

TWO DIMENSIONAL SHAPE MEASUREMENT  
VIA VIDEO SIGNAL PROCESSING

by

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on May 12, 1978, in partial fulfillment of the requirements  
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ABSTRACT

A digital circuit was built which accepts television camera video signals and produces 8 bit X- and Y-coordinate pairs of a two dimensional shape.

Combined with software, this video-measuring approach to shape measurement provides a rapid non-contact measurement capability for a range of applications. Experimental results from calibration of the device were used to assess its suitability for control of an adaptive brake forming process.

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## CHAPTER 1

INTRODUCTION

In order to perform adaptive control of the sheet metal brake bending process, a measurement device was developed to measure the shape of the deformed sheet in a fast and accurate manner. This device translates the video signal of the object image into a number of pairs of X- and Y-coordinates.

The viewing field of the television camera is positioned so that the object to be measured is centered. A voltage comparator in the measurement device acts as an image detector, responding to positive voltage peaks in the video signal produced when the vidicon tube in the camera detects the light image to be measured against a darker background.

The Y- and X-coordinates of the measured object are obtained by counting the horizontal scan lines and a 5-MHz oscillator, respectively. More detailed operation principles are discussed in Chapter 2. The implementation of this device is shown detailed in Chapter 3 and Appendix B.

To calibrate this device, an 8080-based microcomputer was used to read the X- and Y-coordinates of the measured object and analyse them. The programs used for calibration are discussed in the software portion of Chapter 3 and listed in Appendix C.

Chapter 4 evaluates this video-measuring system. Its good experimental results indicate its suitability as a general purpose

measurement device. Some of this system's advantages and potential applications are described in Chapter 5.

## CHAPTER 2

PRINCIPLE OF OPERATION2.1 INTRODUCTION

This measurement device is designed to measure the vertical and horizontal coordinates of a two dimensional curve whose image is picked up by a television camera and reproduced on a video monitor. The video signal produced by television camera aiming at the measured curve will be converted into a number of pairs of X- and Y-coordinate for display and output to computer.

This measurement device is primarily made up of integrated circuits. The operational functions can be separated into three major sections. The first, called video signal processing unit, reads the video signal and produces the necessary control signals for the measurement unit. The second section, called the coordinate measurement unit, is the section which produces the coordinate data and stores them in registers. The last section is for data output and display. The system schematic diagram is shown in figure 1.

To assure that the measurement data accurately represents the true shape of the measured curve, the measurement device was calibrated. Calibration and the data characteristics will be discussed in the following chapters.

2.2 VIDEO SIGNAL PROCESSING

## 2.2.1 BASIC CHARACTERISTICS OF VIDEO SIGNALS



In the video signal, the horizontal scanning period is 62.5 microseconds (Figure 2 ) and the field period is 16.67 milliseconds, i.e., 60 frames per second. Each video field is made up of 262.5 scan lines. The television camera used in this experiment is a simple raster scan type, with one field for each frame.

Although the video signal used in broadcasting systems has to meet the IEEE standard (Ref. 4 ), there are still no such regulations that apply to the video signal output of general laboratory camera such as the type used in this experiment.

The white peak, black peak, sync level and blanking level of video signal are different in each television camera produced. Therefore, it is difficult to set up a standard reference voltage used for the voltage comparators in the measurement device. This voltage must be adjusted for the video signal produced by the television camera used in each test. Details for this adjustment will be described in the next section.

The video signal used in present test has a 6 microseconds horizontal sync and a 300 microseconds vertical sync. Sync level is 0 to 0.3 volt (Figure 2 ). Black level voltage is 1 volt and white peak voltage is 2 volt (Figure 2 ).

### 2.2.2 READING THE VIDEO SIGNAL

Two voltage comparators, 2/4 package of LM339, are used to "read"

the syncs and the image of the measured curve carried by video signal. One of the voltage comparators acts as a sync detector, responding to the sync voltage (lower than 0.3 volt ). The other voltage comparator acts as an image detector, responding to the positive voltage produced when the vidicon tube in the camera detects a bright image against a dull black background.

The white peak and black level of the image video signal are affected by the brightness and darkness of the measured objects. So, in order to produce VC2 (Figure 3 ), the different levels of video signal must be checked on oscilloscope and the reference voltage must be set (+) at a level that is higher than any noise level and lower than the white image peak such that only the measured image can be detected. The VC1 signal (Figure 3 ) responds to video syncs that have different levels for different television cameras. So, by the same procedure as setting VC2, we must choose a level for VC1 that is lower than the highest level of syncs and higher than the lowest level of the video signal (Figure 3 (b) ).

The reference voltages to VC1 and VC2 are adjusted by potentiometers labeled VC1 and VC2 respectively. The reference voltages are extracted from a 3-volt reference voltage (Figure 3 (b) ) which is created by a zener diode, 1N5225B. This circuit maintains the reference voltage at a constant value and prevents detection of the wrong signals on VC1 and VC2.

### 2.2.3 SEPARATE THE HORIZONTAL AND VERTICAL SYNC

The horizontal and vertical syncs have the same shape and voltage level. Only the time interval is different. The duration of the horizontal sync is 6 microseconds and the vertical, 300 microseconds. In most video receivers, an integration circuit is used to separate the horizontal and vertical sync (Ref. 1). But in this video signal processing unit, two groups of monostable multivibrators, SN74123, are used to separate them. They also generate control signals for measurement usage (Figure 4 (a) ).

Monostable multivibrators in the first group, MMX(1) and MMX(2), produce a 40 microseconds period in every horizontal scanning line (Figure 4 (b) ). The falling edge of VC1 triggers MMX(1) which produces a positive pulse on output Q for 10 microseconds (Figure 4 (b) ). Similarly, MMX(2) is triggered by the falling edge of the output Q of MMX(1) and then produces a positive pulse on its output Q for 40 microseconds (Figure 4 (b) ). This is called a horizontal gating signal (H.G. ).

The vertical gating signal ( V.G. ), Figure 4 (c), is created by the monostable multivibrators in the second group. MMY(1), MMY(2) and MMY(3) produce a 12.7 millisecond period in every field or frame (Figure 4 (c) ). MMY(1) is triggered by the falling edge of VC1, also. But the MMY(1) is retriggerable (Ref. 6 ). Its unstable period is set so that produces a positive pulse on its output  $\bar{Q}$  only if it does not detect a horizontal sync pulse within a 200 microsecond time interval. Because there is only one 300 microsecond vertical sync at the end of each field or frame, the output  $\bar{Q}$  of MMY(1) is always in low state except to detect

the vertical sync ( Figure 4 (c) ). The  $\bar{Q}$  of MMY(1) will also be triggered following the first falling edge after the vertical sync of VCI has arrived. MMY(2) is triggered by the falling edge of output  $\bar{Q}$  of MMY(1) and produces a positive pulse on its output Q for 2 milliseconds ( Figure 4 (c) ). MMY(3) is triggered by the falling edge of output Q of MMY(2) and produces a positive pulse on its output Q for 12.7 milliseconds.

The horizontal gating signal allows detection only during the central segment of each video line, i.e., 40 microseconds of each 60 microsecond horizontal scanning time. The vertical gating signal allows detection only during the central portion of each video field scan, i.e., 200 lines at central portion of 262.5 scan lines of one frame. These two gating signals construct an invisible rectangular detection area that can be adjusted to any size within the field of view of the camera by using of five potentiometers ( Figure 4 ).

### 2.3 COORDINATES MEASUREMENT

The horizontal and vertical gating signals construct an invisible rectangular detection area on the monitor. This area has its coordinates origin at the upper left corner of the monitor. The X axis runs horizontally across the area from left to right and the Y axis vertically from top to bottom. This coordinate system is called the reference coordinate system and the measurement of coordinates is based on it.

### 2.3.1 HORIZONTAL COORDINATES

There is an 8 bit counter (two packages of SN74161A ) for X or horizontal axis measurement. This counter is triggered by a 5-MHz oscillator or clock ( Figure 5 (a) ) which is constructed by a monostable multivibrator with delay feedback and is adjustable for calibration. This counter and 5-MHz clock are controlled by the horizontal gating signal. The clock is started as soon as the horizontal gating signal is high, and the counter begins counting. The horizontal gating signal remains high for 40 microseconds at the central segment of each horizontal scan line. So the counter can count from 0 to 200 ( in decimal ) in each X axis measurement. It also means that we can divide the rectangular measurement area into 200 divisions in X or horizontal axis on the monitor.

When the image of measured curve is detected, VC2 goes high. This signal will immediately load the X-coordinates registers which store X-axis data being measured. The X-coordinates of the measured curve is determined by the triggering time of VC2, i.e., the position of the image appearing. There is a proportional relationship between the image displacement and the X-coordinates data. The value of the X-coordinate is decreasing when the image is moving toward left on the monitor and, increasing when moving toward the right. Additional details will be discussed in section 2.3.3.

### 2.3.2 VERTICAL COORDINATES

There is also an 8 bit counter ( two packages of SN74161A ) for Y or vertical axis measurement. The trigger source of this counter comes from VC1 ( Figure 5 (b) ), i.e., video sync detection signal. This counter is actuated by the vertical gating signal. This signal is high for 12.7 milliseconds at the central portion of each video field or frame. Only 200 horizontal scanning lines are detected in each video frame. These frames have 262.5 horizontal scanning lines.

The Y-coordinates counter immediately starts to accumulate data at the top of the reference coordinate. That is, the number in this counter is increasing as the video signal scans toward the bottom of the monitor. In each period of the vertical gating signal, this Y-coordinates counter has a capacity to detect upto 200 lines in one video field. It also means that we divide the rectangular measurement area into 200 divisions in Y or vertical axis on the monitor. The measuring principles of Y-coordinates are the same as those of X-coordinates which are described in section 2.3.1.

### 2.3.3 STORING X- AND Y-COORDINATES

All the data bits of the X- and Y-coordinates counters are connected to parallel data inputs of registers. Four packages of SN74173 are used ( Figure 6 (a) ). All of the "clock" pins of these four registers are triggered by the rising edge of a "LOAD" signal. This signal is the Q output of a D type flip-flop (1/2 package of SN74LS74 ) which is triggered by VC2 and synchronized by the complement signal of the 5-MHz CLOCK ( Figure 6 (a) ). (Ref. 2)

Because the arrival of the rising edge of VC2 indicates that the left edge of the measured curve shown on the monitor is detected and that it is asynchronous to the counting system, the rising edge of VC2 has to be synchronized by a D type flip-flop. Thus, the rising edge of "LOAD" signal, produced synchronously with the falling edge of the "CLOCK", will trigger the registers to store the binary numbers that are present in the counters (Figure 6 (b) ).

No matter how wide the measured curve, only its left edge, shown on the monitor, can produce a rising edge on VC2. Only the X- and Y-coordinates of the curve's left edge are placed in the registers. The points being measured are the left edge of the measured curve, shown on the monitor, and must be bright enough to be detected by the video processing circuit. The width in X direction has no affect. The width, however, must be no less than one measurement unit to be detected, i.e., the width of  $1/200$  of the horizontal measurement length, this is shown clearly in figure 6 (b).

The binary numbers of the X- and Y-coordinates once stored in the registers will stay there until a second set of coordinates are stored. Only one pair of X- and Y-coordinates can be kept in this measurement system for each the horizontal scanning period (about 60 microseconds). In order to store coordinates for a complete shape, these measured data have to be output to a computer. Some examples in chapter 3 will show the procedures in detail.

## 2.4 DATA OUTPUT AND DISPLAY

This measurement device has three means for data output (Figure 7 ). First, the data may be read out to LED for direct reading. The second method outputs both X- and Y-coordinates in 16 bit DIP sockets along with a "STROBE" signal. The last method is to output one of three data sets, i.e., "READY" flag, X- or Y-coordinates, under the control of two selection bits on the multiplexer (SN74153). The selection bits appear on DI7 and DI6 pins on the input port (Figure 7 (b) ).

### 2.4.1 LED DISPLAY

In order to make sure the measurement device is working, each data bit of the registers is connected to an inverter (1/6 SN7404) and a LED. A bright lamp represents " 1 " and dark represents " 0 ". LEDs are arranged in two parallel lines, 8 bits in each line which represents the binary numbers of the X- and Y-coordinates (Figure 7 (a) ).

Under normal operating conditions, it is impossible to read the data displayed on the LED due to the rapid changes of the numbers displayed. To permit manual control, a toggle switch is used to hold the data steady. Once this switch is put in the "HOLD" position, the LED show a pair of X- and Y-coordinates as long as the switch on "HOLD". In the "GO" position, the measuring data displayed on the LED will change as fast as the scanning speed of the video signals.



### 2.4.2 X- AND Y-COORDINATES PARALLEL OUTPUT

Each data bit of the 3-state buffer output of the registers can be directly output through a 16 pin DIP socket (Figure 6 (a) ) for both of the X- and Y-coordinates. A "STROBE" signal is used to indicate that the X- and Y-coordinates data is available ( Figure 6 (b) ).

The arrangement of the 16 bit parallel output allows the computer to fetch one data pair by each input action. It should be noted that each data pair remains in the registers only for one scanning line period, so the computer must fetch them within 60 microseconds. In chapter 3, there is a flowchart of the computer program used to read the data.

### 2.4.3 MULTIPLEXER SELECTED OUTPUT

All the data bits of the registers' output port are connected to four multiplexers (SN74153). Either the X- or Y-coordinate can be put onto the 8 bit data bus, under the control of the selection bits of the multiplexer (Figure 7 (b) ).

For slow speed output of this arrangement, there is some support hardware needed (Figure 7 (a) ). A D-type flip-flop (1/2 package of SN74LS74) is used to generate the " READY " signal to inform the computer that data is available. This D type flip-flop is reset by the computer and is set by " STROBE ". Its Q output, "READY" high, holds the data in the register, (the same function as the manual switch in the "HOLD" position), until the computer command to reset it. This permits the computer to fetch one pair of X- and Y-coordinates even if the period

required is longer than the video scanning speed.

To output one of three 8 bit data sets, i.e., "READY" flag, X- and Y-coordinates, the command comes from the MSB and NMSB, i.e., DI7 and DI6 on the input port, of the input signal. The output selections are arranged as follows,

DI7	DI6	OUTPUT
1	1	X-coordinate
1	0	Y-coordinate
0	1	" READY " flag
0	0	open

To reset the " READY " flag, the "clear " pin of the D type flip-flop obtains the signal from LSB, i.e., DI0 on the input port, of the input signal.

There is an " HOLD " mode selecting switch, labeled " INT. HOLD " on one side and " EXT. HOLD " on another side. This switch is switched to " EXT. HOLD " side only in case of holding the data in registers via I/O ports command. On the other hand, " INT. HOLD " side is used to hold the data stored in registers by use of another toggle switch.

## 2.5 OPERATIONS IN WHOLE CIRCUIT

This measurement device is powered by single 5 volts power source. As soon as the video signal is fed into this device, the measurement

function in itself can follow up the scanning speed of the video signal immediately.

The timing diagram shown in Figure 8 is the timing relationships of some important signals which control the operation of this measurement device. In order to connect this device with computers, it is very important to make a best use of these control signals.

## CHAPTER 3

IMPLEMENTATION

In this chapter, both hardware and software are discussed. The function of control signals of the measurement device is described. Detailed circuit diagrams are shown in Appendix B. The basic computer programs used in device calibration are discussed in the software portion. Their flowcharts are given in this chapter and all program listings are shown in Appendix C.

3.1 HARDWARE

## 3.1.1 VIDEO SIGNAL GENERATION AND MONITOR

## A. Whitened Object and Darkened Background

In the viewing field of television camera, the whole area must be black and without reflected light. Only the measured object should be white so that it can reflect enough light into the lens to make a measurement.

The design of this measurement device is such that the points measured are on the left edge of the white detected object and the width of the object must be wider than  $1/200$  of the measured range.

The straight line arranged on the calibration plate is shown on pictures at Appendix A.

## B. Television Camera and Monitor

The pictures that show the television camera and monitor used in

this experiment are attached at Appendix A. The video signal produced by this camera is described in section 2.2.1 and Figure 2.

### C. Special Restrictions on Video Signal

Two important factors on video signal must be checked before processing with this measurement device.

#### (1) Signals level :

To assure that only the sync and image must be detected by the voltage comparators, the reference voltage to VC1 and VC2 may need adjustment. This problem was described in section 2.2.2. 0.2 volt is already set for VC1 and 1.5 volt for VC2 in this device.

