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BIONICS IMAGE RECOGNITION SYSTEM

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FOREWORD

This report was prepared by the LTV Astronautics Division, LTV Aerospace Corporation, Dallas, Texas, as its Engineering Report No. 00.764 under USAF Contract No. AF 33(615)-2317.

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This report covers work conducted from 4 January 1965 to 15 January 1966.

This project was under the Technologies Contracts Manager, Mr. J. M. Williams; Mr. L. G. Polimerou was Project Engineer; Mr. J. V. Patterson was responsible for the design and construction of the current implementation.

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ABSTRACT

This is the final technical report for a Bionics Image Recognition System. This report provides a description of a learning device which can be used to seek and test for an optimum discrimination value between two planar geometric shapes placed on 35 mm slide transparencies. The slide image shape-information is transformed from a function of two independent variables into a function of a single independent variable. Specific values of the transformed image shape-information are used to determine the best value for discriminating between any two images. After this operation, the device is capable of classifying additional planar geometric shapes as being similar to one or neither of the original two shapes which were discriminated.

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SECTION I

INTRODUCTION

This report is submitted as the final technical report of the effort conducted since January 1965, by the LTV Astronautics Division, LTV Aerospace Corporation, under Contract AF 33(615)-2317 on a Bionics Image Recognition System. This report up-dates the second interim report and includes revisions and corrections which supersede the earlier dated work.

The objective of this program was to perform the analytical studies and instrumentation required to demonstrate the effectiveness of combining the concepts of statistical image transformation and probability state variable device into a Bionics Image Recognition System. This system is capable of performing a learning and sorting function in a small universe of arbitrary optical imagery. Analytical studies were undertaken which lead to the development of image recognition systems performing tasks of greater complexity.

This work extends the previous effort originated by contractor-sponsored studies at the LTV Astronautics Division, which led to the definition of an image transformation function known as the $P_F(d)$ statistical image transformation, which is characteristic of the "shape" of a planar optical image falling on an optical plane or retina. The original proposal by the LTV Astronautics Division resulted in the award by the Psychological Sciences Division, Office of Naval Research, of Contract Nonr 3831(00) in May 1962, and was further extended in January and September of 1963 for the purpose of further analytical and experimental study of the statistical image recognition concept.

SECTION II

BIONICS IMAGE RECOGNITION SYSTEM DESCRIPTION

2.0 INTRODUCTION

The Bionics Image Recognition System consists of two major parts - the statistical image transformation system (SITS) and a probability state variable device (PSV). The SITS generator is a device which transforms an image into a function of a single independent variable $P_F(d)$. The $P_F(d)$ function is actually a very simple function that can be used to express the geometric shape of a two-dimensional image as a function of a single dimension. Thus, the $P_F(d)$ function is a function of reduced complexity compared to the original shape-function, yet retains information capable of distinguishing between the shapes of different images. In the present Bionics Image Recognition System, it is required to have a PSV device which is capable of learning two optimum values of two different $P_F(d)$ functions from two different images, say A and B, and then switching to a sort-mode and classifying subsequent images as either belonging to the A or B or "No-Decision" class. Figure 1 provides a general block diagram of the system.

The objective of combining the SITS system with the PSV devices is to preprocess the input information or the image such that learning can be accomplished from a less complex input. Thus, the intelligence level required to make the identification necessary is reduced. Alternatively, only the most significant signal information is retained with less significant information being discarded, so as to make the selection process more distinct.

2.1 SITS GENERATOR

The SITS generator creates the $P_F(d)$ function. The method used for generating the $P_F(d)$ function involves the nutation of a displaced image with respect to the original image. The amount of displacement between the centroid of the original image and the centroid of the displaced duplicate image is equal to "d." For each value of "d," the displaced image is nutated about the original image such that the axes passing through the centroids remain parallel throughout the 360° of nutation motion. During this period of nutation, the generator measures the cumulative amount of overlap of the images throughout 360° or one cycle. The value of "d" is then changed, and the apparatus is reset to zero to integrate the cumulative amount of overlap between the images over the next cycle, for a different value of "d."

The SITS generator provides automatic standardization of images such that all similar images yield the identical $P_F(d)$ function. For instance, each circle of a family of circles yields the identical $P_F(d)$ function. Similarly, each square of a family of squares or each triangle of a family of similar triangles will yield an identical $P_F(d)$ function, respectively, representative of the set. Accordingly, any planar figure that

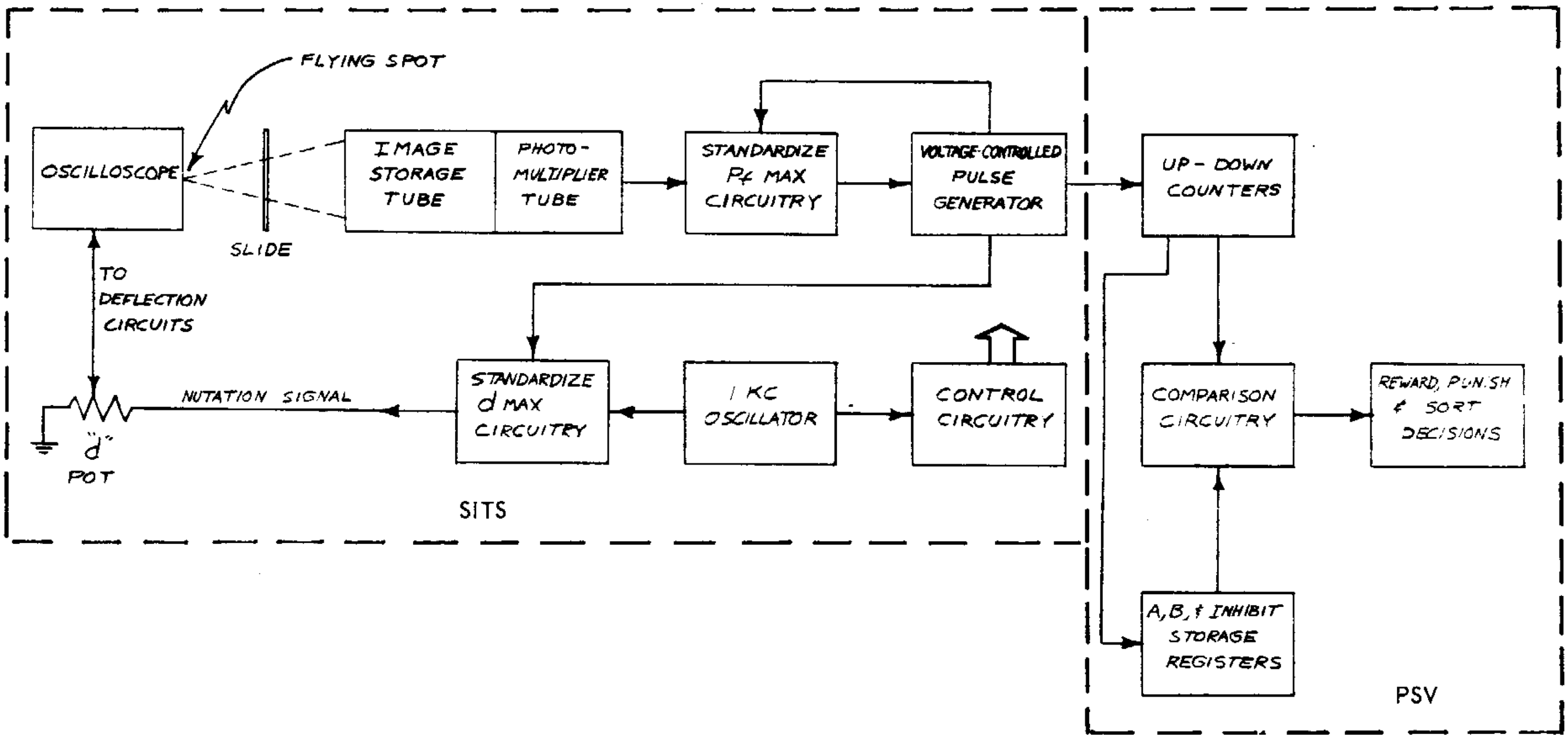


FIGURE 1 IMAGE RECOGNITION SYSTEM – GENERAL BLOCK DIAGRAM

belongs to a set of planar figures that are related by a simple multiplicative constant of size will yield the identical $P_F(d)$ functions because of the integration processes involved combined with the standardization.

There are many ways of producing a $P_F(d)$ function for the same image, all of which are different-valued $P_F(d)$ functions. These different ways of producing different $P_F(d)$ functions for the same image involve variations of the path over which the image is integrated with respect to itself. In the present design, the path of integration is circular; and no attempt is made to render a change in this circular path in an effort to better discriminate for or against a particular class of image shapes. However, it is interesting to note that if it were possible to nutate an image of a square with respect to itself, where the path of nutation (over which integration of areas of overlap occur), is a square with sides parallel to the initial orientation of the square image, then the resulting $P_F(d)$ function would be the optimum discriminant function for that class. Thus, it becomes apparent that the selection of the path of integration plays an important role in the optimum discrimination of geometric shapes.

2.2 PSV DEVICE

The probability state variable (PSV) device presented here is capable of learning two image patterns at a time and sorting or classifying unknown patterns as belonging to either of these two classes or presenting a No-Decision answer.

Since it has already been observed that images that differ in shape by a size constant only are called similar and yield identical $P_F(d)$ functions, then distinct $P_F(d)$ functions are representative of different sets or classes of images (for the noise-free case). The learning of an image by the PSV device then constitutes the learning of the class of similar images (noise free).

In the PSV device, there are two modes of operation - Learn and Sort. During the Learn Mode, the device determines which "d"-value provides a maximum degree of distinguishability between the two classes of images being learned. Once the correct value of "d" is determined, along with the value $P_A(d)$ and $P_B(d)$, the device can be placed in the Sort Mode. An unknown image is compared with the "A" and "B" images by determining $P_X(d)$ at the same "d" previously determined to provide the maximum degree of distinguishability. Once a decision is made as to whether "A" or "B", a further test is made which may rule against presenting a selection between "A" or "B," and, thus the inhibit register can force a No-Decision answer, which implies that the unknown image is not sufficiently similar to the class selected to qualify. The inhibit register contains arbitrarily set values in this simple device, but in the physical world, this inhibit control would be associated with other elements of the environment. Thus, the implication of the logic of the PSV device is that if it becomes important that an error in identification of one of the images be prevented, the inhibit register can be adjusted so as to preclude deviations in excess of a prescribed value.

SECTION III

ANALYTICAL STUDIES

3.0 INTRODUCTION

The analytical studies were performed on the utility of using a point source projection system for generating the $P_F(d)$ function, on the sensitivity of the $P_F(d)$ function to integration path changes, on the nature of the structure of geometrical shapes and related series, and on the selection of operational test patterns for the Bionics Image Recognition System.

3.1 POINT SOURCE PROJECTION TECHNIQUE

In the system which has been designed and which is being mechanized, a point source of light from an oscilloscope illuminates a transparent image slide F1 (see Figure 2). F1 is a transparent letter F on an opaque background. The image of the letter F is projected upon the face of the image storage tube. The image storage tube face is a photo-emitter surface which emits electrons which are collected by the storage grid, thus creating an electron image within the storage tube. Once the image is stored within the storage tube, the mode of operation can be altered to retain the image stored and permit the passage of electrons through the storage grid to strike the viewing phosphor, whenever coincidence of illuminated points exists on both the photo-emitter and the storage grid. Consequently, if an image is displaced with respect to its initial position or the position for which the storage tube retains a copy of the image, only the overlapping areas of the two images will be displayed on the viewing phosphor. If the point of light is displaced from its central position to a new position, "X," the image will be displaced on the photo-emitter surface by a distance "d." The displacement will permit only a fractional part of overlap of the image illuminating the photo-emitter surface with the image stored internally. The fractional part overlapped is visible at the viewing phosphor surface. If then, the spot of light is made to move with circular motion, a corresponding motion will be produced upon the photo-emitter, thus causing the image to nutate about a center point.

At the viewing phosphor, there exists a continuous sequence of shape that represents the shape of the overlapping images during the course of one cycle of revolution of the spot of light of the oscilloscope. If the amount of area shown on the viewing phosphor is integrated during one cycle, the total area is the value of the $P_F(d)$ function for the specific "d" value used. If the value "d" is changed, the integrator output is reset to zero and a new value of $P_F(d)$ is measured during the next cycle for the new value of "d." The motion of the moving spot may occur so rapidly that the phosphor persistance produces a continuous ring. Thus, most, if not all, of the integration over a complete nutation may occur in the optical system prior to the generation of electrical signals. A photomultiplier tube is used to generate an electrical signal from the optical image.

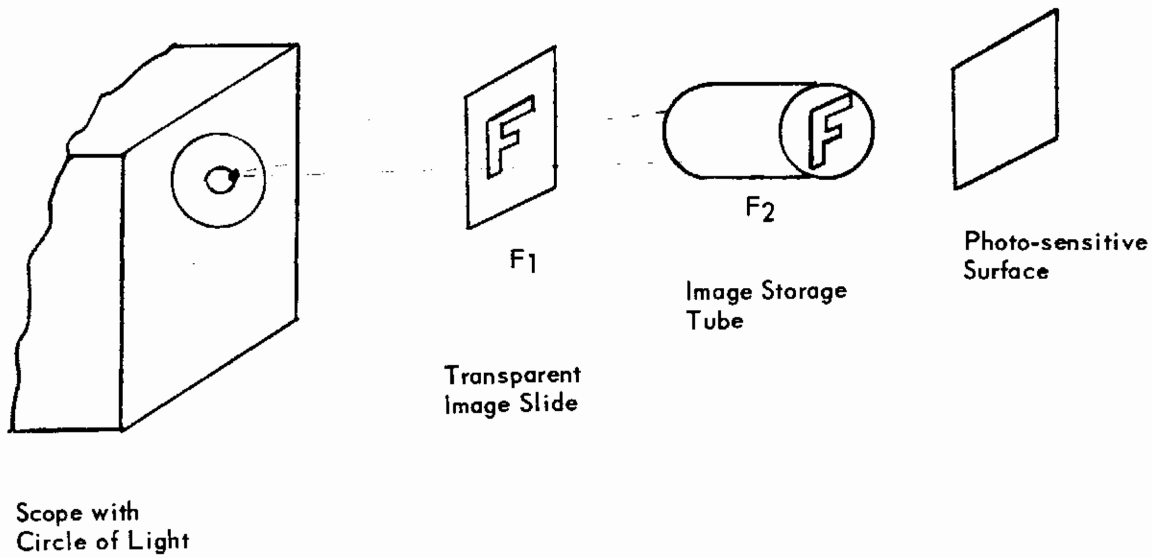


FIGURE 2 SIMPLIFIED ILLUSTRATION OF EQUIPMENT

A voltage controlled pulse generator then transforms this signal into a pulse train, the repetition rate of which is proportional to the signal voltage.

The utility of using a point source projection system such as described above lies in the fact that it is the most versatile system that can be constructed that insures ease of operation plus economy. The main disadvantage of such a system is that contact with the real world is made only through a projection slide transparency. However, the demonstration of the feasibility of combining the SITS and PSV systems is enhanced by the capability of using familiar techniques.

The nutation rate of 1000 cycles per second (except during the erase and write periods which utilize a nutation rate of 100 cycles per second to permit adequate storage tube operation) will enable the Bionics Image Recognition System to calibrate each point of the $P_F(d)$ function at the time a measurement is made. During the Learn Mode, the time required to calibrate and test a single point on one transparency will be approximately 0.5 second. The time required may be more or less, depending on the size of the image itself. The larger images require longer calibration periods. By calibrating or standardizing each point tested for each new value of "d," precision of measurements can be maintained more easily.

The time required for the Learning Mode operation for determining the optimum test value of "d" between two images is a nonlinear function of the complexity of mode variations of the $P_F(d)$ function itself. The selection of suboptimal test values of "d" is random; therefore, false optimum point selection may consume extra time of learning in the Learn Mode. Nevertheless, it appears that on the average approximately one minute will be required for this mode of operation.

Once the Learning Mode has been completed, the Sort Mode can commence. In this mode, the device will classify all subsequent images as belonging to, say class A or B or neither. The speed of this operation will proceed at essentially the same speed as it takes to manually load and unload image transparencies to be classified by the device.

3.2 THE EFFECTS OF INTEGRATION PATH CHANGES ON THE $P_F(d)$ FUNCTION

It has already been observed that similar figures or geometrical elements of the same set, yield identical $P_F(d)$ functions after size standardization operations. The effects of integration path changes on the $P_F(d)$ function will be discussed after due consideration of the standardization procedure employed.

There are two geometric measurements made upon which the automatic standardization procedure depends. The first measurement made is one of size of area of the geometric figure. The system automatically adjusts its gain such as to provide 32 divisions for the maximum value of the $P_F(d)$ function regardless of its area. Secondly, the system automatically adjusts itself to seek and select the maximum value of nutation possible, thus arriving at d_{max} for each geometrical figure. Then, for each geometrical figure, the "d-value" selection potentiometer always has d_{max} as its highest value.

When considering the effects of integration path changes on the $P_F(d)$ function, the standardization operation removes the constant of integration. When the nutation path is circular, the $P_F(d)$ function (with a maximum value of one for d = 0 and zero for $d = d_{max}$) bounds the greatest area for a geometric figure of a circle. When the nutation path is in the form of a square, the $P_F(d)$ function bounds the greatest area for a geometric figure of a square. Figure 3 illustrates this point, thus, it is seen that the integration path changes can be used to optimize the $P_F(d)$ function for geometrical figures corresponding in form to the nutation shape function.

The development of an orientation sensitive transform would then allow for the construction of criteria such as to identify a class according to the maximization of the area bounded by the $P_F(d)$ function as a function of the selected nutation shapes. In the case of a rectangle of extreme dimensions such as would be represented by a narrow straight line of finite width, the nutation of similar nature would possess extreme sensitivity to orientation. The full impact of the utility of such orientation sensitive transforms has not been realized.

3.3 GEOMETRIC SHAPES AND RELATED SERIES

One of the important properties of the $P_F(d)$ function is the isoperimetric property. It has been shown[1] that the first derivative of the $P_F(d)$ transformation evaluated at d = 0 is given by

$$P'_F(0) = -(1/\pi)p \qquad (1)$$

where p is the perimeter of the image in normalized measure. This equation is similar to a theorem of Cauchy quoted by Novikoff[2]. A proof is given by Ball[3]. This theorem is, in Novikoff's words:

> "...if you project a closed convex curve on the direction making an angle Θ with the X-axis, and average the resulting projections; regarding Θ as chosen at random between 0 and π , the result is 2/π times the length of the curve."

This may be stated:

$$\text{Average length} = (2/\pi)p \qquad (2)$$

This equation (2) implies a statistical method of determining the length of an image border (closed curve). The result in equation (1) is more general as it is not restricted to convex figures.

The values of the $P_F(d)$ function evaluated[1] for a circle and a square are:

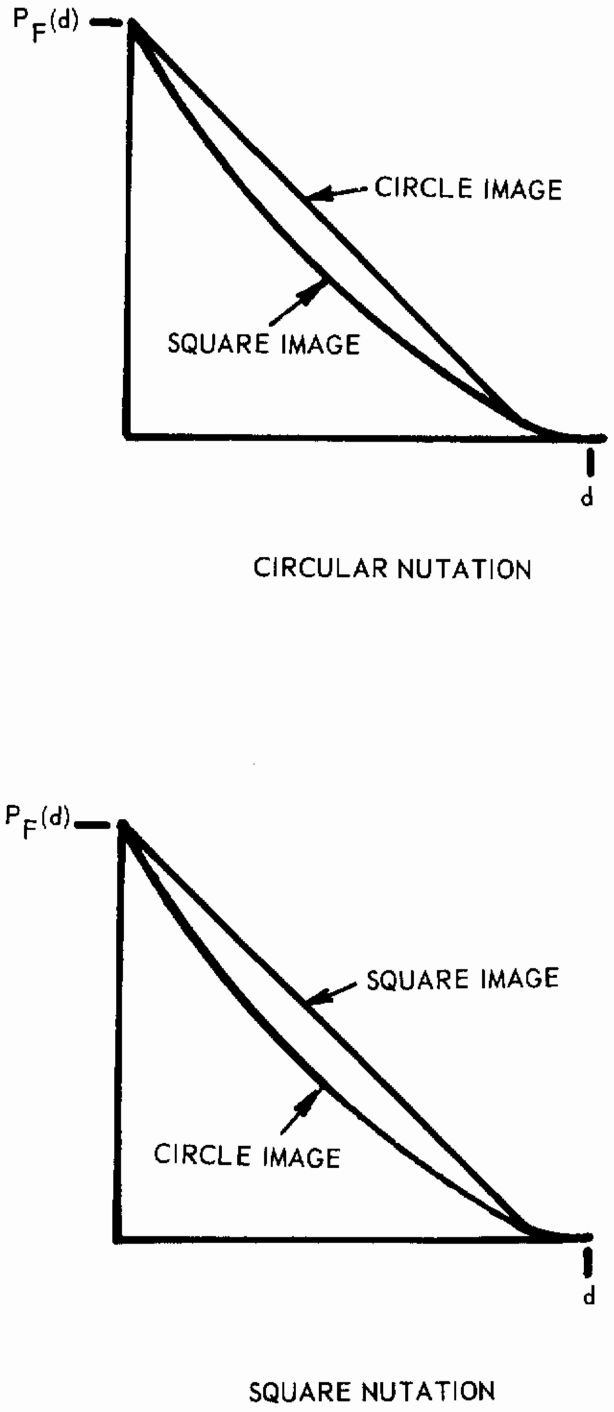


FIGURE 3 EFFECTS OF INTEGRATION PATH CHANGES

Circle: $P_F(d) = 2/\pi \cos^{-1}(\sqrt{\pi}/2\ d) - d\sqrt{1/\pi - d^2/4}$

Square: $P_F(d) = 1 - 4/\pi\ d + 1/\pi\ d^2$

where d is the nutation distance.

The corresponding first derivatives are:

Unit Area Circle:

$$P'_F(d) = -1/\pi\,(\text{perimeter}) = -1/\pi\,(2\sqrt{\pi}) = -2/\sqrt{\pi}$$

Unit Area Square:

$$P'_F(d) = -1/\pi\,(\text{perimeter}) = -1/\pi\,(4) = -4/\pi$$

Being a normalized transformation, the $P_F(d)$ function can be used in the classification of imagery on the basis of shape alone.

In reviewing the derivation and definition of the $P_F(d)$ function for a circle and a square, the writer observed certain relations between circles and squares which permit the construction of certain unusual series or progressions. An attempt has been made to relate these relations with the isoperimetric properties now known.

