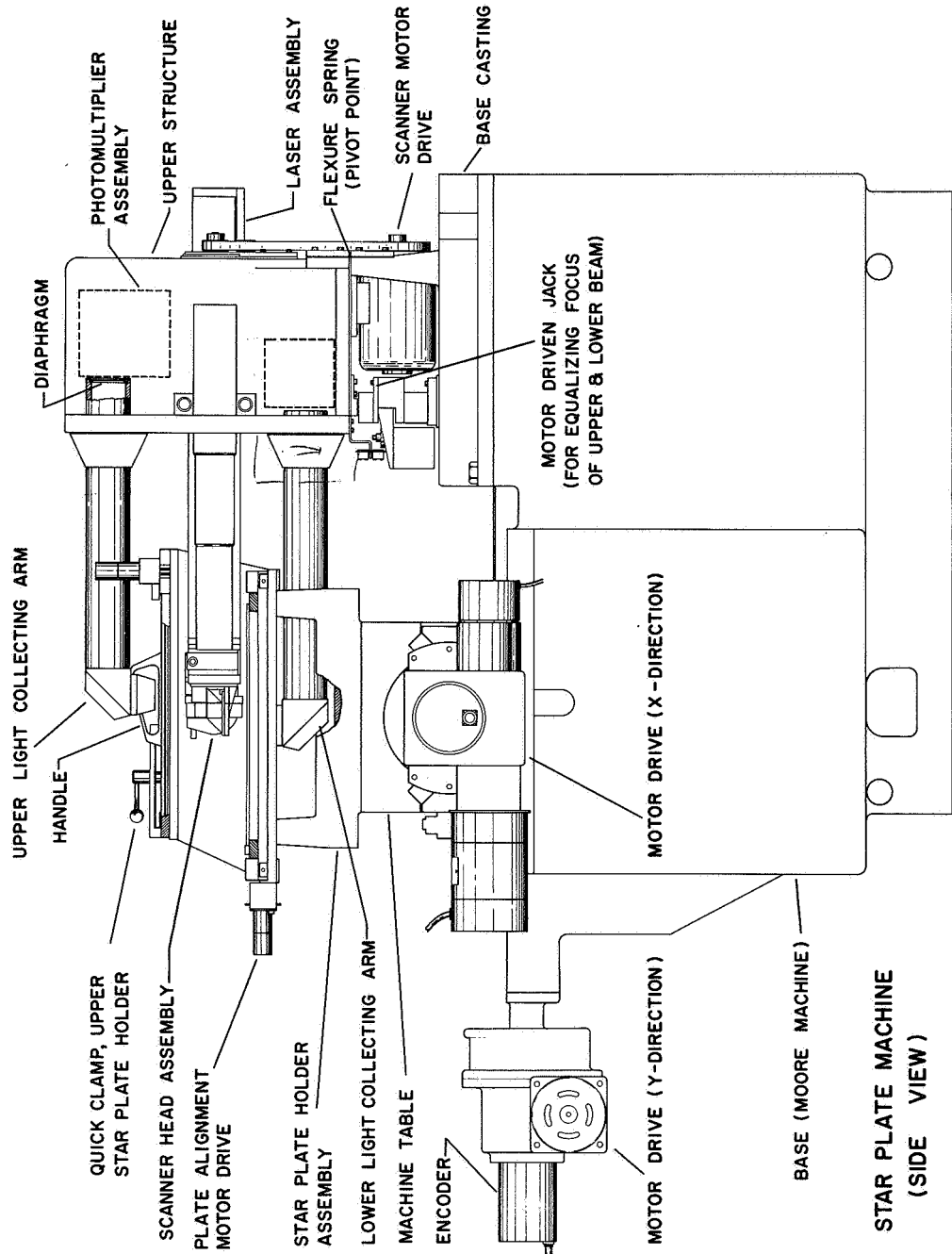


Figure 1: Star Plate Machine, Front View



STAR PLATE MACHINE  
(SIDE VIEW)

Figure 2: Star Plate Machine, Side View

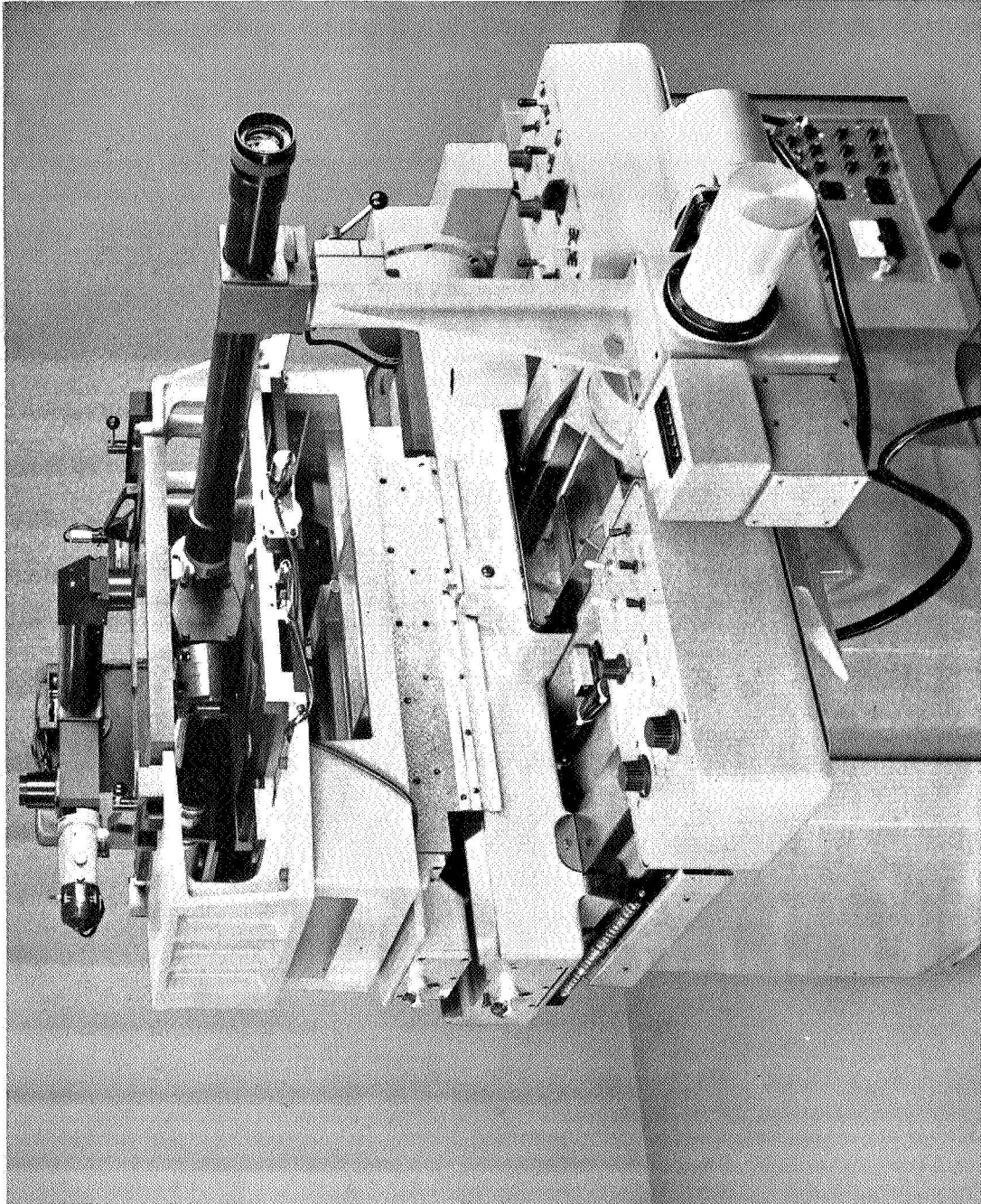


Figure 3: Photo of Scanner Showing Blink Microscope and Control Boxes

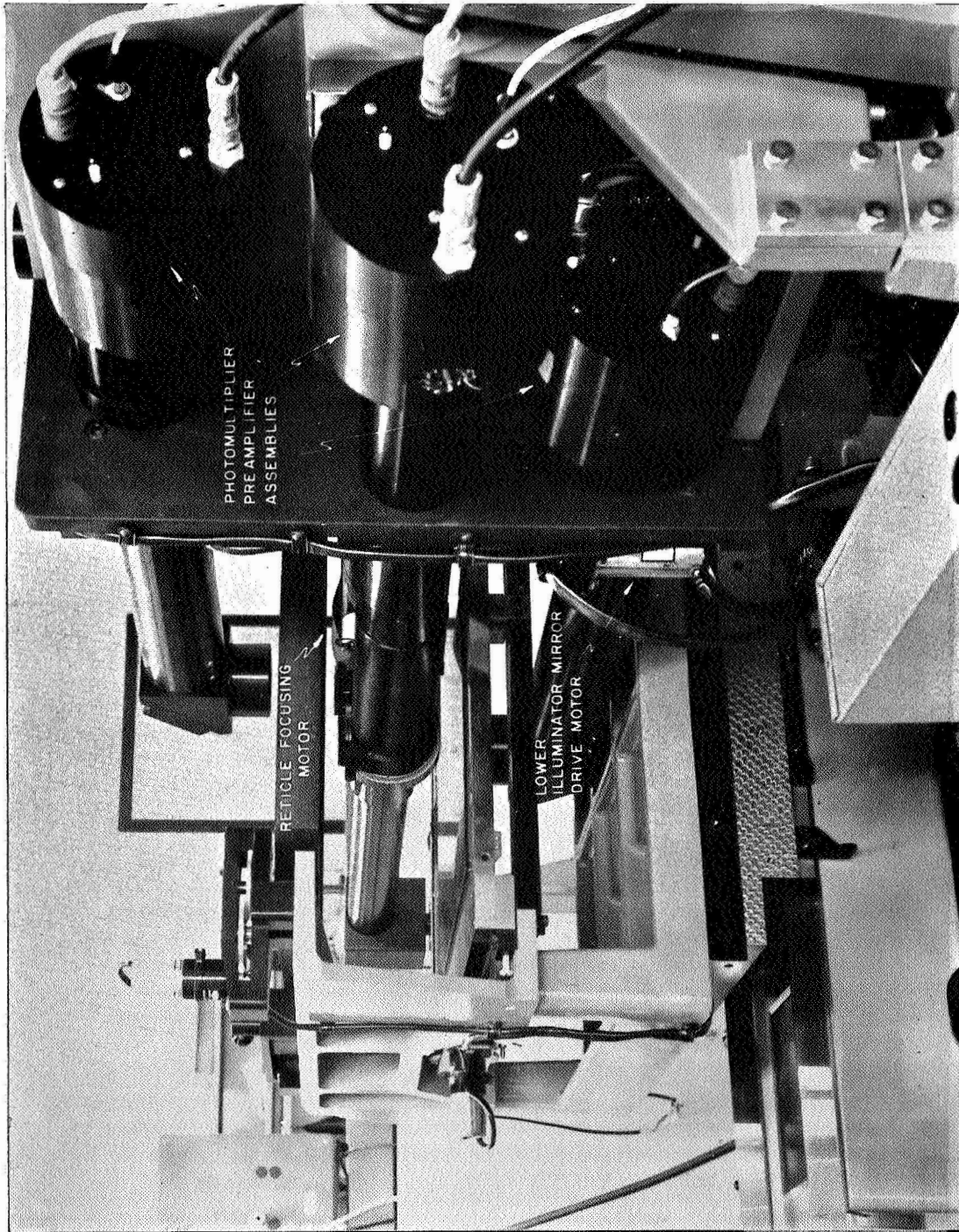


Figure 4: Photograph of Scanner Showing Light Collection Systems

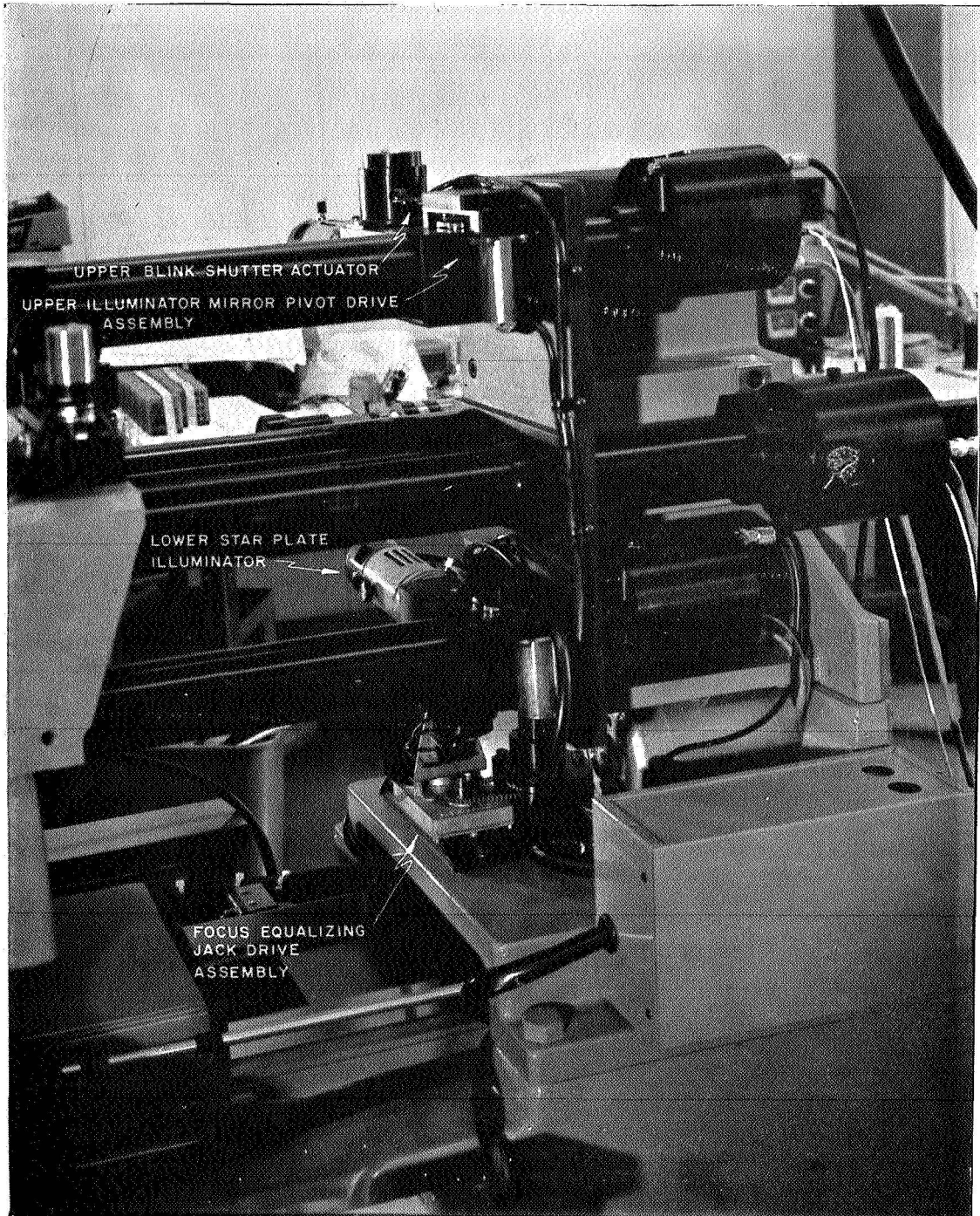


Figure 5: View of Scanner from Light Collector Side



### B. Scanning and Alignment Optics

The scanning optical system is essentially the same as the system shown in Figure 9, page 19, of the previous annual report. However, the optical system was modified to make possible the use of a blink microscope system for visual plate alignment. The modified optical system in the scanning configuration is shown in Figure 6. A photograph of the scanner head with the stationary cover of the rotating prism and the blink microscope removed is shown in Figure 7. A photograph of the laser and the focussing motor for the converging lens is shown in Figure 8.

The optical system in plate alignment configuration is shown in Figure 9. In this configuration a mirror is swung into each light collection tube by a special motor and comes to rest at 45 degrees from the optical axis of the tube. In this position the light from separate microscope illuminators is sent down the tube and illuminates each star plate. A red filter is placed on the upper (original) star plate illuminator and a cyan filter on the lower (duplicate) star plate. The lenses of the illuminators are adjusted so that the image of the filament of each lamp is in sharp focus on each star plate.

The light from the illuminators thus travels along the same path as the laser beam, but in the opposite direction. A microscope placed to receive light coming from the lower star plate to the beam splitting surface nearest the rotating prism will also receive light from the upper star plate as well. The microscope can be focussed on both star plates simultaneously, for the optical path lengths from the exit face of the beam splitter nearest the microscope to each star plate are the same. A further modification required, but not shown on these drawings, is a 90 degree roof on the  $45^{\circ}$ - $90^{\circ}$ - $45^{\circ}$  prism facing the upper star plate to correct a right-to-left reversal difference between the two images and a cylindrical lens on the exit face of the reference beam prism to convert the laser spot to a line parallel to the reticle lines.

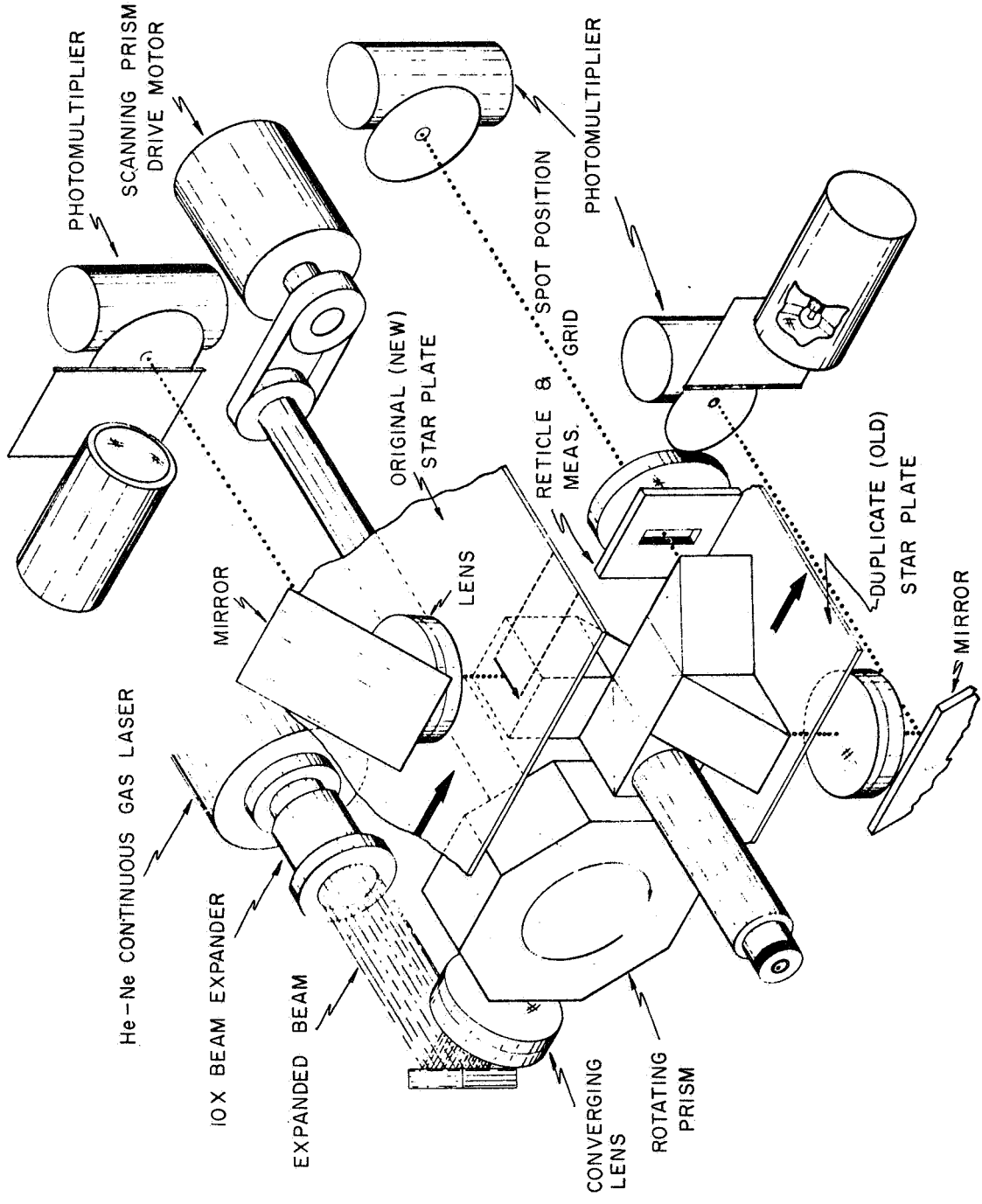


Figure 6: Optical Schematic, Scanning Configuration

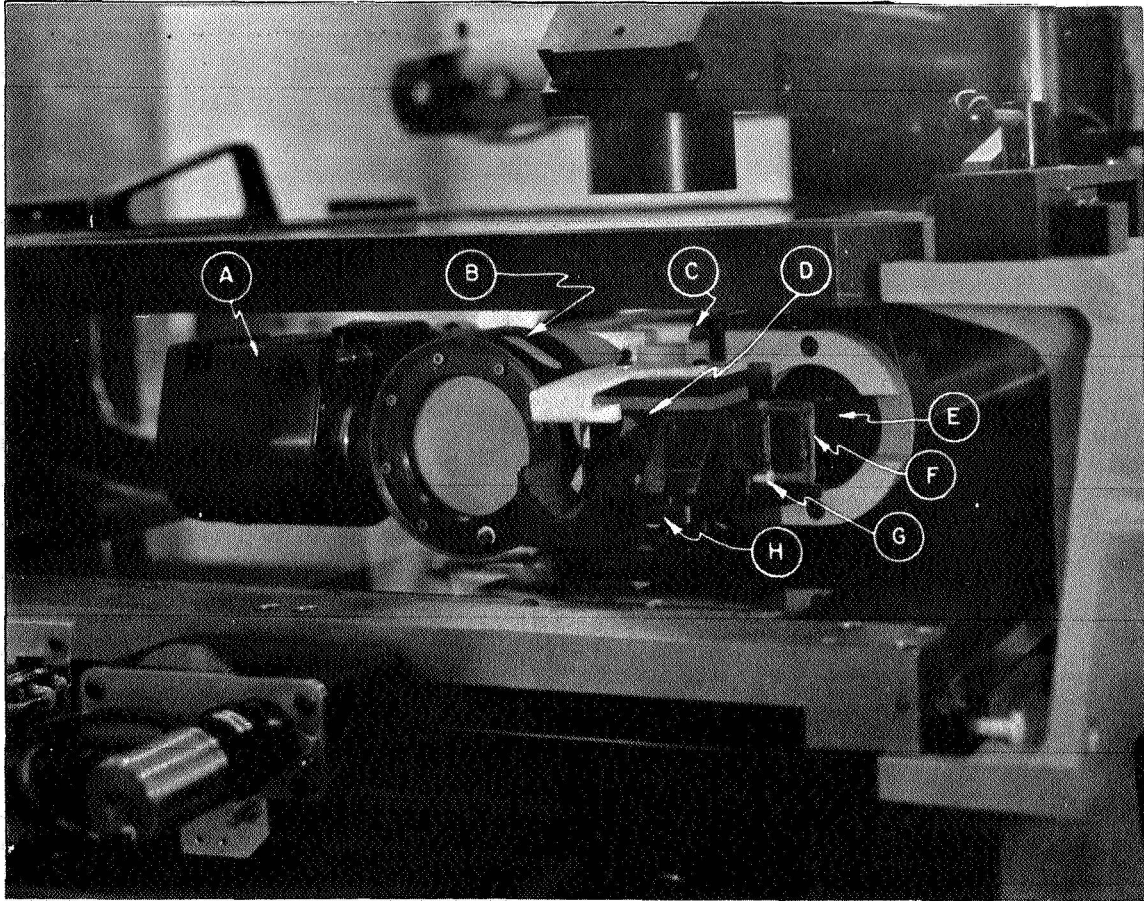


Figure 7: Scanning Head with Stationary Cover of Rotating Prism and Blink Microscope Removed.

A is the housing containing the converging lens and motor driven focussing assembly. B is the rotating octagonal prism producing the scanning motion of the laser beam passing through the converging lens. From the rotating prism B, the laser beam passes through the scan separator prism cluster. One of the beams separated by the beam splitters in the prism cluster passes upward from exit face C to the upper (original) star plate; a second beam passes from exit face H to the lower (duplicate) plate, and the third beam passes through exit face F after being further shaped by a plano-cylindrical lens. This beam strikes the reference reticle E. G is a nylon clamping screw holding the prism in alignment.

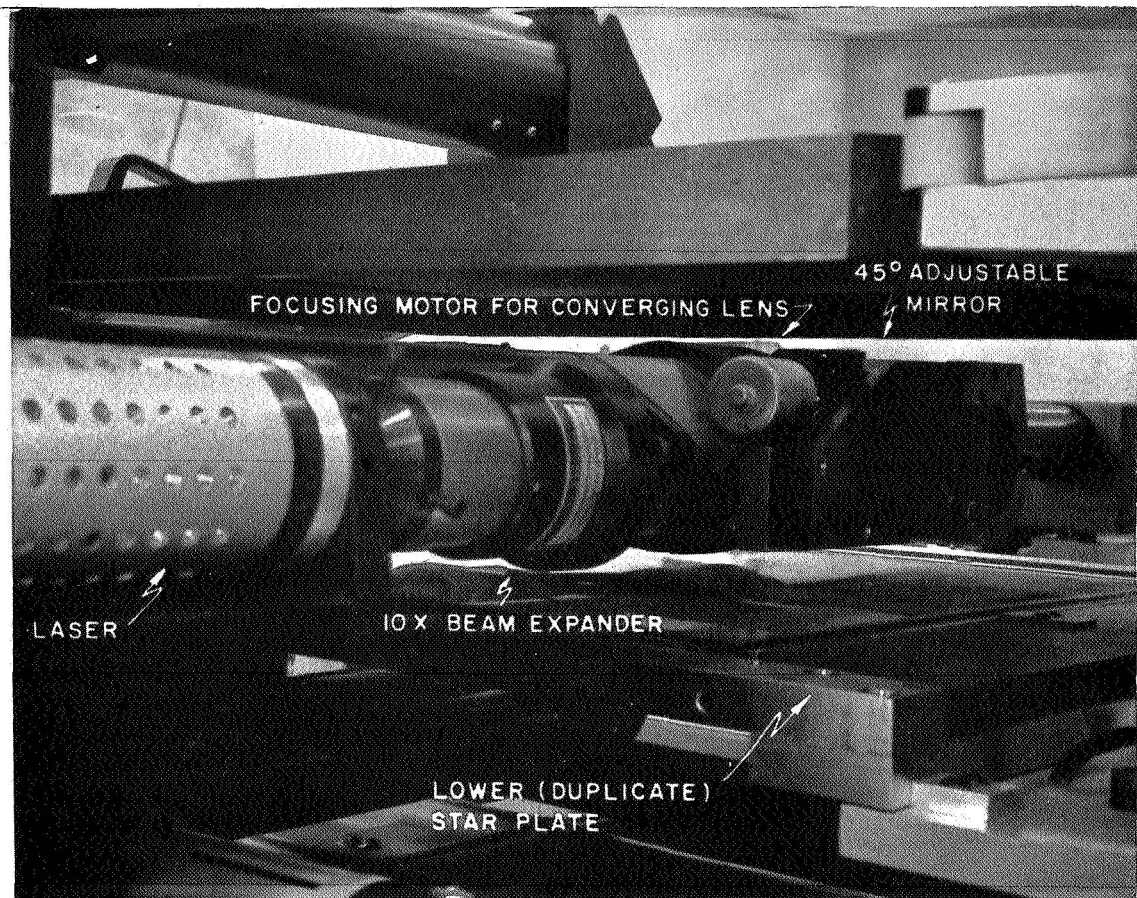


Figure 8: Laser, Scanning Head, and Focussing Motor

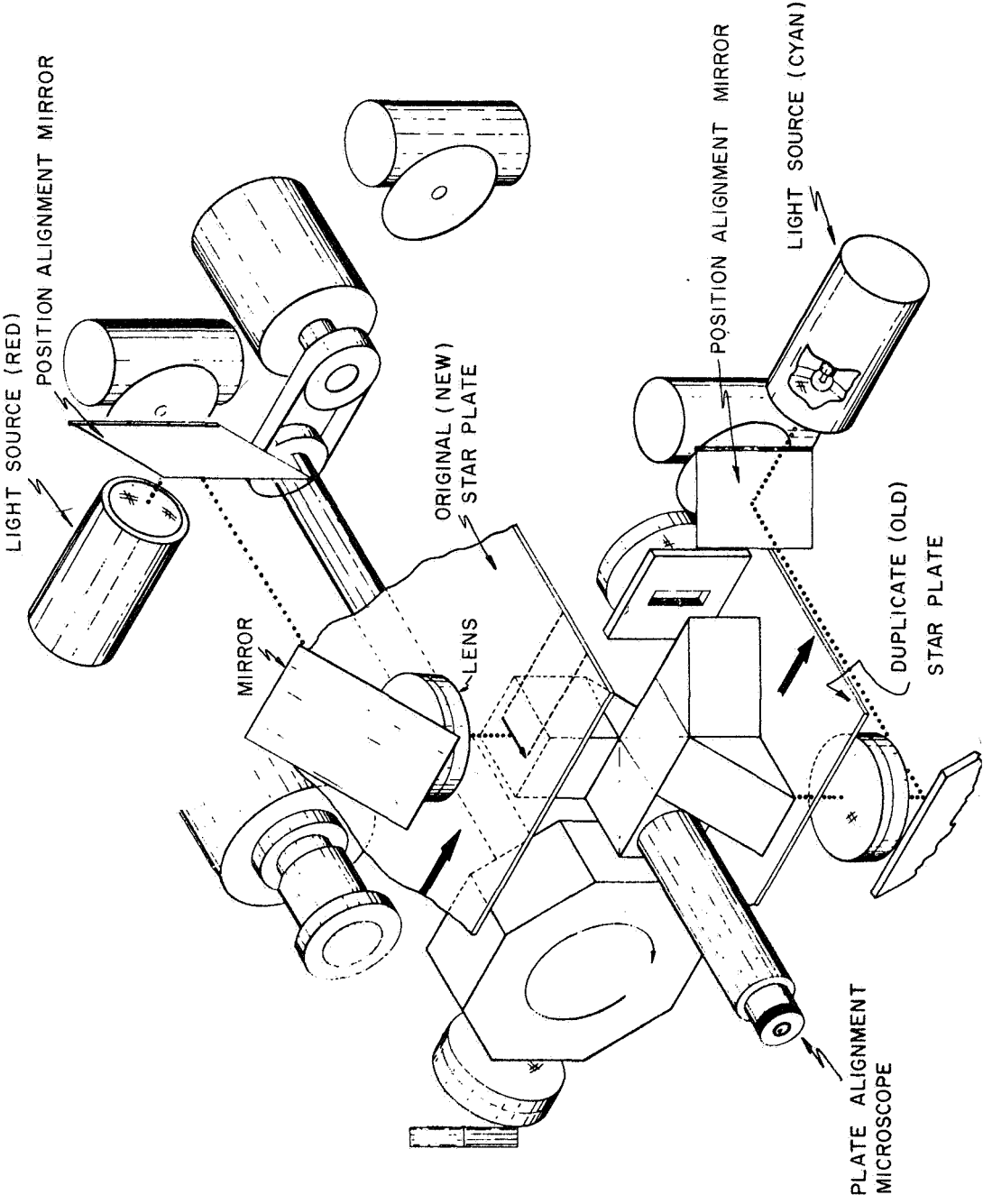


Figure 9: Optical Schematic, Plate Alignment Configuration

In addition to the plate alignment facility, the optical system is provided with electrically actuated shutters on the illuminators. These shutters can be operated at the control panels on the machine in the conventional blink machine method so that results obtained by the automatic machine can be checked by conventional methods if necessary.

