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TECHNICAL REPORT
ON
ELECTRO-OPTICAL DISPLAY SURFACE

GPL Division, Aerospace Group
General Precision, Inc.
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Pleasantville, New York

Contract No. AF30(602)-2745

Project No. 5578

Task No. 557803

Prepared For

Rome Air Development Center
Research And Technology Division
Air Force Systems Command
United States Air Force
Griffiss Air Force Base
New York

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ABSTRACT

Contract AF 30(602)-2745, as issued on May 14, 1962, provided for an investigation and feasibility demonstration of an electro-optical technique for large-scale data presentation. This work would, ultimately, lead to a development program for an active, light controlling but non-emitting display surface.

This Final Technical Report describes the effort exerted by the GPL Division, General Precision, Inc., during the design, development, fabrication and test of a magneto-optical display surface, hereafter referred to as a Reflective Display. Results of the investigation including supporting analyses and tests on a feasibility model of a reflective display conclusively prove that techniques of light absorbing and reflecting surfaces can be suitably controlled for application in large-scale data display systems. Investigations indicate that if effort is maintained, this magneto-optical display technique will lead to a successful large-scale display panel. Special emphasis is placed on recommending improvements to the prototype design which could ultimately be incorporated to optimize subsequent designs.

This report has been prepared for the Rome Air Development Center, Air Force Systems Command of the United States Air Force in fulfillment of Requirement Item No. 4 of Exhibit A of Purchase Request Continuation Sheet for P. R. No. 152120, under Contract AF 30(602)-2745.

Title of Report RADC-TDR-63-101

PUBLICATION REVIEW

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1. INTRODUCTION

1.1 General

This document describes the function, performance, design, fabrication and test effort required to show the feasibility of the Reflective Display Unit. This device may, in an expanded and further refined state, be used in a panel array for the large-scale display of alpha-numeric and symbol information for the presentation of maps, graphs, etc. or as a read-out device for various digital or analog inputs. Some information contained herein has been incorporated from the Quarterly Memorandum and is intended as background data.

Exhibit "A" of the contract requires an "Investigation and Feasibility Demonstration of an Electro-Optical Display Surface". GPL's effort is the development of a blackboard-type display surface that will present line and symbol data in response to electronic input signals. The illumination of the device will be derived from the ambient light and will eliminate self-generating light techniques. The development work has terminated with the construction of an approximate 21" x 21" (64 elements x 64 elements) breadboard device and the submission of this report. Although the contract exhibit permits the investigation of electro-optical, magneto-optical, electro-mechanical and electro-chemical techniques; the contract was awarded to GPL on the basis of engineering performed in the field of magneto-optical phenomena during previous company sponsored programs and accordingly concentrated on this approach.

1.2 Description of Display Techniques

An explanation of the approach and objectives thereto is as follows:

Magnetically polarized spheres or elements which are light reflecting (white) on one side and light absorbing (black) on the other (Figure 1-1) are selectively scanned and rotated by the influence of individual, surrounding, magnetic fields. The elements are mounted behind a transparent panel where their light reflecting or light absorbing surfaces are used to form alpha-numeric characters, symbols or lines in response to electronic input signals. The nucleus of the device is, therefore, the magnetic circuit. A major effort of the study phase has been to develop a magnetic circuit that would meet the functional requirements and optimize this circuit in regard to simplicity, power consumption and reliability so that performance goals may be achieved.

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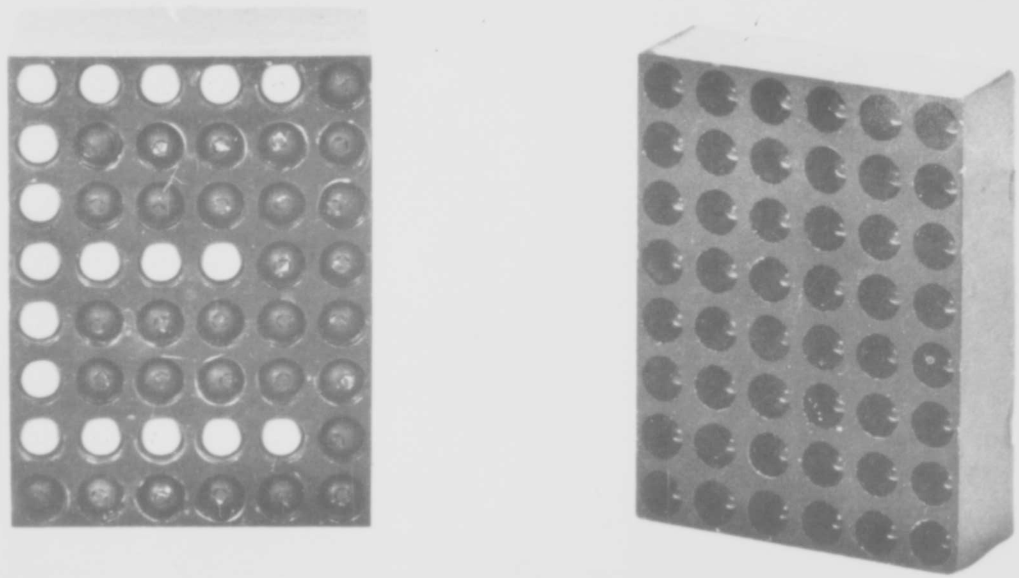

Figure 1-1 Single Character Display Module

2. REPORT ORGANIZATION

The technical sections of this report are arranged in accordance with the development of the Reflective Display concepts and techniques as they progressed at GPL. Appendicies are provided as background data and also contain (Appendix 2) fabrication and specification drawings for the Reflective Display models.

3. CONTRACT GOALS

The approach selected to fulfill the technical requirements of Exhibit A of Purchase Requisition #152120 under AF 30(602)-2745 exhibits potential for achieving the following performance requirements:

3.1 Screen Size

The display configuration and proposed backup logic is expandable to accommodate a display surface of at least 5' x 3.75'. A display panel of this size could be provided as a modular array and conform to the specifications listed herein.

3.2 Resolution

Elements for existing models are .250" in diameter with a center-to-center distance of 0.33". Finer resolution can be obtained if packaging techniques and magnetic circuit designs are modified.

3.3 Luminance

Zinc sulphide pigment is mixed with a clear acrylic to mold the spherical elements. The reflective characteristics of both materials approximates that of Magnesium Carbonate (reflective constant 0.993) so that a maximum average ambient of no more than 70 foot-candles is required to meet the 50 foot-lambert reflective requirement.

3.4 Viewing Angle

A single character reflective display module is readily visable over the range ± 45° horizontal and ± 45° vertical with essentially no degradation of legibility. Characters may be distinguished up to an included maximum angle of 140°.

3.5 Response Speed

The present panel display is driven by a tape reader and electronic switching in conjunction with stepping relays. The driver speed can be adjusted to exceed the response of the display by a factor of 2.

The 5-second display change requirement for a 5' x 3.75' panel can be met by sophisticated logic techniques and parallel character address methods.

3.6 Storage

Since this device utilizes a technique for display which is dissimilar from decaying self-luminescent displays, storage or retention of data poses no problem. An array of display modules or any protion thereof will remain static until an update command signal is received.

3.7 Drive Requirements

Present equipment power consumption is held to an acceptable minimum but further total power specification will be dependent upon selected logic schemes.

3.8 Color

Color techniques, although not required by the contract, have been initially considered. Although color is applicable by alternate methods, the deliverable equipment is a bistable or two-color display and will present only black and white information. It is apparent, however, from the configuration of the Reflective Display that some color techniques may be used. Certain elements may be surfaced with a light sensitive material such that they would appear white but when excited by a black light source would transmit color. Another configuration might consist of a polarized, filter-type cover rather than clear plexiglass over the entire display panel. Here, phenomena of complementary light will lend to a color display.

3.9 Reliability

The Reflective Display is comprised of extremely long life, non-decaying components and a minimum number of different types of components which in itself lends to reliable equipment. It can, therefore, be stated that reliability is inherent to the equipment design and is high.

3.10 Measurements

Data has been recorded for various aspects of operation of the Reflective display. Rather than list individual sets of data in this section, the reader will find statements of measurement in subsequent technical sections.

4. HISTORY OF PROGRAM

4.1 Contract and Amendments

Contract AF 30(602)-2745 as issued on May 14, 1962 referenced Exhibit A of Purchase Requisition No. 152120 which presented engineering requirements for an Electro-Optical Display Surface and required delivery of the following items:

4.1.1 Investigation and Feasibility Demonstration of a technique for large-scale data presentation which shall be light emitting but not light-generating.

4.1.2 A Breadboard Unit representing the efforts of developing the above techniques.

4.1.3 A Quarterly Memorandum in accordance with requirements of Exhibit RADC-3002; Contractor Prepared Research and Development Reports.

4.1.4 A Technical Report in accordance with requirements of Exhibit RADC-3002; Contractor Prepared Research and Development Reports.

4.1.5 Engineering Change "A" to the contract, dated May 14, 1963, authorizing the design, fabrication and delivery of a Driver capable of addressing the breadboard Reflective Display. This is item 1D of the work statement.

4.2 Quarterly Memorandum

A preliminary report dated August 30, 1962, was submitted to RADC to provide them with as much information as possible covering the design approach selected by GPL to develop and fabricate a Reflective Display as well as to report on the status of the administrative program. This Quarterly Memorandum provided RADC with a basis for evaluating the original proposal material which was submitted on February 2, 1962, in response to RFP 152120.

4.3 Program Background

GPL sponsored display studies which preceded the award of the subject contract were devised to meet a set of conditions which were encountered during the course of various system and equipment development programs. These problems have fallen into three general groups: a) System Functional Analysis, b) System Design Analysis, c) Device Design Analysis. Under this program an examination of display devices has led to a categorizing of all known types. These catagories are reflective, transmissive and self-generating.

It is not the intention to belabor the point of past functional analysis but rather to emphasize that the study of a specific display technique, namely, reflective and magneto-optical, was undertaken only after considerable study by both Rome Air Development Center and GPL Division. With firm convictions, the contract work was directed toward and limited to this specific type of display.

5. FEASIBILITY INVESTIGATIONS

The previous sections of this report have provided descriptive background information related to the Reflective Display, the technical design parameters and approaches thereto and provides a brief history of magneto-optical development. Subsequent information within this section will explain that principles used to develop the Reflective Display concept were established not only on the basis of the requirements of Exhibit A of the contract but also as a result of developmental and experimental data obtained from previous company sponsored programs. Details of design and analysis are also contained in this section.

5.1 Characteristics of the Display Model

A critical analysis of one of the original display models as shown in Figure 5-1 revealed certain requirements which necessitated improvement to subsequent units. Although the basic electromagnetic principles and some physical characteristics were retained, the Feasibility Model system has incorporated many redesigns. A comparison of the original model with regard to some techniques continued under the scope of this contract is listed.

Figure 5-1 First (Pre-contract) Reflective Display Model

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5.1.1 The principles of operation of the model (Figure 5-1) are similar to those previously developed for operation of modules suggested in the GPL proposal and later explained more definitively in the Quarterly Memorandum. Some points of comparison are as follows:

1. Elements of the deliverable unit are coated to provide a light absorbing (black) and light reflecting (white) surface.
2. Elements are polarized by imbedding a small permanent magnet in their center.
3. Elements are free moving i.e., there are no axles used to affect rotation for the selection of display surfaces.
4. Elements are rotated for display by supplying a current to an electro-magnet so that the flux will act in conjunction with the permanent magnet of the element to produce a torque.

Although the basic characteristics of the model, Figure 5-1, have been used to develop the concepts of a deliverable display, the following limitations did exist and efforts were concentrated during the program on their solution:

1. The paths of magnetic flux were poorly defined and element rotation was not predictable. Additionally, cross-talk or magnetic interaction with adjacent elements frequently influenced the movement of random elements in addition to the selectively scanned element.
2. It was not possible to rotate the elements of the model by using an inexpensive scan technique. Coincident current scan systems could not be applied and the addition of diode circuitry to enhance this logic was considered impractical.
3. In addition to random rotation, a condition of forces of rotation in equilibrium frequently occurred and this inhibited element rotation. A thorough analysis of magnetic forces was made to understand this malfunction and the results thereof may be found in Section 5.4.

5.2 Magnetic Circuit Development

Previous data has revealed that the magnetic circuit for the first complete GPL test model (Figure 5-1) produced an undesirable rotational force which required major analysis. Figure 5-2 shows the component structure of the model. The object of this configuration was to rotate a display element, having a permanent nagnet imbedded in its core, through the interaction of magnetic fields produced by the permanent magnet and the electro-magnet. An effective North pole would be produced at the electro-magnet by applying a current of proper polarity to the coil which is adjacent to North pole of the permanent magnet. Under certain conditions, the repelling forces of the two poles would not cause element rotation within the cell housing. Subsequent investigation of this problem (Figure 5-2A through 5-2D) indicated that the flux pattern produced between the permanent magnet of the element and the electro-magnet often created symmetrical and opposing forces which in turn produced axial translation rather than rotation. Interaction between individual elements also posed a problem in this basic configuration. If a specific element in a 3 x 3 matrix was pulsed for display, it was found that

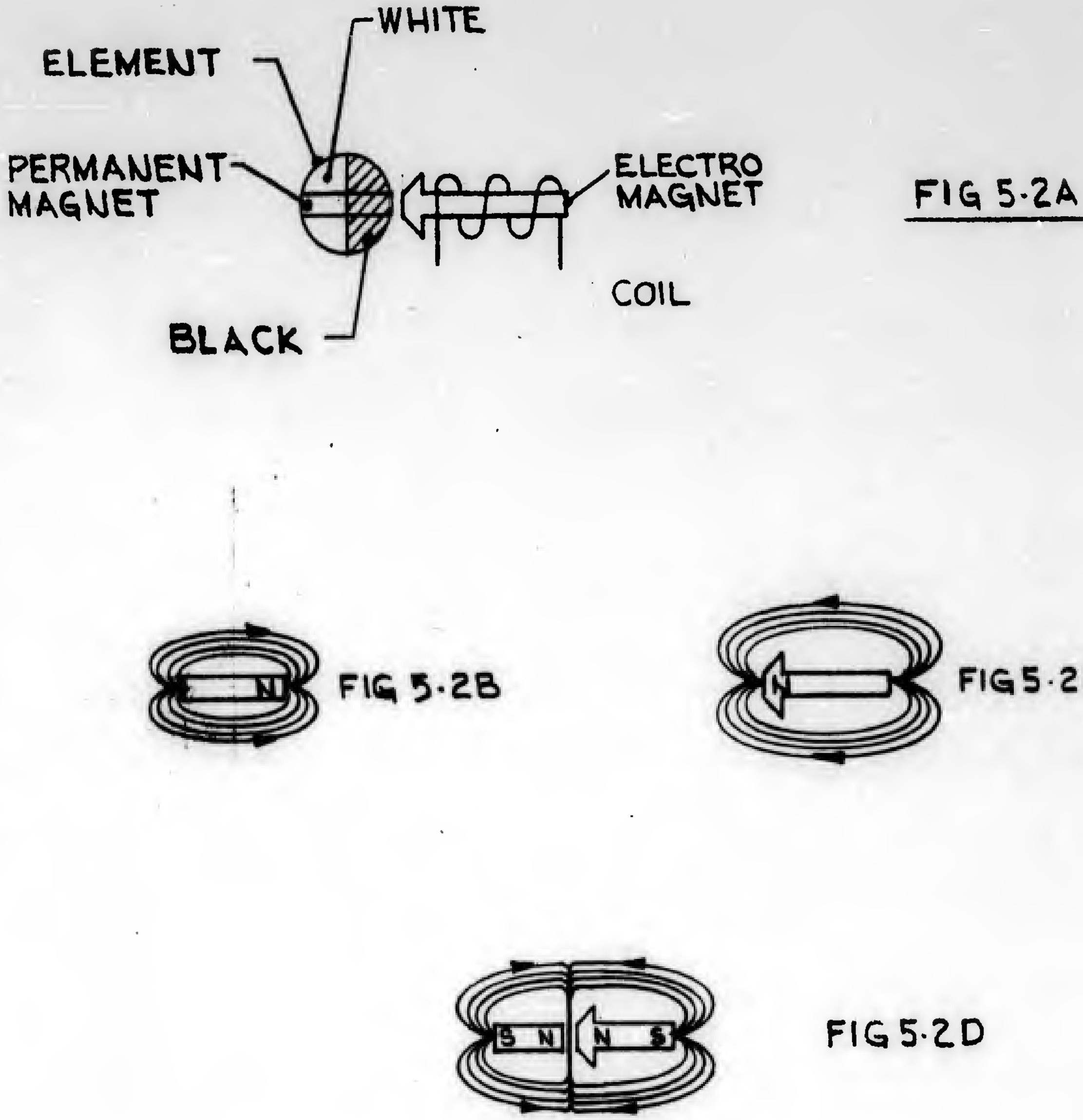

FIGURE 5·2
MAGNETIC CIRCUIT AND FLUX PATTERNS
FOR
ORIGINAL DISPLAY MODEL
(FIG. 5·1)

coincident rotation occurred for some of the surrounding elements. It was anticipated that further refinement of the components would not aid the situation but rather reduce the rotational component.

Experimental work was conducted to create a relatively large rotational component to overcome the force symmetry, as noted above, and in effect, put the system in a constant unsymmetrical state. Some mechanical methods, i.e., the relocation of the axis of revolution, the decentering of magnets, etc. were breadboarded and analyzed but proved ineffective since these configurations too would tend to reach their own point of equilibrium and cause the elements to remain stationary. A mathematical analysis of this phenomenon is included as part of Appendix 1.

5.3 Magnetic Circuit Refinement

The magnetic circuit design, as it is presently used in the feasibility model, was evolved by recognizing that two prime conditions much be met in order to produce a reliable and successful magneto-optical display panel. First, the element must have at least two stable states and second, the magnetic flux from both the stationary and moving components of the circuit must produce a suitable and reliable rotational force. Additionally, the GPL design incorporated an X, Y scanning process so that a rapid and efficient method would be developed to pulse a selected element. Reference to Figure 5-3 shows how a representative matrix of 9 elements may be operated. Assume that element X_2Y_1 is to be rotated. Since the rows are connected in series, as are the columns, the following occurs: A reset signal is applied to column Y_1 and then a display pulse is applied to the coils of row X_2. These signals could either be time coincident or time serial. Element X_2, Y_1 will be the only one to rotate at this time although a display pulse has been applied to the complete row X_2. This condition will remain until a neutralizing or reset pulse is applied to subsequent Y columns.

5.3.1 <u>Magnetic Circuit Description</u>

The conditions mentioned in paragraph 5.3 (bistable state, available rotational force and scan capabilities) are fulfilled by the following magnetic circuit which now uses the state of equilibrium as an inherent

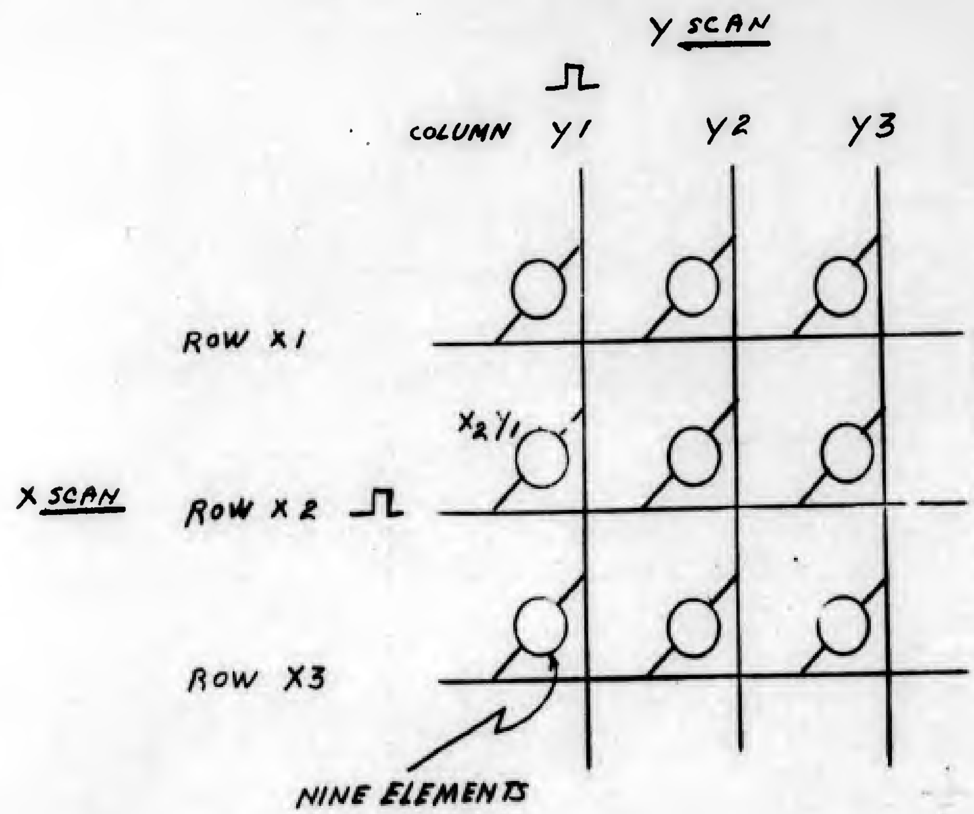

FIGURE 5-3
THREE ELEMENT ARRAY

TABLE I

RELATION OF EXTERNAL FLUX FIELDS TO ELEMENT POSITION

Initial Position of Element (Color as seen by observer)	Direction of Applied Flux (See Note 1)	Final Position of Element (Color as seen by observer)	Direction of Rotation (As seen from top)
1. Black	Right to left	Neutral (See Note 2)	CCW
2. Neutral	Back to Front	White	CCW
3. White	Right to Left	Neutral	CW
4. Neutral	Front to Back	Black	CW

NOTE 1 No attempt has been made to show the distortion of flux patterns due to interaction of the permenant magnet flux on the flux from the electromagnets. See Figure 5-4.