If a unit circle and a unit square are constructed (Figure 4), and if consecutive alternating squares and circles, respectively, are circumscribed about these figures, the following progressions can be observed about the areas in each set of figures:

Starting with the areas circumscribed about the unit circle, they are:

$$1,\ 4/\pi,\ 2,\ 8/\pi,\ 4,\ \ldots \qquad (3)$$

and starting with the areas circumscribed about a unit square, they are:

$$1,\ \pi/2,\ 2,\ \pi,\ 4,\ \ldots \qquad (4)$$

These geometric progressions differ from the usual geometric progressions in that they require two alternating multiplicative factors to generate succeeding terms of the progression. Also, the same two multiplicative factors are found in both progressions. In addition, it has been noted that the term for the product of the two progressions yields the progression:

$$2^0,\ 2^1,\ 2^2,\ 2^3,\ 2^4,\ \ldots \qquad (5)$$

The multiplicative factors appear as the second term in each of the original progressions since the first term is normalized or unit area. These terms are $4/\pi$ and $\pi/2$. Furthermore, if the perimeter is held

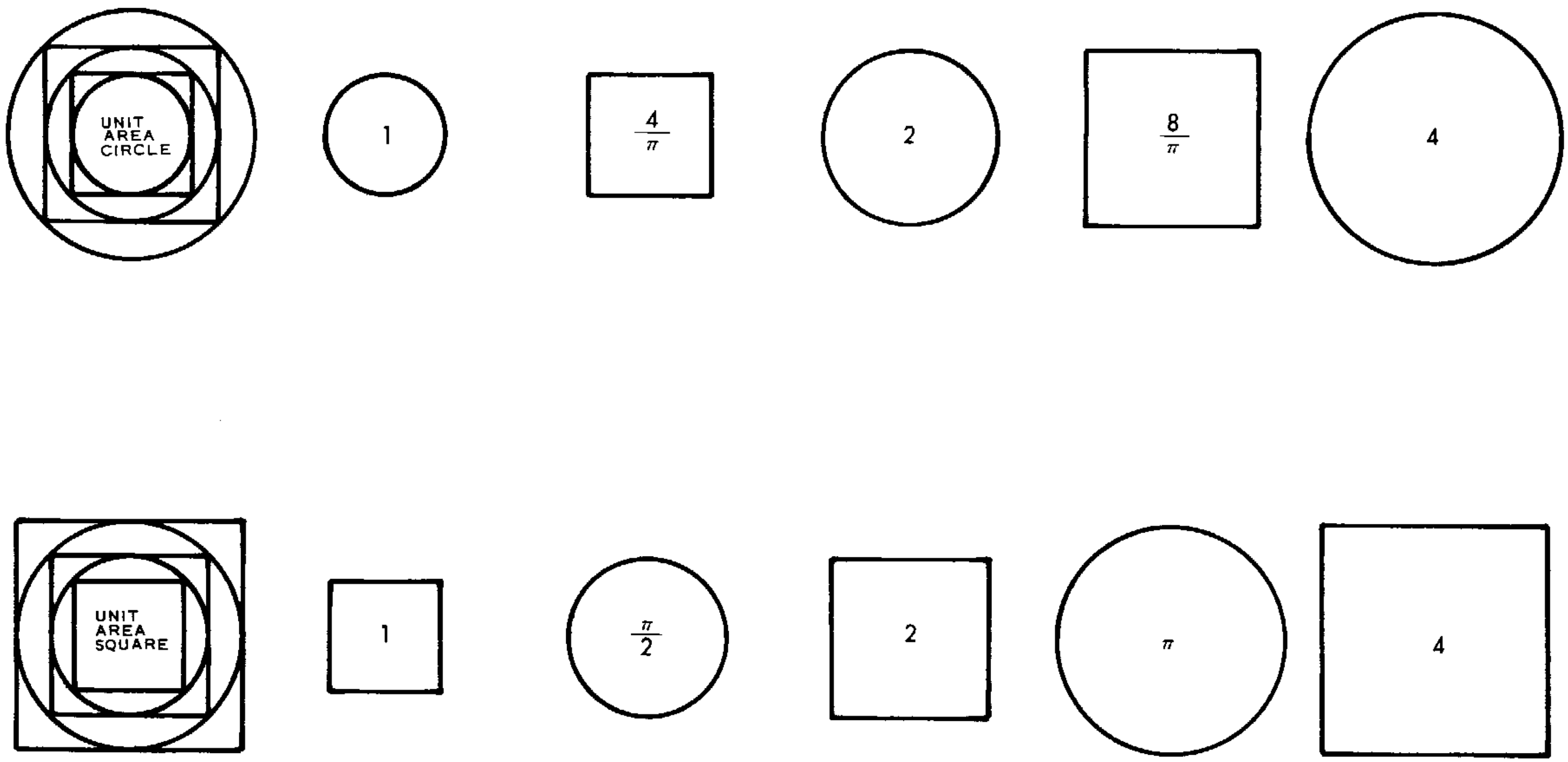
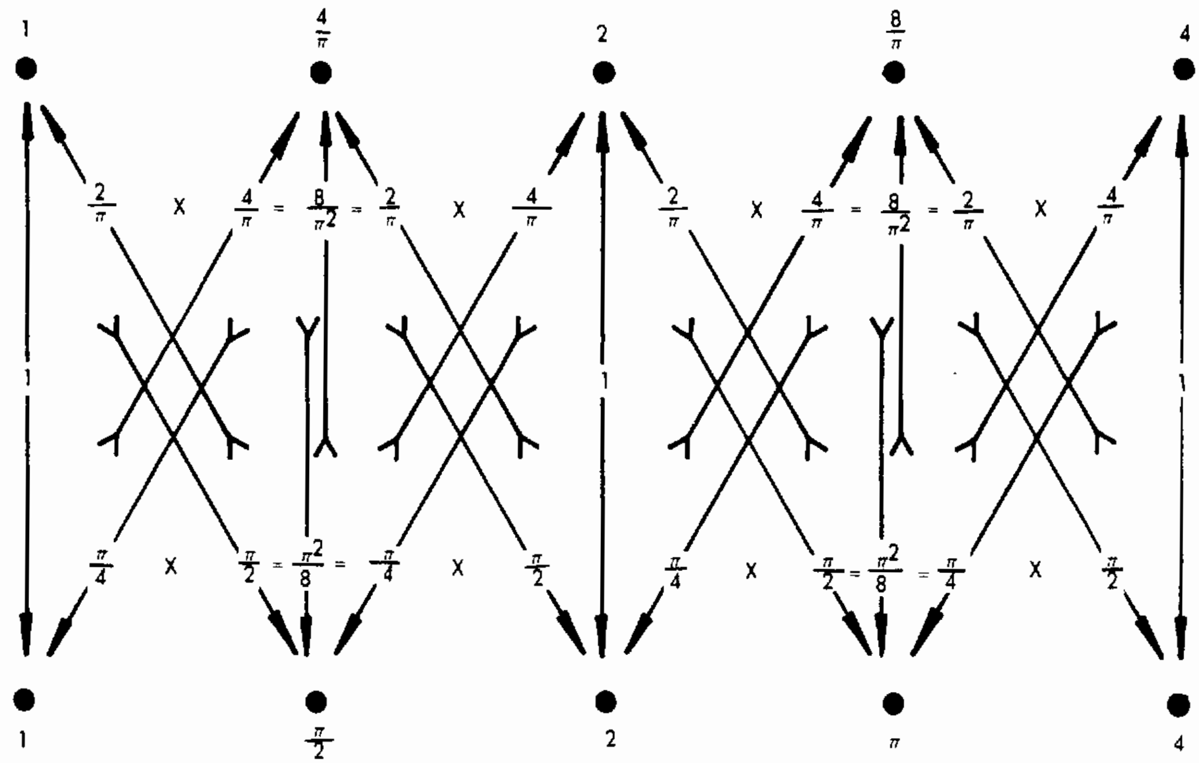


FIGURE 4 GEOMETRIC PROGRESSION OF SHAPES

constant while permitting the unit square [progression (4)] to mutate to a circle, the resulting area is equivalent to the square about the unit circle [progression (3)]; or determining the factors required to traverse multiple paths between the two progressions without regard to geometrical transformations, they are indicated below:



The establishment of these given relations represents the progress to date in relating the properties of geometric shapes to analytic expressions.

3.4 OPERATIONAL TESTS

Operational tests were performed to test the ability of the system to select the optimum "d" point signifying the point of maximum distinguishability of two images and thereafter classifying additional planar geometric shapes as being similar to one or neither of the original shapes. The ability to distinguish minute details as well as gross changes of patterns tested. This provides a measure of the response of the resolution of this system which is currently quantized to include 32 different step values of the $P_F(d)$ function in the range associated with normalized $P_F(d)$ function, namely zero to one. The value "d" is a continuous variable which determines the size of the circle of nutation and varied manually in steps. The range of the "d" function varies from zero to d_{max}, where d_{max} is determined by actual measurement for each image automatically each time it is viewed. In addition, specified sets of patterns were tested under distorted conditions to test the sensitivity and selectivity of the inhibit register of the PSV device. In total, over 1000 runs were made to test the Bionics Image Recognition System.

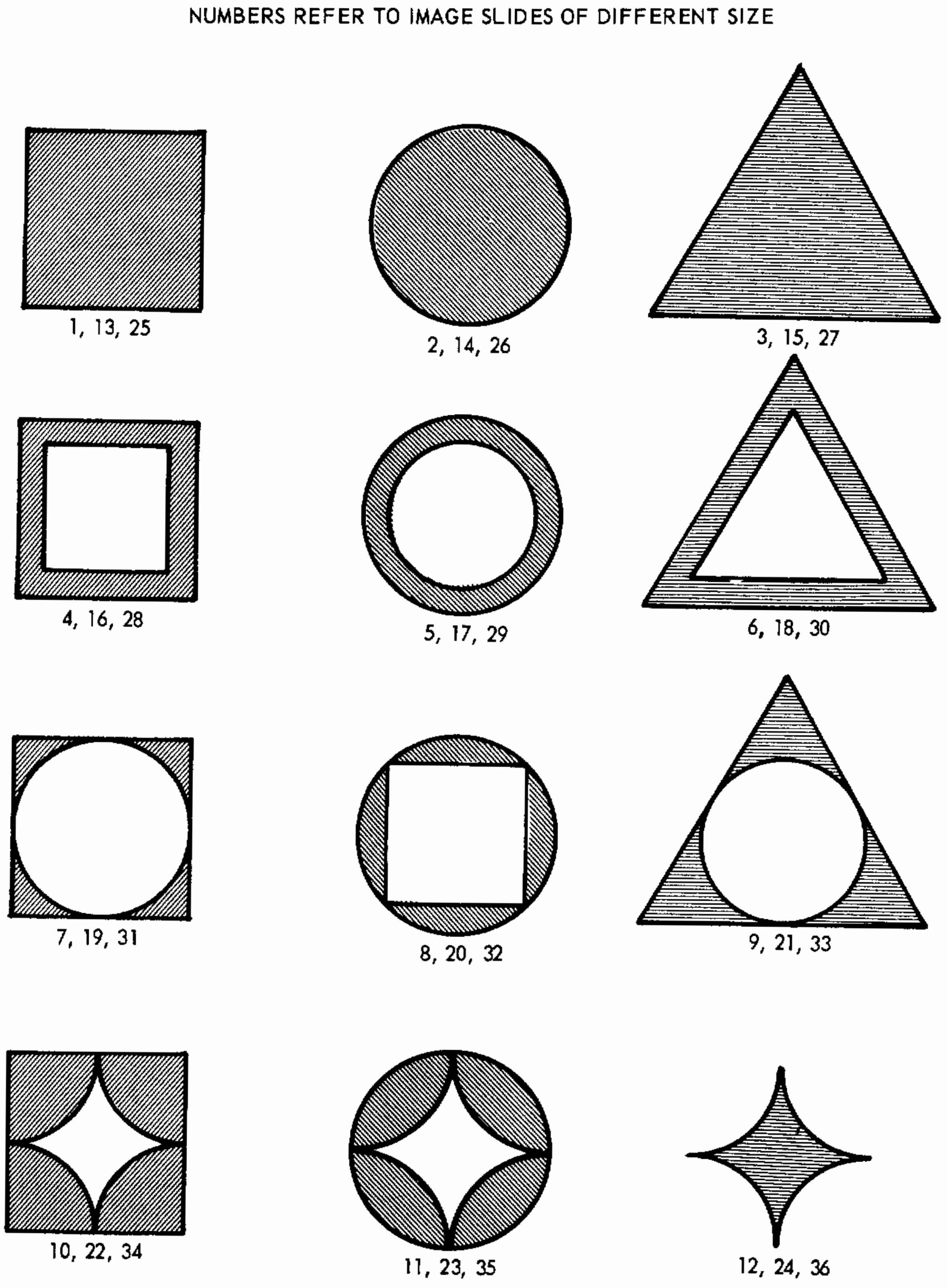


FIGURE 5 GEOMETRIC COMPOSITE IMAGES

OPERATIONAL TEST IMAGE AREAS
(in square inches)

1. $\pi/8$
2. $\pi/8$
3. $\pi/8$
4. $\pi/16$
5. $\pi/16$
6. $\pi/16$
7. $\frac{\pi^2}{32}$
8. $(\frac{\pi}{8} - \frac{1}{4})$
9. $\pi/8\ (1 - \frac{1}{3}\frac{\pi}{\sqrt{3}})$
10. $(\frac{\pi}{8} - \frac{\pi^2}{32})$
11. $\frac{\pi}{4} - \frac{1}{2}$
12. $\frac{1}{2} - \frac{\pi}{8}$
13. $\pi/16$
14. $\pi/16$
15. $\pi/16$
16. $\pi/32$
17. $\pi/32$
18. $\pi/32$
19. $\pi^2/64$
20. $(\pi/16 - \frac{1}{8})$
21. $\pi/16\ (1 - \frac{1}{3}\frac{\pi}{\sqrt{3}})$
22. $\pi/16 - \pi^2/64$
23. $\pi/8 - \frac{1}{4}$
24. $\frac{1}{4} - \pi/16$
25. $\pi/32$
26. $\pi/32$
27. $\pi/32$
28. $\pi/64$
29. $\pi/64$
30. $\pi/64$
31. $\pi^2/128$
32. $\pi/32 - \frac{1}{16}$
33. $\pi/32\ (1 - \frac{1}{3}\frac{\pi}{\sqrt{3}})$
34. $\pi/32 - \pi^2/128$
35. $\pi/16 - \frac{1}{8}$
36. $\frac{1}{8} - \pi/32$

FIGURE 6 OPERATIONAL TEST IMAGE AREAS

OPERATIONAL TEST IMAGE MAXIMUM LINEAR DIMENSION
(in square inches)

1.	0.63	2.	0.71	3.	0.95
4.	0.63	5.	0.71	6.	0.95
7.	0.63	8.	0.71	9.	0.95
10.	0.63	11.	0.71	12.	0.71
13.	0.45	14.	0.50	15.	0.67
16.	0.45	17.	0.50	18.	0.67
19.	0.45	20.	0.50	21.	0.67
22.	0.31	23.	0.50	24.	0.50
25.	0.31	26.	0.35	27.	0.47
28.	0.31	29.	0.35	30.	0.47
31.	0.31	32.	0.35	33.	0.47
34.	0.31	35.	0.35	36.	0.35

FIGURE 7 OPERATIONAL TEST IMAGE MAXIMUM LINEAR DIMENSION

3.4.1 Operational Test Patterns

Imagery used in providing tests for the new system consisted mainly of a large set of geometric images. This set includes composites of portions of regular figures which are solid planer in form and also hollow planer in form. These figures are shown in Figure 5 and represent special geometric forms which are compatible with the geometric shapes and related series discussed in the previous section. Each figure selected has three magnitudes of size and 10 trials were used to determine adequate normalization and consistency of results. Figures 6 and 7 give tables showing the areas and maximum linear dimensions of images utilized. These are 12 patterns with three different sizes yielding a total of 36 images. These patterns contain images which are of equal area and different d_{max} values and also images with equal d_{max} values with different areas. Thus, opportunity is afforded for testing the standardization of both area and d_{max} directly by read-out of the correct register, P_F or d_{max}.

3.4.2 Operational Test Results

No difficulty was encountered in producing meaningful differences for the image pairs given in the table below: (Figure 8)

1 - 2	2 - 3
4 - 5	5 - 6
7 - 8	8 - 9
10 - 11	11 - 12
13 - 14	14 - 15
16 - 17	17 - 18
19 - 20	20 - 21
22 - 23	23 - 24
25 - 26	26 - 27
28 - 29	29 - 30
31 - 32	32 - 33
34 - 35	35 - 36

FIGURE 8 BASIC IMAGE COMBINATION TEST TABLE

With these basic combinations, an additional number of tests were performed using each of these for the learning procedure and their corresponding similar pair for image recognition. In each instance recognition was achieved with a high degree of repeatability. In addition, other numerous tests were performed to qualitatively determine the effect of the inhibit function register on certain image recognition tests.

In general, it was determined that a dynamic range for P_F standardization in excess of 4:1 was easily achieved with the equipment theoretical limit designed for a range of nearly 8:1 for a fixed light intensity level. Within the achievable range for a fixed light intensity setting, the lower recognition levels exhibit the most variability due to the limited resolution of the system. A $|\Delta P_F|$ of approximately 4 is the least difference that can be used reliably due to digital round off error and other cumulative effects including optical errors. Other tests included deliberate misalignments in the optical system for introducing distortion into the image recognition process. Image recognition with the large images was achieved with nutation center displacements as large as 1/8".

SECTION IV

SYSTEM DESIGN

4.0 INTRODUCTION

There are four basic functions which must be performed by this circuit, which learns and recognizes images using the $P_F(d)$ transform. They are as follows:

(1) Transform Generation - Generation of a P_F signal from an optically nutated image

(2) Standardization - The two end points of the P_F transform curve must be standardized to permit comparison of two functions, these points being $P_{F_{max}}$ and d_{max}

(3) Learning - "Reward" of each new value of "d" if it results in a better value of $|\Delta P_F|$ than the previous choice; "Punish" if it does not

(4) Sorting - Comparison of learned P_F values with the P_F value of an unknown image scanned using the learned value of "d", resulting in a recognition decision.

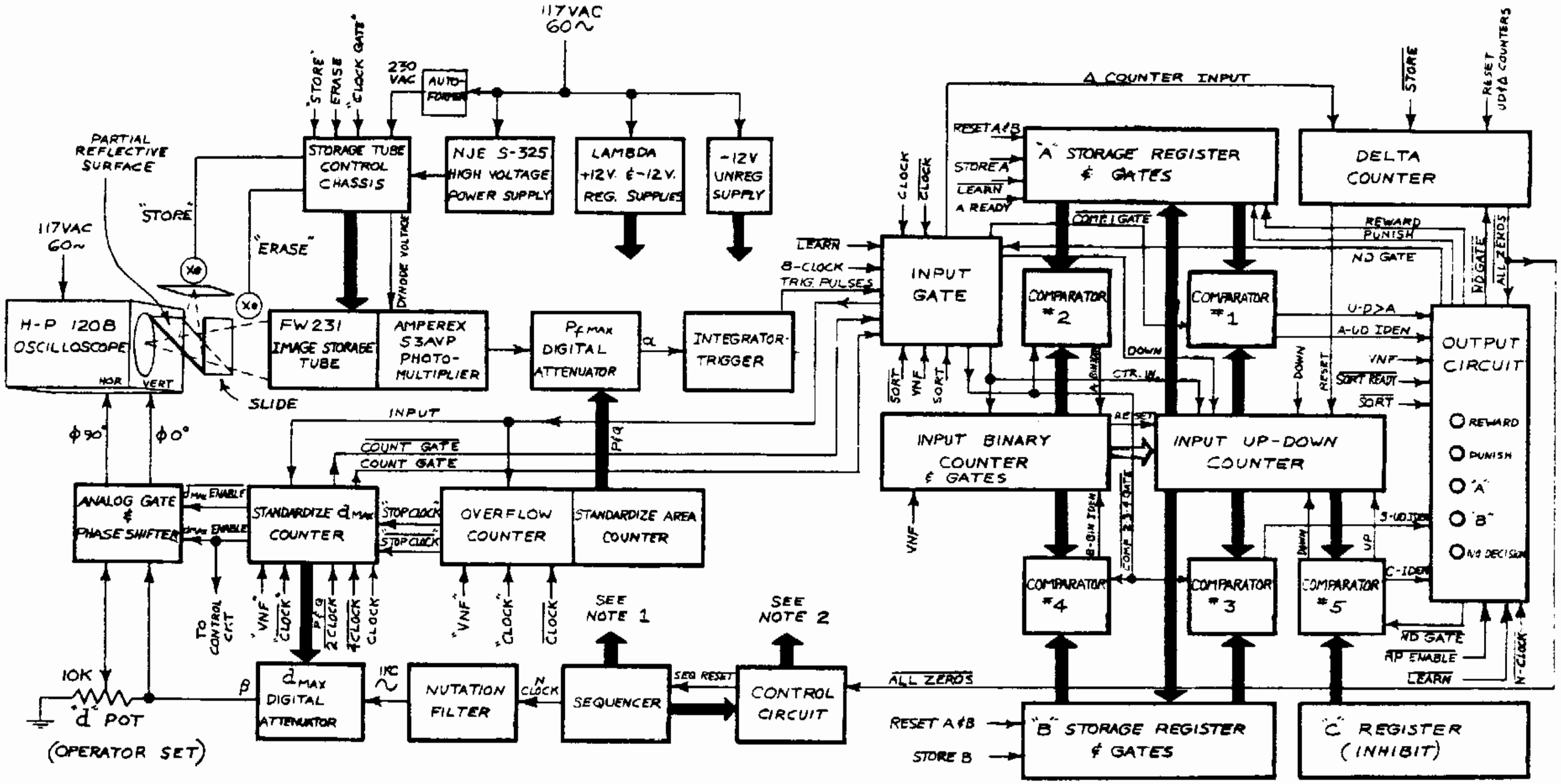
These four functions can be arranged such that the system is divided into two major parts - the SITS and PSV sections. These four functions are arranged such that Transform Generation and Standardization form the SITS System, while Learning and Sorting form the PSV System. This subdivision is shown in the general block diagram, Figure 1. A more detailed breakdown can be found in Figure 9.

4.1 SITS - NUTATING SPOT OF LIGHT DESIGN

A technique allowing rapid generation of values of the P_F (d) function was sought. A design figure of approximately one second was attained. This allows for the construction of equipment that permits the processing of a relatively large number of images in a reasonable length of time.

4.1.1 $P_F(d)$ Generation

A spot of light from a cathode ray oscilloscope is used as a point source. A glass slide composed of transparent and opaque sections creates an image when illuminated by the point source of light. The image created by the light transmitted through the slide is cast against the photo emitter of the storage tube. The photo emitter, in turn, is responsible for emitting electrons which are collected by the storage grid, thus creating an electron image stored within the storage tube. Once the image is stored within the storage tube, the storage tube mode of operation can be altered to retain the image stored and permit the passage of electrons through the storage grid to strike the viewing phosphor, whenever coincidence of illuminated points exists on both photo emitter and the storage grid. Consequently, if an image is displaced with respect to its initial position or the position for which the storage tube retains a copy of the image, only the overlapping areas of the two images will be displayed on the viewing phosphor. If the point of light



NOTES ~ SIGNALS ORIGINATING AT THE SEQUENCER AND CONTROL CIRCUIT ARE SHOWN AT THEIR TERMINAL ENDS ONLY, FOR CLARITY. THEY ARE AS FOLLOWS:

① SEQUENCER

- N-CLOCK
- $\overline{\text{N-CLOCK}}$
- 8-CLOCK
- $\overline{\text{4-CLOCK}}$
- $\overline{\text{2-CLOCK}}$
- CLOCK
- $\overline{\text{CLOCK}}$
- $\frac{1}{4}$ CLOCK
- $\frac{1}{8}$ CLOCK
- $\overline{\frac{1}{8}\text{ CLOCK}}$
- $\frac{1}{16}$ CLOCK
- CLOCK GATE

② CONTROL CIRCUIT

- ERASE
- STORE
- $\overline{\text{STORE}}$
- STORE A
- $\overline{\text{STORE B}}$
- $\overline{\text{LEARN}}$
- $\overline{\text{A READY}}$
- $\overline{\text{SORT READY}}$
- SORT
- $\overline{\text{SORT}}$
- $\overline{\text{R-P ENABLE}}$
- VNF
- RESET U-D & Δ COUNTERS
- LEARN OR SORT S.S.
- RESET A & B
- SEQUENCER RESET
- DOWN

FIGURE 9 IMAGE RECOGNITION SYSTEM – COMPLETE BLOCK DIAGRAM

is displaced from its central position to a new position, "X", the image will be displaced on the photo emitter by a distance "d". The displacement will permit only a fractional part of overlap of the image illuminating the photo emitter surface with the image stored internally. The fractional part overlapped is visible at the viewing phosphor surface. If then, the spot of light is made to move with circular motion, a corresponding motion will be produced upon the photo emitter thus causing the image to nutate about a center point. At the viewing phosphor, there exists a continuous sequence of shape that represents the shape of the overlapping images, during the course of one cycle of revolution of the spot of light. If the amount of area shown on the viewing phosphor is integrated during one cycle, the total area is the value of the $P_F(d)$ function for the specific "d" value used. If the value "d" is changed or correspondingly if the diameter of the circle created by the rotating spot is changed, the integrator output is reset to zero and a new value of $P_F(d)$ is measured during the next cycle for the new value of "d". The motion of the moving spot may occur so rapidly that the phosphor persistence produces a continuous ring. Thus most, if not all, of the integration of the P_F function over a complete nutation may occur in the optical system prior to the generation of electrical signals.

Due to the limited brightness of the flying spot, a photomultiplier tube is used to generate an electrical signal from the optical image. A voltage controlled pulse generator then transforms this signal into a pulse train, the repetition rate of which is proportional to the signal voltage.

4.1.2 Standardization of P_F Curve End Points

The signal from the image storage tube prior to nutation (the flying spot held stationary) represents P_{Fmax}, since the projected image exactly coincides with the stored transparency. This value must be made the same for all images regardless of their size or brightness. This is accomplished by an attenuator which the pulse generator adjusts automatically until a specific output pulse repetition rate is attained.

Next, the sine wave which nutates the flying spot must be adjusted in amplitude until the signal applied to the top of the "d" pot just barely reduces the P_F signal to zero. At this point, nutation is occurring with a diameter d_{max}. This is accomplished by an attenuator, initially closed, which gradually opens until no more pulses are forthcoming from the pulse generator during a specific time interval.

This standardization procedure must be performed each time an image is scanned.

4.2 PSV GENERAL DESIGN

The probability state variable device presented here is capable of learning two image patterns at a time and sorting or classifying unknown patterns as belonging to either of these two classes or presenting a "No Decision" answer.

4.2.1 Learning

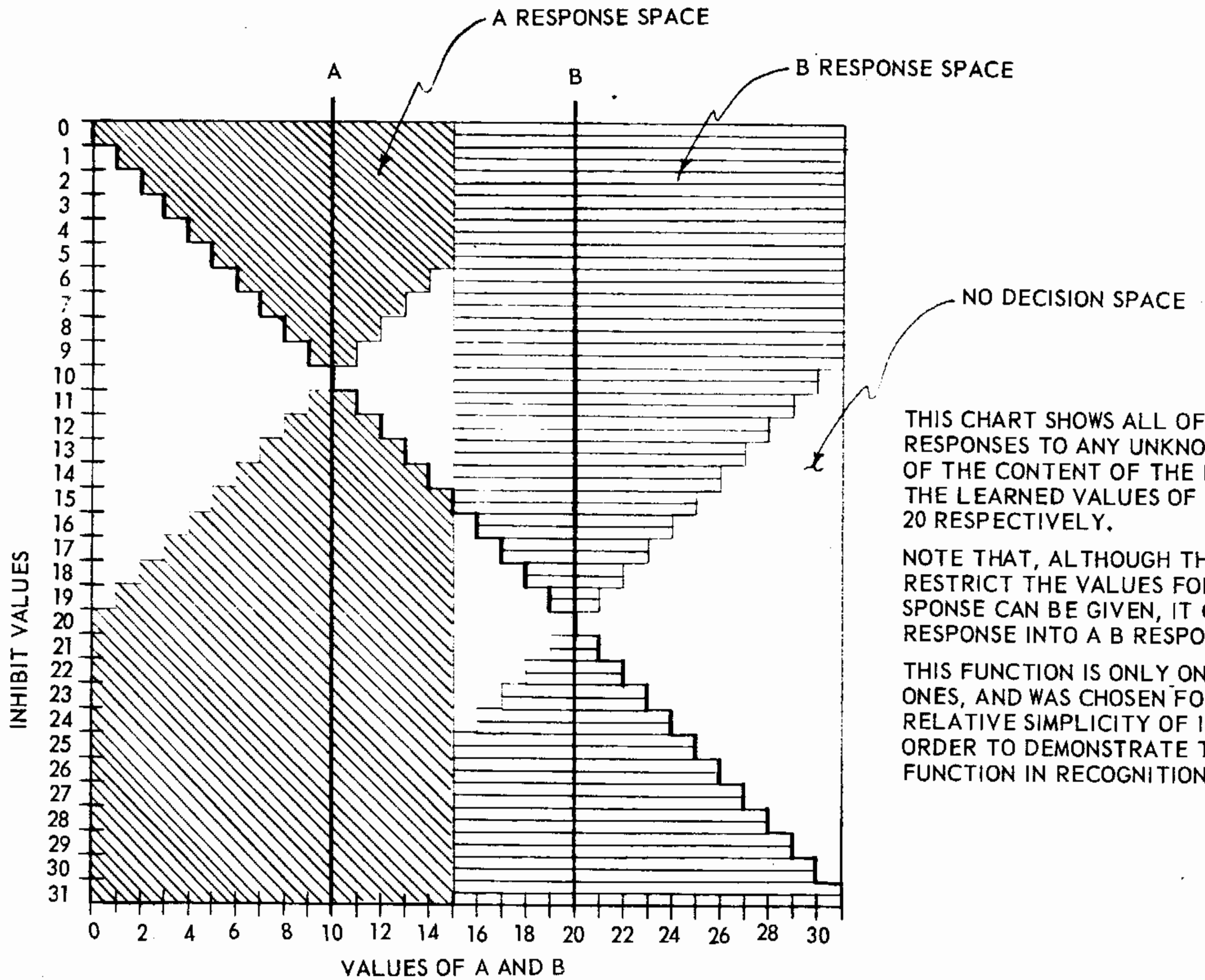
The "d" pot is set by the operator who will make subsequent settings in a creeping random manner, gradually converging on an optimum value. Image "A" is scanned, and the pulses from the pulse generator occurring during a specific sample interval are counted as an up-down counter counts up. Next, image "B" is scanned, and the counter counts back down again in such a manner that the count remaining is the absolute difference, $|\Delta P_F|$, between the two P_F values. This value is stored in the "A" storage register. This procedure is repeated again with different settings of the "d" pot. If the new $|\Delta P_F|$ is less than the best previous value, a "Punish" light is lit. If the new value is greater than the best previous value, the new value replaces the best previous one in the "A" register, and the "Reward" light is lit. This process continues until the optimum $|\Delta P_F|$ is attained. At this time, using the learned value of "d", the stored value of $|\Delta P_F|$ is erased, and P_A and P_B are stored in the "A" and "B" storage registers, respectively. The system is now ready to identify unknown images.