### C. Mechanical Structure of the Scanner

The basic position measurements made with the scanner are made between the star plates mounted on the measuring table of the Moore Measuring Machine and the scanner head which is fixed to the base of the machine. The motion of the star plates is produced by the motion of the cross slides of the measuring machine along orthogonal axes. The lead screws and cross slides can measure the position of the star plates within the 14" x 14" area of the plates. The positions of the plates along the two axes are reported to the nearest micron by incremental angle encoders directly coupled to the two lead screws and delivering one pulse per micron of table travel. The axis of table travel parallel to the axis of rotation of the scanning prism is referred to as the Y axis, and the axis of table travel motion perpendicular to the axis of rotation of the scanning prism is referred to as the X axis. The X axis motion is continuous during the scanning of a plate; the Y axis motion is step-wise, occurring at the end of the scan of each stripe.

The Y axis steps are set by a series of cams mounted on the laser side of the base casting. A photograph of the cams is shown in Figure 10. Note that the cams move with respect to the roller actuated switch as the slide moves in the Y direction. The position of the cams can be adjusted by rotating the cams on the threaded rod on which they are mounted. Y axis table travel limit switches are also mounted in this assembly, shown in the photograph with the cover removed.

Table motion along the X axis is provided by a three speed synchronous motor. Table speeds available are six, three, and one and one-half millimeters per second. A synchronous motor was used to synchronize the motion of the star plates with the motion of the scanning laser spot at the three table speeds chosen. The laser spot-table motion provides five microns between successive scans. Electric brakes are provided to stop the table motion as soon as the power is removed from the drive

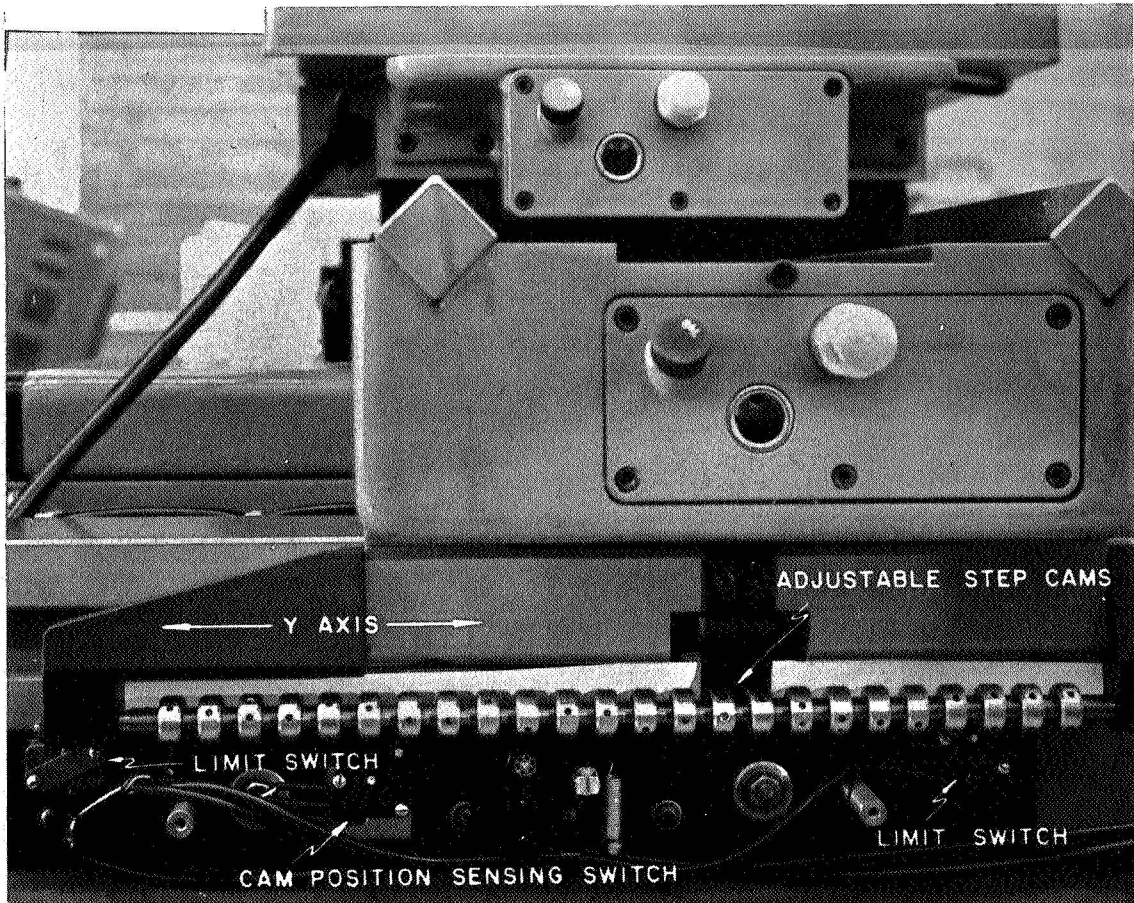


Figure 10: Y Axis Step Cams



motors. Limit switches are provided to stop table motion when the scanner reaches the boundary of the scanning area. A two speed induction motor with an electric brake is provided for the Y axis; a synchronous motor was not needed for this motion because no scanning would occur while it was being used.

The star plates are mounted in individual star plate holders. The star plate holder assembly, consisting of the two plate holders and a spacing and supporting structure, is mounted on the cross slide of the Moore Measuring Machine. Adjustments of the relative alignment between the two star plates are made by translational motions in the X and Y directions of the lower star plate holder over a limited range, and rotation of the upper star plate holder about the center of the star plate over a limited range. All motions are accomplished by stepper motors controlled by switches at the control panels located in the front of the scanning machine. Two operating speeds are provided for each stepper motor.

The fixed portion of the scanner is built around a column which is mounted on the base plate. The column and base plate are fixed to the base of the Moore Measuring Machine. The column assembly is composed of the column, the scanner arm assembly, the light collection system with the photomultipliers, and the laser as the major elements. The column is supported at three points; two points are stiff flat springs, and the third point is a motor driven adjustable jack which can be operated from either the control panels in the front of the scanning machine or at the control console. This adjustment allows the scanner head to be moved up and down in the space between the two star plates to compensate for varying glass thicknesses of plates used. A photograph of the jack and its motor drive from the laser side of the scanner is shown in Figure 11. The equalizing jack is also shown in Figure 5.

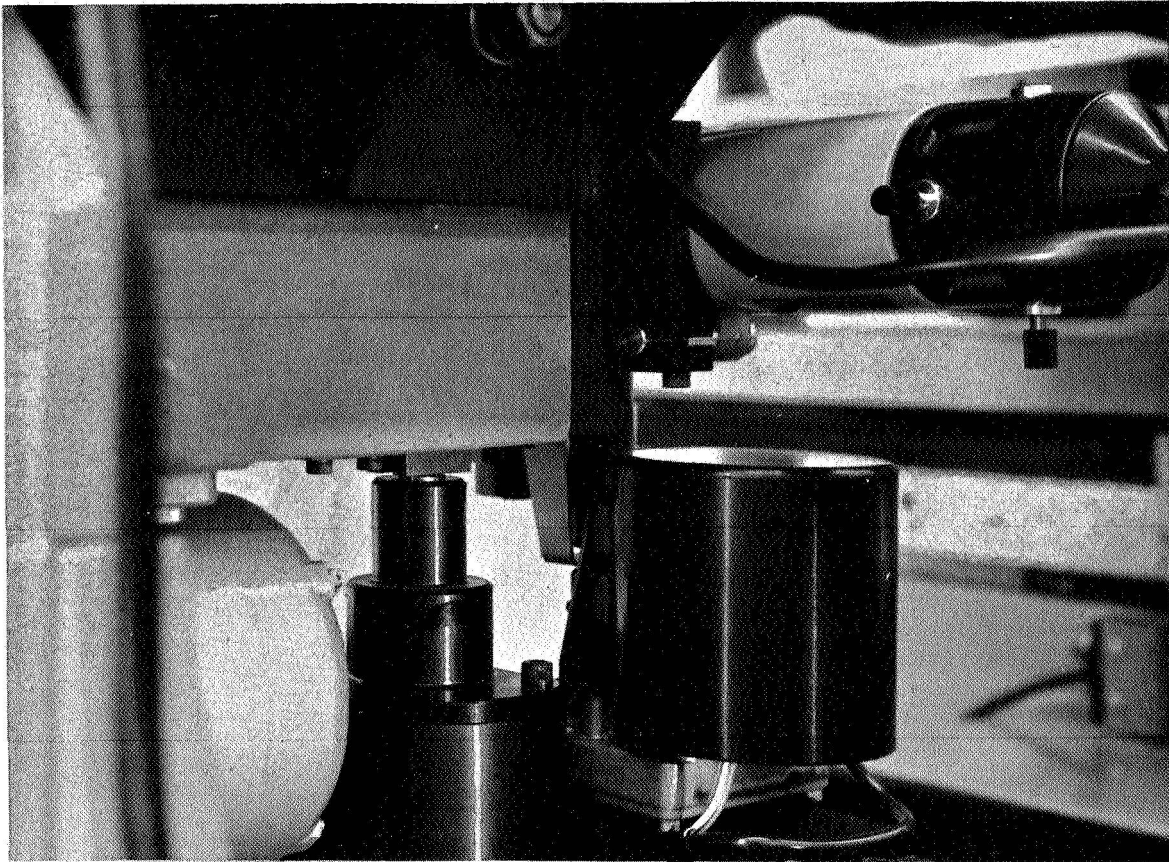


Figure 11: Photo of Equalizing Jack from  
Laser Side of Scanner

The scanner head assembly shown in the photograph of Figure 7 consists of a  $45^{\circ}$  front surface mirror, a converging lens in a motor driven focussing mount, the rotating octagonal prism and its associated shaft and precision bearings, the beam splitting prism cluster, the blink microscope objective support, and the reference beam reticle in a motor driven focussing mount. Both the converging lens and the reference beam reticle focussing motors are controllable by switches at the control panel in the front of the scanning machine and at the control console. The rotating octagonal prism in its mounting cage is both dynamically and statically balanced so that no discernible vibration occurs at the 9000, 4500, and 2250 RPM speeds at which the scanning machine operates.

The scanner head is mounted on the scanner arm which is mounted on the column. The scanner arm contains the prism drive spindle, also very accurately balanced both statically and dynamically on precision bearings. The spindle is connected by belt and pulley to a three speed synchronous motor mounted on the underside of the column.

The three light collection tubes are mounted on the front deck and serve to bring light from the beam splitting prism cluster to the photomultipliers through the two star plates and the reference beam reticle. The light collection tubes for the upper and lower star plates are alike; closest to the star plate in each case is a converging lens, followed by a  $45^{\circ}$  front surface mirror to reflect light from the laser beam down the collector tube to the adjustable diaphragm which is located immediately in front of the photocathode of the RCA 1P21 photomultiplier. The diaphragm is located at the focal distance of the light collector lens. The tilt of the  $45^{\circ}$  mirror is adjustable in two axes by set screws located in the mirror housing.

The mechanism for changing the system from normal scanning configuration to visual plate alignment configuration is near the photomultiplier

end of the upper and lower star plate light collection tubes. A housing containing the illuminator, blink shutter, and pivoting mirror is mounted on the front deck surface intersecting the light collection tubes. A motor turns the mirror so that it comes to rest at an angle of  $45^{\circ}$  to the optical axis of the light collection tube. In this position, light from the illuminator can pass through the blink shutter and down the light collection tube to illuminate the star plate. The motor and the blink shutter are controlled from the control panels at the front of the scanning machine; controls capable of varying the current to the illuminators are on the same control panels.

The photomultiplier-preamplifier housing shown in the photograph of the side of the scanner (Figure 4) is connected to the light collection tube by a clamp which slides over the end of the tube. Supply and signal cables are mounted on the rear surface of the housing. The laser is mounted on the column with independent adjustments on all three axes for alignment with the scanning optics.

The blink microscope is assembled in a long tube with the objective lens, a 150 mm focal length  $f/5.6$  Schneider Componon lens mounted close to the exit face of the beam splitting prism cluster and a 32 mm focal length Erfle wide angle eyepiece on the other end. The tube length of 31 inches was required in order that the eyepiece clear the star plate holders for all table positions and that the observer be located in such a position as to conveniently operate the plate alignment controls while looking through the microscope. The wide field eyepiece coupled with the large tube length required that the eye of the observer be placed quite close to the lens of the eyepiece; the eyepiece conversion unit has been designed which uses the same eyepiece but additional optics to produce a much greater eye relief at a higher magnification. An optical schematic of the conversion unit is shown in Figure 12. The objective end of the microscope slides into the V block and plastic clamp shown in Figure 7.

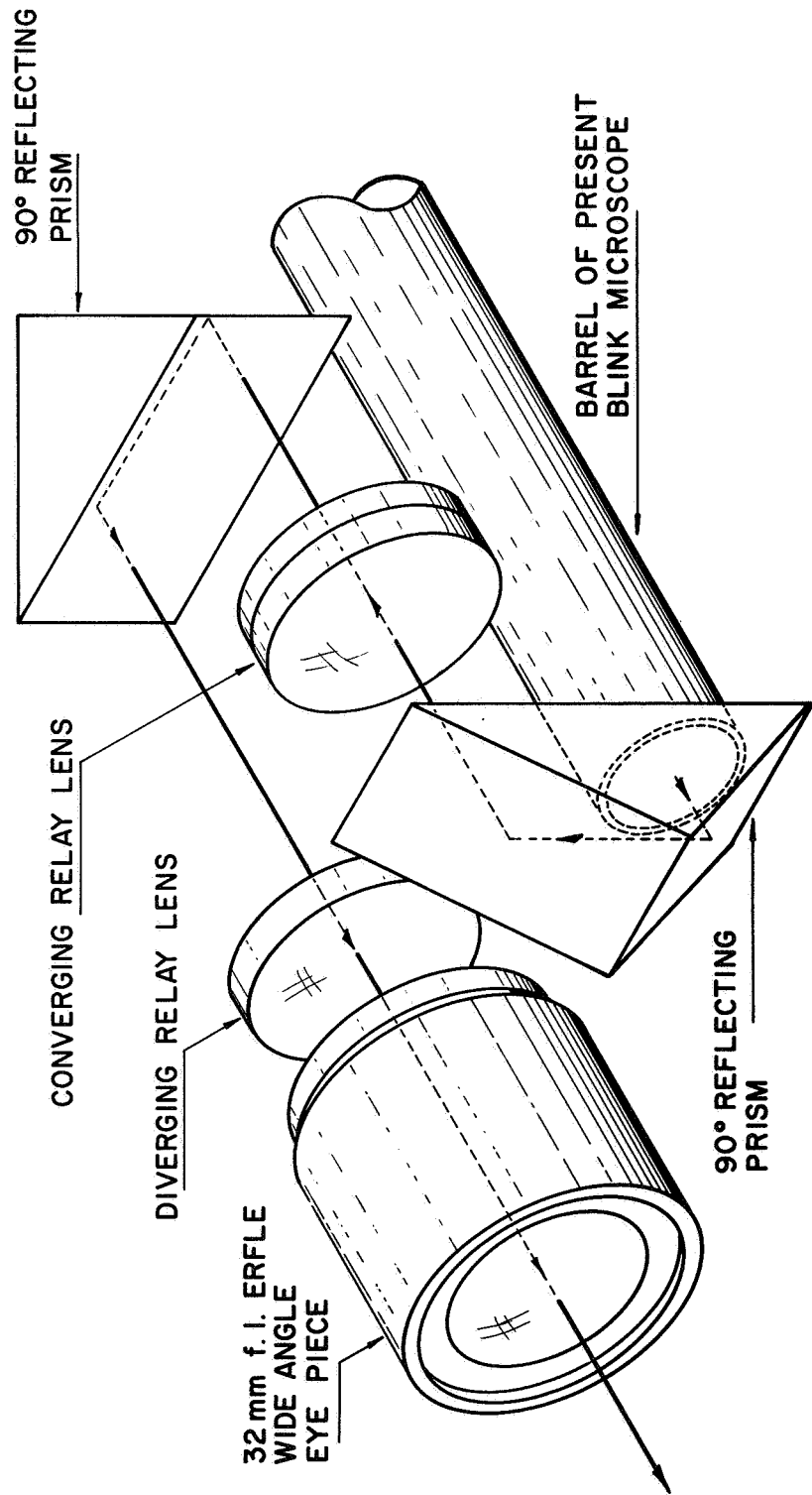


Figure 12: Eyepiece Conversion Unit

The eyepiece end fits through a clamping block which locks into the mount erected on the Y axis lead screw motor drive box as shown in Figure 3. The hole in the clamping block is much larger than the microscope tube; the tube is held in place by two pivot pins diametrically opposite each other in the horizontal plane. The pivot pins allow the microscope to tilt when the focus equalizer jack changes the position of the scanner head between the two plates; the locking mechanism permits repeatability of observations when the microscope must be removed and replaced.

#### D. Scanner Control Electronics

##### 1. Functions of the Scanner Controls

The operation of the scanning machine in its various modes requires ten motors, two rotary actuators, two illuminators, and two electric brakes. The modes of operation are selected by the positions of switches in the control areas of the machine. The scanner control electronics provide a safe and line-transient-free connection between the setting of the switches and the application of power to the electromagnetic devices listed above. The scanner control circuits are housed in a cabinet in the rear of the machine and cabled to the control areas and motors.

The control area located in the front of the scanner is intended for use when there must be direct interaction between the machine and the operator; these modes of operation are: plate change, visual alignment and/or blinking plates, testing video outputs, and non-automatic plate scanning. The control area is divided into two parts located on either side of the microscope stand. The left control panel and star entry box are shown in Figure 13. The most important switch on this panel is the switch in the lower lefthand corner labeled "mode." It is this switch which determines the energizing of all other controls and determines the type of operation which can take place on the machine. A listing of the effect of the choice of mode switch setting on each of the machine operations is shown in Table I. Each of the functions listed on the switch will be discussed below, starting with "Plate Change" and progressing clockwise.

##### a. Plate Change

The Plate Change mode is used when the operator wishes to replace the star plates. Selection of this mode will cause the carriage to move so that the scanning head is positioned at the extreme left rear corner of the plate holder. At this point, the motion interlocks are activated, carriage motion ceases, and all carriage motion controls are disabled.



Figure 13: Left Control Panel and Star Entry Box



TABLE I  
CONTROL AND EQUIPMENT STATUS  
SCANNER CONTROL PANEL

LOCAL - REMOTE SWITCH - LOCAL

MODE SWITCH	PLATE CHANGE	VISUAL	VIDEO	SCAN
Carriage Motion (X and Y)	0	X	X	0
Fast-Slow (X and Y)	0	X	X	0
Plate Alignment (X, Y, $\theta$ )	X	X	X	X
Fast-Slow (X, Y, $\theta$ )	X	X	X	X
Scan Speed	0	0	X	X
Scan Control (Scan, Reverse, Index)	0	0	0	X
Laser	0	0	X	X
High Voltage	0	0	X <sup>3</sup>	X <sup>3</sup>
Light Intensity	0	X	0	0
Blink Shutter	0	Blink Align X      0	0	0
Focus (Beam, Reticle, Equalizing)	0 <sup>2</sup>	0 <sup>2</sup>	0 <sup>2</sup>	0 <sup>2</sup>

1 - Forced reverse until limit switch stops motion.

2 - May be enabled with focus enable switch.

3 - May be disabled with high voltage disable switch.

LEGEND

X - ENABLED

0 - DISABLED

The laser, high voltage, and alignment lamps are off, and overhead illumination is turned on. The overhead lamp will be off for all other modes of operation.

b. Visual

The visual mode is a dual purpose configuration. It is used primarily in the plate alignment procedure. A secondary function enables the machine to be used for manual blinking of the star plates. The Blink-Align switch enables the blink shutter mechanisms for manual blinking.

In this mode the prism motor, laser, and high voltage are turned off, the alignment lamps are on, and two retractable mirrors are lowered into the light collector tubes. These mirrors direct light from the alignment lamps in the opposite-to-normal direction through the optical system. The superimposed star fields from the plates are viewed through the blink microscope. The X and Y table motion switches are used to position the star plates so that the desired field is seen in the microscope. The fields from the two plates may then be superimposed with the alignment controls or compared with the blink shutter.

c. Video

The video mode will be used primarily for testing and adjustments at the machine. The preamplifier output signals are available at each of the three photomultiplier assemblies and may be viewed with an oscilloscope placed at the machine. The laser and high voltage are turned on, the alignment lamps off, and the mirrors are retracted from the light collection tubes. The table may be positioned with the manual controls to obtain a line scan of the plate images.

d. Scan

The scan mode enables the operator to program manually the scanning sequence used in automatic data acquisition. This mode, also, has been

provided as an aid for testing and adjustment. The table will scan a stripe, return, and proceed to the next stripe when the Scan, Reverse, and Index controls are actuated in sequence. The laser and photomultipliers are operative, and the video may be monitored at the photomultiplier assemblies.

In the upper left corner of the control panel of Figure 13 is the scan speed control switch. This switch is actuated only in the video and scan modes, and sets the speed for the prism rotation and the X axis traverse such that the scanning spot advances five microns per scan.

In the lower right of Figure 13 are the switches which perform manually the operations of scanning which are done automatically during the usual scanning process--scanning along the X traverse, reversing the X traverse to return to the start of the scan, and indexing the Y axis to the next strip position.

In the upper right of Figure 13 are two interlock controls which serve as protection during normal operation. Unless the switch marked "Focus" is in the enable position, none of the three focus motors can be actuated, thereby reducing the possibility of accidental defocussing. The switch to the right of the "Focus" switch is designed to make it possible for an operator to turn off the high voltage to the photomultiplier tubes to reduce the danger of shock and/or accidental exposure to room light with the power on the photomultipliers.

The "Local-Remote" selector switch in the upper center of the panel transfers control from the panel above ("Local") to the control console ("Remote").

The star entry box in the lower right corner of Figure 13 is used to put the coded identification of a star image on the tape as the machine

is scanning it; the right ascension and declination of the star and its measured position on the plate are used to read out positions of the other stars in terms of either plate coordinates or right ascension and declination.

The control panel located on the right side of the microscope stand is shown in Figure 14. In the lower left quarter are the star plate alignment controls to be used by the operator as he observes the two star plates through the blink microscope. The speed selection switch, the directional toggle switch, and the momentary contact rotary switch control the actions of the three stepper motors mounted on the star plate holders. Two speeds of operation are available for all of the stepper motors; the fast speed is used for the relatively coarse adjustments in the initial phases of the plate alignment process, and the slow speed, for the final precise adjustments. The speeds are selected by the speed adjustment toggle switch at the extreme lower left. Next to the speed selection switch is the translational motion adjustment toggle switch; moving the handle of the toggle switch in the directions of the arrows on the panel moves the lower star plate in the direction of the arrow. Rotation of the switch handle to the right of the translational motion switch produces a rotational motion of the upper star plate in the direction of rotation of the switch handle.

Translational motion of the carriage on which both star plate holders are mounted is accomplished by the large momentary contact switches to the right of the plate alignment switch group. The motion of the carriage is indicated by the arrows in the direction in which the end of the switch is deflected. Two speeds of carriage motion are available; these are selected by the switch immediately above the X axis carriage motion control switch.

The absolute and the relative intensity of the light from the two

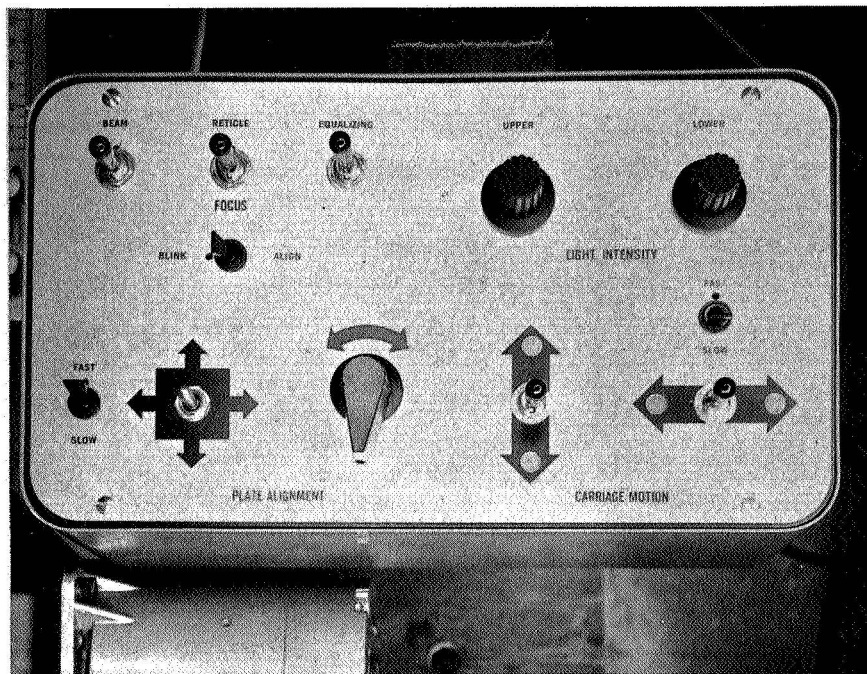


Figure 14: Right Control Panel

illuminators used in the blink and align modes can be controlled by the rotation of the two light intensity knobs in the upper right-hand corner of the control panel. These controls allow the operator to obtain the best visual balance between the illuminations of the upper (red light) and the lower (cyan light) illumination to produce the most pronounced separation between the colored and black images.