#### (2) Vertical sync :

200 microseconds is the minimum pulse width of vertical sync. No equalizing or vertical serration pulse can be inserted into this sync. That is, a pure low level pulse, longer than 200 microseconds, must be used in vertical sync (Figure 2).

## 3.1.2 MEASUREMENT IMPLEMENTATION

### A. Control Signals

#### (1) VC1 and VC2 :

These signals respond to the sync and image in the video signal. They are discussed in section 2.2.2. The circuit used is drawn in Appendix B, Figure B.1.

(2) CLOCK :

This adjustable 5-MHz clock is used for X-coordinate measurement. For greater stability, a crystal-controlled oscillator may be substituted. The "CLOCK" generation circuit is shown in Appendix B, Figure B.2.

(3) LOAD :

In order to "write" down the stable data in counters, the "LOAD" signal is generated to trigger the registers. This triggering causes the registers to store the measured coordinates data on time. Its circuit is shown in Appendix B, Figure B.3.

(4) SWITCH1 :

In order to keep the output data steady, this signal is generated by a toggle switch, labeled "HOLD" and "GO" on sides. Its circuit is a latch, as shown in Appendix B, Figure B.4.

(5) SWITCH2 :

To select either "INT. HOLD" or "EXT. HOLD" control, a toggle switch is used to generate the signal, as shown in Appendix B, Figure B.5.

(6) READY :

This flag informs the outside world that the output data stored in registers are steadily available as long as "READY" is high, i.e., logic "1". Only the external command, coming from the input port DIO, can reset this flag. Its circuit is shown in Appendix B, Figure B.6.

## (7) STROBE :

In "GO" and "INT. HOLD" mode, a new image's coordinates are available for output as soon as the rising edge of "STROBE" flag arrives. Its timing diagram is shown in Figure 8. And its circuit is shown in Appendix B, Figure B.7.

## B. Measurement

## (1) In X-coordinate

The circuit diagram including counters, registers and all control signals is shown in Appendix B, Figure B.8.

## (2) In Y-coordinate

This circuit diagram also includes counters, registers and all control signals. It is shown in Appendix B, Figure B.9.

## 3.1.3 DATA OUTPUT IMPLEMENTATION

## A. LED Display

The binary outputs of X- and Y-coordinates can be displayed by use of the LED's. The bright is "1" and the dark is "0". This circuit is shown in Appendix B, Figure B.10.

## B. I/O Ports

To output an 8 bit data and input the external command, the circuit diagram is shown in Appendix B, Figure B.11.

## 3.2 SOFTWARE

### 3.2.1 DATA ACQUISITION

#### A. By "EXT. HOLD" control

In order to hold the output data steadily for a time period that the computer can completely read them, the "EXT. HOLD" control must be used. The computer can acquire the coordinates data via either 16 bits data output port or multiplexers 8 bits data output port. The command given by the computer program enters the input port on this measurement device.

An 8080-based microcomputer, shown in Appendix A, has been used to calibrate this measurement device by using of basic programs. The one used only for data acquisition is called DATALIST. It reads the X- and Y-coordinates via multiplexer selected output port. Its flowchart is shown in figure 9 and program listing in Appendix C.

#### B. Using "STROBE" Flag

As long as the output data is not held by control signal, the rising edge of the "STROBE" flag informs the outside world that a new pair of X- and Y-coordinates data is presently available. This feature can give the computer a good data acquisition method. For instance, the "INTERRUPT" or "LOAD" instructions of 8080 microprocessor can be used, with some minor hardware arrangement, to read the data via the 16 bits data output port. These method are faster and more efficient than those discussed in last section. But one important restriction must be emphasized again, any new pair X- and Y-coordinates data stay in the



the registers for only about 60 microseconds if no "HOLD" control is used. The computer operation speed, therefore, should be evaluated for using "STROBE" flag.

A simple "INTERRUPT" flowchart (Figure 10) is shown as an example to use the "STROBE" flag.

### 3.2.2 DATA MANIPULATION

#### A. Consecutive Y-coordinates

If the computer can read the coordinates output fast enough so that all the detected points on the measured curve can be recorded in one video frame scanning, then the Y-coordinates data are consecutive integers. These data can be manipulated easily for shape comparison.

To demonstrate the feature of coordinates transformation, a program flowchart is shown in figure 11. It must be noted that this program can only be used in the acquisition of consecutive Y-coordinates.

For slow data fetching, the Y-coordinates read will not be consecutive integers. The treatment of nonconsecutive Y-coordinates is discussed in the next section.

#### B. Nonconsecutive Y-coordinates

The slower data fetching, the fewer coordinates be recorded in each video frame. The 8080-based microcomputer used for calibration could not operate fast enough to give us the consecutive Y-coordinates data in each video frame scanning. A number of pairs of X- and Y-coordinates

must be collected first and then analysed. Five basic programs are used to calibrate this measurement device. Their flowcharts are shown in Figure 12 and 13. And the program listings are given in Appendix C. The major functions of these programs in data manipulation are discussed in following.

(1) Program DATALIST

This is a simple program to read the data from the 8 bits output port of the measurement device and also to print them onto the CRT.

(2) Programs DATADRAW-90 and DATADRAW-45

To check the linearity of the measurement with respect to the measured line, these two programs are used to convert the coordinates data into a plot on the CRT. The extension 90 and 45 means the vertical and 45 degrees decline line respectively. The flowchart is given in figure 12 and the program listings in Appendix C.

(3) Programs ANALYSIS-90 and ANALYSIS-45

These two programs analyse 800 pairs of X- and Y-coordinates by rearranging them into the consecutive Y-coordinates and calculating the average of each X-coordinates. The results of the analysis data are stored into the disk for accurate calibration. The flowchart is given in Figure 13 and the program listings in Appendix C.

## CHAPTER 4

EVALUATION4.1 EXPERIMENTAL APPARATUS

## (1) Calibration plate

This plate has 25 pin holes on it. 5 holes are in each row and column and 2 inches apart ( Appendix A, Figure A.1 ). The hole pitch accuracy of this plate is 1 mil., i.e., 0.0254 mm.

## (2) TV Camera and Monitor

TV Camera: Solid State TV Camera, HV-50, LA-4102

SHIBA ELECTRIC CO., LTD.

TV Camera Controller: HV-50U

Video Monitor: 12-inch, Black and White.

( Shown in Appendix A, Figure A.2 )

## (3) 8080-Based Microcomputer

PolyMorphic 8800 series with CRT display ( Appendix A, Figure A.3 ).

## (4) Measurement device

The IC board is shown in Appendix A, Figure A.4.

## (5) Layout

The distance between television camera and the calibration plate is 7.5 inches. ( Appendix A, Figure A.5 )

#### 4.2 CALIBRATION PROCEDURE

- (1) Experimental setup: Shown as Figure 14.
- (2) Adjust the video sync detector: See section 2.2.
- (3) Adjust the image detector: See section 2.2.
- (4) Measurement data calibration: Described as following.

#### 4.3 RESULTS

##### 4.3.1 LINEARITY IN Y DIRECTION

Analysis of the experimental data (Appendix A, Table A.1), the linear measurement, comparing with its resolution, in the Y direction is apparent. The scale factor in Y-coordinate,  $R(Y)$ , is calculated in Figure 15. The difference between measured and actual value is smaller than 0.45 percent (Figure 16 and 17).

##### 4.3.2 LINEARITY IN X DIRECTION

The experimental data (Appendix A, Table A.1) can be used to calculate the scale factor in X-coordinate,  $R(X)$ , within the test area (Figure 18 and 19). By repeating this test procedure across all the viewing field of camera, the linearity in X-coordinate can be determined.

#### 4.4 DISCUSSION OF EXPERIMENTAL RESULTS

##### 4.4.1 SCALE FACTOR

The scale factor is the ratio of the image size to the size of measured object. A different distance between television camera and measured object requires a different scale factor. A different lens on TV camera would produce the same result as well.

Comparing the results of Figure 17 and 19, we can find two scale factors.

$$R(Y) = 1 \text{ mm/LSB of Y-coordinate}$$

$$R(X) = 47/51 \text{ mm/LSB of X-coordinate}$$

Since

$$P_n = \frac{\Delta X_a}{\Delta X_m} P_o$$

Where  $P_o$  = Period of 5-MHz "CLOCK" = 200 nanoseconds

$\Delta X_a$  = Actual difference in X-coordinate.

$\Delta X_m$  = measured difference in X-coordinate.

We can get the new "CLOCK" period,  $P_n$ , which forces the scale factor in X-coordinate,  $R(X)$ , equal to that in Y-coordinate,  $R(Y)$ , and hence both of them are equal to 1.

Any combination of the length scale and layout can be used in this system as long as the scale factor was previously found.  $R(Y)$  depends on the system layout, whereas  $R(X)$  can be adjusted to any convenient constant.

#### 4.4.2 STABLE MEASUREMENT

For a long period of operation, six hours in this experiment, the output data of the measurement device are extremely stable.

To obtain a good measurement requires two important items, a high quality TV camera to pick up the image of the measured object, and a suitable video signal.

#### 4.4.3 NON-CONSECUTIVE Y COORDINATES

In this experiment, 800 pairs of X- and Y-coordinates were sampled at random times by the program "ANALYSIS". These coordinates are rearranged by grouping the same Y-coordinates and calculating the average value of the X-coordinates. Three sets of results from this procedure are listed in Appendix A, Table A.1. One aspect of this sampling procedure is that some Y-coordinates are lost. Also the number of X-values which form the average is not the same for each Y-coordinate.

#### 4.4.4 DISTORTION

Some distortion of the image displayed on the monitor was observed. This distortion of the video signal made it difficult to discuss the exact linearity of measurement system.

There were two kinds of video distortion observed in this experiment. First one is the round image which comes from a right angle corner of the measured object. This is caused by the inherent non-linearity of the signal conversion of the TV camera been used. The other distortion is the image split which comes from the malfunction of sync generation of TV camera controller.

#### 4.4.5 RESOLUTION

Although the resolution of this video-measuring system is always  $1/200$  of measured range in each X- and Y-directions, the measured range can be selected by rearranging the image. Therefore, the resolution

of the measurement of the object will be changed, also.

#### 4.4 6 POTENTIAL IMPROVEMENT

In order to store the X- and Y-coordinates covering the entire measured curve, without depending upon the operation speed of the computer, it would be convenient to add 200 bytes RAM to this measurement device. Y-coordinates would be used as the addresses of memory in which to store the X-coordinates corresponding to the former. Then the measurement device could automatically store all the coordinates measured into the RAM for one video frame scan. The computer could then read them without any timing restrictions.

## CHAPTER 5

ADVANTAGES, LIMITATIONS, AND EXTENDED APPLICATIONS5.1 ADVANTAGES

This measurement device provides several advantages over general measurement systems. The major advantages such as its speed, resolution and non-contact features will be described in following.

## 5.1.1 MEASURING SPEED

This system's most obvious and important advantages over presently used methods are the speed of its measurement. The complete curve coordinates, up to 200 points, can be measured 60 times per second.

## 5.1.2 RESOLUTION

Another advantage of the video-measuring system over other similar measuring systems lies in its resolution determined by the size of the image. Increasing resolution can easily be achieved in this video-measuring system by magnifying the image through an appropriate lens on the television camera.

## 5.1.3 NON-CONTACT MEASUREMENT

One of important advantages of this video-measuring system is remote and non-contact measurement. This feature offers considerable convenience for selecting the measuring position. In addition, the device can stand far away from a dangerous environment and keep its measurement accurate for a long operation period.



## 5.2 LIMITATIONS

The video-measuring system is not without limitations. There are both inherent limitations which are caused by video signals and some special limitations caused by specific hardware design.

### 5.2.1 LIGHTING

The primary limitation of the video-measuring system is that the object to be measured must necessarily be lighter than any other point in its background. Technically, voltage comparators are minimally sensitive to a difference of approximately 4 to 5 millivolts between their inputs. This represents the magnitude of the difference between the measured object's brightness and its background level. The variable background levels of light and the noise signal in the video signal, therefore, create detection problems. It is, therefore, necessary to check the video signal levels to obtain proper information.

### 5.2.2 MAXIMUM MEASURING SPEED

Although the measuring speed of this video-measuring system is faster than that of other systems, there still is a maximum limit. It should be noted that the 60-Hz video-scan rate is both the maximum and the minimum rate to measure all the points coordinates on the measured curve. This is a special inherent limitation in the hardware.

### 5.2.3 DATA STORAGE

In this measurement device, only one 8 bit data register is used for each X- and Y-coordinate, i.e., only one pair of X- and Y-coordinate can be stored in this system. It should be noted that measured X- and

Y-coordinates follow the video scanning position. The most recently measured data substitutes itself for the previous one. So it is necessary to read and store all the measured data into the memory of computer. This limitation is caused by hardware design of the measurement device which is relatively simple and cheap, i.e., money can cure this limitation.

#### 5.2.4 MEASUREMENT APPLICATION

This measurement device is specially designed to measure the X- and Y-coordinates of a two dimensional shape. It performs this function by detecting the position of the left edges of a light image. The horizontal width of the light image cannot be measured without changing the design of the device. This additional function could be accommodated by additional hardware.

### 5.3 EXTENDED APPLICATIONS

This measurement system represents an initial developmental stage and, with some minor modifications, could perform additional tasks. Some special suggestions are discussed in following.

#### 5.3.1 THREE-DIMENSIONAL MEASUREMENT

The three-dimensional coordinates could be arranged to measure by positioning a mirror next to the measured object at a proper angle to provide the camera with a side view of the object. This modification would require both control of the television camera and some programming changes.

### 5.3.2 TIME-SHARING MEASUREMENT

Having powerful measurement speed, several measurement systems that don't need such fast measuring speed can alternately share this measurement device. Multiple video signals could be selectively fed into this measurement device by an analog multiplexer. This modification would require a program to separate and store coordinates measured for each different measurement system.

### 5.3.3 COMPUTER VISION SYSTEM

Using the television camera as the system's "eye", the computer, combined with our measurement device, becomes a "seeing" computer which can perform measurement, inspection and decision making functions. This kind of application is useful to the automation industry, to inspect parts. They can serve as eyes for robots, making possible automatic part transfer and assembly. They can reliably perform difficult assembly-line tasks. And they withstand hazardous environments. (Ref. 3)

## CHAPTER 6

CONCLUSION

Having a powerful measurement speed and adequate resolution, this newly developed measurement device is a instrument for measuring the shape of a two dimensional curve. This device can automatically convert video signals into 8 bit X- and Y-coordinates of a sufficiently lighted curve within the field of view of the television camera. The function of this measurement device is specially designed for measuring the shape of the deformed sheet of metal in a brake bending process. The applicability of the device, therefore, must be considered if other conditions used.

## REFERENCES

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2. Hill, F.J., and Peterson, G.R., "Introduction to Switching Theory and Logical Design," Second Edition, pp. 213-217, 1974.
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5. Lubinski, K.S., Dickson, K.L., and John Caerns, Jr., "Microprocessor-Based Interface Converts Video Signals for Object Tracking," Computer Design, Dec., 1977.
6. Texas Instruments Incorporated, "The TTL Data Book for Design Engineers," Second Edition, 1976.
7. Zworykin, V.K., and Morton, G.A., "Television," Second Edition, 1954.