4.2.2 Sorting

The unknown image is scanned at the learned optimum "d" setting, and its P_F value stored in the up-down and binary counter. This value is then compared with the stored P_F values for images "A" and "B". If the unknown value is closer to P_A, the new image is identified as "A". If it is closer to P_B, it is identified as "B".

4.2.5 The "Inhibit" Function

Obviously, the unknown image may be neither A nor B. Or perhaps we may wish that a class of images with a specific range of variations be identified as "A" or "B". Under these circumstances, we shall want to define the range of values within which an identification may be made. For this purpose, an "Inhibit" function is introduced. In a more complex system, this function may originate from a part of the system which has learned to recognize entirely different images. In this device, the "Inhibit" register consists of switches on the control panel whereby the operator may set in the inhibit value at will. This function causes certain values of the unknown P_F function to produce a "No Decision" response instead of "A" or "B". Many different functions could be employed for this purpose. The specific one used here is defined in Figure 10. It will be noted that when inhibit values at either end of the scale are used, the system is reduced to the simple "A" or "B" decision described earlier. Figure 11 presents a table that gives the accepted range of the A and B values for the unknown image as a function of the "Inhibit" register for selected values of A and B for the learned images corresponding to Figure 10.



THIS CHART SHOWS ALL OF THE POSSIBLE DECISION RESPONSES TO ANY UNKNOWN IMAGE AS A FUNCTION OF THE CONTENT OF THE INHIBIT REGISTER, WHEN THE LEARNED VALUES OF $P_F A$ AND $P_F B$ ARE 10 AND 20 RESPECTIVELY.

NOTE THAT, ALTHOUGH THE INHIBIT REGISTER CAN RESTRICT THE VALUES FOR WHICH AN A OR B RESPONSE CAN BE GIVEN, IT CANNOT CHANGE AN A RESPONSE INTO A B RESPONSE, OR VISE-VERSA.

THIS FUNCTION IS ONLY ONE OF MANY POSSIBLE ONES, AND WAS CHOSEN FOR ITS VERSATILITY AND RELATIVE SIMPLICITY OF IMPLEMENTATION, IN ORDER TO DEMONSTRATE THE VALUE OF AN INHIBIT FUNCTION IN RECOGNITION CIRCUITRY.

FIGURE 10 EFFECT OF INHIBIT SIGNAL ON SORT RESPONSES

IF INHIBIT VALUE IS AS BELOW:	THE EFFECT ON RANGE OF ACCEPTED	
	A VALUE IS:	B VALUE IS:
0	0 – 15	15 – 31
1	1 – 15	15 – 31
2	2 – 15	15 – 31
3	3 – 15	15 – 31
4	4 – 15	15 – 31
5	5 – 15	15 – 31
6	6 – 14	15 – 31
7	7 – 13	15 – 31
8	8 – 12	15 – 31
9	9 – 11	15 – 31
10	10	15 – 30
11	9 – 11	15 – 29
12	8 – 12	15 – 28
13	7 – 13	15 – 27
14	6 – 14	15 – 26
15	5 – 15	15 – 25
16	4 – 15	16 – 24
17	3 – 15	17 – 23
18	2 – 15	18 – 22
19	1 – 15	19 – 21
20	0 – 15	20
21	0 – 15	19 – 21
22	0 – 15	18 – 22
23	0 – 15	17 – 23
24	0 – 15	16 – 24
25	0 – 15	15 – 25
26	0 – 15	15 – 26
27	0 – 15	15 – 27
28	0 – 15	15 – 28
29	0 – 15	15 – 29
30	0 – 15	15 – 30
31	0 – 15	15 – 31

NOTE: THE LEARNED VALUE OF P_A AND P_B ARE ASSUMED TO BE 10 AND 20, RESPECTIVELY

FIGURE 11 INHIBIT VALUE AND RESPONSE TABLE

4.3 DETAILED CIRCUIT DESCRIPTION

The complete block diagram of the system as it is presently built is shown in Figure 9. Figures 12 through 33 show the detailed circuitry or digital logic represented by the individual blocks in the complete diagram. The function of each block is described below.

4.3.1 Optical System

The optical system is represented by Figures 12 and 13. These figures show the optical system circuitry and details of the storage tube control chassis. In Figure 12, the main components include the oscilloscope, the motor drive and associated circuitry, store and erase xenon flash bulbs, the image st rage tube, and the photomultiplier tube.

The oscilloscope with a P-11 phosphor is used to produce the flying spot which projects the image of the slide being viewed into the image storage tube. Although this spot is quite satisfactory for the "read" portion of the cycle, it is not bright enough for the "store" and "erase" functions. For this purpose, xenon flash lamps, operated by the control circuitry, are used. The "store" lamp shines through a small hole which is optically superimposed on the same part of the storage tube as the flying spot by means of a partially reflecting plate. The "erase" lamp simply illuminates the entire sensitive surface of the storage tube prior to "store" and "read" operations.

Since the oscilloscone spot is limited in brilliance, a very faint image is produced on the viewing screen of the image storage tube. For this reason, a photomultiplier tube (Amperex 53AVP) is used to produce the electrical output signal.

The motor drive and associated circuitry are used to position a two-position image slide holder for input to the image recognition system. The slide holder position is actuated from the internal logic.

In Figure 13, a detailed circuit diagram of the storage tube control chassis is presented. The important functions of this figure are to provide operating voltages to the image storage tube to permit "erase" and "store" operations. In addition, actuation voltages for the xenon flash tubes are generated. The inputs to this circuit are: ±1750 VDC, -12VDC, clock gates 115 VAC, "erase" instruction, ground, and "store" instruction. The outputs are connected to backing electrode, photomultiplier dividers, collector electrode, "store" xenon anode, photocathode, "erase" xenon anode. In addition, the specified signal outputs are: "store" xenon trig and "erase" xenon trig.

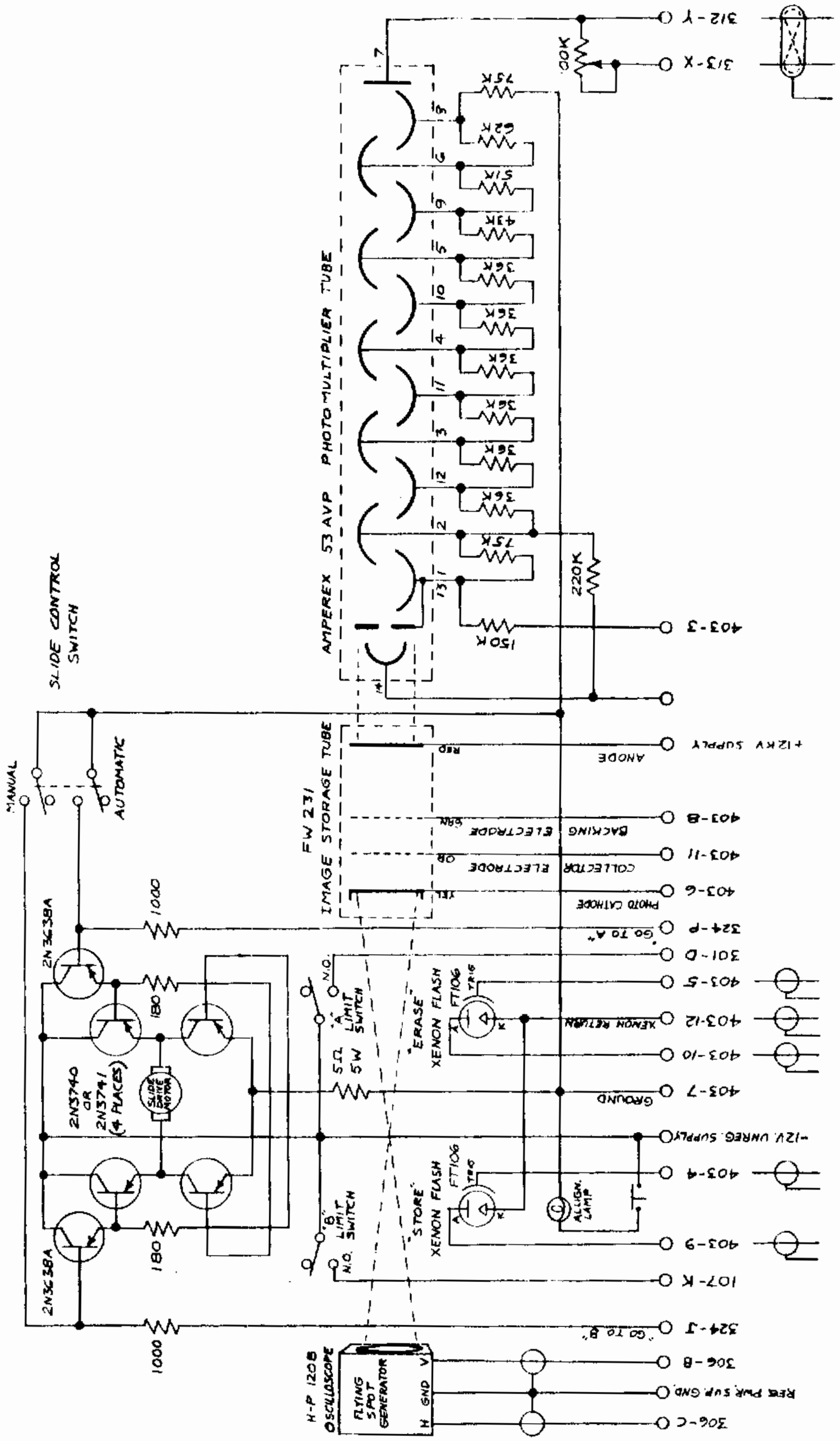


FIGURE 12 OPTICAL SYSTEM CIRCUITRY

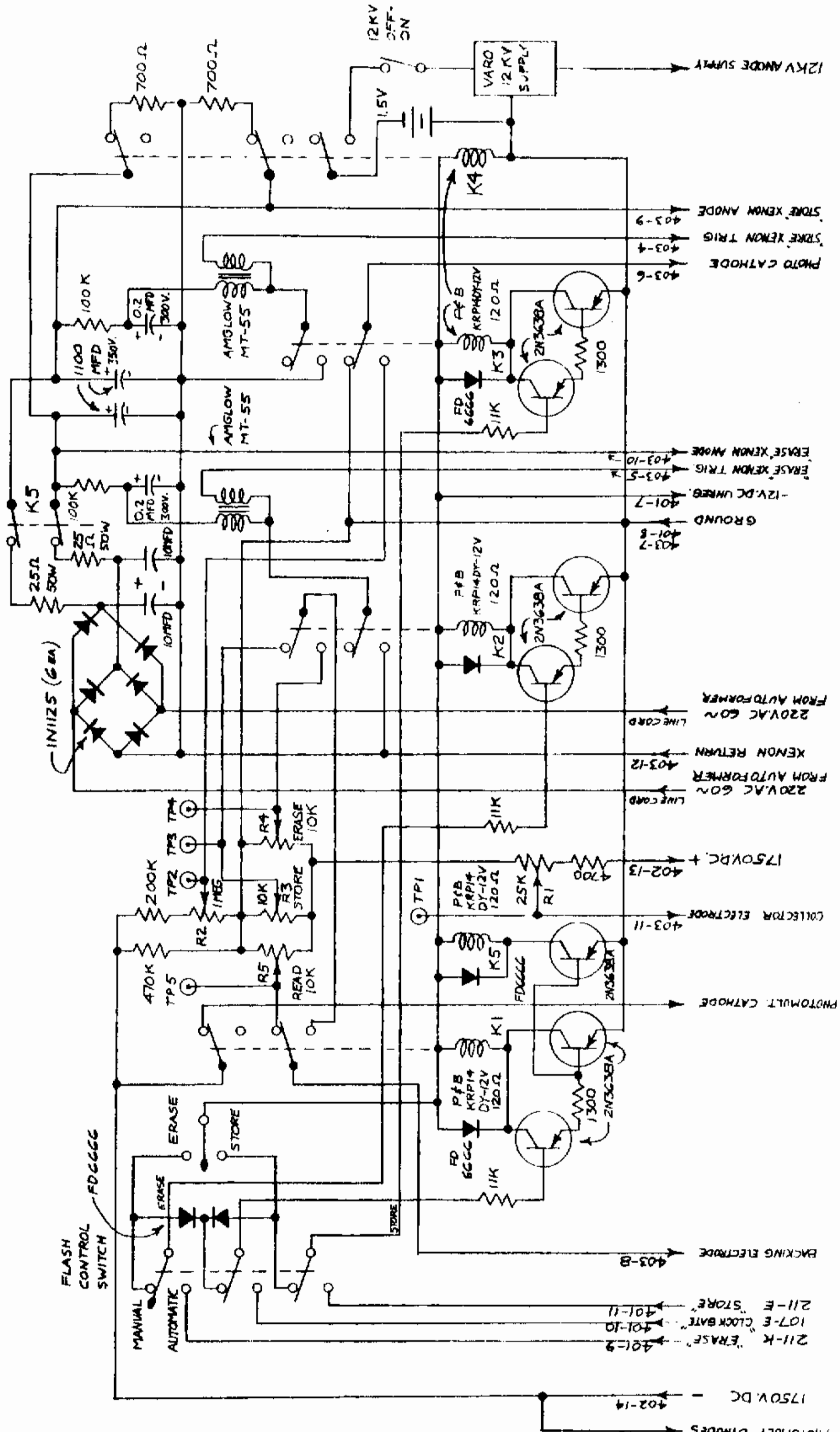


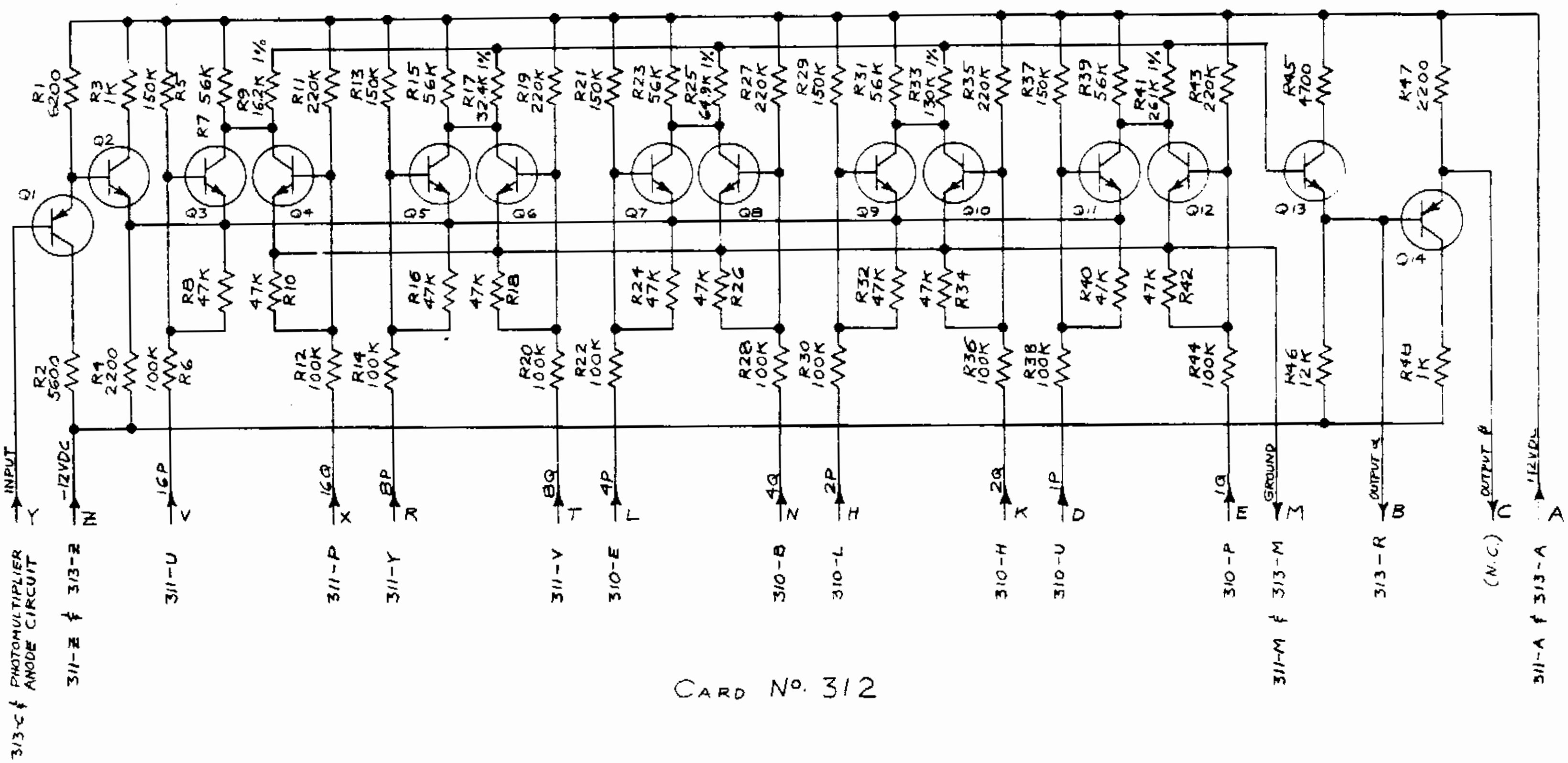
FIGURE 13 STORAGE TUBE CONTROL CHASSIS

The key inputs are: Clock gate, "Erase" and "Store". The "Erase" occurs each time a view next figure (VNF) instruction is given. The "Store" operation stores the new image on the Image Storage Tube. The power supply voltages are supplied from appropriate sources with the equipment and not shown on this schematic.

4.3.2 $P_{F_{max}}$ Standardization

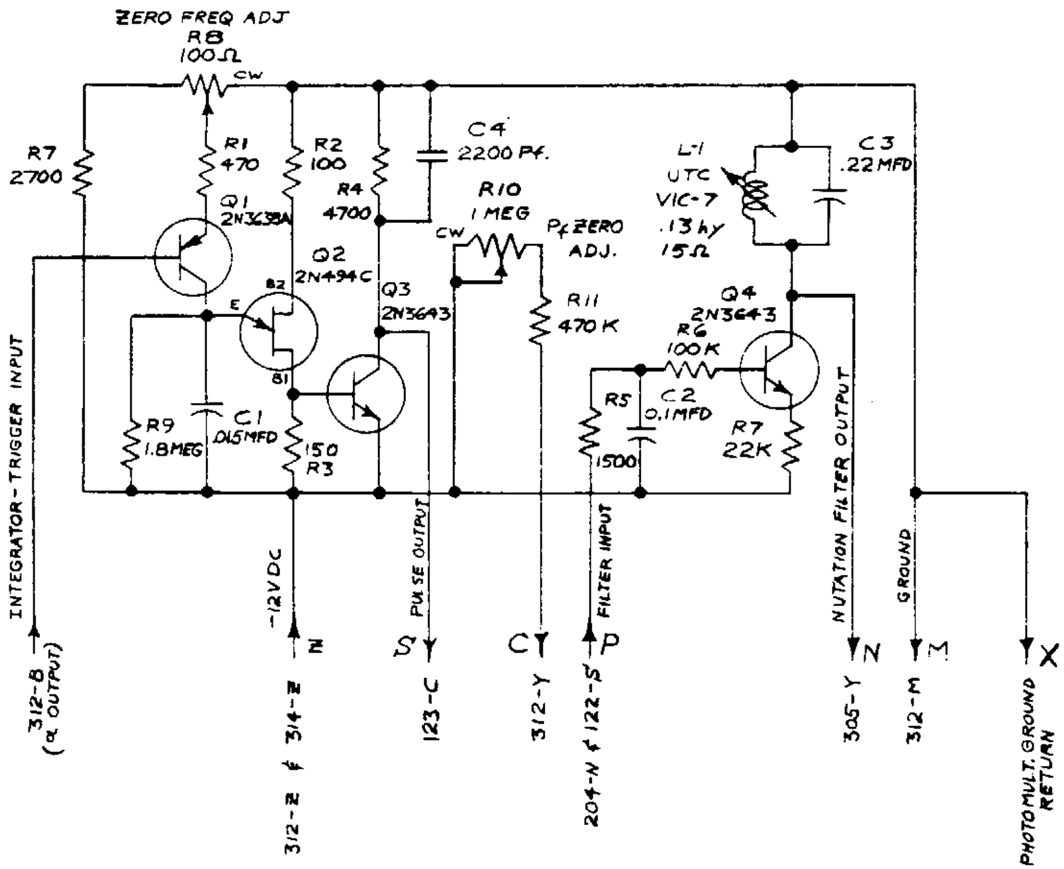
The $P_{F_{max}}$ standardization is achieved with the use of the $P_{F_{max}}$ digital attenuator (Figure 14), the integrator trigger and nutation filter (Figure 15), and the "overflow" and "standardize area" counters (Figure 16). The digital attenuator is a switching circuit in which the attenuation of the input signal can be controlled in 32 discrete increments of attenuation represented by numbers 0 through 31. In order that any images with the same shape produce the same $P_F(d)$ function, it is necessary that $P_{F_{max}}$ be represented by the same number in the system, regardless of the actual size or brightness of the image. This number is 31, the maximum possible count on a 5-bit counter or digital attenuator. Attenuation of the photomultiplier output signal to a standard level is accomplished by means of a digital attenuator, located between the photomultiplier and the pulse generator. It consists of five precision resistors, each one half the resistance of the preceding one, which are switched into either the upper or lower half of a voltage divider, in parallel, by means of transistor gates. These gates are operated by the five binary stages of the "standardize area" counter. Initially, this attenuator is fully open (no attenuation) and the pulse generator produces considerably more than 31 pulses during the eight milliseconds sampling period. The "overflow" counter counts up to 31, and spills over into the "standardize area" counter. During each successive sampling period, the "standardize area" counter increases its contents by one count, closing down the digital attenuator slightly each time until the pulse rate is barely sufficient to fill the "overflow" counter without spilling over into the "standardize area" counter. At this point, standardization of $P_{F_{max}}$ is complete, further pulses are gated out, and the count is held for the duration of the learn or sort cycle in process. The "overflow" and "standard area" counters (Figure 16) are part of the same logic counter which has been designated as two counters. Actually, the "overflow" counter is the lower section of the "standard area" counter. These counters provide the required signals to the digital attenuator. There are two digital attenuators in the system. The "overflow" and "standard area" counters accept four automatic signal inputs which are "VNF," "input from trigger," "clock," and "$\overline{\text{clock}}$." These counters in turn provide output signals "stop clock," "$\overline{\text{stop clock}}$" "1P," "1Q," "2P," "2Q," "4P," "4Q," "8P," "8Q," "16P," and "16Q." The "standard area" counter shown in Figure 16 has additional identical stages which are not used.

