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The purpose of this work is to develop a 350 x 600 element X-Y addressed electrophoretic image display (EPID). Development of the fabrication techniques for this display continues. Near-perfect seals between the substrate and grid dielectric were obtained. Ion-beam milling of Mylar in 70% oxygen: 30% argon has eliminated operational difficulties encountered with pure oxygen. No change in either the absolute or differential milling rates was observed as a result of the addition of the argon to the oxygen. Several tests have confirmed the compatibility between the materials used in fab-

20. ABSTRACT (Cont'd)

ricating the device and the components of the electrophoretic suspension. Digitization and ordering of the photolithographic masks for the 512 character display is complete. Design of the display electronics and packaging are in progress. A microprocessor interfaced to the IEEE-488 bus and an ASCII-to-5x7 character generator will provide the necessary signals to the integrated row and column drivers. The display will be mounted, using conductive elastomer interconnections, to a printed circuit board which will provide sockets for connection of the cables from the electronics package. This system will accept ASCII information from a computer connected to an IEEE-488 bus and display the printable information on the EPID as 16 lines of 32 characters each.

PREFACE

This work is being performed by Philips Laboratories, a Division of North American Philips Corporation, Briarcliff Manor, New York under the overall supervision of Dr. Barry Singer, Director, Component and Device Research Group. Mr. Richard Liebert, Metallurgist, is the Program Leader; Ms. Beverly Fitzhenry, Chemist, was responsible for evaluation and testing of electrophoretic suspensions; Mr. Joseph Lalak, Electronic Engineer, is responsible for cell fabrication and technology. Mr. Karl Wittig, Electrical Engineer, is responsible for circuit design.

This program is sponsored by the Defense Advanced Research Agency (DARPA) and was initiated under Contract No. MDA903-79-C-0439. Dr. Robert E. Kahn is the Contracting Officer's Technical Representative for DARPA.

The work described in this third Quarterly Technical Report covers the period from 1 February 1980 to 30 April 1980.

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SUMMARY

The purpose of this work is to develop a 350 x 600 element X-Y addressed electrophoretic image display (EPID). Development of the fabrication techniques for this display continues. Near-perfect seals between the substrate and grid dielectric were obtained. Ion-beam milling of Mylar in 70% oxygen: 30% argon has eliminated operational difficulties encountered with pure oxygen. No change in either the absolute or differential milling rates was observed as a result of the addition of the argon to the oxygen. Several tests have confirmed the compatibility between the materials used in fabricating the device and the components of the electrophoretic suspension. Digitization and ordering of the photolithographic masks for the 512 character display is complete. Design of the display electronics and packaging are in progress. A microprocessor interfaced to the IEEE-488 bus and an ASCII-to-5x7 character generator will provide the necessary signals to the integrated row and column drivers. The display will be mounted, using conductive elastomer interconnections, to a printed circuit board which will provide sockets for connection of the cables from the electronics package. This system will accept ASCII information from a computer connected to an IEEE-488 bus and display the printable information on the EPID as 16 lines of 32 characters each.

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1. INTRODUCTION

Improvement of the device fabrication technology continued during this quarter. Operating life tests begun in the first and second quarters were completed, and the compatibility of the suspension, epoxy, and Mylar was demonstrated. The drawings for the photolithographic masks were finished and the masks have been ordered; delivery is scheduled for the third week of May. The design of the electronic driver and packaging has begun. A personal computer for exercising the display has been ordered. Software has been written to facilitate use of this computer as the input device for the display.

2. FABRICATION TECHNOLOGY

2.1 Display Dimensions

Prior to this quarter, test cells were fabricated in a size approximating that of the Phase I display; the size of the display was established at the end of the previous quarter. During this quarter, all of the jigs and fixtures for the display were designed and fabricated; test cells of this final size are now being fabricated. The dimensions are given in Table 1.

TABLE 1

	Horizontal (mm)	Vertical (mm)
Grid Substrate		
Active Area	57.93	37.70
Inside of Seal	60.50	40.70
Outside of Seal	67.00	47.20
Overall	85.00	63.00
Viewing Substrate		
Overall	66.50	46.70

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2.2 Mylar Sealing

Improvements have been made in bonding the 12 μm thick Mylar to the In_2O_3 coated glass substrates. The epoxy is now applied to the In_2O_3 coated glass substrate by spinning instead of coating one side of a large sheet of Mylar and allowing the excess to drain off. The epoxy layer is visibly much more uniform in thickness.