In the upper left corner are the controls for the three focussing motors: the beam motor, which controls the position of the converging lens which forms the spots on the two star plates, the reticle motor which controls the position of the reticle in the beam coming from the cylindrical lens in the prism cluster, and the equalizing motor which operates the jack which changes the centering of the scanner head between the two plates.

The toggle switch between the focus and plate alignment controls selects whether or not the electrically actuated blink shutters will be used. If the "Blink" position is selected in the visual mode, either the upper or lower star plate may be viewed through the blink microscope using the blink shutter switch on the left control panel; selection of the "Align" mode disables both blink shutters and allows the observer to see both plates simultaneously.

If the Local-Remote switch is placed in the Remote position, machine control will be transferred to the control console. The major mode and motions controls are located in the center horizontal panel. A photograph of this panel is shown in Figure 15. The scan speed and carriage motion controls are identical with the controls at the machine. The significance of the mode switch settings differ from those at the machine. A listing of the effect of the choice of mode switch setting on each of the machine operations is shown in Table II. The function of each of the switch settings is presented below.

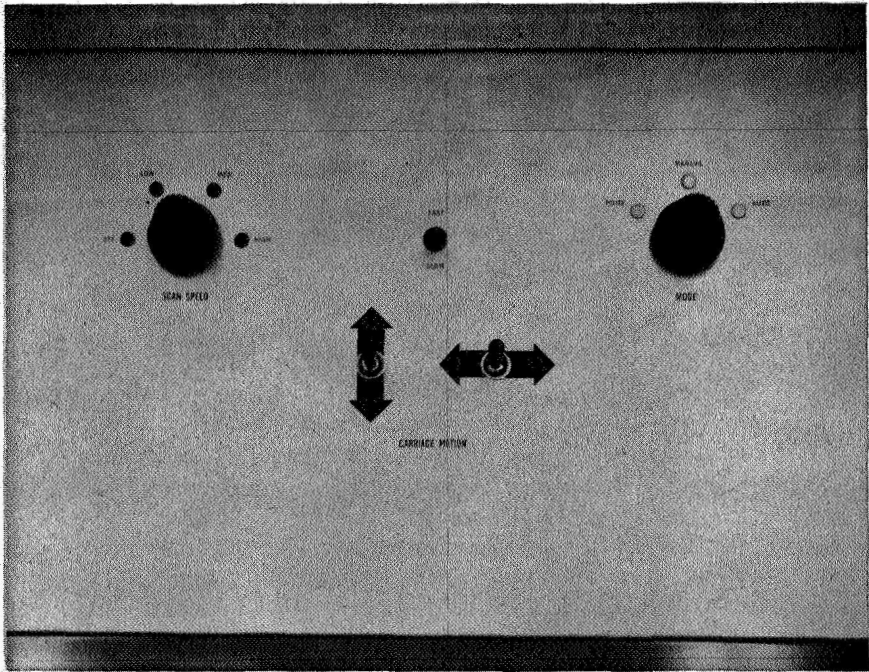


Figure 15: Center Control Panel on Console

TABLE II  
CONTROL CONSOLE

LOCAL - REMOTE SWITCH - REMOTE

MODE SWITCH	HOME	MANUAL	AUTO
Carriage Motion (X and Y)	0 <sup>1</sup>	X	0
Fast-Slow (X and Y)	0	X	0
Scan Speed	X	X	0
Focus	0 <sup>2</sup>	0 <sup>2</sup>	0 <sup>2</sup>

Machine carriage motion controlled by interface logic HV and laser always on.

Alignment lamps and shutter always off.

Alignment (X, Y,  $\theta$ ) always off.

Note: 1 - May be enabled with focus enable switch.  
2 - Forced reverse until limit switch stops motion.

### Home

The home mode is used to initialize the position of the table prior to automatic scanning. Selection of this mode will cause the table to move so that the scanning head is positioned in the left rear corner of the plate holder. The laser and high voltage are on and the prism is rotating at the selected speed. All table motion controls are disabled.

### Manual

In the manual mode, the table motion controls may be used to position the scanner head to any desired position on the plates. An indication of the position of the scanner head will appear at the console of the Scan



Position display. Normal video from the signal channels is present. The main uses of this mode will be in setting the photomultiplier gain controls and in focussing, where the scanner head will be moved to obtain suitable star pulses. A secondary use is for positioning the scanner head prior to a partial scan operation.

### Auto

Selection of the auto mode transfers machine carriage motion control to the interface logic. Scan (and prism motor) speeds are locked in the last position. If the operator desires to change the scan speed he must select manual or home.

## 2. Control Circuits

### a. Circuit Design Objectives

The scanner control circuitry is required to translate operator commands into responses by three polyphase motors, three stepper motors, one single phase motor, four direct current motors, two magnetic actuators, two brakes, and the overhead illumination. There is a real requirement to minimize switching transients as these could cause errors in the interface logic. To this end, all motor and actuator functions that occur during the normal plate change, alignment, and scanning process have been designed for interference-free switching.

A second design objective was to minimize the amount of circuitry required for transistor-relay coil interfacing. This has been accomplished by using relay logic from the motor power controls to the interface inputs. Certain selected circuits requiring timing functions are solid state, as are the RFI-less motor power switches.

The following sections will discuss the operation of several important control areas from a functional standpoint.

b. Table Motion and Prism Motor Controls

The X axis, Y axis, and prism are driven by three-phase, fractional horsepower motors. Line transients caused by simple relay contact power switching of these motors are intolerable. An interference-free power switching scheme has been designed around a full-wave SCR switching circuit. A functional diagram of this circuit is shown in Figure 16.

The control switch is normally closed, holding off the drive to SCR1. Since SCR1 must conduct to provide drive for SCR2, the circuit is inoperative. When the control switch is opened the SCR drive circuit will charge on the next negative half cycle. Note the polarity of D1. When the positive half cycle begins, drive has therefore been applied to SCR1 and it will conduct load current through D2 and L. The function of D2 is to bypass most of the load current around L. When the supply voltage reaches zero, conduction through SCR1 ceases. As the voltage swings negative the drive current supplied to SCR2 from the stored energy in L causes it to conduct. This sequence will repeat until the control switch is closed, removing the drive from SCR1. It is thus seen that this circuit will pass an integral number of full cycles of load current, always beginning at zero voltage and ending at zero current. The control switch may be opened and closed in random fashion, and no load transients, either current surges or voltage spikes, will result.

c. Power Routing

The X axis and prism motors are three speed, and the Y axis motor is two speed. Speed changes are accomplished by means of separate windings in the motors. In addition, the X axis and Y axis motors must be reversed. If separate zero-point switching circuits were used to perform all of these functions, the number required would be prohibitive. Therefore, power switching relays are interposed between the zero-point circuits and the loads. It is noted that the contact configuration or state of the power relays may not be changed while power is applied to the load. This condition



is met by timing the relay coil switching with the state control circuits, which will be discussed later. A block diagram of a typical power switching arrangement (Y axis) is shown in Figure 17. It is noted that SCR zero-point switches are required in only two legs of the three phase power.

d. State Control

The purpose of the state control circuit is to insure that the contacts of the Y Reverse and Y Slow relays will not switch power. This is accomplished with the circuit configuration shown in Figure 18.

The State Control switch is physically part of the Y Reverse and slow relay coil control switching and is momentarily opened and then closed again when the control setting is changed. Assume that the state control switch is closed and the SCR relay energized, applying drive to the SCR switches (Figure 17). If one of the Y speed controls is changes, the state control switch will open. This sets the flip-flop, opening the SCR relay contact and applying a trigger to the one-shot multivibrator A. When the SCR contact opens drive is removed from SCR1 on Figure 17, and load current ceases at the end of the current cycle of alternating current. The timing interval of one-shot A is long enough to insure that no load current is flowing when A terminates, triggering one-shot B. During the interval of B, the release relay contact is open. This contact is in series with the locking contacts on Y Reverse and Y Slow. All motor power relay coils will, therefore, be deenergized. The system will remain in this state, with the SCR switches off and all power relays deenergized, until the state control switch is closed. Closing the state control switch applies a trigger to the holdover circuit, which times out an interval somewhat longer than the combined length of one-shots A and B. This insures that the release relay will have operated before the holdover applies a trigger to one-shot C. One-shot C operates the interrogate relay during its period. The interrogate contact momentarily completes the control switching path to the power relays. The power relay coils will pull up in the new state

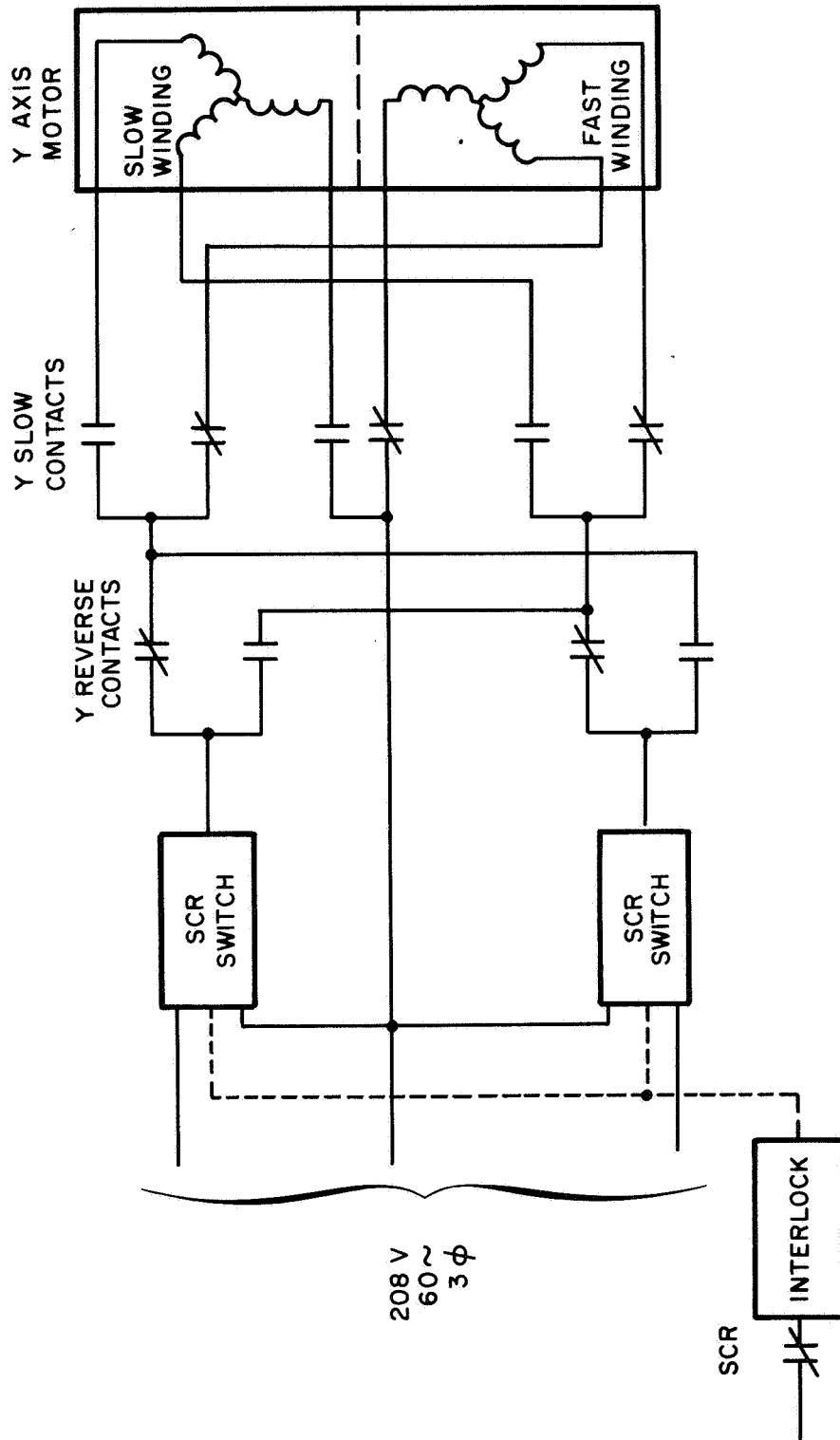


Figure 17: Block Diagram of Power Switching Arrangement

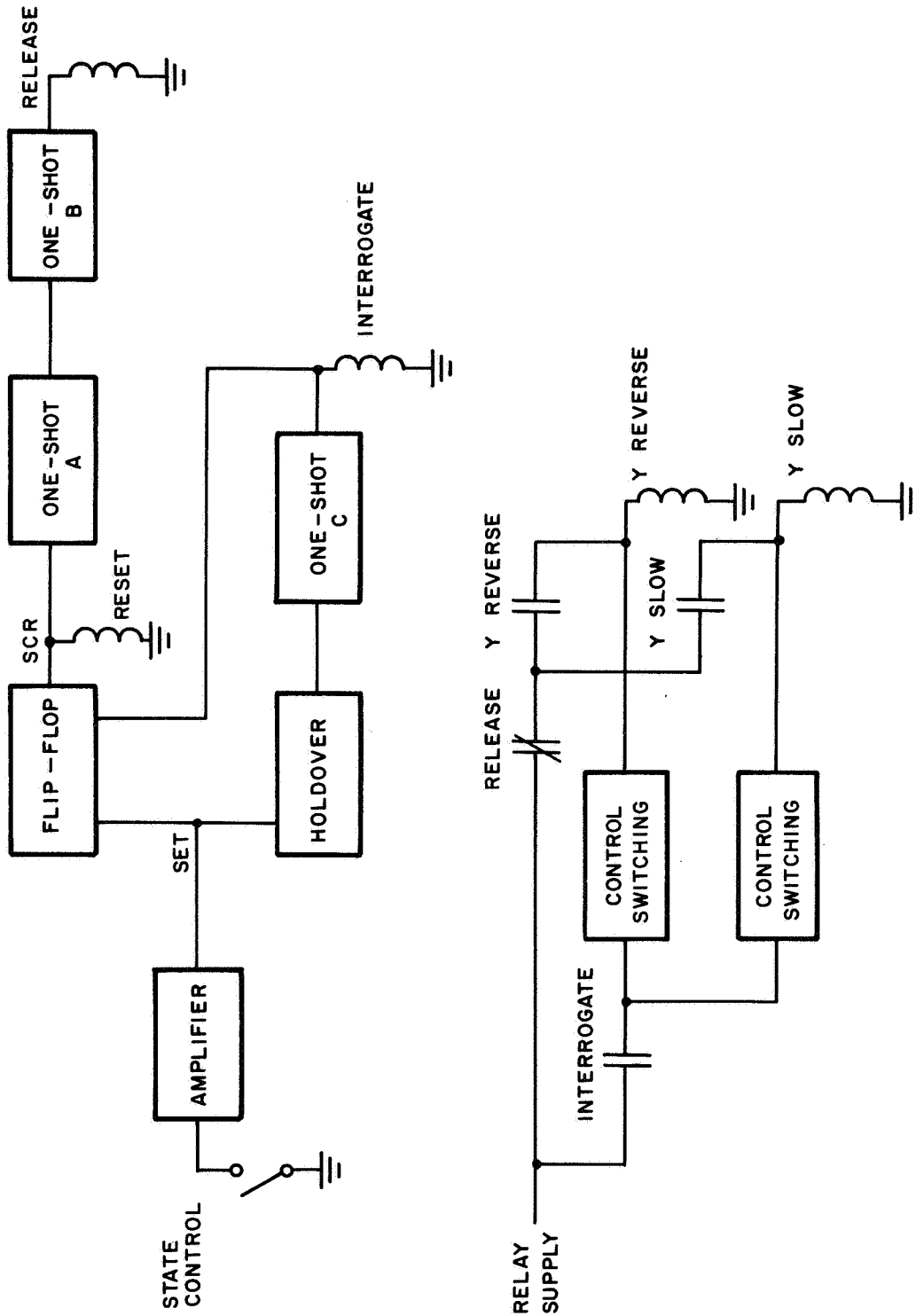


Figure 18: Functional Diagram of the State Control System

configuration and lock through the release contact, which is now closed. At the termination of one-shot C, the interrogate coil is deenergized and a reset pulse is applied to the flip-flop. This energizes the SCR coil, applying drive to the SCR switching and power to the motor.

e. Alignment Motor Controls

The X, Y, and  $\theta$  plate alignment motors are two-phase stepper motors. A functional diagram of the motor control and drive is shown in Figure 19. The output of the two-phase motor drive is two trains of square waves,  $90^\circ$  out of phase. These are generated by switching that is gated by a pulse train at the input. If the pulse train is applied to the forward input, the output phasing causes the motor to run in one direction; application to the reverse input causes it to reverse. The pulse train is generated by the pulse generator and applied to the dual gate. It is routed to the appropriate output by means of a bias voltage controlled with the forward-reverse switch. The drive circuits are disabled by the remote relay contact, so that the alignment may not be disturbed during scanning.

f. Focus Motor Controls

Focussing is accomplished by means of the AC focus jack motor plus two DC motors on the scanner head assembly. Switching of power to these motors is performed with relay contacts. This is permissible from an interference standpoint since focussing will not be included in the series of operations required for data acquisition.

g. Blink Shutter and Mirror Motors

The mirror motors are permanent magnet DC motors. Power to them is switched with relay contacts. Since these motors are used in the alignment mode, they must be rendered interference-free. This is accomplished by means of diodes and brush noise filters.

The blink shutter is a magnetic actuator, controlled by the blink

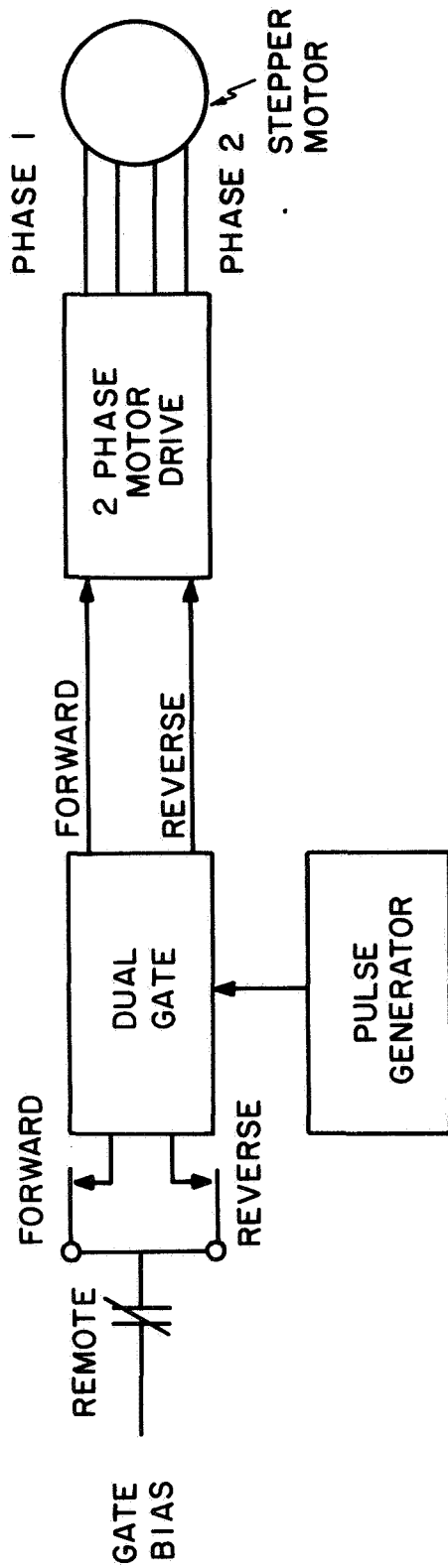


Figure 19: Functional Diagram of Stepper Plate Alignment Motor Drives



switch. It is protected from turn-off spikes by a diode.

#### h. Alignment Lamps and Overhead Illumination

Power switching to the alignment lamps and overhead illumination is controlled with zero-point SCR switches identical to those used for the table motion and prism motors. This insures that power surges to the alignment lamp variable autotransformer or to a fluorescent lamp ballast transformer will not occur.

A photograph of the front panel of the scanner control electronics cabinet is shown in Figure 20. The top row of rectangles are the end panels of the pull-out circuit drawers designated D1, D2, D3, and D4 reading from left to right. The next lower panel is the power supply section for the switching circuitry and the X and Y axis shaft encoders. The lowest panel contains the circuit breakers for the entire system, fuses for the equipment located at the scanner, and the laser power supply. The circuit drawers pulled out of the cabinet are shown in Figure 21. Two of the circuit cards are shown in the extended position used for inspection and testing.

The contents of the circuit drawers are as follows:

- D1
  1. Three relay amplifiers to convert the remote scan, index, reverse signals from transistor to relay logic.
  2. Two relay amplifiers and timing circuits associated with the mirror motor controls.
  3. Two pulse generators (slow and fast) for the alignment motors.
  4. Three sets of alignment motor pulse train gates.
  5. Three alignment motor drive modules.
  
- D2
  1. Control relays.
  2. Power relays for the X motor, Y motor, and prism motor.

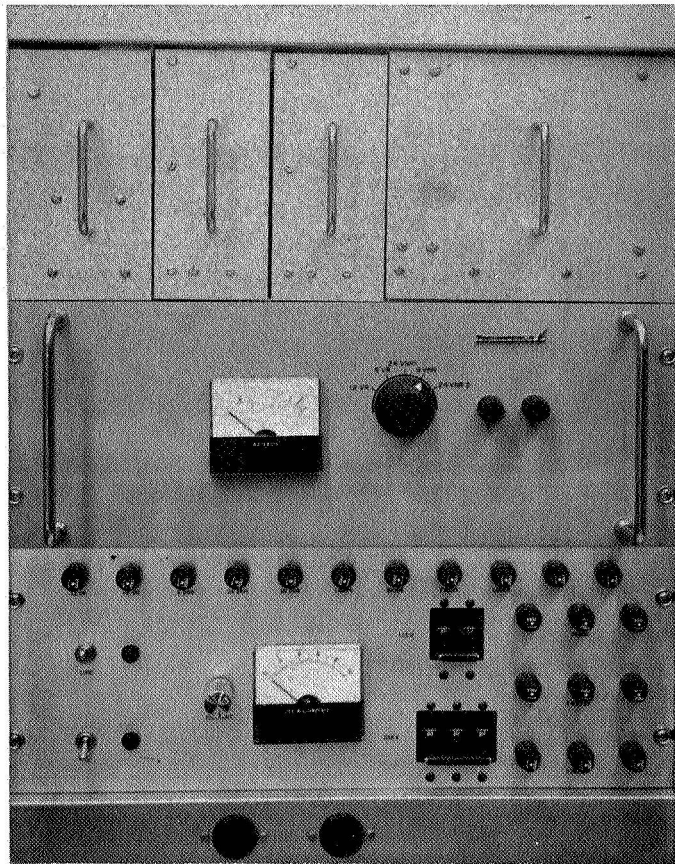


Figure 20: Front Panel of the Equipment Enclosure

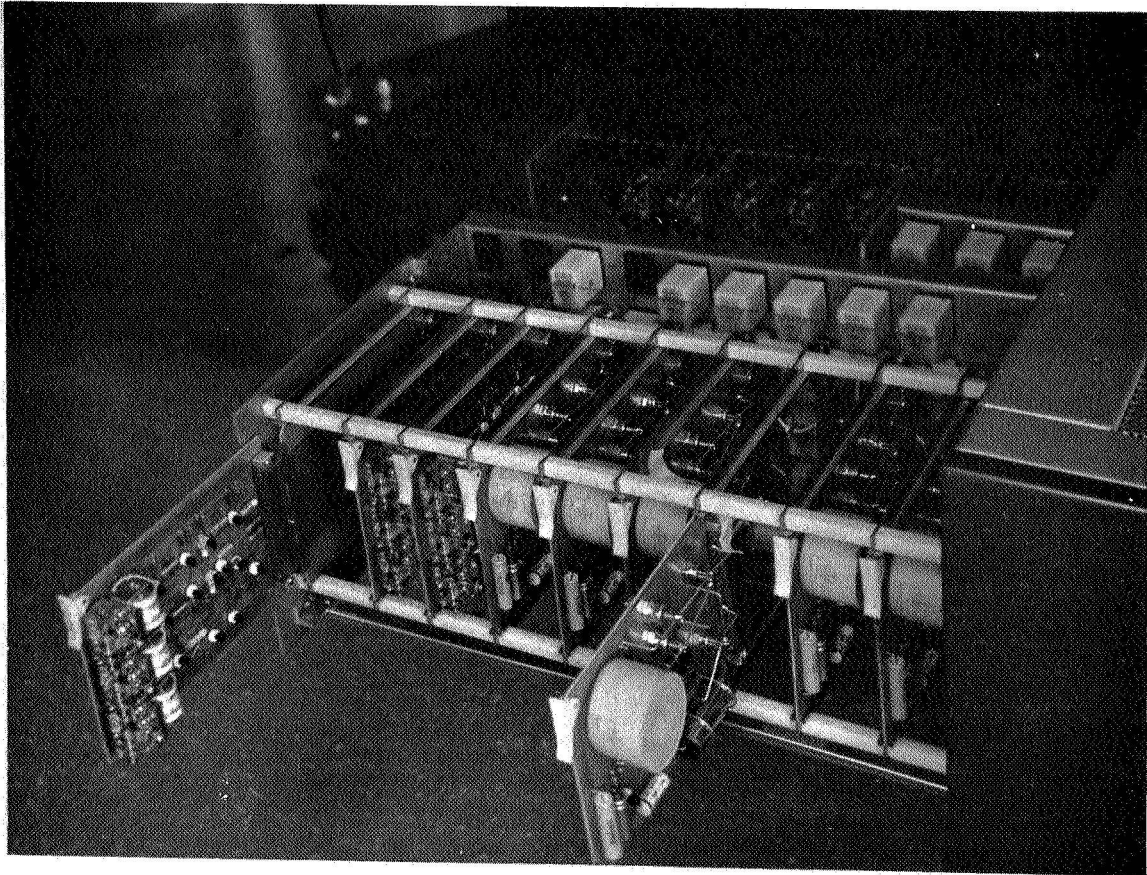


Figure 21: Circuit Drawers of the Scanner Control Equipment Enclosure

D3 1. Control relays.

- D4 1. Three state control circuits for the X motor, Y motor, and prism motor.
2. Eight SCR switches for the X motor, Y motor, prism motor, alignment lamps, and overhead illumination.

### III. OPERATOR AIDS AND DISPLAYS ON THE CONTROL CONSOLE

The configuration of the system for actual scanning of plates is shown in Figure 22. The scanning machine will be placed in a separate, darkened clean room, and the control console, tape unit, and associated equipment in a separate lighted room adjacent to the scanner. The necessary connections between the control room and console are made with cables and detachable connectors.