NOTE ~ PNP TRANSISTORS ARE 2N3638A
NPN TRANSISTORS ARE 2N3643



CARD No. 312

FIGURE 14 $P_{F_{max}}$ DIGITAL ATTENUATOR



CARD N° 313

FIGURE 15 INTEGRATOR TRIGGER AND NUTATION FILTER

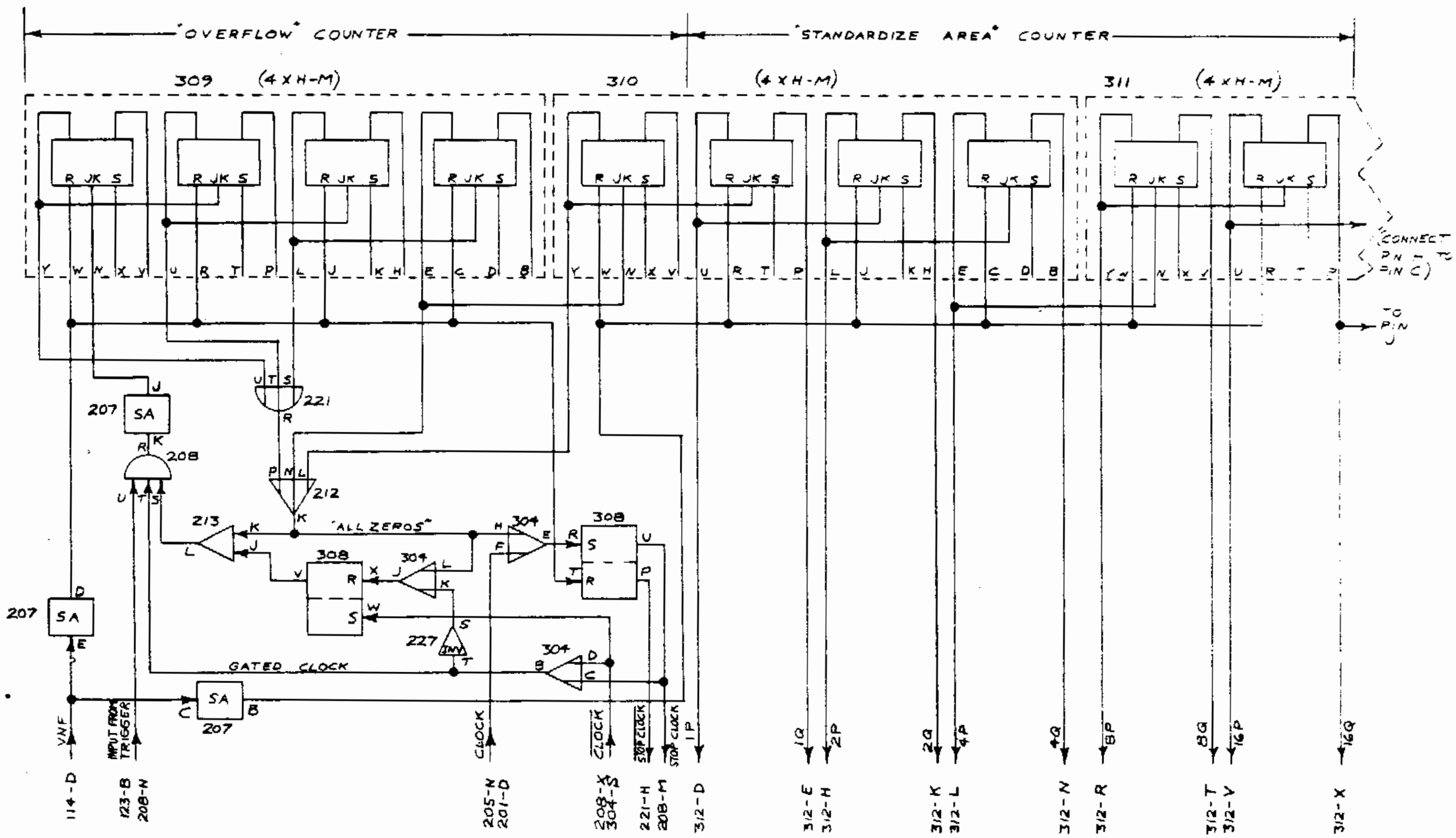


FIGURE 16 OVERFLOW AND STANDARDIZE AREA COUNTERS

In Figure 15, the integrator-trigger provides a digital output proportional to the varying dc input. The signal from the photomultiplier controls the pulse repetition rate of a voltage-controlled pulse generator. The number of pulses occurring within an eight millisecond time interval represents the value of the P_F transform in a form readily handled by digital circuitry. Also, the nutation filter is used to selectively filter the fundamental of the multivibrator and produce a pure sine wave. This sine wave provides the nutation frequency required. There is no functional reason that the integrator-trigger and nutation filter have been constructed on the same board other than utilization of available space.

4.3.3 d_{max} Standardization

The d_{max} standardization is achieved with the use of the "standardize d_{max} counter" (Figure 17) and the "d_{max} digital attenuator" (Figure 18). In order to standardize d_{max}, the sine wave nutation signal at the top of the "d" pot (shown in Figure 9) must always produce nutation at the maximum "d" for the particular image being viewed. A d_{max} digital attenuator, initially closed, controls the amplitude of the signal. During standardization, the nutation signal, normally taken from the "d" pot wiper, is taken from the top of the "d" pot.

Upon completion of the "standardize P_F" operation, a logic signal ("stop clock") gates the pulse generator output into the "standardize d_{max}" counter, which opens up (more signal) the digital attenuator slightly with each pulse until no further pulses are forthcoming from the pulse generator during a specific compiling period. This completes the standardization of d_{max}, the counter is gated shut, nutation output is again taken from the pot wiper, the count is held for the duration of the "learn" or "sort" cycle in process.

The "standardize d_{max} counter" shown in Figure 17 is similar to the counter shown in Figure 16. The "standardize d_{max} counter" controls the β digital attenuator shown in Figure 18. It accepts six automatic signal inputs which are "VNF", "$\overline{\text{stop clock}}$", "$\overline{\text{2 clock}}$", "clock", "$\overline{\text{clock}}$" and "input from trigger". It, in turn produces "1Q", "$\overline{\text{1P}}$", "$\overline{\text{2Q}}$", "2P", "4Q", "4P", "8Q", "8P", "16Q," "16P" "count gate," and "$\overline{\text{count gate}}$" as outputs to the d_{max} digital attenuator.

4.3.4 Analog Gate and Phase Shifter

The analog gate and phase shifter (Figure 19) permits the passage of the signal required to provide nutation of the flying spot on scope face. The phase shifter provides 90° phase shift of the sine wave with respect to itself in order to provide circular nutation. The inputs are "d pot wiper", "d_{max} enable", "$\overline{d_{max}}$ enable", and "d pot hi side". The outputs are "Ø 0° output" and "Ø 90° output".

4.3.5 "Learn" Circuitry

The basic "learn" operation was described briefly in paragraph 4.2.1. In terms of circuitry, the essential part of the operation is the means by which a new $|\Delta P_F|$ value is compared with a previously stored value to produce a "Reward" or "Punish" decision. In this system, a small portion of

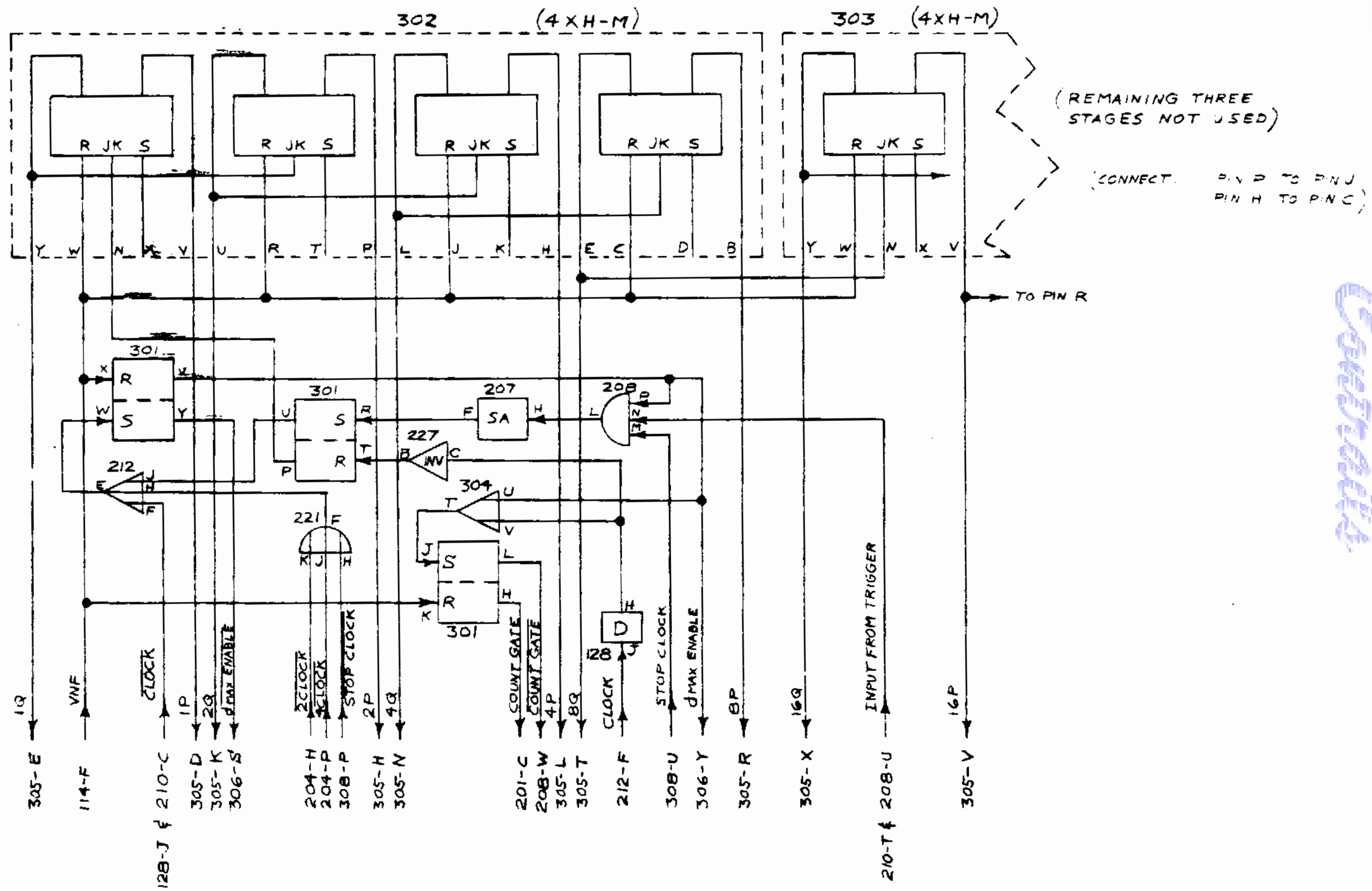
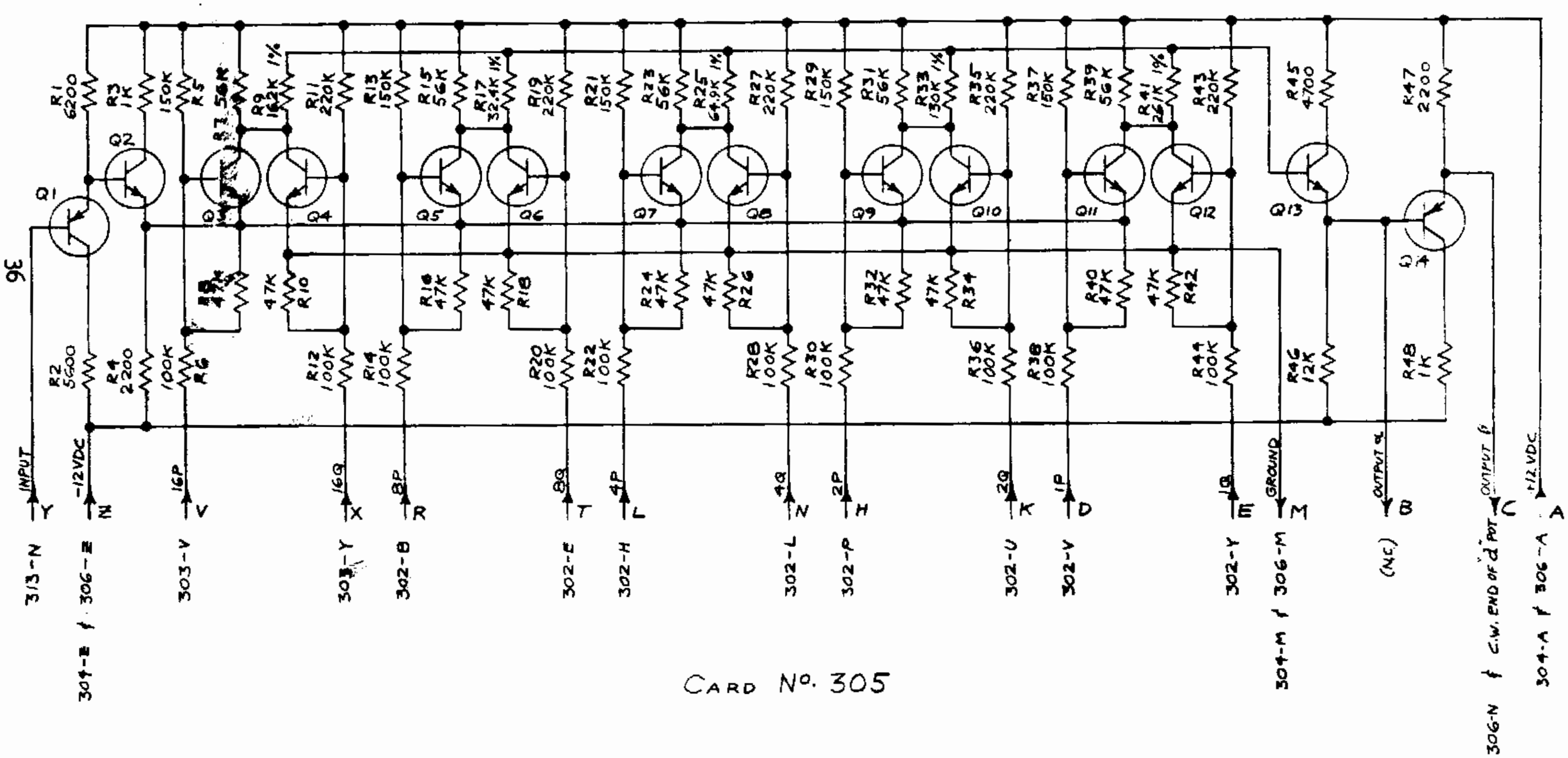


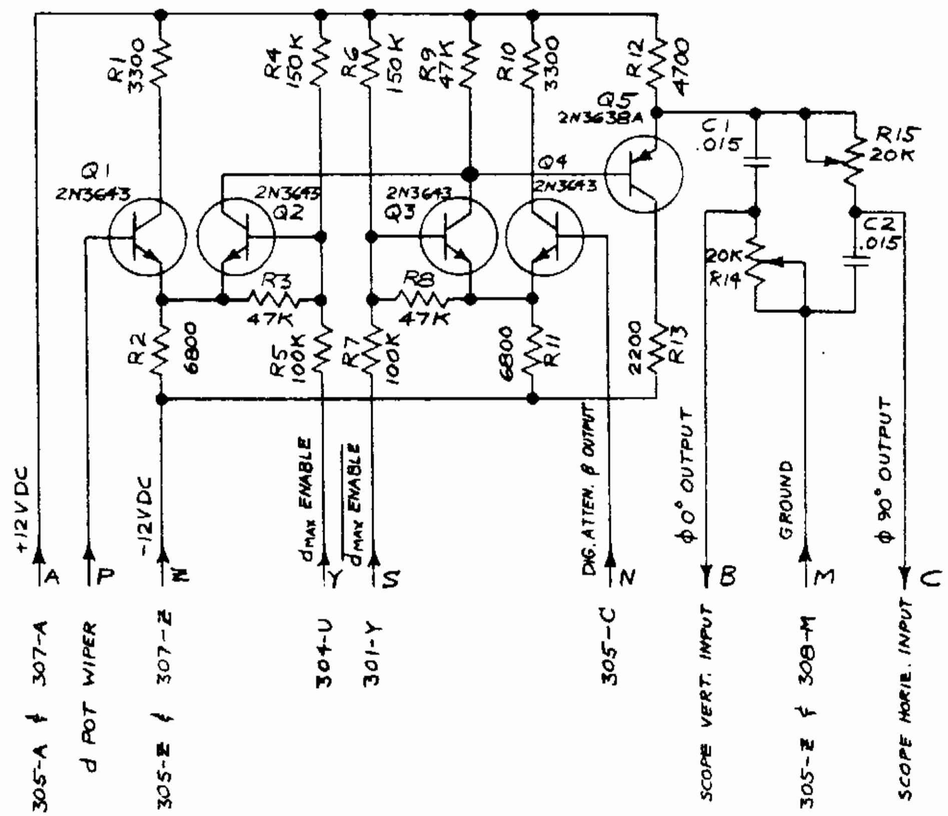
FIGURE 17 STANDARDIZE d_{max} COUNTER

NOTE ~ PNP TRANSISTORS ARE 2N3638A
NPN TRANSISTORS ARE 2N3643



CARD No. 305

FIGURE 18 d_{max} DIGITAL ATTENUATOR



CARD No. 306

FIGURE 19 ANALOG GATE AND PHASE SHIFTER

the more complex circuitry required for the "sort" operation is used for learning. The Input Gate and Output Circuit (Figure 20) provide access to the learn and sort circuitry and provide output signals to the control panel for operator information. The input gate provide information to the Up-Down Counter (Figure 21) and to the Input Binary Counter (Figure 22). However, only the Up-Down counter is utilized in the learn mode operation. The Up-down Counter (Figure 21) counts up with P_A , and down with P_B , counting through zero and counting back again, should P_fB prove to be the larger number, thus arriving at the absolute value of the difference between P_A and P_B. This difference is $|\Delta P_f|$. Comparator No. 1 (Figure 23) is the only one of five comparator circuits (Figures 23 through 27) utilized during learn mode. Comparator No. 1 compares the contents of the Up-down Counter with the contents of the "A" register. At this time, the "A" Register contains the best previous value of $|\Delta P_f|$. Should the new value of $|\Delta P_f|$ be less than the stored value, the "punish" light comes on, and nothing further occurs. Should the new $|\Delta P_f|$ value be greater than the best previous value, the "reward" light comes on, and the new value is stored in the "A" Register in place of the old one. The "reward" and "punish" signals originate in the output circuit, Figure 20.

4.3.6 "Sort" Circuitry

In the "sort" operation the circuits that become operable include the input/output circuitry (Figure 20), the up-down and binary counters (Figures 21 and 22), the comparators (Figures 23 through 27), the "A" and "B" registers (Figures 28 and 29), the delta counter Figure 30) and the sequencer and control circuits (Figures 31 and 32). In the "sort" operation, an unknown figure will be tentatively identified as that learned figure, either A or B, whose stored value is nearest in absolute value to the unknown. This decision, in turn, will be changed to "No Decision", should the contents of the inhibit register be closer in absolute value to the stored value identified than is the unknown. This is accomplished as follows:

The Up-down Counter (Figure 21) and the Input Binary Counter (Figure 22) both count up to the P_f value of the unknown figure. Then a 500 cycle clock signal from the sequencer (Figure 31) is fed into both counters. The Input Binary Counter counts Up and the Up-down Counter counts down, until one or the other reaches a number identical with either of the numbers in the "A" or "B" registers. When this occurs, an identity signal will be produced by one of four comparators:

Comparator No. 1 - A vs. Up-Down Counter Identity (Figure 23)
Comparator No. 2 - A vs. Binary Counter Identity (Figure 24)
Comparator No. 3 - B vs. Up-Down Counter Identity (Figure 25)
Comparator No. 4 - B vs. Binary Counter Identity (Figure 26)

Meanwhile, the Delta counter (Figure 30) is counting up with the same clock signal. When an identify occurs, therefore, the Delta counter will

