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SLAC SPIRAL READER PROJECT*

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I. MECHANICAL

A. Projection System

The projection system of the spiral reader splits the film image into two paths, one to the scanning drum and the other to the viewing table. An overall schematic is shown in Fig. 1.

Light from a 500-watt incandescent lamp is projected onto the film platen by an aspheric and two spherical lenses. The lamp box, of black-anodized aluminum, is L-shaped to hold two cold mirrors which transmit infrared. In the schematic, the sequence of lamp, two lenses, and first mirror have been drawn as though viewed from above; the lamp actually stands vertically. The lamp is housed in a water-cooled copper jacket and is cooled, along with the other components, by an air jet. A flow-switch cuts off lamp power at a set minimum water flow.

The film is led from reels and storage loops, around a drive capstan, to the film platen. Rectangular glass plates support the three film views side by side. Film is clamped by vacuum, applied through a narrow groove entirely around each glass plate, and by five transverse slots beyond each end of the glass. The slots prevent creep of the film when the platen is moved rapidly during measurement, for example, when moving from an auto-fiducial mark to a vertex. A measuring engine, driven by ball screws in x and y, moves the platen from view to view as well as to points within a view. Engine position is maintained within the computer by counts from a linear optical encoder on each axis. A zero reference for each axis checks for lost counts by means of a photodiode and knife-edge.

Above the film plane, a 50-50 beam splitter sends half of the beam to the scanning drum with an image magnification of 5.06. The drum is a cylinder driven by a synchronous motor, with a narrow mirror mounted in a cone at one

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end, and an encoder disc at the other. The mirror rotates at 15 rps, reflecting the image onto the plane of a slit, .001 by .060 inches. The slit moves along the drum axis under computer control of a ball-screw on the periscope. The combination of drum rotation and linear travel of the periscope causes the slit to sample the image in the characteristic spiral pattern. When the optical axis is centered on a vertex, the slit, whose long dimension is aligned radially, coincides closely with tracks leaving the vertex with low curvature. These dark pulses are reflected into a fiber light pipe by a small mirror under the slit. The pipe, which rotates with the periscope and drum, conveys the light signals back to the axis and into a photomultiplier tube that travels with the periscope but does not rotate.

Two small lamps project light through two channels on the encoder disc into fiber light pipes and thence to PM tubes. The outer channel carries 16384 lines for measuring angular position while the inner channel starts one pulse each revolution to provide a zero reference angle.

The half of the projected light that is transmitted by the beam splitter is focused onto the viewing table with a magnification of 9.5. A small mirror above the lens reflects the beam to a large mirror above the table. A television camera (without lens) looks upward through a 10 × 13 mm glass window in the center of the table. Its field of view is shown magnified on a TV monitor sitting at the back of the table. A bulls-eye on the window appears in the picture as a central aiming point.

To minimize calibration effort, the beam splitter, 240 mm lens, and periscope axis are aligned with optical tooling. The viewing table is aligned to match this system by adjusting the 300 mm lens until a point on the film that is projected onto the center of the drum is also projected to the bulls-eye of the TV camera.

As the slit scans around a vertex, the values of θ and ρ at which pulses occur are mapped as x and y on the storage scope mounted at the back of the viewing table. This display provides a visual check on the information recorded on the output tape.

Fiducial marks can of course be measured like vertices by moving the engine manually with the tracking ball (mounted at one side of the table) until a mark is centered in the TV. To speed measurement, readers for auto-fiducial marks are installed in the table. A thin cross in the table top is made up of single rows of .005-inch light fibers. The two legs of the cross are gathered separately into light bundles facing photodiodes. When an auto-fiducial mark is swept across the reader in the y direction, the average of the pulse positions in the two legs gives the y coordinate. The difference of the pulse positions give the distance in x from the path of the sweep.