Silicon rubber is placed against the glass, and clean 12 μm Mylar is placed onto the epoxy-coated In_2O_3 layer. On top of this is placed a "TUFRAN" coated flat aluminum platen which will not stick to the Mylar at the sealing temperature. TUFRAN is a Teflon-impregnated anodized layer which has been ground flat and smooth. This method has replaced the use of oil as a release agent and has eliminated imperfect seals due to oil contamination.

2.3 Ion-Beam Milling

A suitable photolithographic process has been developed for use with the vacuum print frame and 5 in. exposure system. Acceptable line-width control and uniformity can be obtained in thick photoresist layers. These photoresist layers withstand the ion-milling process for aluminum, and wet chemical etching will not be required.

It was determined that the Mylar should be ion-beam milled in an oxygen/argon atmosphere instead of a pure oxygen atmosphere because of the difficulty of operating the thermionic filament in a 100% oxygen atmosphere. 15% oxygen plus 85% argon has enough oxygen to reduce the etch rate of aluminum close to that obtainable in 100% oxygen but the etch rate of Mylar is too slow. 70% oxygen plus 30% argon seems to work well. The gas mixture can be easily ionized in order to operate the ion-beam miller, and the etch rate of the Mylar and aluminum are approximately the same as when 100% oxygen is used. These rates are given in Table 2 for 2×10^{-4} torr, 0.25 W/cm^2, at a 20° angle.

TABLE 2

Atmospere	Aluminum (μm/min)	AZ1375 Photoresist (μm/min)	Mylar (μm/min)	Epoxy (μm/min)
100% O_2	0.005	0.4	0.2	
70% O_2/30% Ar	<.01	0.4	0.2	0.2
15% O_2/85% Ar	<.01	0.07	0.08	
100% Ar	0.02	0.03	0.1	

2.4 Cell Filling and Testing

Previously, cells were filled from a pipette through a hole drilled in the glass substrate. A second hole was required to allow air to escape. These holes were then plugged with Teflon spheres and sealed with epoxy. Eliminating all of the air from the cell was a tedious process. A vacuum filling method was used to fill two of the test cells fabricated during this quarter. Instead of drilling holes in the substrate, a single gap was left in the perimeter seal. The cell and suspension are placed in a container which is then evacuated. The container is tipped so that the suspension now covers the gap in the seal. When air is readmitted, the suspension is forced into the cell which it completely fills without bubbles. The gap is then sealed with a rapid-curing epoxy.

Completed test cells, free of electrical shorts or opens, made with epoxy-bonded Mylar were tested. These devices did not operate properly because pigment could not be loaded into the wells. In earlier test cells made without the epoxy adhesion layer, the presence of a small amount of Mylar in the bottom of the wells could be tolerated (see Aug-Oct 1979 Qtly Tech Rpt). However, this is not the case with epoxy in the bottom of the wells. This epoxy retains a charge which prevents pigment from fillir the wells. Microscopic examination of the cross-section of one of the nonoperating cells confirms the presence of the epoxy in the bottom of the wells.

2.5 Comments

The use of the epoxy adhesion layer requires the perfection of the ion-milling technique to ensure complete removal of the epoxy. This must be done without destroying the underlying In_2O_3 layer. Preliminary indications are that this can be done since the spun-on epoxy layer is very uniform in thickness. Careful microscopic examination between short periods of milling at the end of the process can indicate when the last of the epoxy has been removed.

An alternative to the present epoxy is being sought since it is not available domestically, has a limited shelf-life, and is only available in very large drums. A similar epoxy was obtained and is being evaluated.

3. MATERIALS INTERACTIONS

The operating life test (started in the first quarter) to assess the epoxy-coated Mylar seal has been concluded. After 4.9×10^3 hours and 7×10^7 switches, four of the five cells sealed with Mylar alone have failed and the fifth is failing. Only four of twelve cells with the epoxy-coated Mylar seals have failed. One of those failures occurred in a cell with a leaky fill hole and another in a cell which was purposely heated for less than the desired time during sealing. There was still no visible attack of the seal by the suspension. We conclude that epoxy coated Mylar is a suitable seal.

Two tests to determine the effect of the dyes (used in the suspension) on the Mylar have also been concluded. In the first test, Mylar sheets were stored in dyed solvent. After 13 weeks the Mylar was removed, rinsed, and examined for color change. As stated in the previous quarterly technical report (Nov 79-Jan 80), neither of the Automate dyes, Red 11 or Blue 10, caused any change in the color of the Mylar; however, the BASF OSDB-BB does adsorb on the surface of the Mylar.