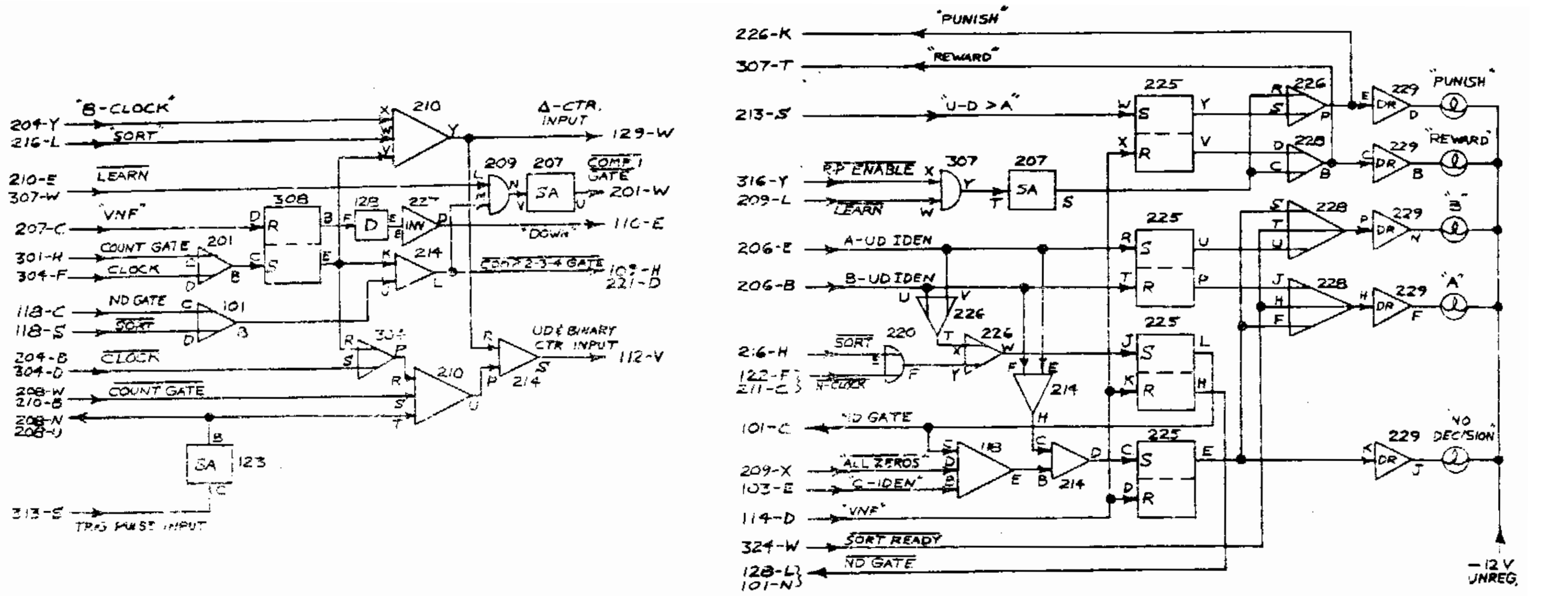


FIGURE 20 INPUT GATE AND OUTPUT CIRCUIT

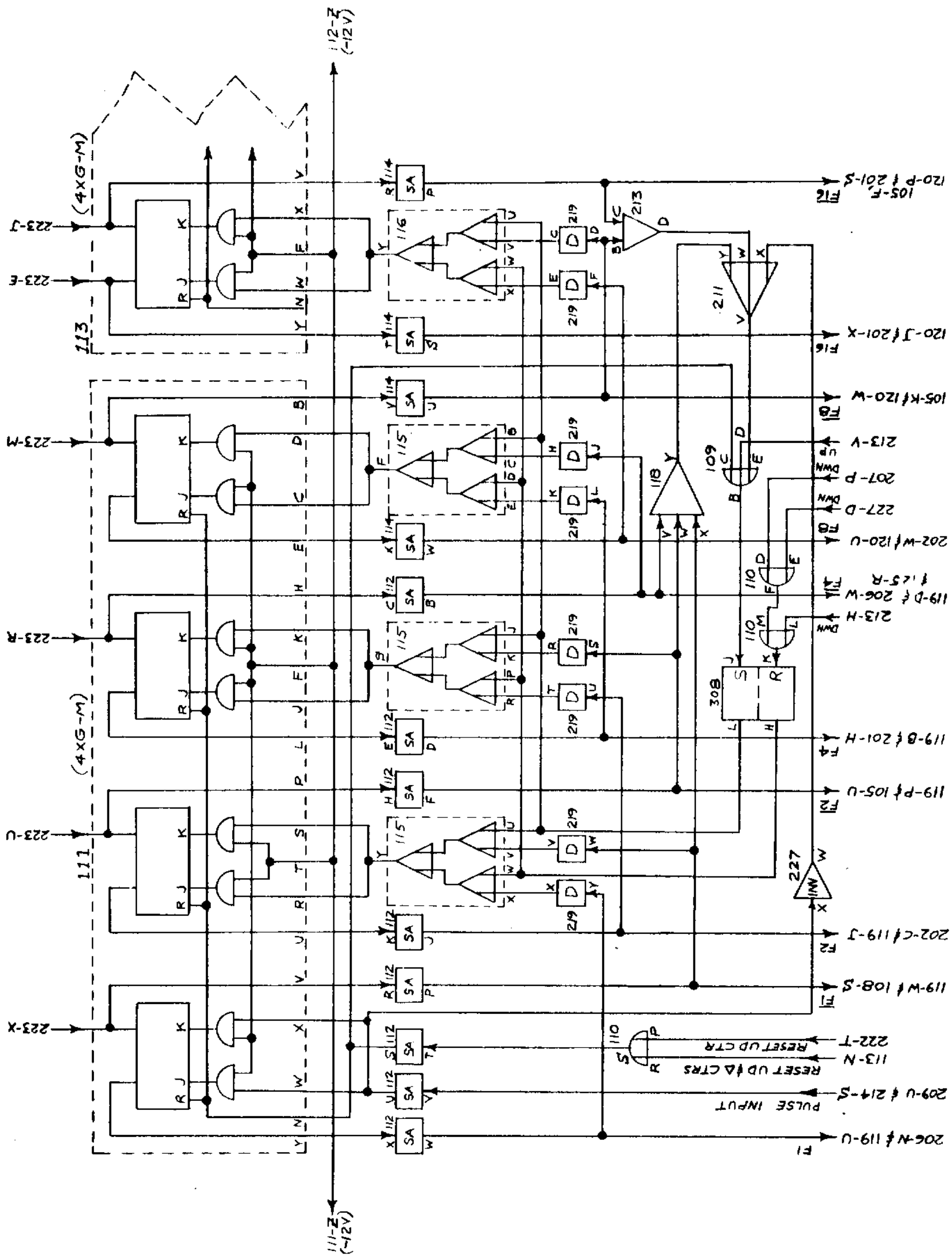


FIGURE 21 UP-DOWN COUNTER

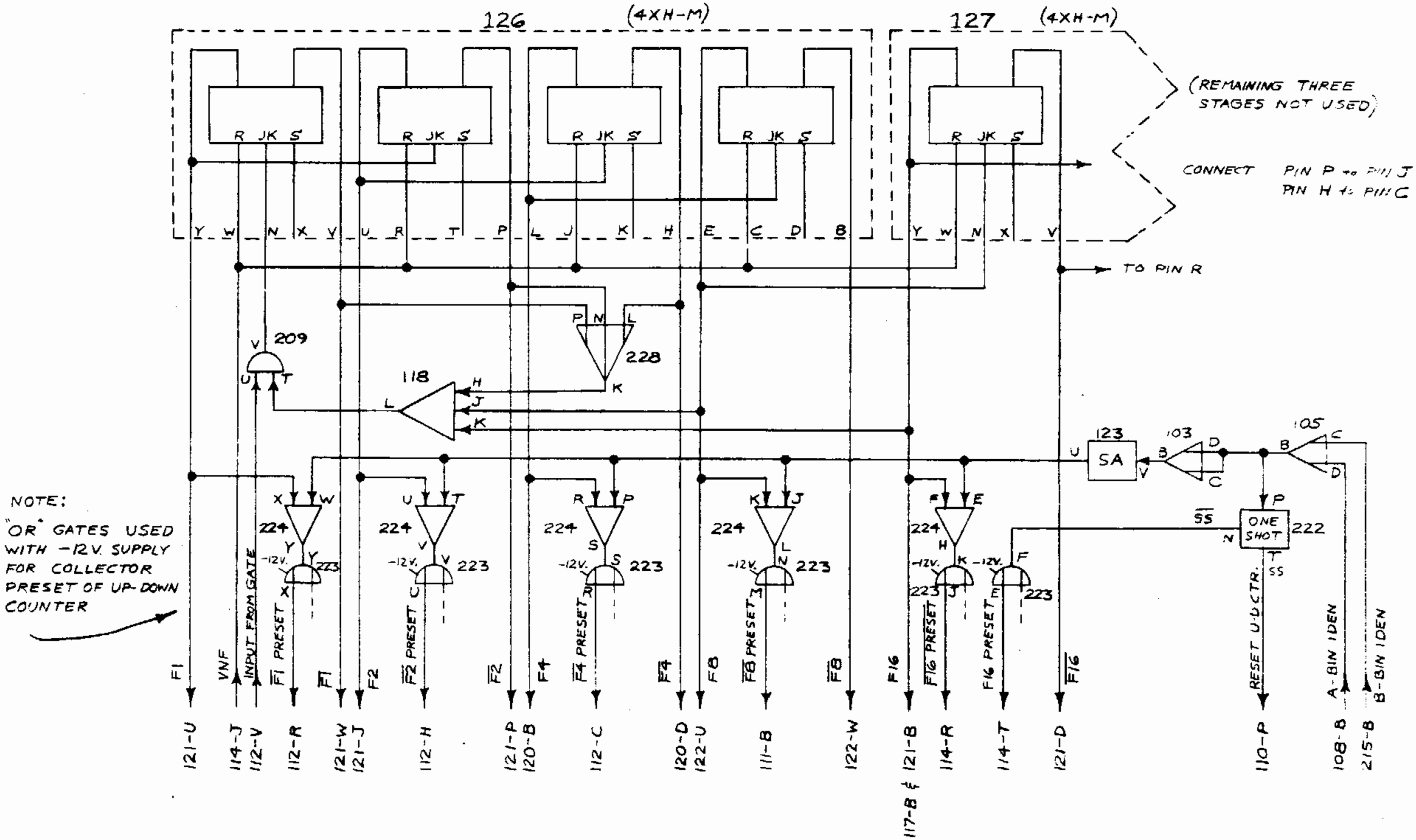


FIGURE 22 INPUT BINARY COUNTER AND TRANSFER GATE

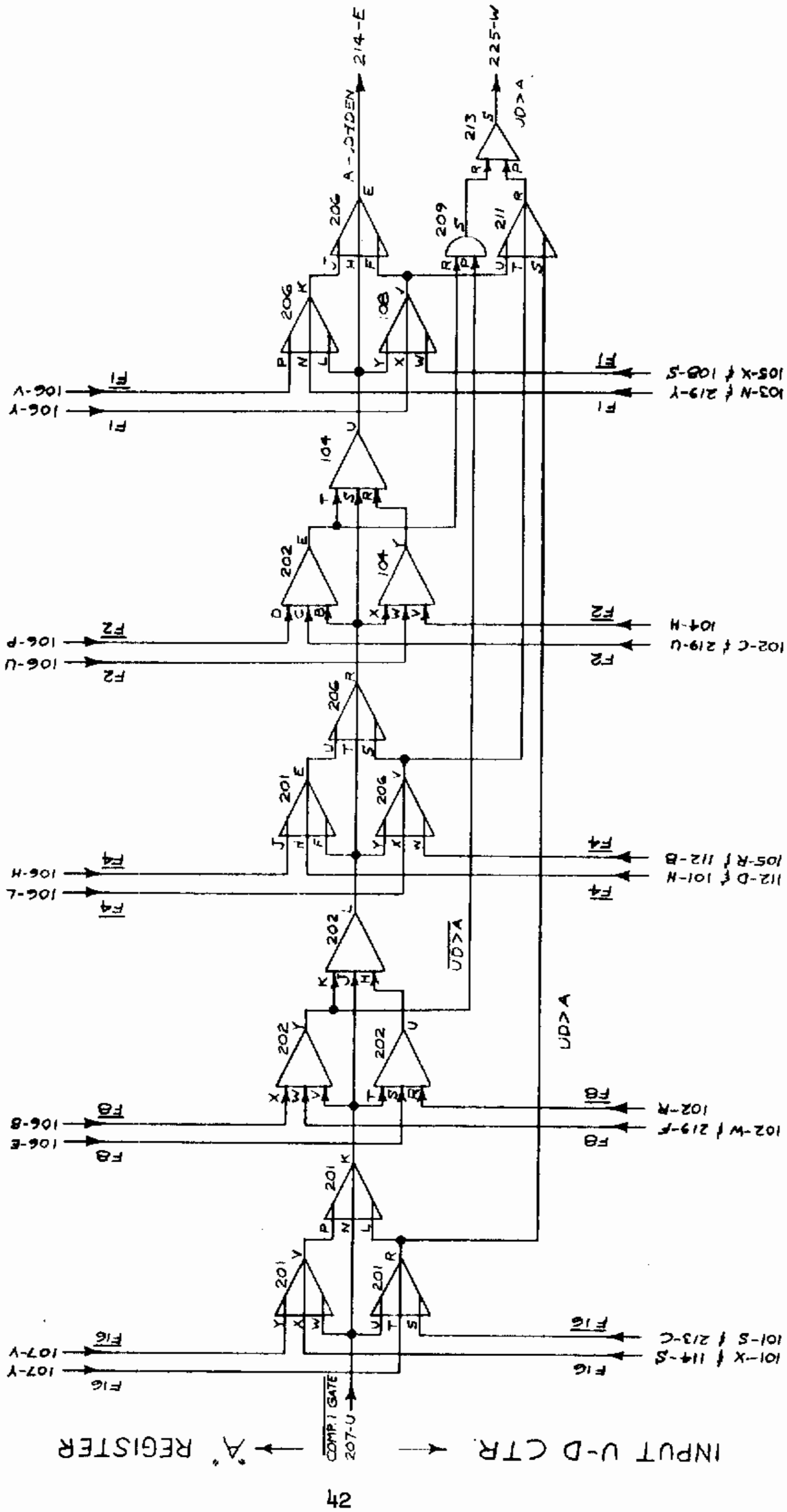


FIGURE 23 COMPARATOR #1 (A–UD)

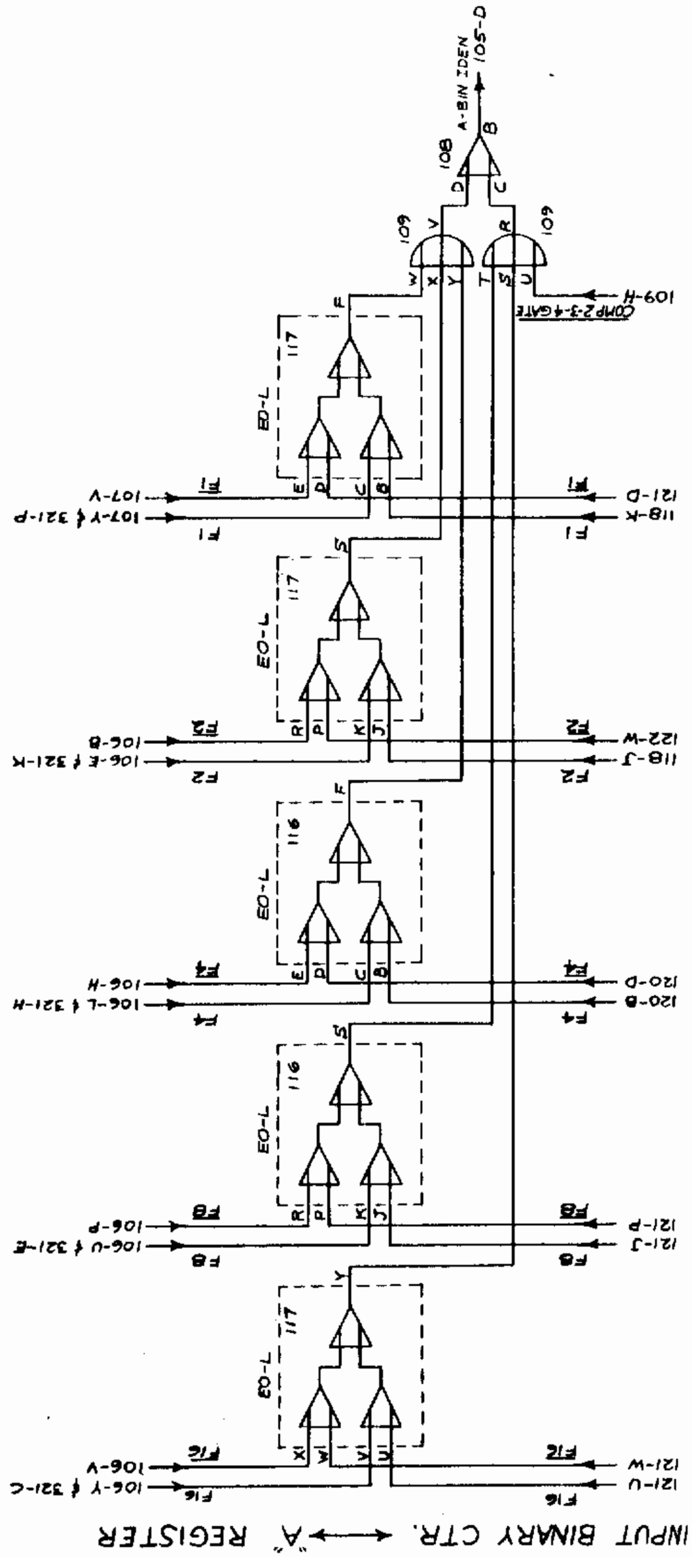


FIGURE 24 COMPARATOR #2 (A-BIN)

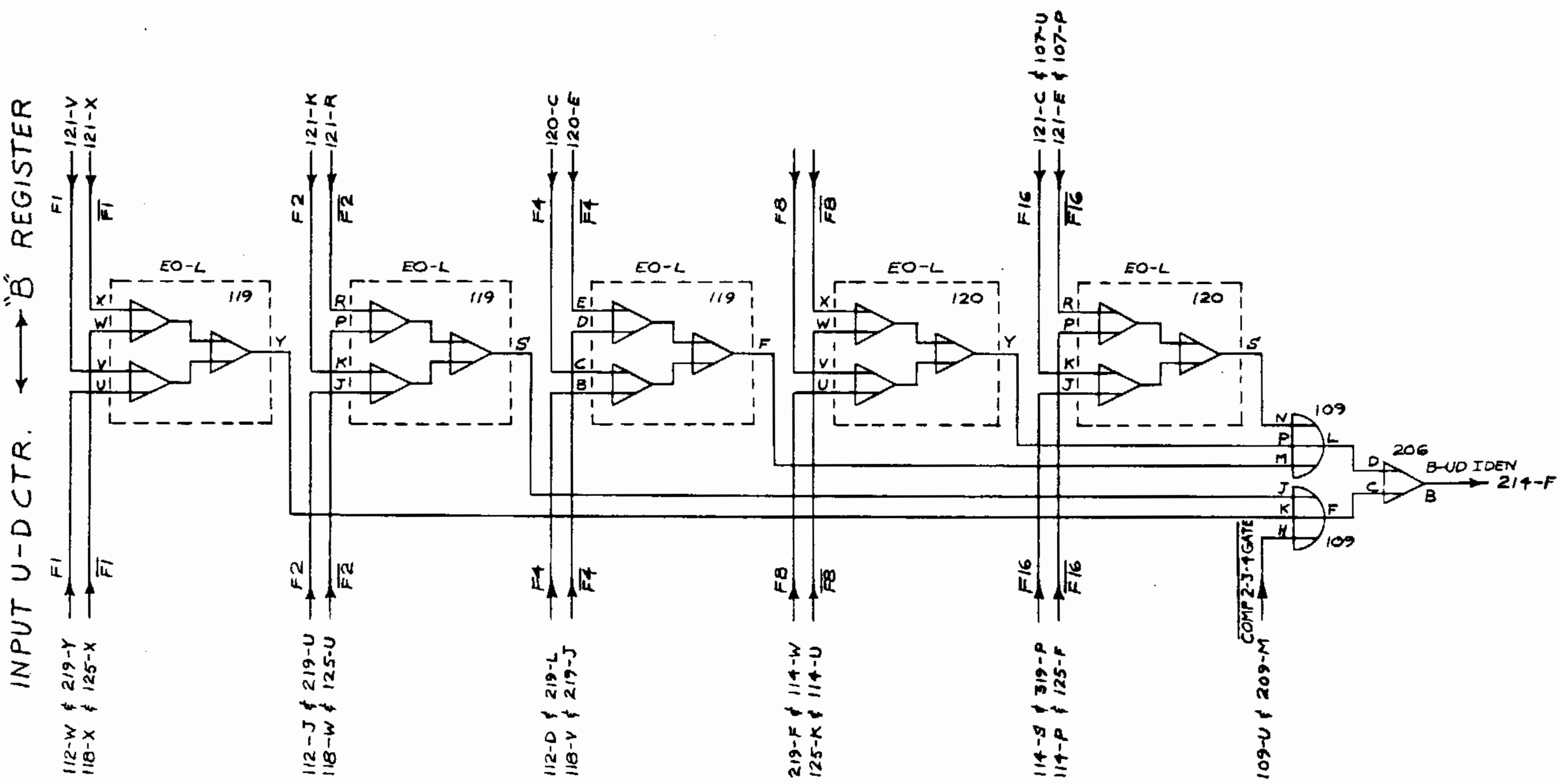


FIGURE 25 COMPARATOR #3 (B–UD)

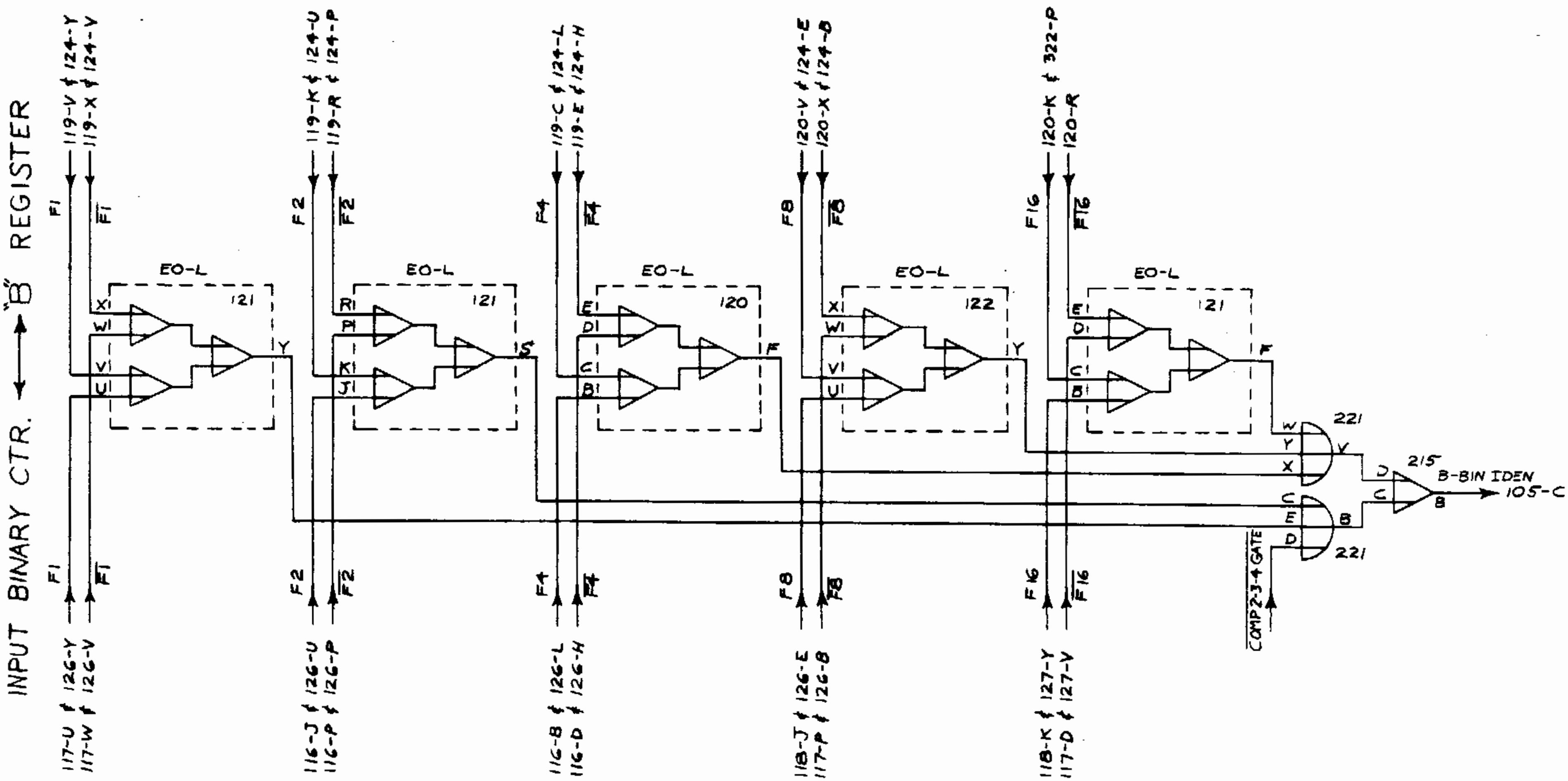


FIGURE 26 COMPARATOR #4 (B-BIN)

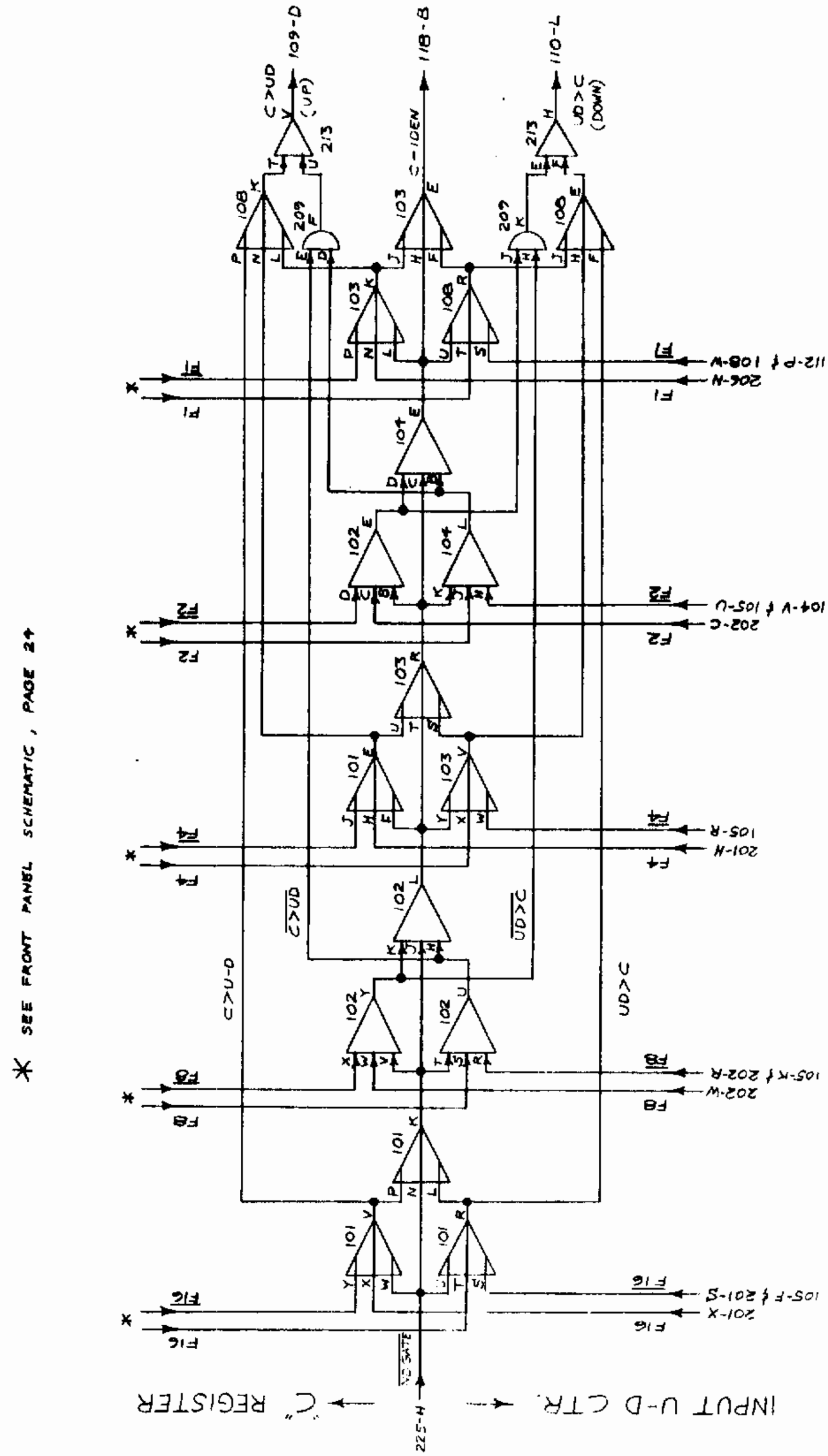


FIGURE 27 COMPARATOR #5 (C-UD)

