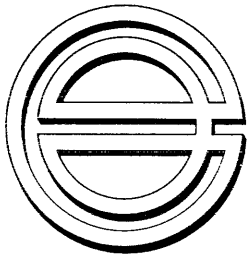
TEXAS INSTRUMENTS

TM 990

Color Video Using TMS 9918 and UNIVERSITY BASIC

MICROPROCESSOR SERIES™

Application Report



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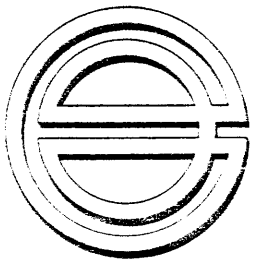
We're available to assist you however we can. Please feel free to call on us.

Sincerely,

Richard M Hartley
Marketing Manager

RMH/ch



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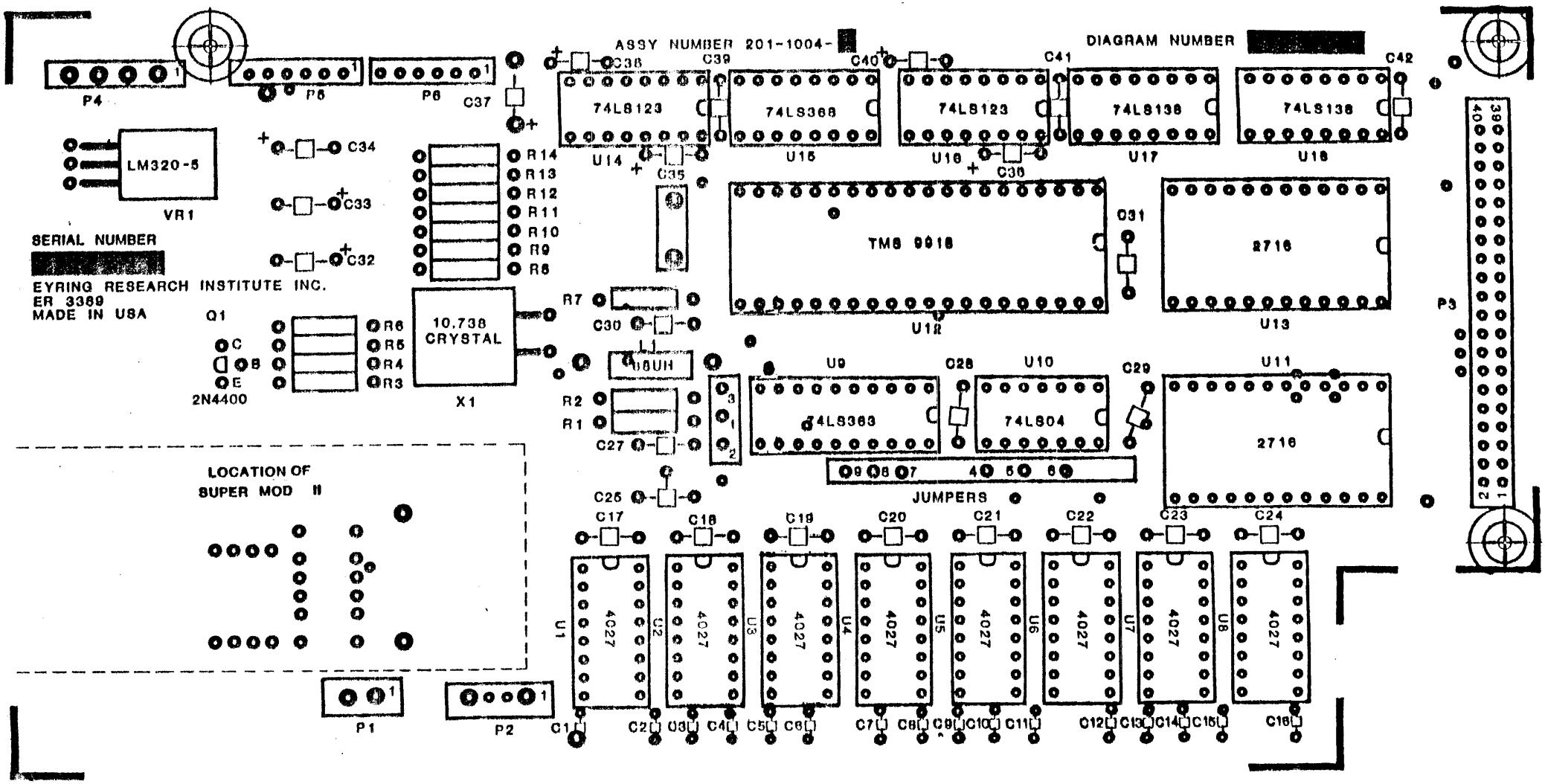
ER3389
COLOR VIDEO BOARD
LOADING DIAGRAM

Eyring Research Institute, Inc.
1455 West 820 North
Provo, Utah 84601
(801) 375-2434



Assy. No. 201-1004-2

ER3389 VIDEO DISPLAY BOARD
PARTS LIST

PART NUMBER	DESCRIPTION	QTY.	LOADING DIAGRAM NUMBER(S)	RECOMMENDED MANUFACTURER
TMS 9918	IC VIDEO DISPLAY PROCESSOR	1	U12	TI
GXA4500	TRIMMER CAPACITOR	1	C27	Sprague
10.738635MHZ	Crystal P-MODE HC-18	1	X1	NDK
201-1004	PC BOARD	1		ERII
9210-68	COIL CHOKE 11 Mhz, 68 uH	1	L2	Miller
4027-15	IC RAM	8	U1-U8	
74LS138	IC 3 TO 8 LINE DEC/MUX	2	U17,U18	
LM320T-5-0	IC VOLTAGE REGULATOR	1	VRI	
2N4400	TRANSISTOR	1	Q1	
B37981C0103M050	CAPACITOR DECOUPLING .01uf	16	C1-C16	Siemons
	CAPACITOR, .022 uf 25V CERAMIC DISK	14	C17-25,28,29, 31,41,42	
ST841G226M016N	CAPACITOR FILTER, 22 uf 15V	5	C30,32-34,37	Siemons
	RESISTOR, 100 ohm .25W 5%	1	R5	
	RESISTOR, 330 ohm .25W 5%	1	R6	
	RESISTOR, 470 ohm .25W 5%	2	R2,3	
	RESISTOR, 10K ohm .25W 5%	2	R4,7	
	RESISTOR, 470K ohm .25W 5%	1	RI	
AP 929975-20	CONNECTOR HEADER 40 PIN	1	P3	AP Products
41-044	CONNECTOR 4 PIN .1C	1	P2	GC Electronics
41-244	CONNECTOR 4 PIN .156C	1	P4	GC Electronics
41-334	CONNECTOR 4 PIN .156C	1	P4	GC Electronics
ICN-16	SOCKET IC 16 PIN	10	U1-8,17,18	
ICN-40	SOCKET IC 40 PIN	1	U12	
	5/8" RUBBER FOOT	1		

JOYSTICK OPTION

74LS123	IC DUAL ONE SHOT	2	U14,16	
74LS368	IC DUAL ONE SHOT	1	U15	
ICN-24	SOCKET IC 24 PIN	2	U11,13	
41-126	CONNECTORS, 6 PIN JOYSTICK	2	P5,6	GC Electronics
	CAPACITOR 1uf 35V TANTALUM	4	C35,36,38,40	
	RESISTOR, 1K ohm .25W	1	R11	
	RESISTOR, 5.1K ohm .25W	4	R8,9,12,14	
	RESISTOR, 10K ohm .25W	2	R13,10	
	JOYSTICK	2		

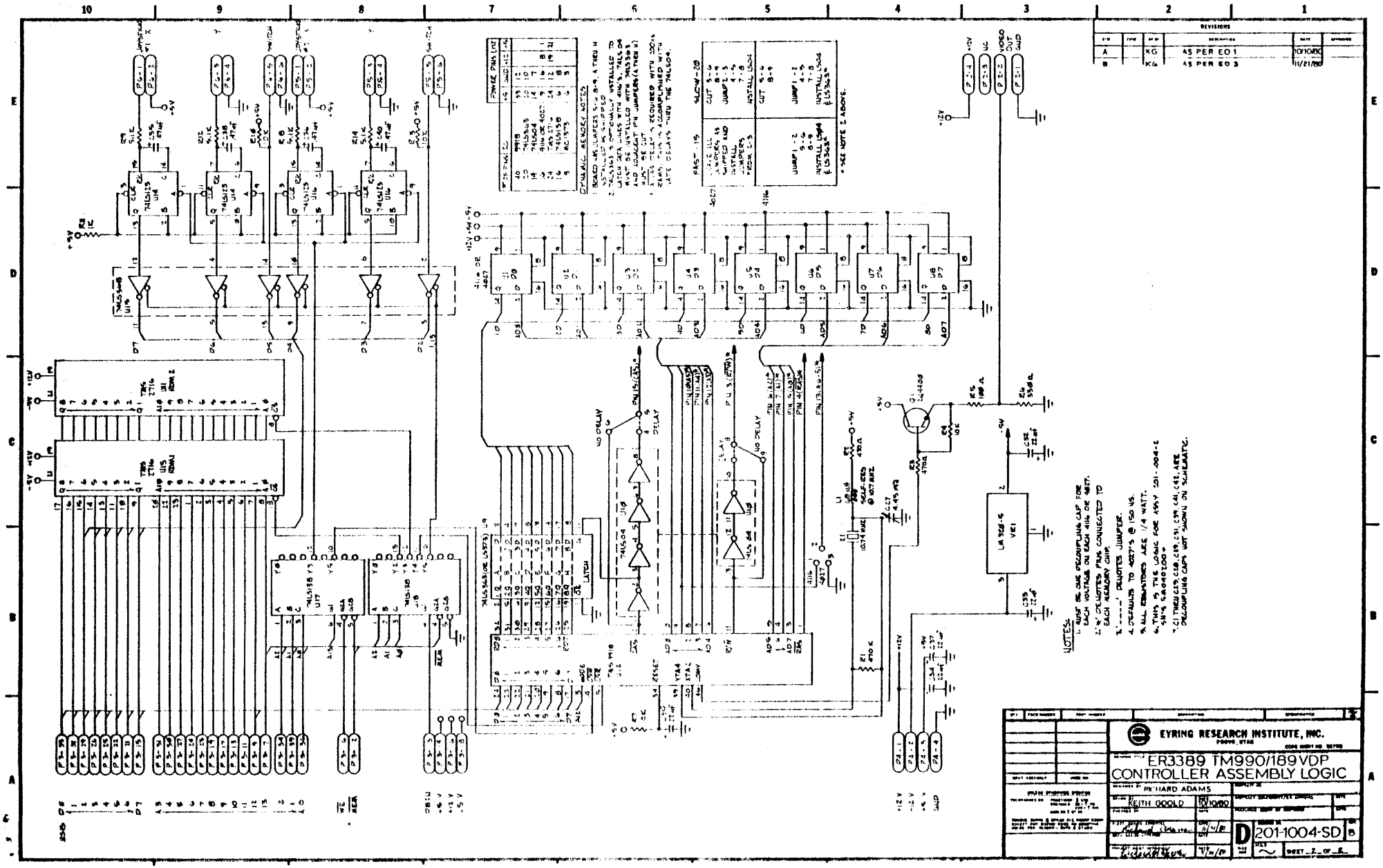
NOTE 1: To rendor the VDP Board operational, your TI 189 Board must contain the offboard memory expansion materials listed on page 9-3 of the TM 990/189 Microcomputer User's Guide (January 1979).

NOTE 2: In the event that the crystal is cut on the low side of the center of frequency, a coil may be added at location next to C-35 after trace has been cut.

NOTE 3: The recommended RF modulator is the SUP "R" MOD II, manufactured by M&R Enterprises of Sunnyvale, California.