The second test involved the use of electrical stress. Cells were constructed with 12 μm Mylar covering both electrodes. One-half of the Mylar was ion-beam milled to provide a surface similar to that in the actual device. Cells 50 μm thick were filled with dyed solvent and with solvent alone as a control. A bias of 50 Vdc was applied to the electrodes (6.7×10^3 V/cm). After 1130 hours, the cells were removed from the test. There were no leaks or other obvious changes. After emptying, a slight stain could be seen in the cells which had contained dye. The stain appeared darker in the areas which had been milled. All were rinsed with solvent. This effectively removed the stains left by the Automate dyes and partially removed the stain left by the BASF dye. Ultrasonic agitation in solvent did not result in additional stain removal in the case of the BASF dye.

From these two tests we conclude that the use of the Automate dyes in suspensions for the display device is acceptable but that BASF dye could result in some reduction in brightness due to surface adsorption on the Mylar control grid dielectric.

An operating life test to evaluate the replacement epoxy discussed in Section 2 will begin in the next quarter.

4. DRIVER DESIGN

4.1 Electronics

4.1.1 Interface/Controller

Since it is a popular and well standardized bus, we have chosen the IEEE-488 bus for communication between the computer data source and the electrophoretic display. The electronics will consist of three main sections: the interface/controller, the row drivers, and the column drivers.

The IEEE-488 bus and the control circuitry for the EPID display drivers are interfaced by an Intel 8291 IEEE-488 interface chip and a set of non-inverting buffers.

The controller for the display is a single-chip microcomputer (Intel 8748). Since operation of the display requires a number of scanning, counting, and timing functions, such a device affords a considerable economy in the component count over an equivalent implementation using discrete logic. The microcomputer data bus is connected to the IEEE-488 interface chip, as well as the ASCII-to-5x7 character generator ROM. The various latched I/O bits are used to control the display drivers. Figure 1 shows the circuit diagram for the interface and controller.

4.1.2 Row Driver

The drivers for the 144 rows (bottom of potential wells) are high-voltage drivers (Dionics DI-300) with open collectors, to which two approximately equal resistors are connected in series as a pullup. The drivers are normally OFF, so that every row is normally at the pullup voltage which is fairly positive. When a particular row is selected, the driver is turned ON, and, since the row electrode is connected to the junction of the two series resistors, it will be at approximately one-half the pullup voltage. This is the condition for writing in that row. The condition for erasing, however, is that every row be brought down to zero. To do this, every row electrode is connected, through a diode, to the collector of one NPN transistor with a grounded emitter. When it is turned on, it pulls down every row through the forward-biased diodes. When it is off, the diodes serve to isolate each individual row from all of the rest. For writing a row, the selection of a particular high-voltage driver to be turned on is made by a 1-of-16 decoder and a 1-of-9 decoder (giving 144 possible combinations). The bases and emitters of the (input) driving transistors are connected in a "matrix" arrangement so that when one set of emitters is