NOTE 2 Neutral is defined as an element showing a half-white and half-black surface to the observer.

holding mechanism during a display. Figure 5-4 shows a single element and the various flux patterns produced by the permanent magnet in conjunction with the electro-magnetic display and yoke coils. The cross sectional views shown are those that would be seen by an observer looking down on the top edge of a blackboard type display surface. With this view in mind, the rotation of elements under the influence of controllable flux can be tabulated as in Table I.

A magnetic circuit that will exhibit the display capabilities as shown in Table 2 is depicted in Figure 5-5. The additional component shown in Figure 5-5 is a soft-iron detent which is used to provide part of the optical memory of the display. That is, when an element is rotated to a black or white display position the permanent magnet is aligned so that it will be attracted to the detent to provide optical memory. A neutralizing pulse creates a torque sufficient to overcome the detent attraction thereby rotating the element from this position.

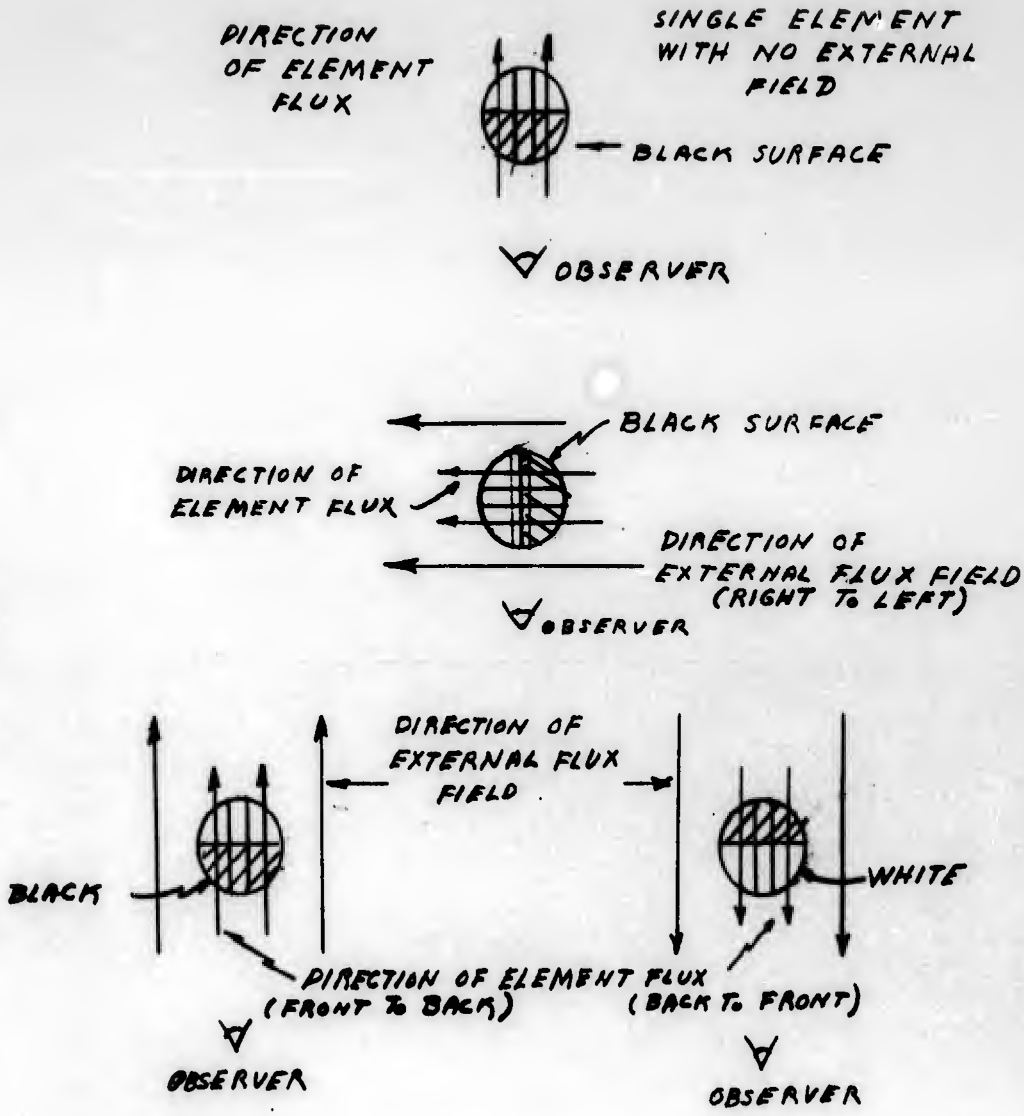

FIGURE 5-4
SIMPLIFIED FLUX PATTERNS
FOR
NEW MAGNETIC CIRCUIT

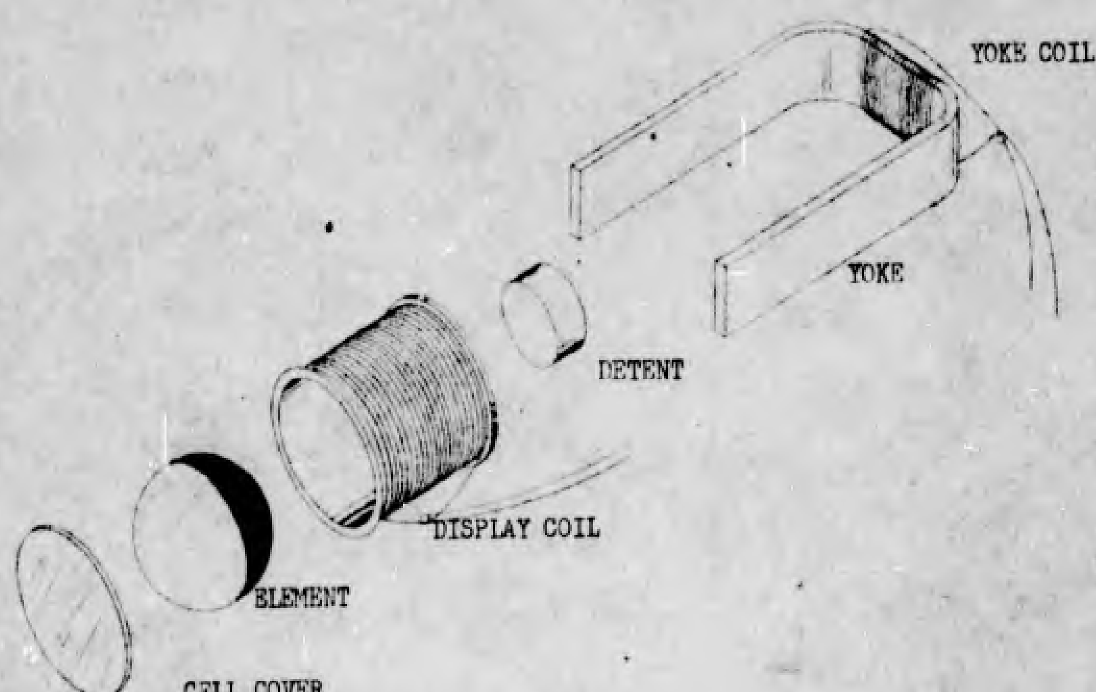

FIGURE 5-5

MAGNETIC CIRCUIT COMPONENTS

5.3.2 Scan Technique

Section 5.2 discussed those forces which created a state of equilibrium for the elements of Figure 5-2. The magnetic forces generated by the refined magnetic circuit prevent this occurrence so that a reliable selection and rotation of elements is always possible. If the element is held by the soft iron detent (optical storage) it is only necessary to pulse the "U" or magnetic yoke coils and it will rotate to the neutral position, overcomming frictional forces and the magnetic attraction of the detent. If, on the other hand, it is desirous to have an element remain in a particular display state, an inherent "locking mechanism" is available. When a white or black element coil is pulsed by a current (of like color), the lines of flux produced are parallel to the already displayed element and no net torque is produced. This mechanism is the basis of the scan technique and is described in detail in the next paragraph.

The various forces of magnetism and equilibrium moments which are used to rotate the elements together with the equilibrium forces which constitute the display system have been described above. The interrelationship between the two sets of forces can be described most easily by following one scan cycle of the display module.

Reference to Figure 5-6A shows the display after the first three elements (1, 2 and 3) have been rotated to the desired positions. A schematic showing the connections of the yoke and neutral coils is shown in Figure 5-6D for the same array. In Figure 5-6B elements 4, 5 and 6 have just been set to their neutral position by application of a pulse to column (yoke) coil 2. Elements 1, 2, 3, 7, 8 and 9 will not rotate since column coils 1 and 3 have not placed their elements in a neutral state. Element 4, 5 and 6 are now set in their display position as shown in Figure 5-6C by application of a selectively polarized pulse to the row coils 1, 2 and 3. Note that in this example, elements 4, 5 and 6 are now in the opposite position (black for white and white for

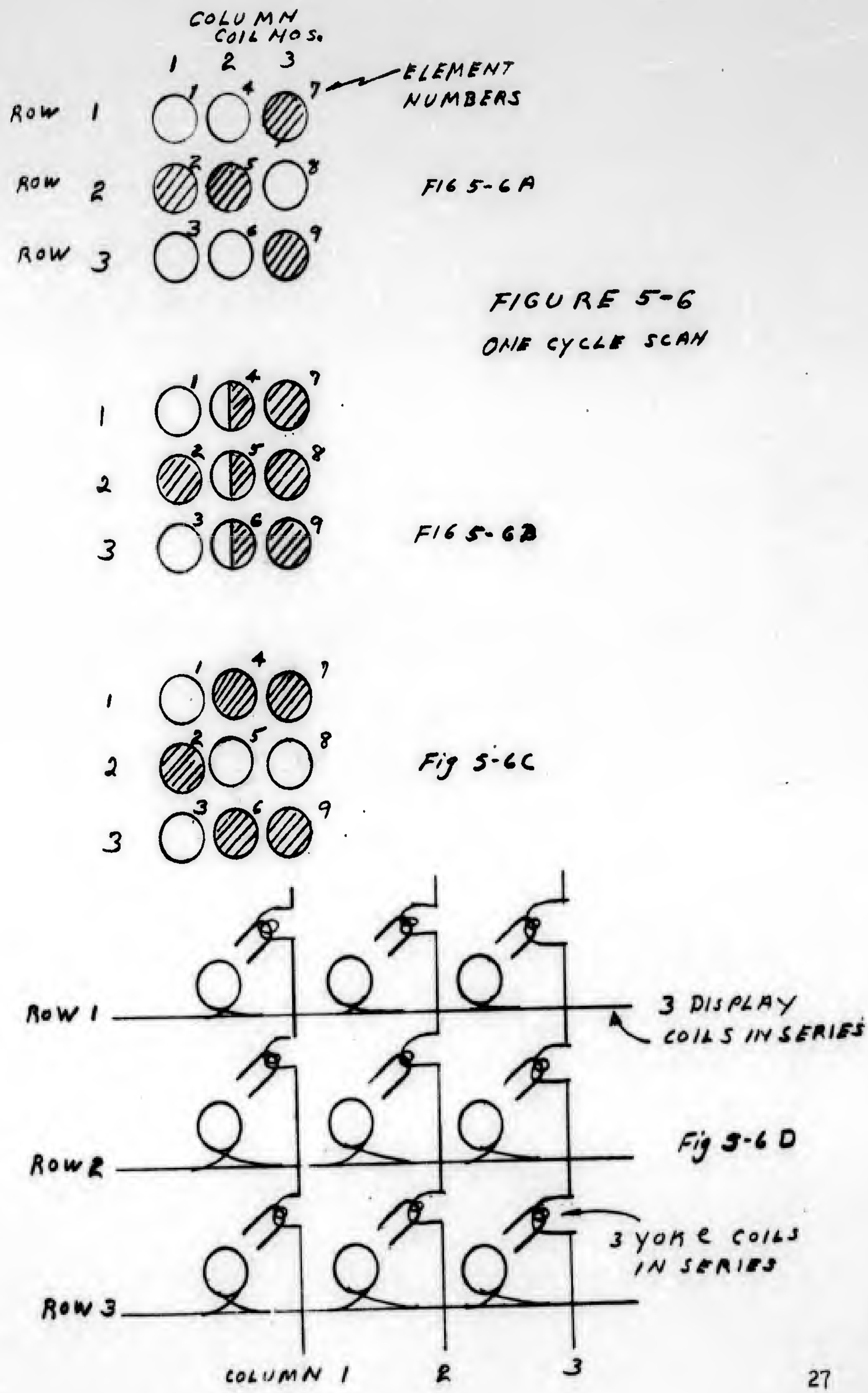

FIGURE 5-6
ONE CYCLE SCAN

black). It is important to note that elements 1 and 3 will remain in their white position when a black pulse is applied to rows 1 and 3 because the flux produced by the row coils is in a state of magnetic equilibrium with the flux pattern of the permanent magnets and no torque component is available to rotate these elements. The same situation exists for element 2 but the flux direction is reversed. Elements 7, 8 and 9 will not rotate because the polarity of that row pulse is such that they will remain in their present position.

5.4 Analysis of Forces in the Display Unit

The operating torques of the display units are generated by forces exerted on the permanent magnet poles by (1) the cocking field produced between the arms of the yoke by current in the column winding, and (2) the setting field produced in the interior of each row winding when energized. Restraining torques are provided by the attractive force between the detent and the nearer magnet pole in the set position, and by the attractive force between the magnet poles and the arms of the yoke in the cocked position.

While these torques are easily understood qualitatively, it is a much more difficult problem to determine their values to any order of accuracy. No attempt was made at direct measurement since GPL was unable to devise a measurement technique showing reasonable promise of success.

Simplified mathematical formulas have been developed for the fields produced by the cocking and setting currents and have assumed that these fields will not be seriously distorted by the presence of the permanent magnet. Field measurements made on a scaled-up model of a unit have been in agreement with the values predicted by the simplified formulas.

5.4.1 Calculation of Cocking Field Strength

The simplified formula assumes that the arms of the yoke can be regarded as surfaces of equal magnetic potential and that, as a first approximation, the total magnetic potential between them is equal to the product of current, I, x N, where N is the number of turns in the yoke winding.

Under these assumptions, the average magnetizing force in the volume between the arms is $\frac{NI}{d}$ where d is the distance between the arms in inches. In this form the units are ampere turns per inch. Converting to c.g.s. units the expression becomes $H = .495 \frac{NI}{d}$ (1) (where d is measured in inches, but H is expressed in Oersteds).

Since air has a permeability of unity, flux density is equal to magnetizing force. The total flux between the arms of the yoke is then $\phi = .495 \frac{NI}{d} : A_a$ (2) where A_a is the product of the length and depth of the yoke in centimeters.

It is necessary to compute the flux density in the material of the yoke in order to verify or correct the initial assumption that no significant magnetic potential drop occurs in the yoke. The formula for this flux density is,

$$B_s = \frac{\phi}{A_s} \quad (3)$$

where As is the cross sectional area of the yoke material.

Using nominal permeability curves for the yoke material, it is now possible to calculate the magnetic potential drop in the yoke,

$$H \cdot L = \frac{Bs}{\mu s} L \quad (4)$$

If this drop is a significant fraction of the total product N x I, the calculation must be repeated for a newly assumed value of magnetic potential between the yoke arms.

The following is a calculation using actual values of current and actual dimensions of the yoke. Dimensions may be found in Appendix 2.

When

$$N = 24$$

$$I = 2.5 \text{ amperes}$$

$$d = .29 \text{ inches}$$

therefore:

$$H = .495 \times \frac{24 \cdot 2.5}{.29} = 102 \text{ Oersteds} \quad (1)$$

$$A_a = .65 \times 2.55 \times (2.54)^2$$

$$A_a = 10.7 \text{ cm}^2$$

$$\phi = 10.7 \times 102 = 1090 \text{ lines} \quad (2)$$

$$A_s = .014 \times 2.55 \times (2.54)^2$$

$$A_s = .23 \text{ cm}^2$$

$$B_s = \frac{1090}{.23} = 4800 \text{ gauss} \quad (3)$$

$$B_s = 4800 \times (2.54)^2 = 31000 \text{ lines/inch}^2$$

The magnetization curves for this material show, for $B_s = 31000$ $H = 1.5$ ampere turns/inch. The potential drop in the yoke is therefore about 0.5 ampere turns in a total of 60 ampere turns and is not significant.

5.4.2 Calculation of Setting Field Strength

The field on the axis of a long solenoid is expressed by the formula

$$H_o = 4\pi n I \quad (4)$$

where n is the number of turns per centimeter and I is current in electro-magnetic units. Measurements recorded on a scaled up model indicate agreement with the formula over a cross section of the solenoid near its center. Presence of the yoke and detent did not appear to distort the field pattern significantly.

The following is therefore used to predict the strength of the setting field in the display unit.

With the present configuration:

$$n = \frac{12}{.203 \times 2.54} = 23.2 \text{ turns/cm}$$

$I = 2.5$ amperes $= 0.25$ e.m.u.

$H = 4\pi \cdot 23.2 \cdot 0.25$ (5)

$B_a = H = 73$ gauss

This is taken to be the field strength in the interior region of the solenoid.

5.4.3 Calculation of Operating Torque

In the Quarterly Memorandum of August 30, measurements of the magnetic moments of the permanent magnets used in the display elements were described. A sampling of several magnets showed reasonably wide variations in moments. A nominal value would appear to be about 2 unit poles x centimeters. A photograph of the magnetometer is shown in Appendix 3.

Using this value and the field strength, calculated in the preceding sections, the operating torques may be computed as follows.

Cocking Torque = 2 x 102 = 204 dyne cm.

Setting Torque = 2 x 73 = 146 dyne cm.

It should be noted that these are the initial values of torque, with the magnet axis at right angles to the applied field. As the element rotates, the torque diminishes as the cosine of the angle of rotation.

5.4.4 Calculation of Detenting Forces

The detenting forces can be calculated by evaluating the energy represented by the air gap flux and the variation in this energy as the air gap is infinitesimally lengthened.

In the set position, if we assume that all the flux emerging from the nearer pole of the magnet enters the detent, the following formula can be written for air gap energy:

$$W = \frac{1}{8\pi} \cdot \left(\frac{\phi}{A}\right)^2 \cdot A \cdot L$$

where W is total energy, ϕ is the total flux emerging from the magnet pole, A is the effective cross sectional area of the air gap (allowing for fringing field) and L is the gap length. Using representative values of:

$$\phi = 50,$$

$$A = 0.031\ cm^2$$

and $$L = 0.033\ cm,$$

$$W = \frac{1}{8\pi} \times \frac{2500}{0.031} \times 0.033 = 106 \text{ ergs or}$$

dyne centimeters.

Assuming uniform axial distribution, the energy per unit length of gap is $\frac{106}{0.033} = 3200$ dyne cm/cm. If the gap were lengthened by a small increment, the rate of change of energy per unit displacement would have the same value. The computed tractive force on the magnet is, therefore, 3200 dynes.