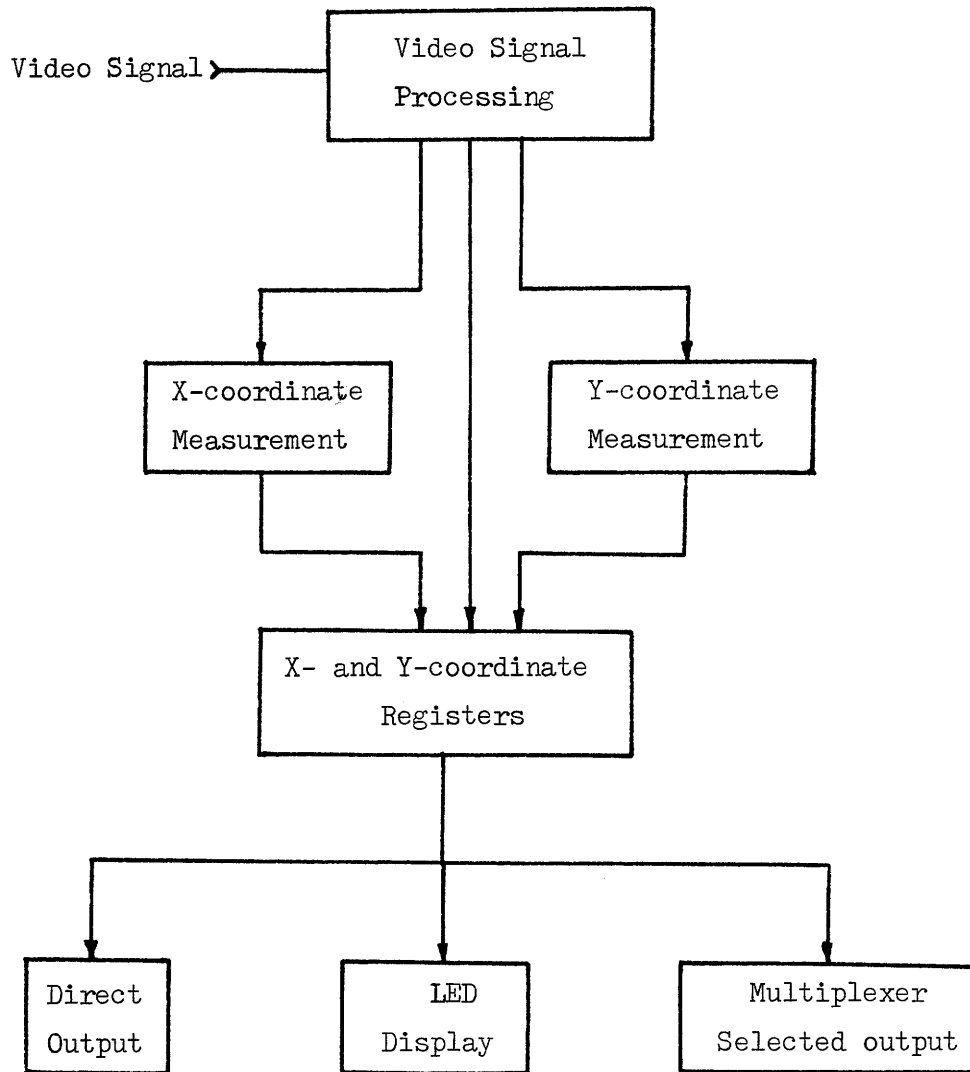
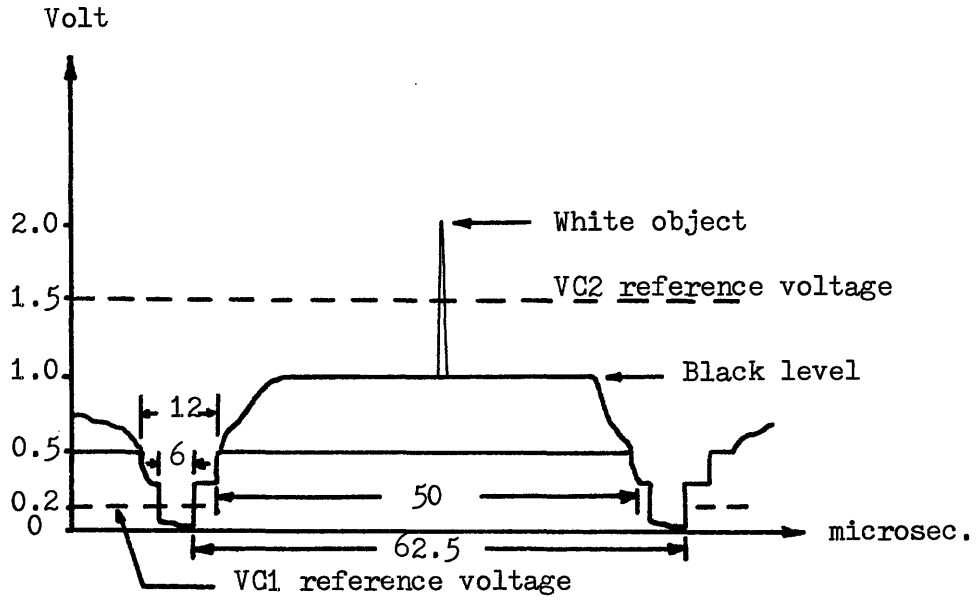
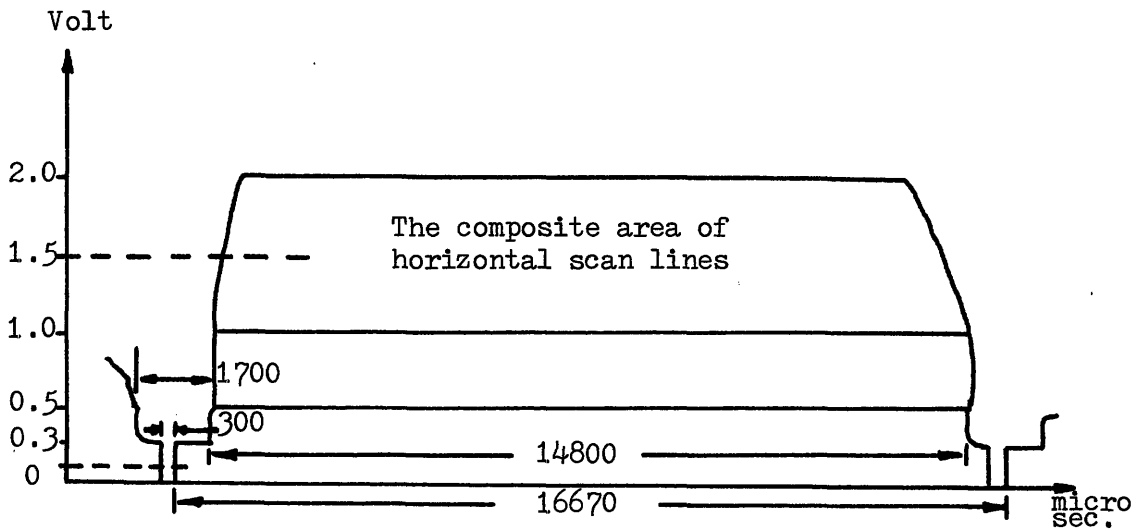


FIGURE 1 SCHEMATIC DIAGRAM OF THE MEASUREMENT DEVICE

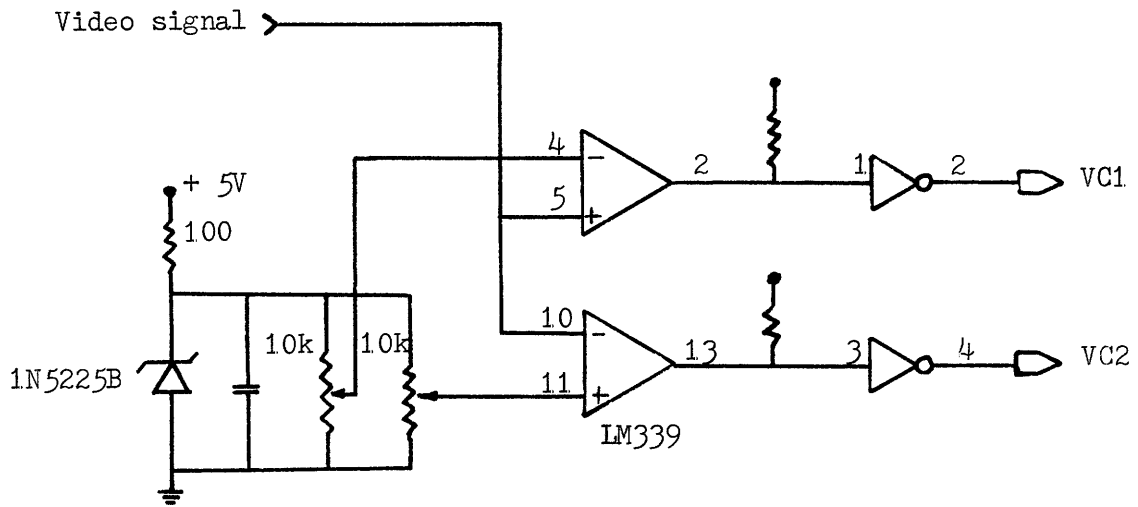


(a) ONE HORIZONTAL SCAN LINE

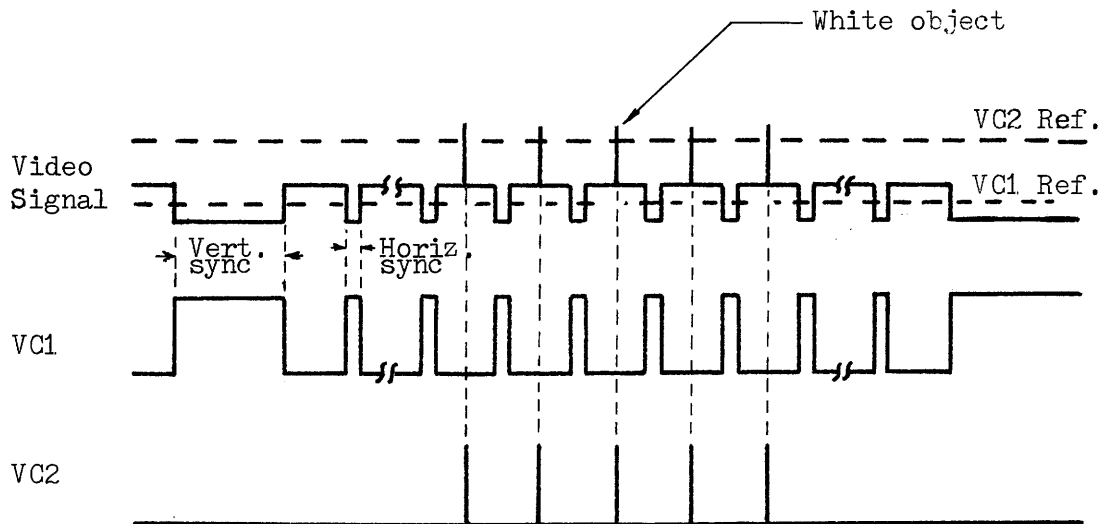


(b) ONE FIELD SCAN

FIGURE 2 TYPICAL VIDEO SIGNALS USED IN THIS EXPERIMENT



(a) CIRCUIT



(b) TIMING DIAGRAM (not to scale)

FIGURE 3 CIRCUIT TO GENERATE VC1 AND VC2 AND TIMING DIAGRAM



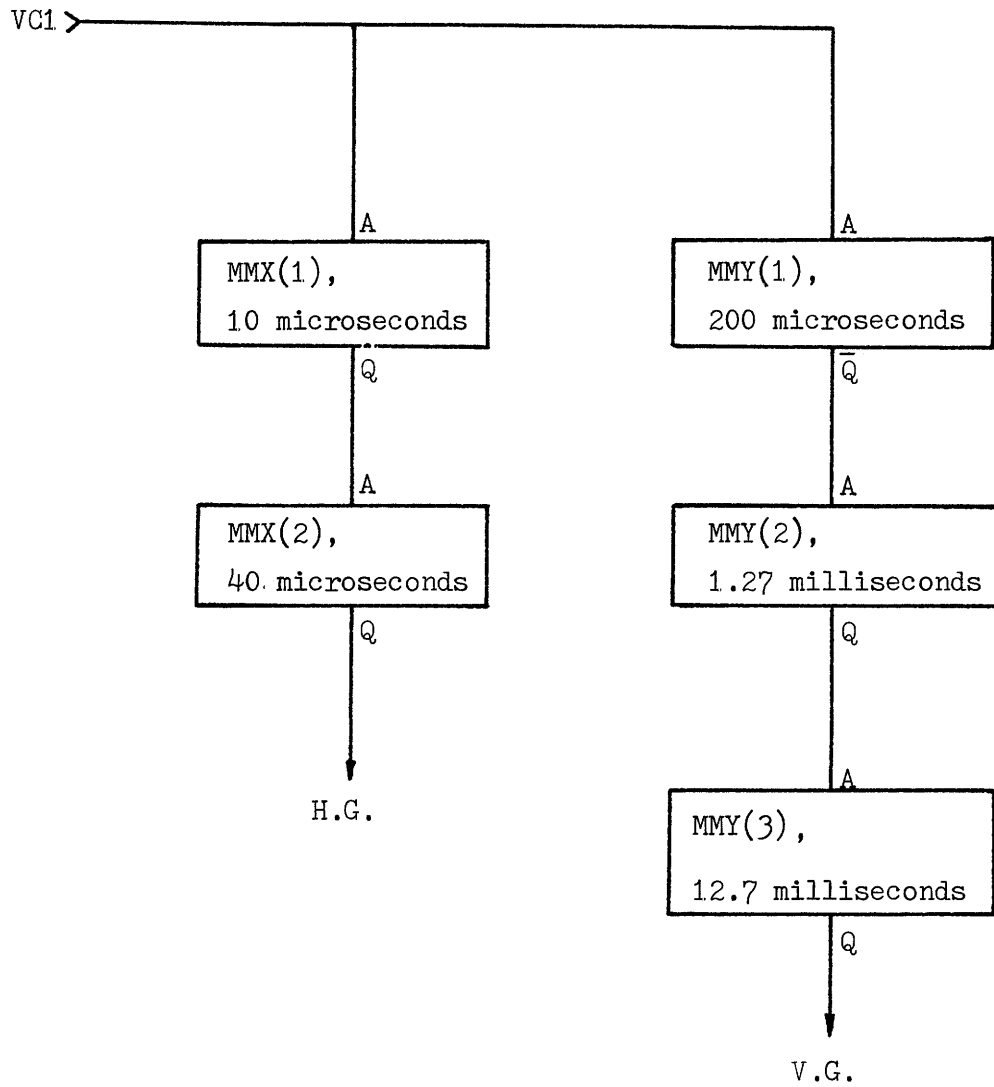
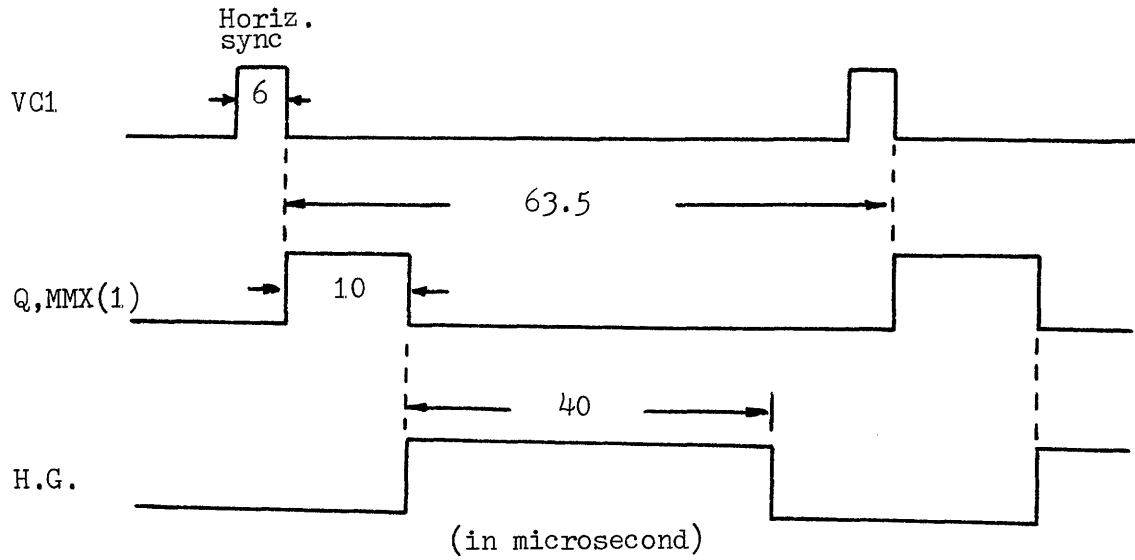
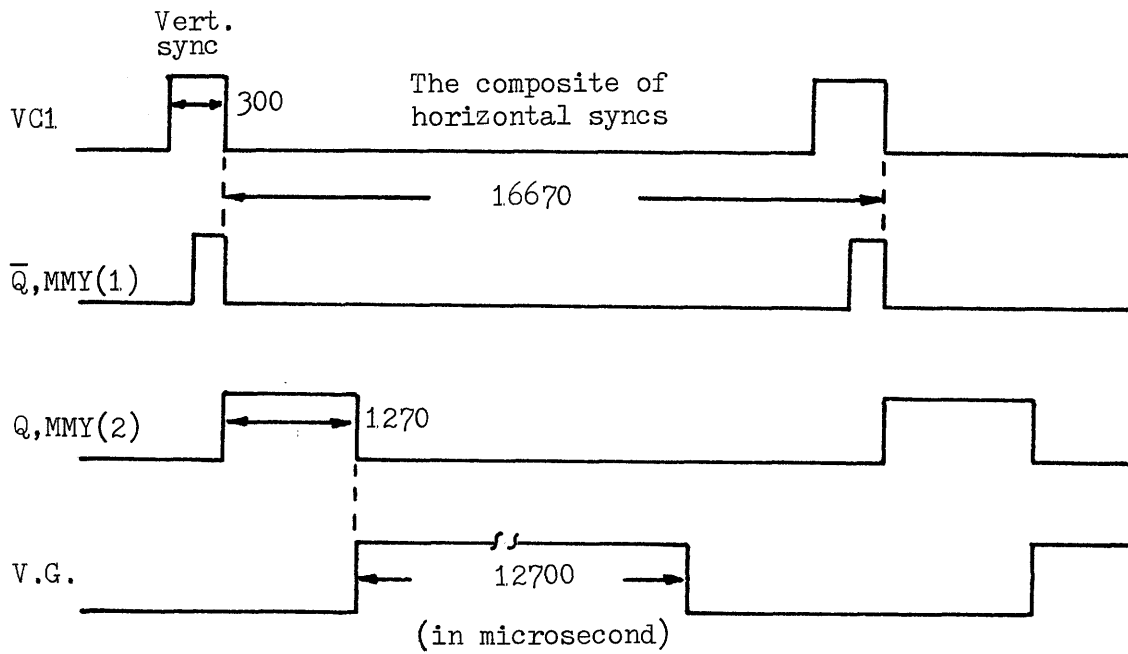


FIGURE 4(a) SCHEMATIC OF HORIZONTAL GATING AND VERTICAL GATING SIGNALS. (H.G. AND V.G.)