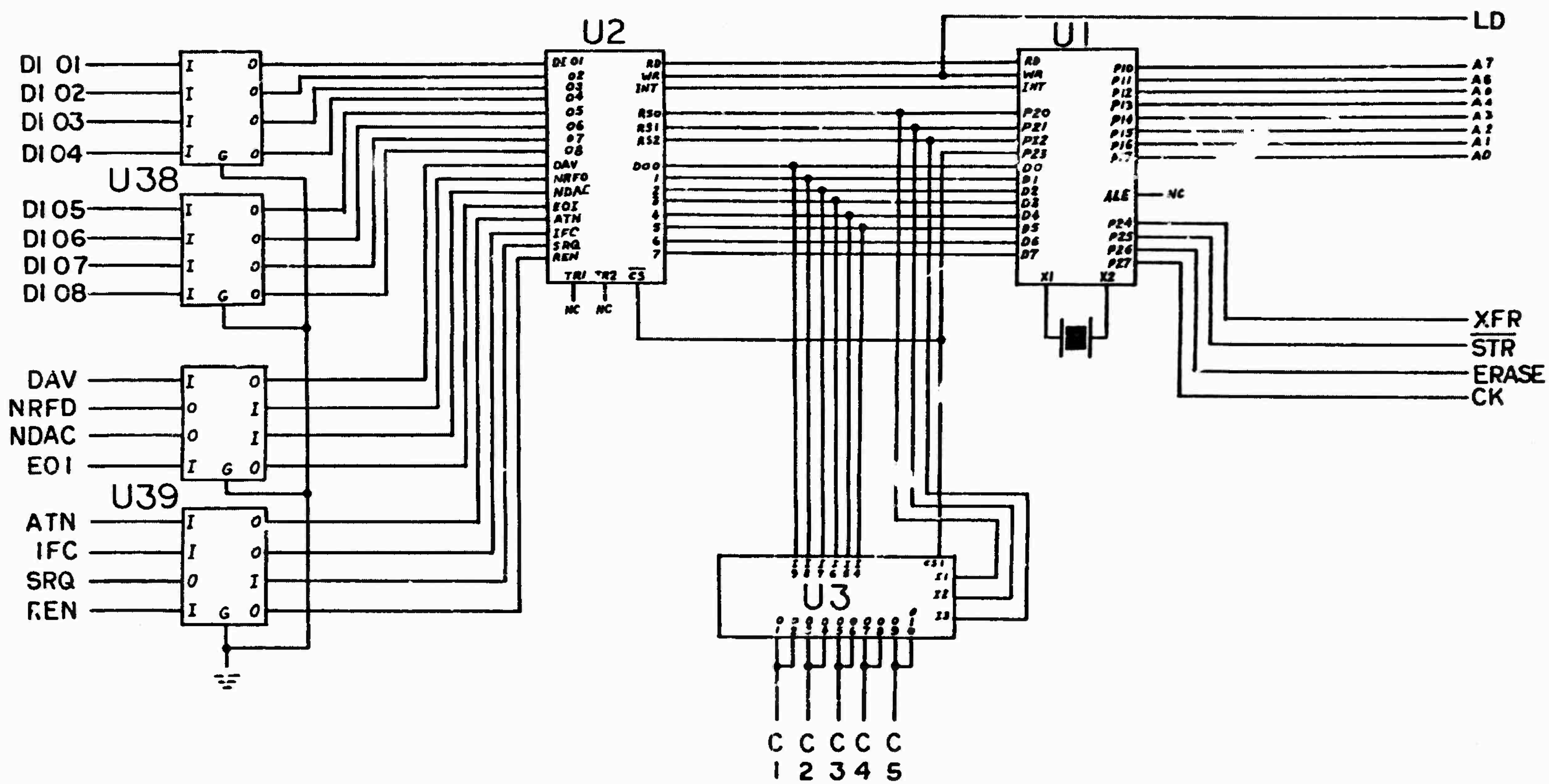

Figure 1: Circuit diagram for interface and controller.

high and a set of bases is low, only that transistor common to both sets will turn on, thus activating the driver and bringing the selected row to half-maximum voltage. The 1-of-9 decoder provides active-low outputs, and therefore is connected to the transistor bases. The 1-of-16 decoder also provides active-low outputs which are inverted and serve as the active-high outputs required by the emitters. The eight address bits required by the two decoders are provided by the microcomputer outputs as is the strobe input which controls the duration of the write pulse on the electrode. Figure 2 shows the circuit diagram for the row driver.

4.1.3 Column Driver

The drivers for the 228 columns (control electrodes) are provided by seven 33-bit shift registers with 30 V active-high drivers (National MM5559). When a particular row is written, it is necessary to have each column element that is to be written in that row at a high voltage (30 V), and each column element that is not to be written at a low voltage. It is also necessary that the data for every column by present at the time that the selected row is pulsed. This means that a register with 228 parallel outputs is required. To minimize the number of inputs to this register, a shift register with a serial input can be used. This is in fact what is done. Since each character is 7 elements wide (with spaces), the output of the ASCII converter ROM (5 outputs) and two spaces (seven inputs total) are fed into an 8-input parallel-to-serial shift register, which is, along with the larger register, clocked seven times, at which point the next character is loaded. This is repeated until all 32 characters of a line (228 elements, with spaces) have been loaded into the register. The write pulse can now be applied to the row. For every line of characters, it can be seen that seven rows of elements are required (nine with spaces), and these are addressed in the character generator ROM. A total of 16 lines of characters can be written on the 144 rows of the EPID array. To erase the array, every column must be at