B. Spiral Reader Film Transport System

Specifications:

Film Speed	6 M/sec.
Acceleration	15 to 30 M/sec.^{2}

Film Tension	
(70 mm)	.75 kg
(46 mm)	.5 kg
(35 mm)	.37 kg

At present we are using a film drive with a mechanical film take-up loop. This loop uses an air bearing translating carriage to provide film tension. The reel boxes are mounted on stanchions to either side of the platen-measuring engine assembly. The single capstan is mounted on the take-up reel box.

This system is being replaced by a new set of drives using vacuum loops to provide film tension. These drives will be mounted to the right of the platen (viewed from the operator's position). Each of the three units incorporate a complete film handling system with feed and take-up reels, two vacuum boxes, and two capstans. Single-strip film will have its feed and take-up reels on separate units to accommodate the film offset due to the wrap around platen. The vacuum boxes and all rollers are made so that we can convert easily from one film size to another. The capstan drive pulleys are driven by a single motor through one-way clutches in the pulley hubs to allow the measuring engine to over-ride the capstan during measuring. Control of the film loop is done by a servo loop deriving its feedback signal from the pressure in an auxiliary chamber attached to the vacuum box. This chamber communicates with the main box through a thin vertical slit which the loop crosses. The pressure in the auxiliary box thus becomes a function of the position of the film loop.

The source of vacuum is a 500-cpm (max) centrifugal blower mounted outside the building.

II. ELECTRONICS AND COMPUTER INTERFACE LOGIC

A. Spiral Reader Electronics

A rough diagram of the Spiral Reader electronic hardware is shown in the figure (c.f. Fig. 2).

The computer was purchased from Digital Equipment Corporation with the API (Priority interrupt) and EAE (Extended arithmetic) options. The computer comes with the console typewriter and paper tape reader included. The tape units are Ampex TM-7's. All of the other items in the figure were described and built at SLAC.

The magtape controller was designed with limited capabilities to save time and money. It will read, write, and backspace single records, generate and detect file gaps, generate and check vertical and longitudinal parity, and rewind tapes in 9-channel IBM compatible format. The controller will only operate one tape unit at a time.

The high speed pulse detect logic and the associated AGC were designed and built at SLAC. The AGC circuits were drastically simplified from the Berkeley design and, at present, AGC is available for both dark and bright field illumination, each one a single logic card. The high speed pulse detection logic was designed to accurately detect pulses as narrow as 10 μs. To do this it uses a sophisticated high speed counting technique to measure the pulse height to 6-bit accuracy. The pulse must exceed a certain threshold before it can be accepted, and likewise on the trailing edge of the pulse this same threshold must be exceeded from the peak down before the pulse is input into the computer. When this occurs three words are input into the computer: (1) Pulse height and threshold (fixed); (2) 16-bit radius count; and (3) 16-bit angle count. When the pulse drops below the original threshold a 15-bit pulse width count is input into the computer. These four words are input via the Direct Memory Access Channel at 1 μs apiece.

The Control Button, IPD and Auto Fid Logic contain flip-flops and interrupts for the 10 control buttons, two 14-bit scalers for the image plane digitizer (Mangiaspago), and flip-flops and interrupts for the auto-fiducial diodes. The IPD encoders are Gurley optical encoders with 2000 cts per revolution. The auto-fiducials will be detected in the image plane (table top) using light sensitive diodes.

The X, Y, P Film drive logic contains the necessary interface between the computer and the six position axes on the Spiral Reader. Each axis has manual control. (1) The periscope through a potentiometer near the logic; (2) The X-Y stage through an air-supported tracking ball; and (3) The three separate film drives through a joystick and control buttons. Computer control for all 6 axes is via 6-bit velocity registers (± 32 steps), 6-bit D-A converters and summing amplifiers. All 6 axes use PMI 400 motors driven by SLAC-developed SCR triggered circuits. Each axis has its own interrupt with four possible interrupt conditions. The position scalers for all 6 axes reside in memory and the encoders are as follows:

1. Periscope uses a small Heidenhain circular encoder with 1000 lines and a zero reference point. The count is scaled up logically to 2000 counts per revolution or 64,000 over the 32 revolution total travel of the periscope;

2. The X-Y stage is encoded with Heidenhain linear encouders with 8 μ line spacing. This spacing is reduced logically to 2 μ in the present case, although the logic has the capability of 1 μ least count. The X-Y axes have diodes mounted for reference information; and

3. The film drives have Gurley optical encoders with 2000 cts per revolution, but in practice these were found to be of no value since they were mounted quite some distance from the platen. The film positioning is now accomplished using the reference diodes, one diode mounted on the platen to detect Brenner marks.

III. ON-LINE CONTROL PROGRAM AND CALIBRATION PROGRAM

A. Spiral Reader Control Program — System Genie

The spiral reader control program — System Genie — is designed to have built-in flexibility. That is, adding or deleting part of the system should not affect in any way the performance of the system. This modular concept is very important, since different physics experiments require different mechanical, electrical, and electronic set-ups. Thus from a total system viewpoint, the software system must be designed in a fashion that is totally modular.

System Genie could be divided into three general sub-systems. Namely, the executive, the peripheral I/O control program, and the control program for the spiral reader. The executive consists of several supervisors. The function of each of the supervisors is self-explanatory by its name. For example, they are the job supervisor, job executive, job dispatcher, software priority interrupt supervisor, program interrupt supervisor, magtape job supervisor, and teletype job supervisor. The peripheral I/O control program consists of several I/O control programs with individual interrupt handlers. These programs are: the R-θ channel control, the periscope control, the x-y stage control, the magtape control, and teletype control. All these I/O controls, if so desired, can be operated simultaneously through the executive. The control program for the spiral reader consists of programs that dictate how each I/O device or several I/O devices are to function and when to function. The control programs consist of reading MRQ tape, moving the stage to different views, to different fiducials, to different vertices. Furthermore, the control program can connect several functions to work simultaneously; namely at a push of a button, the periscope, the R-θ channel, and the magtape are working together. Also, the coordination of the MRQ information with stage and film motion is controlled by the control program.

System Genie presently is occupying approximately 5 K words of memory. At its completion it will probably take up to 6.5 K words of memory, and the other 1.5 K words memory will be used for the future improvement of the system.

B. Spiral Reader Calibration

There are two distinct ways of looking at the calibration of the Spiral Reader:

1. Checks can be made to attempt to analyze particular anomalities that might be present in the hardware. Some of these might be:

   (a) distortions in the mirrors due to mounting,
   (b) aberrations in the lens,
   (c) alignment of optical axis,
   (d) alignment of periscope,
   (e) stability of encoders (reproducibility of measurements).

2. To construct a transformation allowing us to map the (ρ, θ) parts into (x, y) parts as accurately as we can measure (< 1/2 track width).

Many of the calibration procedures are, of course, done by hand. Scaling and count checks are made in the control program by use of the zero references. The critical aspect of the calibration procedure is however (2) above.

By carefully selecting the fitting procedure for the computation of the transformation from (ρ, θ) to (x, y) it also becomes possible to obtain some information concerning some of the hardware distortions.

The method that we are planning to use is basically quite simple and has proven to work quite well on LRL Spiral Reader data. The method is as follows:

$$\begin{array}{ccc} (\rho, \theta) & \xrightarrow{\ t\ } & (x, y) \\ f \downarrow & \nearrow & \\ (u, v) & g & \end{array}$$