Experimental determination of the tractive force between magnet and detent yielded results of the order of 0.6 grams or 600 dynes. The discrepancy between computed and measured forces can be accounted for by assuming that only 43% of the total magnet flux actually enters the detent. This is not an unreasonable assumption. In any event, the experimental measurement of this parameter is probably more reliable than the calculated value.

In the cocked position, the detenting force occurs between the magnet poles and the arms of the yoke. Since the two poles are subject to opposing forces the ideal net tractive force on the magnet would be zero. However, manufacturing tolerances will affect the two air gap lengths sufficiently to produce fairly large imbalances. In no case though, should the net force reach the value of 600 dynes measured for the set position.

5.4.5 Restraining Torques Produced by Detent Forces

Since the display elements are not restrained by axles, their axes of rotation are completely undefined, particularly for the initial small rotations where the detenting forces are most significant. An element may rotate about its principal axis, it may move in translation, or it may pivot about some point on its surface.

In the case of rotation about the principal axis, the initial detenting torque would be zero, increasing to a maximum at some small angle, then diminishing to zero for 90° rotation. The geometry of this problem is so complex and so much affected by dimensional tolerances that no attempt has been made to calculate a theoretical value.

For other types of rotation or for translation, the same difficulties of analysis exist, multiplied by the number of possible situations. It appears that one must rely, for the present, on experimental determination of an optimum detenting situation.

5.4.6 Calculation of Torque Required

A calculation of the torque required to rotate an element is given below. The tractive force (magnetic pull) of .6 grams has already been calculated (see paragraph 5.4.4) and a value of .5 for the coefficient of friction (μ) has been assumed. A chart showing some typical values for μ is included for reference in Appendix 10. The general case for the calculation of torque is also provided in Appendix 1B.

It will be noted that the calculated torque available (see Para. 5.4.3) is in excess of the calculated torque required for operation which indicates that the element will always be capable of rotating to a new position. In the new position, the rotational component will diminish to essentially zero. While there are many assumptions made in the calculations, the agreement is close enough to substantiate the design.

5.5 Scan and Logic Techniques

5.5.1 General

The following statements can be made for any digital display device that can be energized by a coincident current, x-y, or similar scan technique. Generally, the advantage of each statement listed, over other known energizing techniques, becomes more important as the size of the display increases.

a. Minimum number leads, connections, cables, etc.

b. Maximum flexibility - display panel may be subdivided and modularized in any manner to match the buffer.

c. Unrestricted format - any characters in any location using full resolution capabilities.

d. Capability of presenting maps, charts, etc. with full resolution capability.

e. Minimum demands on input devices.

5.5.2 Breadboard Driver Description

5.5.2.2 Theory of Operation

In order to obtain the simplest and most reliable drive circuit for the writing speed required, an electro-mechanical system utilizing stepping

switches and transistors was used.
The functional diagram for the system is shown in Appendix 5.

The 64 yoke coils in any one row are addressed sequentially by stepper switches S1 and S2. S1 is connected to all of the odd numbered yokes, and S2 is connected to all of the even numbered yokes. S1 and S2 are stepped alternately by the clock circuit, flip flop and stepper coil drivers. One shot #4 pulses gate #1 to "ON" for approximately 25 ms every time a new sprocket hole appears in the reader. S1 or S2, therefore, is pulsed for 25 ms at the beginning of each read time period.

In order to describe the complete addressing sequence of one 8 ball column, assume that the coil of switch S2 is being pulsed to the next even yoke while S1 is stationary and connected to an odd yoke. Assume also, that S3 is in the position shown on the functional diagram.

When a sprocket hole appears, S2 is pulsed as assumed above. One shot #1 is triggered and turns gate #2 "ON" for the time of the one shot. Yoke driver #1 is pulsed and all of the balls in the odd yoke are turned 90^{o} (half black and half white).

When one shot #1 reaches the end of its pulse time, one shot #2 is triggered, providing a 15 ms delay after which one shot #3 is triggered. One shot #3 then, simultaneously gates "ON" all 8 bi-directional drivers. This positions the balls white for a tape hole and black for a tape no-hole. The addressing of one odd ball column is now complete. S1 is pulsed to the next odd column during the same time that the next even column is going through the addressing sequence. When S2 reaches the 66th position, a pulse is transmitted to driver #5 which moves S3 to position 2.

The second row of 8 ball columns is ready to be addressed. The process continues until the entire board is addressed. The timing diagram on the functional shows the sequence explained above.

5.5.2.2 Speed

The speed of operation is controlled by the frequency of the clock oscillator. A front panel control is provided for this.

The maximum speed at which the driver can operate without pulse over lapping is given by the inverse of the sum of the pulse times of one shots 1, 2 and 3:

$$\text{Max speed} = \frac{1}{T_1 + T_2 + T_3}$$

Adjustments are provided on these one shots and also on one shot #4.

5.5.2.3 System Components

A. Display panel including all stepping switches.

B. Rack Cabinet including:

1. Photo-electric tape reader capable of reading up to 8-hole punched tape.
2. Electronic deck using solid state circuitry.
3. Power supply for supply coil current.

5.5.2.4 <u>Tape Preparation</u>

The preparation of the punched paper tape requires a keyboard tape punch such as a Frieden Flexowriter.

The tape is "stencil" punched such that the alpha-numeric characters are formed on the tape. Characters are comprised of a matrix of 7 vertical and 5 horizontal holes.

The method used for punching the holes in the proper position is by means of a x-y coordinate system.

A code or legend is required for the tape punch being used which will enable the operator to punch a hole at any position in the 5x 7 hole matrix.

It is necessary to backspace manually for characters which have more than one hole in a vertical column such as an E, T, etc.

As an alternate to the above x-y procedure, a transposing format can be determined to reduce the manual time required for stencil coding. Essentially this procedure enables more than one hole to be punched simultaneously by establishing a conventional alpha-numeric code for each column of the stencil configuration.

5.5.3 Logic Techniques

Table II lists seven methods of updating a display panel that has 10^3 elements in the horizontal and 10^3 elements in the vertical directions. The methods of updating extend from activating all elements in parallel to activating all elements in series with advantages to each, depending on the buffer available and the display requirements. Each column heading is self explanatory with the exception of Diodes Required and Leads Required, which are explained below.

5.5.3.1 Leads Required to Display Panel

(See Table II)

Control Leads

One (1) control lead is required for each bit or element which is simultaneously activated. Therefore, Control leads = Buffer storage required.

Neutral Leads

One (1) neutral lead is required for each group of bits or elements which are activated in series. Since the assumed display matrix contains 10^6 total elements, the number of neutral leads required is:

$$\text{Neutral leads} = \frac{10^6}{\text{Number of bits in parallel}}$$

In subsequent determinations of logic configurations on the basis of a 10^3 element matrix, CL x NL must equal 10^6.

5.5.2.2 Diode Requirements (See Table II)

Control Diodes

In order to permit strobing of the parallel elements, one (1) AND gate (2 diodes) is required for each bit energized in parallel. The number of control diodes is therefore:

Dc = 2 x Buffer storage required.

Proposed Logic Techniques

Table II

Updating Technique $10^3 \times 10^3$ Bit Matrix	Buffer Storage Required Bits	Time per Character (5H x 7V) T Seconds	Time per Display T Seconds	Diodes Required	Leads to Panel Required	
All bits in parallel	10^6	T	T	$2 \times 10^6 + 2$	Control + Neutral	106 1
Column of bits in parallel; Rows in Series	10^3	5T	10^3T	$2000 + 11 \times 10^4$	C + N	10^3 10^3
7 Vertical bits in parallel; Rows in Series	7	5T	$\frac{10^6T}{7}$	$14 + 2.72 \times 10^6$	C + N	7 143,000
7V x 5H (1 char.) in parallel; Character Rows in Series	35	T	$\frac{10^6T}{35}$		C + N	35 28,600
1 column of char. in parallel; Row of character in Series	5×10^3	T	$\frac{10^3T}{5}$	$1800 + 10^4$	C + N	5,000 200
1 row of char. in parallel; Column of char. in Series	7×10^3	T	$\frac{10^3T}{7}$	$1287 + 1.4 \times 10^4$	C + N	7,000 143
All Elements in Series	1	35T	10^6T	$2 + 21 \times 10^6$	C + N	1 10^6

Neutral Diodes

The neutral diodes are sequentially energized from a binary counter. One (1) diode for each binary digit of the counter plus (1) diode for the strobe times the total count is required.

For example, if 35 bits or elements are energized in parallel, each neutral pulse simultaneously sets 35 elements to a neutral state. Since there are 10^6 total elements in the maxtix, the number of neutrals is:

$$\frac{10^6}{35} = 28,600$$

Since $2^{14} = 16,284$

and $2^{15} = 32,568$

It is therefore evident that a 15 binary digit counter is required where each of the digits is connected, through a diode, to each of the approximate 28,600 neutrals and 28,600 x 16 neutral diodes. A generalized equation can be stated as:

$$D_N = \frac{10^6\ (n + 1)}{\text{Buffer Storage Required}}$$

where n is found from 2n = K

and K is the smallest power of 2

which is greater than $\left(\frac{10^6}{\text{Buffer Storage Required}}\right)$

5.5.4 Typical Simplified Logic Technique (SK 25773)Appendix 5

The following simplified logic block diagram is representative of the general scheme which can be applied to most X, Y scanning devices. A more detailed explanation cannot be provided at this time since the control panel inputs are not specified.

The reader should be mindful of the following conditions when evaluating this logic scheme:

1. The logic diagram is simplified and may require a periodic check and correction for the counter. If a strobe pulse is lost, the counter does not step, the next neutral is not set and succeeding computer inputs will switch an improper column i.e., the count is one less that it should be.
2. Rather than counting pulses, the entire count could be shifted from the main computer buffer to a storage register. This would eliminate the count error problem.

3. A 36-element column was selected to present this logic scheme since it requires a 26-bit input word to switch all elements of a column in parallel and many computers utilize a standard 36-bit word.

Figure 5-7

SK 25773 Logic Diagram Reflective Display

31 x 36 Matrix

This is a foldout drawing located in Appendix 5.

6. REFLECTIVE DISPLAY DESCRIPTION

6.1 General

Figures 6-1 and 6-2 are photographs of completed one character modules, including their component parts. These modules were constructed primarily for experimental purposes but the component specifications and fabrication techniques are identical to those used in the deliverable breadboard. The breadboard contains modules approximately 2 2/3 times as large. Additionally, the fabrication technique is not excessively costly and is representative of production techniques. It should be noted that the nature and size of the display panel made it necessary to expend a fair effort on design, tooling and other processes that normally would apply to a developmental program rather than a feasibility study. The specific requirements that necessitated this additional work were the individual cell tolerances and the quantity of elements.

6.2 Detailed Description

A complete set of component specifications are supplied in Appendix 2. Components and materials are specified by trade names in lieu of detailed data. Since all dimensions of the molded epoxy module are controlled by the model, no overall module drawing has been made. A drawing of the mold is supplied.

With the exception of the element itself, most tolerances have been controlled by the cell pin. That is, 1) the cell depth and

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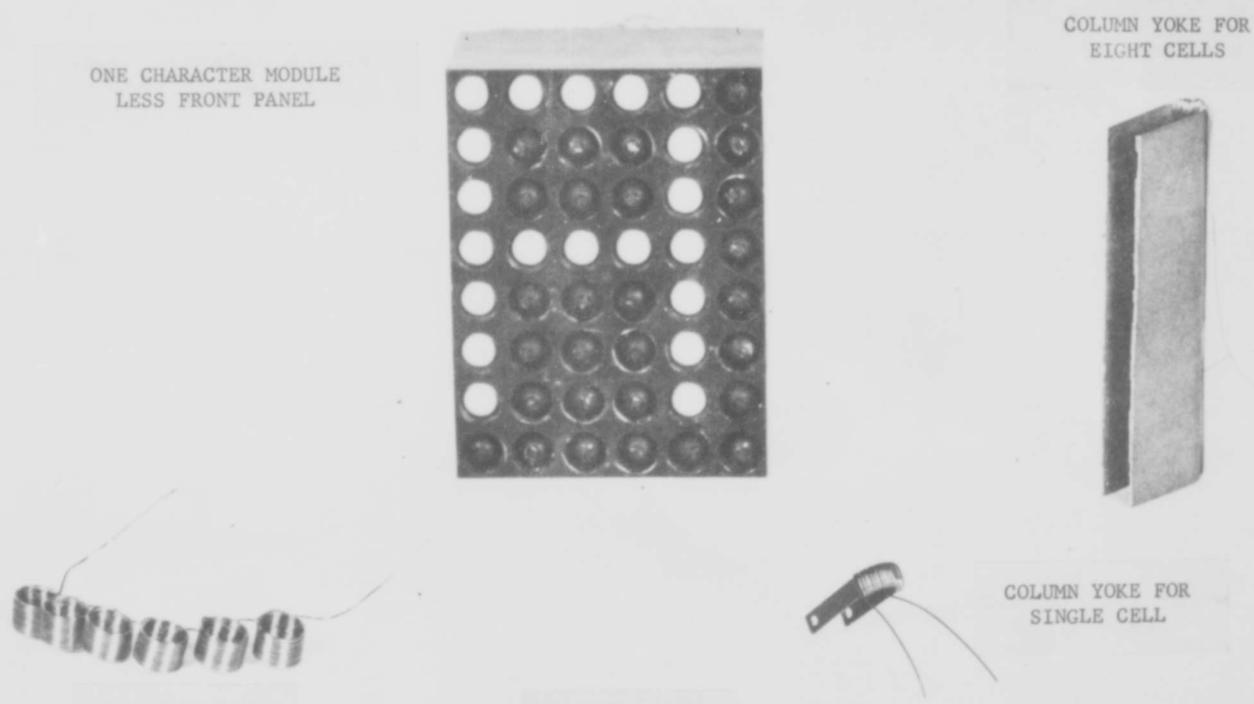

Figure 6-1 Coil Assemblies for Rows and Columns

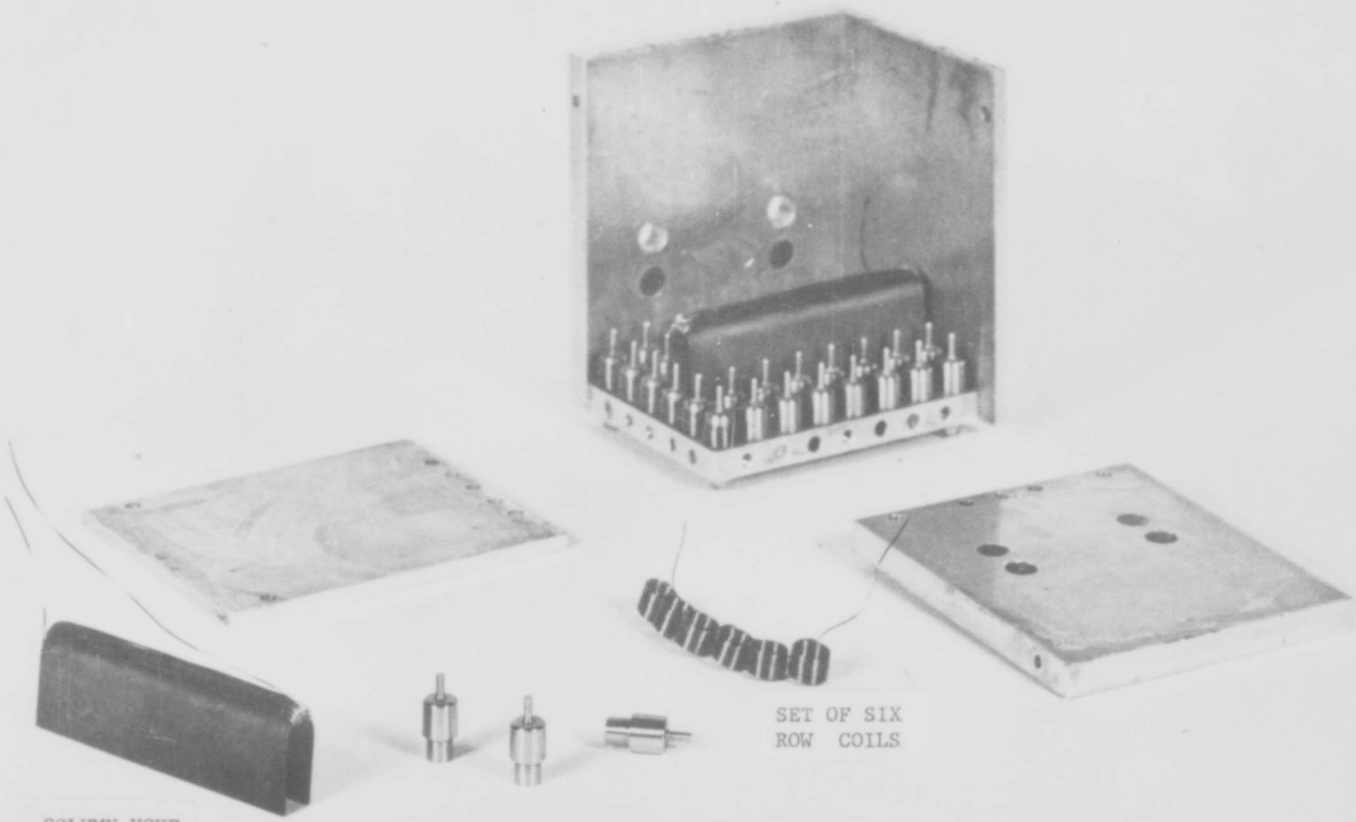

Figure 6-2 Molding Apparatus

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diameter, 2) the location and concentricity of the display coil, 3) the location and concentricity of the detent and 4) the center-to-center dimension (pitch) between the cells has all been maintained by the mold cell pin.

6.3 Physical Description

The original display module (Figure 6-1) was a rectangular, epoxy-molded unit 2 5/8" vertical x 2" horizontal consisting of a honeycomb array of cells in which magnetically polarized and essentially frictionless spheres are installed.

Each cell consists of epoxy-embedded components as follows:

a. A "U"-shaped metal yoke embedded so that it surrounds each vertical column of cells. There is a coil wound on its vertical axis so that when energized, a flux pattern is created and revolves the spherical elements to a neutral state (half black, half white) until an information pulse is applied to the display coil to reset the elements for a data display. Figure 6-2 shows two types of yokes. The long yoke permits 8 elements to be cocked (brought to the neutral position) at once and is obviously cheaper to manufacture. The short yoke will rotate a single element. Only one type is used in a single module and either type permits individual addressing of an element.

b. A soft iron detent which acts as a keeper when elements are to the neutral state.

c. An epoxy spacer which provides the proper air gap between the element magnet and the detent.

d. A finely wound display coil encircles the element cell. When pulsed by appropriately buffered input signals, it creates a uniform flux pattern which is used to revolve the spherical element for an information display.

e. A molded plastic sphere or element in which a small (1/16" x 1/4") permanent magnet is embedded to react, in conjunction with the magnetic flux, to cause the element rotation. The elements are light absorbing (black) on one side and a light reflective (white) on the other.

SK34806 shows the wiring configuration of the deliverable modules. A terminal board is attached to the rear of each module to provide terminations for the internal coil leads and connections to the driver circuitry. SK34807 is a schematic showing the coil to terminal board connections. These are located in Appendix 5.

6.4 Fabrication Process

A brief description of the fabrication process follows:

a. The mold is disassembled and cleaned with epoxy solvent. Mold cell pins remain in the base plate.

b. The mold is reassembled and coated with mold release.

c. Sixteen sets of coils are accurately positioned over the mold cell pins.

d. Yokes are positioned over coils and pins. Leads are dressed as required.

e. The epoxy is mixed, heated (approximately 150°F) and poured into the mold. The mold containing the epoxy is then evacuated.

f. The mold is cured for 2 to 3 hours at 150°F.

g. Casting is removed from the mold with special knock-out pins.

h. Detents and air gap spacers are inserted and cemented.

i. The terminal board is wired in place.

j. Elements and cover plate are added.

Some of the problems encountered during the molding process should be discussed at this point.

The original 5 x 7 module was molded with commercially available epoxy resin. However, when the larger modules were molded (8 x 16 elements) problems arose which made the use of this epoxy resin impractical. Material shrinkage, after curing was excessive and caused warping of the module. Dimensional stability is very critical since the detent pins which are used to maintain the ball position are a press fit into the molded hole.