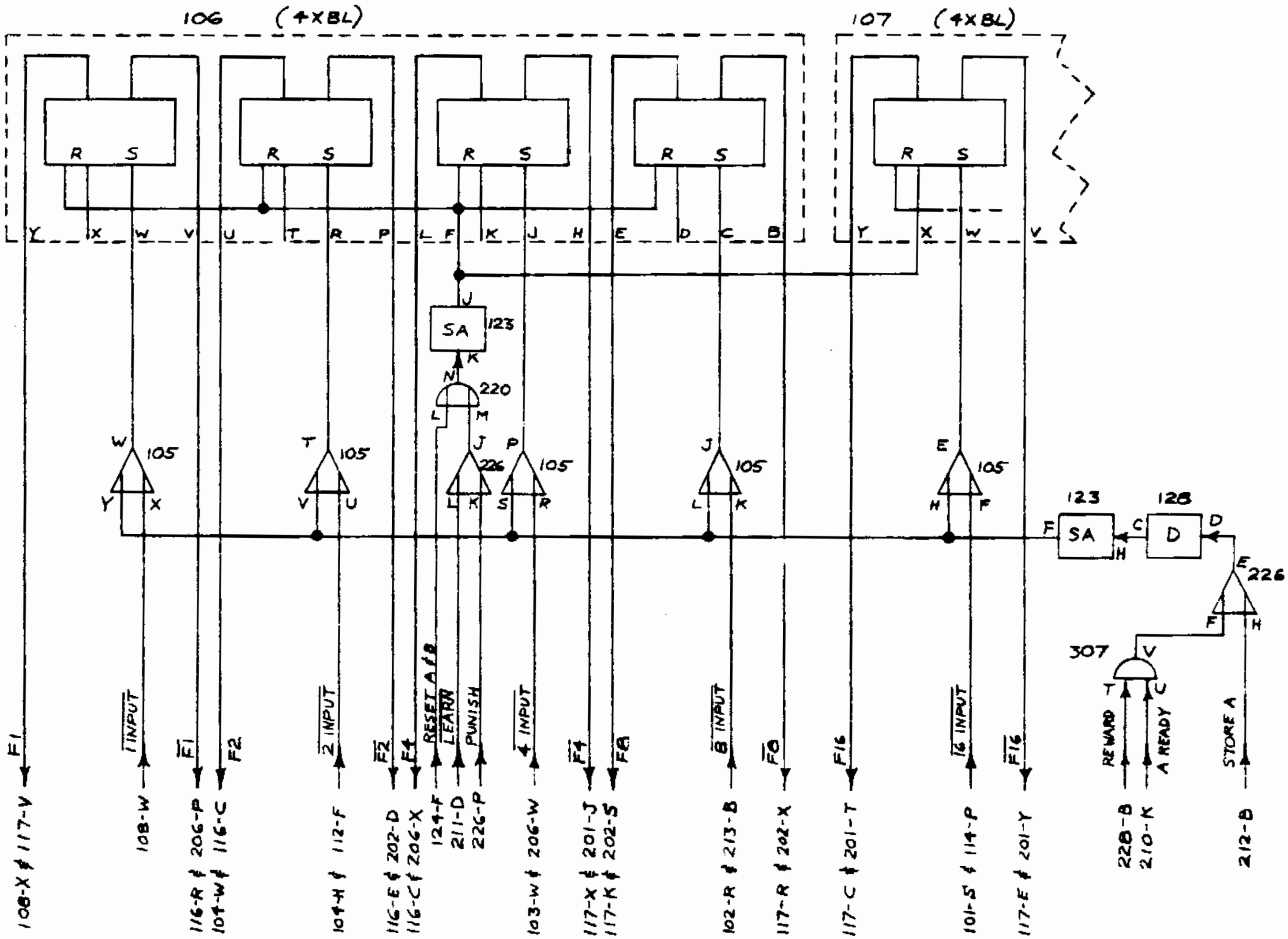


FIGURE 28 A STORAGE REGISTER AND GATES

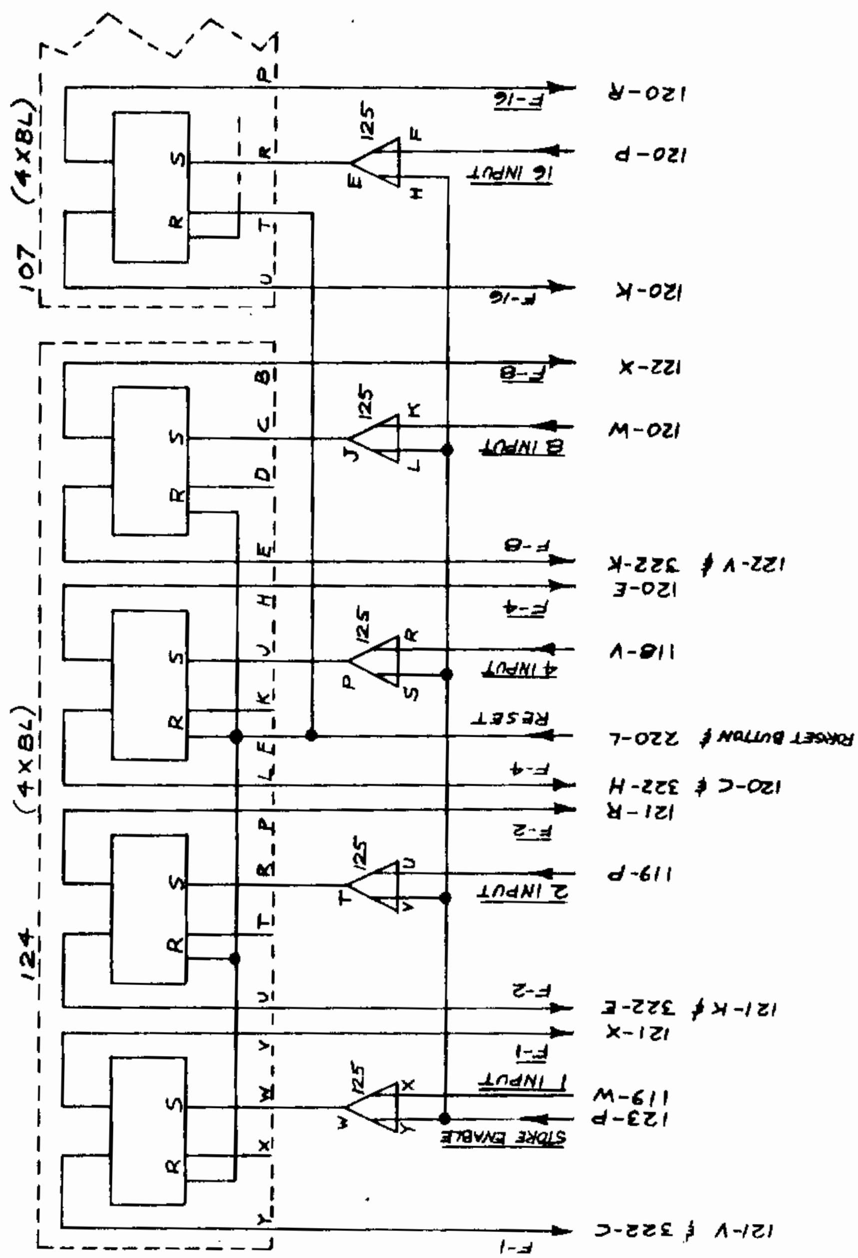


FIGURE 29 B STORAGE REGISTER AND GATES

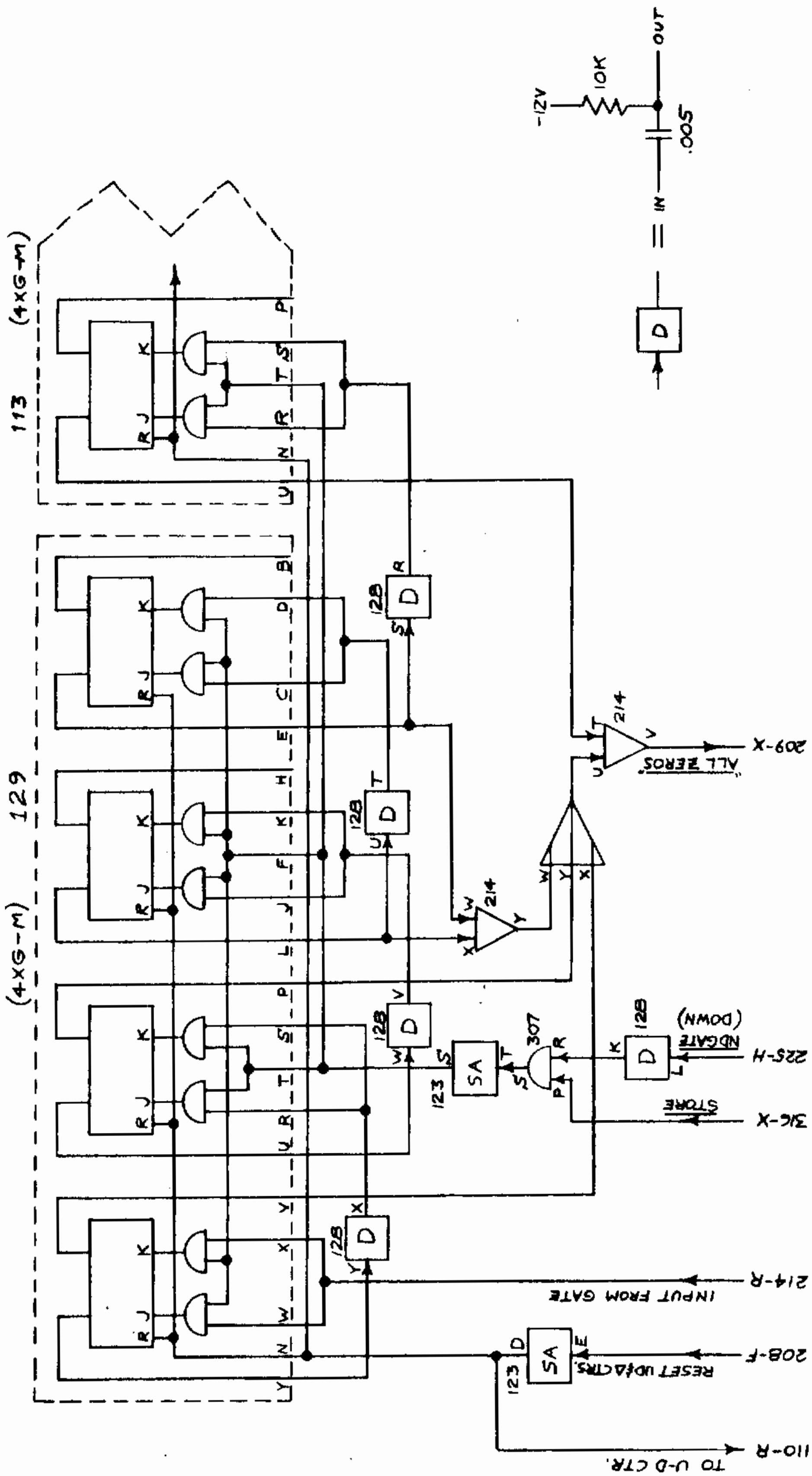


FIGURE 30 DELTA COUNTER

contain a number equal to the difference between the unknown P_f value and the stored number, either A or B, closest to it in absolute value.

When this identity occurs, a tentative "A" or "B" decision is set into the flip-flop in the output circuit (Figure 20) which controls the "A" and "B" decision lamps. The lamps are not yet gated on, however, pending a scan of the inhibit register.

If the identity occurred with the Binary Counter, its contents are now transferred into the Up-down counter. Thus, the Up-down counter now contains the identified number, either "A" or "B", regardless of which of the two counters originally arrived at the identity.

At this time, another flip-flop in the output circuit is turned on, producing a signal "$\overline{\text{ND Gate}}$" which enables Comparator No. 5 (Figure 27). This comparator compares the contents of the Up-down counter with the "Inhibit" Register, producing one of three outputs:

a. Inhibit value > Up-down Counter Contents
b. Inhibit value < Up-down Counter Contents
c. Inhibit value = Up-down Counter Contents

Should the two values be equal, the "A" or "B" decision is passed through to the proper lamp, and the cycle comes to an end. Should the Inhibit value be less than the Up-down counter contents, the Up-down counter is given a down command, and vice versa if the Inhibit value is greater. Thus, the Up-down counter now begins to count in the direction of the Inhibit value. Simultaneously, the Delta counter begins to count down. Should the Delta counter reach zero before the Up-down counter reaches the Inhibit value, this means that the unknown value was nearer to the closest of the stored "A" or "B" values than was the Inhibit value; the "A" or "B" decision is passed on to the proper decision lamp, and the cycle ends. However, should the Up-down counter reach an identity with the Inhibit Register before the Delta counter reaches zero, the "A" or "B" decision is blocked; the "No Decision" lamp comes on, and the cycle ends.

To sum up, the "sort" operation consists of the following stages:

a. The unknown P_f value is stored

b. A search occurs for the stored number closest in absolute value to the unknown

c. A determination of whether the Inhibit value is greater or less than the identified number is made

d. The identified number is clocked in the direction of the Inhibit value. If the Inhibit value is nearer than the unknown value, a "No Decision" occurs. Otherwise, the "A" or "B" decision is allowed to stand.

Note that the Inhibit Register cannot mutate an "A" decision to a "B" or vice versa. It can only change the output to a "No Decision" or allow the decision to stand.

A word about the Delta counter would be instructive here. The Delta counter is an up-down counter of a special type. Its operation depends upon the fact that a binary number is the same distance from the bottom of the count (00000) as its complement is from the top of the count (11111). A binary number is changed into its complement by reversing the state of all counter stages. In the Delta counter, a stored number is counted down by reversing all counter stages, counting up with the number to be subtracted, and reversing the counter stages again at the end of the count. The resulting number will be the same as if the second number had been counted down.

4.3.7 Sequencer and Control Circuit

The sequencer and control circuit provide basic intelligence wired into the equipment which establish the control and sequence of all events.

In the sequencer circuit (Figure 31), there are three automatic inputs "sequencer reset," "EOS enable," and "comp enable." The sequencer contains a 1KC and 100 CPS multivibrators which provide the basic timing operation by providing the signal "N clock" and "$\overline{\text{N}}$ clock," and other sub-frequencies. These two signals represent the two possible phases of the square wave provided by the 1KC multivibrator. "N clock," filtered, nutates the oscilliscope flying spot, and is counted down in the sequencer to supply all of the clock signals used throughout the system.

The primary function of the control circuit is to provide the proper logic signals required to complete the entire automatic sequence of events, from the initial "learn" functions to the final "sort" functions.

In addition, clock pulses are generated by the sequencer as represented by "1/16 clock", "1/8 clock". "$\overline{\text{1/8 clock}}$", "1/4 clock", "8 clock", "clock", "$\overline{\text{clock}}$", "N-clock", "$\overline{\text{N-clock}}$","clock gate", "2 clock", and "Learn or Sort ss". Throughout the system, numerical values are handled in the form of 5-bit binary digits. Thus a resolution of one part in 32 is attained. Logical "Zero" is represented by 0 volts, and logical "One" by -12 volts. Wyle Laboratories' logic cards are used where applicable, and are represented by logic symbols in the detailed circuit drawings.

In the control circuit (Figure 32), there are three manual inputs originating on the control panel. These are "Forget," "Learn or Sort," and "Store" push buttons. The "Forget" button resets the proper digital states in the control circuit and provides a "Reset A and B" signal to the "A" storage register and to the "B" storage register in order to initiate a new sequence of events. The new sequence of events is "Learn", "Store", and

"Sort." The "Learn or Sort" button provides a "Learn" command while in the "Learn" mode (or before the "Store" operation) and a "Sort" command while in the "Sort" mode (or after the "Store" operation).

In addition, in the control circuit there are eight automatic signal inputs. These are "all zeroes", "1/16 clock", "clock", "d_{max} enable", "N-clock", "$\overline{\text{1/8 clock}}$", "1/8 clock", and "1/4 clock". These signals and combinations of these signals provide the output signals generated by the control circuitry. The output signals are "reset A and B", "A Ready", "Reset U-D and Delta counters", "$\overline{\text{sort}}$", "R-P enable", "store B", "store A", "sequencer reset", "$\overline{\text{sort ready}}$", "down", "learn or sort ss", "view next figure (VNF)", "learn", "sort", "$\overline{\text{store}}$", and "erase".

There are three visual outputs which are presented by a panel light -- "A" ready light, "B" ready light and "sort" light. These lights provide instructions to enable the operator to determine his next move and instructs the operator as to the mode of operation -- Learn or Sort.

In order to prevent excessive noise in the circuits from improper coupling of the various circuits, the grounding system shown in Figure 33 was utilized.

4.4 MECHANICAL DESIGN DESCRIPTION

The major mechanical assembly and layout drawings are presented in this section in Figures 34 through 37. These drawings cover one overall Rack Assembly -- Image Recognition System, a Layout and Schematic -- Control Panel, a Card Module Layout, and Optical System Assembly drawing.

4.4.1 Rack Assembly -- Image Recognition System

The Rack Assembly -- Image Recognition System drawing (Figure 34) presents three views of the finalized equipment. The three views include a front view, left side view and top view. The front view is presented with the upper right three panels removed for viewing the individual logic bays. The control panel is easily visible from the front and top view and is seen projecting forward in the left side view. All of the optical system sits on the top of the double-rack width console. The storage tube control chassis is found beneath the control panel projection. All of the power supplies are situated on the bottom section of the console.

4.4.2 Layout and Schematic -- Control Panel

The layout and schematic of the control panel is presented in Figure 35. On the left of the panel are two push-button switches which represent the "Learn-Sort" operation and the "Store" operation. A blue and amber light indicates a "sort" operation when lit and "learn" operation, when not lit. These indicators are used to assist the operator in pressing the "Learn-Sort" button or the "Store" button. In the center portion of the control panel, there are two indicator lights -- green light for "Reward" and red light of "Punish." The "Reward" light indicates that a better value of P_F has been found, while the "Punish" light means that the value in the storage register is the best or largest value of P_F found. Below the "Reward" and "Punish" lights is a set of five switches which represent a binary representation of numbers from 0 to 31 which are inputs to the "Inhibit" register. On the bottom of the center section, a set of 3 indicator lights gives the result of the sort operation as identifying the unknown image as an "A" image (blue) or as a "B" (amber) image or as giving a "No Decision" (yellow) answer. On the right side of the panel is the "d" value pot which is randomly set manually by the operator according to a random number table (or similar input). Beneath the "d" value pot is a "Forget" push button which is pressed whenever the machine is given a new problem. The power on-off switch and indicator light is also located beneath the "d" value pot.

4.4.3 Card Module Layout

The card module layout (Figure 36) shows the location of various elements of the circuit which are constructed on circuit board cards. The card description numbers are Wyle circuit type designation except for 4 special circuit boards designed and built at LTV. Sequence numbers for the three modules are shown at the top of each module. Function groupings are shown where applicable.

4.4.4 Optical System Assembly

The optical system assembly sits on top of the control console where the image slide holder is easily accessible for loading and unloading image slides. The optical system (Figure 37) consists of an optical housing within which the electron storage tubes and photomultiplier mount. Also, the partially reflective plate, xenon flash tubes, and other small components are mounted to the housing. A precision image slide holder device with actuators for supplying images to be viewed is built into the optical housing. A Hewlett-Packard 120 B oscilloscope (less graticule) is coupled to the optical housing for providing the flying spot projection.