We factor T into two components f and g, where $f = (r^k \cos \theta,\ r^k \sin \theta)$, and $g = (AX + B$, A, B, complex and $X = (u, v))$. First pick a k in expression f such that $1/2 \leq K \leq 3/2$. Then using this k transform by f to obtain (u, v). Now perform a least-square fit to obtain the coefficients A and B. Using these coefficients, compute the residual. Therefore, for each k we obtain an average residual $\overline{\rho}$. Now $\overline{\rho}$ as a function of k has a particular form called the "characteristic subfunction" for f and g. In this case the form happens to be quadratic. Therefore, we repeat the above procedure sufficiently often to obtain enough data to fit a quadratic. Having fit for the "characteristic subfunction", we then compute its minimal and thus obtain our fit for the parameters k, A, B. Other parameters can be introduced in f and the procedure is carried out analogously. It is clear that in this case k might well represent the "key-stone" effect in the mounting of the cone mirror.

In order to obtain the (ρ, θ) and (x, y) data and errors it is necessary to develop a test pattern. It is straightforward to measure the center of crosses on the stage with the stage measuring engine. However, to obtain the corresponding centers of crosses in (ρ, θ) is quite difficult. In order to solve this problem we have developed special radial test patterns which will allow us to obtain the (ρ, θ) centers by histogramming.

Looking at Fig. 3, the reader will quickly see the principle of center location by histogramming.

First of all we will operate the periscope at sufficiently small speeds to cover the whole scan with the slit at least once. Therefore, depending upon the starting point, we will obtain at least 4 pts per cross if the AGC is set to pick up a point when the slit is half eclipsed. Since the crosses are radial, histogramming for θ-center of each row becomes possible. Similar arguments show how we find the ρ-center of each cross.

The procedure described above for finding the centers of the crosses in (ρ, θ) can, if carefully worked out, be executed on the PDP-9 using those portions of the control program necessary to drive the periscope and measure stage points. Further, the least-squares fit $q:(u, v) \rightarrow (x, y)$ can also be performed on the PDP-9. All that is needed in this case is the k parameter. Hence it is possible to perform calibration checks on the PDP-9 by employing the k parameter that is computed in an offline fit on the 360/91.