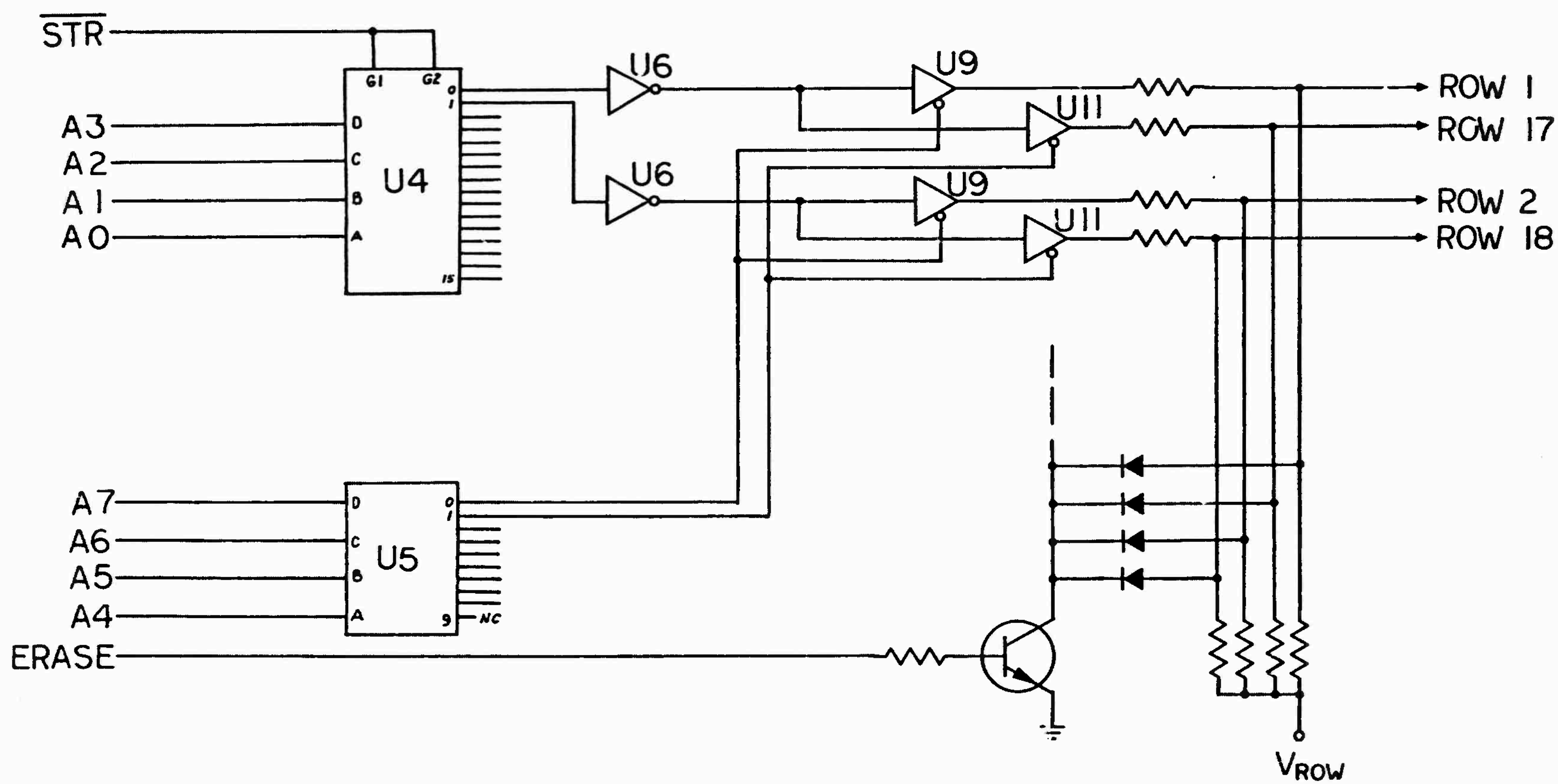

Figure 2: Circuit diagram for row driver.

zero, so that it is necessary to shift zeroes serially into the register for this operation. Figure 3 shows the circuit diagram for the column driver.

4.1.4 Comments

For clarity the power supplies have not been shown in Figures 1 through 3; the components shown in these figures are listed in Table 3.