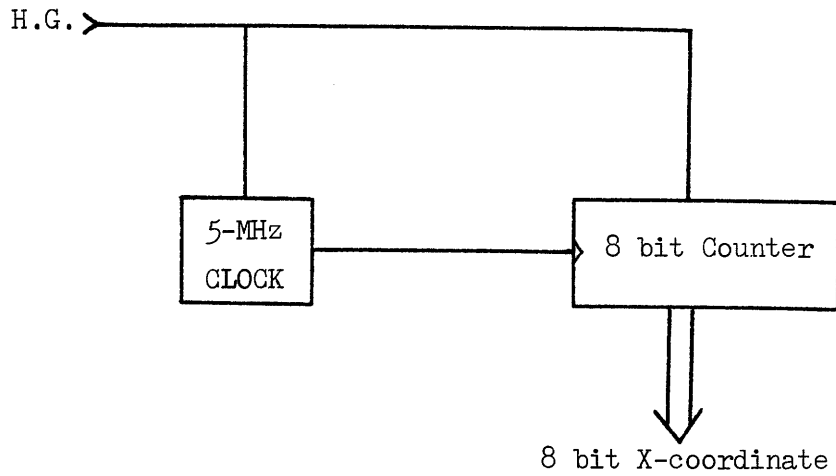


(b) TIMING DIAGRAM OF HORIZONTAL GATING SIGNAL ( H.G.)

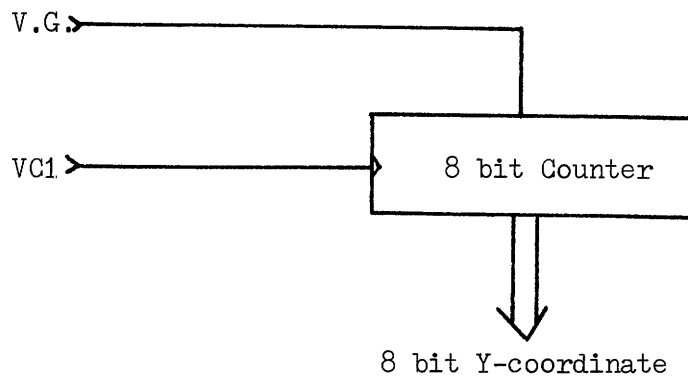


(c) TIMING DIAGRAM OF VERTICAL GATING SIGNAL ( V.G.)