Assy #201-1004-2

3389 ASSEMBLY LOGIC
COLOR VIDEO BOARD
ASSEMBLY NO. 201-1004-2



ER3389
COLOR VIDEO BOARD
LOADING DIAGRAM

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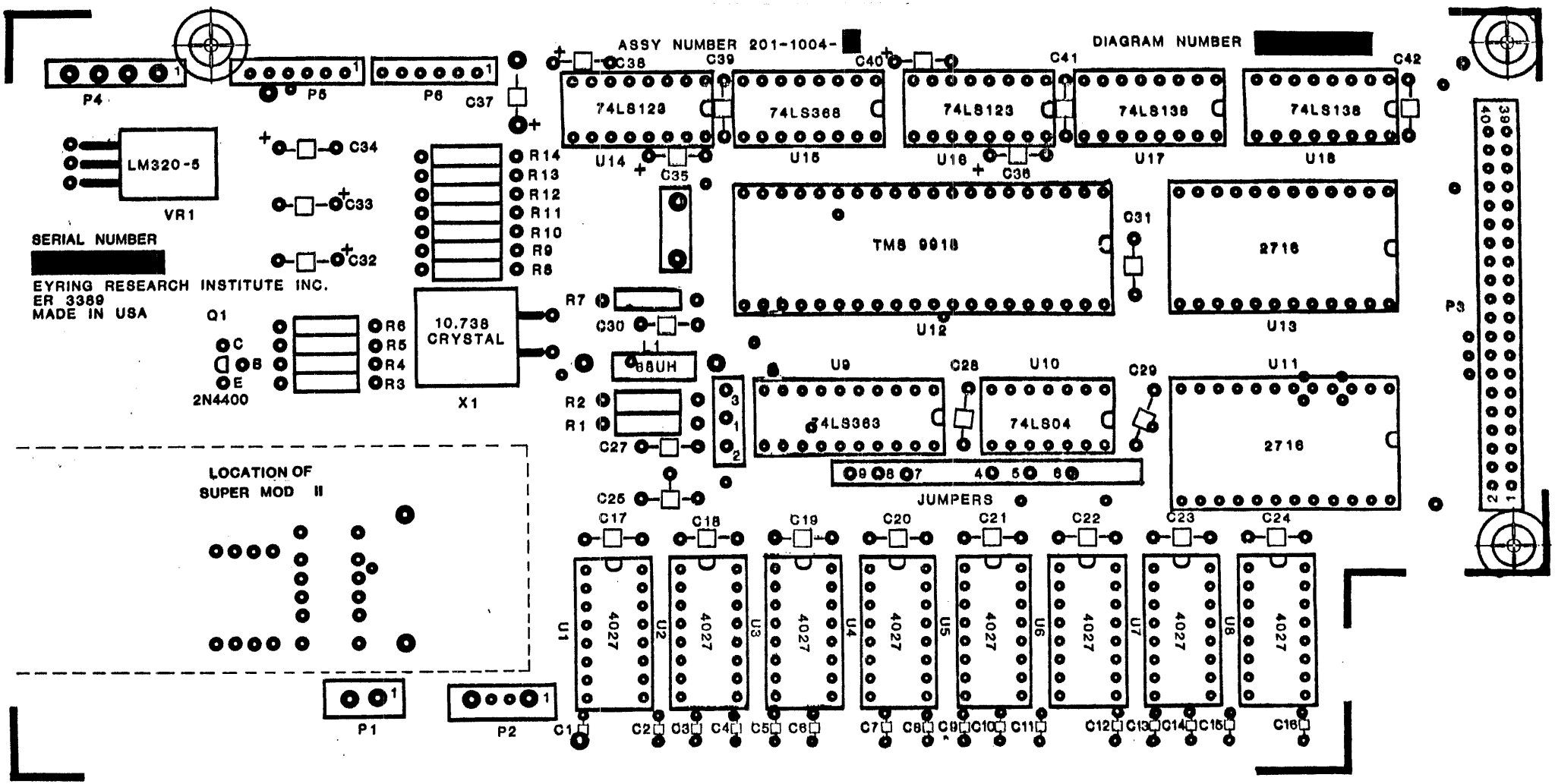

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B37981C0103M050	CAPACITOR DECOUPLING .01uf	16	C1-C16	Siemons
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ST841G226MO16N	CAPACITOR FILTER, 22 uf 15V	5	C30,32-34,37	Siemons
	RESISTOR, 100 ohm .25W 5%	1	R5	
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	RESISTOR, 470 ohm .25W 5%	2	R2,3	
	RESISTOR, 10K ohm .25W 5%	2	R4,7	
	RESISTOR, 470K ohm .25W 5%	1	R1	
AP 929975-20	CONNECTOR HEADER 40 PIN	1	P3	AP Products
41-044	CONNECTOR 4 PIN .1C	1	P2	GC Electronics
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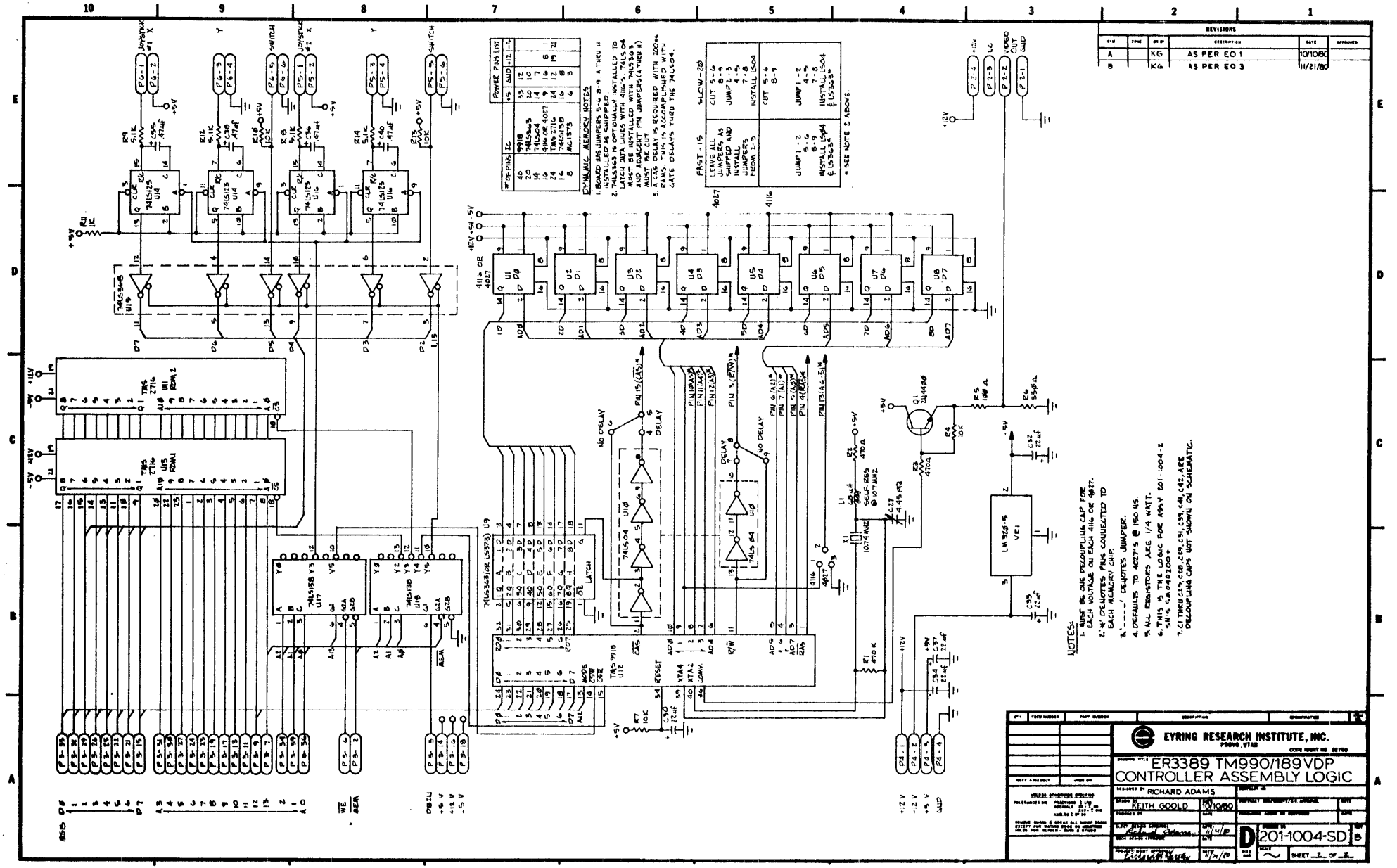
COLOR VIDEO BOARD
ASSEMBLY NO. 201-1004-2



Manual Update

MANUAL TITLE: COLOR VIDEO USING TMS9918 AND UNIVERSITY BASIC APPLICATION REPORT

REVISION CHANGE: * to A MP or MPB NUMBER: 723 P/N: 1602114-9701

PRINTING DATE: _____ DATE OF CHANGE: October 28, 1980

ECN NUMBER: 456419 MANUAL UPDATE NUMBER: 469AR-*-1

CHANGES/ADDITIONS REQUESTED

PAGE CHANGE OR ADD

Copyright Texas Instruments acknowledges Eyring Research Institute, Inc. 1455 West 820 North, Provo, Utah 84601 for their contributions to the product and its documentation. Recognition is extended to Eyring in the following specific areas:

- Development of the VDP Interface Board
- Development of the three demonstration programs reprinted in Appendix B with Eyring's permission
- Development of the Color Enhancements Incorporated in University BASIC
- Preparation of color primitive documentation

1 ✓ 1st paragraph, 3rd line from bottom...Change four to three so the sentence reads:

Three demonstration programs will also be presented at the conclusion of this report....

10 ✓ After the 2nd set of mode commands beginning MODE 0,0 add the following note:

The COLOR command must be executed to enable the text display after the MODE 16 command is executed.

13 ✓ Change the 2nd to last paragraph to read:

The X coordinate ranges from 0 to 287. Positions 0 through 31 will bleed the sprite in from the left hand side, and positions 255 through 287 will bleed the sprite off the right hand side of the TV.

15 ✓ The screen positions depicted for the pattern mode at the top of the page should be changed to read (see next page):

0	1	2	3	4	5	6	7	8	9	...	29	30	31
32	33	34	35	36	37	38	39	40	41	...	61	62	63
64	65	66	67	68	69	70	71	72	73	...	93	94	95
96	97	98	99	100	101	102	103	104	105	...	125	126	127
128	129	130	131	132	133	134	135	136	137	...	157	158	159
160	161	162	163	164	165	166	167	168	169	...	189	190	191
192	193	194	195	196	197	198	199	200	201	...	221	222	223
224	225	226	227	228	229	230	231	232	233	...	253	254	255
256	257	258	259	260	261	262	263	264	265	...	285	286	287
288	289	290	291	292	293	294	295	296	297	...	317	318	319
320	321	322	323	324	325	326	327	328	329	...	349	350	351
352	353	354	355	356	357	358	359	360	361	...	381	382	383
384	385	386	387	388	389	390	391	392	393	...	413	414	415
416	417	418	419	420	421	422	423	424	425	...	445	446	447
448	449	450	451	452	453	454	455	456	457	...	477	478	479
480	481	482	483	484	485	486	487	488	489	...	509	510	511
512	513	514	515	516	517	518	519	520	521	...	541	542	543
544	545	546	547	548	549	550	551	552	553	...	573	574	575
576	577	578	579	580	581	582	583	584	585	...	605	606	607
608	609	610	611	612	613	614	615	616	617	...	637	638	639
640	641	642	643	644	645	646	647	648	649	...	669	670	671
672	673	674	675	676	677	678	679	680	681	...	701	702	703
704	705	706	707	708	709	710	711	712	713	...	733	734	735
736	737	738	739	740	741	742	743	744	745	...	765	766	767

PAGE

20 ✓ Replace the existing schematic with the attached schematic.

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PREFACE

The following manuals present additional information relative to the use of University BASIC*, the TM990/189 microcomputer, and the TMS9918 single-chip VDP.

- University BASIC User's Manual, MP302
- TM990/189 Microcomputer User's Guide, MPB06, 1602004-9701
- 9900 Family Systems Design and Data Book, LCC4400, 97049-118-NI
- TMS9918 Video Display Processor Data Manual, MP010

*University BASIC is a trademark of Texas Instruments Incorporated

INTRODUCTION

University BASIC, a member of TI's TM990 family of software products, is designed to run on the TM990/189 Microcomputer. This combination is an ideal training tool for students and engineers wishing to become familiar with the POWER BASIC language and TM990 architecture. When a video display processor (VDP) and the appropriate commands are interfaced to the TM990/189, a very powerful (yet relatively inexpensive) product emerges, offering uses ranging from consumer games and home computers to industrial applications. This application report will deal with the TMS9918 single-chip VDP and the University BASIC commands that control color, movement, patterns, and sprites, as well as the VDP itself. ~~Four~~ 3 demonstration programs will also be presented at the conclusion of this report to provide some practical examples of using this configuration.

DESCRIPTION

The TMS9918 Video Display Processor is an N-channel MOS LSI device housed in a standard 40-pin plastic package and used in video systems where data display on a color television or monitor CRT is required. The VDP generates all necessary video, control, and synchronization signals. Additionally, it controls the storage, retrieval, and refresh of display data in the dynamic screen refresh memory. The interfaces to the microprocessor, refresh memory, and the monitor or television are defined so as to require a minimum of additional electronics.

Three video color display modes are supported by the VDP: text mode, multicolor mode, and pattern graphics mode, each of which will be discussed in detail in the following sections. The video display itself consists of 35 display planes (external video, backdrop, pattern, and sprites 0-31) which will also be discussed in later paragraphs.

VIDEO DISPLAY BOARD INTERFACE

Connection of the VDP to the TM990/189 microcomputer, is facilitated by a small circuit board (refer to Figure 1). Compatible with any 8-bit CPU, this module joins directly to the /189 microcomputer at the P4 connector as shown in the following figure, and contains 8 dynamic RAM chips for 4k or 16k bytes of video memory, a crystal oscillator, two decode/select chips, and a buffer for the composite video output to a monitor or modulator. Two sockets are reserved for EPROMs which may carry University BASIC application programs, and circuitry for 2 pushbutton joysticks is also supplied. Reference Appendix A for a schematic of this interface board.