After various attempts at decreasing shrinkage such as less heat during curing, air curing, a combination of both, and discussions with the manufacturer, it was decided to use an epoxy which GPL was familiar with and had high dimensional stability.

The GPL transformer department was given the task of molding all future modules using an epoxy of their choice.

No further shrinkage problems were encountered.

6.5 Panel Assembly

The complete panel assembly consists of 32 modules (4 horizontal and 8 vertical.) The modules are butted with each other and retained in the frame with rear and side screws and the front plexiglass plate. The coils are connected and wired to the stepper switches. Two output connectors are provided for driver interconnection.

7. RELIABILITY OF REFLECTIVE DISPLAY

For the purposes of a discussion on reliability of the display, only part failure malfunction will be discussed. Failures of an element to position properly will not be included here but will be discussed in detail in Section 8.

There are two major reasons for display malfunction due to part failure. These are:

1. Open row coil
2. Open yoke coil

The failure rate of a yoke coil is estimated to be about 5 failures per 10^6 hours of operating time. Since there are 16 yokes per module the failures per 10^6 hours becomes 5 x 16 or 80.

The failure rate of a set of coils is estimated to be about 4 failures per 10^6 hours. Since there are 16 sets of row coils per module the failures per 10^6 hours becomes 4 x 16 or 64.

The total now becomes 64 + 80 or 144 failures per 10^6 hours which is a MTBF of approximately 7000 hours of actual operating time.

8. TEST RESULTS

Measurements and test data taken on the final assembly are discussed as follows:

8.1 Response Time

A one-character experimental module which was driven from a stepping switch operated reliably at 12 cps and required two cycles per column. At this rate each column requires 166 milliseconds for updating. A one-character (5x7 matrix) module requires 5x166 or 830 milliseconds since 7 column elements are operated in parallel. Preliminary tests have shown that a single element will rotate in 50 milliseconds. On this basis a single character would, assuming an average value of 50 milliseconds, require .050 x 5 elements x 2 cycles (one row and one column) = .5 seconds per character.

Further tests were run at the completion of the program using the driver and panel which showed that for reliable operation the pulse length for row and column excitation should be 100 milliseconds instead of the 50 as previously stated. This results in a rate of 1 character per second which, as the test data shows, is the optimum speed for the display as presently wired.

Considering the display area listed in the exhibit of 3.75 times 5.00 feet we may calculate the total response time.

If the elements had a center-to-center distance of .250 inch (present units are .330 inch) the display panel would contain 3.75x12x4 = 180 by 5.0x12x4 = 240 elements. Since there are 180x240 or 43,200 elements in this panel and there are 35 elements in a one-character module, it could take 43,200 ÷ 35 x 1 second to operate the entire panel. This is approximately 1230 seconds. However, this method of drive would not be taking full advantage of scan characteristics or modular form of the display device. First, it is entirely practical to operate an entire vertical column of 180 elements at one time instead of 7 although additional drivers will be required. This is an improvement in the response time by a factor of 25.7. Secondly, it is advantageous for other reasons (total resistance in a set of row coils) to operate several row modules in parallel. We have operated 48 row coils in series successfully so that panel might be divided into 240 ÷ 48 or 5 separate modules. This is a second improvement in response time; a factor of 5. The response time of the panel row is 1230 seconds ÷ 5 ÷ 25.7 or approximately 9.6 seconds. With more expensive buffers, it is possible that a 1000x1000 element display could be operated in the same lenth of time. The complete flexibility of the device permits trade-off between response time, buffer complexity, power, etc.

8.2 Power Considerations

A complete analysis of the power required becomes very complex unless the exact configuration is known. However, it is easy to show the figures for three cases: 1) a one-character module, 2) an 8x16 element module, and 3) the 180x240 element display described above.

a. Each single element row coil has a resistance of .043 ohms and takes 2.5 amps or .27 watts per coil.

b. Each 8-element column coil has a resistance of .45 ohms and takes 2.5 amps or 2.83 watts.

A single character module (6x8) has <u>one</u> column coil on 50% of the time or 2.83 watts ÷ 2 = 1.41 watts and <u>all</u> row coils on 50% of the time or 6x8x.27 ÷ 2 = 6.5 watts. The total power is therefore 6.5 + 1.41 or 7.91 watts per character per unit time. Incidentally, a single character module will not dissipate 8 watts continuously without objectionable heat rise because of the poor heat transfer characteristics of epoxy.

An 8x16 module may be calculated as above. (1.41 watts) + 16x8x.27 ÷ 2 = 18.8 watts per unit time.

For the 240x180 element display described above the power may be calculated as follows:

One column coil of 180 elements = 180x2.83 ÷ 2 = 32.5 watts

180 rows of 48 coils per row = 180x48x.27 ÷ 2 = 1170 watts

Five modules are required and = (1170 + 32.5)x5 = 6012 watts

The figure of 6012 watts is obviously high because the power was predicted on the assumption that every element (43.200) would be changed every ten seconds.

8.3 Test Results

Test data, using punched paper tapes of various patterns, were taken to establish maximum speed and readability of the completed display.

Paper tapes were punched to display the following patterns:

1. Horizontal black and white alternating lines
2. Vertical black and white alternating columns
3. Checkerboard pattern (combination of 1 and 2)
4. Message

Three runs were taken for each pattern and the average errors for the three runs were tabulated. An error is defined as an incorrect color position of any ball used in the data runs as determined by the tape input.

All data was taken using the same set of modules. Four modules were used which were located in the center of the display. All data were based on a total of 512 elements per run; therefore, 1536 elements per tabulation. Runs using various pulse lengths were also taken. As shown in Table I, runs were taken for 100, 50, and 25 millisecond pulse lengths.

TABLE I

PATTERN	PULSE LENGTH	ERRORS
Horizontal Lines	100 ms	.59%
Vertical Lines	100 ms	17.3%
Checkerboard	100 ms	5.9%
Message	100 ms	12.7%
Checkerboard	50 ms	25.6%
Checkerboard	25 ms	46.5%

A study of the particular cells in which errors occurred showed that various parameters such as coil placements, detent spacing and ball and magnet assembly had some correlation to the reliability of positioning.

Certain cells were found to be inferior mainly in the placement of the coil and in the detent spacing. From the data it was observed that certain cells produced errors in all their runs. These errors were assumed to be due to bad cells or balls. The replacement of balls had no appreciable effect. It was then concluded that the repeatable errors were due to poor cell tolerances.

The percentage errors were then recalculated, discounting the errors which repeated in all the runs. The errors were found to decrease slightly. As shown in Table II.

Percentage error was calculated as follows for each pattern:

$$\frac{\text{Errors - Run \#1 + \#2 + \#3}}{\text{3 x 512 (Total No. of elements in test sample)}} \times 100$$

TABLE II

PATTERN	PULSE LENGTH	NON-REPEATABLE ERRORS
Horizontal Lines	100 ms	.59%
Vertical Lines	100 ms	16.6%
Checkerboard	100 ms	5.6%
Message	100 ms	9.38%
Checkerboard	50 ms	22.5%
Checkerboard	25 ms	27.%

From Table II it becomes apparent that the errors are not only a function of the pulse length (speed) but also of pattern configuration.

The horizontal line pattern shows the least amount of errors. This is primarily due to the fact that the row current pulse does not change polarity.

The vertical alternate black and white pattern shows the largest amount of errors. This is primarily due to the fact that the row current changes polarity each time a column is set.

A particular element may rotate to the correct color position but when the row current polarity is reversed, as in the vertical line pattern, that element may rotate 180° to the wrong color position. As explained earlier, once an element has been set it should not rotate unless a cocking pulse is applied. However, this condition occurs frequently as evidenced by the data and may be due to magnetic interaction, insufficient detenting, or inductive feedback.

The probability that the improper display of one or more elements will cause the observer to misread a character or render the character illegible is not the subject of this report. However, a message error of 10% is obviously too high for legibility.

An investigation of character legibility versus random element error will be a necessary part of a follow-on engineering program.

9. CONCLUSIONS AND RECOMMENDATIONS

The investigations conducted in this program and an analysis of the data accummulated on the breadboard model have determined that a large area reflective display based on a magneto-optical technique is feasible. This was demonstrated by display tests that were in the order of 90% accurate. Although this achievement is encouraging, further development in the areas detailed below is necessary before the potentials of this display technique are realized. Specifically, this technique is potentially capable of the following features:

1. Large Area Display	Display elements can be combined without limit to form a large area display.
2. Optical Memory And Reflectivity	Ambient illumination is reflected by a display panel in the same way that a black and white sign reflects light, thus making maximum use of the adaptability of the human eye. The optical patterns (information) are maintained without continuous power.

3.	Response and Update Time	A large area display may be completely updated (changed) in a matter of seconds.
4.	Power Requirements	Total power is dependent on the frequency of updating. However, the power required for updating at a reasonable rate is acceptable.
5.	Reliability	The basic module design insures high reliability. This results from the inherent simplicity of a ball rotating freely in a socket and a totally encapsulated coil assembly.
6.	Resolution	Characters are presently 2 1/4" high. Future development is expected to reduce this dimension in half.
7.	Drive Technique	The display can be computer driven. A selective scan technique (leads to one side and top only) is used. Scan-ability provides tremendous advantage in reduced driver

complexity, increased flexibility of use and adaptability to various input devices.

Although the breadboard display/driver system delivered on this program has demonstrated technique feasibility, many unresolved limitations presently exist. Consistent with objectives of the initial program, efforts were concentrated on completing a system configuration for an overall technique appraisal. In order to contain the program scope, it was necessary to proceed toward this objective without optimization of each design and construction detail. Experience gained during the transition from concept to demonstration model has revealed several specific areas for product improvement. Following is a list of areas that warrant further consideration in the next phase of this development program.

1. The present design incorporates suspensionless rotating ball elements. These balls are not constrained to rotate about a fixed axis and are, therefore, at some liberty to become misaligned with the magnetic vectors. A considerable improvement in detent action and a reduction in power consumption could result from a design using either a pivot axis for the balls or a cylindrical-shaped rotating element to define the axis of rotation.

2. Associated with the improvement in detent action attempted in item A should be a study of the relationship between detent functioning and detent spacing. Also further investigation should be given to an electro-magnetic or mechanical detent to permit positive detenting without requiring strong permanent magnets. Because the detent forces must be overcome during rotation of the ball elements, an improvement in detent efficiency enables a direct reduction in power consumption.

3. Element response time and power requirements are detrimentally affected by frictional losses. Accordingly, an investigation should be made of various potting plastics in regard to both damping and friction coefficients and an analysis should be made of the effects of both mechanical and magnetic manufacturing tolerances. A reduction in production costs could accrue from this study item.

4. As described in this report, the present design exhibits a tendency for positioned elements to be influenced by the magnetic forces acting on adjacent elements. A reduction in this interaction would decrease the probability of positional errors. An investigation is, therefore, recommended into increasing the shielding between adjacent elements and altering the coil geometry to enhance independent action.

5. An effective reduction by a substantial factor in display response time is possible for alpha-numeric information by arranging the coil connections such that a single character is addressable in any location without updating the entire display. The coil arrangement to achieve this feature is practical insofar as the display module is concerned; however, an evaluation of the associated computer interface complexity is required.

Utilizing the knowledge gained from this program, GPL is confident that a modest next phase development program would result in significant functional improvement of the device. This would be accomplished by thorough investigation of the afore-mentioned problem areas with optimization of pertinent parameters. The result would be a much improved demonstration model from which could be derived a final production design.

10. GLOSSARY OF TERMS

Element	The revolving spherical portion of the display in which a permanent magnet is embedded. The element has light reflective (white) and light absorbing (black) surfaces.
Magnetic Yoke	A U-shaped metal piece molded into the vertical (column) plane and on which the neutralizing coils are wound. Flux patterns setup when these coils are energized (cocked pulse) causes the elements to be rotated to a neutral (half white, half black) state.
Display Coil	A coil which is wound about each element cell and, when a current of appropriate direction is applied (setting pulse), causes a magnetic flux so that the element will rotate to a black or white state.
Detent	A soft iron dowel which is inserted behind each element. This dowel will be attracted to the permanent magnet of the element in a display state and assist in the optical storage capabilities of the equipment.
Cell	The epoxy-molded chamber in which the display elements and detents are installed and around which the neutralizing and display coils are located.

Reflective Display	Previously termed Magneto-Optical Display Surface.
Column	A vertical series of display elements.
Row	A horizontal series of display elements.
Character Matrix	An arrangement of specific light absorbing and light reflecting surfaces used to form one character or symbol.
One Character Module	A matrix of 6 horizontal x 8 vertical elements which is capable of displaying a single alpha-numeric character or a component of line data.
Cocking Pulse	Refer to Magnetic Yoke.
Setting Pulse	Refer to Display Coil.

Appendicies

1. Forces and Friction
2. One Character Module Component and Tool Specifications
3. Torque Measuring Magnetometer
4. Evolution of Models, Reflective Display

Appendix 1

Forces and Friction

1A Equilibrium Forces

1B Calculation of Moment

1C Coefficients of Friction for Plastic Material

Aopendix 1A

Equilibrium Forces - General Case

In order to determine the force required to rotate a cylindrical element, it is necessary to find the sum of all frictional and magnetic forces which must be overcome.

Referring to Figure I-1, we may write $F_r = F_1 - F_2$

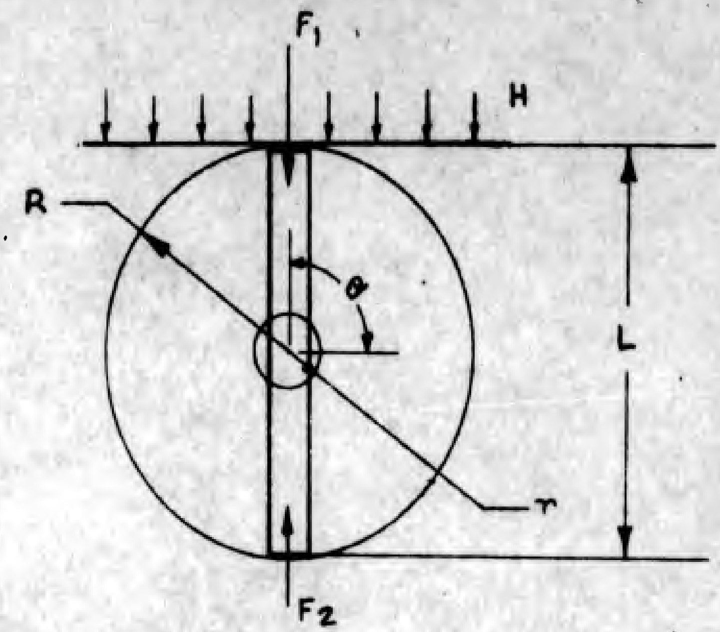


FIGURE IA

This defines the vector sum of the attractive and repulsive forces due to the fixed magnet in the cylinder. The frictional force which arrises as a result of this magnetic force is

$$F_f = F_r \sigma$$

The total turning torque required is the sum of this force and the frictional force due to element mass.

$$T_f = F_f r \sigma + WR \sigma$$

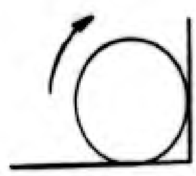
or if all weight is on the center pin

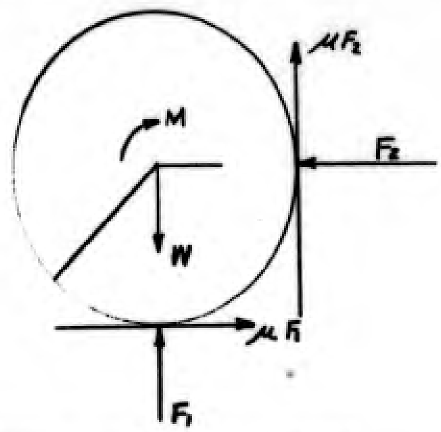
$$T_f = \sigma r(F_f + W)$$

Appendix 1B

Calculation of Moment - General Case

The moment necessary to rotate a sphere 1/4" in diameter, which is restrained by the walls perpendicular to each other, is given below:





$F_x = 0$ Summation of forces in x direction

$UF_1 - F_2 = 0$

$F_y = 0$ Summation of forces in y direction

$F1 + UF_2 - W = 0$

$M_a = M$ Summation of Moments

$-UF1\ r - UF_2\ r + M = 0$

Solving the simultaneous equations we find:

$$M = \frac{(1 + u)\ uW_r}{(1 + u^2)}$$

with r = 1/8 inch = 0.318 cm
u = 0.5 assumed drag coefficient

M becomes

M = .190W in gm cm

A steel ball of 1/4" diameter weight 0.87 gms and a nylon ball weighs .259 with magnet.

Therefore, M = 0.165 gm-cm or 16.2 dyne cm for steel
M = .0494 gm-cm or 4.94 dyne cm for nylon

Appendix 1C

Coefficients of Friction for Plastic Materials

Although the materials used for the elements and basic module have comparatively low coefficients of friction, a drag coefficient (small surface contact) of 0.5 has been pessimistically assigned to the system. Judicious selection of materials for subsequent units will permit specification of about 0.25 drag coefficient and which will conceivably reduce operating power requirements and still be quite conservative.

Coefficients of Friction

Materials	Static		Dynamic	
	Dry	Oil Lubricated	Dry	Oil Lubricated
Nylon on Steel	.31 to .74	-	.17 to .43	.02 to .11
Nylon on Bronze	-	-	.15	.08 to .14
Nylon on Nylon	.36 to .46	-	.11 to .19	.07 to .08
Delrin on Steel	1. to .3	.05 to .1	.1 to .3	.05 to .1
Delrin on Bronze	.33	-	.30	-
Delrin on Delrin	.38 to .61	-	.16 to .22	-
Delrin on Nylon	.13 to .2	-	.08 to .11	-

Coefficients of Friction (Con't)

Materials	Static Dry	Static Oil Lubricated	Dynamic Dry	Dynamic Oil Lubricated
Phenolic on Aluminum	.28 to .29	-	.25 to .27	-
Phenolic on Steel	.19 to .21	-	-	-
Phenolic on Bronze	.19 to .21	-	-	-
Teflon on Steel	.04 to .1	-	.04 to .08	-

Notes:
1. Data at 70 to 70°F.
2. Dynamic data for 95 to 156 ft/min.
3. Delrin and nylon data obtained from Dupont publications.