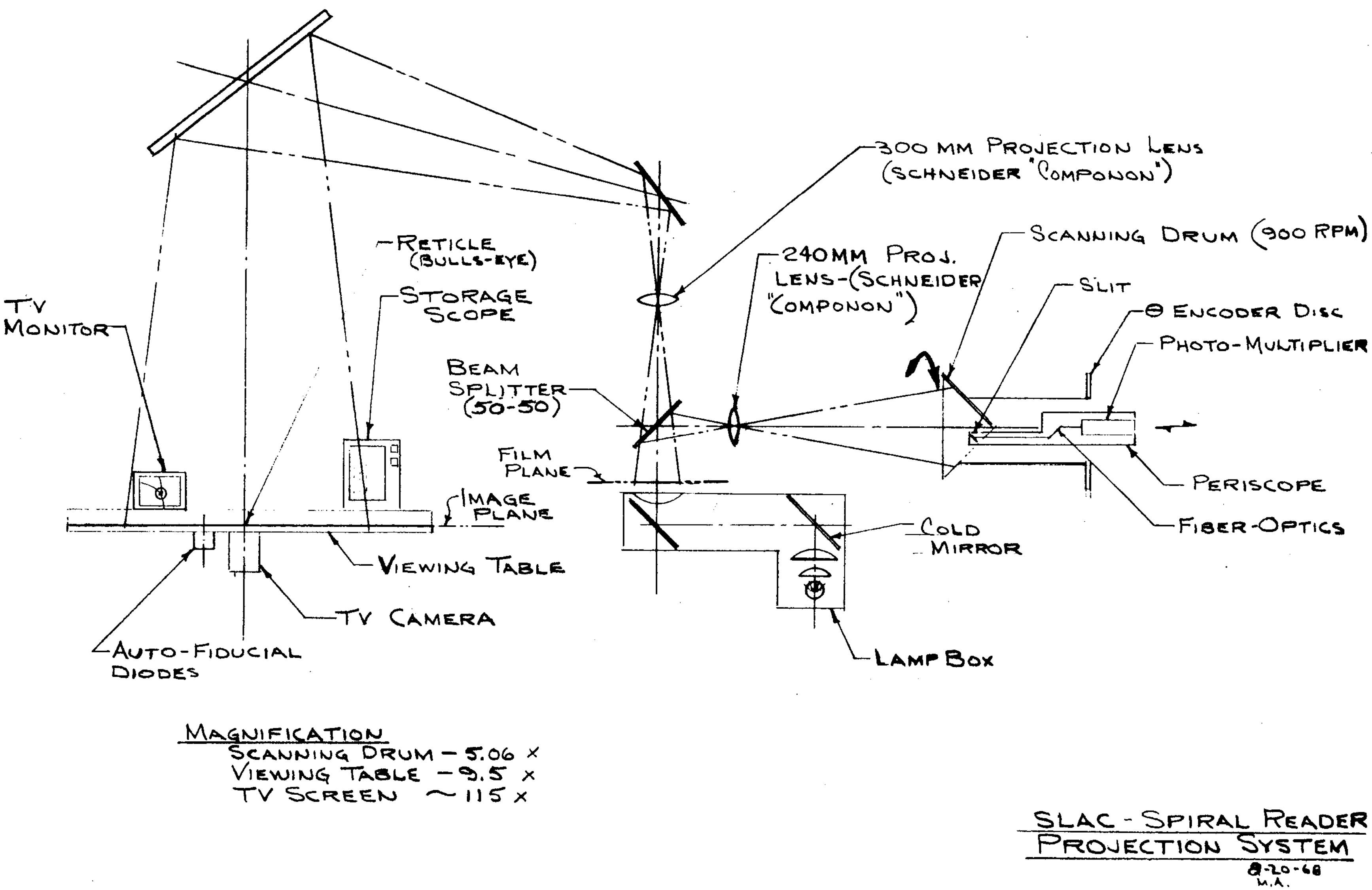

300 MM PROJECTION LENS (SCHNEIDER "COMPONON")
SCANNING DRUM (900 RPM)
240MM PROJ. LENS-(SCHNEIDER "COMPONON")
SLIT
Θ ENCODER DISC
PHOTO-MULTIPLIER
RETICLE (BULLS-EYE)
STORAGE SCOPE
TV MONITOR
BEAM SPLITTER (50-50)
FILM PLANE
IMAGE PLANE
PERISCOPE
FIBER-OPTICS
COLD MIRROR
VIEWING TABLE
TV CAMERA
AUTO-FIDUCIAL DIODES
LAMP BOX
MAGNIFICATION
SCANNING DRUM – 5.06 ×
VIEWING TABLE – 9.5 ×
TV SCREEN ~115 ×
SLAC - SPIRAL READER
PROJECTION SYSTEM
8-20-68
M.A.