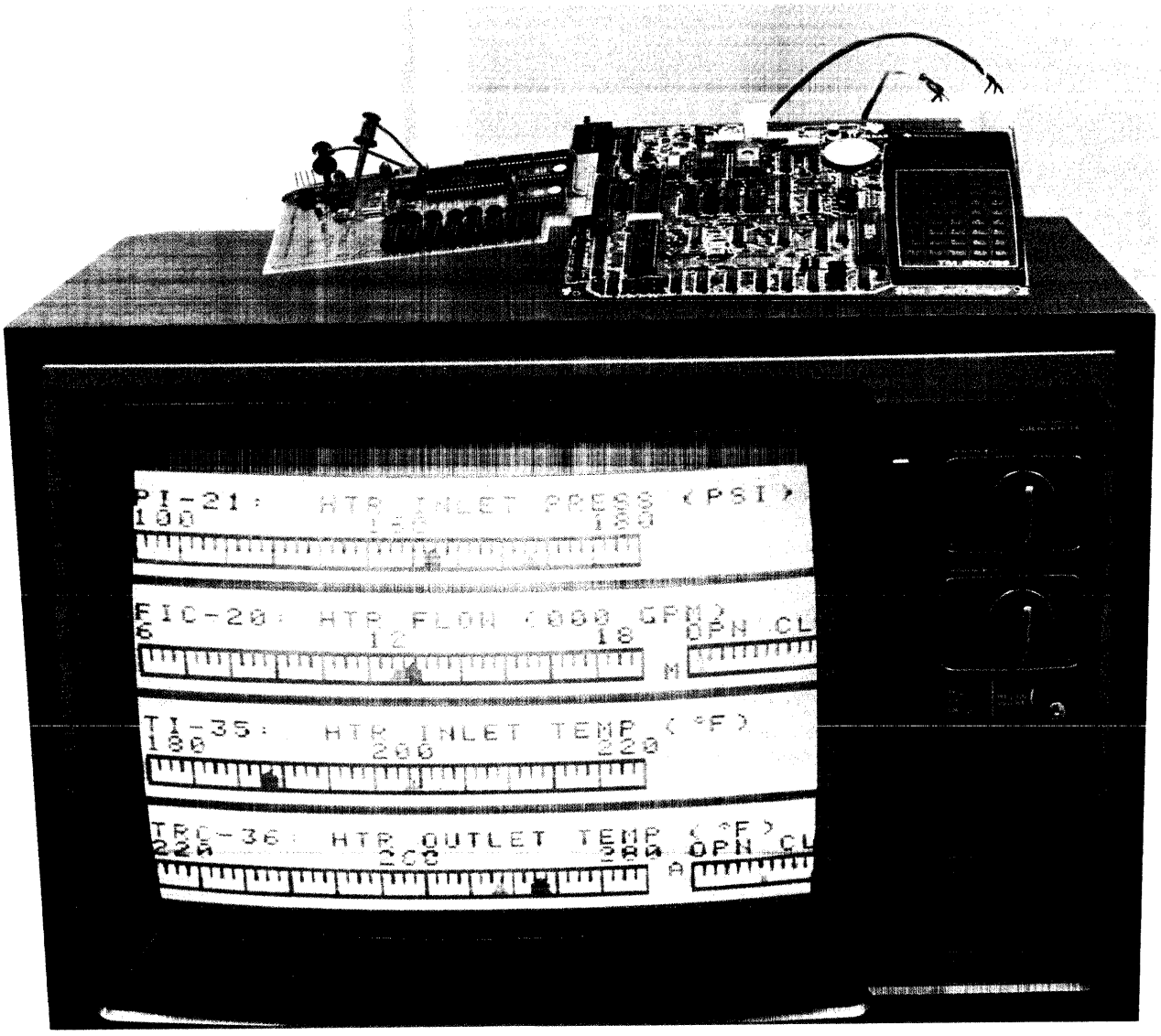


FIGURE 1 – TM990/189 MICROCOMPUTER WITH VIDEO DISPLAY BOARD INTERFACE

THE VDP

The VDP has 3 interfaces: CPU, color monitor, and dynamic refresh RAM, referred to as VRAM (refer to Figure 2). Communication between the VDP and the CPU takes place via an 8-bit bidirectional data bus, 3 control lines, and an interrupt. Through this bus, the CPU assists the VDP in its job of mapping the contents of VRAM by loading the VRAM with the appropriate values, loading the 8 VDP registers with control and mode information, and specifying the location of information in VRAM that will be used in screen mapping. The 3 control lines determine the interpretation of the data transfer.

The Composite Video Output pin is wired to the video display board, interfacing it to the monitor. The VDP sends a Video Output signal that incorporates all necessary horizontal and vertical synchronization signals (as well as luminance and chrominance information), to drive a National Standards Committee (NTSC)-compatible color monitor.

Dynamic Video Refresh RAM (VRAM) resides on 8 dynamic RAM chips for either 4k or 16k bytes of video memory.

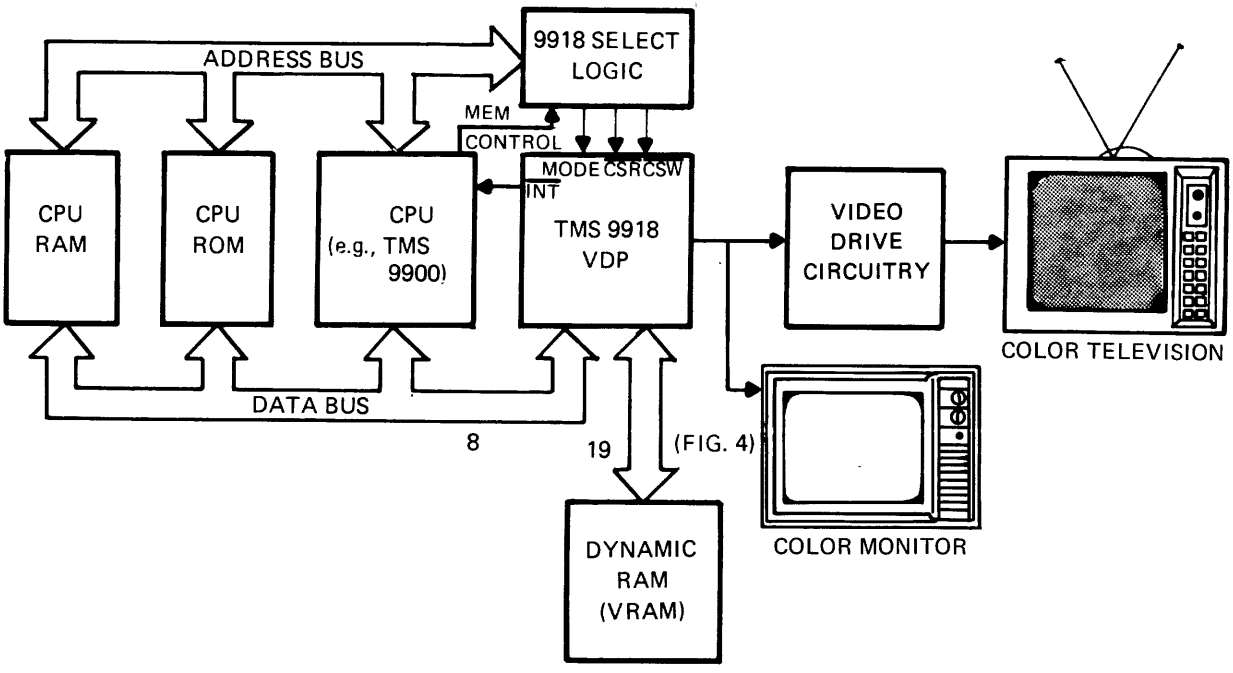
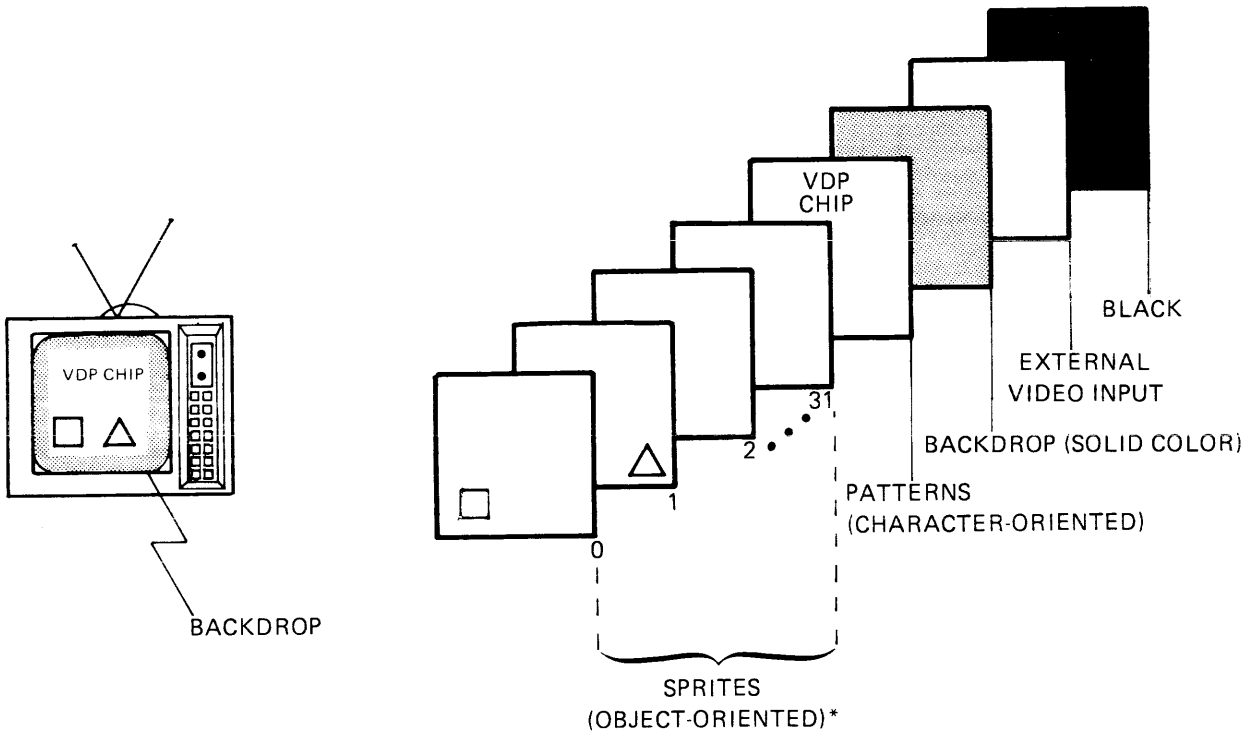


FIGURE 2 – SYSTEM BLOCK DIAGRAM

VIDEO GRAPHICS

Video graphics are accomplished by the VDP through a series of "stacked" planes, arranged in priority order. These may be envisioned as 35 planes sandwiched one on top of the other over a final black background. Figure 3a depicts these planes and the priority of each.



*NOT AVAILABLE IN TEXT MODE.

FIGURE 3a. VDP DISPLAY PLANES

As the figure suggests, the background in the series is always black. The external video input plane may be defined from a camera, some other VDP, or another source through the external video input pin. This plane has the lowest priority and can only be seen through the transparent portions of the remaining 34 planes.

The "backdrop" or solid color plane is larger than the other planes, and so forms a border around the video screen. It may be set to any of 16 colors (including transparent), the default

color being stored in VDP Register 7. (If this register contains the transparent code, and the external video mode is not selected, the backdrop will automatically default to black.)

The "pattern" plane is used for textual and fixed-graphics images. It may be a solid color, all transparent, or a mixture of any two colors (including transparent). or a mixture of the two. Images are produced on this plane by mapping them from memory in a byte-oriented format.

The 32 "sprite" planes (0-31) may each contain a "sprite", or object whose position on the screen is defined by horizontal and vertical coordinates located in VRAM. When two sprites overlap, the sprite with the highest priority will mask the lower priority sprite behind it. Thus, an image such as that of the body of a tree (refer to the following figure) blocks that of the car passing behind it. by the same token, the image of a cloud will mask the color of the sky behind it, giving the viewer a 3-dimensional impression of the whole scene. (Note that multicolored objects can be constructed using two or more sprite planes.)