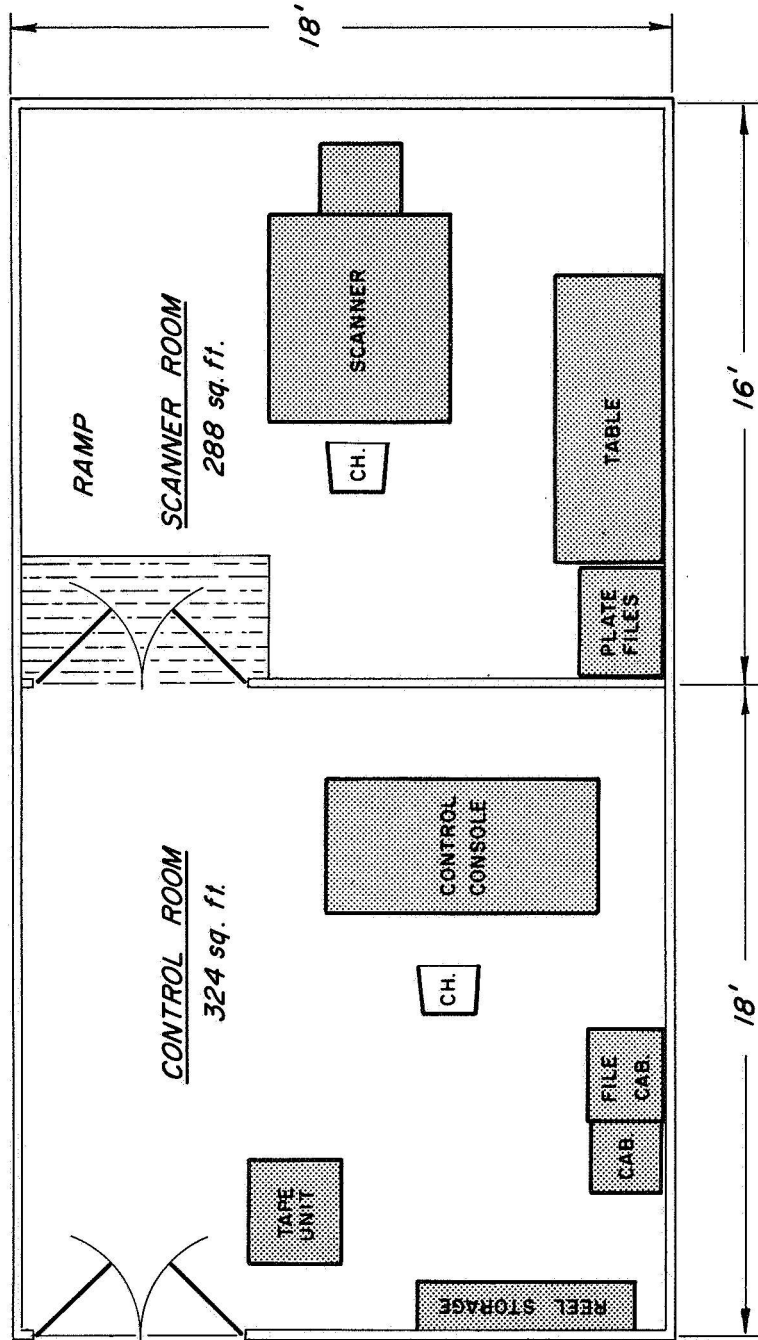
A photograph of the control console in its present state of completion is shown in Figure 23. The left hand and center modules contain the operator aids and displays for controlling and monitoring the scanner and its output. The right hand module contains the data acquisition and data flow controls. The lower portion of the console extends beyond the data acquisition module and contains the core memory and its associated power supplies. The following discussions will be grouped by function and module, starting with the left hand module.

The operator will be required to judge the quality and correctness of many analog waveforms, evaluate data flow, and monitor the scanning process in general. The operator aids and displays provide him with the tools to perform these tasks. The control console contains this equipment, which may be subdivided as follows.

#### A. Video Display

A standard oscilloscope is used to display waveforms from the patch panel. The electronic switches and buffer amplifiers contained in the signal processing electronics are considered to be part of this display.

The video display unit, shown in Figure 24, is a Tektronix RM15 oscilloscope. It may be used to observe any of the waveforms available on the patch panel. Its primary purpose, however, is to display video with superimposed image detector settings from any two of the three



SPACE LAYOUT FOR PROPER MOTION SURVEY PROJECT

Figure 22: Space Layout for Proper Motion Survey Project

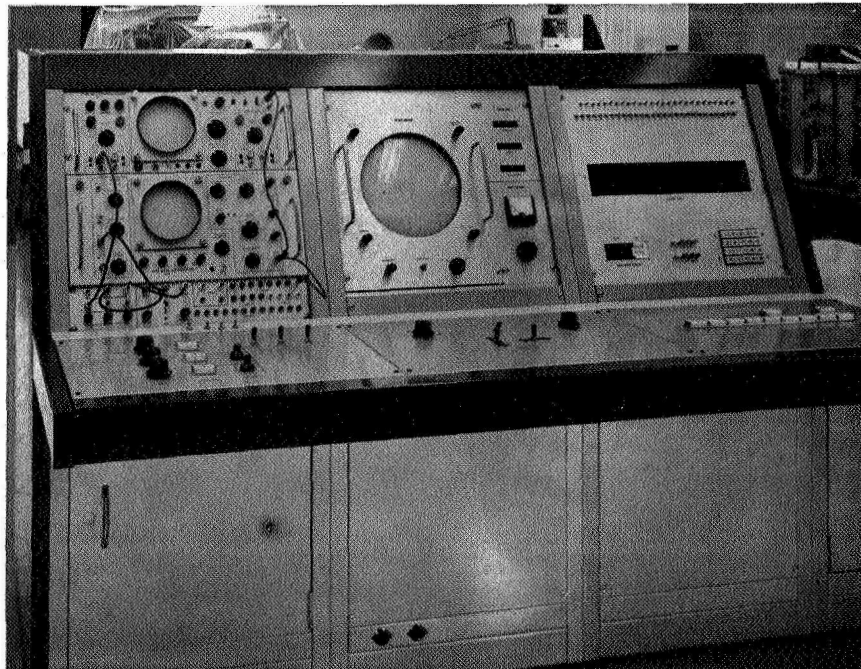


Figure 23: General View of Control Console

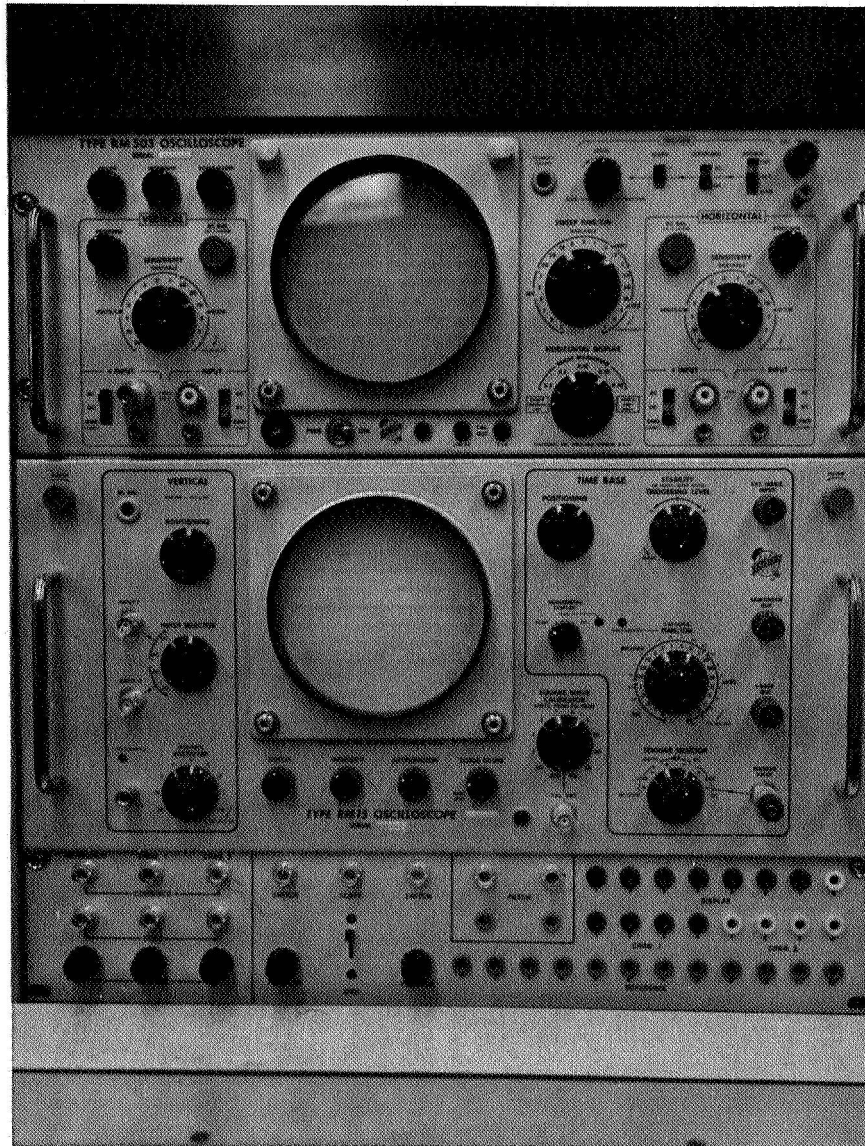


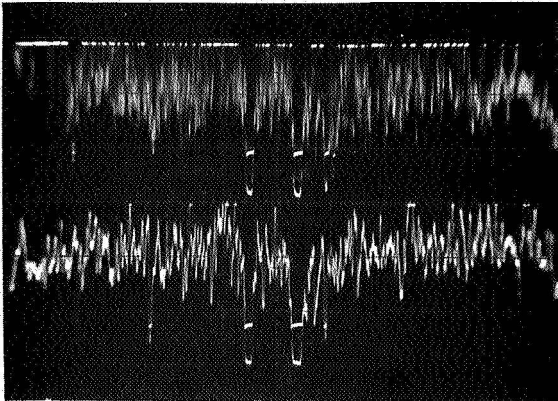
Figure 24: Video Display Unit on Console



channels (Channel 1, Channel 2, Reference). Photographs of various combinations of these waveforms are shown in Figures 25, 26, 27, and 28. Note the expanded display. The horizontal lines through the star pulses indicate the setting of the image detector level control. This waveform is obtained by writing, on alternate traces, the raw video and then the video passed through a fast data-hold circuit. The data-hold circuit is triggered with the image gate, and holds the video level at that which existed when the image was detected. It is released when the image gate terminates and the video signal is again displayed. The display showing two sets of video with superimposed image gate data is, therefore, four different traces. The method of generating this display is shown in the functional block diagram of Figure 29.

The raw video signal is passed through two parallel buffer amplifiers. The output of one goes directly to the channel analog switch. The output of the other is fed to a fast data-hold circuit. This circuit is gated by the image detector output and holds the value of video voltage present when the detector triggers. At all other times, its output is a replica of the video with a slight DC offset. The superposition control at the input to the data hold buffer is used to remove the offset so that the raw video and data hold video signals have precisely the same DC level. The output of the channel analog switch is one input to the display analog switch. An identical set of circuitry to the above generates the other input to the display analog switch, using video and image gates from another channel.

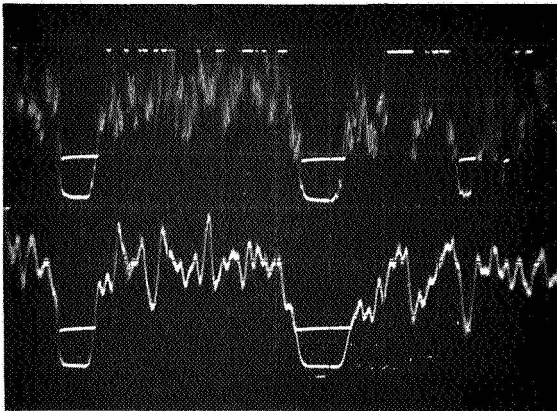
The sequence of gates required to operate the analog switches are generated as follows. The scan sync pulse is used to trigger a symmetrical trigger flip-flop. This circuit changes state each time an input pulse of the proper polarity is applied. The output of the flip-flop is fed to a gate generator which converts the logic-level swing to a large gate swing that drives the display analog switch. The display analog switch



Channel 1 (Combined)

Channel 2 (Combined)

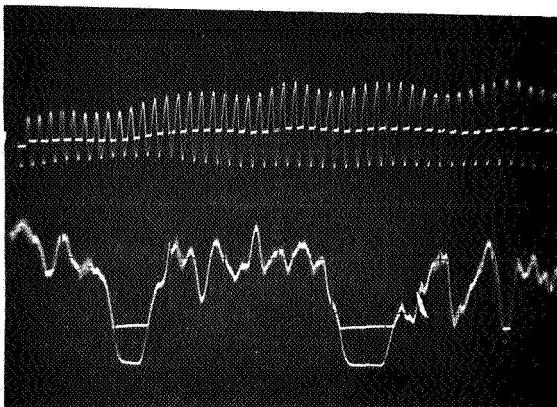
SWEEP: FULL SCAN



Channel 1 (Combined)

Channel 2 (Combined)

SWEEP: ONE-FIFTH SCAN

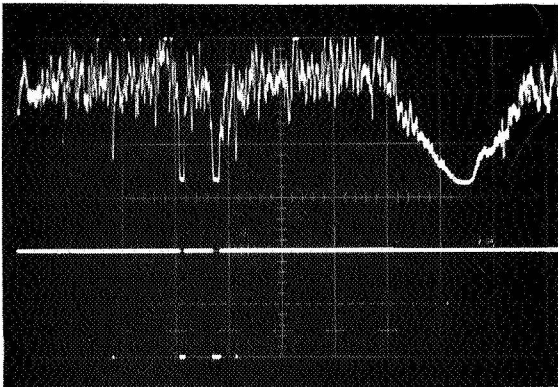


Reference Channel (Combined)

Channel 2 (Combined)

SWEEP: ONE-FIFTH SCAN

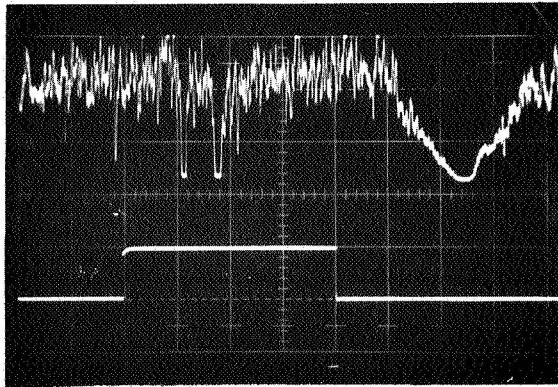
Figure 25: Video Displays



Channel 2 Video

Image Gates

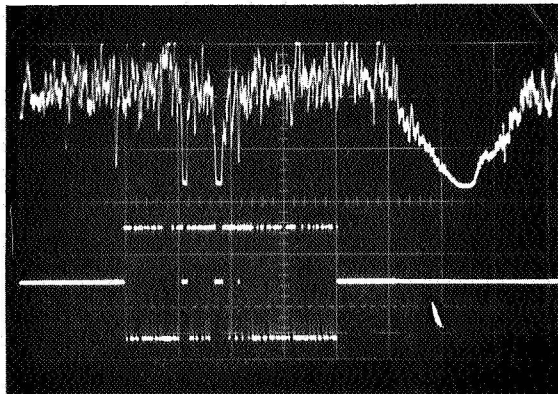
SWEEP: FULL SCAN



Channel 2 Video

AGC Duration

SWEEP: FULL SCAN

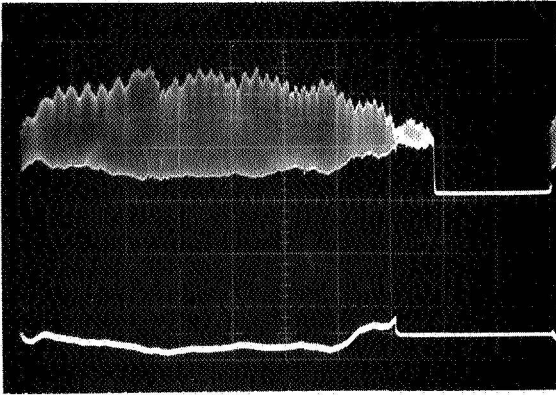


Channel 2 Video

AGC Current Control

SWEEP: FULL SCAN

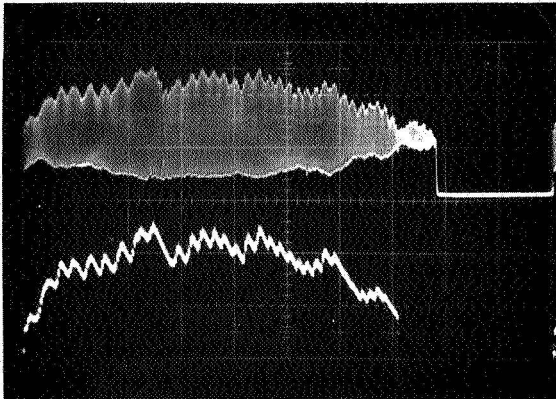
Figure 26: Patch Panel Signals, Channel 2



Reference Channel Video

Minimum Video

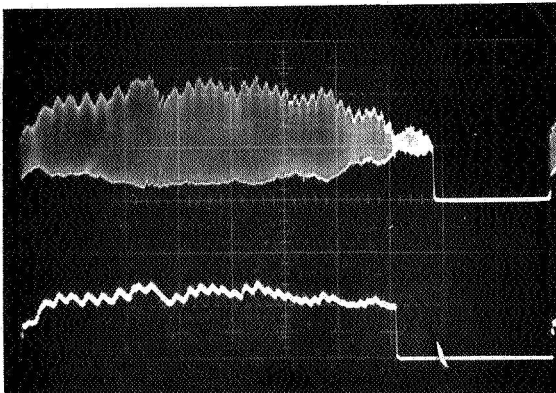
SWEEP: FULL SCAN



Reference Channel Video

Maximum Video

SWEEP: FULL SCAN

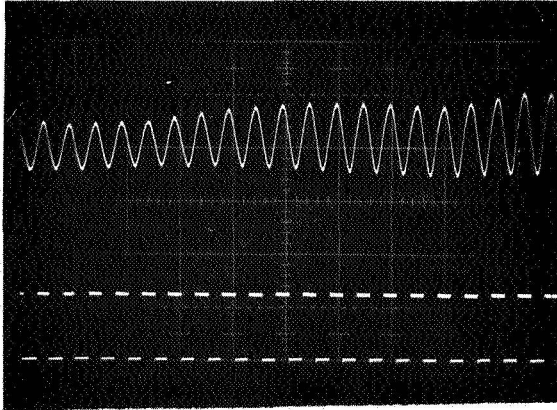


Reference Channel Video

Average Video

SWEEP: FULL SCAN

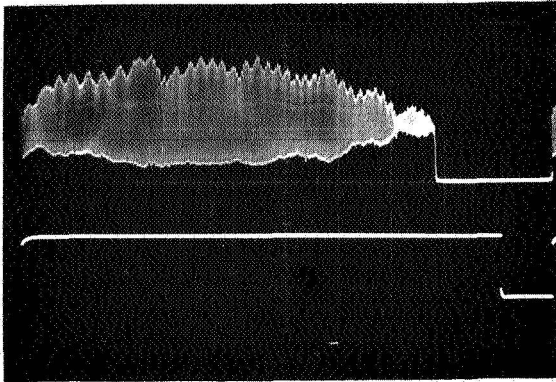
Figure 27: Patch Panel Signals, Reference Channel



Reference Channel Video

Spot Position Detector

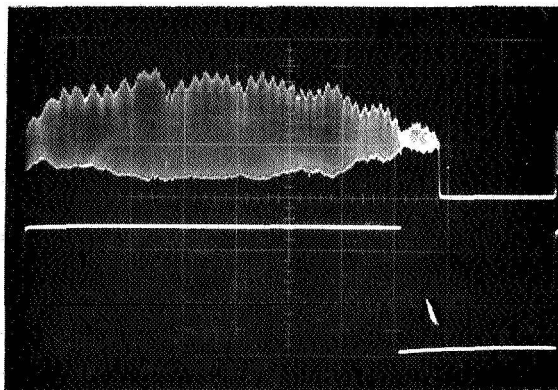
SWEEP: ONE-FIFTH SCAN



Reference Channel Video

Lockout Multi

SWEEP: FULL SCAN



Reference Channel Video

Positive Scan Gate

SWEEP: FULL SCAN

Figure 28: Patch Panel Signals, Reference Channel Gates and Lockouts

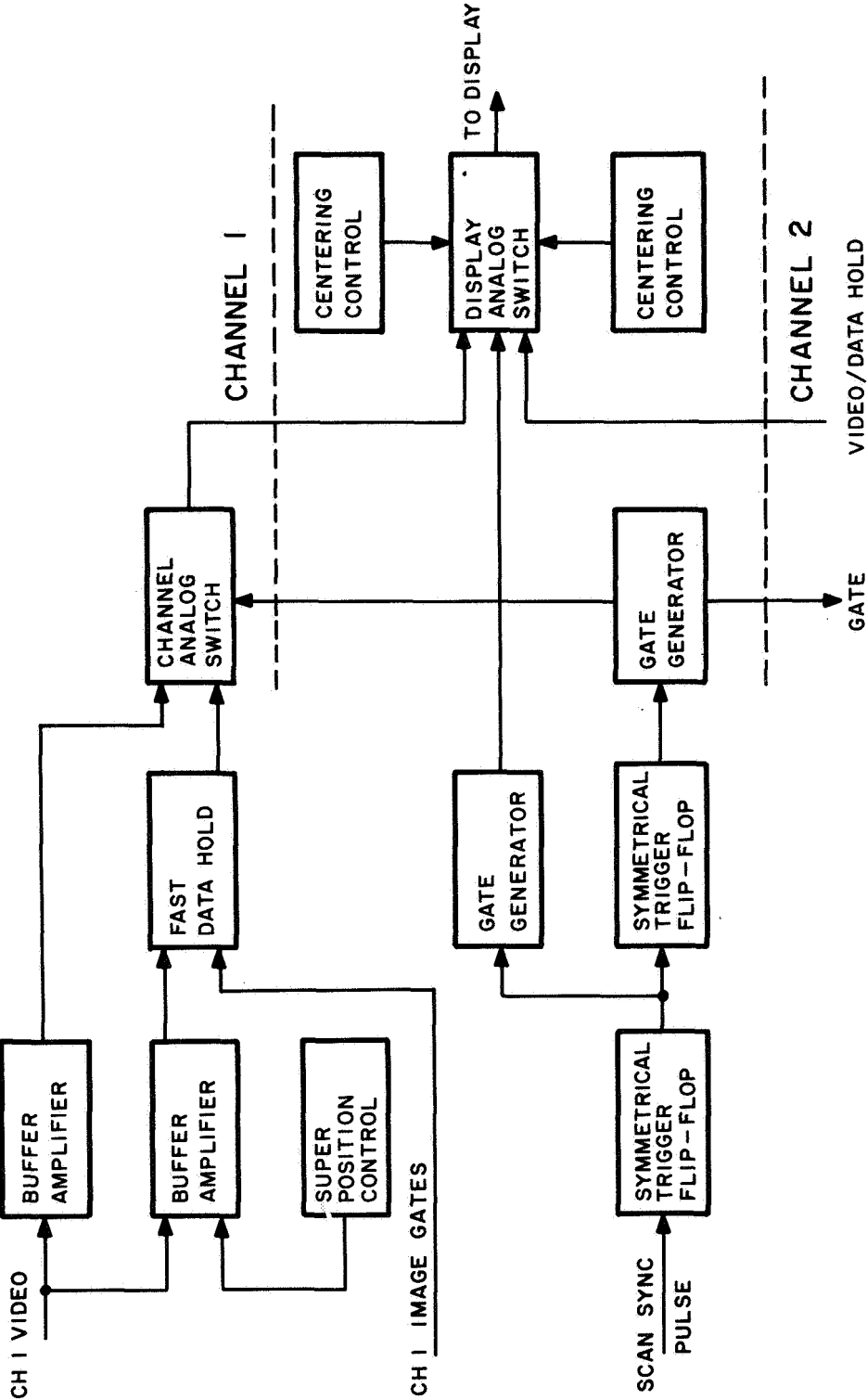


Figure 29: Method of Display Generation

will, therefore, sample Channel 1 and then Channel 2 on successive scans. The output of the first flip-flop is also fed to another symmetrical trigger flip-flop. Since the trigger must be of the proper polarity, the second flip-flop will change state once for every other state change in the first flip-flop. The second flip-flop drives a gate generator which drives the channel analog switch. The channel analog switch, therefore, samples the video for two successive scans and then the data hold for two successive scans. Since the switch itself is being sampled by the display switch every other scan, the display switch will see alternate video and data hold signals.

The video and data hold signals from a channel are superimposed on the display by means of the superposition control. The sets of video from Channel 1 and Channel 2 are separated on the display with the centering controls.

### B. Video Controls

These are the AGC indicator lamps, photomultiplier high voltage adjustments, and image detector level adjustments. The video controls comprise the three photomultiplier high voltage adjustment knobs, the three AGC indicator-pushbutton assemblies, and the two image detector level adjustments for the star plate channels. The image detector level in the reference channel is set automatically. These controls are used in conjunction with the video display as follows.

To adjust the AGC, the AGC HI-LO indicator is depressed. This lights both lamps and disables the automatic gain control circuits. The photomultiplier tube high voltage is then set so that the video is well saturated. The AGC indicator is depressed again enabling the AGC and presenting normal video on the display.

The image level detector may be set to a specified percentage by using the manual mode and table motion controls to find a suitable star pulse(s) on the video display. The level detector is then adjusted until the horizontal bars through the star pulses are at the desired level.



### C. Patch Panel

The patch panel provides access to all signals required in normal checkout and operation of the equipment. It is shown in the lower part of Figure 24. It contains two types of jacks, BNC and Pomona, plus several control knobs. A description of the different areas on the panel follows.

The area on the extreme left contains three vertical rows labeled Reference, CHAN 1, and CHAN 2. These provide the signals normally viewed on the video display. The row of BNC jacks labeled COMBINED carry the superimposed video and image detector signals. The row labeled VIDEO have only the raw video signal. The row of BALANCE knobs superimpose the video and trigger signals at the COMBINED plugs. The next area to the right contains the display switch inputs and outputs plus associated controls. Each jack labeled SWITCH is connected to a desired signal source. The jack labeled SCOPE is connected to the RM15 input. The POSITION controls are used to place each trace in the desired location on the video display screen. The GND level ground both switch inputs so that a zero reference may be placed on the display.

The small rectangular area labeled PATCH is intended to convert the signals at the pomona jacks, which may be at relatively high impedance, into low impedance signals at the BNC jacks. In practice, the signals are connected from the DISPLAY, CHAN 1, CHAN 2, or REFERENCE area to the PATCH area with pomona tip jumpers, and the BNC jacks are connected to the display switch or directly to the video display scope.

A list of the signals presently available in the pomona area is given in Figure 30. Photographs of these waveforms are shown in Figures 25 through 28.

DISPLAY

1. Ground (reference ground bus)
- 2.
- 3.
- 4.
- 5.
- 6.
- 7.
8. Scan Sync Pulse

CHANNEL 1

1. Image Gate
2. AGC Duration
3. AGC Current Control
4. AGC Integrator

CHANNEL 2

1. Image Gate
2. AGC Duration
3. AGC Current Control
4. AGC Integrator

REFERENCE

1. Spot Position Detector
2. AGC Integrator
3. Lockout Multi
4. Positive Scan Gate
5. Negative Scan Gate
6. Minimum Video
7. Maximum Video
8. Average Video
- 9.
- 10.
11. Video Reference Voltage
12. Timing Reference Voltage

Figure 30: Patch Panel Test Points

#### D. Plate Image Display

The plate image display is built around a ten inch diameter, long persistence cathode ray tube. Its function is to display a rectangular raster that shows a magnified picture of the star images as seen by the image level detector. The picture is written repetitively as the scan progresses, showing a different section of the stripe with each horizontal sweep. A block diagram of the display is shown in Figure 31. A photograph of a star plate scan is shown in Figure 32.