FIGURE 4 GENERATION OF HORIZONTAL AND VERTICAL GATING SIGNALS

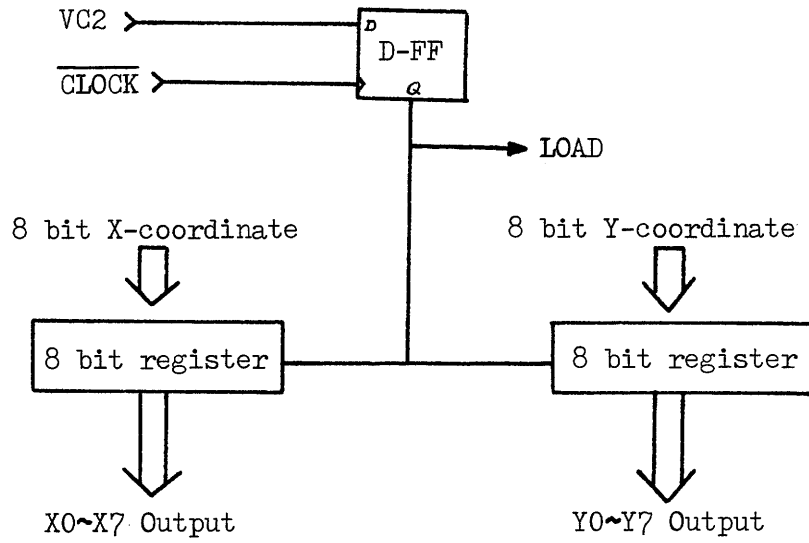


(a) X-COORDINATE MEASUREMENT

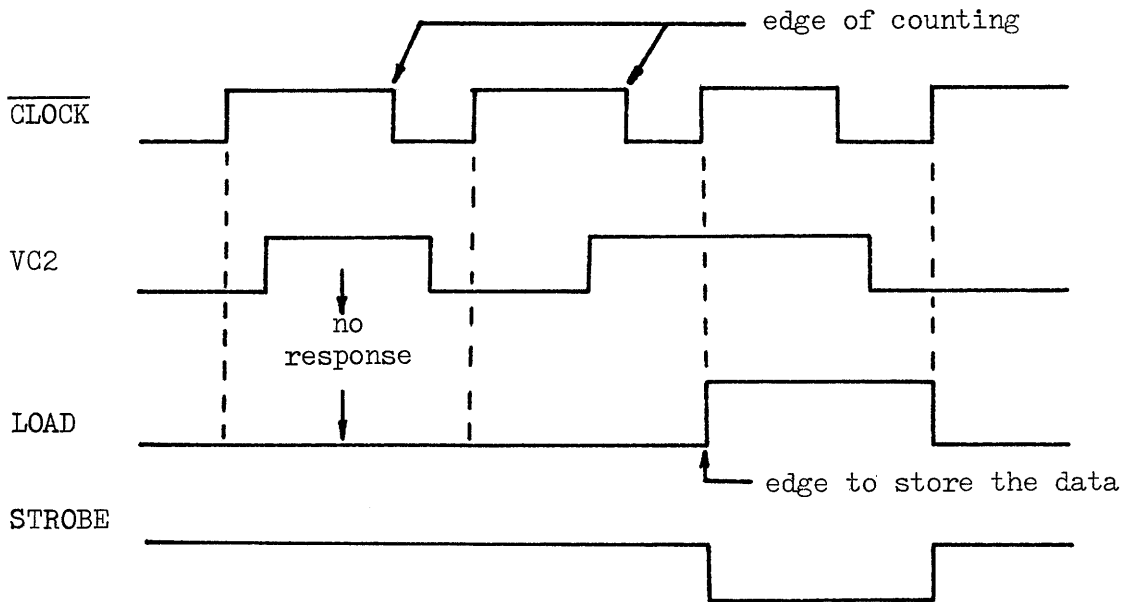


(b) Y-COORDINATE MEASUREMENT

FIGURE 5 THE X- AND Y-COORDINATE COUNTERS

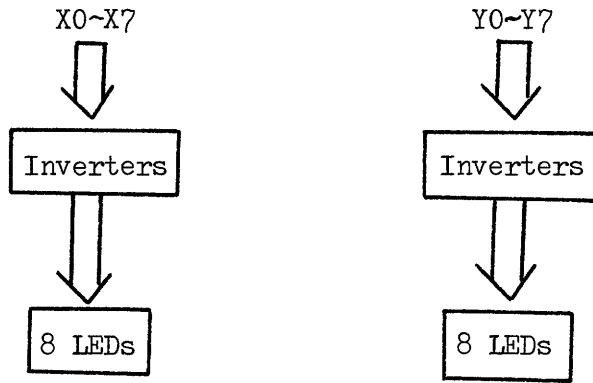


(a) STORING THE X- AND Y-COORDINATE DATA

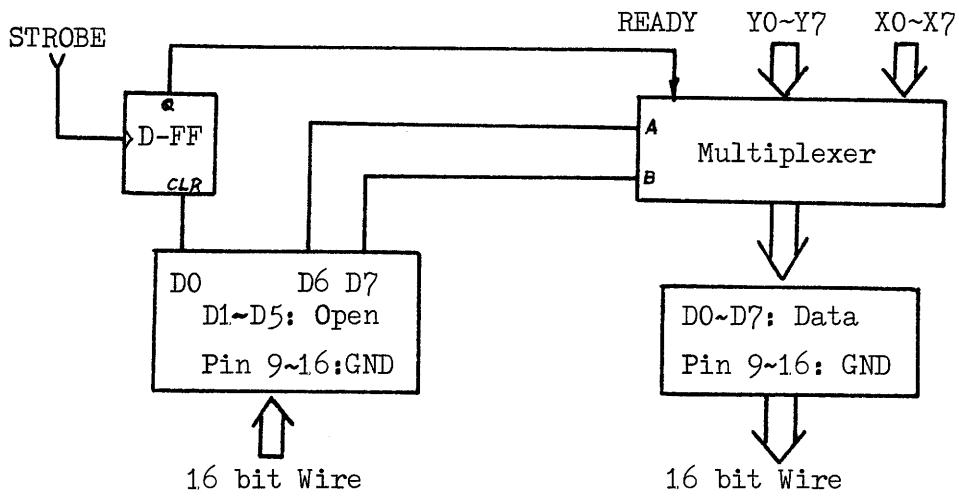


(b) SYNCHRONIZED "LOAD" TIMING DIAGRAM

FIGURE 6 THE X- AND Y-COORDINATE REGISTERS



(a) LED DISPLAY



(b) MULTIPLEXER SELECTED OUTPUT AND I/O PORTS

FIGURE 7 DATA OUTPUT ARRANGEMENT

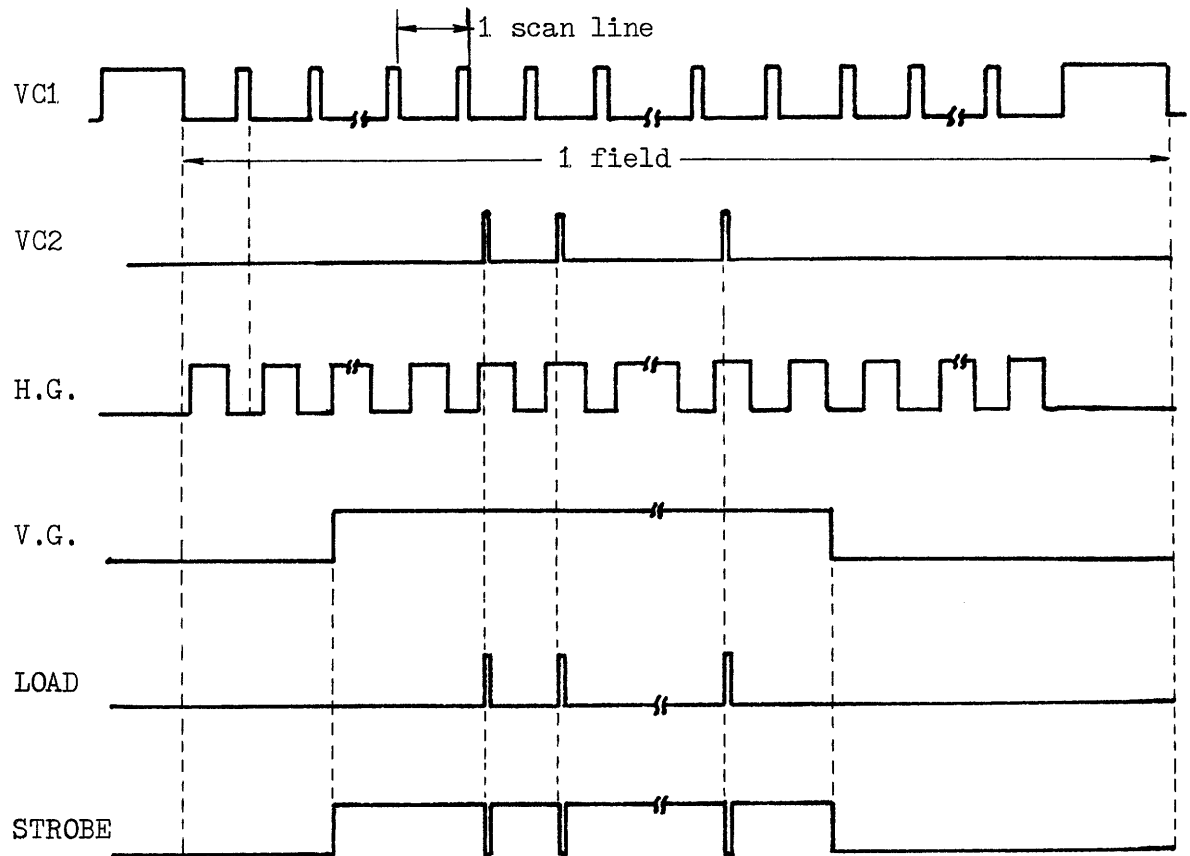


FIGURE 8 THE TIMING DIAGRAM OF IMPORTANT SIGNALS

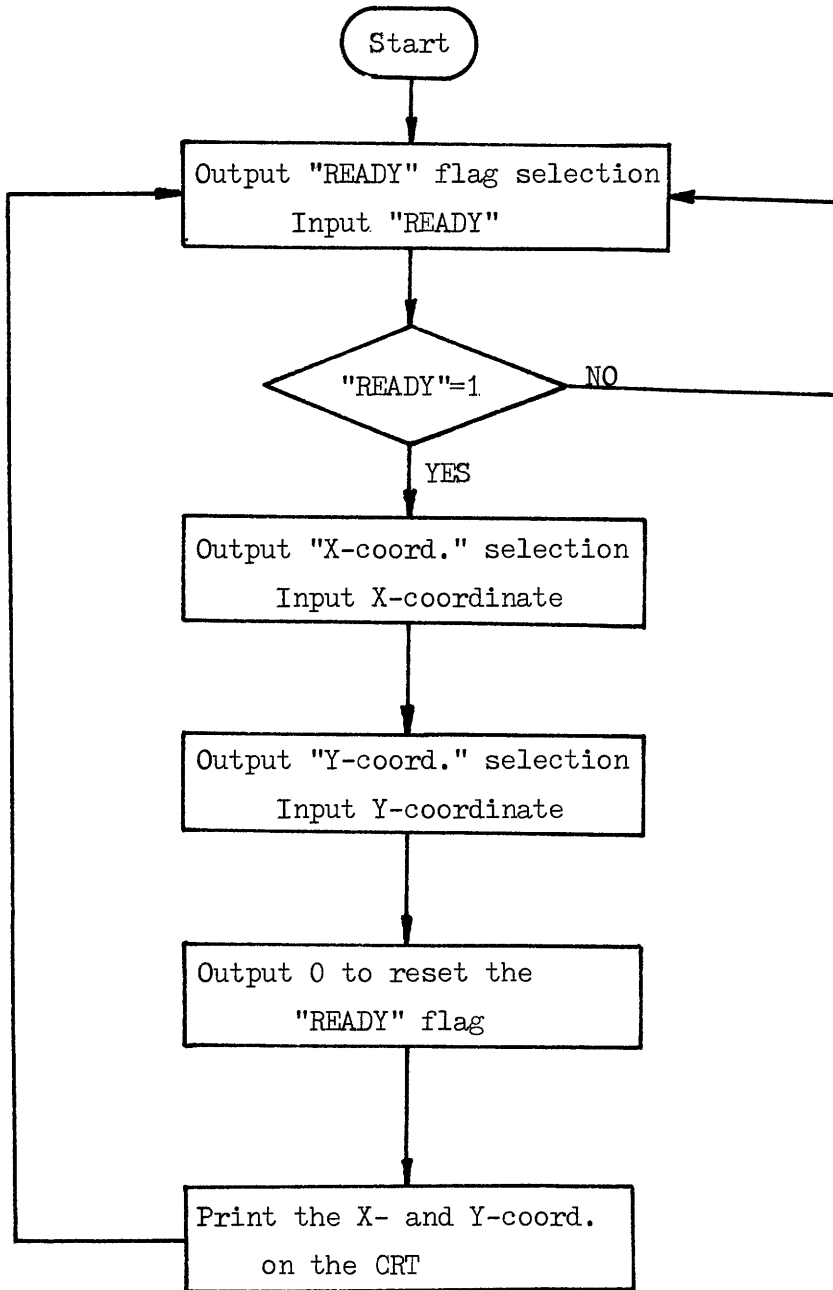


FIGURE 9 THE PROGRAM FLOWCHART OF READING THE X- AND Y-COORDINATES

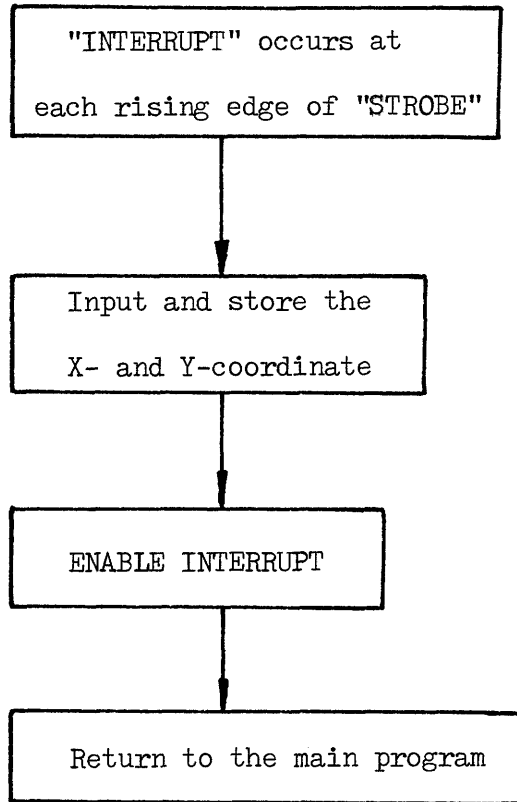


FIGURE 10 THE "INTERRUPT" SUBROUTINE FLOWCHART



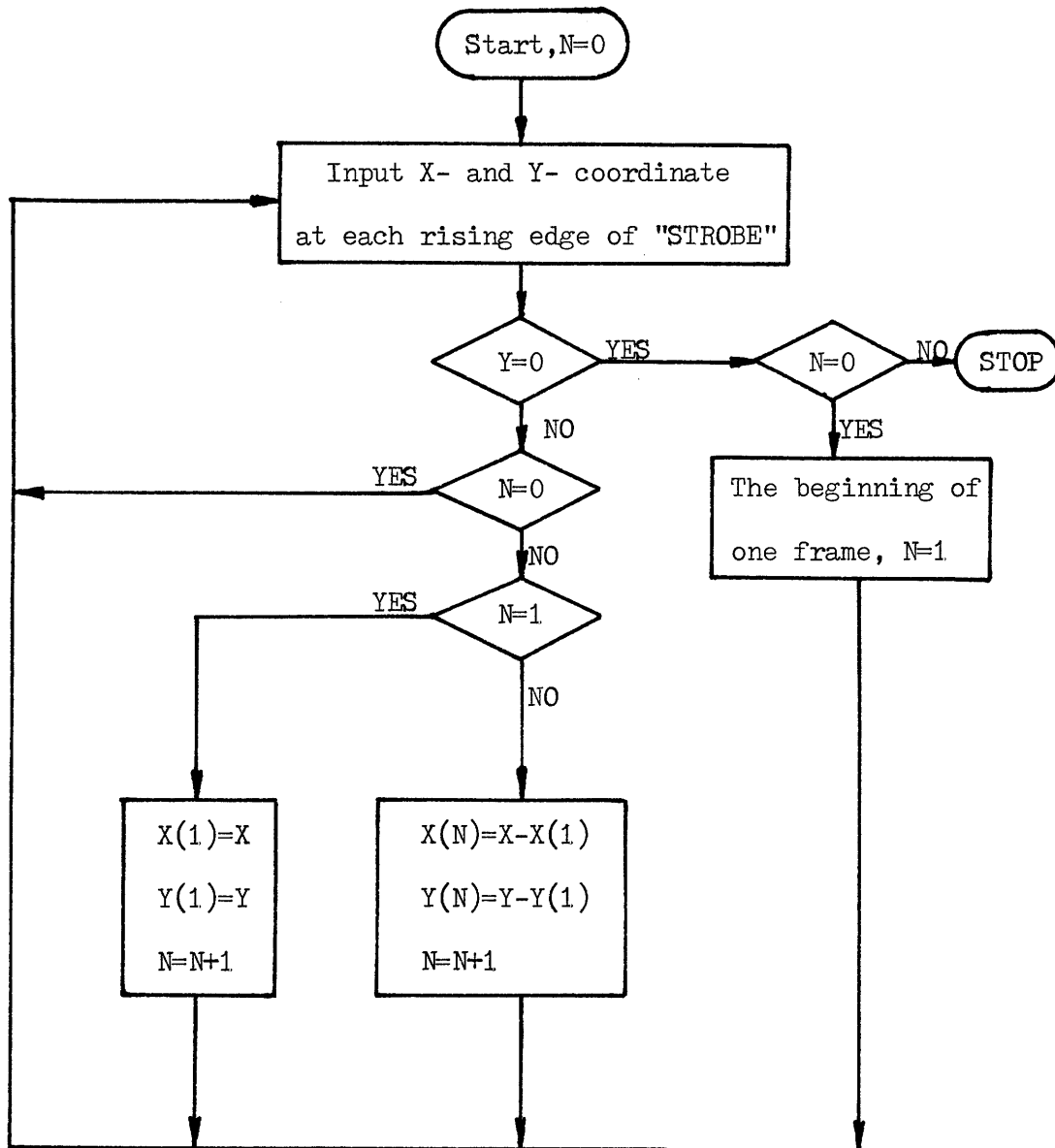


FIGURE 11 THE PROGRAM FLOWCHART OF THE COORDINATES PARALLEL TRANSFORMATION

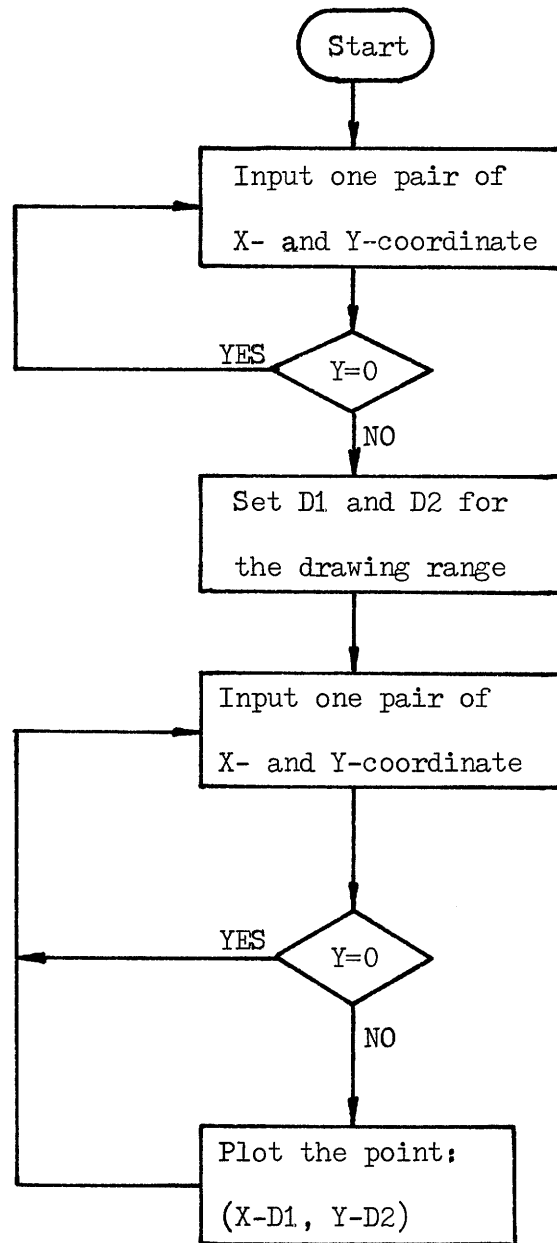


FIGURE 1.2 THE FLOWCHART OF "DATADRAW" PROGRAM

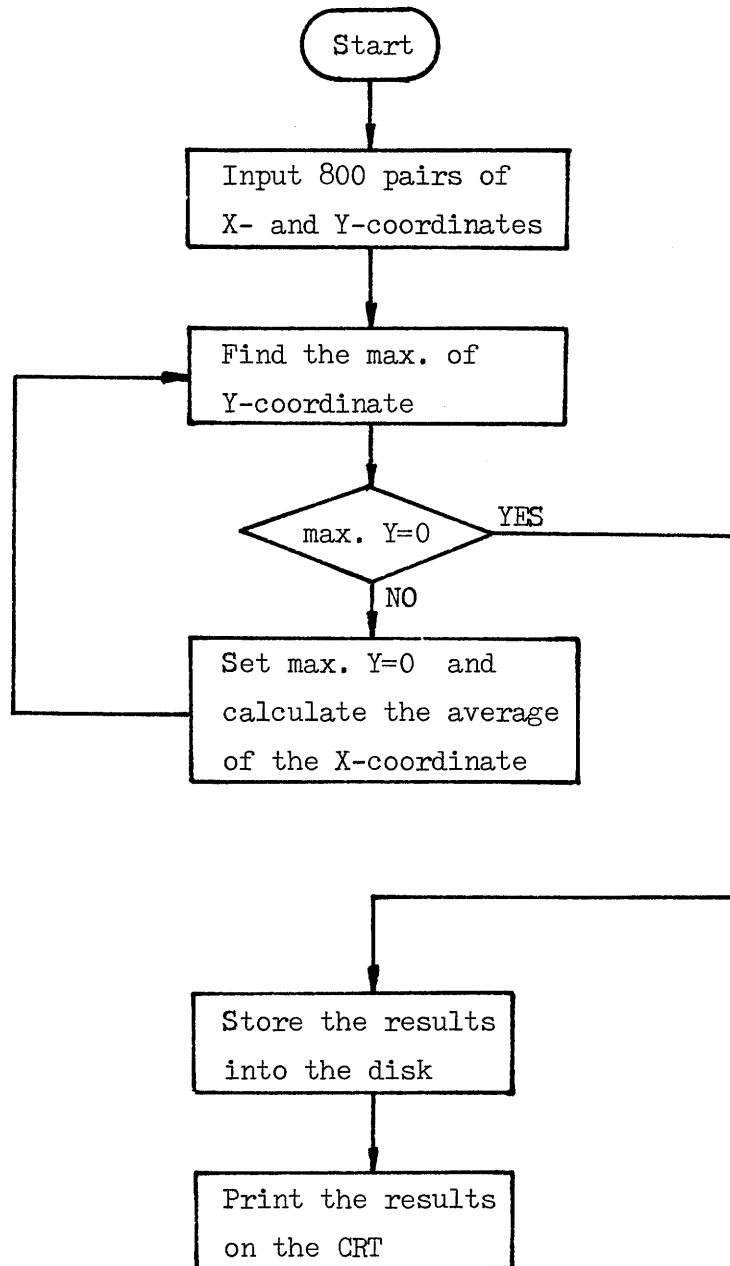


FIGURE 13 THE FLOWCHART OF "ANALYSIS" PROGRAM

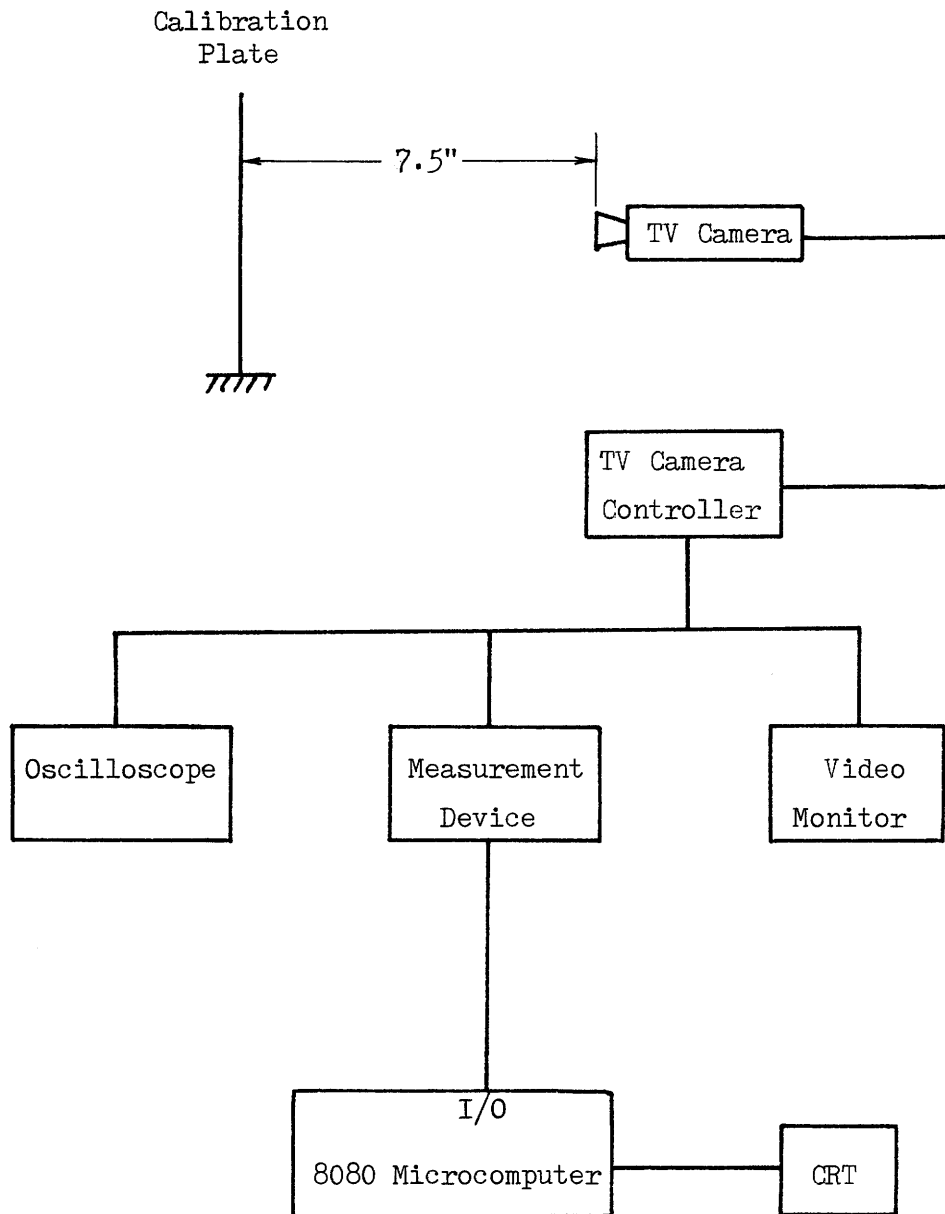
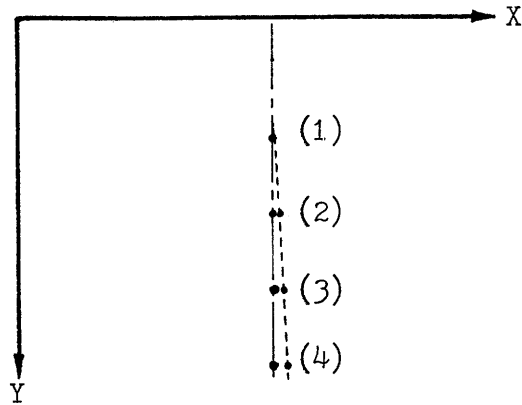


FIGURE 14 EXPERIMENTAL SETUP



	Actual position		Measured position	
	X	Y	X	Y
(1)	99	5	99	25
(2)	99	55	100	75
(3)	99	106	102	126
(4)	99	156	105	176

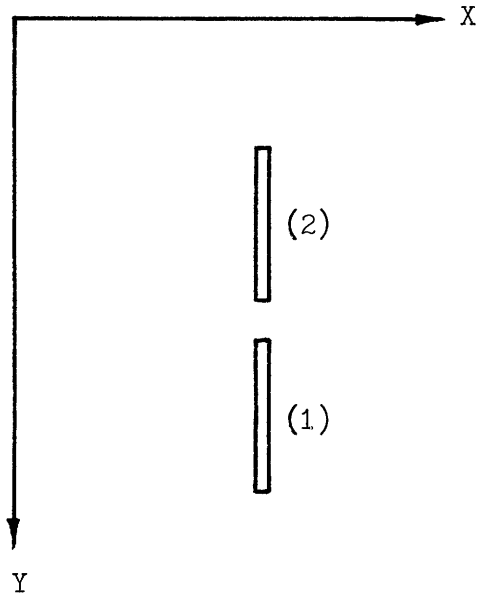
$$R(Y) = \frac{\Delta Y_m}{\Delta Y_a}$$

$$R(Y)_{1-2} = \frac{75 - 25}{55 - 5} = 1$$

$$R(Y)_{2-3} = \frac{126 - 75}{106 - 55} = 1$$

$$R(Y)_{3-4} = \frac{176 - 126}{156 - 106} = 1$$

FIGURE 15 CALCULATION OF THE SCALE FACTOR IN Y-COORDINATE,  $R(Y)$ .