Appendix 2

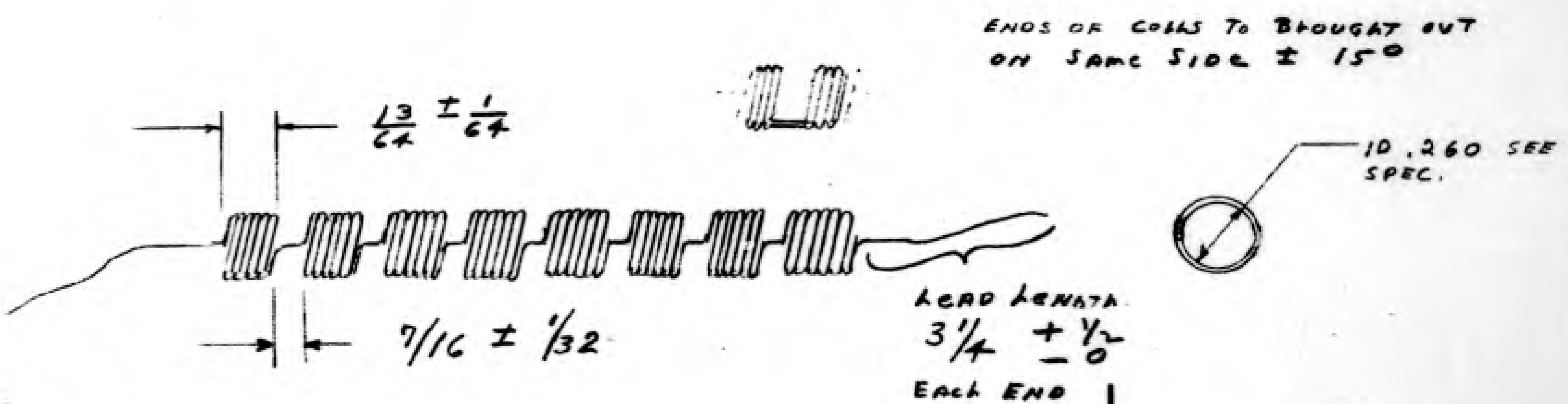
One Character Module Component and Tool Specifications

1.	SK 34700-11	Coils, Reflective Display
2.	SK 34700-13	Magnet, Reflective Display
3.	SK 34700-14	Magnetic Yoke, Reflective Display
4.	SK 34700-16	Detent, Reflective Display
5.	SK 34700-21	Mold Pin, Reflective Display
6.	SK 34653	Mold, Reflective Display

DWG CLASS	ISSUE DATE	BY	DWG SIZE	DWG NO.	REV
	12-19-62		A	SK 34700-11	

REVISIONS

SYM	DESCRIPTION	DATE	APPROVAL



SPECS

8 COILS PER SET

NO. 26 WIRE – FORMVAR BONDEZE OR EQUIVALENT

12 TURNS PER COIL ± 0 TURNS

TURNS TO BONDED TOGETHER

COILS TO FIT OVER .260 PIN

COILS TO PASS THRU .2968 (19/64 in) CYLINDER

NEXT ASSY	USED ON	NEXT ASSY	FINAL ASSY
APPLICATION		QTY REQD	

UNLESS OTHERWISE SPECIFIED

GPL GENERAL ENGINEERING SPECIFICATION 5140-29 IS PART OF THIS DRAWING

TOLERANCES

FRACTIONAL ± DECIMAL ± ANGULAR ±

DATE STARTED

DR

CHK

ENGR John C McGuire

APPD JPM

COILS

REFLECTIVE DISPLAY

GENERAL PRECISION LABORATORY INCORPORATED

PLEASANTVILLE NEW YORK

MATERIAL

MATL SPEC. FINISH

DWG CLASS

SCALE NONE

DWG SIZE A

DRAWING NUMBER SK 34700-11

K+E ALBANENE 195GL-5 GUIDE LINE 83205

DWG CLASS	ISSUE DATE	BY	DWG SIZE	DWG NO.	REV
	1/19/62		A	SK34700-13	

REVISIONS

SYM	DESCRIPTION	DATE	APPROVAL

NOTE ALL SURFACES TO BE GROUND
FINISHED MAGNET TO BE DELIVERED
IN MAGNETIZED STATE

MATERIAL ALNICO 2

ASSIGNMENT NO 101-16230

NEXT ASSY	USED ON	NEXT ASSY	FINAL ASSY
APPLICATION		QTY REQD	

UNLESS OTHERWISE SPECIFIED

GPL GENERAL ENGINEERING SPECIFICATION 5146-29 IS PART OF THIS DRAWING

TOLERANCES

FRACTIONAL	DECIMAL	ANGULAR
±	±	±

DATE STARTED
DR
CHK
ENGR JC McGuire
APPD JBM

MAGNET
REFLECTIVE DISPLAY

GENERAL PRECISION LABORATORY INCORPORATED
PLEASANTVILLE NEW YORK

MATERIAL
MATL SPEC. FINISH

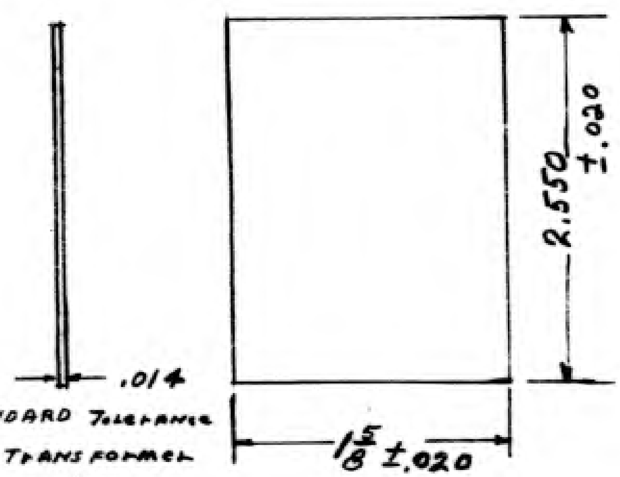
DWG CLASS		SCALE	DWG SIZE	DRAWING NUMBER
			A	SK34700-13

H-E ALBANENE 195GL-8 GUIDE LINE 82303

DWG CLASS	ISSUE DATE	BY	DWG SIZE	DWG NO.	REV
	12/18/62		A	SK34700-14	

REVISIONS

SYM	DESCRIPTION	DATE	APPROVAL



STANDARD Tolerance For Transformer LAMINATIONS

ASSIGNMENT NO 101-16230

NEXT ASSY	USED ON	NEXT ASSY	FINAL ASSY
APPLICATION		QTY REQD	

UNLESS OTHERWISE SPECIFIED

GPL GENERAL ENGINEERING SPECIFICATION 5146-29 IS PART OF THIS DRAWING

TOLERANCES

FRACTIONAL ± DECIMAL ± ANGULAR ±

DATE STARTED

DR

CHK

ENGR

APPD J.P. McGUIRE

MAGNETIC YOKE

REFLECTIVE DISPLAY

GENERAL PRECISION LABORATORY INCORPORATED

PLEASANTVILLE NEW YORK

MATERIAL TRANSFORMER GRADE AUDIT "A"

MATL SPEC. FINISH

DWG CLASS

SCALE

DWG SIZE A

DRAWING NUMBER SK34700-14

K+E ALBANENE 196GL-8 GUIDE LINE

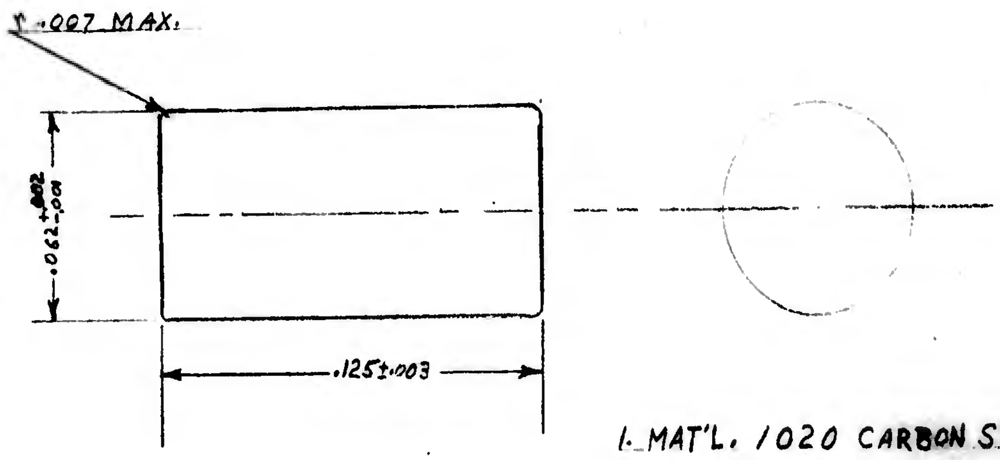
2-1

REVISIONS

REV	SYM	DESCRIPTION	DATE	APPROVED

DRAWING NUMBER G

SIZE A



1. MAT'L. 1020 CARBON STEEL
2. TUMBLE - TO BREAK EDGES
3. FINISH THIS SURFACE 63-125 BOTH ENDS

ISSUE 2 2/5/63 JGM
ISSUE 1 2/4/63 JGM

~~GPL GENERAL ENGINEERING SPECIFICATION 5146-29-18 PART OF THIS DRAWING~~

GPL DIVISION-GENERAL PRECISION, INC.
PLEASANTVILLE NEW YORK

DRAWING GRADE
DR J. BUPIVI
CHK
ENGR
APPD JGM
ISSUED BY

REFLECTIVE DISPLAY
DETENT

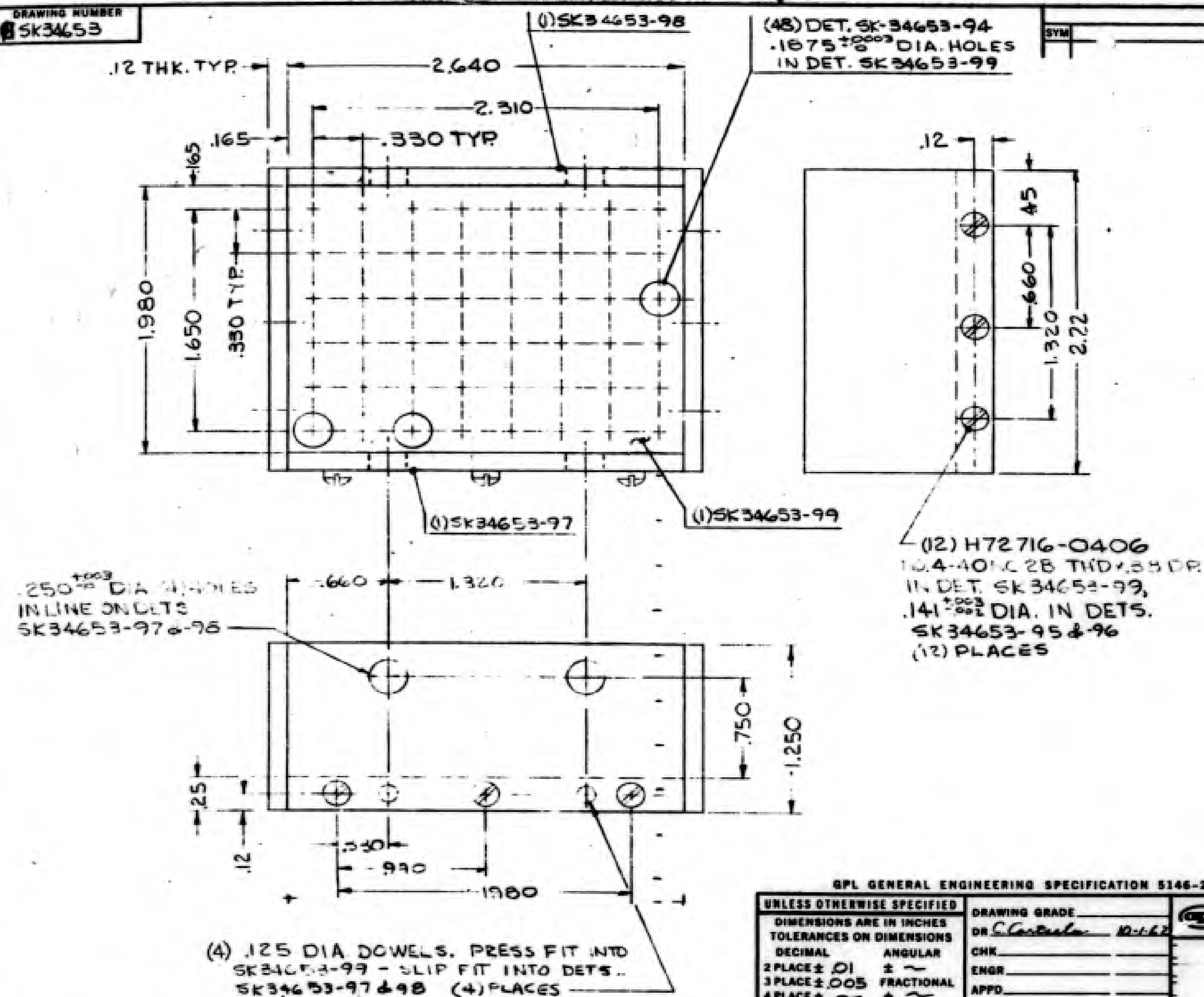
CODE IDENT NO.	SIZE	
84347	A	G SK 34700-16

SCALE 20:1 SHEET

K&E CO., N.Y.

DRAWING NUMBER SK34653

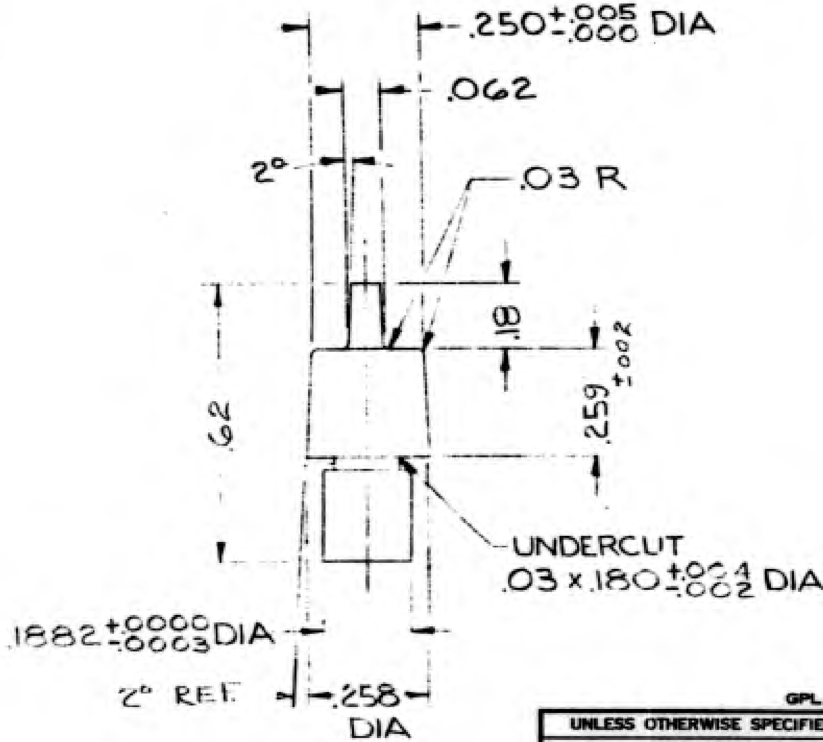
REVISIONS			
SYM	DESCRIPTION	DATE	APPROVED



GPL GENERAL ENGINEERING SPECIFICATION 5146-29 IS PART OF THIS DRAWING

UNLESS OTHERWISE SPECIFIED	DRAWING GRADE	GPL DIVISION-GENERAL PRECISION, INC. PLEASANTVILLE NEW YORK
DIMENSIONS ARE IN INCHES TOLERANCES ON DIMENSIONS	DR C Castada 10-1-62	MOLD REFLECTIVE DISPLAY
DECIMAL: 2 PLACE ± .01, 3 PLACE ± .005, 4 PLACE ± ~	CHK	
ANGULAR: ± ~; FRACTIONAL: ± ~	ENGR	
	APPD	
	ISSUED BY	
MATL		CODE IDENT NO. 84347 — SIZE C — SK-34653
FINISH		SCALE 2/1 — SHEET 1 of 2

SIZE C DRAWING NUMBER SK34653 REV



REV				
DRAWING NUMBER	SK34703-21			
SIZE	B			

REVISIONS

SYM	DESCRIPTION	DATE	APPROVED
A	CHANGE MATERIAL From 416 To 303	1/5/63	[illegible]

GPL GENERAL ENGINEERING SPECIFICATION 5146-29 IS PART OF THIS DRAWING.

UNLESS OTHERWISE SPECIFIED		
TOLERANCES	DRAWING GRADE	GPL DIVISION-GENERAL PRECISION, INC. PLEASANTVILLE NEW YORK
2 PLACE DECIMAL ±.01	DATE STARTED	MOLD PIN
3 PLACE DECIMAL ±.005	DR C. Castella 10-2-62	
4 PLACE DECIMAL ~	CHK	
ANGULAR ±1/2°	ENGR	
MATERIAL 303 Stainless Steel	APPD [illegible] 1-7-63	
	ISSUED BY / DATE	CODE IDENT NO. 84347 / SIZE B / DRAWING NUMBER SK347[illegible]-21
FINISH Best 125		SCALE 4/1 / SHEET 2 OF 2

Appendix 3

Torque Measuring Magnetometer

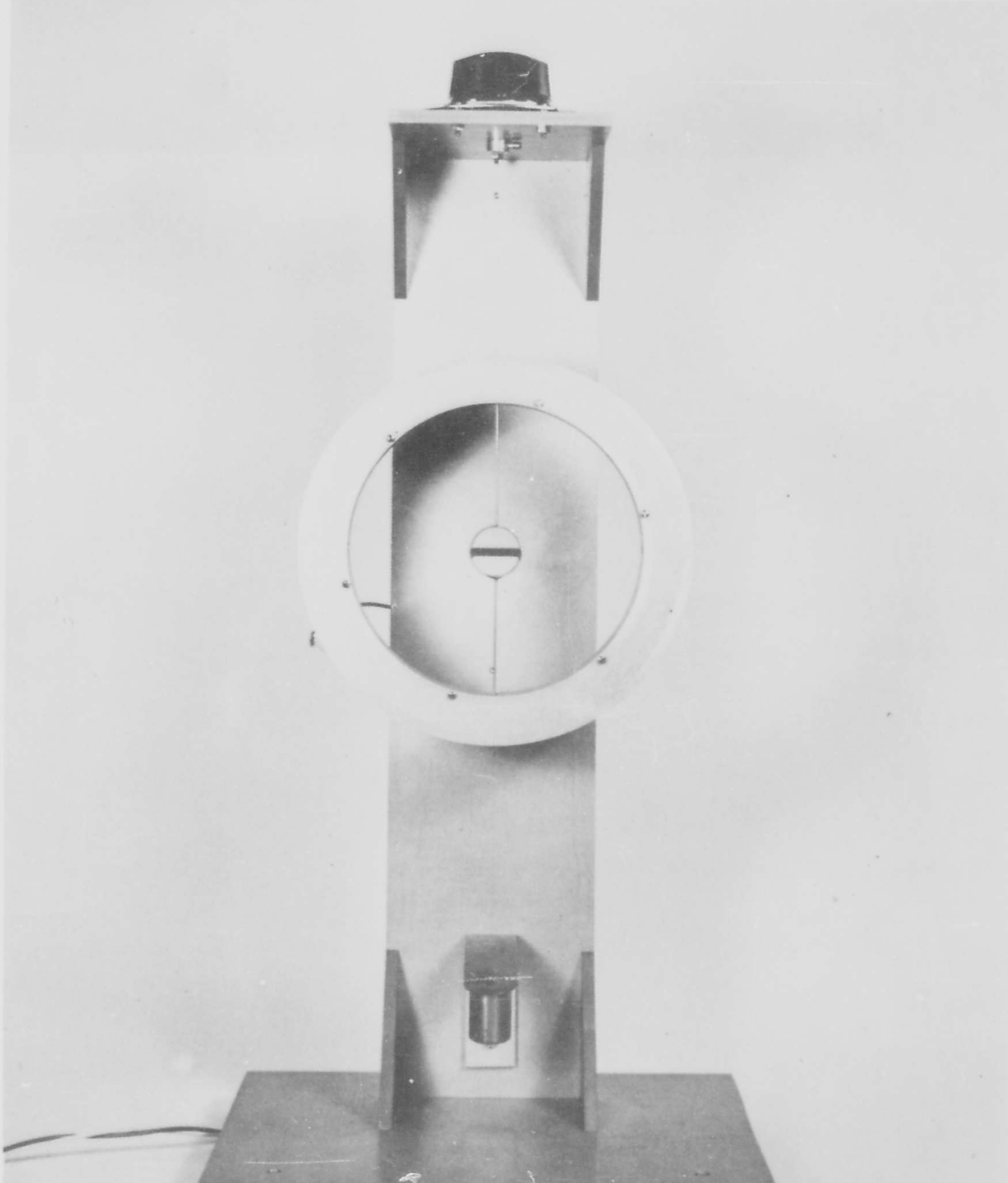


Figure 3-1 Magnetometer

6391-20-1-47

Appendix 4

Evolution of Models - Reflective Display

The attached drawings are representative of the evolution of design the Reflective Display.