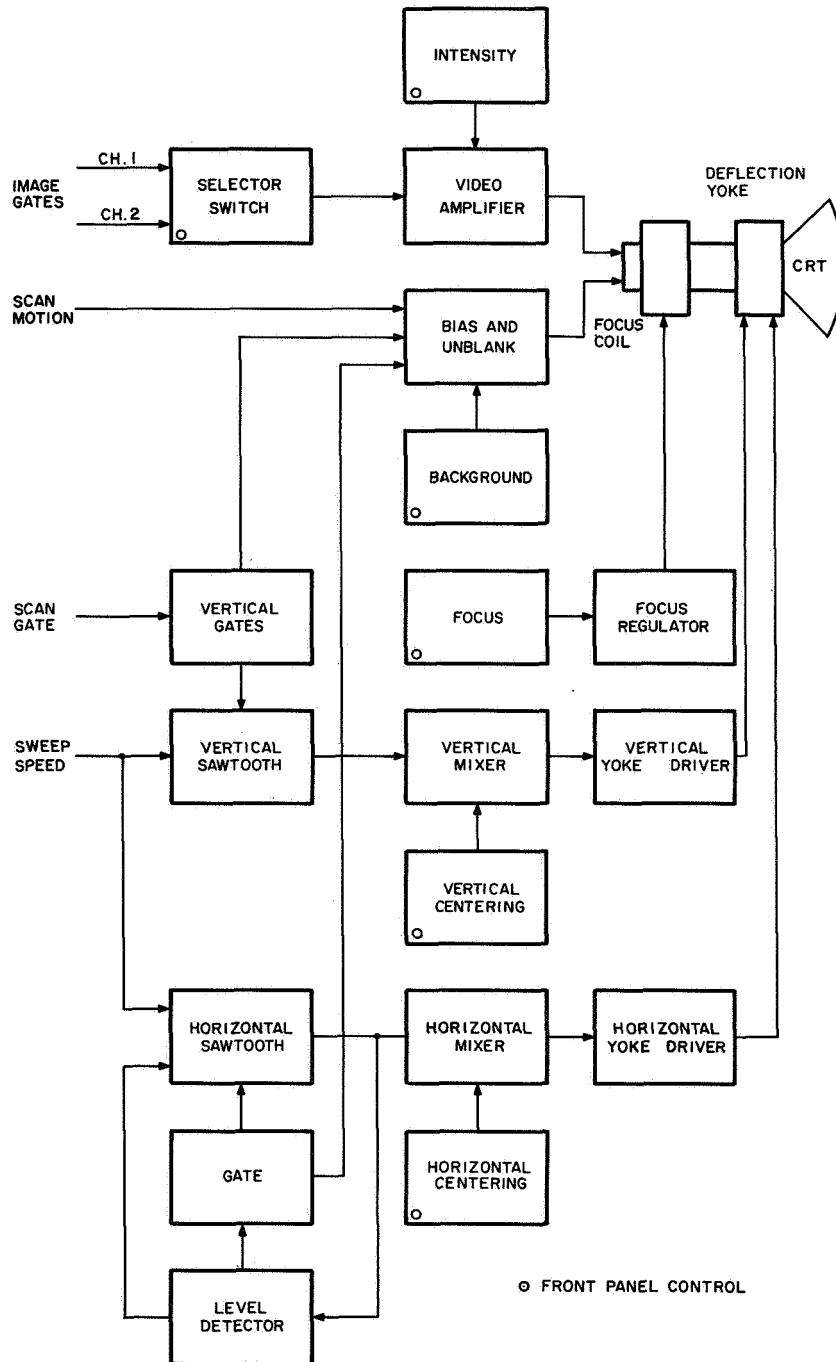


Figure 31: Block Diagram of Plate Image Display

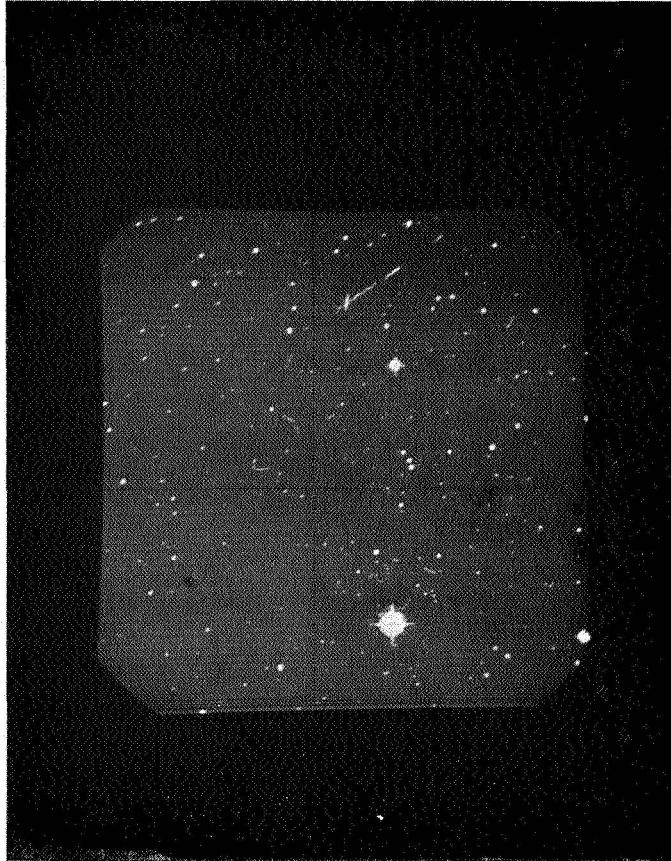


Figure 32: Plate Image Display of a Star Plate Scan

E. Pulse Rate Meters

The pulse rate meter circuitry is not designed as of this report. Its purpose will be to provide an indication to the operator of the average rate of scan transits across star images on two meters, one for each plate. A third meter will indicate the rate of transit occurrences that are essentially non-coincident. This should provide an indication of plate misalignment or of large numbers of dust particles on the plates.

#### IV. DATA ACQUISITION LOGIC

##### A. Star Image Scanning

The function of the data acquisition logic is to quantize and record the information on each of the pair of photographic plates in such a manner that the quantization data can be used by a computer to reconstruct the star field of each plate in its memory. The quantization of each detectable star image consists of the X and Y coordinates of the apparent ingress of the star as the scanning beam moves by it and the width of the star as measured along the scan path.

As mentioned in previous reports, the scanning of the laser spot is accomplished by means of a rotating eight-sided prism. Each face of the prism produces a scan of approximately 16 mm length in the Y direction of the machine coordinate axis. As the laser spot moves in the Y direction, the plate holder is translated in the X direction at a constant speed so as to produce five microns of X displacement for each scan of the spot. Thus the spot traces a path as shown in Figure 33. Since each plate is scanned along a 16 mm wide stripe, several stripes must be scanned in order to cover the entire plate. The indexing from one stripe to the next is adjusted so that the two stripes overlap by a small amount. In order to understand the requirement for the overlap, it is first necessary to realize that the computer search for proper motion stars is performed by comparing the positions of the stars in a stripe of one plate with the positions of the stars in the corresponding stripe of the other plate. Thus it is possible that a star appearing along the edge of one stripe would not appear along the edge of the corresponding stripe of the other plate either because of a large proper motion of the star or a vertical (Y) misalignment of the plates. Therefore, in order to insure that a given star will appear in at least one pair of corresponding stripes, the indexing of the plate holder in the Y direction is adjusted so that each stripe overlaps the previous stripe by a small amount.

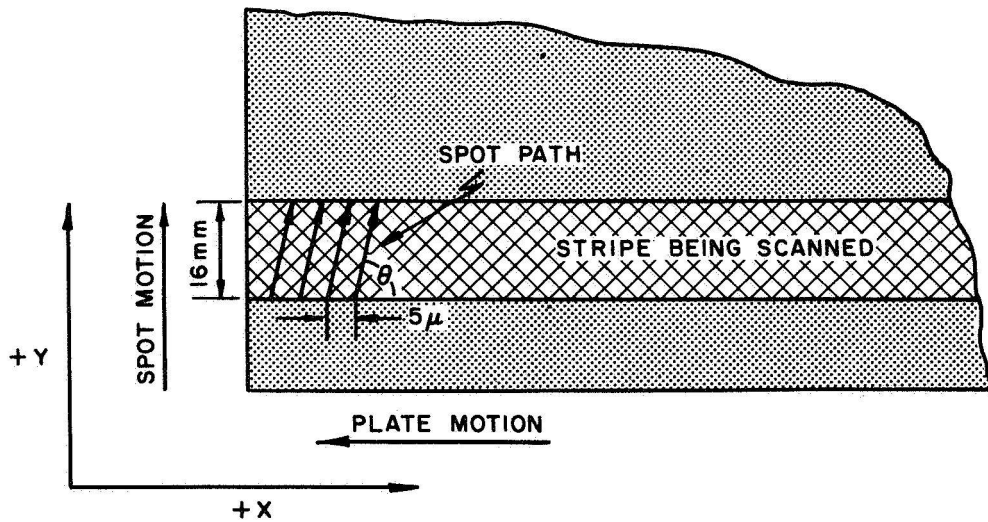


Figure 33: Path Traced by Laser Spot as Stripe is Scanned

The location of each detectable star is defined as the location of the centroid of the star image. Thus the quantization data must be suitable for determining the centroid of each star image. Figure 34 shows the information which is recorded during the scanning of a stripe. This information consists of the following:

- (1) the horizontal distance ( $X$ ) from the  $Y$  axis to the point along the base of the stripe at which the scan begins,
- (2) vertical distance ( $Y$ ) from the  $X$  axis to the base of the stripe being scanned,
- (3) vertical distance ( $y_0$ ) from the base of the stripe to a reference position which occurs prior to the star transit,
- (4) vertical distance ( $y_1$ ) from the  $y_0$  reference position to the point at which the scanning beam starts to transit the star,
- (5) vertical distance ( $y_2$ ) from the  $y_0$  reference position to a second reference position which occurs prior to the point at which the beam completes its transit of the star,



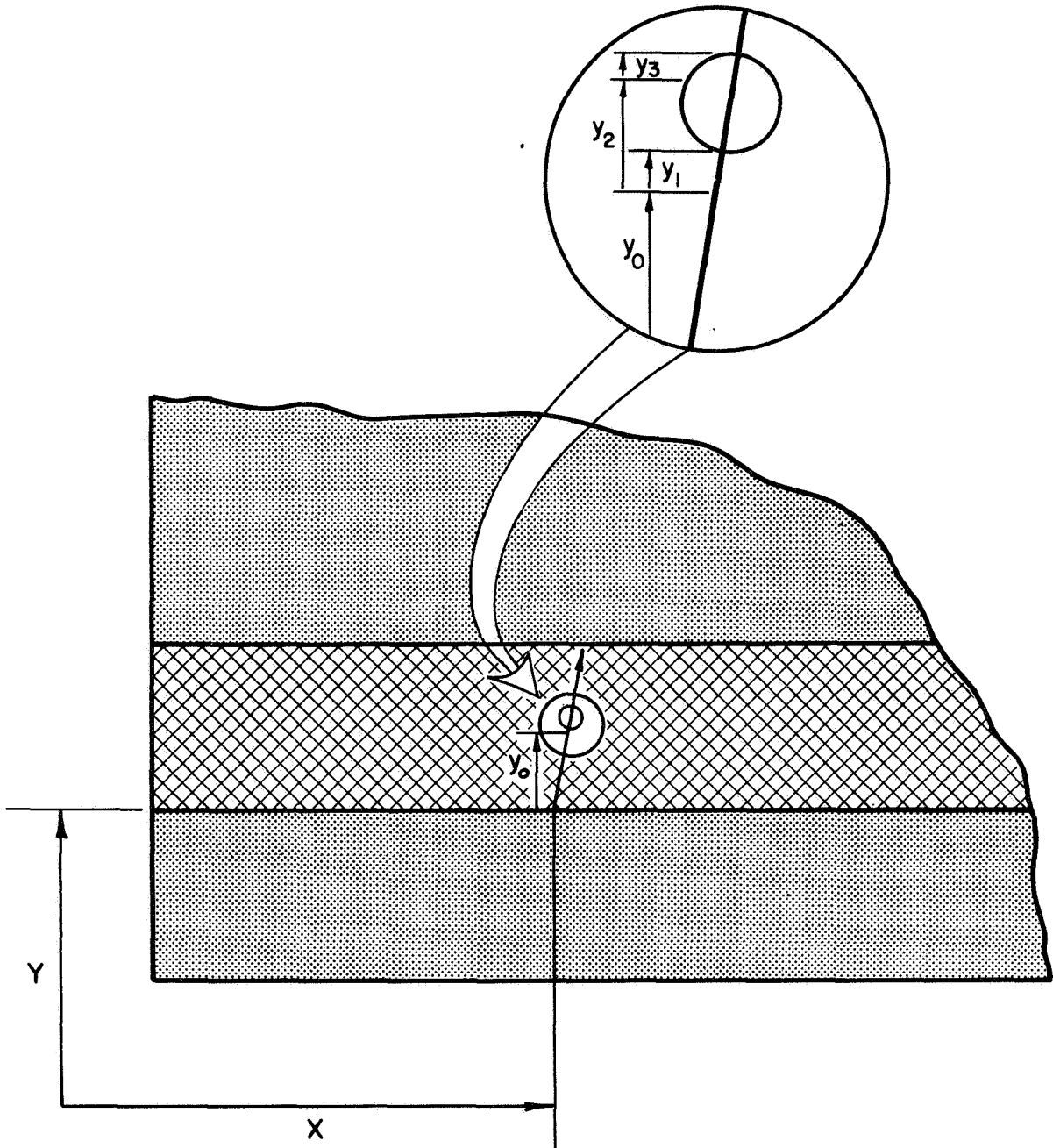


Figure 34: Information Recorded as Stripe is Scanned

- (6) vertical distance ( $y_3$ ) from the  $y_2$  reference position to the point at which the beam completes its transit of the star.

We note from Figure 34 that the horizontal distance from the  $Y$  axis to the point at which the scan path intersects the star image may be obtained by adding a correction term onto the value of  $X$  associated with the beginning of each scan so as to account for the slope of the scan path. Thus we have

$$x = X + y \text{CTN}\theta \quad (1)$$

where  $\theta$  is the acute angle between the  $X$  axis and the scan path. The scan path will pass through the typical star several times as the scanning progresses. Thus the star image can be partitioned into several elemental areas of constant width  $\delta X_i = 5\mu$  and height  $\delta y$ . The centroid of the star image about either the  $X$  or  $Y$  axis may be obtained by summing up the first moments of the elemental areas about the desired axis and dividing the result by the sum of the elemental areas. Since the measurements shown in Figure 34 are sufficient for the determination of the centroid of the star image, the next task is to consider how these measurements are implemented.

### B. Star Plate Position Measurement

The X and Y measurements indicate the position of the plate holder, and, consequently, they may be obtained by measuring the rotation of the lead screws which position the plate holder along the X and Y axis. Lead screw rotation is monitored by means of an optical-type angle encoder. This device basically consists of a three-tracked apertured disk which is free to rotate about its center and is connected to the lead screw. Figure 35 shows the three tracks of the disk. Note that the pattern of clear and opaque regions of Track 1 is offset ninety degrees from the pattern of Track 2.

The disk is interposed between a light source and three photodiodes in such a manner that each track can interrupt and transmit the light incident on one of the diodes as the disk is rotated. The output of each diode is then amplified and passed through a threshold detector to provide a binary (on-off) type of output. Figure 36 shows the variation of the light incident upon the diodes of Tracks 1 and 2 and the output of the threshold circuit associated with each track as the encoder disk is rotated in a clockwise direction. Note that if the direction of rotation is reversed, the phasing of the two tracks is reversed so that the increase in light level to the Track 2 diode precedes the increase in light level to the Track 1 diode. Thus the direction in which the bi-directional X or Y counter will index is determined by the phasing of the output signals from Track 1 and Track 2.

The third track provides an angle position reference once during each revolution of the encoder disk. This track is used in conjunction with the plate position limit switches to provide a parity check on the counter. This check is based on the realization that the contents of the counter must have a predictable value when the plate holder is at a known position. For example, let us consider the X angle encoder and its associated counter.

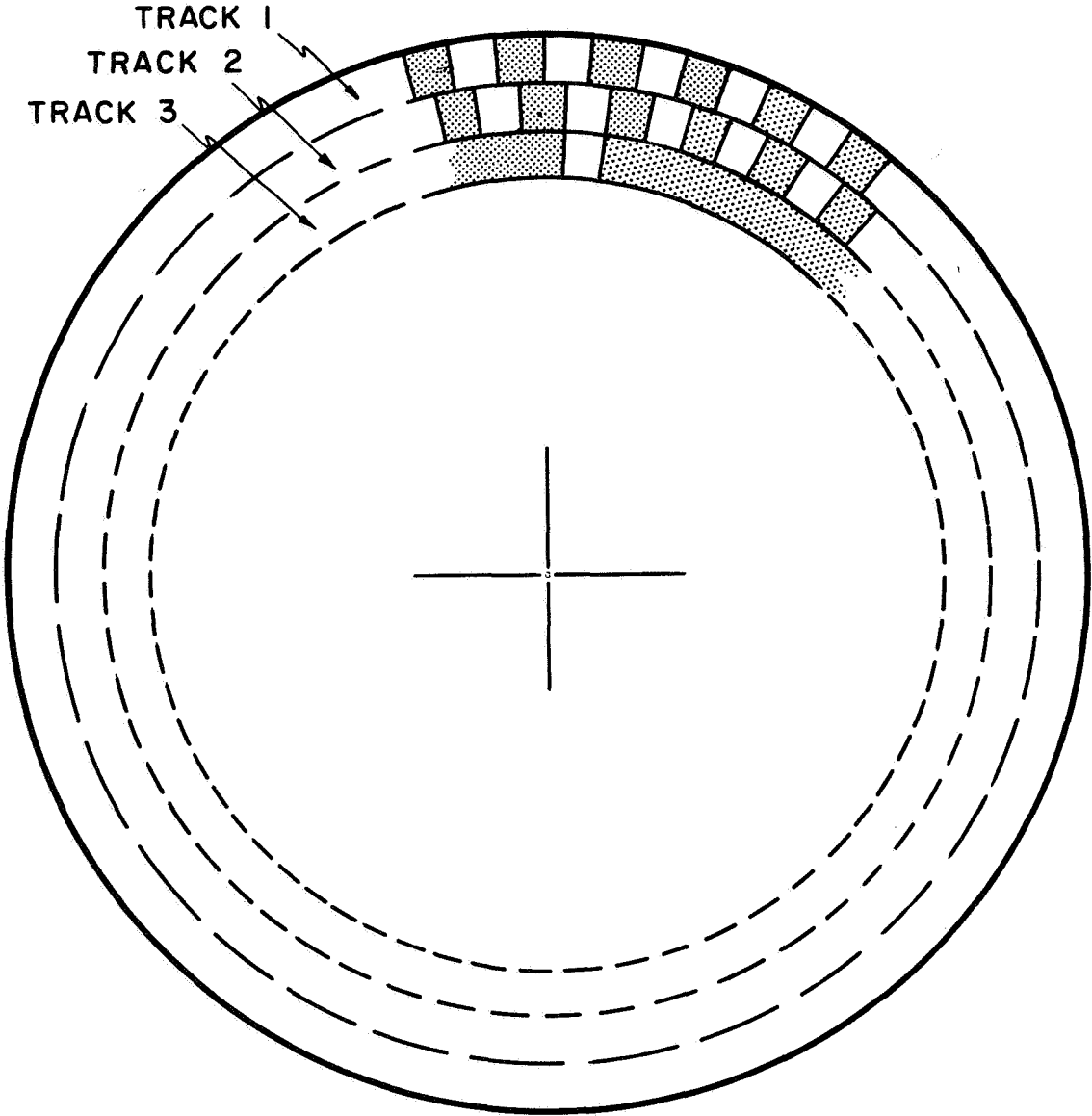


Figure 35: Encoder Disk Geometry

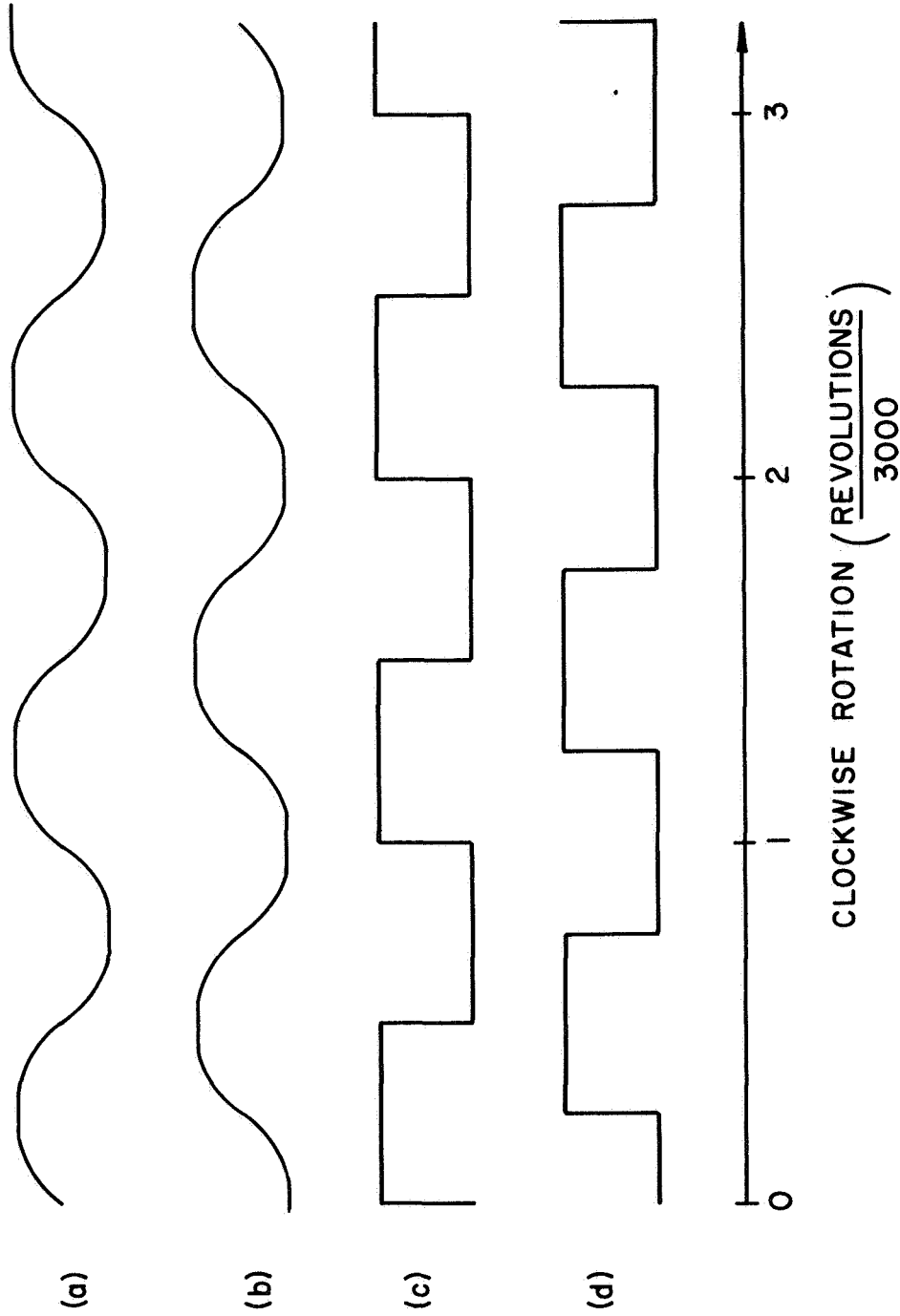


Figure 36: Output of Incremental Angle Encoder

- a) Variation of light incident on Track 1 photodiode as disk is rotated.
- b) Variation of light incident on Track 2 photodiode as disk is rotated.
- c) Output of threshold circuit on Track 1 as disk is rotated.
- d) Output of threshold circuit on Track 2 as disk is rotated.

Prior to scanning a stripe, the plate holder is in contact with the left limit switch. Shortly after the plate holder has been set into motion, a known position can be defined by the first Track 3 pulse to occur after the plate holder has broken contact with the limit switch. When this pulse occurs, the X counter is cleared, i.e., zeroed out, and thus a known counter value has been established at a known position. Subsequent pulses from Track 3 will cause the parity logic to make a zero check on the contents of the X counter; however, the contents of the counter will not be altered. If the contents of the X counter is zero at the time of the Track 3 pulse, the X = 0 flip-flop is set. However, if the contents of the X counter is not zero, the X = 0 flip-flop will be issued a clear signal--even though it may already be in the cleared state.

The counter parity check is made at the time that the plate holder contacts the left-hand limit switch. This event signifies that the last Track 3 pulse occurred at the reference position. If the X = 0 flip-flop is not set at this time, then a parity error is indicated. A similar scheme of parity checking is used with the Y angle encoder and its counter.

### C. Instantaneous Scanning Spot Position Measurements

Having considered the implementation of the X and Y measurements, let us now shift our attention to the measurement of the vertical positions ( $y_0$ ,  $y_1$ ,  $y_2$ , and  $y_3$ ) of the laser spot.

The optical system of the scanner is arranged in such a manner that the laser beam is split into three separate scanning beams whose motions completely duplicate each other. Thus, if one beam is beginning its scan, the other two beams are also beginning their scans. Two of the beams scan the star plates while the third beam is used as a reference to determine the position of the other beams at any instant. The reference beam scans a reticle plate which consists of alternate clear and opaque bars which are spaced 32 microns apart. Thus the center-to-center spacing between consecutive transparent or opaque bars is 64 microns. These bars are aligned perpendicular to the scan path and cause the light to be modulated in much the same manner as the light passing through Track 1 or Track 2 of the encoder disk (cf., Figure 36). This modulated light falls upon a photomultiplier tube whose amplified output is fed to a threshold detector.

One complete on-off cycle at the output of the threshold detector denotes 64 microns of beam travel. Thus, the beam position can be determined within 64 microns by counting the pulses at the output of the threshold detector. The output of the threshold detector drives two counters. One of these counters measures the number of reticle bars from the base of the stripe to any point along the scan path. This counter provides the  $y_0$  measurement of Figure 34 while the second counter provides the  $y_2$  measurement. Since the total number of opaque and transparent bars on the reticle plate is fixed, the first reticle counter mentioned above should always be at a predictable state at the end of each scan. Thus a parity check can be performed on the reticle counter simply by comparing the final counter state with the value that it should have at the end of each scan.

Since many of the stars of interest will be of the order of 20 microns, the 64 micron spacing between transparent bars on the reticle plate is too coarse for measuring the leading and trailing edge positions of the stars. It is therefore necessary to interpolate between successive reticle bars. This interpolation is accomplished by driving a 6-bit counter at a rate which is 64 times as great as the rate at which the reticle bars occur. Thus the interpolation counter subdivides the reticle spacing into 64 parts and permits the indication of beam position to one micron. This counter provides the  $y_1$  and  $y_3$  measurements shown in Figure 34. The interpolation scheme is based on the assumption that the spot speed is constant throughout the length of the 16 millimeter scan. This assumption is close but not completely correct and consequently it may be necessary to include a correction table in the computer program which processes the star data.

We see from the above that the star transit data does not provide a direct measurement of the width  $\delta y$  of the star as measured along the scan path; however, this quantity can be computer from the transit data. Referring to Figure 34 we see that

$$\delta y = y_2 + y_3 - y_1 \quad (2)$$

This quantity is computed prior to transferring the star transit data to the memory.



D. Data Flow Into and Out of Core Memory

Having considered the type of data which is associated with each star transit we next shift our attention to the flow of data from the sources to the magnetic tape.

Figure 37 shows the basic block diagram for the data acquisition system while Figures 38, 39, and 40 show the system in greater detail. Referring to Figure 37, as X, Y, or star transit information is generated on one of the channels, the information is transferred to a group of vertically stacked buffer registers. These buffers allow star transit data to accumulate while the memory is either busy recording data from one of the other channels or is reading data for transfer to the magnetic tape unit. The buffers also serve a second function of allowing short bursts of data to be accumulated at a faster rate than the memory can record it.

Each channel is allocated one-half of the memory, and, as a given channel fills half of its available storage, the memory controls initiate the transfer of that data to the tape unit. Thus data is transferred to the tape unit in blocks of 1024 words (i.e., one-fourth of the memory). As information is read from the memory it is passed through an adder. If the information represents the X position of the spot or the Y position of the stripe, it is passed through the adder unaltered. However, if the information represents a star transit, it is operated on so as to obtain the star width,  $\delta y$ , as given by Equation (2). The star width and the vertical distance at which ingress occurred,  $y_0 + y_1$ , are then transferred to tape.