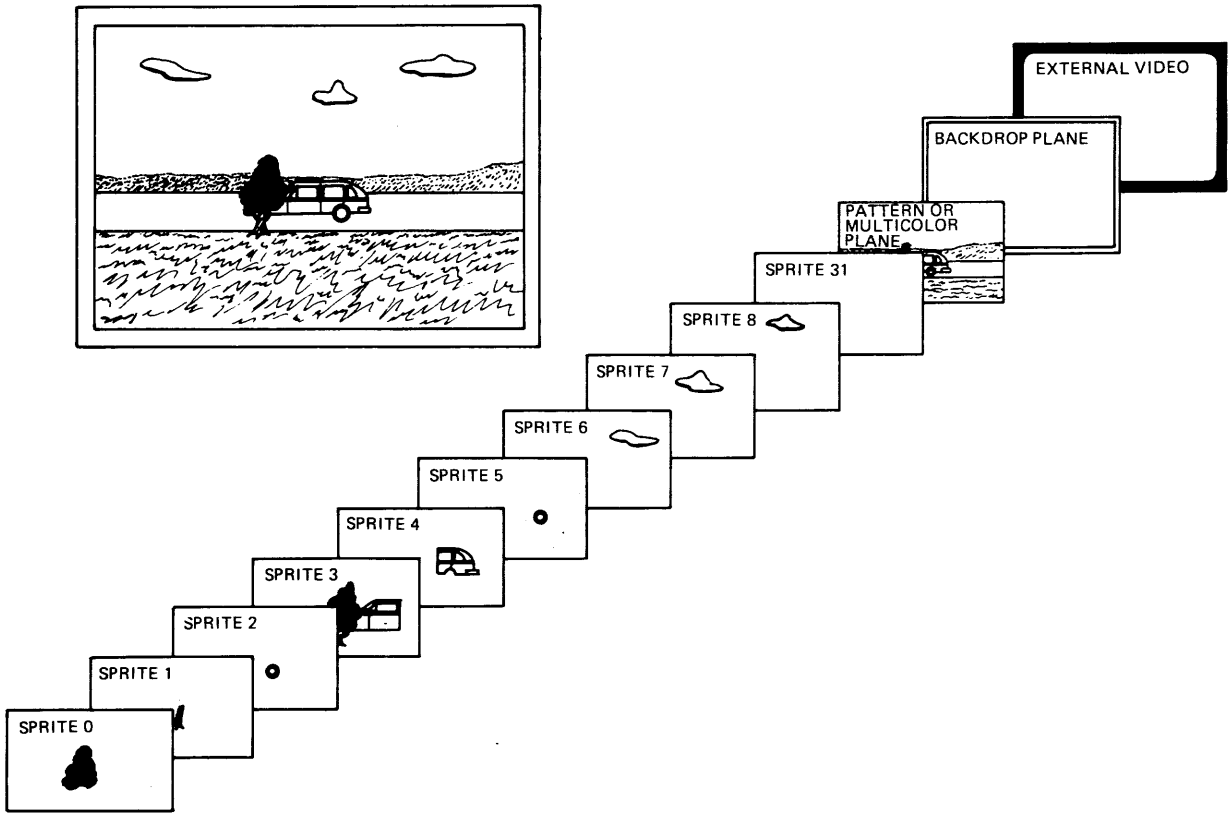


FIGURE 3b. VDP DISPLAY PLANES

The area surrounding a sprite is transparent, and all or part of the sprite itself can be transparent, also. Sprites are composed of "pixels" (i.e., the smallest point of a monitor screen that can be controlled), and come in 3 sizes: 8 x 8 pixels, 16 x 16 pixels, and 32 x 32 pixels.

MODES OF OPERATION

The VDP has three modes of operation: pattern, multicolor, and text. The MODE command (reference the section titled "University BASIC VDP command definitions") allows the user to set these modes. For detailed information regarding the VDP modes of operation, reference the TMS9918 Video Display Processor Data Manual, MP010.

Pattern Mode

In the Pattern Mode, the pattern plane is divided into a grid of 32 (across) by 24 (down) pattern positions. Each position consists of 1 each, 8 x 8 pixels, and each is allowed two unique colors. Three tables occupying a total of 2848 bytes of VRAM are used to generate the pattern plane. These are the Pattern Generator Table, the Pattern Name Table, and the Pattern Color Table.

Multicolor Mode

In the Multicolor Mode, the pattern plane is divided into an unrestricted 64 x 48 color square display, each 4 x 4 pixels in size. A total of 3072 squares, each square can be made any of 16 colors, including transparent. All 16 can be used simultaneously in this mode, and the backdrop and sprite planes are active.

Only two tables are required in this mode; the Pattern Color Table is not needed.

Text Mode

In the text mode the screen is divided into a grid of 40 (across) and 24 (down), each position 6 pixels across by 8 pixels down. The Pattern Plane is generated by the Pattern Name Table and the Pattern Generator Table, providing up to 256 unique patterns at any one time. Pattern definitions are stored in the pattern generator table. VRAM contains a Pattern Name Table which maps the pattern definitions into each of the 960 pattern positions on the pattern plane. Only two colors may be specified for patterns in this mode. These colors are defined in Register 7 of the VDP. Note that sprites are not available in Text Mode.

SPRITES

"Sprites", or special animation patterns providing smooth motion and multilevel pattern overlaying, are moved around the video display pixel by pixel. Each of the 32 high-priority sprite planes has a sprite, each of these covering an 8 x 8, 16 x 16, or 32 x 32 pixel area on its plane. Any part of a plane not covered by a sprite is transparent, and all or part of a sprite itself can be transparent. When all or part of a sprite is transparent, the color of the underlying sprites may be seen. If, however, the sprite has a color, it masks any coincident color on the plane behind it. (The sprite plane on top has a higher priority than the one beneath it, etc.) Sprite planes are used in both the Pattern and Multicolor Modes, but are transparent in the Text Mode.

Sprites are defined in the Sprite Attribute Table: 128 bytes of contiguous memory in VRAM There are 32 entries in this table, each 4 bytes long. Each entry corresponds to the sprites on the sprite planes, the first corresponding to the sprite 0 plane, the second to the sprite 1 plane, etc. this table specifies where the sprite will go on the screen.

University BASIC VDP COMMAND DEFINITIONS

Commands used in conjunction with the color video option offered with the TM990/189 University microcomputer and University BASIC will be listed and described fully in this section; examples are provided where necessary.

COLOR Command

Format: COLOR <exp>

The COLOR command sets both Pattern Mode colors and background color depending upon the sign of the argument. A positive sign sets the background color and loads the argument into Register 7 of the VDP chip. The range is from 0 to 15. If,however, the VDP is in TEXT mode, the range is from 0 to 255 since a color is specified from both the 1's and 0's of the character patterns.

If the argument of the COLOR command is negative, the ASCII character equivalent pattern colors (>20 through >5F) are loaded with absolute value. The range is from 0 to 255. The character patterns are loaded by the MODE -2 command which executes a COLOR -31 command (black on white).

The colors are represented as follows:

0 = Transparent	8 = Medium Red
1 = Black	9 = Light Red
2 = Medium Green	10 = Dark Yellow
3 = Light Green	11 = Light Yellow
4 = Dark Blue	12 = Dark Green
5 = Light Blue	13 = Magenta
6 = Dark Red	14 = Gray
7 = Cyan	15 = White

Some high-resolution color combinations are:

-18 through -31	Black on any color
-47	Medium Green on Black
-79	Dark Blue on Gray
-95	Light Blue on White
-107	Dark Red on Light Yellow
-111	Dark Red on White
-143	Medium Red on White
-195	Dark Green on Light Green
-207	Dark Green on White
-236	Gray on Dark Green
-239	GRAY ON WHITE
-243	White on Light Green
-252	White on Dark Green

MODE Command

Format: MODE <exp> {,<exp>}

The MODE command sets the mode of University BASIC color functions by altering Register 1 of the VDP chip and loading the other registers with specific parameters. It also clears the VDP RAM memory and loads the ASCII characters into patterns numbered >20 through >5F. The displaying of terminal data is also specified by the MODE command. A positive MODE command must be executed before any other VDP commands are used in order to initialize the VDP chip.

The negative MODE functions are as follows:

MODE -1	Clear VDP memory
MODE -2	Load ASCII character patterns

The mode control MODE functions are as follows:

MODE 0	Pattern Mode
MODE 8	Multicolor Mode
MODE 16	Text Mode

Sprite size and magnification are selected by adding 0, 1, 2, or 3 to the above positive commands. These are defined as follows:

```
MODE M+0      Single SPRITE
MODE M+1      Double SPRITE
MODE M+2      Quad SPRITE
MODE M+3      Double Quad SPRITE
```

An optional parameter to positive mode commands allow the TV screen to be used for terminal displays. This second argument specifies the range of the scrolling function and ranges from 0 to 768 in Pattern mode, and 0 to 960 in Text mode. Pattern mode has 24 line of 32 characters while Text mode has 24 lines of 40 characters. If the value is negative, this display function is disabled.

```
MODE 0,0      Use full screen for display
MODE 16,480   Text mode with 1/2 screen display
MODE 0,704    Pattern mode with bottom 2 line display
MODE 0,1      Disable display
```

Note: The COLOR command must be executed to enable the text display after the MODE 16 command is executed

MOVE Command

Format: MOVE <exp>
MOVE <exp>,<exp>,<exp>

The MOVE command allows sprite movement to be done by the University BASIC system clock without program control. The MOVE command generates specific University BASIC variables for the purpose of monitoring and altering the sprite positions in real time. The MOVE command sets X and Y delta velocities as well as limits which automatically reflect the sprite images.

First, to use the clock move functions, a table must be generated to hold sprite positions and limits, and corresponding variables are added to the symbol table of the University BASIC interpreter. This is done by specifying only 1 argument which ranges from 1 to 32. The variables added begin with the letters 'X' and 'Y' followed by the sprite number. This ranges from 'X1' through 'XP' and form 'Y1' through 'YP'. Note that if more than 9 SPRITES are to be moved, 'X:', 'X;', 'X<', 'X=', 'X>', 'X?', 'X@', and corresponding Y's are not accessible by University BASIC.) MOVE 0 will disable any movements. For example:

```
MOVE 5      Create table for SPRITEs 1-5 and variables
            X1, Y1, Y2, X3, X4, Y4, and X5, Y5.
MOVE 0      Disable any movements
```

The sprites are then set in motion by specifying the sprite number followed by the delta X and Y movements. Those movements correspond to the amount added to a sum by each move clock. The sprite is moved according to the sum/256. Hence, if the delta movement were 2, then 128 move clocks would be required to move the sprite 1 pixel.

```
MOVE 1,256,512      Move SPRITE 1 once in X axis and twice in Y
                    axis for every move clock
MOVE 4,128,16       Move SPRITE 4 once in X axis every other
                    Move clock and once in Y axis every 16
                    move clocks.
```

If the sprite is already moving and a new positive delta movement is given, the sprite will continue to move in the same direction with the new delta velocity. If the new delta movement is negative, the sprite will begin to move in the opposite direction with the new absolute delta velocity, reflecting the sprite. Hence, in order to direct a moving sprite in a specific direction, the sprite must first be stopped and the signed delta velocity be given.

Example:

```
MOVE 1,DX,DY          Set SPRITE 1 in motion
MOVE 1,DX+10,-DY      Increase X velocity by 10 and reflect Y
MOVE 1,0,DY;1,-DX,DY  Set SPRITE 1 in right to left motion
                      from current position.  Y is unaffected.
```

The move clock is a derivative of the system clock which runs at 1.6 ms. The system default is: 8 clocks = 1 move clock. This value can be altered by the user with the MEM command and is at location MEM(57). This value can be lowered for faster sprite movement but programs will run proportionally slower.

```
MEM(57)=16      Slow movement
MEM(57)=3       Fast movement
```

The reflection limits are specified with a negative first argument followed by the X and Y limits. These limits are generated by multiplying the lower limit by 256 and adding the higher limit. The lower limit should be less than the upper limit. The X upper limit ranges from 0 to 255, while the Y upper limit ranges from 0 to 192.

Example:

```
MOVE -2,255,192       X ranges from 0 to 255
                      Y ranges from o to 192
MOVE -3,25720,20630 X ranges from 100 to 120 (100*256+120=25720)
                      Y ranges from 80 to 150 (80*256+150=20630)
```

PATTERN Command

Format: PATTERN <exp>,<string>

The PATTERN command defines graphics characters in the Pattern Generator Table of the VDP RAM. The first argument specifies the number of the graphics charcter to be defined and ranges from 0 to 255. The second argument defines the character in two hex

digit increments. A 16 character string is required to define a complete character. The definitions are not limited to 16 characters, however, and multiple pattern characters may be defined with a single PATTERN command.

The pattern table is the same table loaded by the MODE -2 command. Hence, patterns 32 through 95 and corresponding colors are loaded into the pattern table by MODE -2 and are the ASCII equivalent character set.

```
      byte 1                    byte 8
          \                      /
PATTERN 0,"FFFFC3C3C3C3FFFF"      CREATE BOX IN PATTERN 0
PATTERN 32,"1010FE7C386C4400"     Change ASCII spaces to stars

          F    F
byte 1  11111111
        11111111
        11000011
        11000011
        11000011
        11000011
        11111111
byte 8  11111111
```

The pattern generator table is grouped in blocks of 8 patterns in order to assign colors from the pattern color table. The MODE -2 and COLOR command load only those pattern colors associated with patterns 32 through 95. A different color is assigned to the 1's and 0's of the pattern and is defined by the 1's color times 16 plus the 0's color. The color table is accessible with the VDP command and is defined as follows:

```
VDP(960) = Patterns 0-7
VDP(961) = Patterns 8-15
VDP(962) = Patterns 16-23
VDP(963) = PATTERNS 24-31
VDP(964) = Patterns 32-39
VDP(965) = Patterns 40-47
VDP(966) = Patterns 48-55
VDP(967) = Patterns 56-63
VDP(968) = Patterns 64-71
VDP(969) = Patterns 72-79
VDP(970) = Patterns 80-87
VDP(971) = Patterns 88-95
VDP(972) = Patterns 96-103
VDP(973) = Patterns 104-111
  .
  .   etc.
  .
VDP(990) = Patterns 240-247
VDP(991) = Patterns 248-255
```

```
SP ! " # $ % & '
 ( ) * + , - . /
 0 1 2 3 4 5 6 7
 8 9 : ; < = > ?
 @ A B C D E F G
 H I J K L M N O
 P Q R S T U V W
 X Y Z [ \ ]^ _
```

SPRITE Command

Format: SPRITE <exp>,<string>
SPRITE -<exp>,<exp> {,<exp>}
SPRITE <exp>,<exp>,<exp>

The SPRITE command generates special animation patterns which can be smoothly moved by either the SPRITE or MOVE commands. These patterns have a multilevel overlay effect when used in conjunction with Pattern and Multicolor modes. Sprites are not active in Text mode.