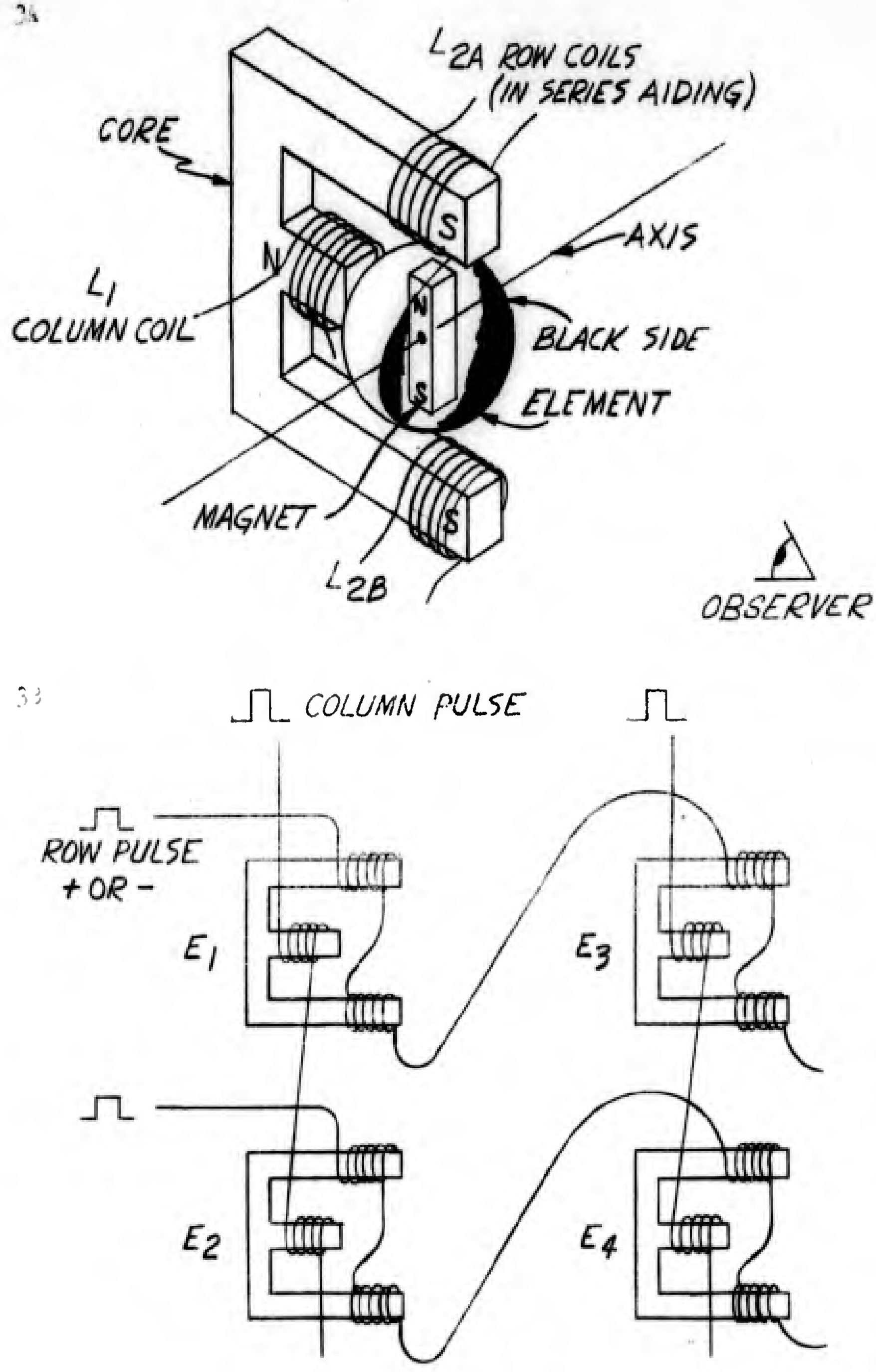


FIGURE 4-1
Element Cell Configurations
(A and B)

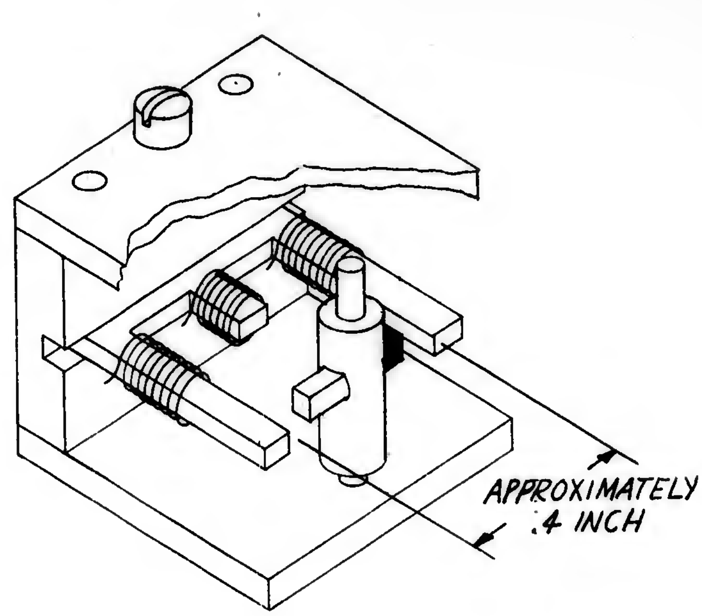


FIGURE 4-2
MODEL NO. 1
TEST CONFIGURATION

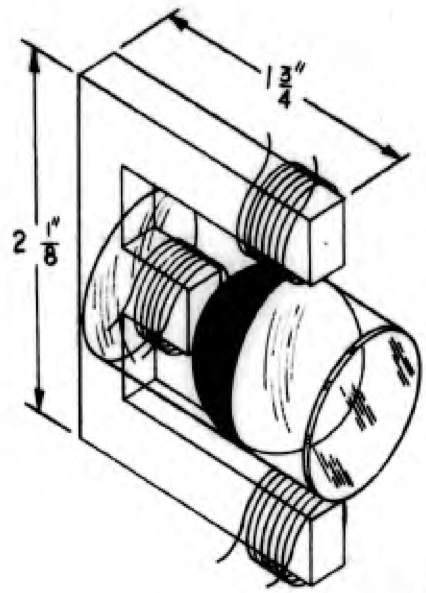


FIGURE 4-3
TEST CONFIGURATION
MODEL NO.2

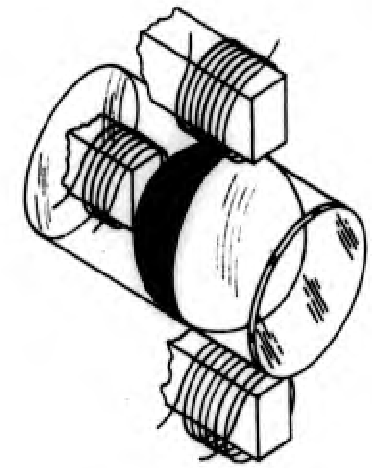


FIGURE 4-4
TEST CONFIGURATION
MODEL NO. 3

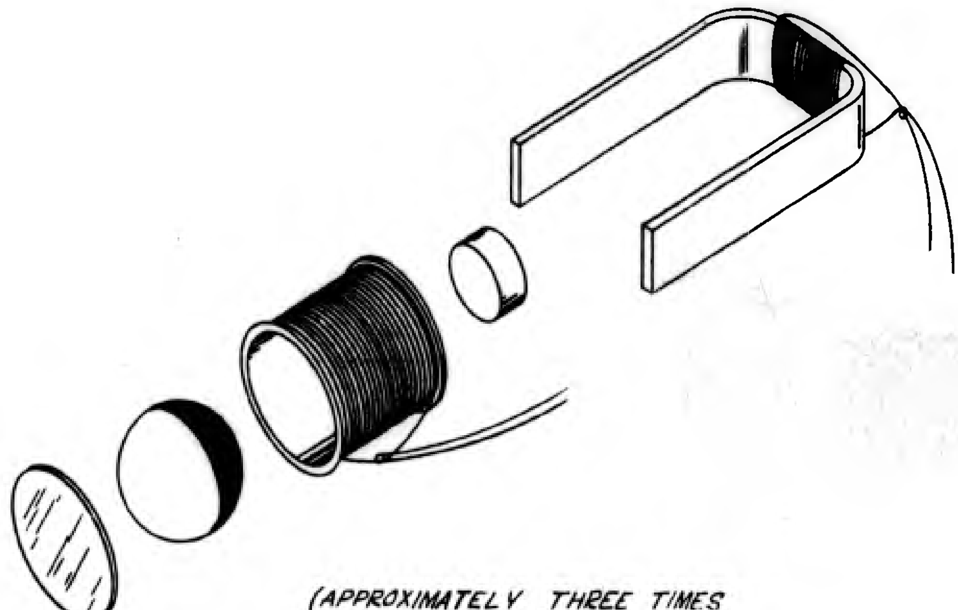


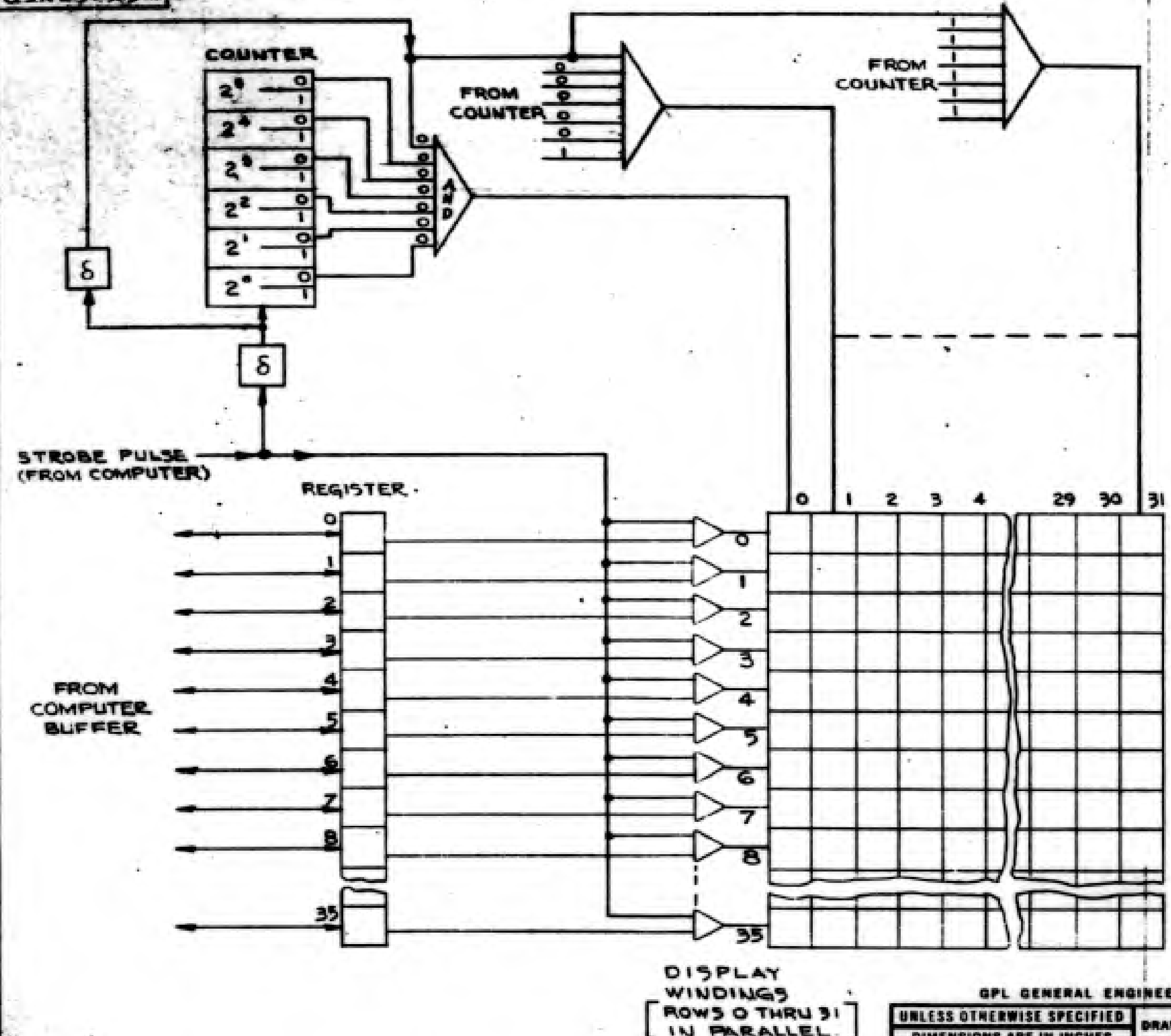
FIGURE 4-5
TEST CONFIGURATION
MODEL NO. 4

Appendix 5

Schematics

1.	Proposed Logic Diagram	SK 25773
2.	Delivered Driver Functional	SK 34815
3.	Module Schematic	34806
4.	Module Wiring Diagram	34807
5.	Interconnection Diagram	SK 34805
6.	Driver Schematic	SK 34812

G5K 25773



REVISIONS			
SYM	DESCRIPTION	DATE	APPROVED

GPL GENERAL ENGINEERING SPECIFICATION 5146-29 IS PART OF THIS DRAWING

UNLESS OTHERWISE SPECIFIED
DIMENSIONS ARE IN INCHES
TOLERANCES ON DIMENSIONS
DECIMAL 2 PLACE ± 3 PLACE ± 4 PLACE ± — ANGULAR ± — FRACTIONAL ±
MATL
FINISH

DRAWING GRADE
DR R.A.F. 2-3-63
CHK
ENGR 2/1/63
APPD 2/4/63
ISSUED BY

GPL DIVISION-GENERAL PRECISION, INC.
PLEASANTVILLE NEW YORK

LOGIC DIAGRAM 31 x 36 MATRIX REFLECTIVE DISPLAY

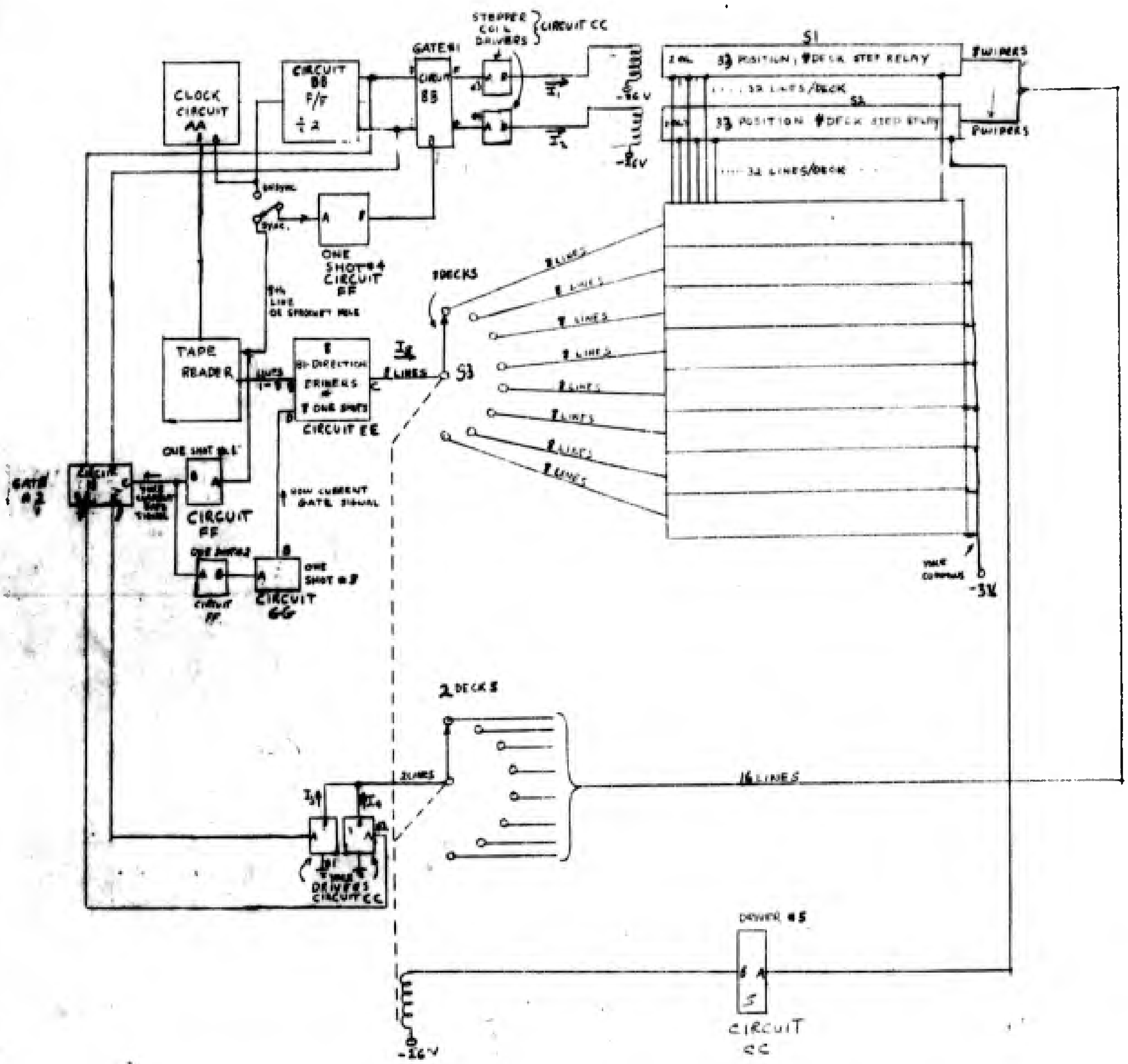
CODE IDENT NO. 84347 | SIZE C | G5K 25773
SCALE | SHEET

SIZE C | DRAWING NUMBER G | REV -

3 | 2 | 2

G

C



STEPPER COIL DRIVERS
CIRCUIT CC
S1
GATE #1
CIRCUIT BB F/F ÷2
CLOCK CIRCUIT AA
WIPERS
32 LINES/DECK
ONE SHOT #4 CIRCUIT FF
8 DECKS
TAPE READER
CIRCUIT EE
S3
CIRCUIT FF
CIRCUIT GG
2 DECKS
16 LINES
DRIVER #5
CIRCUIT CC
-36V