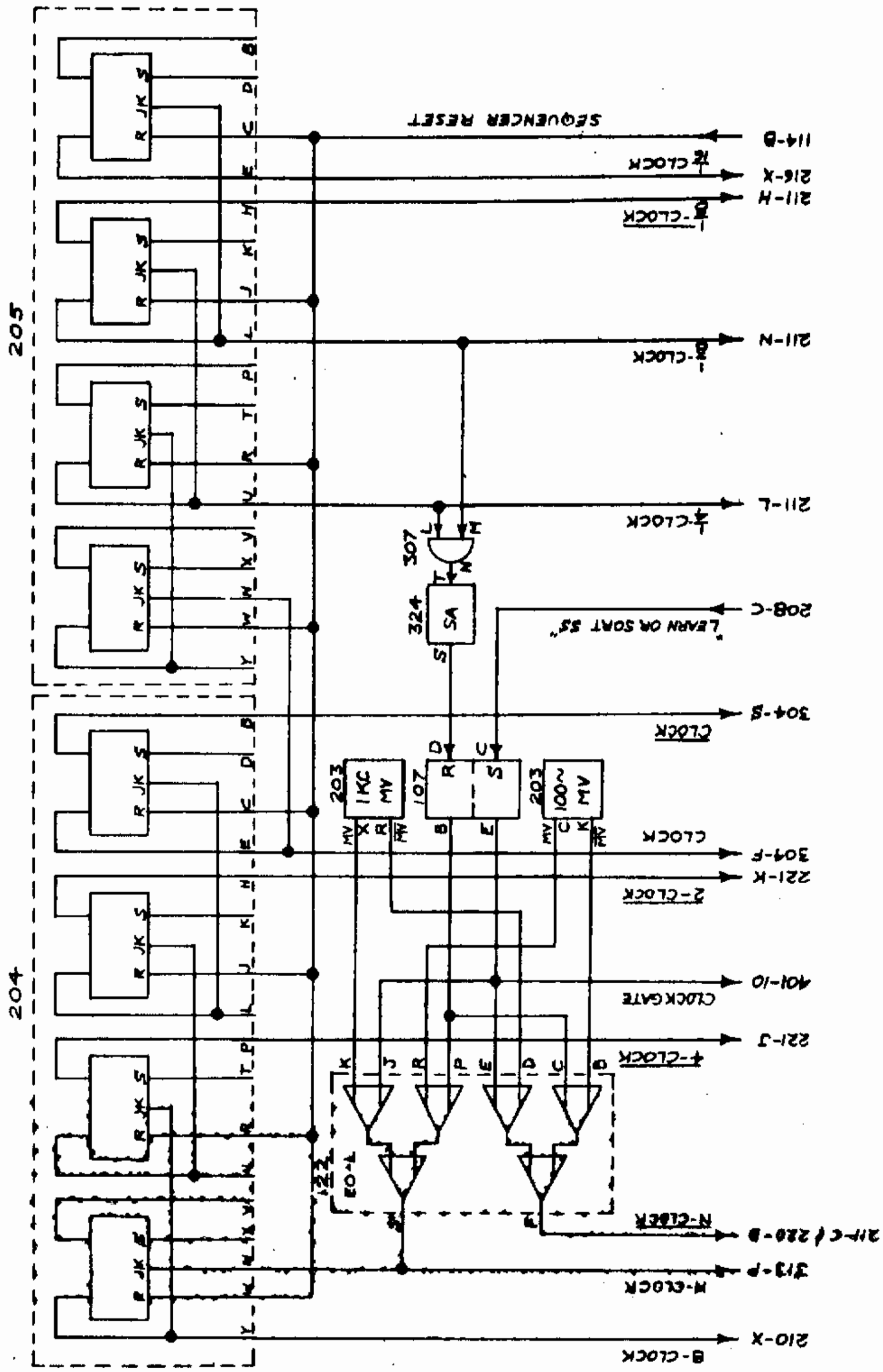


FIGURE 31 SEQUENCER

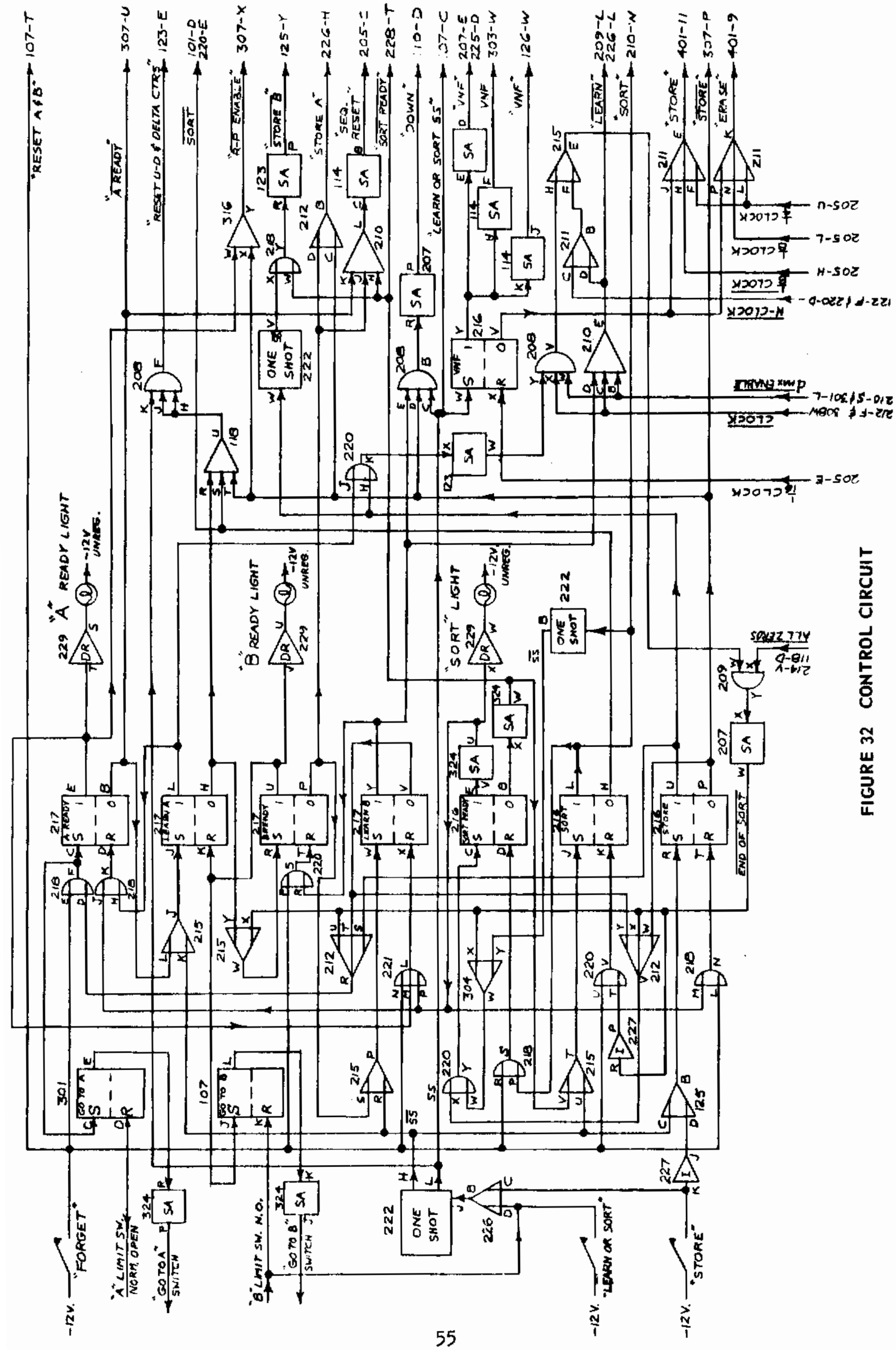


FIGURE 32 CONTROL CIRCUIT

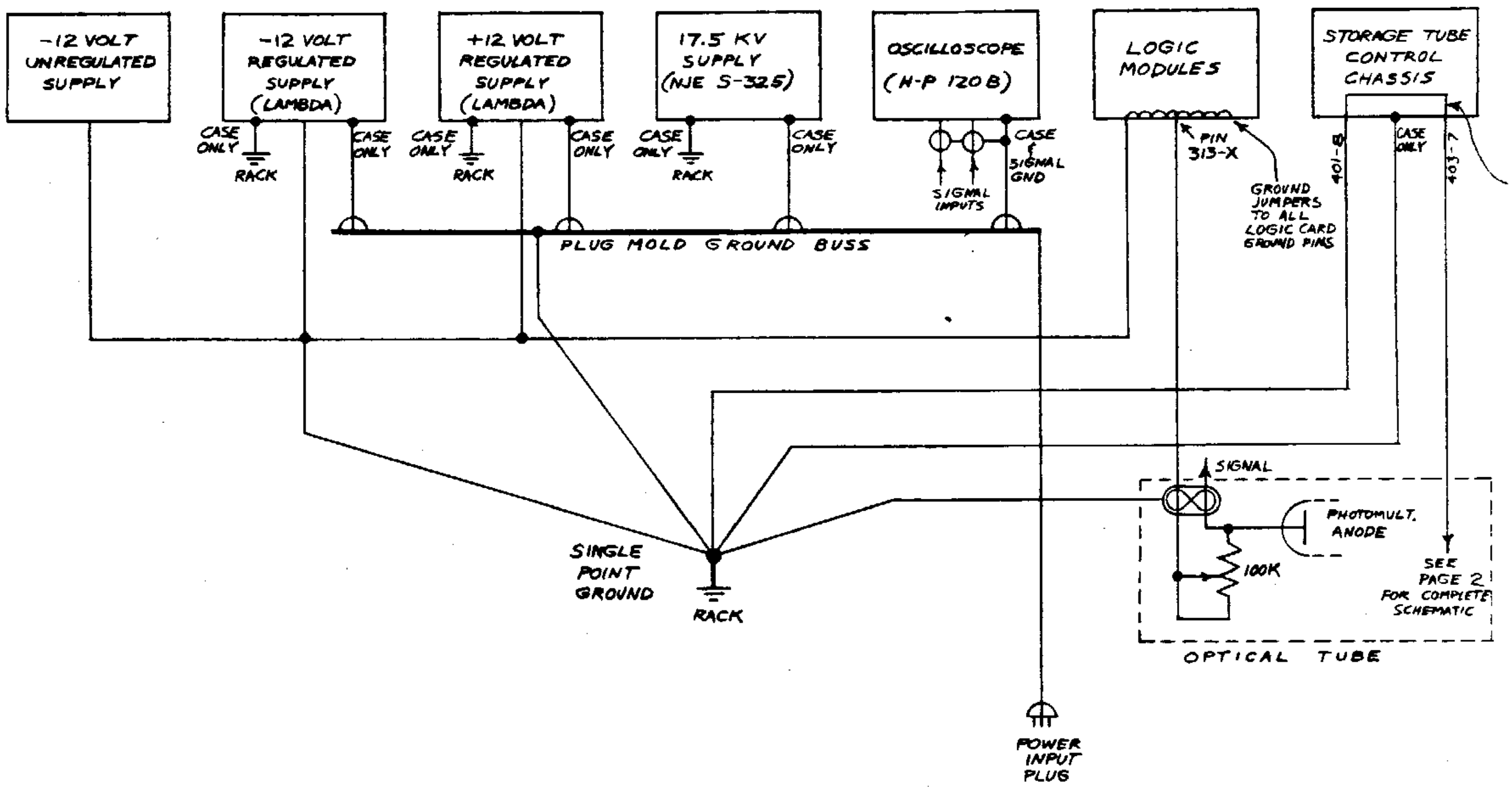


FIGURE 33 GROUND SYSTEM SCHEMATIC

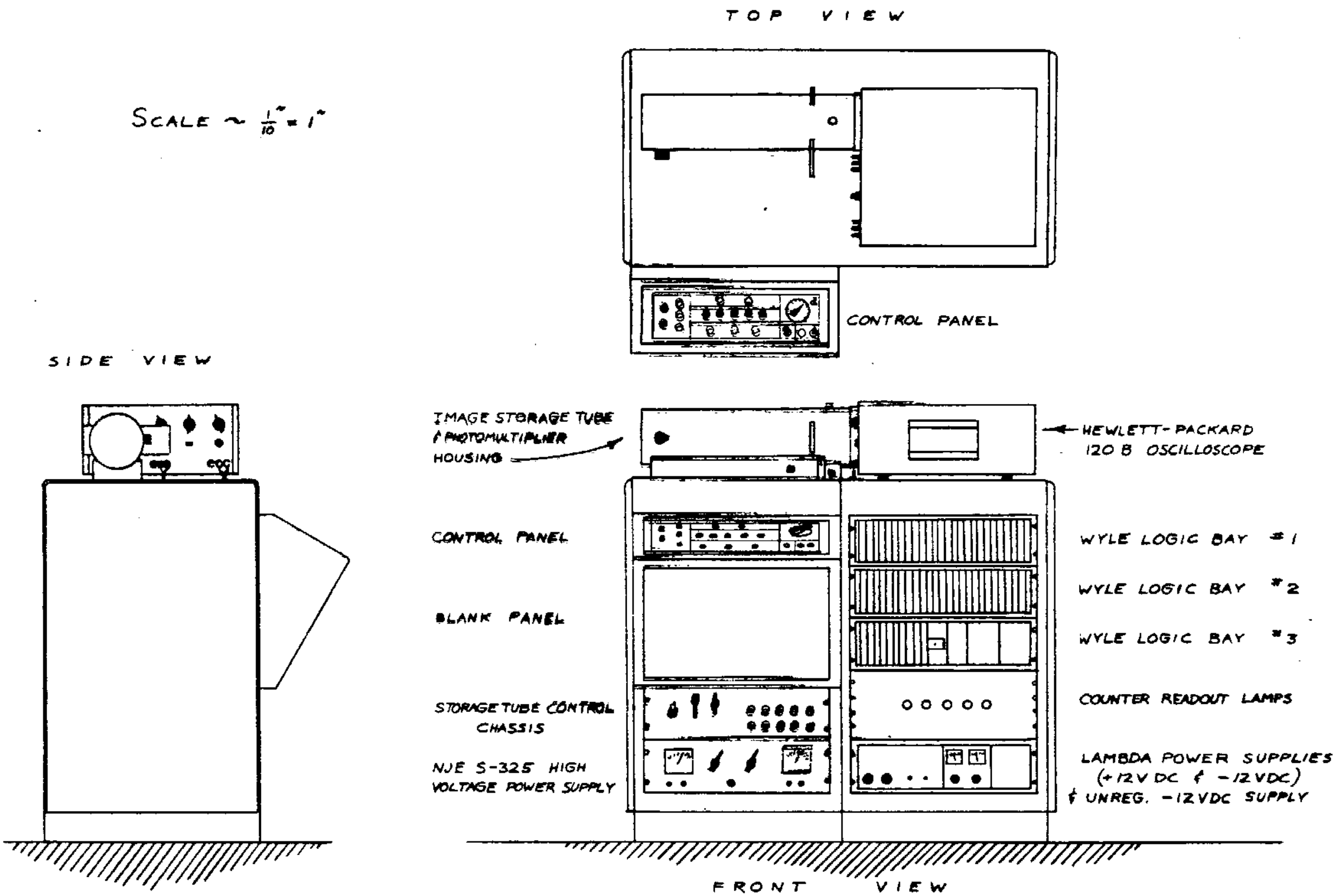


FIGURE 34 RACK ASSEMBLY – IMAGE RECOGNITION SYSTEM

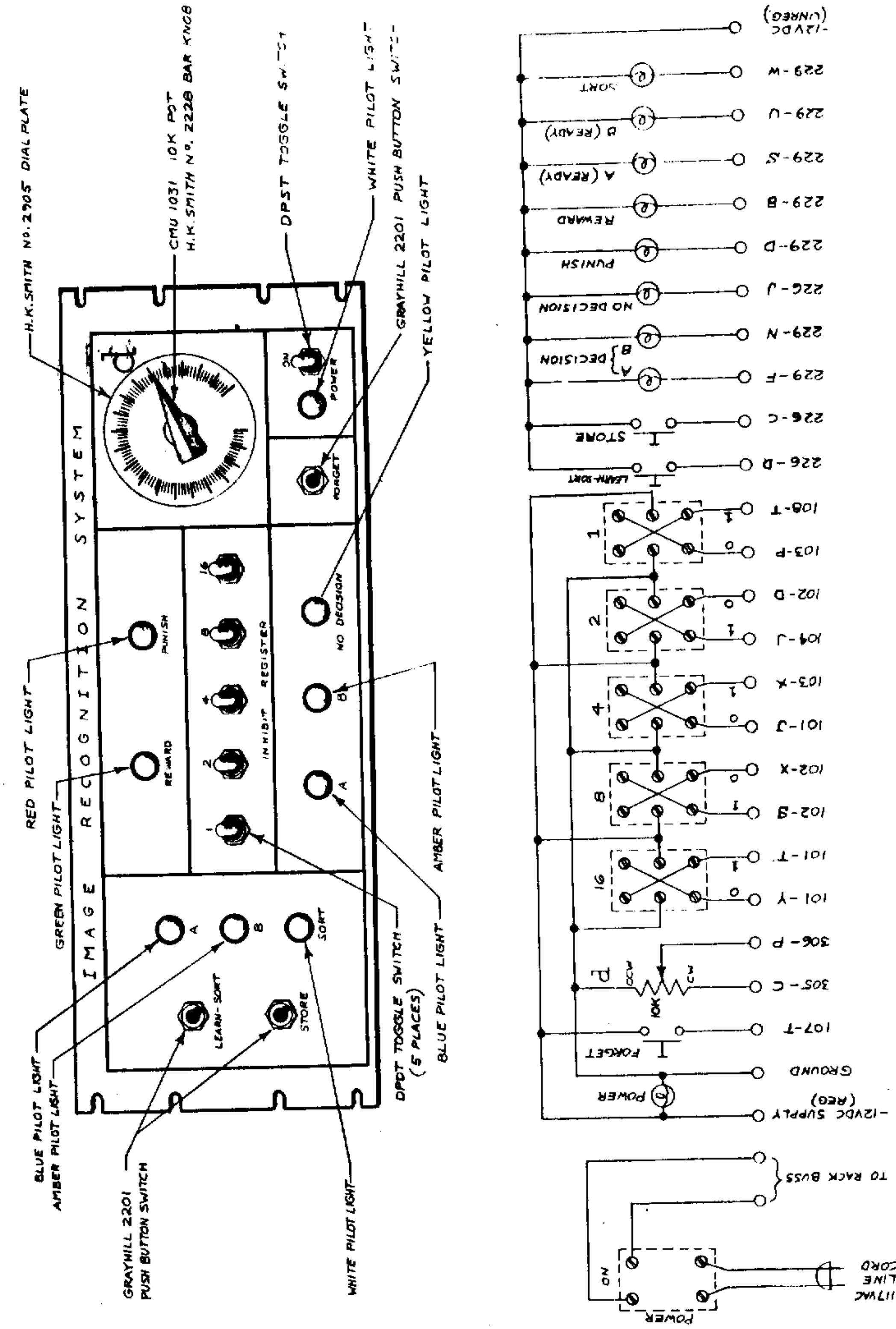


FIGURE 35 LAYOUT AND SCHEMATIC – CONTROL PANEL

Module 1 slot	Module 1 card	Module 2 slot	Module 2 card	Module 3 slot	Module 3 card
101	N35-L	201	N35-L	301	4XB-L
102	S34-M	202	S34-M	302	4XH-M
103	N35-L	203	2AM-M	303	4XH-M
104	S34-M	204	4XH-M	304	N26-L
105	N26-L	205	4XH-M	305	DIGITAL ATTENUATOR
106	4XB-L	206	N35-L	306	ANALOG GATE & PHASE SHFT
107	4XB-L	207	8SA-M	307	A26-M
108	N35-L	208	A35-M	308	4XB-L
109	O35-L	209	A26-M	309	4XH-M
110	O26-L	210	S34-M	310	4XH-M
111	4XG-M	211	N35-L	311	4XH-M
112	8SA-M	212	N35-L	312	DIGITAL ATTENUATOR
113	4XG-M	213	S26-M	313	INTEG-TRIG & NUT. FILTER
114	8SA-M	214	S26-M	314	X
115	EO-L	215	N26-L	315	X
116	EO-L	216	4XB-L	316	S26-M
117	EO-L	217	4XB-L	317	* 8PA-D STD PI COUNTER
118	S34-M	218	O26-L	318	* 8PA-D STD dMAX COUNTER
119	EO-L	219	DIFFERENTIATOR	319	* 8PA-D UP-DOWN COUNTER
120	EO-L	220	O26-L	320	* 8PA-D INPUT BINARY COUNTER
121	EO-L	221	O35-L	321	* 8PA-D A REGISTER
122	EO-L	222	4SS-M	322	* 8PA-D [illegible] REGISTER
123	8SA-M	223	O26-L	323	* 8PA-D DELTA COUNTER
124	4XB-L	224	S26-M	324	8SA-M
125	N26-L	225	4XB-L	325	X
126	4XH-M	226	N26-L	326	X
127	4XH-M	227	8IA-M	327	X
128	DIFFERENTIATOR	228	N35-L	328	X
129	4XG-M	229	8PA-D	329	X

* FOR STORAGE REGISTER DISPLAY, ONLY ONE SLOT SHOULD BE OCCUPIED AT A TIME.

FIGURE 36 CARD MODULE LAYOUT

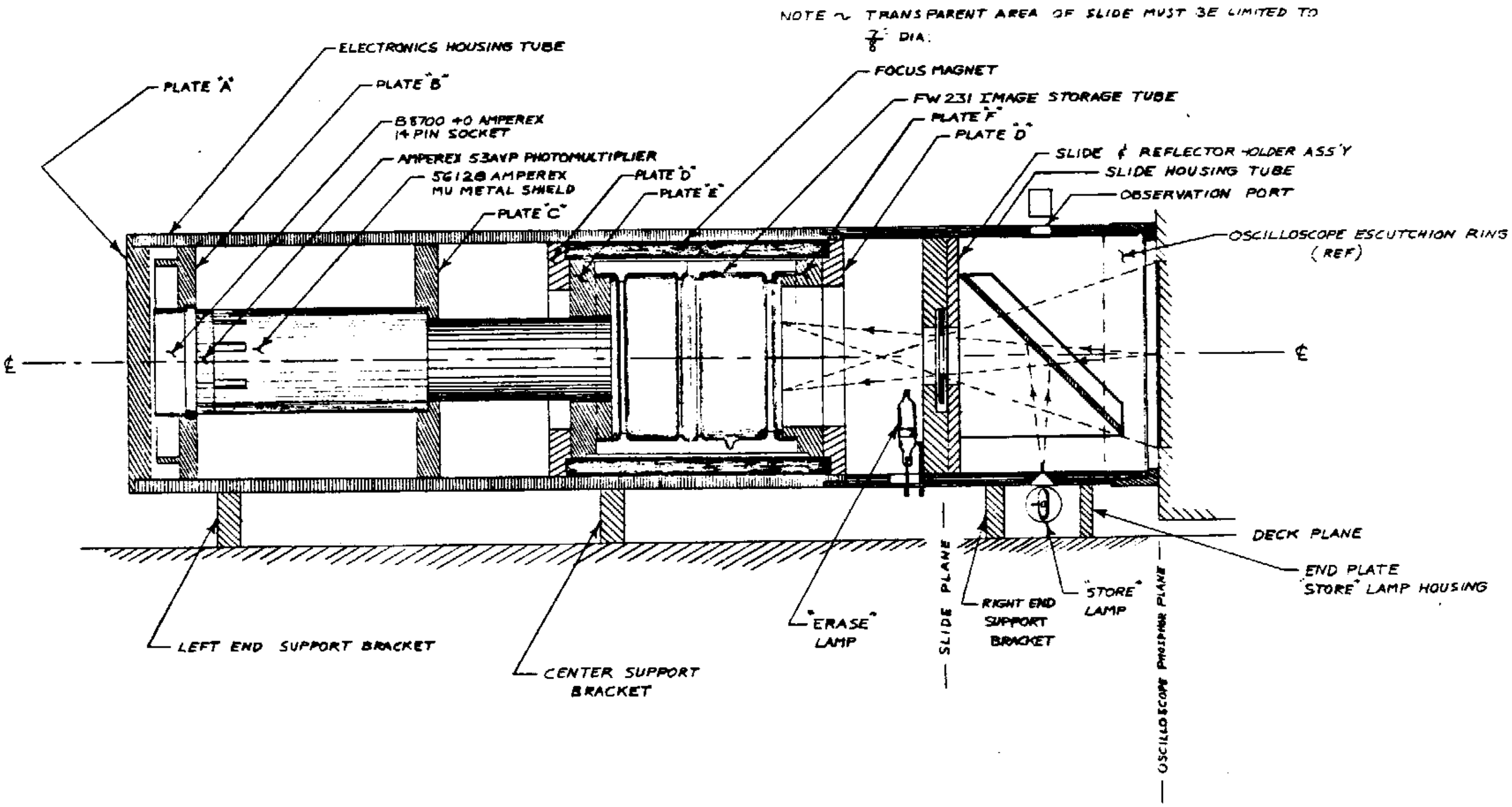


FIGURE 37 OPTICAL SYSTEM ASSEMBLY

SECTION V

ANALYTICAL DEFINITION AND PRELIMINARY SPECIFICATIONS FOR A BIONICS IMAGE RECOGNITION SYSTEM OPERATING IN A UNIVERSE OF N-CONCEPTUAL IMAGES

5.0 INTRODUCTION

In the present Bionics Image Recognition System, it is required to be able to learn two optimum values of two difference $P_F(d)$ functions from two different figures, say A and B, and then switch to a sort-mode and classify subsequent images as either belonging to the A or B or "no decision" class. The construction of this system demonstrates the integration of the simulated PSV system and the transformation generator into a Bionics Image Recognition System. This is a significant achievement, but, in order to achieve practical use, a Bionics Image Recognition System Operating in a universe of n conceptual images must be built. To this end, an evaluation of the problems associated with this aim are discussed and analytical definitions and preliminary specifications are presented.

5.1 PROBLEMS ASSOCIATED WITH THE DESIGN OF A BIONICS IMAGE RECOGNITION SYSTEM OPERATING IN A UNIVERSE OF N-CONCEPTUAL IMAGES

In a two image recognition system, the problem of distinguishing between each of the images or neither can be done with relative ease. However, in an n-image system, the complexity of comparing each image with every other image in the learning mode increases as the number of combinations of n images taken two at a time. Consequently, the period of learning is commensurably increased. For large values of n, the number of points to test for in order to determine the maximum degree of distinguishability between any two curves also increases, such that for each combination of two curves, a set of differences must be defined and tested for maximum distinguishability between the two curves. The size of the set of points increases for large n as well as the number of possible values each point of the set can assume. Provided that meaningful differences may be small, large number of values are required as possible variations of each point of the set for each combination of two.

At this point, it appears that a rather large number of neurotrons would be required to make the learning process feasible. An alternative solution would utilize an orderly comparison process with conventional memory (random access or sequential). Consider the problem of learning to distinguish among one additional curve or equivalently to learn to distinguish among three curves. Figure 38 shows the three curves to be learned plus the unknown curve which is to be selected as being A or B or C or neither. The unknown curve shown as a dash line is more readily aligned with the B curve. However, the single point of maximum distinguishability between A and B is the least of the three points A vs. B, B vs. C and A vs. C. So, therefore, a selection based

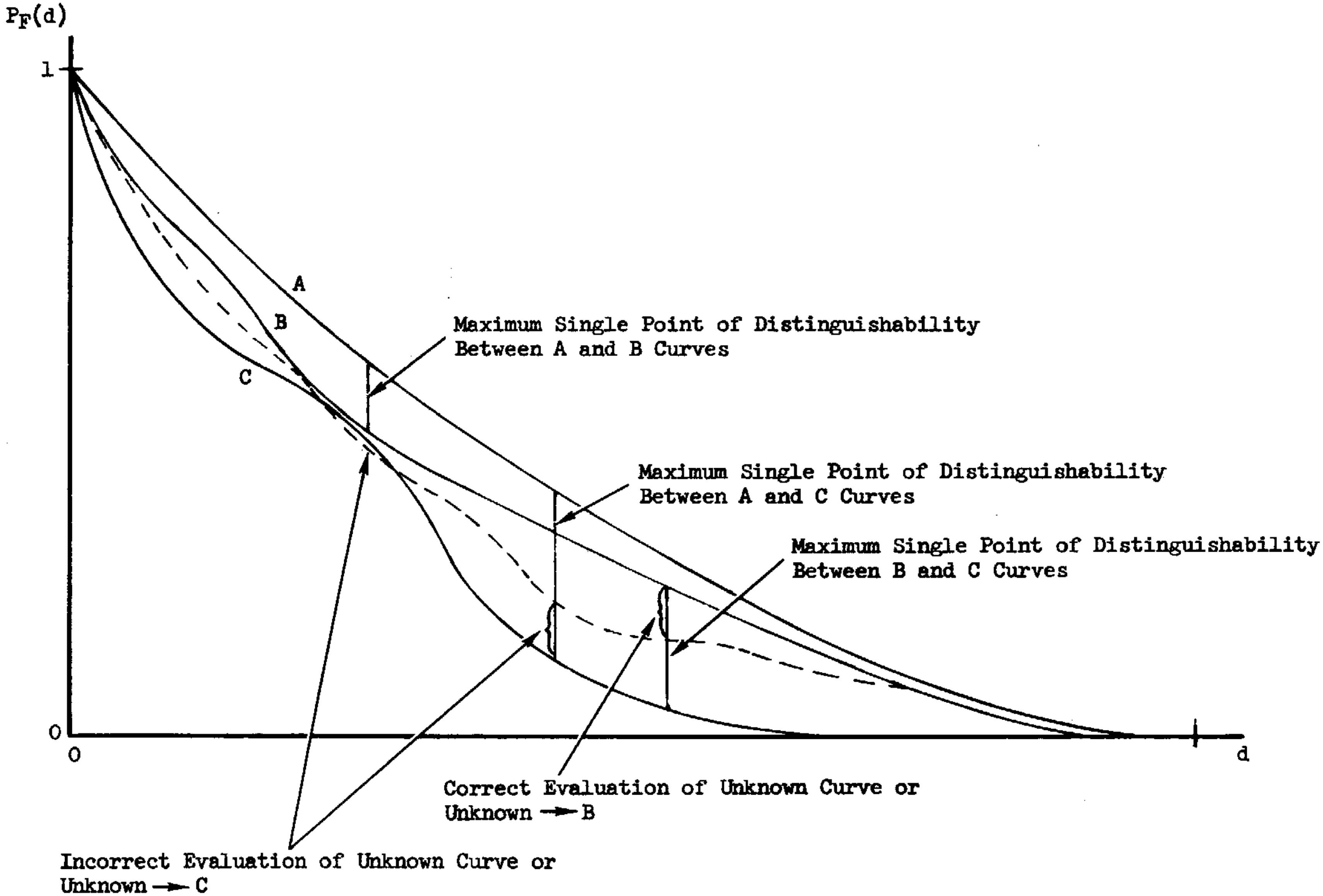


FIGURE 38 OPTIMUM DISCRIMINATION VALUES WITH THREE P_f FUNCTIONS

on a single point would invariably produce many false answers among three curves. Needless to say, the complexity of the decision and the need for other criteria are shown to be quite evident.

5.2 TEMPLATE MATCHING SYSTEM

A template matching system can be made to satisfy the requirements of a practical Bionics Image Recognition System operating in a universe of n-conceptual images. A large number of P_F functions could be stored magnetically which would serve as a reference of all images which can be identified in this system. An unknown image would be processed so as to create its $P_F(d)$ function and a "best match" criteria can be employed to identify the unknown image with one of the stored P_F functions representing the field of stored images. Sequential testing and comparison of the stored images would be performed. Furthermore, the degree of "best fit" could be implemented as a rejection mechanism if certain minimum standards are specified.

In a practical system, at least 50 images would be required in a single group identification problem. Any number of groups containing 50 images might be preselected for testing and comparison. Typical of such a storage system might be a magnetic core storage device capable of storing P_F information for 50 images with a magnetic tape loading device that would contain any number of groups of 50 images each. Thus, a computer system could be mechanized to implement a Template Matching System that would have real practical value in a Bionics Image Recognition System operating in a universe of n-conceptual images.

In order to be able to provide the degree of distinguishability that might be required in such a system, each P_F curve could be digitally constructed such that the curve would contain 50 values of d, between $d = 0$ and d_{max}. In addition, the $P_F(d)$ values at each of the 50 d-values would possess a range of 6 bits for values of $P_F(d)$ between $P_F = 0$ and $P_F \doteq 1$. Refinements in these figures can probably be made with further study; however, these figures can serve as a reasonable estimate or preliminary specification. The template matching system seems the plausible approach in handling the n-conceptual image problem.

5.3 OPTICAL SENSORS

There are two possible sensors that can be favorably utilized with the template matching system in creating a Bionics Image Recognition System operating in a universe of n-conceptual images. These two sensors are a special electronics tube providing both optical sensing and nutation capabilities and a mosaic photoelectric system in which external logic circuits provide nutation by switching logical inputs. It is expected that greater usable resolution can be achieved with the special electronics tube, but that there may be some region in which photoelectric mosaics may provide simplicity of operation and reliability.

5.4 PROBABILITY STATE VARIABLE

Probability state variable equipment such as the neurotron may find extended use in pattern recognition equipment provided that it can be used to supplant or reduce the amount of magnetic memory required while remaining economically feasible. However, in all probability, an extensive period of time and study will be required prior to the use of such a substitution which will prove to be as valuable as magnetic memory systems are in current computer equipment.

SECTION VI

CONCLUSION

The design and construction of a Bionics Image Recognition System has been completed. This system demonstrates the feasibility of combining the concepts of statistical image transformation and probability state variable device into an image recognition system and indicates methods and techniques for advancing the state of the art to image recognition systems performing tasks of greater complexity such as to be found in a system of n-conceptual images. The present system contains certain flexibility for increased performance with some modifications of the storage registers for increased resolution capacity.

SECTION VII

RECOMMENDATION

Expansion of the current system into a larger system performing tasks of greater complexity is realizable. A Bionics Image Recognition System can be designed and built to operate in a universe of n conceptual images. It is recommended that effort be exerted to continue the work just initiated in this year's effort. The current system delivered under this contract has considerable potential for expansion and the most useful ways for performing this expansion should be sought. The usefulness of the $P_F(d)$ function has by no means been exhausted. Information that would be useful in generalization of image classification is inherently available in the current system but this information is being integrated out to make the system insensitive to orientation. Methods should be studied to utilize information available for generalization of images into image families such as rectangles, triangles, and other general categories.

APPENDIX I

ALIGNMENT PROCEDURE

I.0 General

The main power switch on the Control Panel operates all power supplies. In addition, the following supplies must be switched on at their respective panels:

12	KV	Supply	
1750	Volt	Supply	
- 12	Volt	Regulated Supply	simultaneously off
+ 12	Volt	Regulated Supply	and on

To prevent damage to equipment, make sure that the 1750 volt supply and the + 12 volt and - 12 volt regulated supplies are set at voltages not much above their normal levels, before turning power on. The ± 12 volt supplies should be turned off and on simultaneously to prevent certain logic states from sustaining continuous flash tube glow.

After adjusting power supplies, allow equipment to warm up for about 20 minutes prior to making further adjustments. During this warm-up time, Oscilloscope Intensity should be turned to zero to prevent phosphor damage.

Most adjustments are stable enough to require checking very infrequently. Critical adjustments, or adjustments subject to considerable drift are identified in the procedure which follows.

I.1 Power Supply Voltages

I.1.1 -12 Volt Unregulated Supply (not adjustable) Supplies power for slide motor, relays and panel lamps (except for "power on lamp"which operates from the -12 volt regulated supply).

I.1.2 -12 Volt Regulated Supply (left side, bottom panel, right bay) Adjust to -12 volts ± 0.25 volts. Drift is not significant. Use external meter to adjust. Since controls are external, take care to prevent accidental mis-adjustment.

I.1.3 +12 Volt Regulated Supply (center, bottom panel, right bay) Adjust to +12 volts ± 0.25 volts. Drift is not significant. Front panel meter is adequate for adjustment. Since controls are external, take care to prevent accidental mis-adjustment.

I.1.4 1750 Volt Supply (bottom panel, left bay) Adjust to 1750 volts ± 20 volts. Front panel meter is adequate for adjustment. Drift is not significant. CAUTION! VOLTAGES IN THIS SUPPLY, IN THE CHASSIS ABOVE IT, AND IN THE OPTICAL TUBE ARE HIGHLY LETHAL !