The data which is transferred to the magnetic tape consists of a 24-bit number which is disassembled into four 6-bit groups. Each 6-bit group has a parity bit added to it, and the resulting 7-bit number is written on tape as one frame of data. The tape unit records and reads data at the rate of one frame every 12 microseconds; thus, 48 microseconds

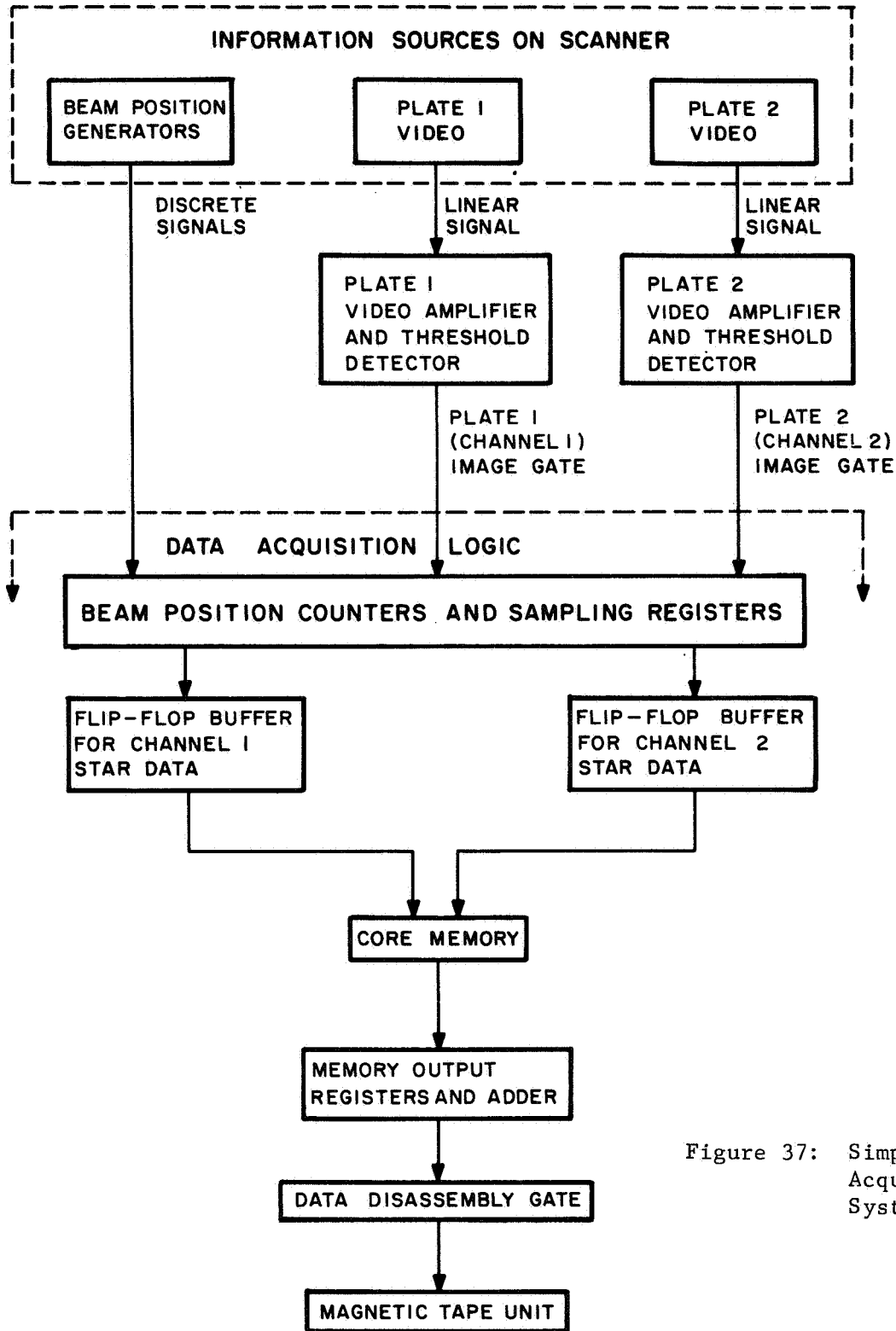


Figure 37: Simplified Data Acquisition System

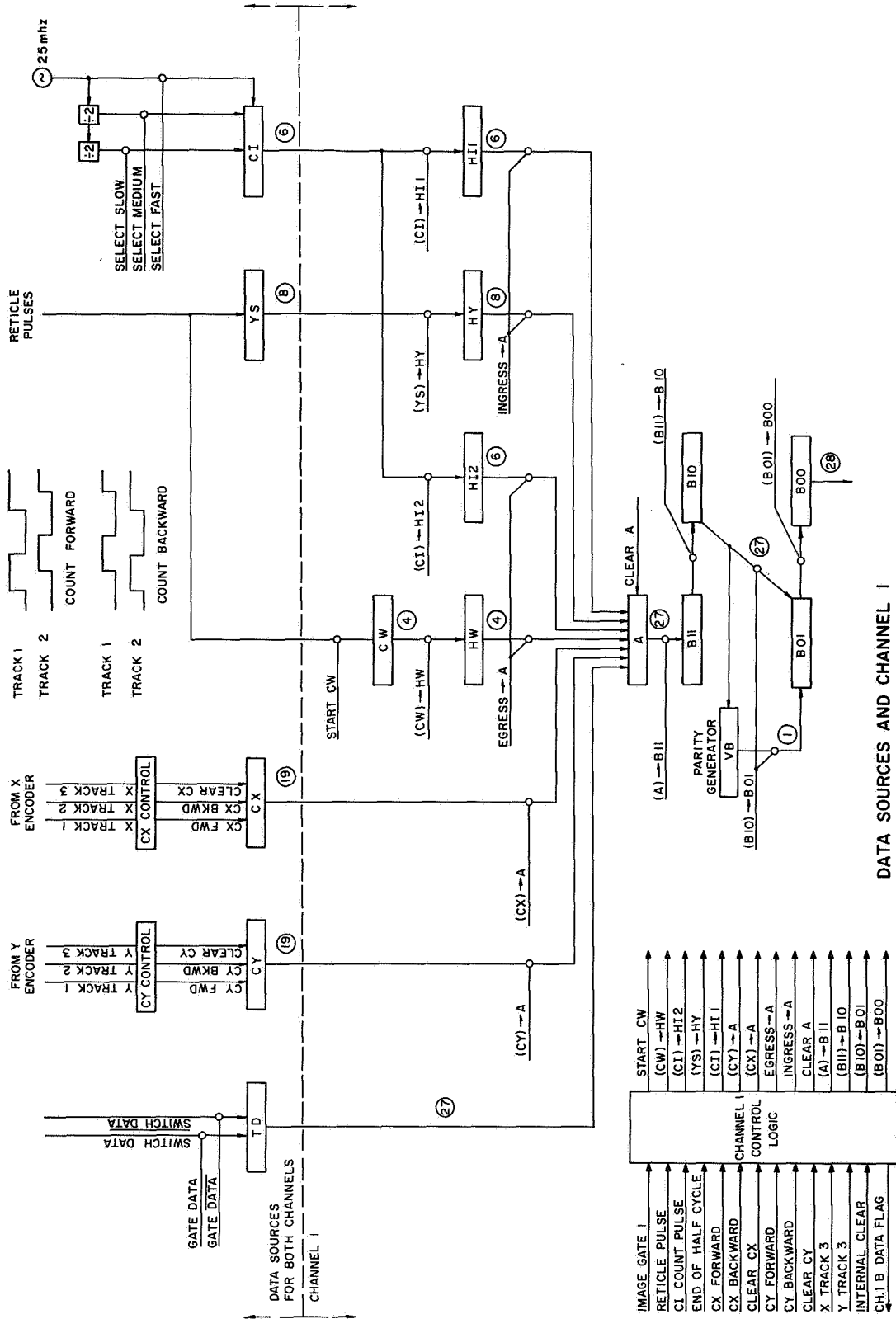


Figure 38: Data Acquisition System, Data Sources and Channel 1

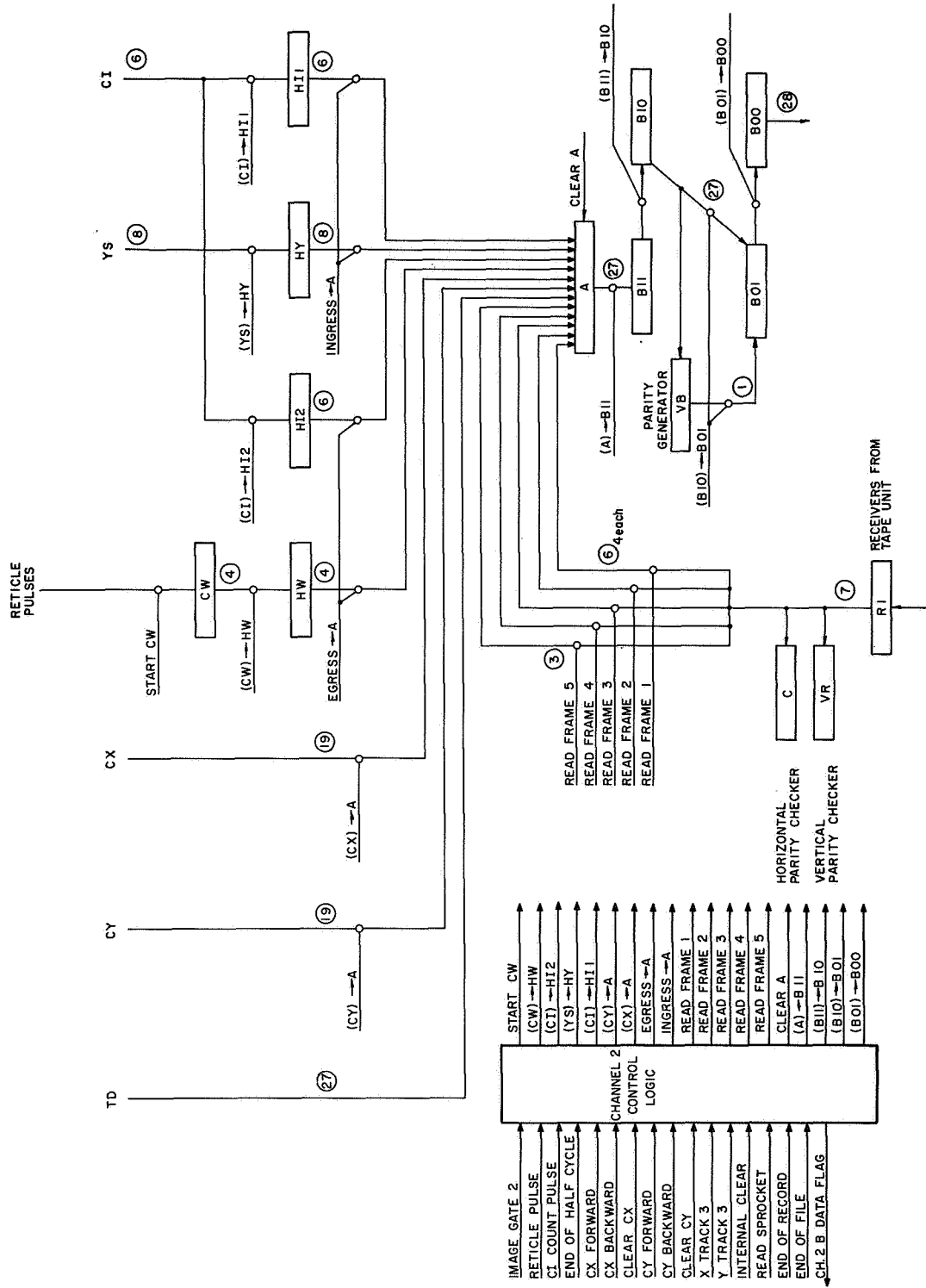


Figure 39: Data Acquisition System, Channel 2

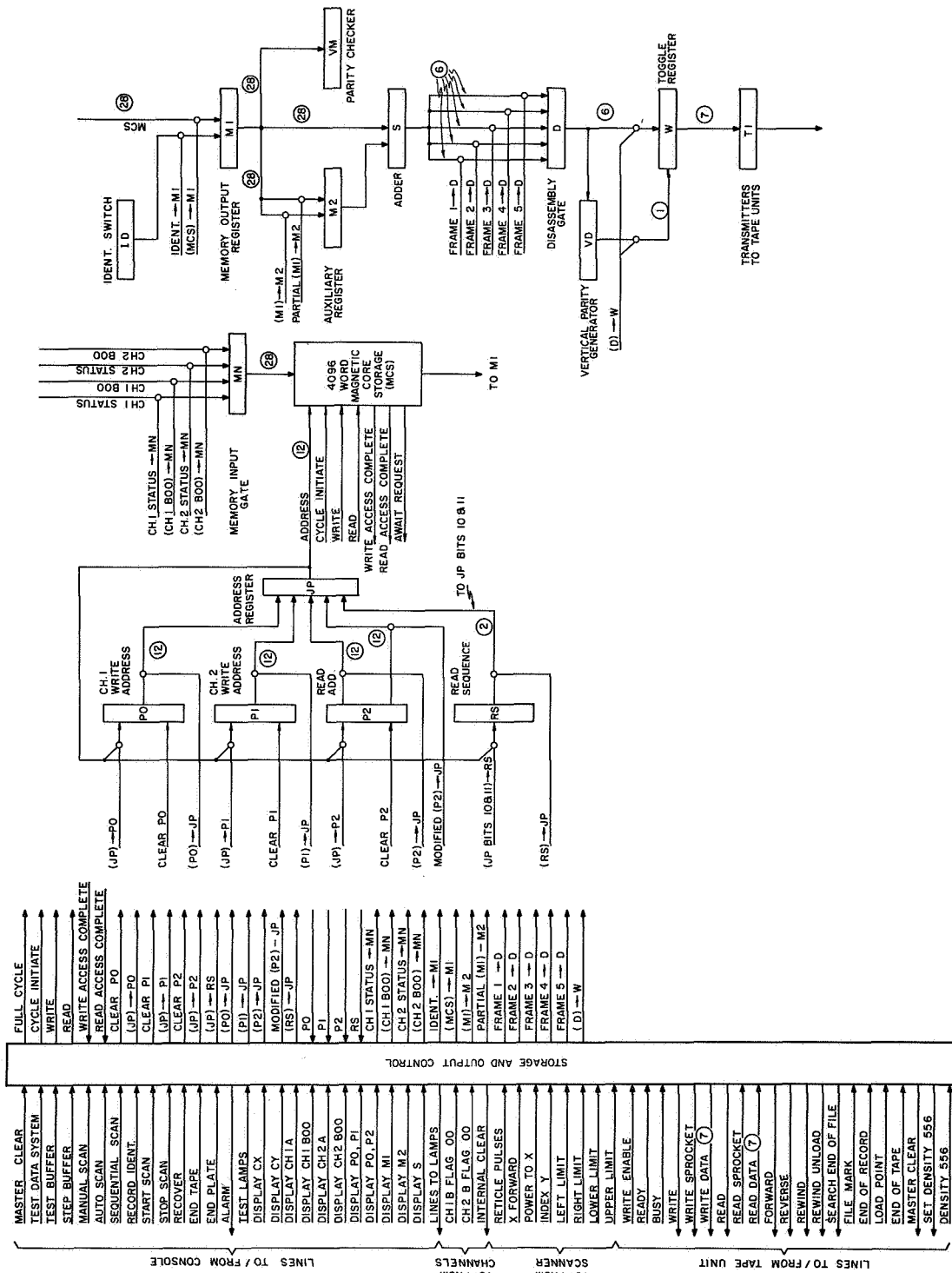


Figure 40: Data Acquisition System, Storage and Output Logic

are required to transfer the information associated with one star transit to tape. This transfer rate of one memory word every 48 microseconds sets the maximum average rate at which star transit data can be acquired from both channels combined.

The 4096 word magnetic core memory serves as a buffer between the star plates and the magnetic tape unit. There are several reasons for using such a buffer. First, the data coming from the star plates occurs at a random rate, while the data transfer to the tape unit occurs at a constant rate of one frame every 12 microseconds. Thus the memory allows data to accumulate asynchronously but permits the transfer of data to the tape unit at a synchronous rate. The second reason for using the core memory is that it has a very fast cycle time--of the order of 700 to 800 nanoseconds. Thus the memory can accumulate bursts of data which occur at a rate far in excess of the rate at which data could be transferred to the tape unit. Another advantage of the memory is that it allows data to be accumulated and transferred to the tape unit in large blocks of consecutive words rather than recording transit data in the order in which they occur. Thus, when the taped data are transferred to the computer, the program must only check one flag bit in order to determine which plate the block of data came from. If the data were recorded in the same sequence in which it occurred, the computer would have to check a flag bit in each word of data to determine the plate that it came from and this could be very time consuming.

Referring to Figure 38, we find that the CX, CY, YS, and CI counters provide the data which are common to both channels. The TD gates also provide data which are common to both channels; however, these gates are only used during system tests. The above four counters along with the CW counter in each channel provide all of the quantities shown in Figure 34. Table III shows the correspondence between the quantities shown in Figure 34

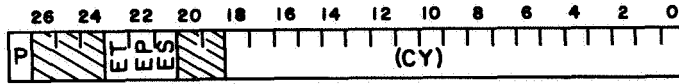
TABLE III  
CORRESPONDENCE BETWEEN QUANTITIES SHOWN IN FIGURE 34  
AND DATA SOURCES SHOWN IN FIGURE 38

Quantity Shown in Figure 34	Source
X	CX
Y	CY
$y_0$	YS
$y_1$	CI
$y_2$	CW
$y_3$	CI

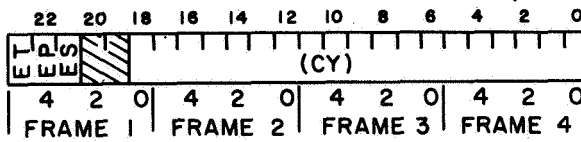
and the counters of Figure 38 which generate them.

The CY counter provides the Y dimension. Since this quantity does not change over the length of the stripe, it is only necessary to sample CY at the beginning of each stripe. The contents of the CY counter are transferred to tape as a single record before star data acquisition is initiated. The CY data is represented by a 19-bit number; however, when this number is transferred to tape, it requires a minimum of four 6-bit frames, i.e., 24 bits. The five bits which are not required for the representation of the contents of the CY counter may be used as flag bits to indicate whether or not scan data follows the YS record. The formatting of the CY data and the flag bits as they appear in the memory and on tape is shown in Figure 41.

The CX counter provides the X dimension and is sampled at the beginning of each scan of the laser spot. Consequently, the CX data is intermixed with the scan data, and it is necessary to provide some means of differentiating between the type types of data. Figure 42 shows the formatting of the



a) Formatting of CY data in memory



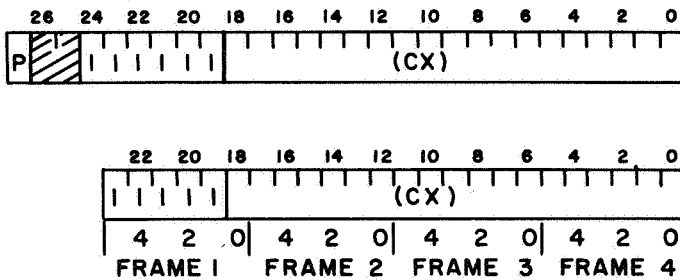
b) Formatting of CY data on tape

- ET = 1 = End of tape
- EP = 1 = End of plate
- ES = 1 = End of partial scan
- P = Parity bit
- = Not used

Figure 41: Formats of CY Data

CX data as it appears in the memory and on the tape. It will be noted that bits 19 through 23 are set to "one" in the CX data. This pattern of bits cannot occur at these bit positions in the star transit data, and thus the computer program has only to check these bit positions in order to distinguish between CX data and star transit data. It was noted earlier that the star transit data must be modified by passing it through an adder before it is transferred to tape. The CX data must not be modified as it is transferred to tape, and, for this reason, it is necessary to be able to distinguish between star transit data and CX data prior to passing it through the adder. This distinction could be made by examining bits 19 through 23; however, since spare bits are available in the memory word, it is easier to test one of these bits. Thus, bit location 24 is assigned the value of "one" for CX data and "zero" for star transit data.





- a) Formatting of CX data in memory
- b) Formatting of CX data on tape

P = Parity bit  
 = Not used

Figure 42: Formats of CX Data

The interpolation counter performs a 6-bit interpolation between successive reticle bars and provides the  $y_1$  and  $y_3$  measurements shown in Figure 34. It will be noted from Figure 38 that this counter is driven by either the direct or scaled output of a 25 mhz oscillator. The rate at which the counter is driven is determined by the speed at which the scanner is being operated. The CI counter is cleared out (i.e., zeroed) in synchronism with the first complete CI count pulse to be generated after the occurrence of the leading edge of each reticle bar. The signal which clears the CI counter also causes the YS counter to be indexed. Thus the combination of the YS and CI counters behaves as though it were one large 14-bit counter with the CI counter providing the lower six bits. The YS counter generates the  $y_0$  measurement shown in Figure 34. This counter is cleared immediately prior to the beginning of each scan and then counts the reticle bars which are passed by the laser spot during the course of the scan. The YS parity check is performed at the end of the scan.

The  $y_2$  measurement is performed by the CW counter in each of the two channels. When this counter is in operation it behaves as though it were an

extension of the CI counter. Thus, the CW counter is indexed at the time that the CI counter is cleared. The indexing of each CW counter is performed by the same timing chain which indexes the YS counter. The CW counter for a particular channel is enabled (turned on) shortly after a star ingress occurs. The exact time at which the counter can be enabled is determined by the state of the timing chain which drives the YS counter and CW (when it is enabled). Thus, if the YS timing chain is in the process of indexing the YS counter at the time of the star ingress, then the CW counter cannot be enabled until the YS counter has completed its indexing cycle. One method of enabling the CW counter is to monitor the high order bit of the 6-bit CI counter. The CW enable can then be set whenever this bit is a "one." Ideally, this bit is set 1.28 microsecond after the YS timing chain is initiated. The YS timing chain requires approximately 400 nanoseconds to cycle to completion. Thus, there is approximately an 800 nanosecond "safety zone" between the time that the YS timing chain halts and the earliest time at which the CW counter can be enabled. It was noted earlier that the YS timing chain was started by the signal which cleared the CI counter. We, therefore, see that the high-order bit of the CI counter can never be in a set state during the time that the YS timing chain is cycling, and, for this reason, the bit makes a very good flag for deciding when to enable CW.

The YS and CW counters feed a holding register in each channel, while the CI counter feeds two holding registers in each channel. These registers continually follow the changes which occur in the counters which they monitor. When a star transit takes place, these registers stop following their counters at appropriate times to obtain the transit data. The star ingress results in the halting of the HY and HI1 registers. These two registers then contain  $y_0$  and  $y_1$ , respectively. The ingress data flag is then set to inform the controls which operate the assembly (A) register that the ingress data is ready to be transferred to the A register. If the A register does not contain the data for the previous star transit,



register the data flag of the first register is cleared, and the data flag of the second register is set. Figures 44 and 45 show the types of data transfers which take place as the buffer register (actually five registers) is progressively filled and then emptied. An arrow directed from one register to the next register in the chain indicates that the pattern of flag bits is such that a data transfer can take place between these two registers. If an arrow does not appear between two registers in a particular subfigure, the pattern of flag bits is such as to prevent any transfer between two registers. We note from subfigures (a) through (e) that the first word to enter the A register simply moves from one register to the next until it reaches the B00 register. When the data flag is set in the B00 register, a request for access is sent to the memory controller. When the memory controller acknowledges this request, the contents of the B00 register can be transferred to the memory; however, it is possible that the controller may be in the process of acknowledging a request to record data from the other channel or reading data for transfer to the tape unit. Under certain conditions the controller may have to acknowledge both of the aforesaid requests before it can service the B00 register of the channel under consideration. During this period of time, data can continue to accumulate and it is possible that the buffer may be entirely filled to its capacity of three words.

This is the situation which is depicted in subfigures (a) through (i) of Figures 44 and 45. It should be noted from subfigures (h) and (i) that when the B00 register is filled and data accumulates in the remaining consecutive even registers, the transfer of data over to the odd registers is not initiated. The reason for not performing these transfers is made evident in subfigures (j) and (k). When the contents of the B00 register are transferred to the memory and the B00 data flag is subsequently cleared, the transfers of data from all even registers having set data flags to the odd registers which they feed are simultaneously initiated. Thus, the interval between the time at which the B00 data flag is cleared and the

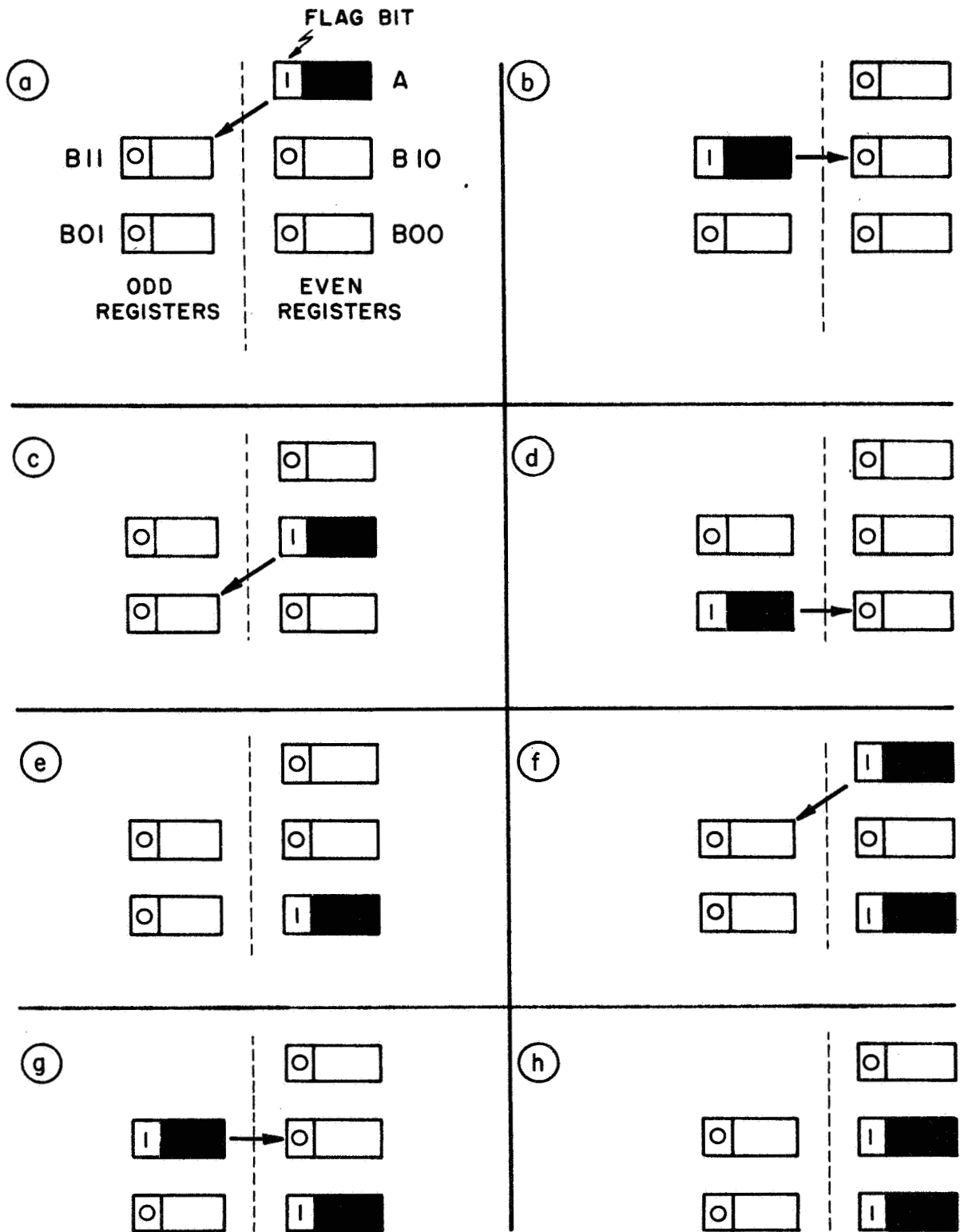


Figure 44: Data Transfers Through Buffer Register as It is Filled and then Emptied

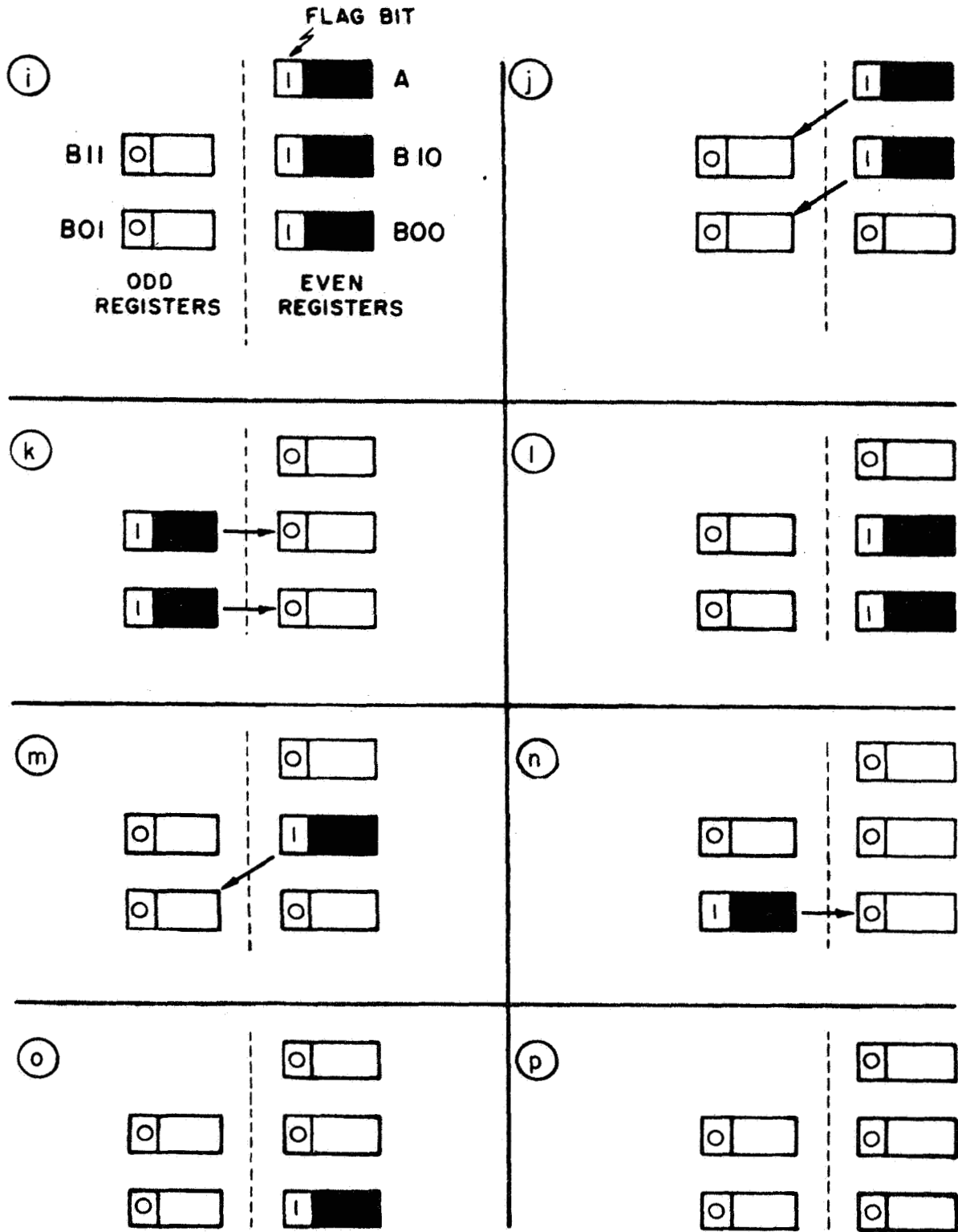


Figure 45: Data Transfers Through the Buffer Registers

time at which the A register is free to record new data consists only of that time required to transfer the contents of A over to the B11 register. This method of data storage and transfer within the buffers can be contrasted with the case where all five registers of the buffer are filled and each data transfer is initiated by a data flag being in a set state in one register and in a cleared state in the immediately following register. In this case the downward flow of data (i.e., from A toward the memory) follows the upward propagation of the cleared data flag which originates at the B00 register. For this case, the interval between the time at which the B00 data flag is cleared and the time at which the A data flag is cleared consists of the time required to perform four register transfers: B01 to B00, B10 to B01, B11 to B10, and A to B11. The consequence of a long delay between the time that the B00 flag is cleared and the time at which the A register is free to accept new data is that there is a greater probability of missing a star than is the case when a short propagation delay exists as in Figures 44 and 45.