A sprite image is created by following the sprite pattern number with a string argument much in the same way as the PATTERN command. A sprite image is defined as one or four of these patterns depending upon the sprite mode of the VDP chip. The sprite patterns range from 0 to 255.

```
SPRITE 0,"FFFFC3C3C3C3FFFF"     Create a box in sprite pattern 0
SPRITE 1,"FFC3A59999A5C3FF"     Create a box with X inside
                                for sprite pattern 1
MODE 0                          Single sprite patterns
MODE 3                          Quad sprite patterns
```

A Sprite Name Table is used to assign a sprite pattern, color, and position to the sprite image on the video plane. up to 32 sprite images can be active at one time, each on a different video plane. Sprites of lower number have priority and overlap sprites of a higher number. A maximum of four sprites can be displayed on one horizontal line. If this rule is violated, the four sprits with the lowest numbers will be displayed normally. The fifth and subsequent sprites are not displayed for that line.

The pattern and color assignments are done with a negative sprite number (-1 to -32) in the first argument followed by the sprite pattern number (0 to 255) and optionally, a sprite color (0 to 15).

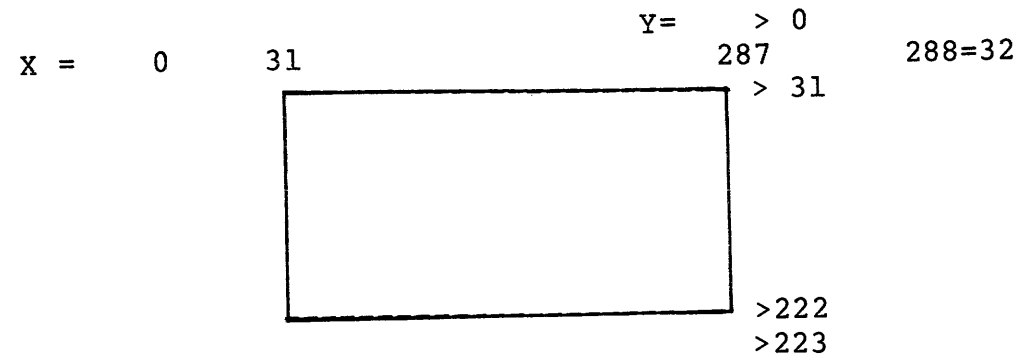
```
SPRITE -1,0,6     Assign sprite pattern 0 to sprite 1
                  with a dark red color
SPRITE -2,0,2     Also assign sprite pattern 0 to sprite
                  2 with a medium green color
SPRITE -2,1       Reassign sprite 2 to pattern 1 and
                  leave medium green
```

The sprite location is defined by the top left-hand corner of the sprite pattern. The sprite is positioned on the video plane by referencing the sprite number (1-32) and the X and Y coordinates.

The X coordinate ranges from 0 to 287. Positions 0 through 31 will bleed the sprite off the [illegible]-hand side of the TV, AND 265-287 will bleed off Right Hand side. LEFT
The Y coordinate ranges from 0 to 223. Positions 0 through 31 will bleed the sprite in from the top of the screen while

positions 190 through 223 bleed the sprite off the bottom of the screen.

These positions are illustrated as follows:



If the Y coordinate of sprite n is set to 240, the sprites n and larger will not be displayed. Also note that these X and Y coordinates are 32 greater than the X1,Y1.... variables generated by the MOVE which range from 0 to 255 and 0 to 190, respectively.

```
SPRITE 1,100,200      Move sprite 1 to screen coordinates (68,168)
SPRITE 3,0,240        Display only sprites 1 and 2
```

The special variable 'CF' is set non-zero when any two sprites on the screen have one or more overlapping pixels. Transparent or colored sprites, as well as those that are partially or completely off the screen are also considered. Sprites beyond the Sprite Name Table terminator (Y=240) are not considered. This flag is latched every screen refresh of the VDP chip and reset after it is used.

```
 ....
100 MOVE 2;1,100,250;2,600,300 Set 2 sprites moving
110 IF CF: TONE 5,100          Indicate when sprites coincide
120 GOTO 110
```

PRINT @ Command
INPUT @ Command

The PRINT @ or INPUT command allows direct writing to VDP RAM as if it were the CRT. The @ followed by an expression indicates where in VDP RAM subsequent data bytes are to be written. Of course, strings as well as numbers and expressions can follow as arguments. The operation is terminated when the PRINT or INPUT command ends.

```
PRINT @99;"SCORE =";N/5
INPUT @992;"YOUR GUESS =";G
```

corresponding screen positions in Pattern Mode are:

```
  1   2   3   4   5   6   7   8   9  10 .... 30  31  32
 33  34  35  36  37  38  39  40  41  42 .... 62  63  64
 65  66  67  68  69  70  71  72  73  74 .... 94  95  96
 97  98  99 100 101 102 103 104 105 106 .... 126 127 128
129 130 131 132 133 134 135 136 137 138 .... 158 159 160
161 162 163 164 165 166 167 168 169 170 .... 190 191 192
193 194 195 196 197 198 199 200 201 202 .... 222 223 224
225 226 227 228 229 230 231 232 233 234 .... 254 255 256
257 258 259 260 261 262 263 264 265 266 .... 286 287 288
289 290 291 292 293 294 295 296 297 298 .... 318 319 320
321 322 323 324 325 326 327 328 329 330 .... 350 351 352
353 354 355 356 357 358 359 360 361 362 .... 382 383 384
385 386 387 388 389 390 391 392 393 394 .... 414 415 416
417 418 419 420 421 422 423 424 425 426 .... 446 447 448
449 450 451 452 453 454 455 456 457 458 .... 478 479 480
481 482 483 484 485 486 487 488 489 490 .... 510 511 512
513 514 515 516 517 518 519 520 521 522 .... 542 543 544
545 546 547 548 549 550 551 552 553 554 .... 574 575 576
577 578 579 580 581 582 583 584 585 586 .... 606 607 608
609 610 611 612 613 614 615 616 617 618 .... 638 639 640
641 642 643 644 645 646 647 648 649 650 .... 670 671 672
673 674 675 576 677 678 679 680 681 682 .... 702 703 704
705 706 707 708 709 710 711 712 713 714 .... 734 735 736
737 738 739 740 741 742 743 744 745 746 .... 766 767 768
```

WRONG
See CORRECTION Sheet

VDP Command

Format: VDP(<exp>) = <exp2>
<var> = VDP <exp>

The VDP command reads from and writes to VDP RAM in bytes. If <expl> is negative (-1 to -7), then <exp2> (0 to 255) is loaded into VDP registers rather than VDP RAM. The range of <exp> and non-negative <expl> depends upon the type of RAM used. For 4027, the range is from 0 to 4095 and for 4116, the range is from 0 to 16383.

```
VDP(960)=5*16+15      Set patterns 0-7 to light blue
                      on white
VDP(-7)=2             Set background color to medium green
PP=VDP(20)            Read RAM value at location 20
```

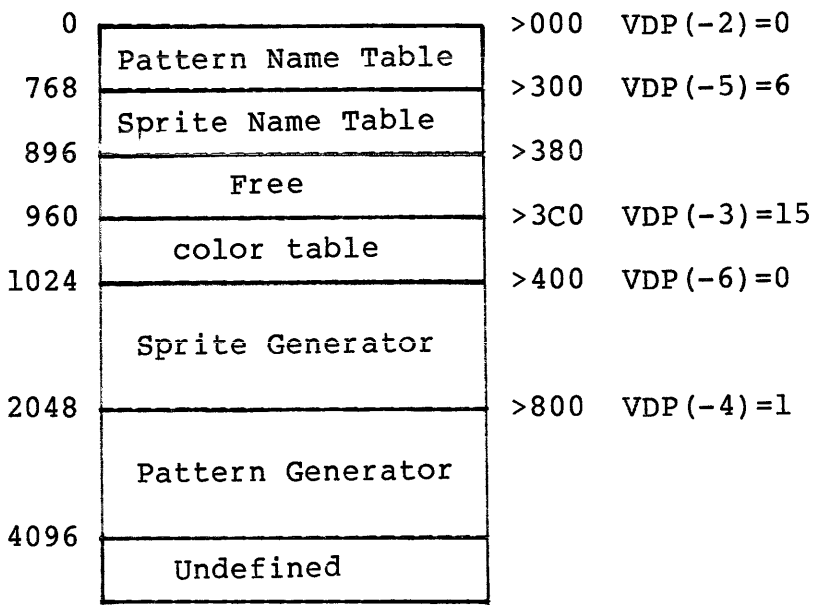
SPECIAL MEMORY LOCATIONS:

The following memory locations affect VDP operations and are defined as follows:

```
MEM(0)=255      REFRESH /189 LED DISPLAY EVERY 1/3 SECOND

MEM(57)=8       SPRITE MOVEMENT COUNTER

MEM(60,61)      RANDOM SEED
```

```
MEM(129)=0      4027
MEM(129)=128    4116

MEM(262,263)    CLOCK FINE COUNTER (1/625 SEC)
MEM(266,267)    CLOCK TIC COUNTER (1 SEC)
```

VRAM ALLOCATIONS:



GLOSSARY

NTSC - National Television Standards Committee which specifies television signal standard for the USA.

pixel - The smallest point on the TV screen that can be independently controlled

sprite - An object whose pattern is relative to a specified X,Y coordinate and whose position can therefore be controlled by that coordinate with a positional resolution of one pixel.

VDP - Video Display Procesor. The VDP is designed to provide simple interface between a microprocessor and a raster-scanned color monitor.

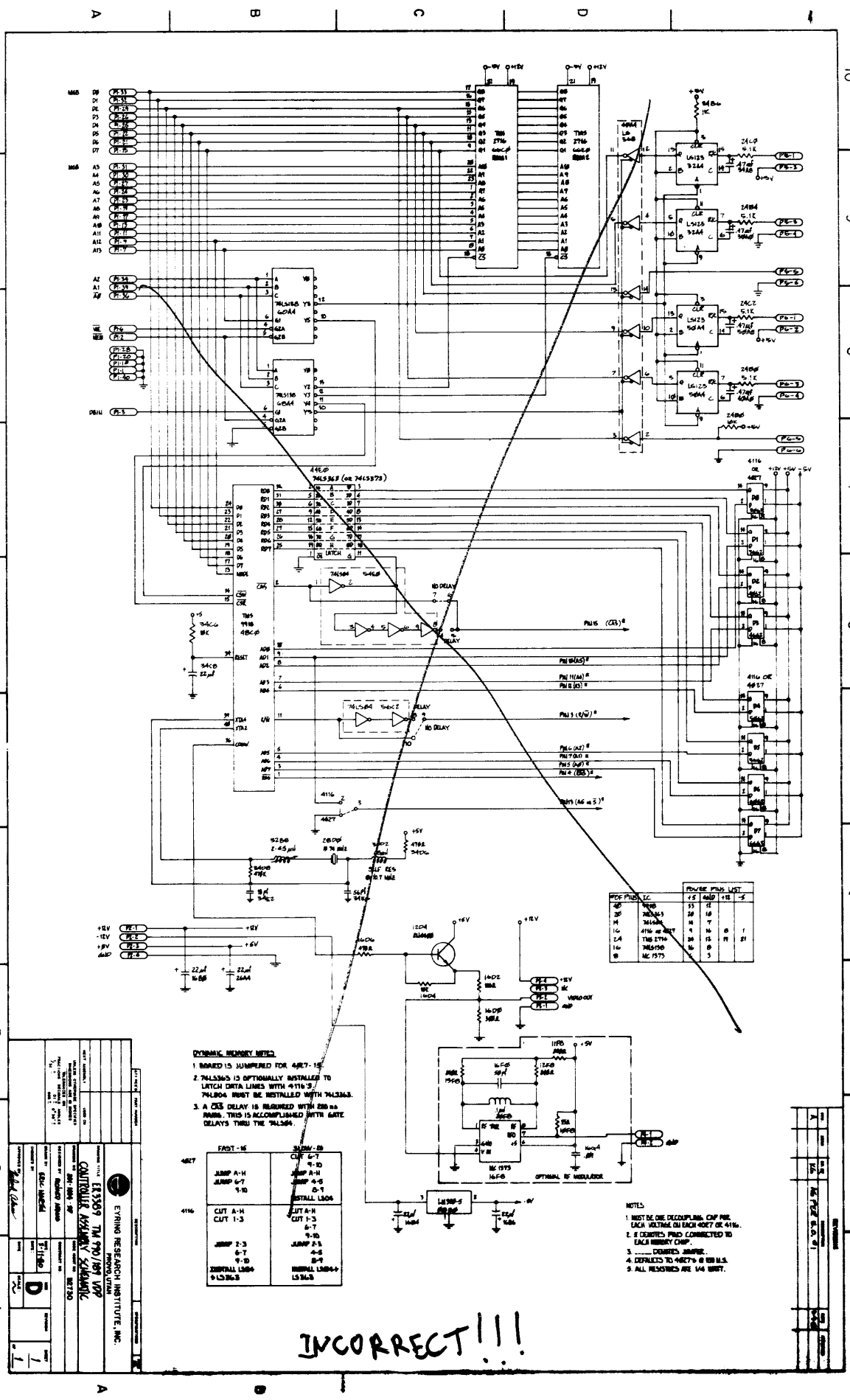
VRAM - Video RAM. This refers to dynamic RAMs that connect to the VDP and whose contents define the TV image.