Fig. 1

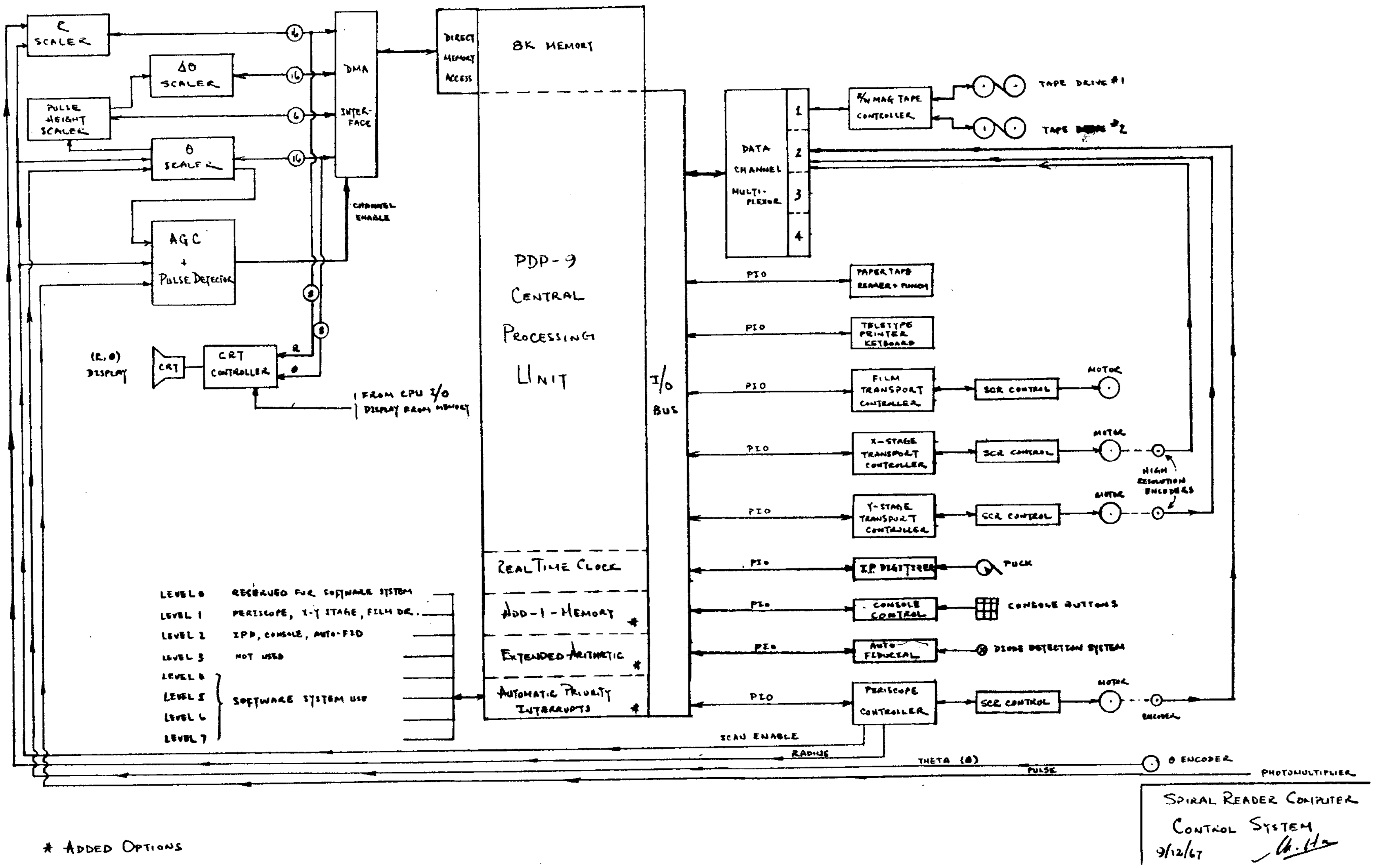
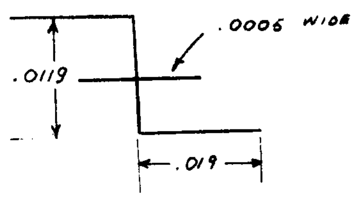
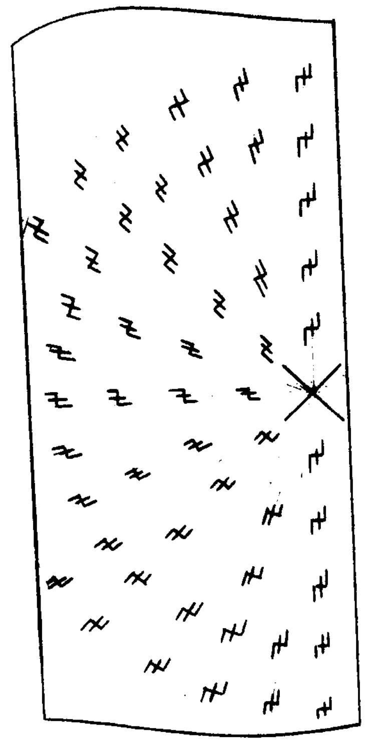