It should be noted from Figure 38 that the contents of the B10 register are fed to both a parity generator and the B01 register. The output of the parity generator is then appended to the contents of the B10 register when the contents of B10 are transferred to B01. The parity generator requires several more levels of decision than are required for the transfer of data from one register to another. Thus the time required to transfer the contents of B10 to B01 is greater than the normal register transfer time by the amount necessary to generate the parity bit. Parity is generated for all data which passes through the buffer register. However, the memory bank status data and the plate identification data (which will be discussed later) do not pass through the buffer register and therefore do not have a parity bit. These two types of data bypass the memory parity checker when they are transferred to tape.

It was noted earlier that both channels share the same memory.

Consequently, it is necessary to divide the memory in such a manner that the data from the two channels can be kept separate. This division is accomplished by addressing the memory as though it consisted of four blocks, or banks, of 1024 words each. Channel 1 is assigned the lower two consecutive banks, i.e., banks zero and one, while Channel 2 is assigned the upper two consecutive banks, i.e., banks two and three. It should be noted that a 12-bit word is required to address any one of the 4096 words of memory. However, since the memory is divided into four banks of 1024 words each, it is only necessary to use ten bits in order to address any word within a given bank. The upper two bits of the 12-bit memory address can then be interpreted as being the bank designator. The interpretation of the memory address bits is illustrated in Figure 46.

At any given instant, the memory may be required to write data from either Channel 1 or Channel 2 or read data from one of the banks for output to the tape unit. Thus, it is necessary to have available the memory address for writing data from Channel 1, the memory address for writing data from Channel 2, and the memory address for reading up data from one of the four banks for output to the tape unit. These addresses are obtained from three counters shown in Figure 40 which are continually updated as the writing and reading progresses. The counters which keep track of the write addresses for Channels 1 and 2 are designated P0 and P1, respectively. The counter which keeps track of the current read

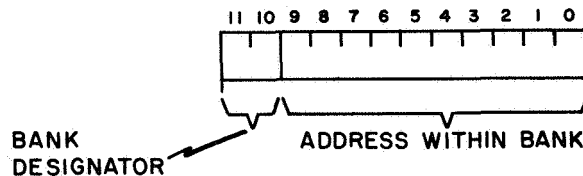


Figure 46: Interpretation of Memory Address Bits



address as one of the four banks is being read is designated P2. The P0 counter can only address banks zero and one, and, therefore, its high order bit (bit 11) is forced to a logical zero. Similarly, the higher order bit of the P1 counter must be forced to a logical one since this counter addresses only banks two and three.

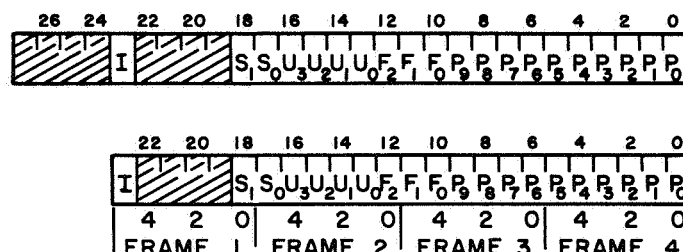
Let us consider the events which take place as information is transferred from Channel 1 into the memory and is subsequently read from the memory for transfer to the tape. Prior to the initiation of scan motion, P0 is set to write into word location one of bank zero, and P1 is set to write into word location one of bank two.

When data becomes available for transfer from the lower rank of the Channel 1 buffer register to the memory, a flag bit is set. This bit informs the memory controller that the contents of the lower rank of the Channel 1 buffer register should be written into the memory location designated by the P0 counter after all higher priority requests for memory access have been honored. When Channel 1 gains access to the memory, the contents of P0 are transferred over to the memory address register (JP). The contents of the lower rank of the Channel 1 buffer register are then transferred to the memory, and, at the same time, the P0 counter is indexed to its next state. As the flow of data from the Channel 1 buffer register to the memory continues, bank zero is eventually filled. As data is written into the last word of bank zero (memory location  $1777_8$ ), the P0 counter is indexed to its next state. Using normal octal counting, the next state to occur after state  $1777_8$  would be state  $2000_8$ . Thus, this next state would correspond to word zero of bank one. It should be recalled, however, that the transfer of data into bank zero was started with bank location one instead of zero. Location zero of all four memory banks is reserved for a status word.

The status word of each bank contains a history of the significant

events which took place during the transfer of data to the bank, and, consequently, this word must be the last word written into the bank. Location zero was selected for the status word since it would then precede the remaining bank information being transferred from magnetic tape to the computer for data processing. Thus, the computer program could decide how to treat the data even before it had been completely read into the computer. The formatting of the status word is given in Figure 47.

We see from the above that when the PO counter is indexed from  $1777_8$ , the next state will actually be  $0000_8$  in order to permit the writing of the status word. As the status word is being written, the PO counter is indexed to its next state. However, at this point, the PO counter may actually be thought of as being two counters: one counter consisting of the lower ten bits of PO and the second counter consisting of bit 10 (bit 11 remains fixed at a logical zero). Thus, when the PO counter is



- I = 0 = Old plate
- I = 1 = New plate
- P = Address within bank at which memory overflow occurred
- F = Prism face producing the scan associated with location 1 of the bank
- U = Number of buffer register overflows to occur while the bank was being filled
- S = Scanner speed

Figure 47: Formatting of Status Word in Memory and on Tape

indexed, the number associated with the lower ten bits will be indexed by one, and the number associated with bit ten will also be indexed by one. The final state of the P0 counter after the status word has been written will then be  $2001_8$ . In other words, the P0 counter will be ready to write data into word one of bank one.

At the same time that the status word is being written into bank zero, the upper two bits of the JP register are transferred to the read sequence register (RS). The read sequence register is actually a vertical stacking of four two-bit registers. Data is inserted into the top register and filters down to the bottom register. It is possible that this register will already contain data at the time that new data is entered into the top register. In this case, the new data will filter down only as far as it can go without replacing the data preceding it. When the two bits generated during the writing of the bank zero status word have filtered down to the bottom rank of the read sequence register, a flag bit will be set. This flag bit informs the memory controller that a bank of memory is filled and is available for transfer to tape. The transfer of data from the memory to the tape unit will be initiated as soon as the memory completes the operation which might have been in progress at the time that the flag bit was set at the bottom rank of the read sequence register. The output of data from the memory is initiated by clearing the JP register and transferring the two bits from the bottom of the RS register to the upper two bits of the JP register. Thus, the first word to be read from the memory corresponds to word zero of the bank which is being transferred from the memory. In this case, the bank is bank zero.

While word zero of the bank being processed is being read up, the contents of the JP register are transferred to the P2 counter, and, thus, the P2 counter is indexed to the next state, which would be word one of the bank being transferred to tape. Once the bank zero status word has been written, the transfer of data from Channel 1 to the memory continues

with bank one. Concurrent with the writing of data into bank one the transfer of data from bank zero to the tape is also in progress. Once the last word of data has been transferred to bank one and its status word written, the writing of star data will revert back to bank zero, starting with word one.

It is conceivably possible that the data transfer to the memory may be considerably faster than the transfer of data from the memory to the tape. It is therefore possible that the writing of data into bank zero may actually catch up with the reading of data from bank zero. If the condition occurs, where the write address as designated by the P0 counter coincides with the read address as designated by the P2 counter, the writing of data will halt until such time as bank zero has been completely transferred to the tape unit, at which time the writing of data into bank zero will be resumed. When bank zero is subsequently filled, the status word at location zero will indicate the location at which the coincidence between the P0 and P2 counters occurred.

It should be noted that whenever the write address coincides with the read address for either channel, the two banks which have been assigned to that channel have both been filled and any additional data occurring will represent overflow of the memory. These overflows represent lost data, and, if they occur too frequently, it will be necessary for the operator to stop the scanning of the stripe and start over at a slower scanning speed. Whenever an overflow condition occurs on either channel, an overflow counter assigned to that channel will be indexed by one. The contents of both channel overflow counters are presented to the operator as a visual display, and, thus, the operator may use his own judgment to determine when the number of overflows is too great for a particular stripe. In lieu of any operator action, audible and visual alarms will be actuated when the number of overflows associated with either channel reaches or exceeds some predetermined number. If the

operator does not take any action at the time that this alarm occurs, the scanning of the stripe will continue to completion. However, the indexing to the next stripe will not take place and the scanner will remain in a quiescent state until the operator makes a decision as to what to do next.

From the above discussion it is readily apparent that there exists a high probability that simultaneous requests for memory access will occur. Thus, it is necessary to establish a set of priorities as to which request will be answered first. It will be recalled that the transfer of data either to or from the tape unit must occur at a uniform rate of one frame every 12 microseconds. Thus, when data is being transferred to the tape unit, it is necessary to read from the memory every 48 microseconds.

Since the tape unit requires data at a uniform rate, all requests for transfer of data from the memory will be given priority over requests for transfer of data to the memory. The write requests issued from either channel are given equal priority. This is accomplished by alternately sampling the data flag associated with Channel 1 buffer register B00 and then the corresponding flag associated with Channel 2. Whenever the data flag for one of the two channels is set, the channel scanner will lock on the channel having the set data flag and will then gate the data from that channel to the memory.

The channel scanner remains locked on the channel having the set data flag until the data has been transferred to the memory, at which time the scanner resumes alternately sampling the two channels for an indication of available data. There is one situation during which the scanner is not released after data has been transferred from one of the channels to the memory. This situation occurs after a last word has been written into a particular bank. The scanner will remain locked until the status word has been written for the bank being completed.

### E. Data Flow from Memory to Tape

Having considered the control of data flow through the memory let us now consider the events which take place when a word is read from the memory and transferred to tape. The transfer of data through the memory is controlled by means of a timing chain. Shortly after this timing chain initiates a memory output cycle, it clears the memory output register (M1) and the auxiliary memory output register (M2). When information becomes available at the output of the memory it is then gated to the set-side inputs of the M1 register. At this point the logic which controls the input of data to the adder (S) must decide how to process the data in the M1 register. If the M1 register contains X or Y information, the information must not be altered as it is passed through the memory. Consequently the M2 register must be left in a cleared state so that zero is added onto the contents of the M1 register. If the M1 register contains star transit data, the adder must generate the star width ( $\delta y$ ) as given by Equation (2). If  $y_1$ ,  $y_2$ , and  $y_3$  of Equation (2) are replaced by the contents of the holding registers which sample these quantities, we obtain

$$\delta y = (HW) + (I2) - (HI1) \quad (3)$$

The quantity  $(HW) + (HI2)$  is a 10-bit number in which the contents of the HI2 register represent the lower six bits and the contents of the HW1 register represent the upper four bits. The contents of the HI1 register also represent a six-bit number; however, the S adder treats this number as though it were a 10-bit number with the upper four bits set to zero. The subtraction indicated in Equation (3) cannot be performed directly, and, consequently, it is necessary to rearrange this equation in such a manner that all terms add. It is shown in Appendix I that this rearrangement can be accomplished by first complementing<sup>(2)</sup> each bit of the number

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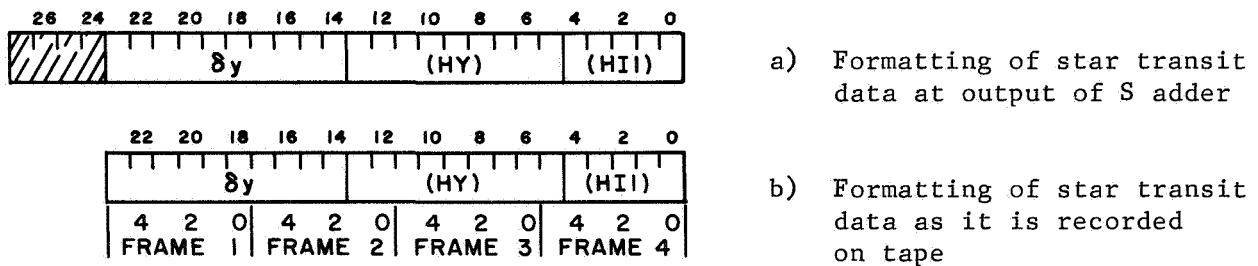
(2) A bit is complemented when its logical significance is reversed. Thus, a logical "1" is the complement of a logical "0", and a logical "0" is the complement of a logical "1".

representing the contents of the HI1 register and adding one to the result. The resulting number is then added to the first two terms of Equation (1). Thus, Equation (3) becomes

$$\delta y = (HW) + (HI2) + \overline{(HI1)} + 1 \quad (4)$$

Figure 48 shows the formatting of the star transit data at the output of the adder and as it is recorded on tape. The star ingress quantity-- $(HY) + (HI1)$ --occupies bits 0 through 13, while the star width  $\delta y$  occupies bits 14 through 23, and bits 24 through 27 are unused.

When information appears at the output of the S adder, it is made available to the disassembly (D) gates which break the 24 bits of data down into four 6-bit frames for transmission to the tape unit. A parity bit is added on to each 6-bit group of data prior to transferring the frame to tape. This bit is set to such a value as to insure that the total number of "ones" in the 7-bit frame is an odd number. An odd parity check is subsequently performed on each frame as it passes by the read head of the tape unit. An additional parity check is performed on each of the six tracks of data after each record is read. A record on tape is



$$\delta y = (HW) + (HI2) + \overline{(HI1)} + 1$$

Figure 48: Formatting at Output of S Adder and on Tape

a grouping of data in consecutive frames which ends with a check character followed by a three-quarter inch gap. The formatting of a record on tape is shown in Figure 49. Note that the check character is preceded by these blank frames. These blank frames tell the tape controller that the next frame of data to be read will be the check character. Note that a blank frame cannot occur with data since there must always be an odd number of ones in each data frame. The check character is generated in such a manner that the total number of "ones" in each truck is an even number. Thus, if an odd number of "ones" are read from one of the six data tracks of a record an error is indicated.

It should be noted from Figure 40 that the disassembly gates have the capability of transmitting five 6-bit gate frames to the tape. This capability is utilized when all 28 bits of each memory word are transferred to tape as a part of the series of system verification tests which are run prior to each day of scanning. These tests attempt to identify possible system troubles before scanning starts; however, they are not all-inclusive. For this reason it is contemplated that the system verification will also include the scanning of a pair of small plates of known characteristics. The data from these plates will be analyzed by the computer prior to analyzing star plate data. If the analysis produces correct results, the star plate data obtained on the same day as the reference plate data will be analyzed. Otherwise, the star plate data will be rejected and the plates rescanned.

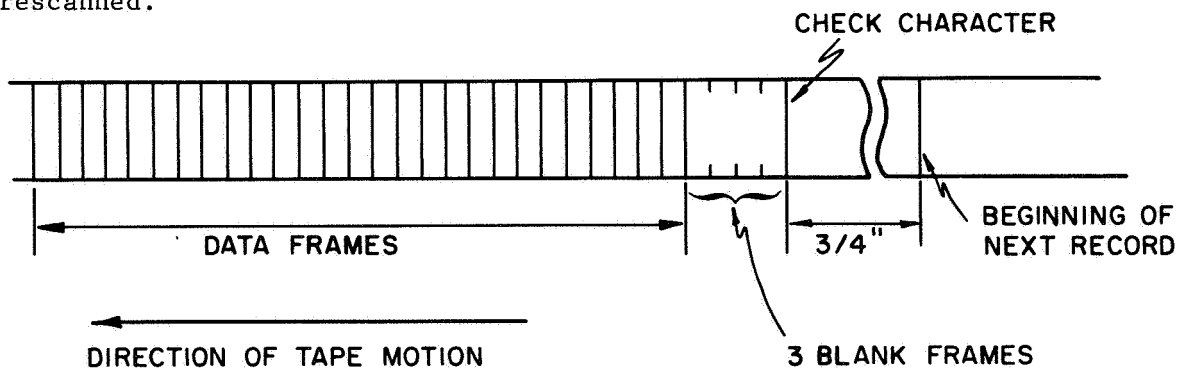


Figure 49: Formatting of a Record on Tape





holder of the scanner. The operator uses the machine-mounted control groupings to visually center each reference star within the field of view of the plate alignment microscope. When a star is centered, the operator sets the STAR IDENTIFICATION thumb-wheel switch to correspond to the table number of the star and presses the ENTER STAR button. Pressing this button causes the contents of the CX and CY counters and the STAR IDENTIFICATION switch to be entered into consecutive locations of bank zero of the memory. Entry of reference star coordinates starts at location  $000_8$ , progresses through banks zero and one, and recycles back to bank zero. As each bank is filled, it is transferred to tape as a record.

When the operator finishes the entry of reference star data, he presses the TERMINATE ENTRY button. Pressing this button causes the remainder of the bank being addressed to be zero-filled. The contents of the bank are then transferred to tape as a record, and the record is then followed by a file mark<sup>(3)</sup> to signify the end of the reference star data. Although an indefinite number of reference stars could be recorded using this scheme, it is doubtful that more than five or six reference stars would be recorded for any given plate pair. The reference star positions would be further refined by the computer analysis. The computer program would use the manually entered reference data to single out the reference stars from the scan data. These stars would then be assigned the positions derived from the scan data. The computer program would then refer to its star tables to find the celestial coordinates of the reference stars. Once the celestial coordinates of the reference stars had been established, the machine coordinate system could be transferred to the celestial coordinate system.

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(3) A file mark consists of a six inch blank spot on the tape following the check character of the last record. This blank spot is then terminated with a frame having an  $017_8$  pattern followed by its check character (which is another  $017_8$  pattern).

We have now considered all of the various types of information which must be transferred to tape during the course of scanning a pair of star plates. This information is grouped in files which are recorded on tape in a predetermined sequence so that it can be properly interpreted by the computer program. The first file consists of the plate/reel identifier. If the first reel is indicated, the second file will contain the reference star data. Otherwise the files between the first and last files will contain stripe data. The data from each stripe will be recorded as a single file. The last file will contain the YS record with either the END OF TAPE flag bit set or both the END OF TAPE and END OF PLATE flag bits set. Figure 51 shows the sequence of events which must take place in order to complete the scanning of a pair of plates. It will be noted that some of the events require operator action, while the remaining events occur automatically.

Once the plates have been loaded into the plate holder the remaining operator actions are confined to pushing buttons and looking at displays. The displays and switches are divided between two consoles. One console is mounted on the scanner base and is used for plate alignment and manual blinking while the other console is remote from the scanner and controls system operation after the plates have been aligned. Three of the switches associated with the data acquisition logic are on the scanner-mounted console. These switches are designated STAR IDENTIFICATION, ENTER STAR, and TERMINATE ENTRY and were described earlier. The remainder of the data acquisition logic controls are contained on the remote console. These controls are shown in Figures 52 and 53.

We see that the switches and displays are divided between the horizontal and sloping panels. With the exception of the PLATE/REEL IDENTIFICATION SELECTOR, all switches associated with plate scanning are mounted on the horizontal panel. These switches and their functions are listed in Table IV. The sloping panel contains all of the switches which are used for system

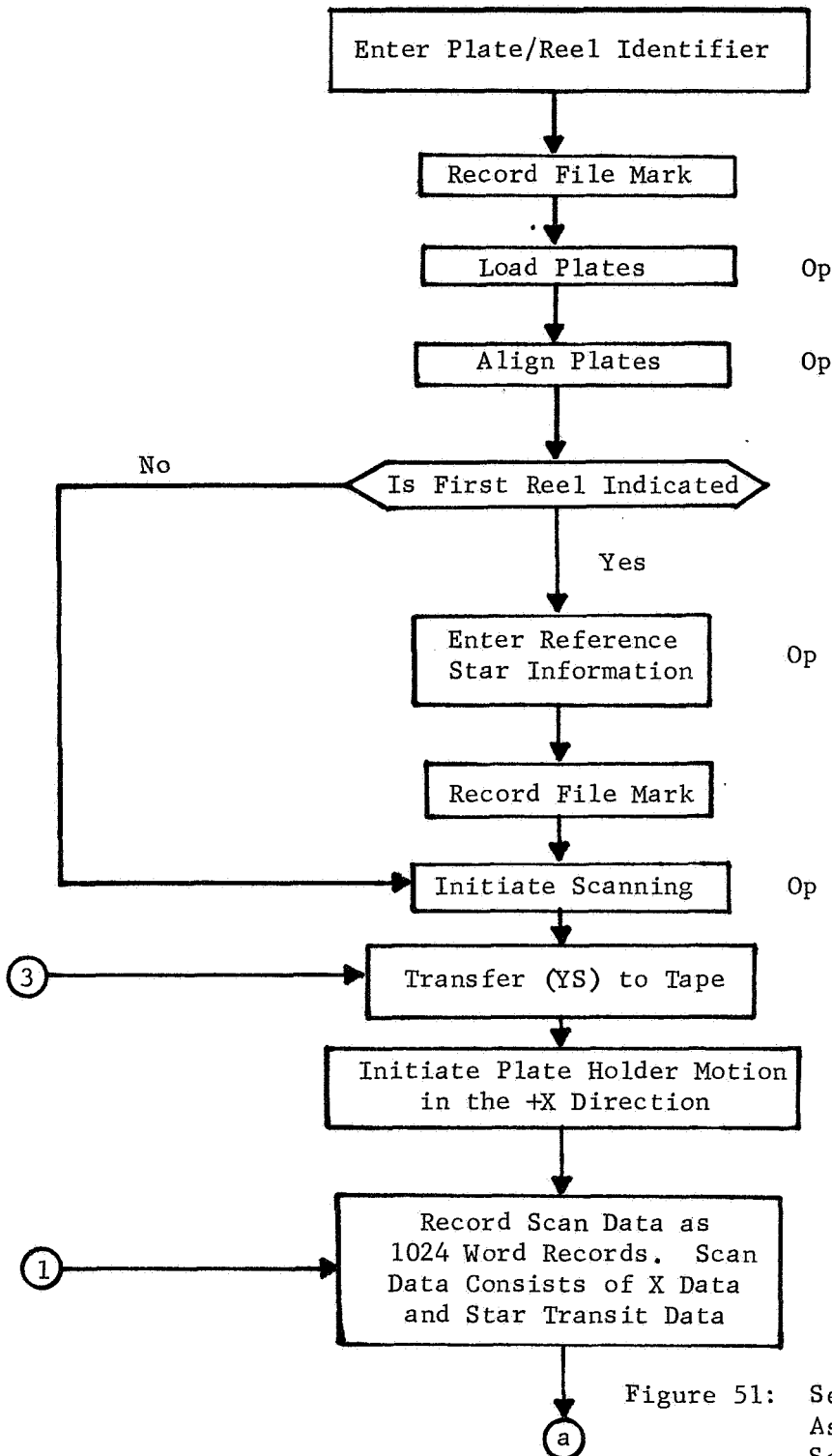


Figure 51: Sequence of Events Associated with Plate Scanner Operation

Op = Function Controlled by Operator

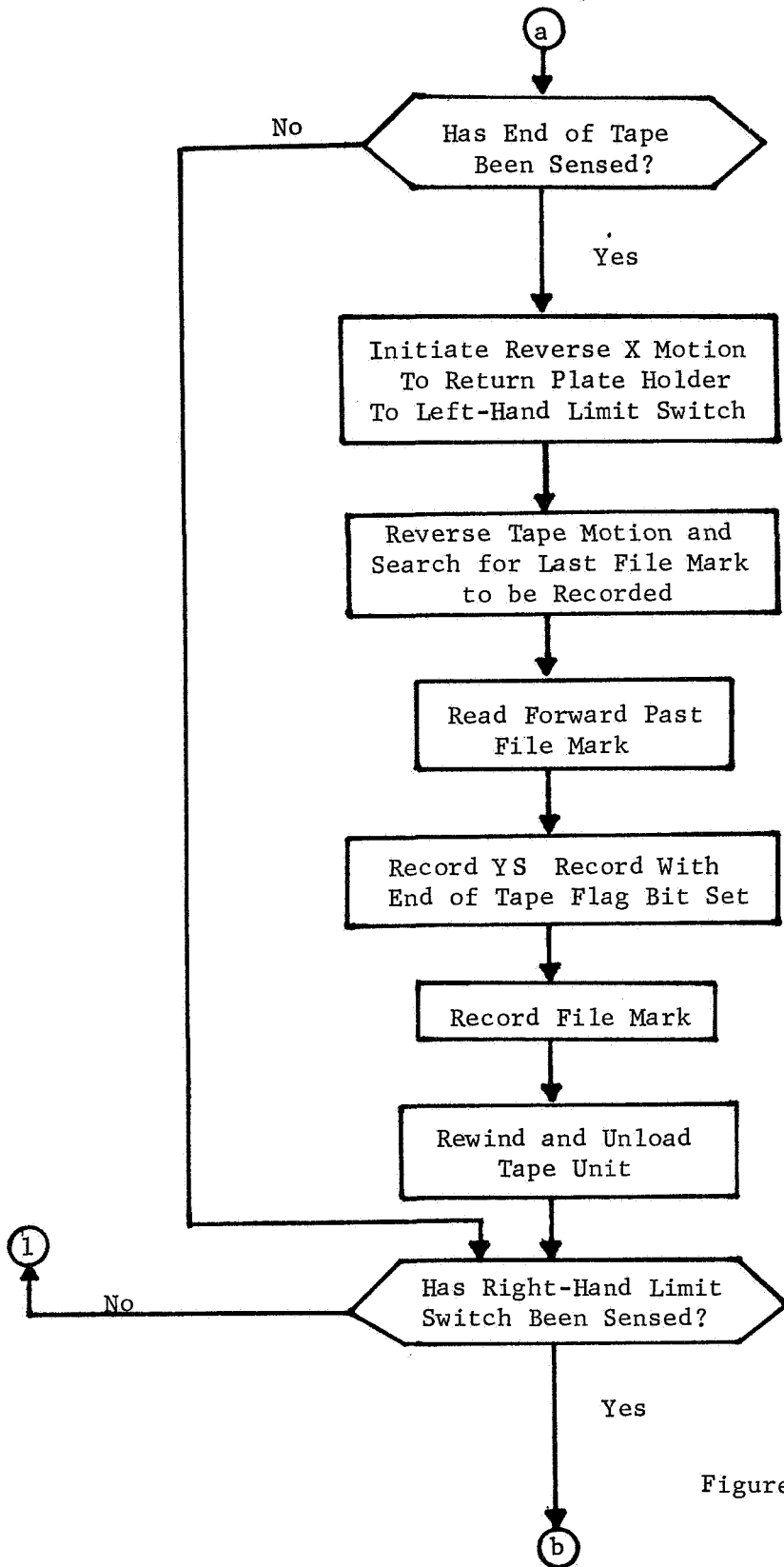


Figure 51: (continued)