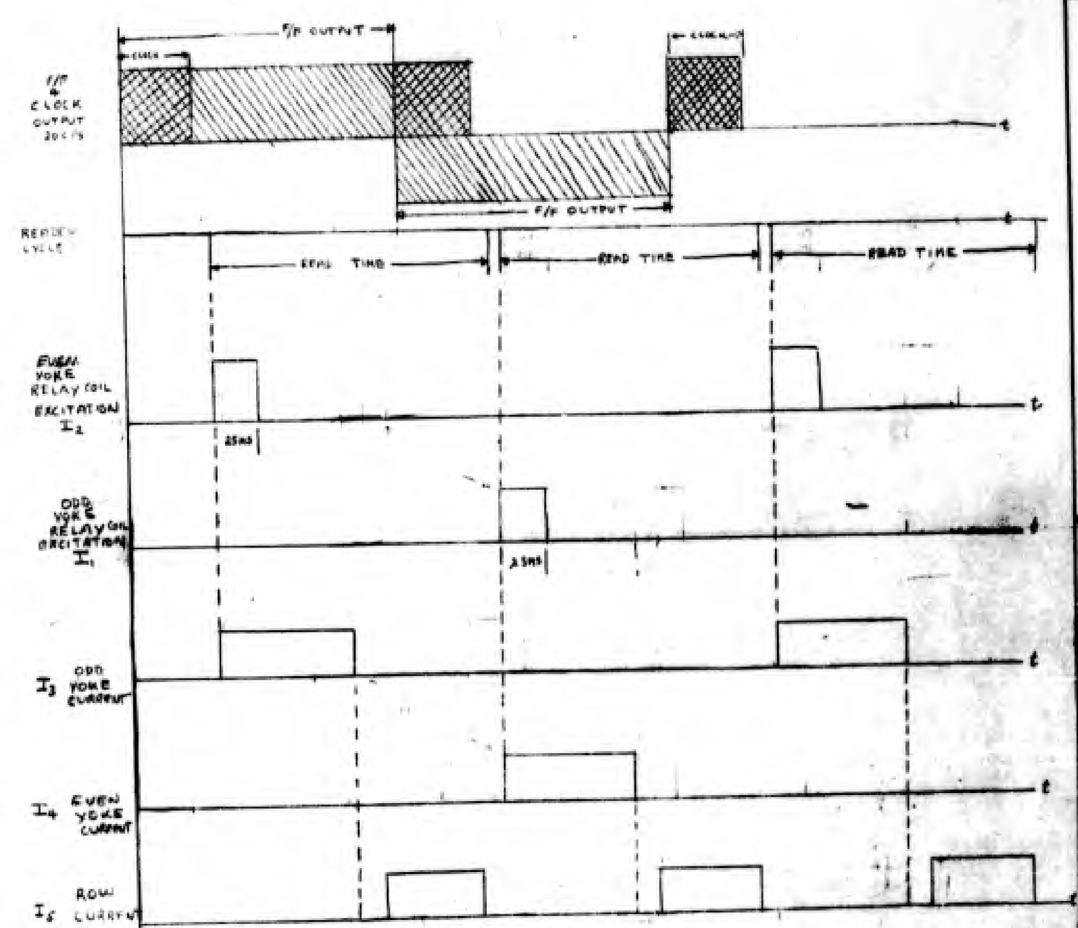
B

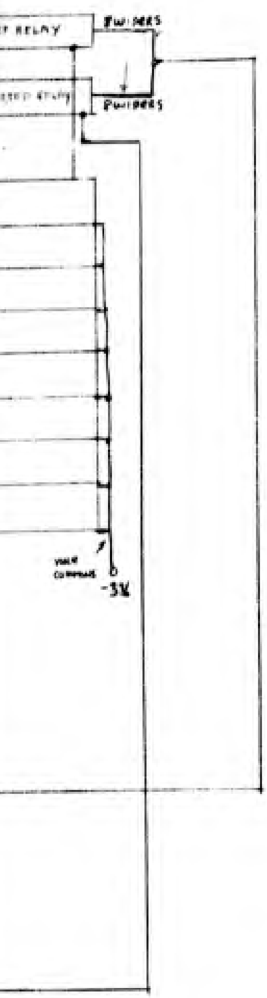
A

3 | 2 | 2

REVISIONS				
SYM	ZONE	DESCRIPTION	DATE	APPROVED
A				

TIMING DIAGRAM

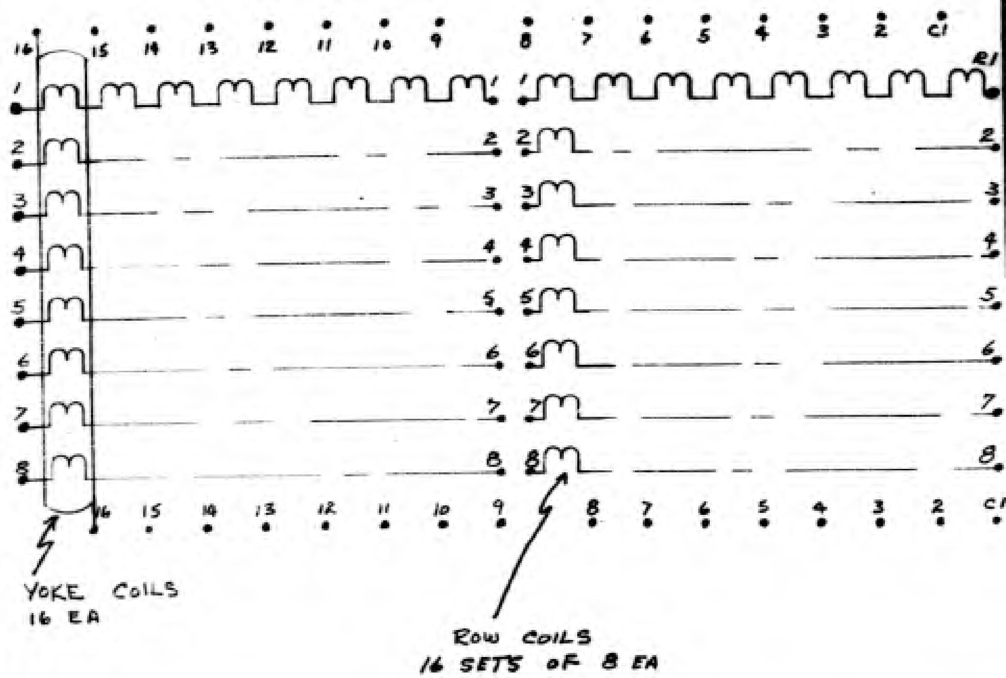




GPL GENERAL ENGINEERING SPECIFICATION 5146-29 IS PART OF THIS DRAWING

UNLESS OTHERWISE SPECIFIED	DRAWING GRADE	GPL DIVISION-GENERAL PREC... PLEASANTVILLE
DIMENSIONS ARE IN INCHES. TOLERANCES ON DIMENSIONS: DECIMAL 2 PLACE ± 3 PLACE ± 4 PLACE ± ; ANGULAR ± ; FRACTIONAL ±	DR. / CHK. / ENGR. / APPD. / ISSUED BY	FUNCTIONAL DIAG... REFLECTIVE DISPLAY DRIVER
MATL		CODE IDENT NO. 84347 — SIZE D — G SK-34815
FINISH		SCALE — SHEET

2



NOTE: NUMBERED TERMINALS INDICATE CONNECTIONS TO REAR TERMINAL BOARD

R- ROW COILS

C- COLUMN COILS (YOKES)

REV	DRAWING NUMBER	SIZE
	G	B

REVISIONS

SYM	DESCRIPTION	DATE	APPROVED

GPL GENERAL ENGINEERING SPECIFICATION 5146-29 IS PART OF THIS DRAWING

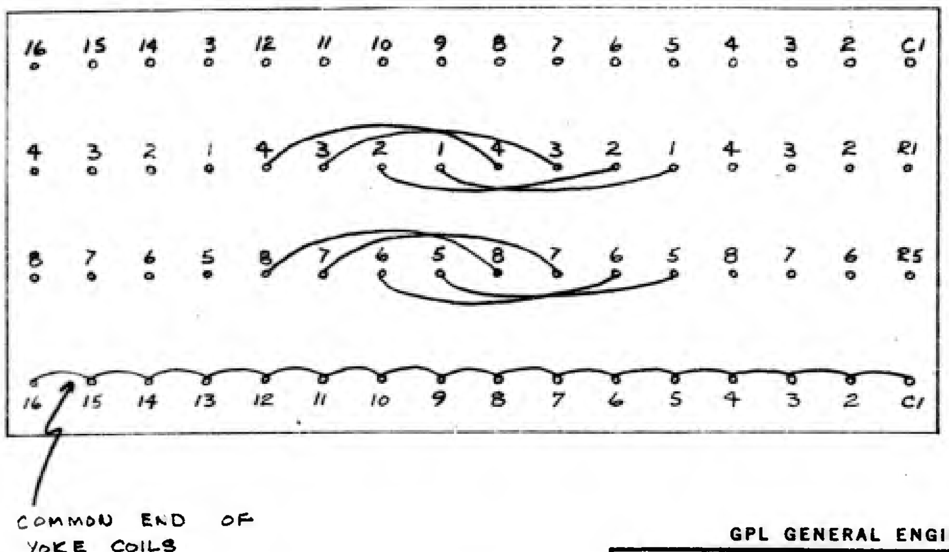
UNLESS OTHERWISE SPECIFIED	
DIMENSIONS ARE IN INCHES TOLERANCES ON DIMENSIONS	
DECIMAL	ANGULAR
2 PLACE ±	±
3 PLACE ±	FRACTIONAL
4 PLACE ±	±
MATL	
FINISH	

DRAWING GRADE
DR R. Marcone 9-12-63
CHK
ENGR R. Marcone 9-12-63
APPD
ISSUED BY

GPL DIVISION-GENERAL PRECISION, INC.
PLEASANTVILLE NEW YORK

SCHEMATIC
TYPICAL DISPLAY MODULE
8 x 16 ELEMENTS

CODE IDENT NO.	SIZE	
84347	B	G SK 34806
SCALE		SHEET



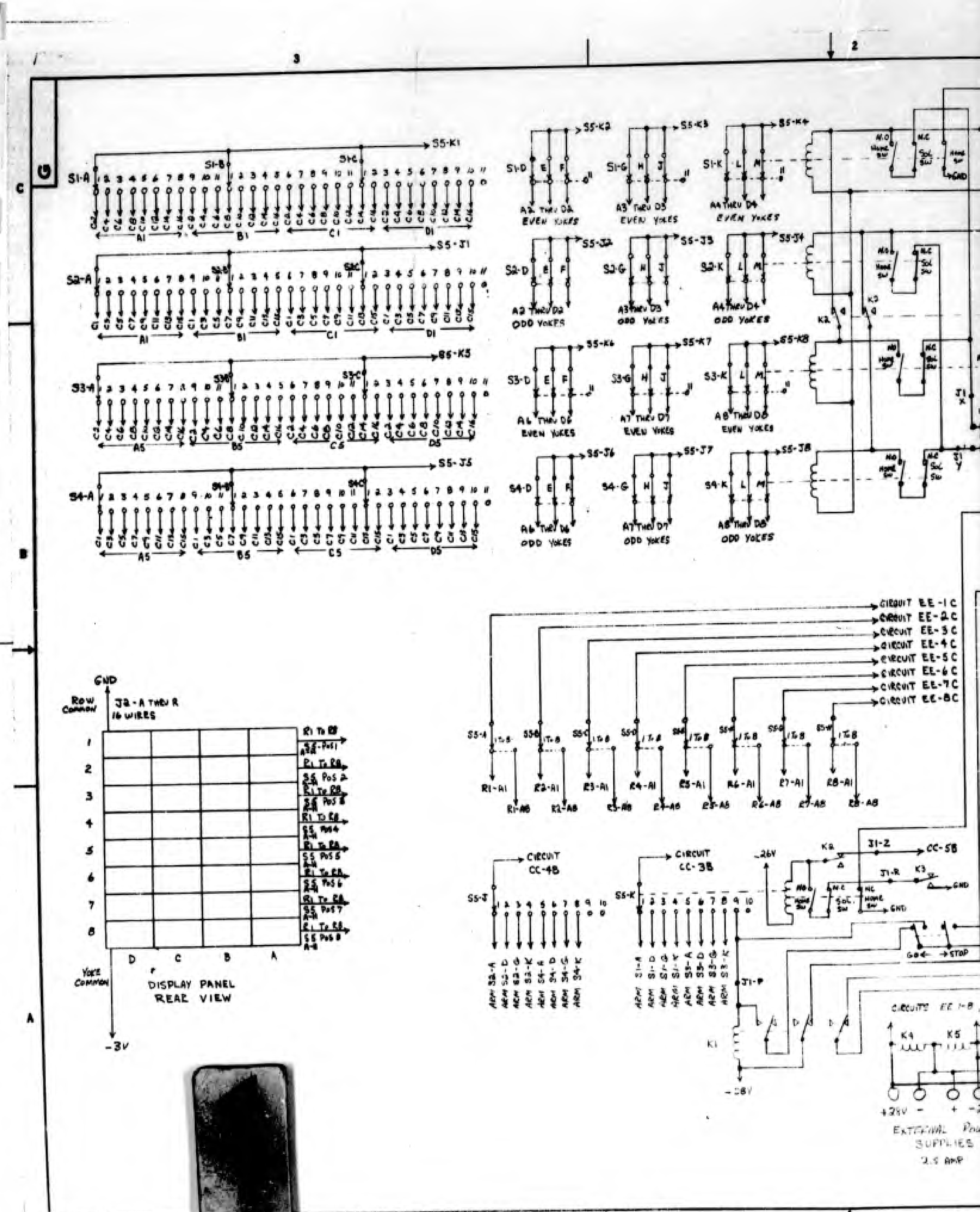
REV	DRAWING NUMBER	SIZE
	G	B

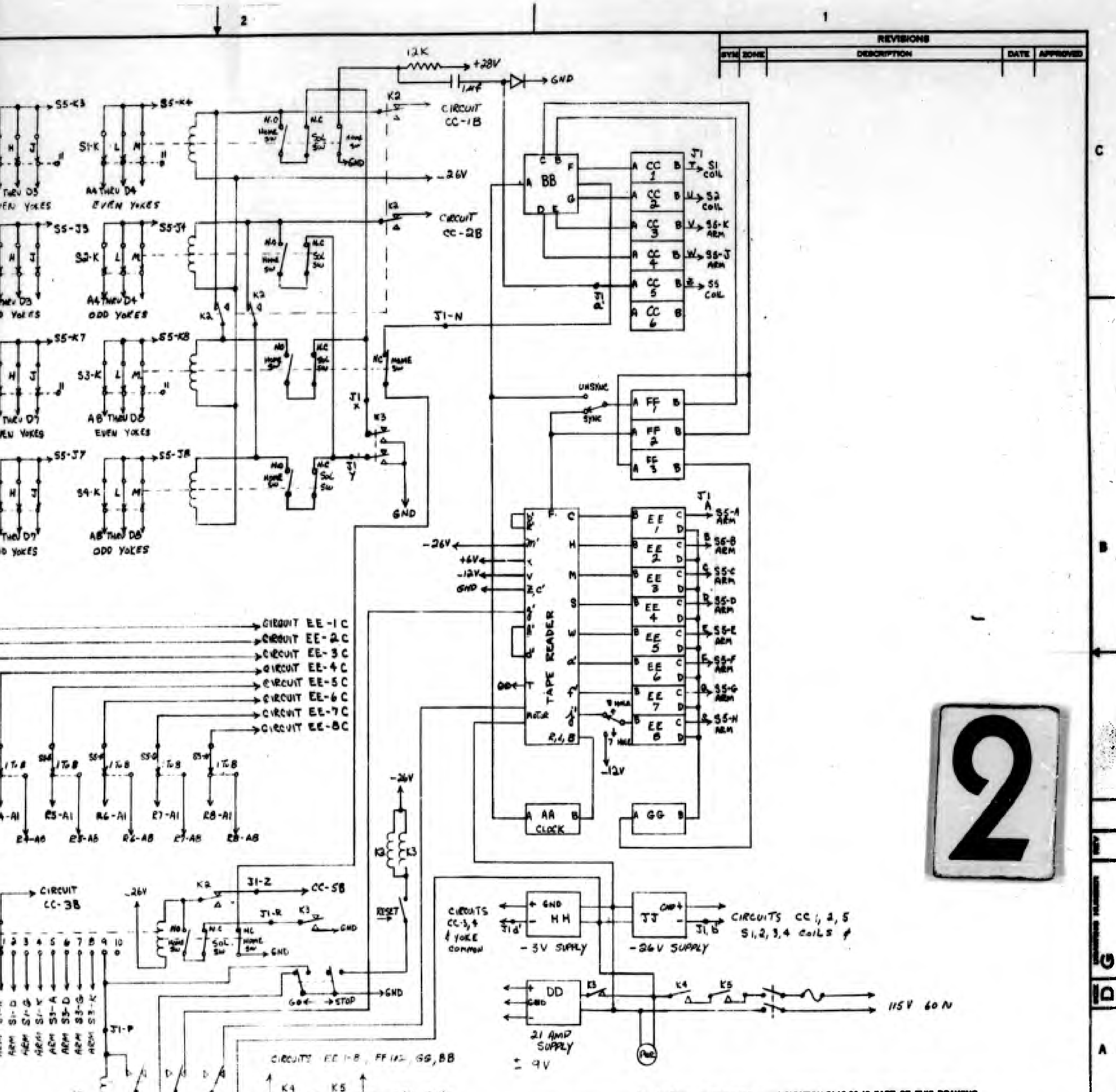
REVISIONS

SYM	DESCRIPTION	DATE	APPROVED

GPL GENERAL ENGINEERING SPECIFICATION 5146-29 IS PART OF THIS DRAWING

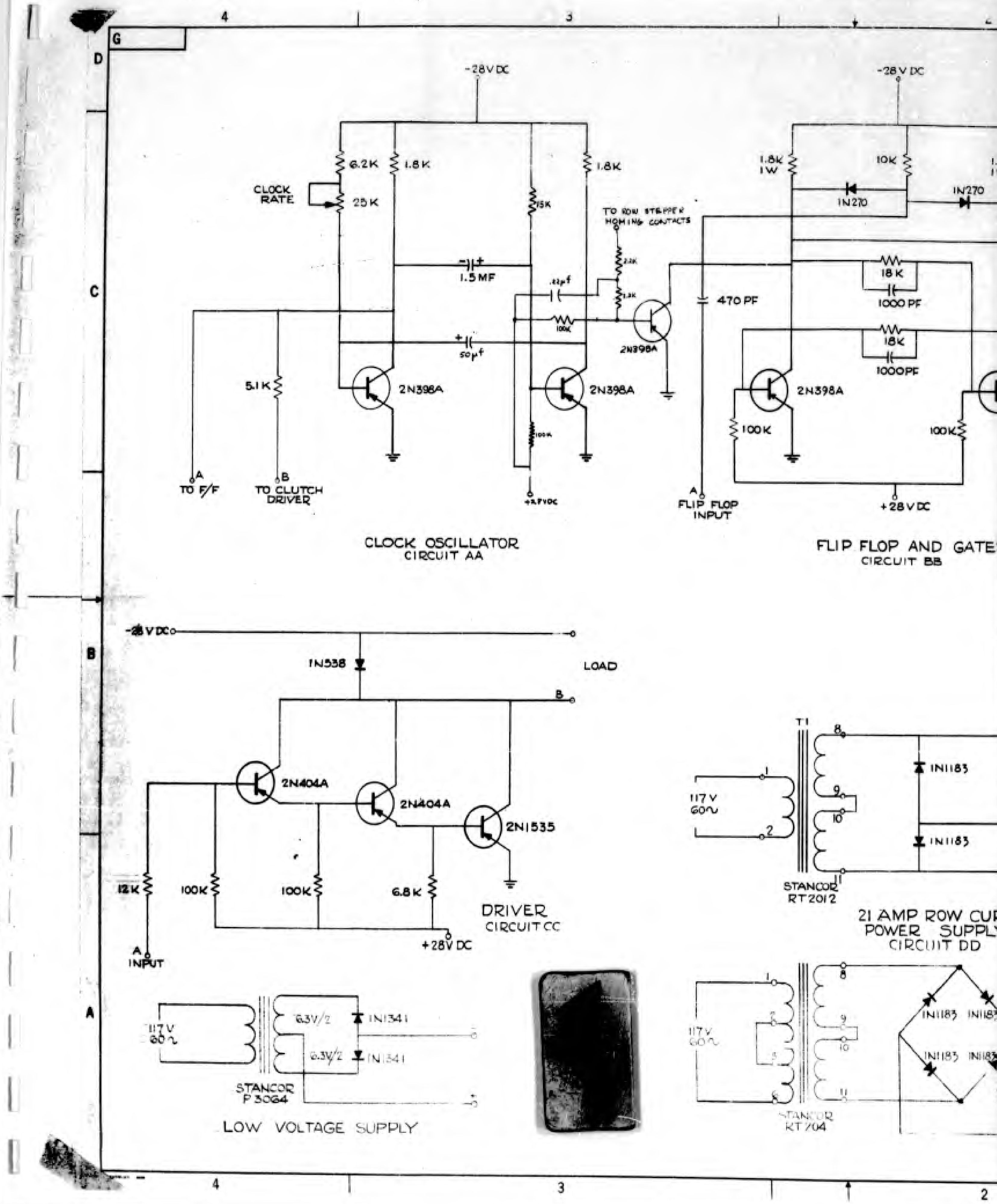
UNLESS OTHERWISE SPECIFIED		
DIMENSIONS ARE IN INCHES TOLERANCES ON DIMENSIONS DECIMAL ANGULAR 2 PLACE ± ± 3 PLACE ± FRACTIONAL 4 PLACE ± ±	DRAWING GRADE DR R. Marcone 9-12-63 CHK ENGR R Marcone 9-12-63 APPD ISSUED BY	GPL DIVISION-GENERAL PRECISION, INC. PLEASANTVILLE NEW YORK WIRING DIAGRAM TYPICAL DISPLAY MODULE TERMINAL BOARD
MATL FINISH		CODE IDENT NO. 84347 · SIZE B · G SK 34807 SCALE · SHEET


S5-K1
S5-J1
S5-K5
S5-J5
S1-A
S2-A
S3-A
S4-A
A1
B1
C1
D1
A5
B5
C5
D5
S1-D
S1-G
S1-K
S2-D
S2-G
S2-K
S3-D
S3-G
S3-K
S4-D
S4-G
S4-K
A2 THRU D2 EVEN YOKES
A3 THRU D3 EVEN YOKES
A4 THRU D4 EVEN YOKES
A2 THRU D2 ODD YOKES
A3 THRU D3 ODD YOKES
A4 THRU D4 ODD YOKES
A6 THRU D6 EVEN YOKES
A7 THRU D7 EVEN YOKES
A8 THRU D8 EVEN YOKES
A6 THRU D6 ODD YOKES
A7 THRU D7 ODD YOKES
A8 THRU D8 ODD YOKES
CIRCUIT EE-1C
CIRCUIT EE-2C
CIRCUIT EE-3C
CIRCUIT EE-4C
CIRCUIT EE-5C
CIRCUIT EE-6C
CIRCUIT EE-7C
CIRCUIT EE-8C
R1-A1
R2-A1
R3-A1
R4-A1
R5-A1
R6-A1
R7-A1
R8-A1
GND
ROW COMMON
J2 - A THRU R
16 WIRES
YOKE COMMON
DISPLAY PANEL
REAR VIEW
-3V
CIRCUIT CC-4B
CIRCUIT CC-3B
CC-5B
-26V
GO
STOP
K1
-28V
EXTERNAL POWER SUPPLIES
2.5 AMP



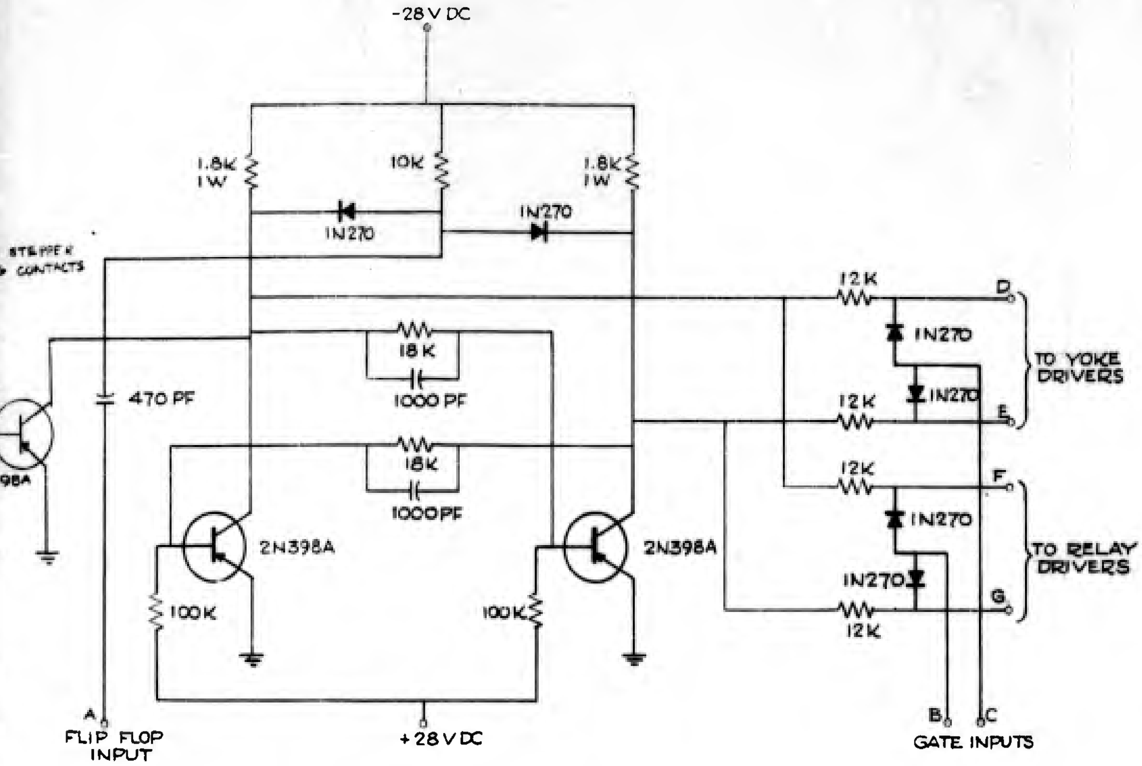
GPL GENERAL ENGINEERING SPECIFICATION 8146-28 IS PART OF THIS DRAWING.