R SCALER
Δθ SCALER
PULSE HEIGHT SCALER
θ SCALER
DMA INTERFACE
CHANNEL ENABLE
AGC + PULSE DETECTOR
(R, θ) DISPLAY
CRT
CRT CONTROLLER
FROM CPU I/O
DISPLAY FROM MEMORY
DIRECT MEMORY ACCESS
8K MEMORY
PDP-9 CENTRAL PROCESSING UNIT
I/O BUS
REAL TIME CLOCK
ADD-1-MEMORY *
EXTENDED ARITHMETIC *
AUTOMATIC PRIORITY INTERRUPTS *
LEVEL 0 RESERVED FOR SOFTWARE SYSTEM
LEVEL 1 PERISCOPE, X-Y STAGE, FILM DR.
LEVEL 2 IPD, CONSOLE, AUTO-FID
LEVEL 3 NOT USED
LEVEL 4
LEVEL 5
LEVEL 6
LEVEL 7
SOFTWARE SYSTEM USE
DATA CHANNEL MULTIPLEXOR
MAG TAPE CONTROLLER
TAPE DRIVE #1
TAPE DRIVE #2
PIO
PAPER TAPE READER + PUNCH
TELETYPE PRINTER KEYBOARD
FILM TRANSPORT CONTROLLER
X-STAGE TRANSPORT CONTROLLER
Y-STAGE TRANSPORT CONTROLLER
IP DIGITIZER
PUCK
CONSOLE CONTROL
CONSOLE BUTTONS
AUTO-FIDUCIAL
DIODE DETECTION SYSTEM
PERISCOPE CONTROLLER
SCR CONTROL
MOTOR
HIGH RESOLUTION ENCODERS
ENCODER
SCAN ENABLE
RADIUS
THETA (θ)
θ ENCODER
PULSE
PHOTOMULTIPLIER
SPIRAL READER COMPUTER CONTROL SYSTEM
9/12/67
* ADDED OPTIONS

Fig. 2

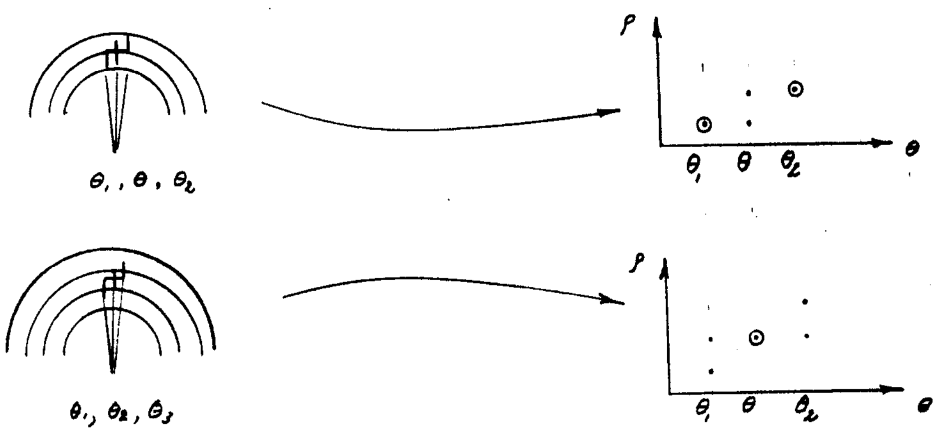
CALIBRATION PATTERN FOR 35 mm LEADER **Fig. 1**



Typical cross



View two shown (View 1,3 opposite hand pattern)



Digitizing a typical cross with the (ρ,θ) encoder at a rate of 14400 cnts/sec.

. = (max ph)/2

⊙ = max ph

Fig. 3