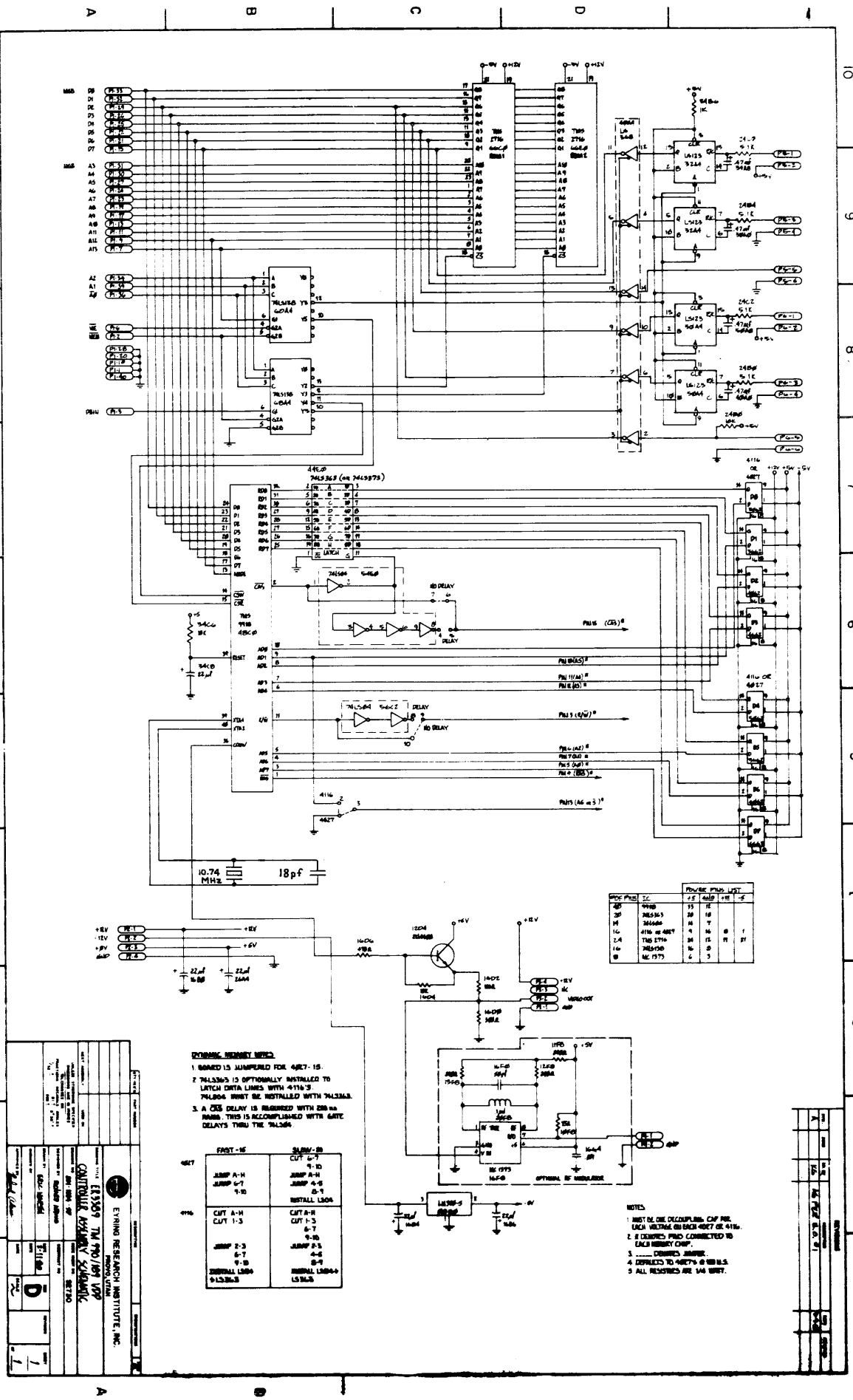
APPENDIX A

VIDEO DISPLAY BOARD

The following schematic details an interface board designed to operate with the TM990/189 microcomputer and University BASIC.*

*Eyring Research Institute
820 North, 1455 West
Provo, Utah 84601
Attn: Marketing Department
Phone: 801-375-2434
Part #: ER3389


DYNAMIC MEMORY NOTES:
1. BOARD IS JUMPERED FOR 4827-15
2. 74LS365 IS OPTIONALLY INSTALLED TO LATCH DATA LINES WITH 4116'S. 74LS04 MUST BE INSTALLED WITH 74LS365.
3. A CAS DELAY IS REQUIRED WITH 200 ns RAMS. THIS IS ACCOMPLISHED WITH GATE DELAYS THRU THE 74LS04.
FAST - 15
SLOW - 20
4827
4116
JUMP A-H
JUMP 6-7
9-10
CUT A-H
CUT 1-3
JUMP 2-3
6-7
9-10
INSTALL LS04
& LS365
CUT 6-7
9-10
JUMP A-H
JUMP 4-5
8-9
INSTALL LS04
CUT A-H
CUT 1-3
6-7
9-10
JUMP 2-3
4-5
8-9
INSTALL LS04 & LS365
NOTES:
1. MUST BE ONE DECOUPLING CAP PER EACH VOLTAGE ON EACH 4827 OR 4116.
2. # DENOTES PINS CONNECTED TO EACH MEMORY CHIP.
3. ____ DENOTES JUMPER.
4. DEFAULTS TO 4827's @ 150 n.s.
5. ALL RESISTORS ARE 1/4 WATT.
EYRING RESEARCH INSTITUTE, INC.
PROVO, UTAH
CONTROLLER ASSEMBLY SCHEMATIC
INCORRECT!!!



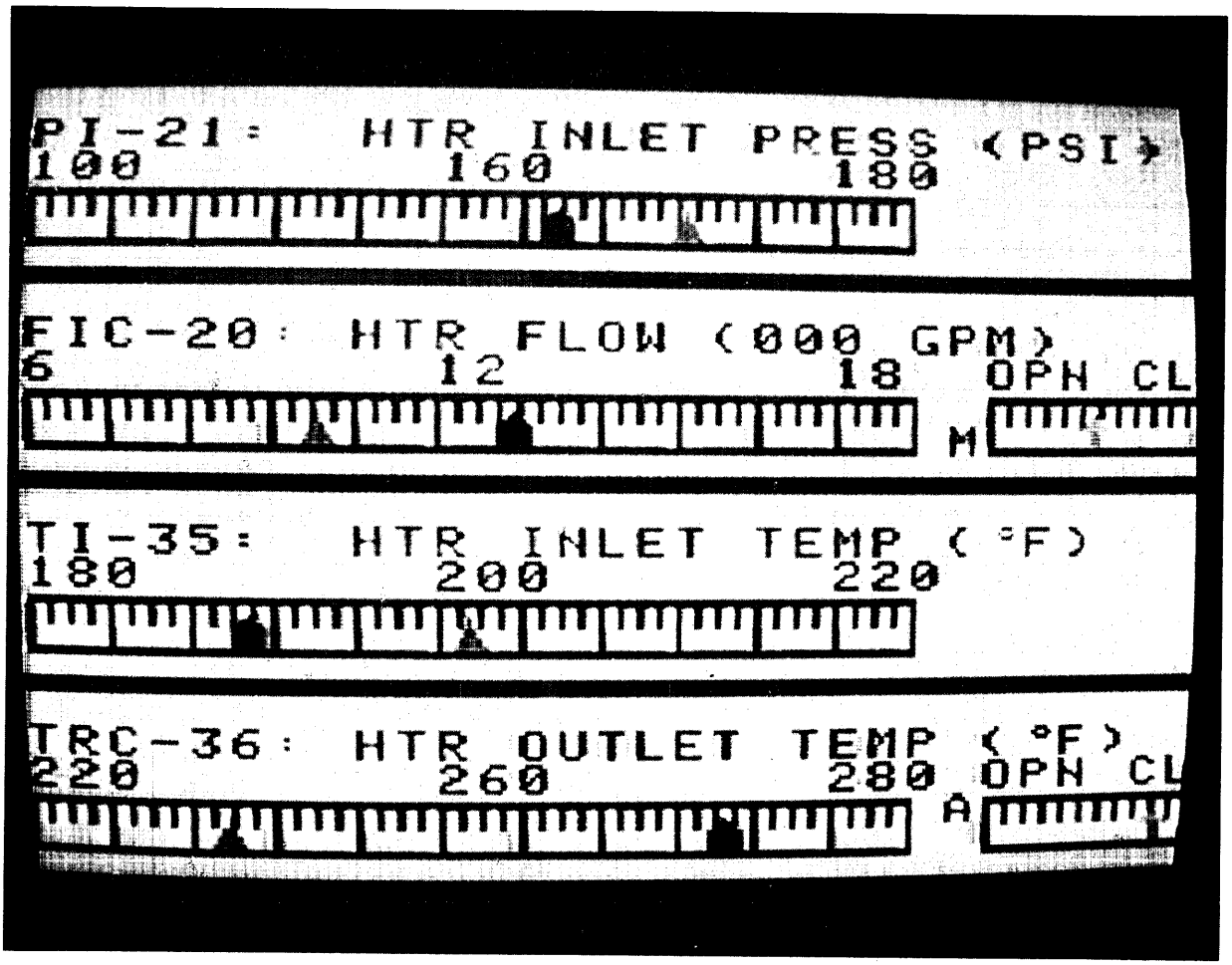
CORRECTED DIAGRAM

APPENDIX B

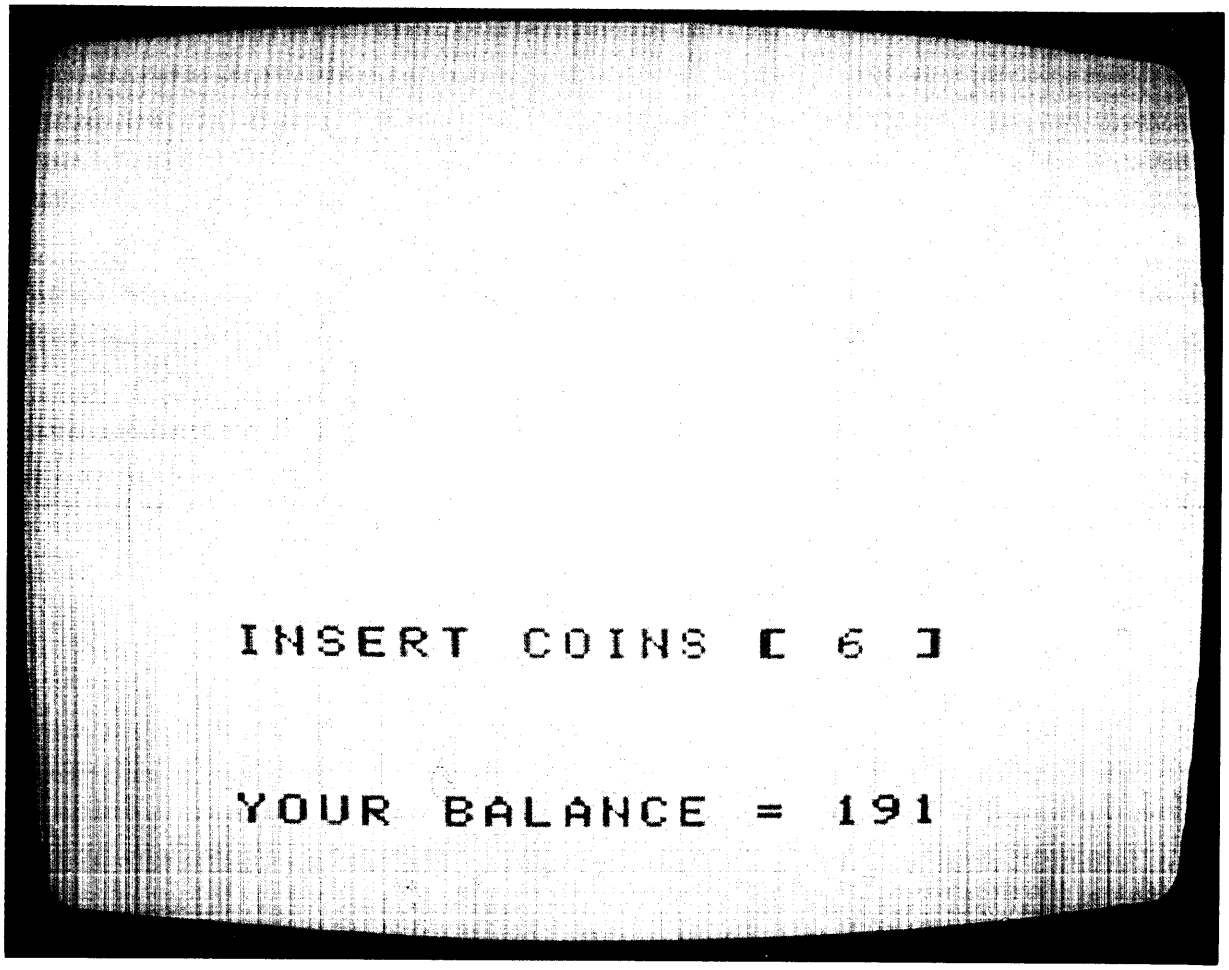
DEMONSTRATION PROGRAMS

The following three programs will give the user "hands-on" experience with the University BASIC Video Commands. The first example depicts an industrial application while the second is a game. The last program exhibits graphics capability, with all 32 sprites moving on the screen at the same time. Note that an illustration of each program is provided following the program listings.