I.1.5 12 KV Supply (not adjustable) This supply is located on the Storage Tube Control Chassis, second chassis from the bottom, left bay. Supply is readily accessible from the rear of the rack without removing the chassis. Power is supplied from a single 1.4 volt mercury battery. Should battery voltage drop below an acceptable level, supply will cease operating altogether. Check battery.

I.1.6 Xenon Flash Tube Supply (not adjustable) This supply is located in the Storage Tube Control Chassis, and is powered from a 220 volt Autoformer bolted to the left side of the left rack bay. It produces 300 volts DC for the Xenon flash tubes. CAUTION ! Four 550 MFD Capacitors charged to 300 volts are located on top of the Storage Tube Control Chassis. These capacitors must be discharged through a suitable resistance after power is turned off prior to working on the chassis or replacing flash tubes.

I.2.0 Clock Frequency Adjustments

Place card number 203 on an extender card, and monitor pin X with an oscilloscope. Signal should be a negative-going 1KC 12 volt square wave. Adjust frequency with uppermost trimpot on card. A calibrated oscilloscope sweep should be accurate enough for this.

Monitor pin C. Signal should be a negative-going 100 cycles 12 volt square wave. Adjust frequency as above using lowermost trimpot on card. These multivibrators need not be synchronized. Drift is not critical. Remove extender card.

I.3.0 Image Storage Tube Adjustments

These adjustments are rather involved, but are not frequently required, since there is little tendency to drift. The procedure should be followed carefully.

I.3.1 Scope Spot To obtain an oscilloscope spot suitable for "read" during storage tube adjustments, proceed as follows:

a. Set "d" pot on control panel to zero
b. Adjust oscilloscope to obtain a spot on the center of the oscilloscope face. Spot may be observed by removing the small plug on the top of the optical tube and looking into the hole. A reflector plate permits direct viewing of the oscilloscope face.
c. Defocus the spot to produce a disc approximately 3/32" in diameter. Do not allow a sharply focused spot to remain on the scope face unless intensity is set very low. Any burning or desensitizing of the phosphor will seriously affect the performance of the system. A uniform disc is produced when defocusing is made counter-clockwise from the sharp focus position.
d. Set intensity control with arrow on knob pointing directly up, or slightly counter-clockwise from this position. Higher intensities should be used only when system is in full automatic operation, and should not be necessary even then.

I.3.2 Removal of Photomultiplier CAUTION ! Before proceeding with disassembly, turn off the 1750 volt supply ! You will be handling components supplied with lethal voltages !

Remove the three phillips-head screws retaining the end cap on the optical tube, and the three screws immediately beyond them. If a stubby screwdriver which can reach the bottom screws is not available, it will be necessary to remove the four screws under the deck plate which retain the optical tube, and slide the tube toward the edge of the cabinet. Remove the end cap. (CAUTION - Fragile) After brief cooling period, remove the photomultiplier bulkhead carefully, working it out with a pair of needle-nosed pliers if necessary. As it comes clear of the tube, remove the photomultiplier tube and its MU-metal shield from the socket. Do not hold the tube by its shield, since the shield fits loosely.

Reach inside the optical tube and remove the plastic light pipe. Place a plastic bag around the photomultiplier bulkhead, since it will contain lethal voltages when power is turned back on.

The Image Storage Tube viewing screen is now in plain sight inside the optical tube. Turn on the 1750 volt supply.

I.3.3 Initial Electrode Voltage Settings Adjustments of Image Storage Tube electrode voltages are available on the front panel of the Storage Tube Control Chassis (see schematic Figure 13) with test jacks immediately beneath the adjustments. Using a VTVM or a high impedence multimeter, check these voltages. The voltages listed below produced good results at the time of final checkout. However, tube characteristics may be subject to long term drift, and should new settings be found desirable, record the new values to be used for subsequent initial alingment settings. Adjust to the following voltages.

R1 (Collector electrode) + 25 volts (not critical)
R2 (Photo cathode) - 400 volts (not critical)
R3 Backing electrode during "STORE" 0 volts (critical)
R4 Backing electrode during "ERASE" + 8.5 volts (critical)
R5 Bakcing electrode during "READ" + 1.5 volts (critical)

I.3.4 "ERASE" "STORE" and "READ" Cycle Set the "Manual-automatic" lever on the front of the Storage Tube Control Chassis to "Manual". The storage tube can now be stepped through its cycle manually by means of the "ERASE-STORE" momentary lever switch, also located on the front of the Storage Tube Control Chassis.

Place a slide in the slide holder. While looking into the optical tube, flip the "ERASE-STORE" switch to the "ERASE" position. The screen should flash bright blue for an instant, followed by complete darkness. Flip the "ERASE-STORE" switch to the "STORE" position. The slide image should flash brightly on the screen, followed by a sustained dimmer image. Should a double image be seen, this means that the scope spot is not aligned. Adjust the oscilloscope spot position until the two images are exactly super-imposed. Both horizontal and vertical oscilloscope channels should be set to "DC" at all times. The stored image may be observed by itself by removing the slide. Should the image be of a quality too poor to recognize its essential properties, should the background not be completely black, should the image fade out too quickly, or should ERASE not remain completely black for at least several seconds, a readjustment of the storage tube voltages is required. Do not fire STORE successively without erasing. This will over-store the image, resulting in subsequent incomplete erasures. A detailed discussion of storage tube characteristics and adjustment is given in Appendix III.

I.3.5 ERASE and STORE Flash Tubes Should the ERASE and STORE flashes not occur, or should flashes not occur every time, the Xenon flash tubes may require replacement. The ERASE flash may be observed directly as a faint flash visible through the slide holder slot. The STORE is visible as a bright flash beneath the right end of the optical tube base.

To replace flash tubes, first unplug the 220 volt autoformer from the plugmold, and discharge the Xenon flash capacitors. The STORE bulb may be replaced from the rear. Replacement of the ERASE bulb requires removal of the optical tube from the deck. Turn the tube on its side. The ERASE bulb is inserted into the underside of the tube.

I.3.6 Optical Tube Reassembly CAUTION ! Before reassembly of the optical tube, turn OFF the 1750 volt supply. Reinsert the plastic light pipe, making certain that the far end passes through the bulkhead next to the Image Storage Tube. Next, insert the MU metal shield, by itself, into the retainer groove in the bulkhead holding the near end of the light pipe. The photomultiplier may now be inserted into the socket in the photomultiplier bulkhead, and the bulkhead replaced into the optical tube. Make certain that screw holes are aligned, and that the cable harness is free of the MU metal shield. The cable hole in the bulkhead is at the bottom. Replace the retainer screws, then replace the end cap and screw in place. If the optical tube has been removed from the deck, replace it. Plug in the Autoformer. Set the MANUAL-AUTOMATIC lever to AUTOMATIC. Turn on the 1750 volt supply.

I.4.0 P_f Circuit Adjustments

I.4.1 Photomultiplier Output Gain Set the Photomultiplier Output Gain control (located on the left front of the optical tube) with the pointer pointing directly to the right. Although some adjustment may be required with certain images, this setting should prove satisfactory for most conditions.

I.4.2 Photomultiplier Output Zero Place card number 313 on an extender card. Monitor pin C with an oscilloscope or VTVM, using pin X as a ground reference (be sure that the test instrument is not also grounded through the line card ground). Place the MANUAL-AUTOMATIC lever on the Storage Tube Control Chassis in MANUAL and fire the ERASE bulb. If the test instrument used is sensitive to transient overloads, disconnect it momentarily while firing the ERASE bulb. Adjust the bottom trimpot on card 313 to produce zero volts within ± 5 millivolts. Since the ERASE may fade in time, make this adjustment within about 5 seconds of firing the ERASE bulb. ERASE may be fired again if necessary. Leave extender card in place for final zero adjust.

I.4.3 Pulse Generator Zero Frequency Adjust Place card number 123 on an extender card and monitor pin B. This signal will consist of negative going 12 volt pulses approximately 15 microseconds wide, varying in frequency during the operating cycle from zero to around 20 Kpps. Fire the ERASE bulb as in I.4.2 above. Adjust the upper pot on card number 313 so that, within 5 seconds of ERASE, the pulse generator just barely does not oscillate. Dropout pulse frequency will be around 50 PPS. Remove the extender card and return the MANUAL-AUTOMATIC switch to AUTOMATIC position.

I.5.0 Nutation Circuitry Adjustments

Card slots 317 through 323 are used with card type 8PA-D lamp drivers. Only one slot is occupied at a time, providing a readout with the lamps on the panel just below the card housing of the counter or register connected with that slot. For adjusting the nutation circuitry, it is useful to monitor the contents of the "Standardize d_{max}" Counter. Place the 8PA-D card in slot number 318.

I.5.1 Oscilloscope Zero Adjust If the Oscilloscope zero procedure in paragraph I.3.4 above ("ERASE", "STORE" and "READ" cycle) has just been performed, additional adjustment at this point will not be necessary. If not, proceed as follows: Turn the spot intensity down until it can barely be seen through the stoppered peep hole on the top of the optical tube. Push the small momentary push button on the right front of the optical tube base. A faint white spot will appear inside the tube. Adjust the scope spot position to coincide with this spot. (CAUTION - Do not fire the flash tubes while looking into this hole. Permanent eye damage may result.)

I.5.2 Oscilloscope Intensity and Focus Adjust A sharply focused oscilloscope spot must never be allowed to remain on the scope face unless the intensity is turned very low, or the spot is defocussed. The system is operated with the spot slightly defocussed. Defocus the spot by turning the focus control counter-clockwise from the sharp focus position until a disc approximately 3/32" in diameter is produced. Set the intensity control with the arrow on the knob pointing directly up. Normal operating intensities will not vary much from this position. Much higher intensities should be used only when system is in full automatic operation, and should not be necessary even then. Any burning or de-sensitizing of the phosphor will seriously affect the performance of the system.

I.5.3 Oscilloscope Phase and Gain Adjust Unbolt the optical tube from the deck, and slide it back away from the oscilloscope face about 4 to 6 inches. This permits direct observation of the oscilloscope display, and allows outside ambient light into the photo-sensitve system.

Set the slide control switch on the front of the optical tube base to MANUAL. Remove any slide that may be in the slide holder and set the slide holder to either slide position.

Set the "d" pot to full scale. Push the "FORGET" button, followed by the "LEARN OR SORT" button. A circule or ellipse will appear on the screen starting from a spot, growing to some maximum size, and cycling over again repeatedly. The image may be stopped in any position by blocking the light into the optical tube with a piece of cardboard. Observe the readout lights below the logic modules. They will display a binary number from 0 to 31 directly proportional to the image size (providing the diaplay card in the proper slot. See paragraph I.5.0 above). Repeat the cycle, pushing the "LEARN-SORT" button and blocking the light into the tube until the maximum image size is obtained. When this occurs all five display lamps will be lit. Do not re-zero the scope, even though the display may be off center.

Next, adjust the oscilloscope display for the largest and most nearly perfect circle obtainable which is still completely visible around its entire circumference. This is done by alternate adjustment of the oscilloscope horizontal and vertical gain controls, and the phase adjustment trimpots on card No. 306.

Additional adjustment of circle purity may be made by tuning the "nutation"filter. This adjustment is an Allen screw on the large inductor case mounted on card No. 313. Circle roundness may be checked by holding an object of the proper size known to be circular over the oscilloscope display. Note: There is some distortion inherent in the cathode ray tube when the maximum size circle is displayed. This may be checked by stopping the display at some smaller size where this distortion is negligible. Upon completion of these adjustments, reassemble the optical components. The system is now ready for final zero adjust.

I.5.4 Final Zero Adjust Monitor the waveform at card No. 313, pin C. Adjust the external test oscilloscope to .05 volts/cm sensitivity and 0.5 milliseconds/cm sweep frequency. Set trace zero at the top of the graticule. Set the "d" pot on the control panel to about mid-scale. Place a slide in viewing position, a circle ideally, but any image with symmetry about at least one axis, and preferrably two. Press the "LEARN OR SORT" button. Upon completion of the cycle, a waveform will be visible on the test oscilloscope which probably contains a considerable 1KC component. Adjust the optical system oscilloscope horizontal and vertical position controls for minimum 1KC content. (Higher frequency components are low in amplitude due to phosphor persistence.) Should the adjustment procedures take longer than about 10 seconds, push the "LEARN OR SORT" button again, to insure a good image. A circle should produce a straight line. Images with no symmetry at all contain natural 1KC components even when the system is properly adjusted, and must not be used for alignment purposes for that reason.

Restore slide control switch to the AUTOMATIC position. At this point, the system is aligned and ready for operation.

This final zero adjustment is more subject to drift than any other in the system. It should be performed only after complete system warm-up, and checked periodically during long periods of operation or stand-by.

APPENDIX II

OPERATION PROCEDURE

II.0 General

It is assumed that the alignment procedure described in Appendix I has been completed, and the system is ready for operation. Normal operation is described here, although the user may find variations of it useful for special purposes.

II.1.0 Initial Slide-holder Position

Insert the slides to be learned into the slide-holder. The slide nearest the operator is slide "A", and the farthest, slide "B". Should the operator prefer to position the slide-holder manually, set the Slide Control Switch to "MANUAL" and position the slide-holder in the "A" position. For automatic slide operation, set the Slide Control Switch to "AUTOMATIC", and position the slide-holder about mid-way between "A" and "B" positions. This permits the slide-holder to gain enough momentum to actuate the limit switch at the end of its travel. (Note: Should the motor continue to run with the stop against the limit switch at any time, push the stop against the switch. The slide-holder should now complete its cycle.)

II.2.0 Forget

Push the "FORGET" button. This clears all storage registers, and places the system in the "A Ready" condition. The "A Ready" lamp should come on. If the Slide Control Switch is in "AUTOMATIC", the slide-holder will move to the "A" position.

II.3.0 Learn

During successive "LEARN" trials, the operator should try various random settings of the "d" pot, gradually converging on the last rewarded "d" setting. The operator should keep a record of the last rewarded setting. The most probable optimum setting is at mid scale, and the operator should start here. Due to the effects of various threshholds, mid scale is at approximately 40.

II.3.1 Automatic Learn Mode

Push the "LEARN OR SORT" button. The system will scan slide "A", move to slide "B", scan slide "B", return to slide "A", and wait. Either the "REWARD" or the "PUNISH" lamp will come on. Repeat the cycle with a new "d" pot setting, gradually converging on the last rewarded "d" pot setting with each successive trial. When the operator is satisfied that the optimum setting has been found, return the "d" pot to the last rewarded setting. The operator may now proceed to the "store" operation.

II.3.2 Manual Learn Mode

With the Slide Control Switch in the "MANUAL" position, the system will scan slide "A" when the "LEARN OR SORT" button is pushed, but will not proceed to slide "B". Instead the "B Ready" lamp will come on. The operator must then place the slide in the "B" position, and push the "LEARN OR SORT" button. (Note: The B limit switch is not disabled in the MANUAL mode. By pulling the slide-holder stop against the "B" limit switch, the operator initiates "LEARN B", and need not push the "LEARN OR SORT" button). The "REWARD" or "PUNISH" lamp will come on as well as the "A Ready" lamp. Return the slide-holder to the "A" position and proceed with successive trials as described under II.3.1 above.

II.4.0 Store

When the operator is satisfied that he has found the optimum "d" pot setting, return the "d" pot to that setting and push the "STORE" button. In the "AUTOMATIC" mode, both slides will be scanned in succession. In the "MANUAL" mode, following the "A" scan, the operator must position the slide-holder in the "B" position and push the "STORE" button again. The system will now be in the "SORT" mode.

II.5.0 Sort

In this mode, the operator must position the slide in either "MANUAL" or "AUTOMATIC" since there is no set procedure for scanning slides to be recognized. The "INHIBIT" register switches should be set to either 0 or 31, unless there is some previously determined value which the operator wishes to use. The system should now properly identify the slides previously learned, as well as slides containing larger or smaller images of the same shapes (within limits). However, other shapes will also be called "A" or "B" as well. It is the function of the Inhibit Register to limit the range of values identifiable as A or B, and produce a "NO DECISION" response for all others.

II.6.0 The Inhibit Register

A graphic representation of the decisions which would result using all possible "INHIBIT" settings when the stored "A" and "B" values are 10 and 20 respectively, is shown in Figure 10. This figure serves to show the nature of the Inhibit function, and to make it possible to represent, mentally, graphically or in tabular form, the "INHIBIT" effects using any stored "A" or "B" values. It can be seen that response to an undesired figure can be inhibited by setting into the Inhibit register some number which lies between the Pf value of the unknown, and the stored value nearest to it.

II.7.0 Observation of Register Contents

It is useful, for various purposes, to observe the contents of the various counters and storage registers in the system. For this purpose, a bank of binary readout lamps is provided on the panel immediately under the logic modules. There is one Wyle Laboratories 8 PA-D Lamp driver card provided which may be inserted into any one of seven slots, connecting the readout lamps to the counter or register associated with that slot, as follows:

Slot No.	Counter or Register
317	"Standardize P_f Counter (Standardize Area)
318	"Standardize d_{max}" Counter
319	"Up-Down" Counter
320	Input Binary Counter
321	"A" Register
322	"B" Register
323	Delta Counter

II.7.1 "Standardize P_f Counter" - (Slot 317)

This count is directly proportional to the total light passing through the image, and is thus proportional to both oscilloscope spot intensity and image area. Zero in the counter represents the minimum light required to achieve image standardization. If no count appears in the counter during standardization, the image is too small to standardize, or the oscilloscope intensity is too low, and incorrect decisions will result. In marginal cases, increasing oscilloscope intensity or increasing photomultiplier gain may correct the problem. Should the counter fill up entirely and flip back to zero, improper standardization or complete failure to complete the cycle will result. Turn down oscilloscope intensity. The range of size of images which can be learned during any one learn and sort trial is limited by these extremes: the smallest must produce a minimum count, and the largest must not cause spill-over.

II.7.2 "Standardize d_{max} Counter" - (Slot 318)

This count is directly proportional to the longest line whose end points fall within the figure being scanned. Should this counter spill over, it may be due to improper P_f standardization, poor stored image in the Image Storage Tube, or improper setting of oscilloscope spot nutation. For these latter two adjustments, see the Alignment procedure.

II.7.3 "Up-Down Counter" - (Slot 319)

Following "LEARN A" and "STORE" this counter contains the actual P_f value of the image being scanned, at the "d" value set in the "d" pot. Following "LEARN B", this counter contains the absolute difference between P_A and P_B, noted elsewhere in this report as $|\Delta P_f|$. Following sort, the number stored is a composite, and is not particularly meaningful.

II.7.4 Input Binary Counter - (Slot 320)

Following "LEARN" and "STORE", this counter contains the actual P_f value of the image being scanned, at the "d" value set in the "d" pot. Following "SORT", the number stored is a composite, and is not particularly meaningful.

II.7.5 "A" Register - (Slot 321)

Following "LEARN A", this register is empty. Following "LEARN B", it contains $|\Delta P_f|$. Following "STORE A", and thereafter, through "SORT", until the "FORGET" button is pressed, it contains P_A .

II.7.6 "B" Register - (Slot 322)

This register is empty throughout the learn process up to and including "STORE A". Following "STORE B", and thereafter, through "SORT", until the "FORGET" button is pressed, it contains P_A.

II.7.7 Delta Counter - (Slot 323)

This is an operational counter which always starts empty and always ends up at 31. Failure to do so is a malfunction.

APPENDIX III

STORAGE TUBE OPERATION

III.0 General

The Image Storage Tube is a device with a photocathode on one end and a phosphor screen on the other, within which an optical image may be stored in the form of electrical charges stored on a dielectric grid.

III.1.0 Physical Configuration

The entire tube is mounted inside a cylindrical permanent magnet. Thus a longitudinal magnetic field exists throughout the interior of the tube, insuring that the spatial arrangement of electrons leaving the photocathode will be maintained throughout their entire free path length, until they strike the phosphor at the far end of the tube, or until they are captured by an intervening electrode.

At the input end is a cesium-antimony semi-transport photocathode which has an S-11 sensitivity, peaking in the blue region of visible light. The next two electrodes are the collector electrode and the backing electrode, in that order. Both are extremely fine grids, whose structure is barely visible to the naked eye. The collector electrode is a conductor, whereas the backing electrode is a conductive film on the back of a dielectric storage grid. At the output is the anode, containing a P-11 phosphor screen (blue). The collector and backing electrodes are located in very close proximity to each other.

III.1.1 Functional Operation

The anode is maintained at +12KV at all times. The sole purpose of this potential is to accelerate the electrons sufficiently to excite the phosphor. The collector electrode is maintained at a constant voltage up to a maximum of +200 volts. In this system, the collector electrode was set at +24 volts at delivery, which should prove quite satisfactory. This adjustment is not critical.

The cathode and backing electrode potentials are changed for different modes of operation, as described below.

III.1.1.1 Erase Mode

The cathode is set at zero volts. The backing electrode is set at a particular negative voltage ranging up to -20 volts, depending on the individual tube and the chosen operating point. (For recommended voltages with the tube delivered with this system, see Appendix I, Alignment procedure).

The cathode is flooded with light. These electrons accelerate toward the collector electrode. Some pass on through and collect on the dielectric front surface of the storage grid and backing electrode. Other continue through the backing electrode and are accelerated through to the anode, illuminating the phosphor. As electrons build up on the storage grid, fewer and fewer pass through. At the end of the ERASE period, the backing electrode is abruptly dropped several volts in the negative direction. The charge on the storage grid now blocks all electrons, and the phosphor is completely dark. The tube is now ready for an image to be written on the storage grid.

III.1.1.2 "Store" Mode

The cathode is dropped to -400 volts (a maximum of -800 volts is permissable) and the image to be stored is projected on the photocathode. Electrons from the illuminated regions of the photocathode accelerate through the collector electrode (a percentage of which, of course, strike the collector electrode and are conducted away) and strike the storage grid. They strike with too much energy to be captured, but instead, cause secondary emission, leaving positive areas on the storage grid, in the same pattern as the image focussed on the photocathode. Electrons thus emitted are swept up by the collector electrode. The cathode is returned to zero volts, and the stored image may be read.

III.1.1.3 Read Mode

In the READ mode, the photocathode is at zero volts, and the backing electrode is at a potential several volts more negative than during the ERASE cycle. The cathode may not be flooded with light, and the stored image observed on the anode phosphor. Thus the storage grid acts like an erase-able photographic transparency. Should another image be focussed on the photocathode in this mode, or the original image focussed on it in a displaced position, only those transparent areas common to both images will be illuminated on the phosphor.

III.2.0 Voltage Adjustments

Many of the interactions within the Image Storage Tube are quite subtle, and, since the tube is still basically experimental, not entirely understood. Some of the more important relationships are listed here to permit adjustment. Some experimentation on the part of the user will provide him with a firmer grasp of the tube's characteristics. For further information, consult the manufacturers literature, or contact the manufacturer, IT & T, Fort Wayne, Indiana.

On the front panel of the Storage Tube Control Chassis are five adjustment pots for the Storage Tube electrodes, each with its own test jack:

R-1	Collector electrode
R-2	Cathode electrode during "STORE"
R-3	Backing electrode during "STORE"
R-4	Backing electrode during "ERASE"
R-5	Backing electrode during "READ"

See Alignment Procedure, Appendix I, for recommended settings at the time of shipment.

The following relationships have been found to hold:

Higher Collector electrode potentials require higher backing electrode potentials, and vise versa.

Higher Cathode potentials produce a more firmly written image, but increase the likelihood of blooming, along with more fifficult erase.

Lower Cathode potentials make erase easier, but increase the likelihood of early break-up or fade of the stored image. In general, cathode potential is not critical.

Most critical is the difference between the backing electrode voltage during "ERASE" and the backing electrode voltage during "STORE" and "READ".

High "ERASE" to "STORE" voltage difference produces a good erase, but a dark, incomplete WRITE. This written image may be made more distinct by decreasing the "READ" potential, but the "ERASE, may become incomplete. (A careful compromise in these settings is needed to produce results completely satisfactory). A lower difference between "ERASE" and "READ" and "STORE" will improve the stored image, but "ERASE" may become incomplete.

III.3.0 Tube Failure

One Image Storage Tube failure was experienced during development of the Image Recognition System, and although it may have resulted from unusual treatment which the tube received during system development, or from faulty manufacture, it is mentioned here so that the user may recognize the failure mode should it occur to the tube presently in the system. The high intensity, short duration "ERASE" flash used with this system has never been used with this type of tube, and the long-term effects of it have not been thoroughly investigated. A description of the failure symptoms follows, with the possible cause.

The symptom is sustained electron emission from the photocathode following the "ERASE" flash, even in the absence of all light excitation. A pattern of pulsating concestric rings appears on the viewing phosphor, with a dark spot in the center. The pattern abruptly winks out shortly afterward (milliseconds or even seconds later). This malfunction manifests itself in the Photomultiplier output signal as large amplitude, low frequency oscillations, ceasing abruptly, followed by an incomplete erase.

The most probably cause is considered to be out-gassing of some component within the tube. When the "ERASE" flash was fired, the flood of electrons produced collided with the gas molecules on the way to the anode. The gas molecules were ionized, and the positive ions rushed toward the cathode, causing secondary electron emission which, in dropping toward the anod, sustained the reaction. Charge build-up of an oscilliatory nature on the backing electrode probably accounted for the concentric rings. The condition ceased abruptly when negative charge build-up on the backing electrode was sufficient to break the cycle.

The cure recommended by the manufacturer, was baking of the tube at 100°C for about two hours, with a small negative potential applied to the photocathode with respect to the other electrodes to prevent evaporation of the cesium-antimony cathode material on the other electrodes.

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13. ABSTRACT

This is the final technical report for a Bionics Image Recognition System. This report provides a description of a learning device which can be used to seek and test for an optimum discrimination value between two planar geometric shapes placed on 35 mm slide transparencies. The slide image shape-information is transformed from a function of two independent variables into a function of a single independent variable. Specific values of the transformed image shape-information are used to determine the best value for discriminating between any two images. After this operation, the device is capable of classifying additional planar geometric shapes as being similar to one or neither of the original two shapes which were discriminated.

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