TABLE 3: Component List

U1	8748 (Intel) Microcomputer
U2	8291 (Intel) IEEE-488 Interface
U3	TMS2501 (TI) 5 x 7 Char. Generator
U4	74C154 1 of 16 Decoder
U5	74C42 1 of 9 Decoder
U6–U8	74C04 Inverter
U9–U26	DI300 (Dionics) High Voltage Driver
U27	DI500 (Dionics) Level Shifter
U28	74LS165 Parallel-in/Serial-Out Shift Register
U29–U35	MM5559 (National) Serial-in/Parallel-out Shift Register
U36–U37	Negative Voltage Regulator (-10 V)
U38–U39	74LS244 Noninverting Buffer Driver

All that is necessary to operate the display will be line voltage and 8 bit ASCII data on an IEEE 488 bus. The character generator to be used for the present will only allow display of the 64 standard 5 x 7 characters.

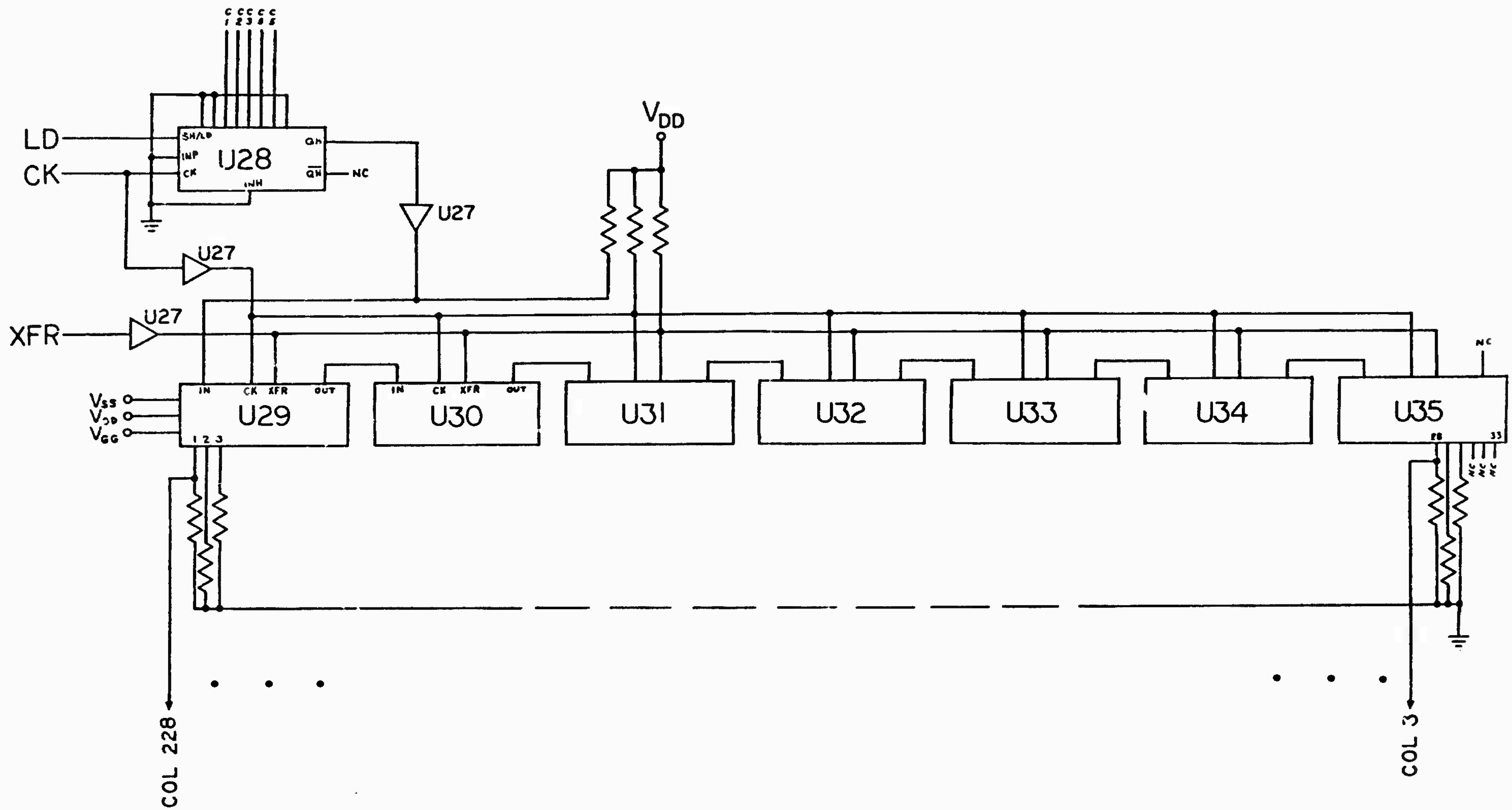

Figure 3: Circuit diagram for column driver.