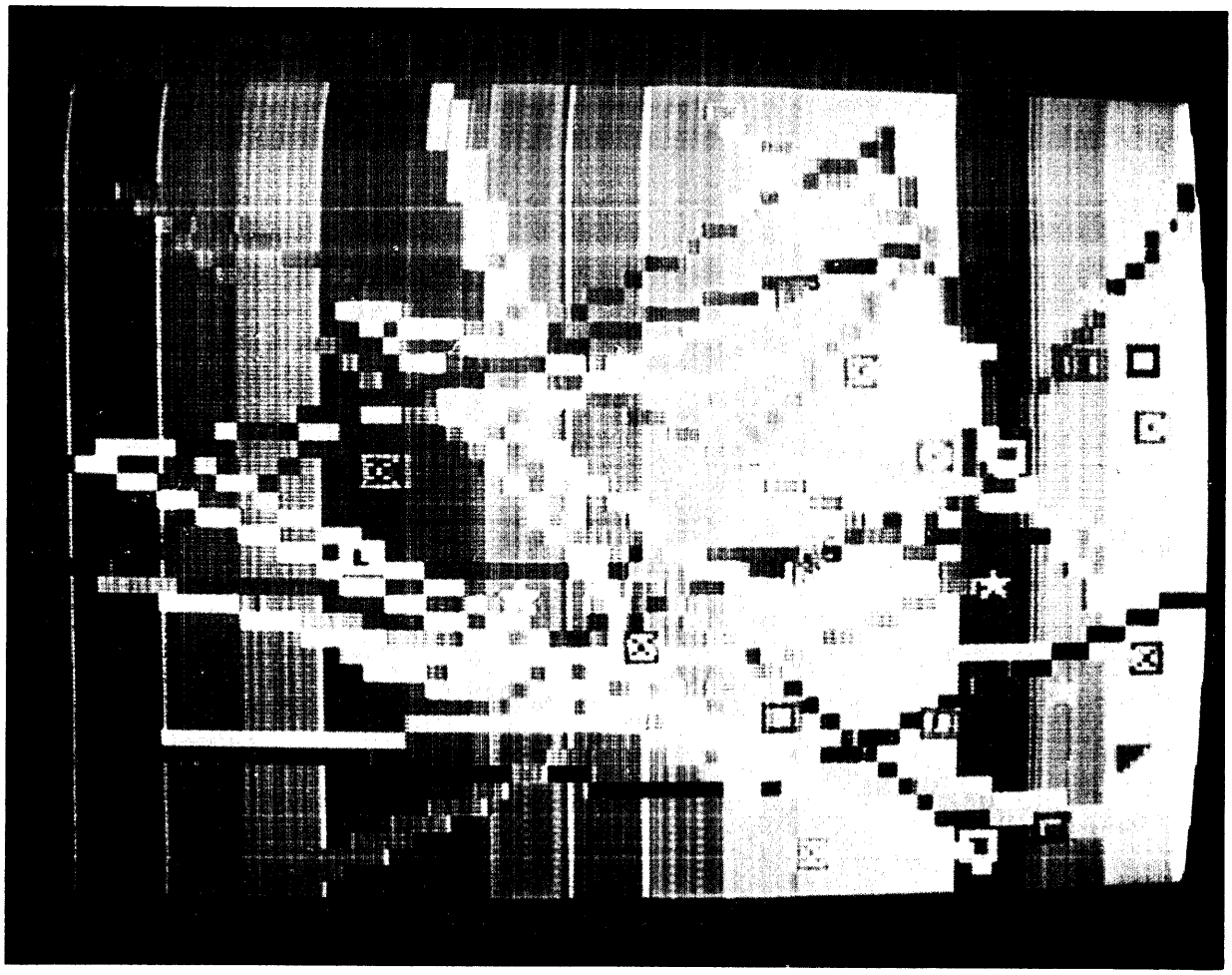
```
NEW
READY
LOAD0
READY
PC DISPLAY

LIST
10 MODE 0:-1:-2: COLOR 5
20 PATTERN 1,"0080808080808080"
25 PATTERN 2,"808080808OFFFF00"
30 PATTERN 3,"0000000000FFFF00"
35 PATTERN 4,"8080808080808000"
40 PATTERN 5,"00FFFF8888888888"
45 PATTERN 9,"FFFFFFFF"
50 PATTERN 64,"1824180000000000"
55 VDP(960)=31: VDP(961)=245
60 FOR I=160 TO 736 STEP 192
65 FOR J=0 TO 31
70 VDP(I+J)=9
75 NEXT J
80 NEXT I
100 PRINT @33"PI-21:  HTR INLET PRESS (PSI)"
110 PRINT @65"100       160       180"
120 PRINT @225"FIC-20: HTR FLOW (000 GPM)"
130 PRINT @257"6         12        18  OPN CLS"
140 PRINT @417"TI-35:  HTR INLET TEMP (@F)"
150 PRINT @449"180       200       220"
160 PRINT @609"TRC-36: HTR OUTLET TEMP (@F)"
170 PRINT @641"220       260       280 OPN CLS"
180 FOR I=97 TO 673 STEP 192
190 FOR J=I TO I+21
200 VDP(J)=5: VDP(J+32)=3+J/2*2-J
210 NEXT J
220 VDP(J)=1: VDP(J+32)=4
230 IF J=119: GOTO 290
240 IF J=503: GOTO 290
250 FOR J=I+24 TO I+29
260 VDP(J)=5: VDP(J+32)=3
270 NEXT J
280 VDP(J)=1: VDP(J+32)=4: VDP(I+56)=2
290 NEXT I
300 SPRITE 0,"10101038387C7CFE10387CFEFEFEFEFE10387CFE38383838"
310 FOR I=1 TO 4
320 SPRITE -I,0,8:-I-6,1,12
330 NEXT I
340 SPRITE -5,2,11:-6,2,11: VDP(344)=77: VDP(696)=65
350 MOVE 6
360 Y1=28: SPRITE 7,140,60: MOVE 1,100,0:-1,24720,0
370 Y2=76: SPRITE 8,132,108: MOVE 2,80,0
380 Y3=124: SPRITE 9,80,156: MOVE 3,130,0
390 Y4=172: SPRITE 10,175,204: MOVE 4,50,0
400 Y5=76: MOVE 5,35,0:-5,-14096,0
410 Y6=172: MOVE 6,60,0:-6,-14096,0
SIZE
USED:1158
FREE:288
```

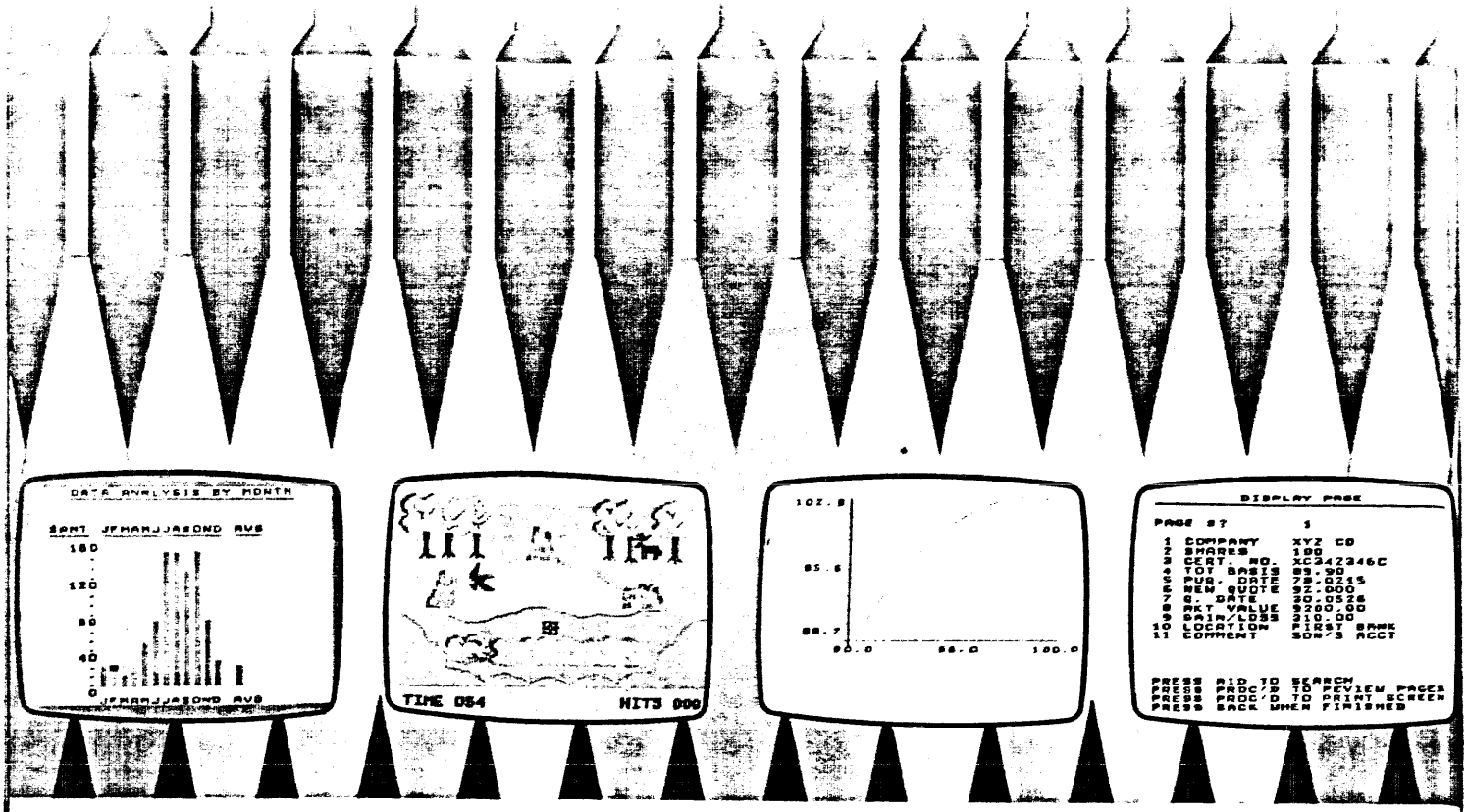

PI-21: HTR INLET PRESS (PSI)
100
160
180
FIC-20: HTR FLOW (000 GPM)
6
12
18
OPN CL
M
TI-35: HTR INLET TEMP (°F)
180
200
220
TRC-36: HTR OUTLET TEMP (°F)
220
260
280
OPN CL
A

```
NEW
READY
LOAD1
READY
SLOT MACHINE

LIST
5 SP=10
8 MEM(60)=MEM 263
10 MODE 0,-1;-1;-2;1: COLOR 3: COLOR -19: DIM C(5)
12 SPRITE 0,"00387CFE7C3800000000668F0F8F870"
14 SPRITE 2,"007CFE7C3810000006CFEFEFE7C3810"
16 SPRITE 4,"1010101038387C100000FE82FE"
18 C(0)=10: C(1)=8: C(2)=12: C(3)=8: C(4)=5: C(5)=4
20 FOR I=1 TO 3
22 SPRITE -I,5,C(5);I,77+32*I,100
24 NEXT I
30 SM=200: VDP(961)=13: VDP(962)=15
32 FOR I=232 TO 244
34 FOR J=0 TO 128 STEP 32
36 VDP(I+J)=8: IF J>0: IF J<128: IF I-I/4*4: VDP(I+J)=16
38 NEXT J
40 NEXT I
50 PRINT @678"YOUR BALANCE ="SM"  "@518"INSERT COINS []
52 IF SP: BT=1+RND SP: PRINT @532;BT" ]": GOTO 56
54 INPUT @532;BT"]"
56 IF BT>0: IF BT<=SM: GOTO 60
58 PRINT @518"BAD BET, STUPID": GOTO 50
60 I1=30+RND 15: I2=I1+30+RND 15: I3=I2+30+RND 15
62 FOR I=0 TO I3
64 IF I<I1: S1=S1+1: S1=S1-S1/6*6: SPRITE -1,S1,C(S1)
66 IF I<I2: S2=S2+1: S2=S2-S2/6*6: SPRITE -2,S2,C(S2)
68 S3=S3+1: S3=S3-S3/6*6: SPRITE -3,S3,C(S3)
70 NEXT I
72 D=0: IF S1=0: GOTO 98
74 IF S1<>S2: GOTO 98
76 IF S1=S3: D=(S1+10)*BT*3+RND 100+200*(RND 8/7): GOTO 100
78 D=2: IF S3>3: D=D+2*(S3-3): IF S1>1: D=D+8+4*(S1-1)
80 D=D*BT
90 PRINT @518"YOU WON"D",LUCKY   ": TONE 50,1500
92 SM=SM+D-BT: IF SM<1: PRINT @518"YOU'RE BROKE!!!": TONE 500,2500: GOTO 10
94 IF SM>2000: PRINT @518"YOU BROKE US!!!": GOTO 10
96 GOTO 50
98 PRINT @518"YOU LOST"BT" !!!    ": TONE 100,1000: GOTO 92
100 FOR I1=1 TO 4
102 FOR I=422 TO 710 STEP 32
104 PRINT @I" *** JACKPOT ***   ": TONE 30+RND 30,10+RND 50
106 NEXT I
108 FOR I=710 TO 422 STEP -32
110 PRINT @I,,: TONE 10+RND 20,30+RND 30
112 NEXT I
114 NEXT I1
116 GOTO 90
SIZE
USED:1226
FREE:220
```


INSERT COINS [6]
YOUR BALANCE = 191

```
NEW
READY
LOAD3
READY
MOVE SPRITES,BARS AND PLOT

LIST
2 S=32
4 MODE 8,-1: MOVE S
6 SPRITE 0,"FFFFC3C3C3C3FFFFFFFEFCF8F0E0C080"
8 SPRITE 2,"1010FE7C386C4400FFC3A59999A5C3FF"
10 FOR I=1 TO S
12 SPRITE -I,RND 4,2+RND 14
14 MOVE I,200+RND 1000,200+RND 1000:-I,255,190
16 NEXT I
20 PLOT 0,0
22 FOR I=1 TO 64
24 PLOT 1,I/4:5,I,0:6,I,48
26 NEXT I
28 GOSUB 50
30 FOR I=1 TO 48
32 PLOT 1,I/3:5,0,I:6,64,I
34 NEXT I
36 GOSUB 50
38 GOTO 22
50 FOR J=1 TO 200
52 PLOT 6,RND 64,RND 48:1,1+RND 15
54 NEXT J
56 RETURN
SIZE
USED:360
FREE:1086
```





Color it TMS9918A. New video display processor. From Texas Instruments.