UNLESS OTHERWISE SPECIFIED		
TOLERANCES	DRAWING GRADE	GPL DIVISION-GENERAL PRECISION, INC. PLEASANTVILLE NEW YORK
2 PLACE DECIMAL	DATE STARTED 9-18-63	INTERCONNECTION DIAGRAM
3 PLACE DECIMAL	DR R. Marrone	REFLECTIVE DISPLAY & DRIVER
4 PLACE DECIMAL	CHK	
ANGULAR	ENGR R. Marrone	
MATERIAL	APPD	
	ISSUED BY / DATE	CODE IDENT NO. 84347 — SIZE D — DRAWING NUMBER G SK 34805
FINISH		SCALE / SHEET

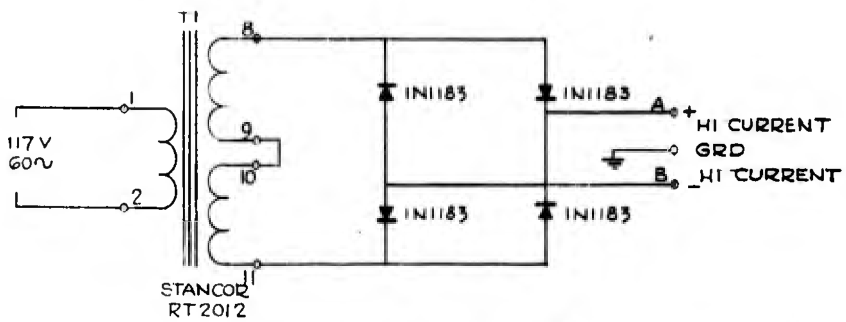


4
3
2
D
C
B
A
G
-28V DC
6.2K
1.8K
CLOCK RATE
25K
15K
1.5MF
.22μf
50μf
TO ROW STEPPER HOMING CONTACTS
2.2K
100K
2N398A
5.1K
A TO F/F
B TO CLUTCH DRIVER
+28VDC
CLOCK OSCILLATOR
CIRCUIT AA
1.8K 1W
10K
IN270
470 PF
18K
1000 PF
A FLIP FLOP INPUT
+28V DC
FLIP FLOP AND GATE
CIRCUIT BB
-28V DC
IN538
LOAD
B
2N404A
2N1535
12K
6.8K
A INPUT
DRIVER
CIRCUIT CC
T1
117V 60~
IN1183
STANCOR RT2012
21 AMP ROW CUR
POWER SUPPLY
CIRCUIT DD
6.3V/2
IN1341
STANCOR P3064
LOW VOLTAGE SUPPLY
STANCOR RT204

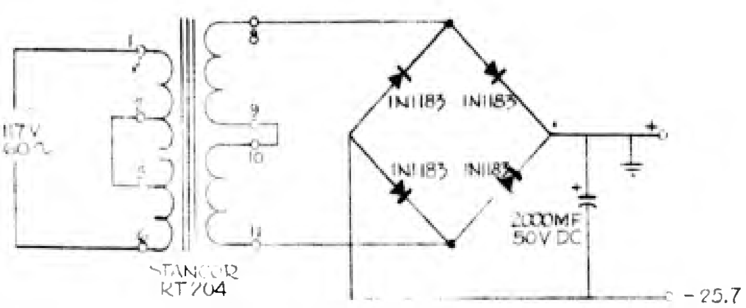
REVISIONS				
SYM	ZONE	DESCRIPTION	DATE	APPROVED



FLIP FLOP AND GATES
CIRCUIT BB



21 AMP ROW CURRENT
POWER SUPPLY
CIRCUIT DD



2

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UNLESS OTHERWISE SPECIFIED
DIMENSIONS ARE IN INCHES
TOLERANCES ON DIMENSIONS
DECIMAL — ANGULAR
2 PLACE ± — ±
3 PLACE ± — FRACTIONAL
4 PLACE ± — ±
MATL
FINISH

DRAWING GRADE
DRW. W. YURKOWSKI
CHK
ENGR W. SCHOPPER
APPD
ISSUED BY

GPL DIVISION-GENERAL PRECISION, INC.
PLEASANTVILLE — NEW YORK

SCHEMATIC DIAGRAM
REFLECTIVE DISPLAY
DRIVER
SHEET 1

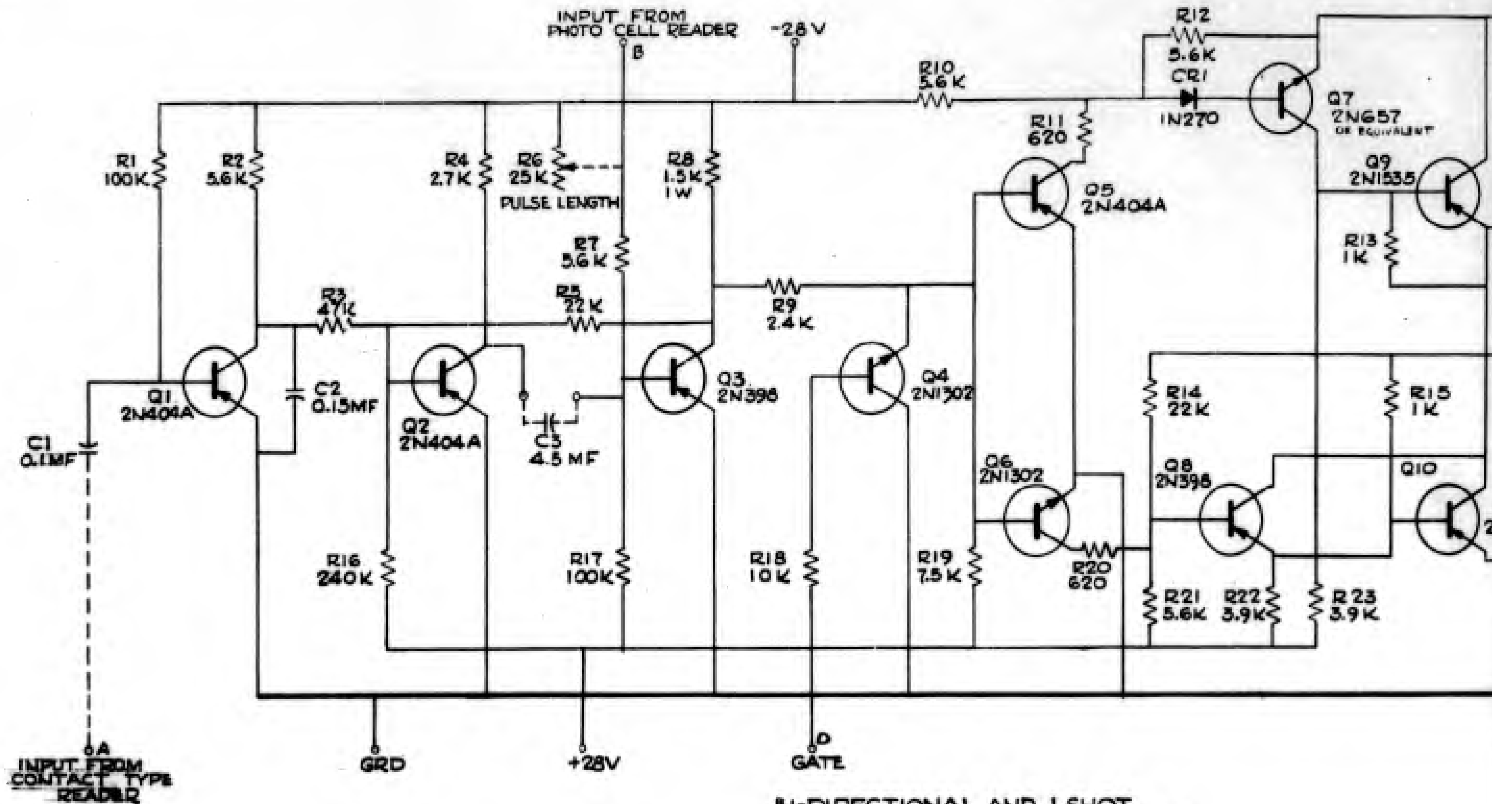
CODE IDENT NO.	SIZE	
84347	F	G SK 34812
SCALE		SHEET

SIZE F | DRAWING NUMBER G | REV

D C B A — 2 — 1

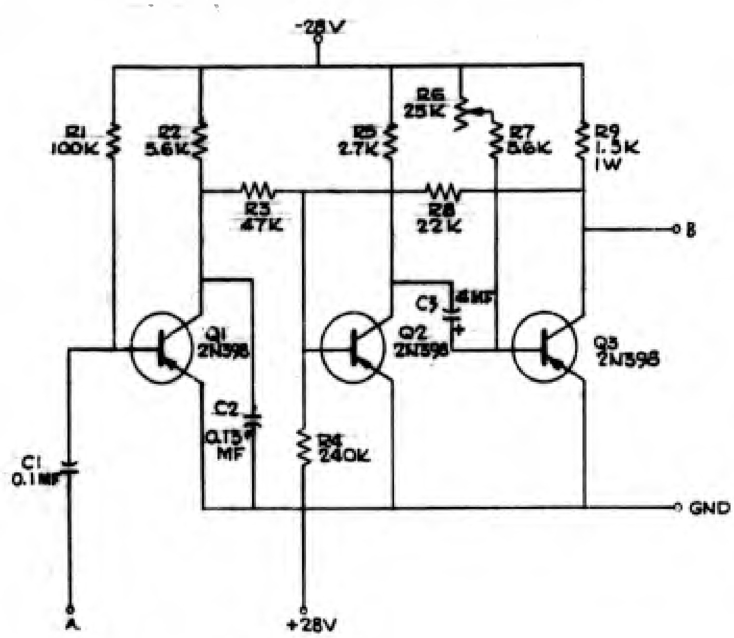
4 3 2

G

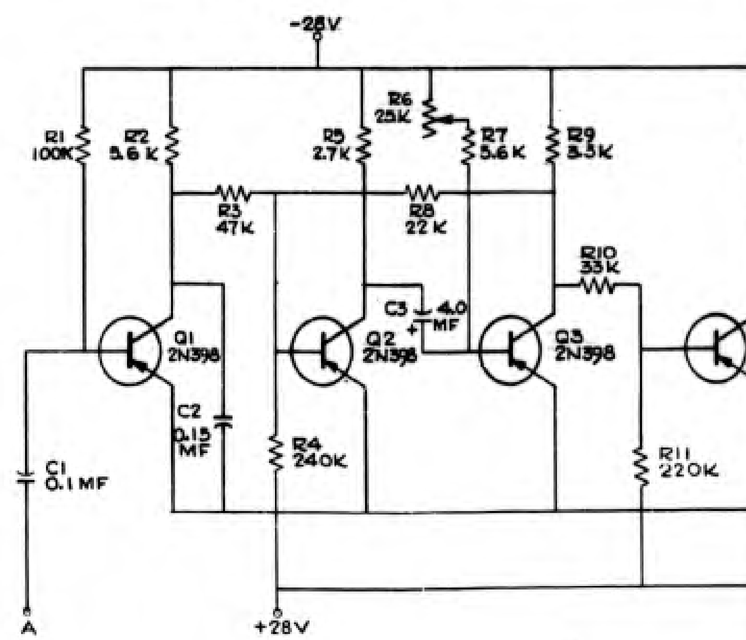


BI-DIRECTIONAL AND 1 SHOT REFLECTIVE DISPLAY DRIVER

CIRCUIT EE



CIRCUIT FF

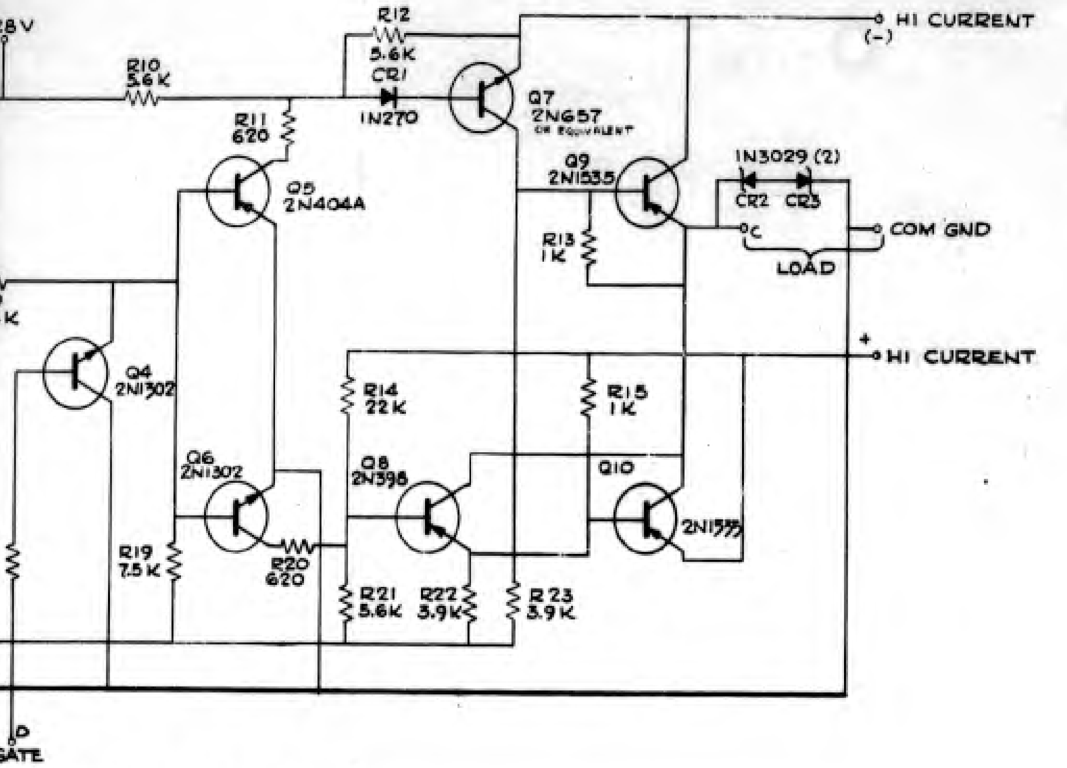


CIRCUIT GG

REFLECTIVE DISPLAY DRIVER

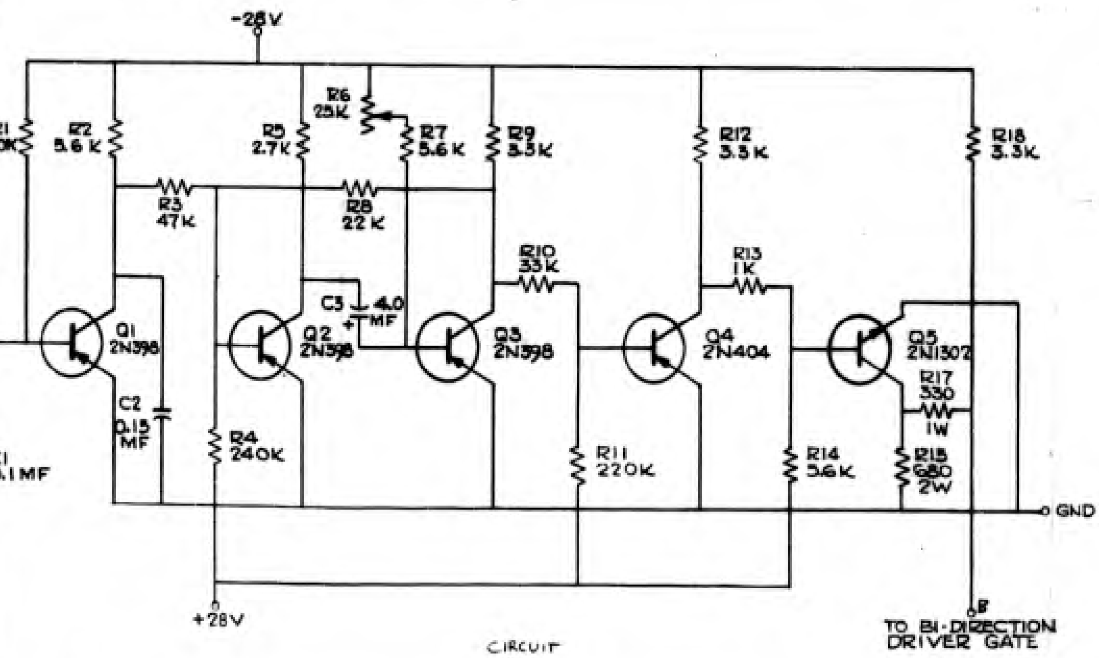
D C B A

REVISIONS				
SYM	ZONE	DESCRIPTION	DATE	APPROVED



-DIRECTIONAL AND 1 SHOT REFLECTIVE DISPLAY DRIVER

CIRCUIT EE



CIRCUIT GG

ECTIVE DISPLAY DRIVER

2

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UNLESS OTHERWISE SPECIFIED	DRAWING GRADE	GPL DIVISION GENERAL PRECISION, INC. PLEASANTVILLE NEW YORK
DIMENSIONS ARE IN INCHES TOLERANCES ON DIMENSIONS DECIMAL / ANGULAR 2 PLACE ± / ± 3 PLACE ± / FRACTIONAL 4 PLACE ± / ±	DR CHK ENGR W. SCHIFFER APPD ISSUED BY	SCHEMATIC DIAGRAM REFLECTIVE DISPLAY DRIVER SHEET 2
MATL FINISH		CODE IDENT NO. 84347 · SIZE F · GSK 34812
		SCALE · SHEET 2 of 2

UNCLASSIFIED

UNCLASSIFIED