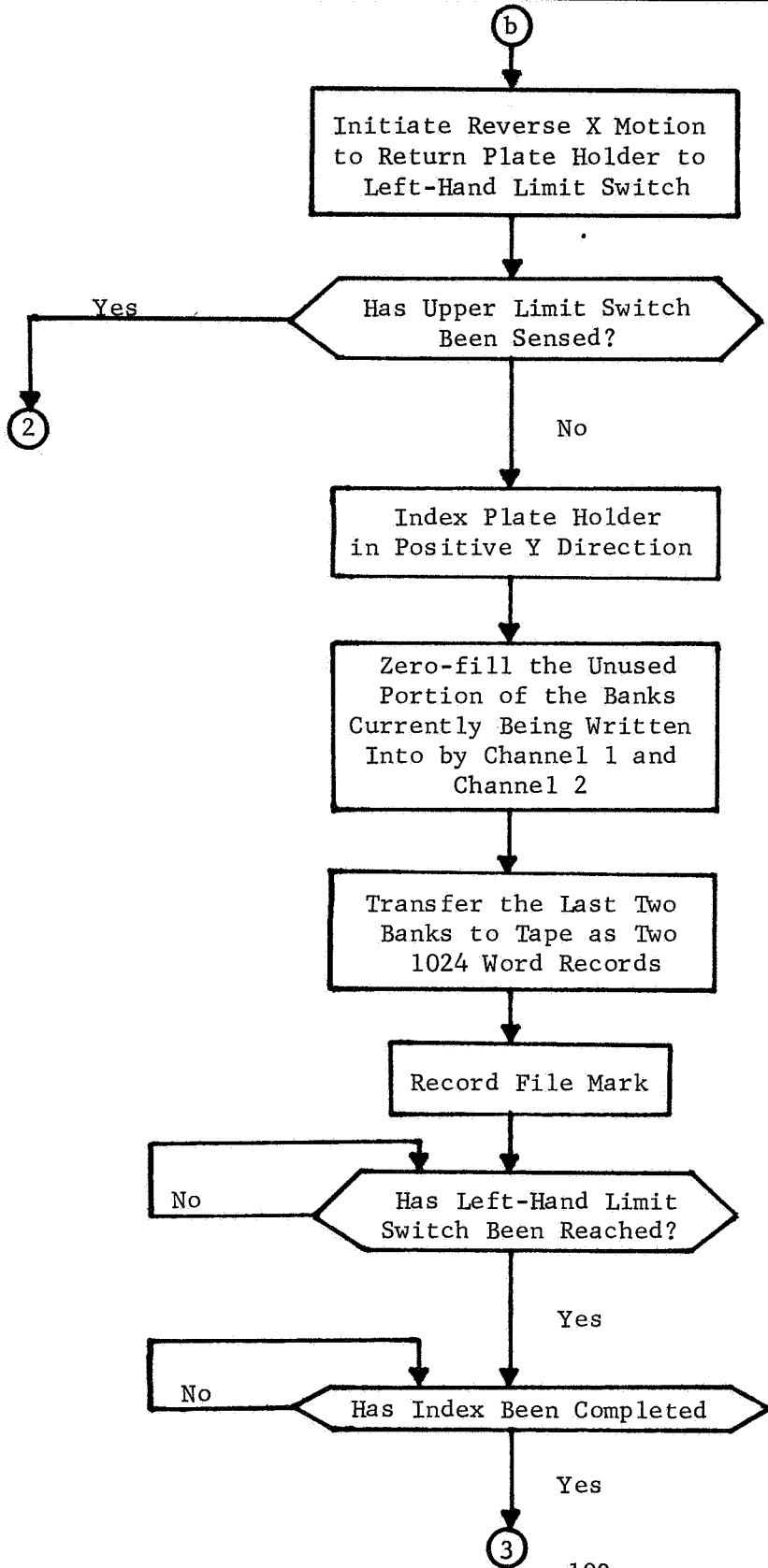


Figure 51: (continued)

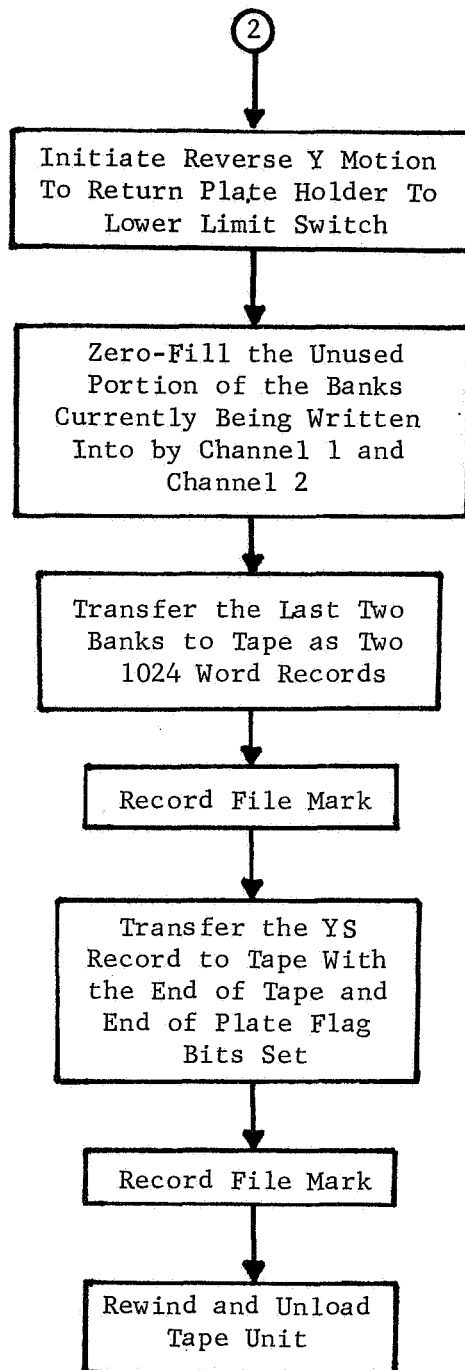


Figure 51: (concluded)

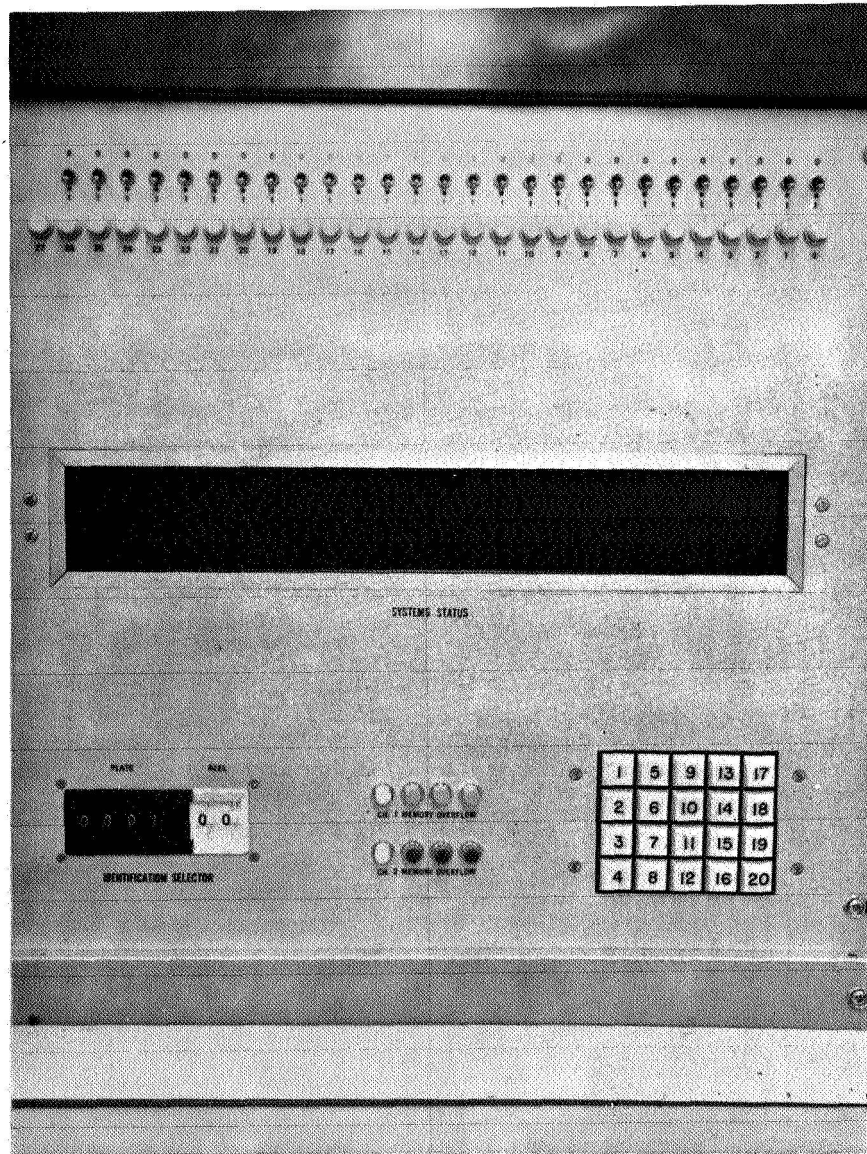


Figure 52: System Checkout, Maintenance and Status Panel at the Console. The top row of numbered toggle switches are used for data entry; data display lamps are immediately below the switches. The system status is indicated by illuminated rectangles within the system status display. The first 12 numbered buttons on the lower right constitute the data display selector; numbers 13 through 20 are the test selector buttons.



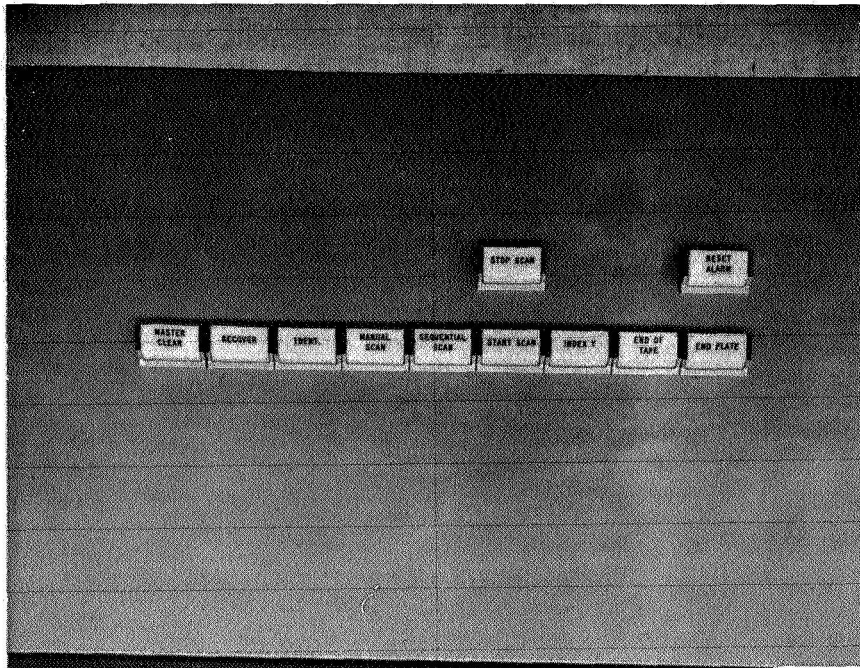


Figure 53: Plate Scanning Control Switches at the Console. The functions of these switches are given in Table IV.

TABLE IV  
SWITCHES USED FOR SCANNING

SWITCH	TYPE	FUNCTION
MASTER CLEAR	M	Sets the logic to a known state prior to initiating an operation with one of the push buttons on the logic console.
PLATE/REEL IDENTIFICATION SELECTOR		This switch is a six position thumb wheel switch which permits the operator to designate the number of the plate being scanned and the number of the reel of tape associated with the plate.
IDENT.	M	Pressing this switch transfers the contents of the IDENTIFICATION SELECTOR to magnetic tape.
RECOVER	M	Pressing this switch causes the tape unit to move the tape backward to the beginning of the last file of data that it recorded. This switch allows the operator to delete data which is erroneous and must be repeated.
SEQUENTIAL SCAN	L	This switch permits the operator to select between simultaneous or sequential scanning. Simultaneous scanning is selected when the SEQUENTIAL SCAN button is not illuminated. When scanning is performed in this mode, data is obtained from both plates as a stripe is scanned. Sequential scanning is selected when the SEQUENTIAL SCAN button is illuminated. When scanning is performed in this mode, data is obtained from only one plate as a stripe is scanned. The stripe is then scanned a second time to obtain data from the other plate.
MANUAL SCAN	L	This switch permits the operator to select between automatic or manual scanning. When automatic scanning is selected, the MANUAL SCAN button is not illuminated; the operator can control scan motion only to the extent that he can start and stop the motion. Scan motion must start from the left limit switch and end at the right limit switch with no stops in between. If the operator stops the scan prior to the plate holder reaching the right limit switch, erroneous data will be generated and an alarm

TABLE IV  
(concluded)

SWITCH	TYPE	FUNCTION
		will be sounded. The stripe will then have to be rescanned. When manual scanning is selected, the MANUAL SCAN button will be illuminated. This mode permits the operator to position the plate holder at any point of interest and to scan any fraction of a stripe that he desires.
START SCAN	M	Pressing this switch initiates scan motion and data acquisition.
STOP SCAN	M	Pressing this switch halts scan motion and data acquisition.
INDEX Y	M	Pressing this switch causes the plate holder to be moved 16 millimeters in the Y direction.
END OF TAPE	M	Pressing this switch places the YS record on tape with the end of tape status bit set.
END OF PLATE	M	Pressing this switch places the YS record on tape with the End of Tape and End of Plate status bits set.
RESET ALARM	M	Pressing this switch turns off the audible alarm after it has been turned on by an error condition. Resetting the alarm does not prevent the alarm from recognizing other error conditions which occur prior to the correction of the first error condition.

M = Momentary Contact

L = Locking

TABLE V  
MAINTENANCE AND DISPLAY SWITCHES

SWITCH GROUP	FUNCTION
TEST SELECTOR	This grouping of switches permits the operator to test various portions of the data acquisition system. These tests can only be initiated when the plate holder is in its home position.
DATA DISPLAY SELECTOR	This grouping of switches permits the operator to display various sources of data. The following sources may be displayed: CX, CY, CH1 B00, CH2 B00, M1, M2, S, P0, P1, P2, and JP.
DATA ENTRY SWITCHES	This group of switches permits the operator to select bit patterns which are entered into the system during various tests.

TABLE VI  
DISPLAYS ON SLOPING PANEL

DISPLAY GROUP	FUNCTION
DATA DISPLAY	This group of 28 lamps displays the information selected by the DATA DISPLAY SELECTOR.
CH1 MEMORY OVERFLOW and CH2 MEMORY OVERFLOW	These two groups of lamps display the number of memory overflows which occur during the course of scanning a stripe.
STATUS DISPLAY	This unit displays messages which indicate the significant events which transpire during system operation.

## APPENDIX I

## PERFORMING BINARY SUBTRACTION WITH AN ADDER

At first thought the idea of subtracting one number from another by using a device which is designed to add two numbers seems contradictory and implausible. This idea can be given some credence, however, if one considers some of the properties of binary numbers. First of all, an n-bit number can form only  $2^n$  binary combinations. The value of each number is given by the relationship

$$\begin{aligned}
 N &= a_{n-1} 2^{n-1} + a_{n-2} 2^{n-2} + \dots + a_2 2^2 + a_1 2^1 + a_0 2^0 \\
 &= \sum_{i=0}^{n-1} a_i 2^i
 \end{aligned}
 \tag{I-1}$$

where the  $a_i$  terms represent the bits of the number and are either "one" or "zero." Thus, the largest number which can be represented by n bits corresponds to the case where all n of the  $a_i$  terms are set to a value of "one." This number has a value of  $2^n - 1$ . If this number is increased by one, the resulting number,  $2^n$ , requires n + 1 bits to represent it. It is important to note that the lower n bits of  $2^n$  are all zero. Thus, adding one to the largest n-bit number produces the smallest n-bit number, namely, zero. This property of an n-bit number is illustrated in Figure I-1. In this figure a circle is divided into  $2^n$  parts by  $2^n$  radial lines. These radials are then assigned consecutive numbers starting with zero. Note that the radial numbered zero follows the radial numbered  $2^n - 1$  when one moves around the circle in the direction of increasing numbers. The zero radial corresponds to the  $2^n$  radial, but it should be recalled that  $2^n$  cannot be represented by an n-bit number. Let us now consider how this recycling of the numbers can be utilized to accomplish the subtraction of one number from another.

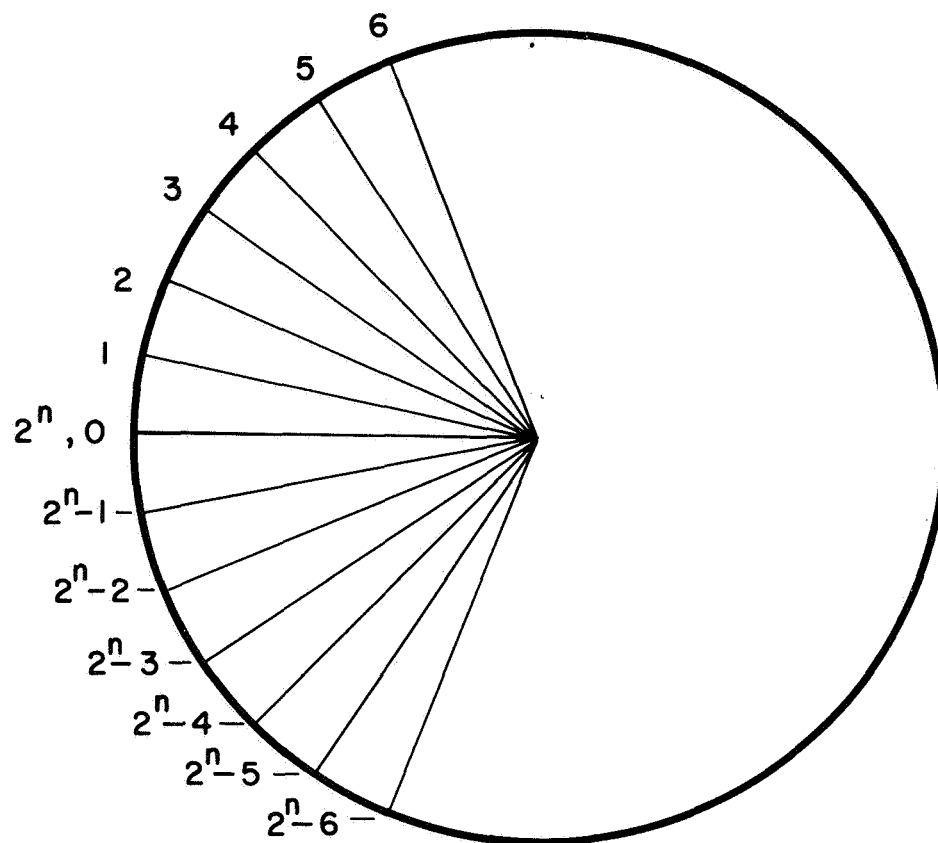


Figure I-1: Illustration of the Cyclic Behavior of an n-bit Number

Assume that it is desired to form the difference A-B. This relationship may be written as follows:

$$A - B = A + (2^n - B) - 2^n \quad (\text{I-2})$$

If  $2^n$  is either added to or subtracted from an n-bit number, the number is unaltered. Thus Equation (I-2) can be written as

$$A - B = A + (2^n - B) \quad (\text{I-3})$$

The next problem is to form the quantity  $2^n - B$ . This quantity can be rewritten as

$$(2^n - B) = [(2^n - 1) - B] + 1 \quad (\text{I-4})$$

It was noted earlier that  $2^n - 1$  is represented by an n-bit number which has all n bits set to one. This number has the property that no borrows are formed when an n-bit number is subtracted from it. The consequence of this property is that the difference,  $(2^n - 1) - B$ , can be formed by complementing each bit of B. That is, each bit of B which is a zero is changed to a one; each bit of B which is a one is changed to a zero. This complementation operation is symbolized by placing a bar over B. Thus Equation (I-4) may be written as

$$2^n - B = \bar{B} + 1 \quad (\text{I-5})$$

Substituting (I-5) into (I-3) we obtain

$$A - B = A + \bar{B} + 1 \quad (\text{I-6})$$

Thus we obtain the result that a difference can be formed by using an adder. This third term of Equation (I-6) is added by forcing a carry into



the low order bit of the adder as A and  $\bar{B}$  enter the adder.

Figure I-2 shows a graphical interpretation of Equation (I-3). This interpretation is not valid if it is desired to represent n-bit numbers and  $A < B$ , since no provision has been made to represent negative numbers. Signed numbers can be represented by adding another bit to the n-bit number. Positive numbers are indicated when the high-order bit is zero, and negative numbers are represented when the high-order bit is one. Figure I-3 shows the distribution of positive and negative numbers for an n-bit signed number. Note that a negative number is formed by subtracting the number from  $2^{n+1}$ . Alternatively, the rule illustrated by Equation (I-5) may be used to form a negative number. In this case each of the  $n + 1$  bits of the positive number is complemented, and one is added to the result.

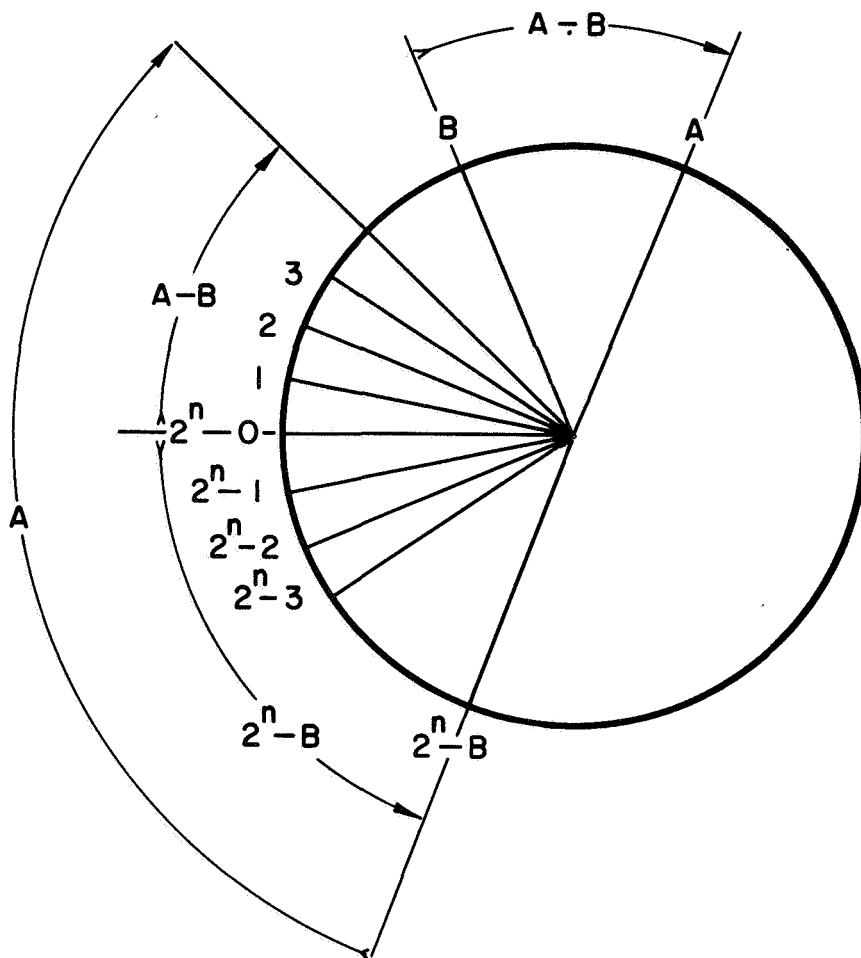


Figure I-2: Graphical Interpretation of Equation (I-3)

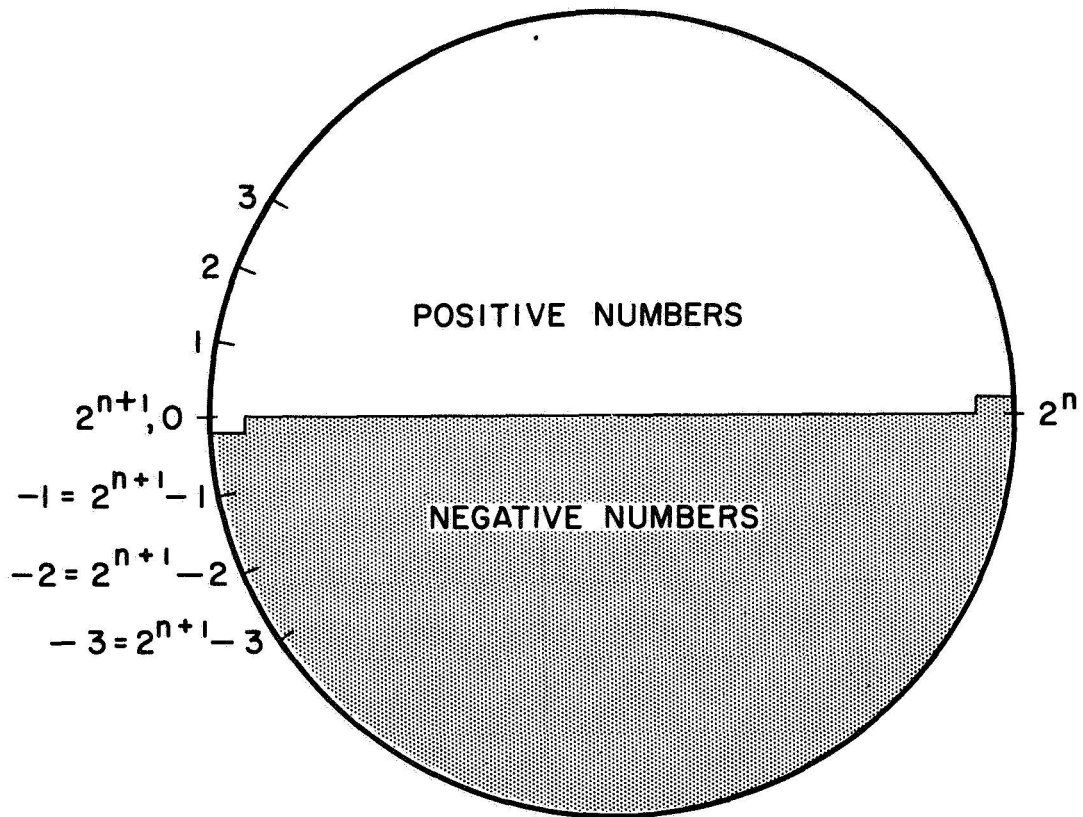


Figure I-3: Distribution of Positive and Negative Numbers from an n-bit, Signed Number