TMS9918A. For color applications never before possible with a single chip.

TMS9918A. For graphics terminals. Video games. Arcade games. Home computers. Industrial process monitoring. Drafting, animation and education systems.

TMS9918A. For generating excitement in sixteen distinct colors.

This 40-pin plastic DIP generates a standard National Television Systems Committee (NTSC) composite video signal to drive a color or black/white monitor — you can tie it to an ordinary home TV antenna — simply by using a suitable RF modulator. The low-power TMS9918A requires only a 5-V supply.

Another leadership peripheral circuit in TI's 16-bit 9900 Family, the TMS9918A is designed with a general 8-bit data bus, allowing interface to virtually any CPU.

3-D capability

TMS9918A allows 3-dimensional simulation through thirty-five prioritized display planes. This unique feature allows objects on the screen to pass in front of one another, just like they were on different planes.

An external video input pin lets you input a standard broadcast signal, have the TMS9918A overlay text/graphics, and output the resultant mix to a color display.

TMS9927 Video/Timer Controller

For high-resolution CRT terminal applications, TI offers the industry standard. A direct second source of SMC's CRT5027, the TMS9927 provides programmable timing and display for standard and non-standard CRT monitors, in both interlaced and non-interlaced formats. TMS9927 and TMS9918A — a powerful combination for full video capability — from Texas Instruments.

Imagine the possibilities this feature offers: subtitles, interactive broadcasting — and more.

Do-it-yourself flexibility

With the patterns defined in RAM, TMS9918A allows quick, easy alternate pattern set implementation. A powerful graphics mode allows complex graphics presentations, utilizing all 16 colors.

Thirty-two pattern objects can be moved smoothly across the screen to a positional resolution of one picture element. For textual applications, a flexible text mode provides resolution of 24 lines of 40 characters.

A typical video subsystem consists of a TMS9918A, eight dynamic RAMs and two TTL devices to generate CPU-9918A select signals.

The TMS9918A is available right now at your nearest authorized TI distributor.

For more information, write to Texas Instruments Incorporated, P.O. Box 1443, M/S 6404, Houston, Texas 77001.

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85612

CIRCLE 35

EDN Software Note #70

Utility program dumps TMS9900's memory

Ralph Tenny
George Goode & Associates Inc, Dallas, TX

Texas Instruments' TM990/189 single-board μC, with its on-board line-by-line symbolic assembler, adapts easily to new tasks. The assembler leaves the application program in memory, ready to run, thereby minimizing start-up time. And after you finish a job, you can use the μC's cassette-dump facility to save the program. Software maintenance would prove much simpler, however, with some means of making hard-copy documentation.

The program shown in the **figure** deals with this need. It produces a standard memory dump in one of two formats. The form shown in the example generates the memory image as 16 columns of single bytes—a format suiting text better than program material. Comments indicate the modifications needed to produce a listing with eight columns of 2-byte words.

The TM990/189 contains a socket that accepts 1k×8 or 2k×8 EPROMs. The listing shows the program starting at the beginning address for that socket. Because the program resides in ROM,

```
0010 0000        *THIS PROGRAM DUMPS MEMORY CONTENTS FROM A TM 990/189
0020 0000        *UNIVERSITY BOARD TO ANY RS232 PRINTER, USING A SIXTEEN
0030 0000        *COLUMN FORMAT.  THE PROGRAM EXPECTS TO FIND THE
0040 0000        *STARTING ADDRESS OF THE DUMP TO BE IN R1 AND THE
0050 0000        *NUMBER OF BYTES IN R2.  SUBSTITUTE A NOP AT LINE
0060 0000        *NUMBER 370 AND >2F06 AT LINE 410 FOR EIGHT-
0070 0000        *COLUMN FORMAT. USE EVEN BYTE COUNT ONLY.
0080                    IDT  'MEMDMP'
0090 0800               AORG >800
0100 0800               DREG                 ASSEMBLER DIRECTIVE
0110 0800 02E0 STRT     LWPI >180            INITIALIZE WORKSPACE
     0802 0180
0120 0804 04E0          CLR  @>36            SWITCH TO EXTERNAL TERMINAL
     0806 0036
0130 0808 C0C1          MOV  R1,R3           SAVE START ADDRESS
0140 080A C102          MOV  R2,R4           SAVE BYTE COUNT
0150 080C 0205          LI   R5,>0D0A        CARRIAGE RETURN AND LINE FEED
     080E 0D0A
0160 0810 0206          LI   R6,>2000        SPACE CHARACTER
     0812 2000
0170 0814 0209          LI   R9,4            SET UP SHIFT COUNT CONSTANT
     0816 0004
0180 0818 2F05          XOP  R5,12           OUTPUT CARRIAGE RETURN AND
0190 081A 06C5          SWPB R5              THEN A
0200 081C 2F05          XOP  R5,12           LINE FEED TO RESET THE
0210 081E 06C5          SWPB R5              PRINTER CARRIAGE
0220 0820 C203 OUT1     MOV  R3,R8           GET CURRENT ADDRESS, THEN
0230 0822 C289          MOV  R9,R10          INITIALIZE SHIFT COUNTER
0240 0824 0BC8 SHF1     SRC  R8,12           SHIFT EACH CHARACTER TO
0250 0826 2E08          XOP  R8,8            LOW ORDER NIBBLE TO SEND
0260 0828 060A          DEC  R10             COUNT THE SHIFT
0270 082A 16FC          JNE  SHF1            LOOP UNTIL DONE
0280 082C 2F06          XOP  R6,12           OUTPUT TWO SPACES
```

Providing hard copy *of programs developed by the TM990/189 μC's symbolic assembler, this utility program simplifies documentation.* *(Listing continues on next page)*

```
0290 082E 2F06        XOP   R6,12       FOR PRETTY FORMAT
0300 0830 04C7 OUT2   CLR   R7          MAKE A COLUMN COUNTER
0310 0832 04CA NMBR   CLR   R10         AND A SHIFT COUNTER
0320 0834 C213 GET    MOV   *R3,R8      GET A WORD OF DATA
0330 0836 0BC8 SHF2   SRC   R8,12       AND SEND IT AS TWO BYTES
0340 0838 2E08        XOP   R8,8        SEPARATED BY
0350 083A 0BC8        SRC   R8,12       A SPACE
0360 083C 2E08        XOP   R8,8        SEND SECOND CHARACTER
0370 083E 2F06        XOP   R6,12       SUBSTITUTE NOP FOR 8 COL. MODE
0380 0840 05CA        INCT  R10         COUNT THE NIBBLES SENT
0390 0842 028A        CI    R10,3       AND TEST FOR THE LAST
     0844 0003
0400 0846 12F7        JLE   SHF2        REPEAT UNTIL DONE
0410 0848 1000        NOP               OUTPUT A SPACE IN 8 COL. MODE
0420 084A 05C3 NEXT   INCT  R3          BUMP THE POINTER
0430 084C 0644        DECT  R4          COUNT BYTE OUTPUT
0440 084E 130A        JEQ   OUT         QUIT WHEN DONE
0450 0850 0587        INC   R7          COUNT COLUMNS
0460 0852 0287        CI    R7,8        TEST FOR LAST COLUMN
     0854 0008
0470 0856 1301        JEQ   RSET        LAST COLUMN, START A NEW LINE
0480 0858 10EC        JMP   NMBR        OR GET DATA FOR NEXT COLUMN
0490 085A 2F05 RSET   XOP   R5,12       SEND A CARRIAGE RETURN
0500 085C 06C5        SWPB  R5          AND THEN
0510 085E 2F05        XOP   R5,12       A LINE FEED
0520 0860 06C5        SWPB  R5          FOR DESIRED FORMAT
0530 0862 10DE        JMP   OUT1        AND GO FOR MORE DATA
0540 0864 2F05 OUT    XOP   R5,12       RESET PRINTER
0550 0866 06C5        SWPB  R5          TO A NEW LINE
0560 0868 2F05        XOP   R5,12       SO WE CAN
0570 086A 06C5        SWPB  R5          PRINT THE ENDING ADDRESS
0580 086C C289        MOV   R9,R10      MAKE A SHIFT COUNTER AGAIN
0590 086E C203        MOV   R3,R8       GET THE ADDRESS
0600 0870 0BC8 SHF3   SRC   R8,12       ISOLATE A NIBBLE
0610 0872 2E08        XOP   R8,8        AND SENT IT
0620 0874 060A        DEC   R10         COUNT IT AND
0630 0876 16FC        JNE   SHF3        LOOP UNTIL DONE
0640 0878 0560        INV   @>36        RETURN TO ON-BOARD TERMINAL
     087A 0036
0650 087C 06A0        BL    @>3000      AND GO HOME
     087E 3000
0660      0800        END   STRT
ERRORS=0
```

however, you'll have to pick one output format—you can't alter it dynamically.

This program is straightforward and suits use with other TMS9900-based systems. One item, however, might prove unfamiliar, even to some TM990/189 users. At lines 120 and 640, the program modifies the data stored at location 36_H. Whenever an output function is called, the program checks this memory location; if its contents are nonzero, the output gets displayed on the on-board terminal rather than the external device. This feature allows you to use both external and internal peripherals under program control.

One other caution: The end count tests for zero in the byte counter. This test fails if you specify an odd byte count in R_2 at run time. **EDN**

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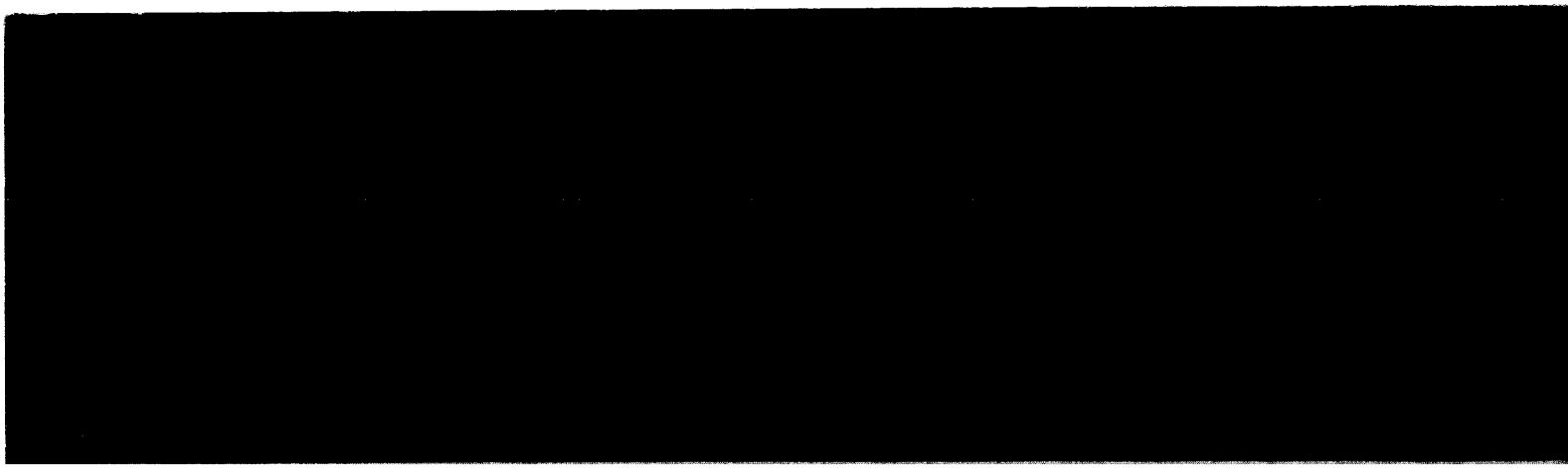

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