Actual position (1)

X= 99 mm

Y= 105-145 mm

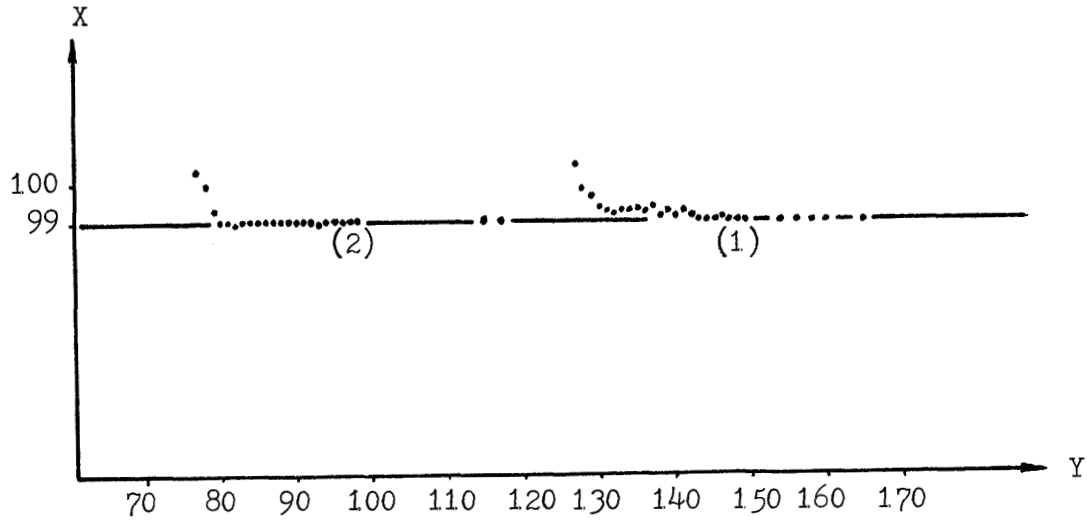
Actual position (2)

X= 99 mm

Y= 55-95 mm

Measured position ( See Appendix A, Table A.1 )

FIGURE 16      ACTUAL POSITION OF THE MEASURED OBJECTS



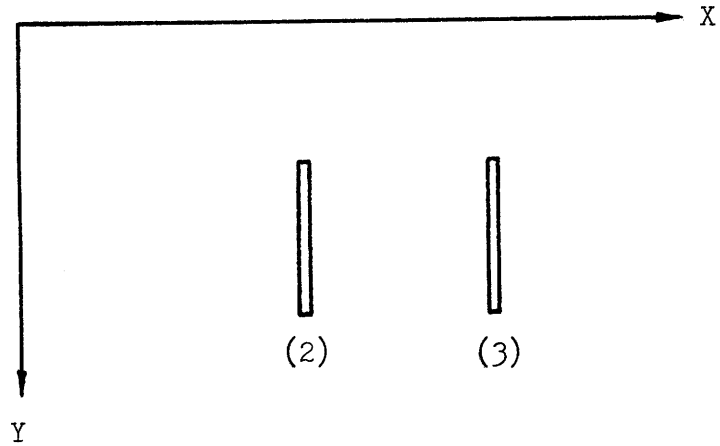
Actual position ( Figure 16 )

Measured position ( Table A.1 )

$$\text{Maximum offset} = \frac{99.444 - 99}{99} = 0.0045$$

Note that the maximum offset is calculated from 99.444 which is the maximum deviated measurement in the central region.

FIGURE 17      COMPARISON OF THE ACTUAL POSITION AND  
MEASURED POSITION



Actual position (2)

X = 99 mm

Y = 55-95 mm

Actual position (3)

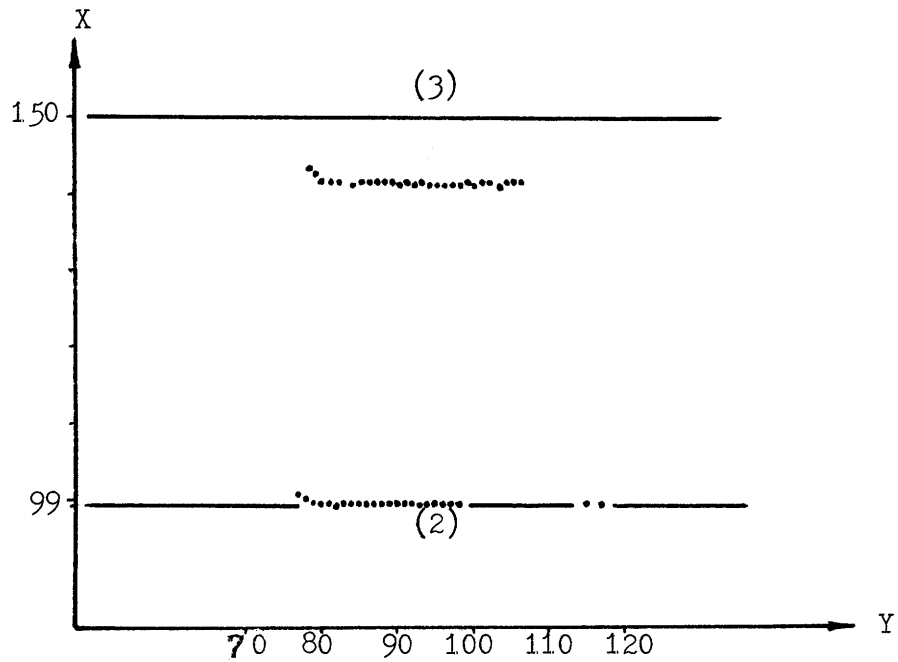
X = 150 mm

Y = 55-95 mm

Measured position ( See Appendix A, Table A.1 )

FIGURE 18 ACTUAL POSITION OF THE MEASURED OBJECTS





Actual position ( Figure 18 )

Measured position ( Table A.1 )

$$R(X) = \frac{\Delta X_m}{\Delta X_a} = \frac{146 - 99}{150 - 99} = 47/51$$

$$\text{Maximum offset} = \frac{99.444 - 99}{99} = 0.0045$$

FIGURE 19      COMPARISON OF THE ACTUAL POSITION AND  
MEASURED POSITION

APPENDIX A

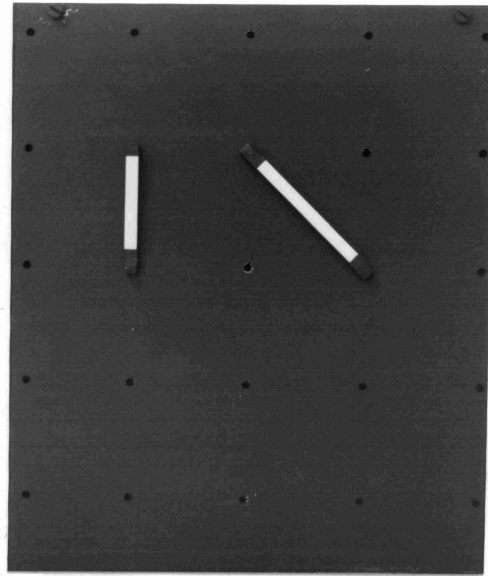


FIGURE A.1 CALIBRATION PLATE



FIGURE A.2 TV CAMERA AND MONITOR



FIGURE A.3 MICROCOMPUTER AND CRT

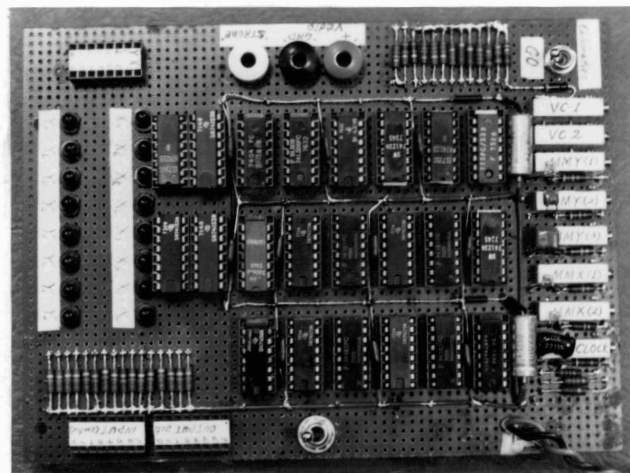


FIGURE A.4 MEASUREMENT DEVICE

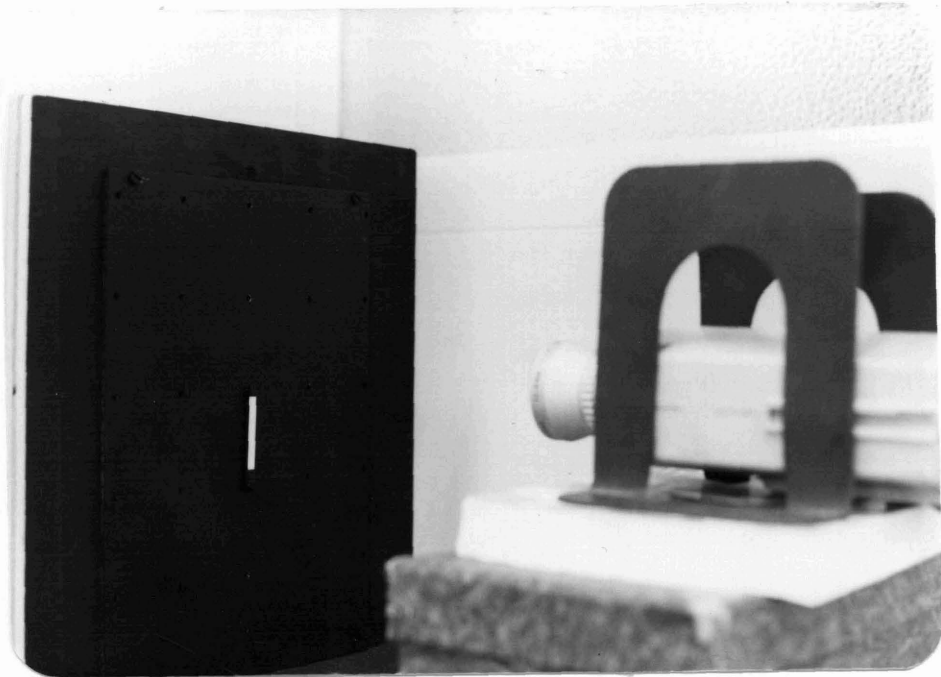


FIGURE A.5 LAYOUT OF TV CAMERA AND CALIBRATION PLATE

Measured position (1),		Measured position (2),		Measured position (3)	
X <sub>ave.</sub>	Y	X <sub>ave.</sub>	Y	X <sub>ave.</sub>	Y
100	165	99	117	146	106
99	160	99	115	146	105
99	158	99	98	146	104
99	156	99	97	145.89	103
99	154	99	96	146	102
99	150	99	95	146	101
99	149	99	94	145.8	100
99	148	98.875	93	146	99
99	147	99	92	145.91	98
99.125	146	99	91	145.92	97
99	145	99	90	145.9	96
99	144	99	89	145.83	95
99	143	99	88	145.875	94
99.1428	142	99	87	146	93
99.428	141	99	86	145.94	92
99.1428	140	99	85	146	91
99.333	139	99	84	145.94	90
99.125	138	99	83	146	89
* 99.444	137	98.945	82	146	88
99.333	136	99	81	146	87
99.385	135	99	80	146	86
99.333	134	99.267	79	146	85
99.285	133	100.206	78	145.875	84
99.182	132	100.958	77	146	82
99.375	131			146	81
99.444	130			146	80
99.833	129			146.73	79
100	128			147.04	78
100.697	127				

\* : The data used in calculation of the max. offset

TABLE A.1 EXPERIMENTAL MEASURED POSITION

APPENDIX B  
CIRCUIT DIAGRAM

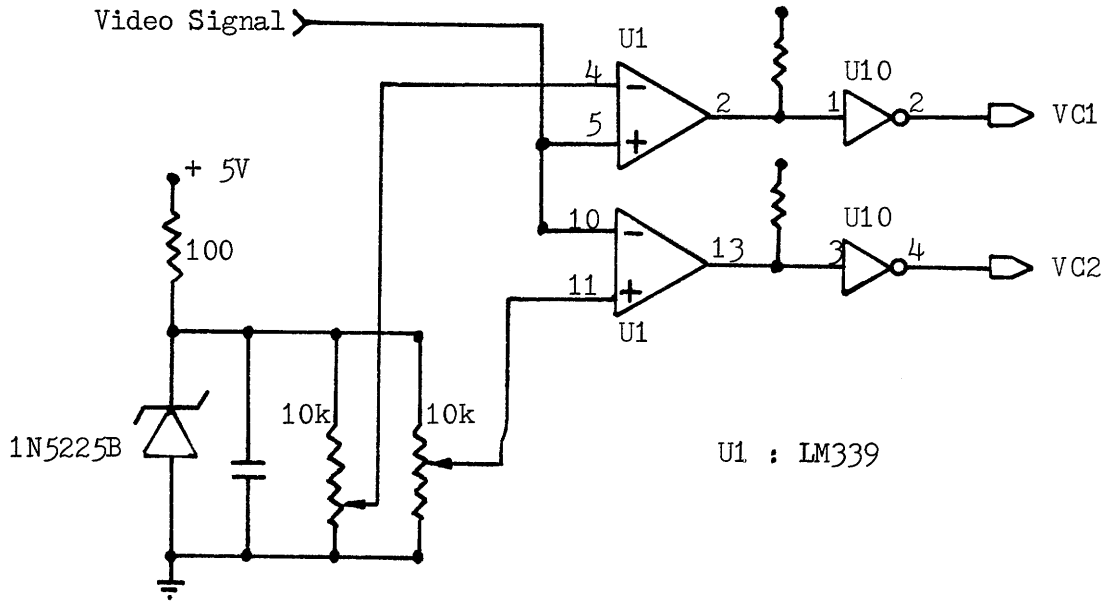


FIGURE B.1 VIDEO SIGNAL SEPARATOR

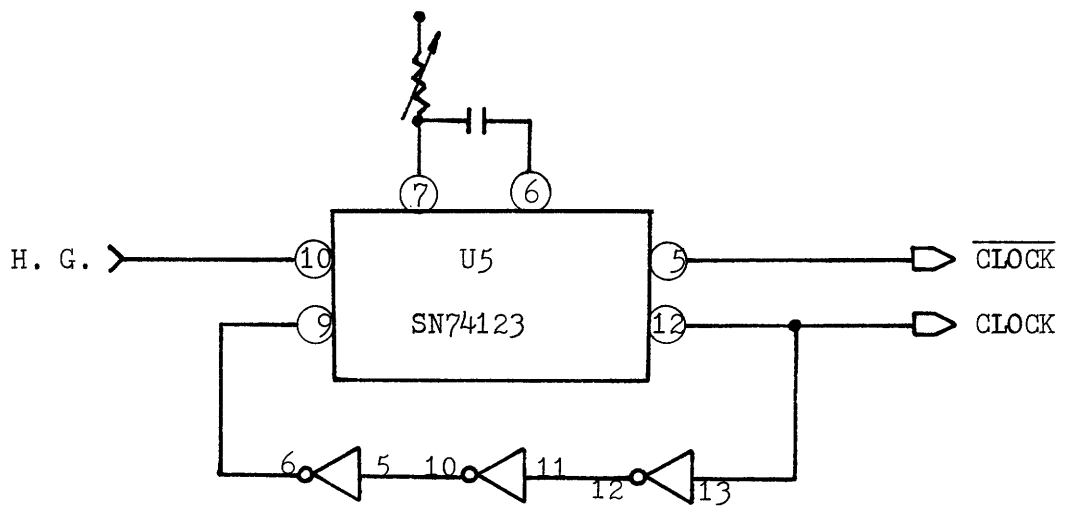


FIGURE B.2 5-MHz OSCILLATOR (ADJUSTABLE)