In the future, other character fonts and graphics are possible by substituting a different character generator or a custom programmed ROM. The microcomputer will be programmed to accept only printable data from the IEEE-488 bus. It will also provide all the necessary timing for loading the shift registers, scanning the row electrodes, erasing and resetting the display, and the necesary handshakes with the bus.

As of this writing, a new high-voltage 32-bit shift register (TI SN75503A) has become available. Its use could greatly simplify the row driver and allow the use of higher voltage on the column driver. With this device, the total number of packages required would be halved. During the next quarter, a design based on this device will be considered.

4.2 Data Simulation

The display has been designed to present 512 5x7 dot matrix characters arranged in 16 rows of 32 characters each. The display driver can only accept certain ASCII codes. Provision must be made to direct characters after the thirty-second to the succeeding line. The driver must recognize end-of-line and end-of-page conditions. Blank characters must be handled properly. These house-keeping functions can be provided by the micro-computer.

To simulate these conditions, a Commodor Business Machines 32 K personal computer and a CBM printer were used. The printer was used to simulate the display. Both operate on the IEEE-488 bus. The CRT display of the computer can display 25 rows of 40 upper case, lower case, or graphics characters. A short program was written that restricts the computer to accept only the 64 standard ASCII upper case characters and a few control characters for editing and line feed. In addition, only 16 lines of 32 characters each are accepted and provision is made to add the blanks necessary to complete partial lines or skipped lines.

With this software, one can use the keyboard of the computer to generate acceptable input to the EPID device with automatic formatting. The editing features of the computer are retained. Thus, a line of data up to 32 characters long may be entered and edited; it can then be sent over the IEEE-488 bus to the EPID. After 16 lines of data are sent, no more will be accepted until the display is reset. Figure 4(a) is the program listing.

The printer was used to simulate the EPID connected to the IEEE-488 bus. Figure 4(b), the result of a simulation, shows: a full line of 32 characters; lines with imbedded, leading, and trailing blanks; skipped lines; and the 16 line page.

4.3 Packaging

The design of the interconnection and packaging scheme for the display and electronics has begun. The display will be terminated on all four edges. It will be mounted on a printed circuit card, with connections between the display terminations and the conductors on the PC card made with conductive elastomer. Ribbon cables from the electronics package will connect to the four sides of the PC card. To provide the necessary fan-out for more than 380 leads, the PC card will be about 8" x 5". The interconnection scheme is shown in Figure 5.

5. PURCHASED ITEMS

As a result of delays in obtaining the parts to modify the sputtering system for deposition of In_2O_3/SnO_2, alternate vendors have been selected. All of the necessary parts will be available by the middle of May, 1980.

The photolithographic masks have been ordered; they will be delivered by the third week in May.

A personal computer using the IEEE-488 bus has been ordered. This will be used both as our input to operate the display and as a means of exercising the device.

```
READY.

 100 CLR: C$="                                   ": REM
 110 PRINT "▒▒▒▒▒▒▒"
 120 B=B+1: POKE 33207,30
 130 IF B=1 THEN PRINT: GOTO 220
 140 PRINT SPC(2-INT(B/10.1));"▒LINE";B-1;B$: D$=B$+LEFT$(C$,A)
 150 OPEN 1,4
 160 PRINT#1,D$
 170 CLOSE 1
 180 B$=""
 190 IF B>9 THEN PRINT "▒"
 200 IF B=17 THEN 390
 210 IF A=0 THEN PRINT "▒";
 220 PRINT SPC(2-INT(B/10));"▒▒LINE";B;
 230 A=32
 240 PRINT "_";
 250 GET A$: IF A$="" GOTO 250
 260 IF ASC(A$)=34 THEN A$="'"
 270 IF ASC(A$)=20 THEN PRINT "▒▒  ▒▒";: GOTO 290
 280 GOTO 310
 290 IF A=31 THEN B$="": A=A+1: GOTO 240
 300 B$=LEFT$(B$,31-A): A=A+1: GOTO 240
 310 IF ASC(A$)=13 GOTO 110
 320 IF ASC(A$)<32 GOTO 250
 330 IF ASC(A$)>95 GOTO 250
 340 PRINT "▒";A$;
 350 B$=B$+A$
 360 A=A-1
 370 IF A>0 GOTO 240
 380 GOTO 110
 390 PRINT "▒▒▒▒▒▒▒▒▒▒END OF PAGE"
 400 END
READY.
```