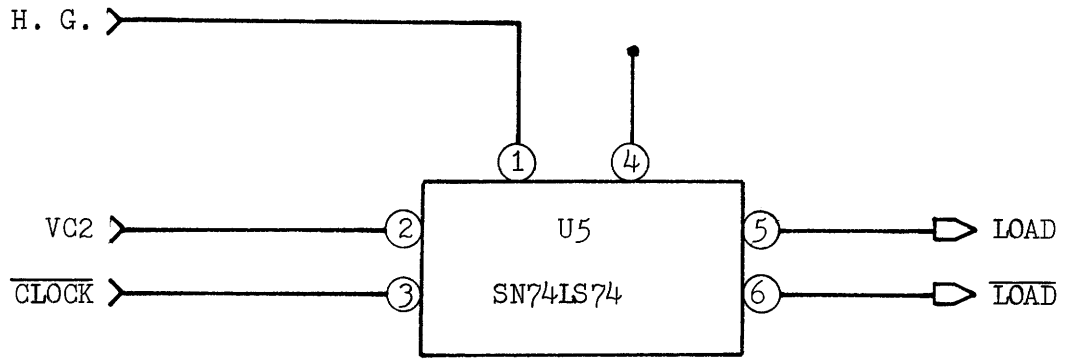


FIGURE B.3 "LOAD" SIGNAL IMPLEMENTATION

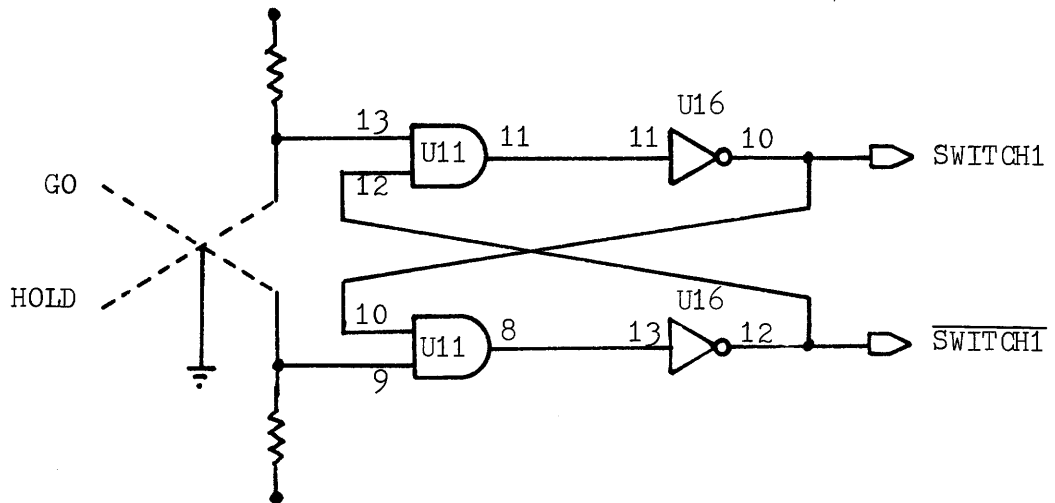


FIGURE B.4 "SWITCH1" LATCH CIRCUIT



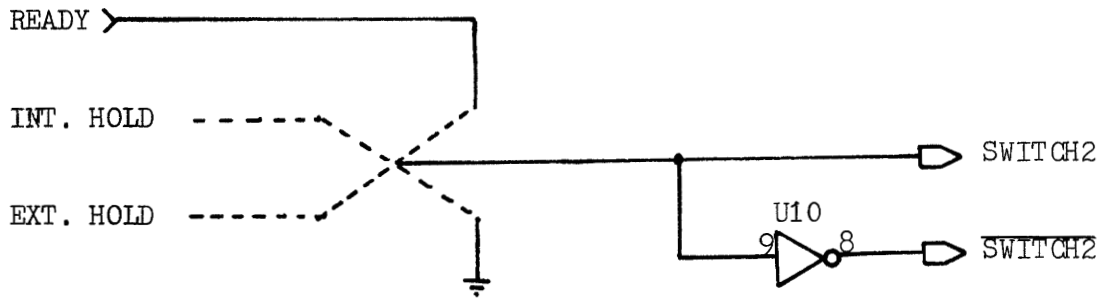


FIGURE B.5 "SWITCH2" SIGNAL IMPLEMENTATION

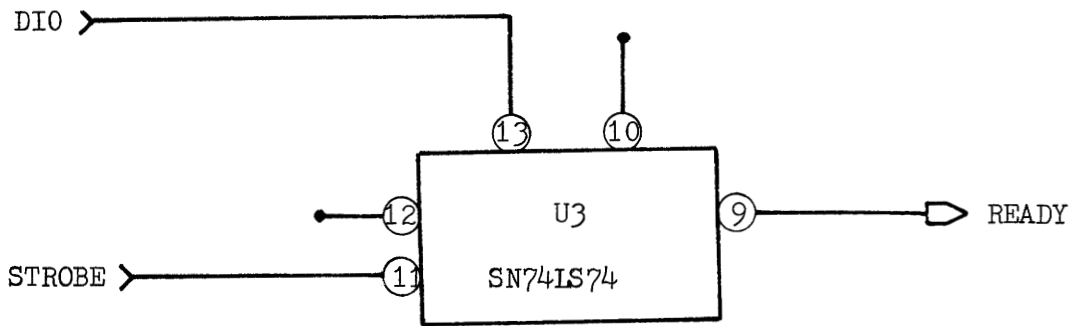


FIGURE B.6 "READY" SIGNAL IMPLEMENTATION

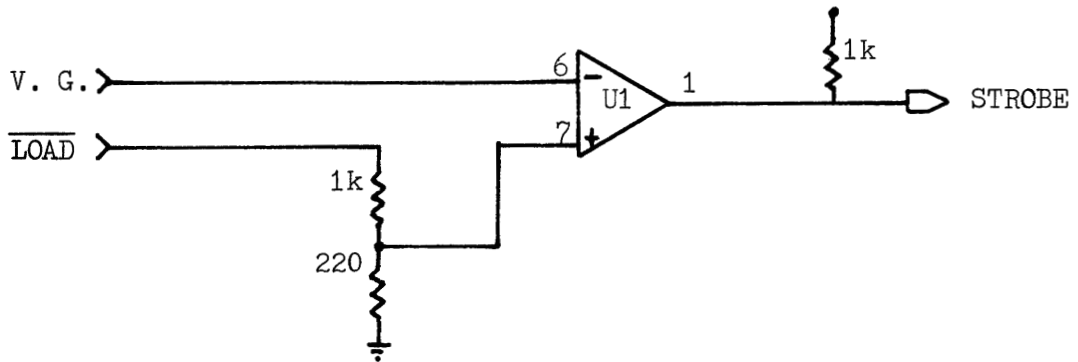


FIGURE B.7 "STROBE" SIGNAL IMPLEMENTATION

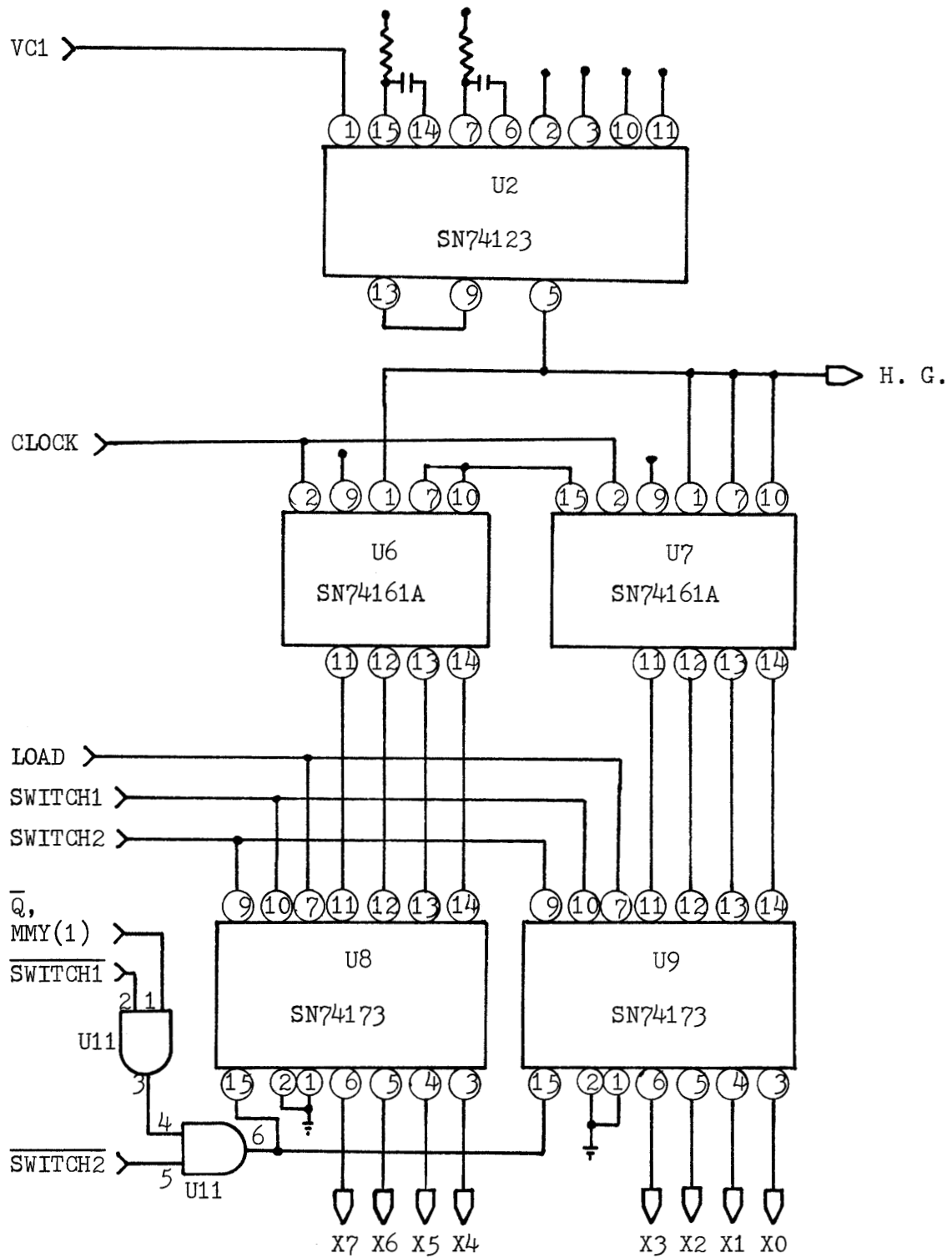


FIGURE B.8 X-COORDINATE MEASUREMENT IMPLEMENTATION

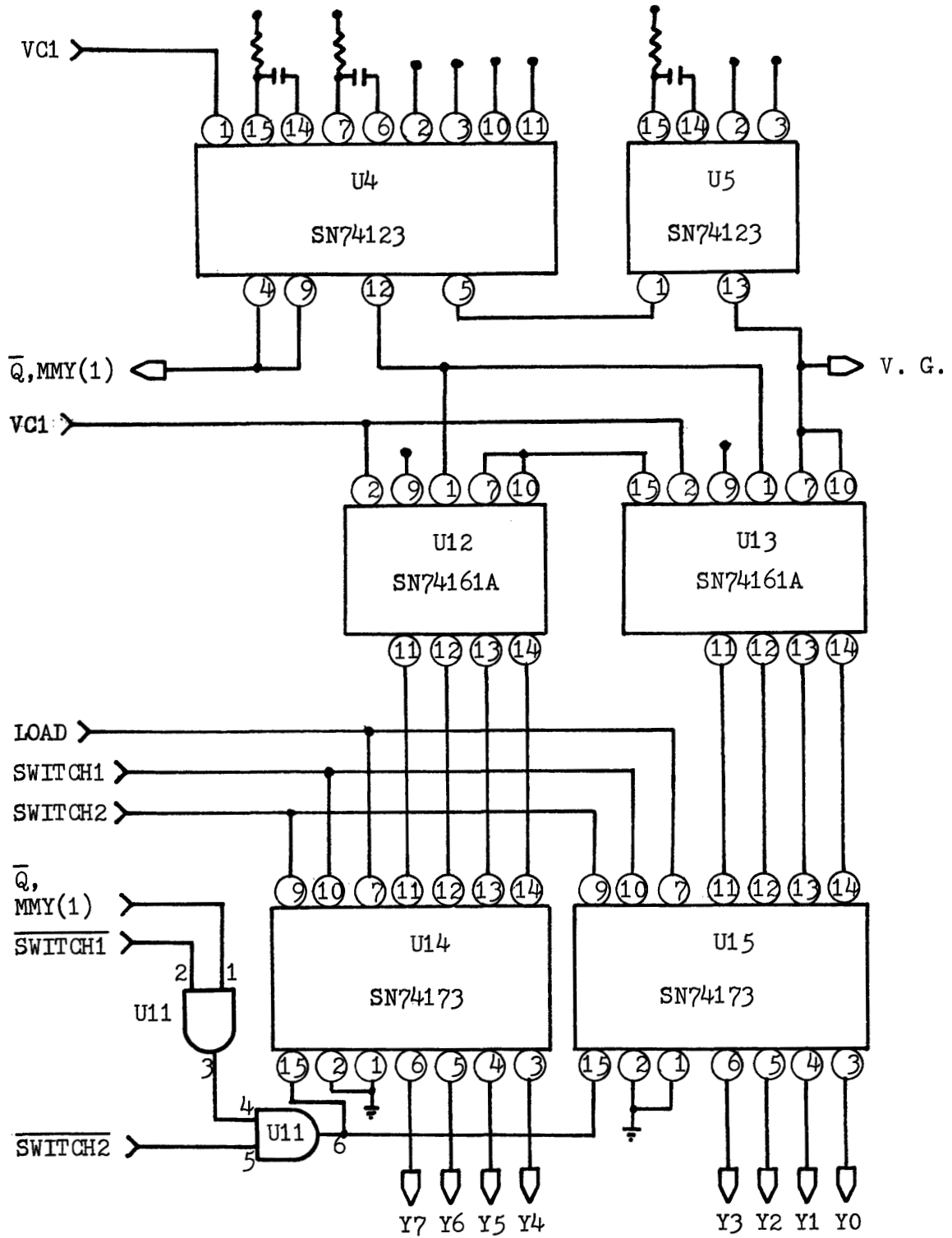


FIGURE B.9 Y-COORDINATE MEASUREMENT IMPLEMENTATION

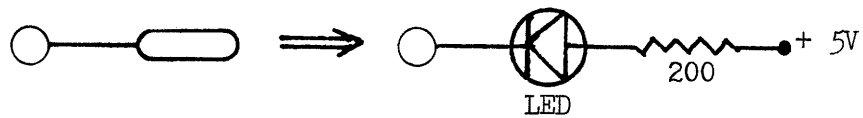
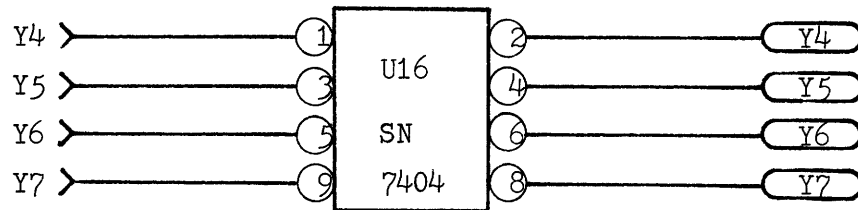
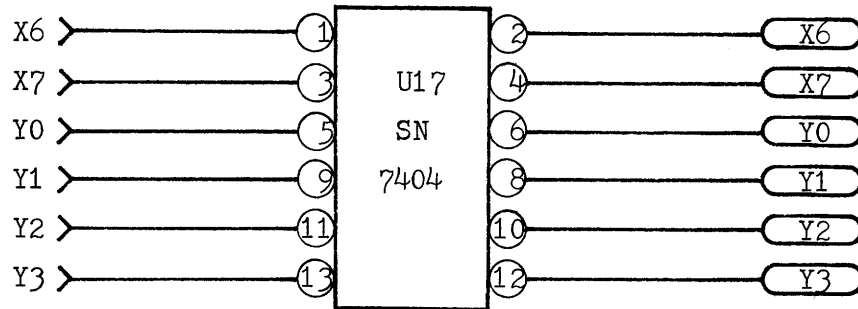
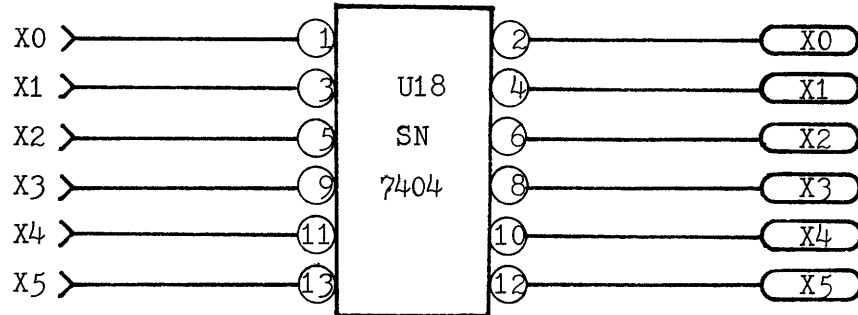


FIGURE B.10

LED DISPLAY IMPLEMENTATION

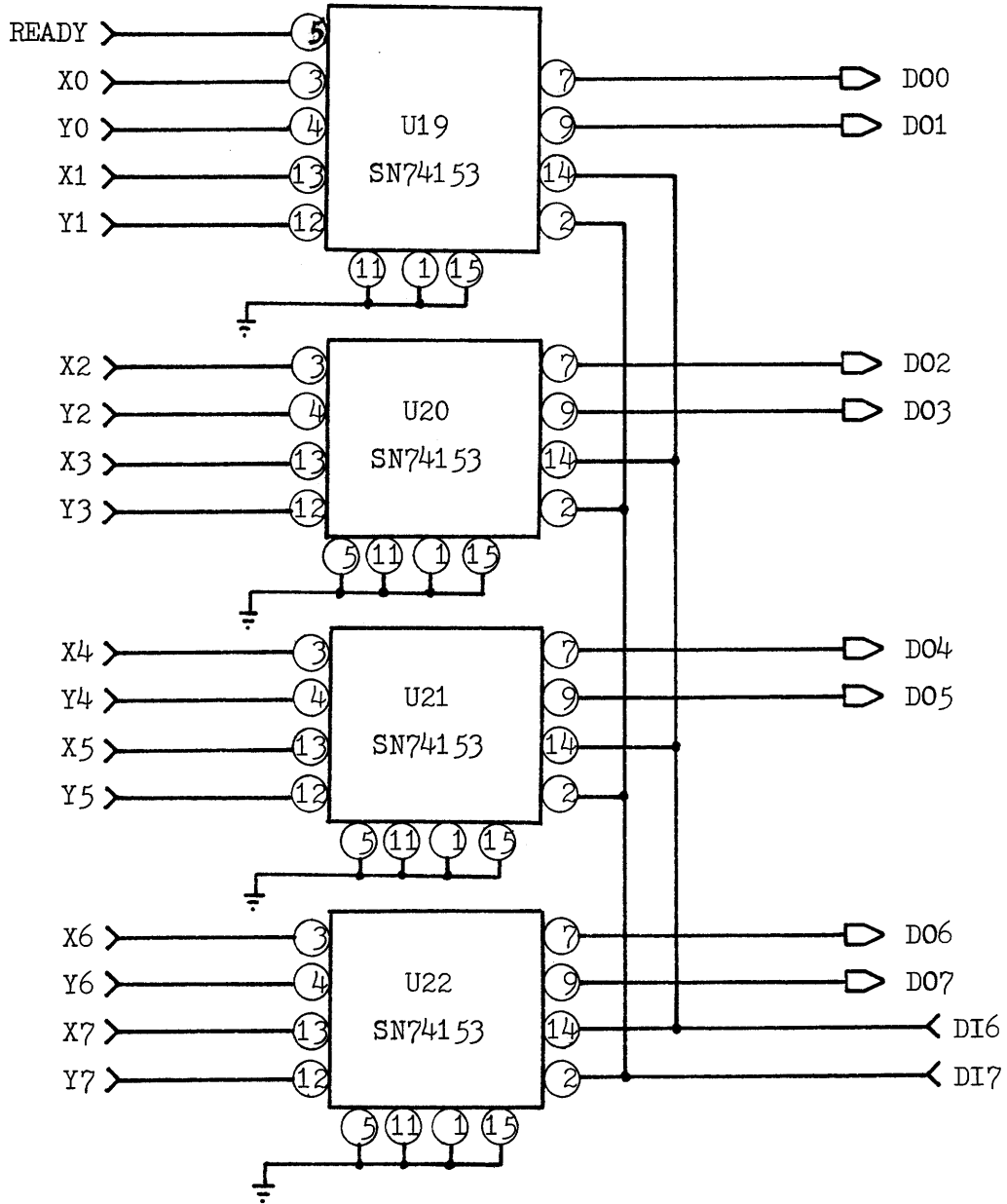


FIGURE B.11 MULTIPLEXER FOR SELECTION OF OUTPUT

APPENDIX C  
COMPUTER PROGRAMS

Basic computer programs were used to sample, store and analyze the outputs of the measurement device. Five basic language computer programs were used in the calibration procedures. The detailed descriptions of the calibration procedures are given in Chapter 4.

Basic Program DATALIST

This program reads X- and Y-coordinates from the output port of the measurement device and gives some control signals to the input port of the measurement device. The sampled X- and Y-coordinates are displayed on the CRT of the microcomputer. Keyboard "CTRL" and "Y" are needed to stop the program. More detailed description of the program is given in the program listing.

Basic Program DATADRAW-90 and DATADRAW-45

These two computer programs translate the X- and Y-coordinates, generated by DATALIST program, into a new coordinates plot on the CRT of the microcomputer. The extensions, 90 and 45, are used for the vertical and 45 degrees declining lines, respectively. The program listings contain some documentations of its usage and description.

Basic Program ANALYSIS-90 and ANALYSIS-45

These two programs can collect 800 pairs of X- and Y-coordinates

generated by DATALIST and give them an analysis. The major analysis are based on the Y-coordinates classification and X-coordinates average. The results of analysis are displayed on the CRT of the microcomputer and also are stored into the data file of the disk. The extensions, 90 and 45, are used in the same function as those in the DATADRAW programs. More detailed descriptions of the programs are given in the program listings.

## " DATALIST "

```
10 REM *** LIST THE X- AND Y-COORDINATES
20 Z=136 \REM I/O PORT ADDRESS OF THE COMPUTER
30 OUT Z, 0 \REM RESET THE "READY" FLAG
40 REM *** CHECK THE "READY" FLAG
50 OUT Z, 65
60 IF INP(Z)=0 THEN GOTO 50
70 REM *** INPUT THE X-COORDINATE
80 OUT Z, 193
90 X=INP(Z)
100 REM *** INPUT THE Y-COORDINATE
110 OUT Z, 129
120 Y=INP(Z)
130 IF Y=0 THEN GOTO 30
140 REM *** PRINT THE DATA ON THE CRT
150 PRINT "X= ", X, TAB(10), "Y= ", Y
160 GOTO 30
170 REM *** STOP THE PROGRAM BY KEYBOARD "CTRL" AND "Y"
```



## " DATADRAW-90 "

```
10 REM *** INPUT ONE SET OF NON-ZERO X- AND Y-COORDINATE
20 Z=136
30 OUT Z, 0
31 OUT Z, 1
40 REM *** INPUT THE "READY" FLAG, X- AND Y-COORDINATES
50 OUT Z, 65
51 IF INP(Z)=0 THEN GOTO 50
60 OUT Z, 193
61 X=INP(Z)
70 OUT Z, 129
71 Y=INP(Z)
80 IF Y>0 THEN GOTO 100
90 GOTO 30
99 REM *** SELECT THE CONSTANT FOR DRAWING
100 IF X<70 THEN D1=25
110 IF X>70 THEN GOSUB 310
120 IF X>120 THEN GOSUB 320
130 IF X>170 THEN D1=175
140 IF Y<100 THEN D2=0
150 IF Y>100 THEN D2=100
174 REM *** DRAW THE COORDINATES INTO A HORIZONTAL LINE ON THE CRT
175 FOR N=1 TO 20
176 PRINT " "
177 NEXT N
180 A=X-D1
181 B=Y-D2
190 PLOT B,A,1
200 OUT Z, 0
201 OUT Z, 1
210 OUT Z, 65
211 IF INP(Z)=0 THEN GOTO 210
220 OUT Z, 193
221 X=INP(Z)
230 OUT Z, 129
231 Y=INP(Z)
240 IF Y=0 THEN GOTO 200
250 GOTO 180
300 REM *** SUBROUTINES FOR D1 AND D2
310 IF X<120 THEN D1= 75
311 RETURN
320 IF X<170 THEN D2=125
321 RETURN
330 REM *** STOP THE PROGRAM BY KEYBOARD "CTRL" AND "Y"
```

## " DATADRAW-45 "

```
10 REM *** INPUT ONE SET OF NON-ZERO X- AND Y-COORDINATE
20 Z=136
21 REM *** RESET THE "READY" FLAG
30 OUT Z,0
31 OUT Z,1
40 REM *** INPUT THE "READY" FLAG, X- AND Y-COORDINATES
50 OUT Z, 65
51 IF INP(Z)=0 THEN GOTO 50
60 OUT Z, 193
61 X=INP(Z)
70 OUT Z, 129
71 Y=INP(Z)
80 IF Y>0 THEN GOTO 100
90 GOTO 30
99 REM *** SELECT THE CONSTANT FOR DRAWING IN X DIRECTION
100 IF X<50 THEN D1=-30
110 IF X>50 THEN GOSUB 310
120 IF X>100 THEN GOSUB 320
130 IF X<150 THEN D1=120
139 REM *** SELECT THE CONSTANT FOR DRAWING IN Y DIRECTION
140 IF Y<50 THEN D2=0
150 IF Y>50 THEN GOSUB 350
160 IF Y>100 THEN GOSUB 360
170 IF Y<150 THEN D2=150
174 REM *** DRAW THE COORDINATES INTO A 45 DEG. DECLINING LINE
175 REM *** CLEAR THE SCREEN
176 FOR N=1 TO 20
177 PRINT " "
178 NEXT N
180 A=X-D1
181 B=Y-D2
190 PLOT A,B,1
200 REM *** FETCH A NEW COORDINATE FOR PLOTTING
201 OUT Z, 0
202 OUT Z, 1
210 OUT Z, 65
211 IF INP(Z)=0 THEN GOTO 210
220 OUT Z, 193
221 X=INP(Z)
230 OUT Z, 129
231 Y=INP(Z)
240 IF Y=0 THEN GOTO 201
250 GOTO 180
300 REM *** SUBROUTINES FOR D1
310 IF X<100 THEN D1=20
311 RETURN
320 IF X<150 THEN D1=70
321 RETURN
```

" DATADRAW-45 "  
(cont.)

```
340 REM *** SUBROUTINES FOR D2
350 IF Y<1.00 THEN D2=50
351 RETURN
360 IF Y<1.50 THEN D2=1.00
361 RETURN
370 REM *** STOP THE PROGRAM BY KEYBOARD "CTRL" AND "Y"
```

## " ANALYSIS-45 "

```

10 DIM X(800), Y(800), S1(150), S2(150), D1(150), D2(150)
20 REM *** RECORD 800 SETS OF COORDINATES
30 Z=136
40 OUT Z, 0
41 OUT Z, 1
50 FOR N=1 TO 800
60 OUT Z, 65
61 IF INP(Z)=0 THEN GOTO 60
70 OUT Z, 193
71 X(N)=INP(Z)
80 OUT Z, 129
81 Y(N)=INP(Z)
90 OUT Z, 0
91 OUT Z, 1
92 IF Y(N)=0 THEN GOTO 60
95 NEXT N
100 REM *** CLASSIFY Y AND CALCULATE THE AVERAGE OF X COORDINATES
110 REM *** FIND THE MAX. Y(N)
120 M=1
125 A=0
130 FOR K=1 TO 800
140 IF Y(K)>A THEN A=Y(K)
145 NEXT K
149 REM *** ANALYSIS IS FINISHED WHEN A=0
150 IF A=0 THEN GOTO 250
160 S2(M)=A
161 J=0
162 S1(M)=0
170 REM *** CALCULATE THE AVERAGE OF X(M)
180 FOR I=1 TO 800
190 IF Y(I)=S2(M) THEN Y(I)=0 \ J=J+1 \ S1(M)=S1(M)+(X(I)-S1(M))/J
200 NEXT I
210 PRINT "X(", M, ")=", S1(M), TAB(20), "Y(", M, ")=", S2(M)
220 M=M+1
230 GOTO 125
250 REM *** STORE DATA INTO DISK
255 FILE: 6, OPEN, "<2>45-DATA1", OUT
260 M2=M-2
265 FOR I=1 TO M2
270 D1(I)=S1(I)-S1(I+1)
275 D2(I)=S2(I)-S2(I+1)
280 PRINT: 6, S1(I), "(X)&", S2(I), "(Y)", TAB(40), D1(I), "(DX)&", D2(I),
"(DY)"
285 NEXT I
290 PRINT: 6, "END OF DATA "
295 FILE: 6, CLOSE
300 REM *** PRINT THE X- AND Y-COORDINATES

```

" ANALYSIS-45 "  
(cont.)

```
310 J=1
311 K=12
312 M=M-1
320 FOR I=J TO K
330 D1=S1(I)-S1(I+1)
340 D2=S2(I)-S2(I+1)
350 PRINT "X(", I, ")=", TAB(15), "DX=", D1, TAB(30), "Y(", I, ")=",
        S2(I), TAB(45), "DY=", D2
360 NEXT I
370 PRINT "MAX. DX IS ", S1(1)-S1(M)
380 PRINT "MAX. DY IS ", S2(1)-S2(M)
390 INPUT "ENTER THE LINE # TO BE CHECKED ", J
400 K=J+11
410 GOTO 320
500 REM *** STOP THE PROGRAM BY INPUT # GREATER THEN 150
```

## " ANALYSIS-90 "

```

10 DIM X(800), Y(800), S1(150), S2(150)
20 REM *** RECORD 800 SETS OF COORDINATES
30 Z=136
40 OUT Z, 0
41 OUT Z, 1
50 FOR N=1 TO 800
60 OUT Z, 65
61 IF INP(Z)=0 THEN GOTO 60
70 OUT Z, 193
71 X(N)=INP(Z)
80 OUT Z, 129
81 Y(N)=INP(Z)
90 OUT Z, 0
91 OUT Z, 1
92 IF Y(N)=0 THEN GOTO 60
95 NEXT N
100 REM *** CLASSIFY Y AND CALCULATE THE AVERAGE OF X
110 REM *** FIND THE MAX. Y(N)
120 M=1
125 A=0
130 FOR K=1 TO 800
140 IF Y(K)>A THEN A=Y(K)
145 NEXT K
150 IF A=0 THEN GOTO 250 \REM ANALYSIS IS FINISHED
160 S2(M)=A
161 J=0
162 S1(M)=0
170 REM *** CALCULATE THE AVERAGE OF X(M)
180 FOR I=1 TO 800
190 IF S2(M)=Y(I) THEN Y(I)=0 \J=J+1 \S1(M)=S1(M)+(X(I)-S1(M))/J
200 NEXT I
210 PRINT "X(", M, ")=", S1(M), TAB(20), "Y(", M, ")=", S2(M)
220 M=M+1
230 GOTO 125
250 REM *** STORE THE DATA INTO THE DISK
255 FILE: 6, OPEN, "<2>90-DATA1", OUT
260 M=M-1
265 FOR N=1 TO M
270 PRINT: 6, S1(N), "(X)&", S2(N), "(Y) ,"
275 NEXT N
280 PRINT: 6, "END OF FILE"
285 FILE: 6, CLOSE
300 REM *** PRINT THE X- AND Y-COORDINATES
310 J=1
311 K=12
312 L=S2(1)-S2(M)
320 FOR I=J TO K

```

" ANALYSIS-90 "  
(cont.)

```
330 PRINT "X(", I, ")=", S1(I), TAB(20), "Y(", I, ")=", S2(I)
335 NEXT I
340 PRINT "THE VERTICAL LENGTH IS ", L, " mm"
350 INPUT "ENTER THE LINE # TO BE CHECKED ", J
360 K=J+11
370 GOTO 320
400 REM *** STOP THE PROGRAM BY GIVING A # GREATER THAN 150
```