(a) Program listing.

```
READY.
11111111111111111111111111111111
2222222       22222222
      3333333333
4


777777
8
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(b) Printed output.

Figure 4: Simulation of data transfer to display.

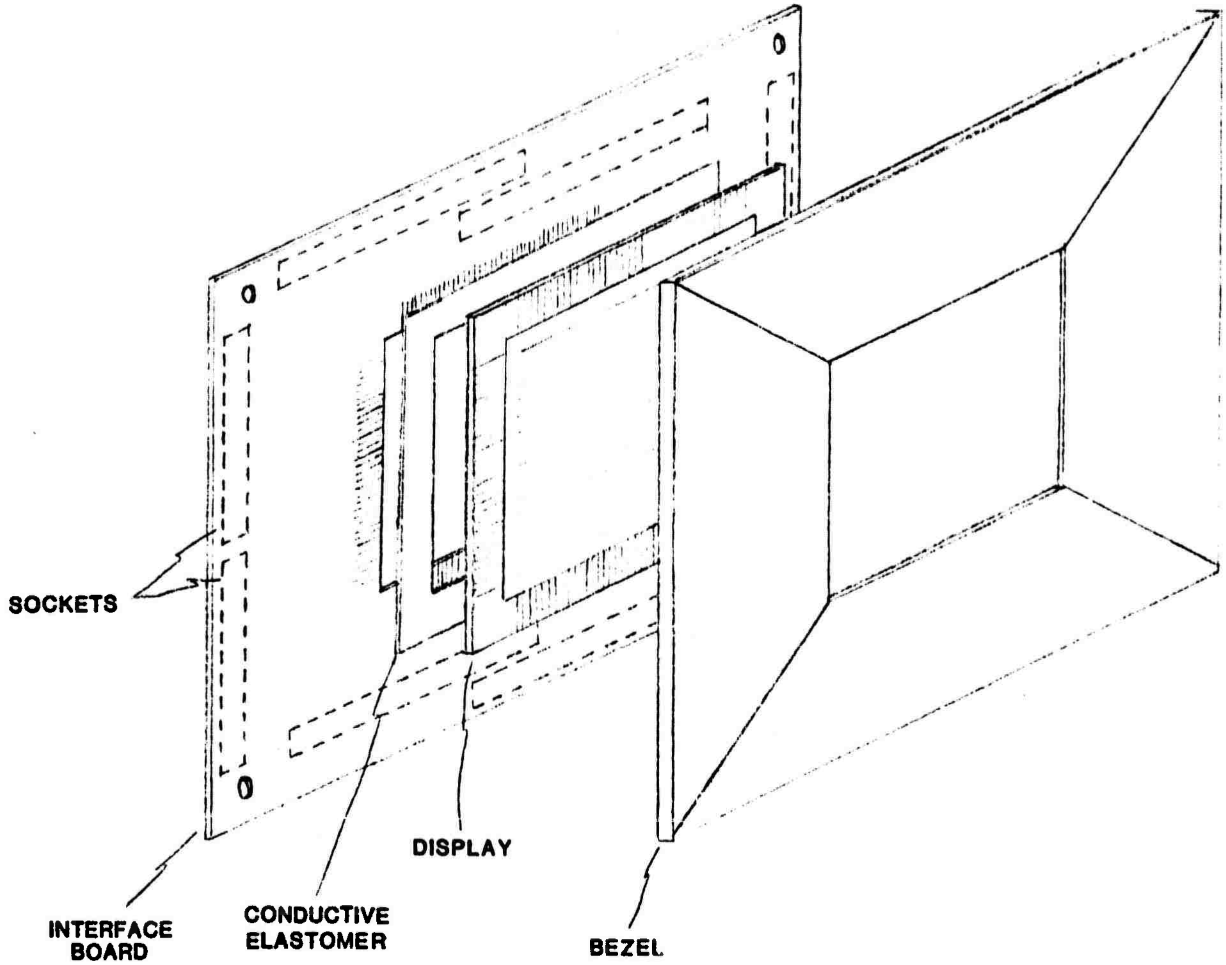

Figure 5: Display mounting scheme.

6. PLANS FOR NEXT QUARTER

a. Set up In_2O_3/SnO_2 sputtering system.

b. Begin fabrication of addressable displays.

c. Improve driver design by incorporating new high voltage shift register.

d. Complete package design and purchase necessary parts.

e. Operate a display in the addressable mode.

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