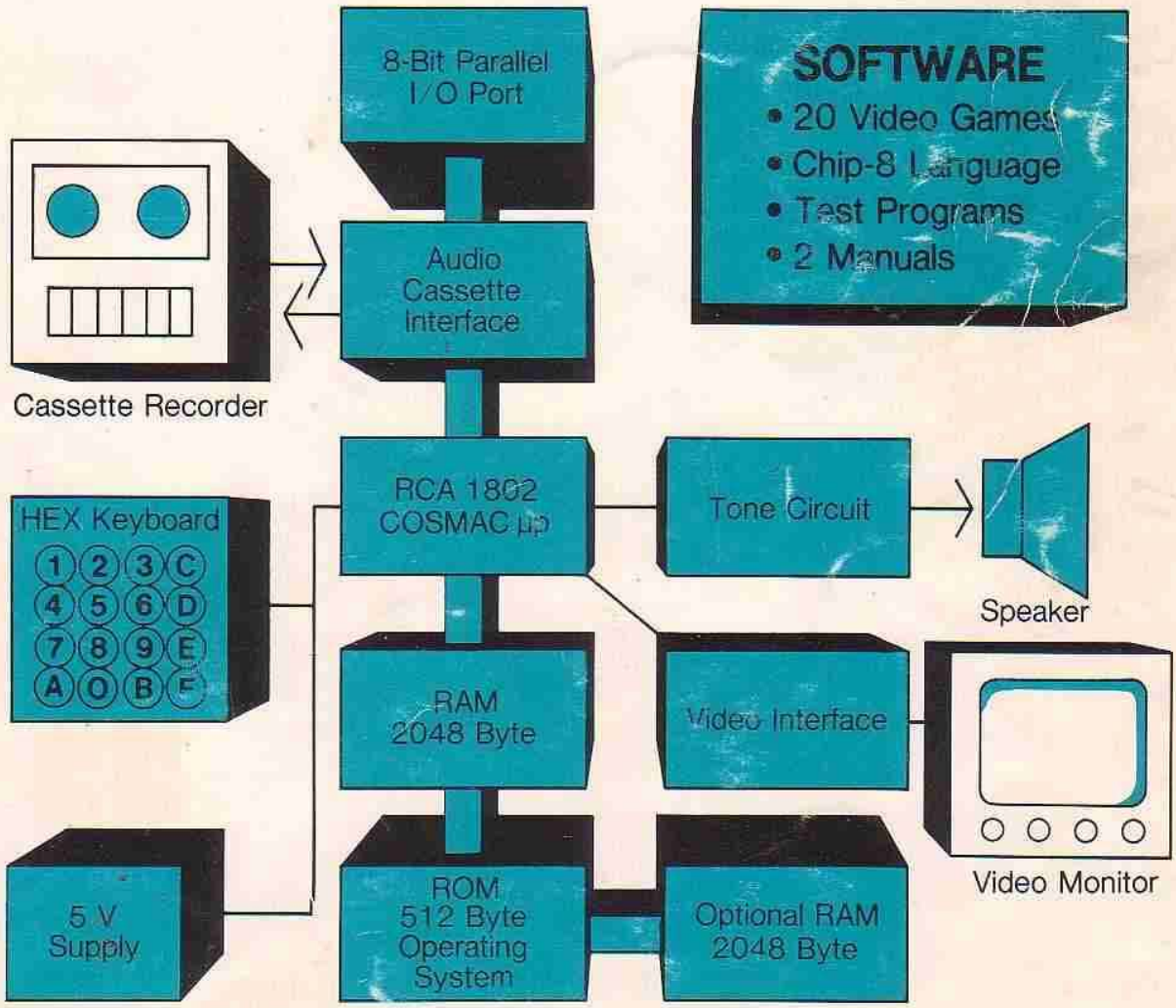
RCA Solid State

RCA COSMAC VIP CDP18S711
Instruction Manual



VIP-311

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RCA COSMAC VIP CDP18S711
Instruction Manual

RCA Solid State Division, Somerville, N. J. 08876

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ACKNOWLEDGMENT

COSMAC VIP has been created by Joe Weisbecker of the RCA Laboratories, Princeton, N.J. so that everyone can have fun and useful personal computer experiences. The elegant and simple hardware system design and the powerful video output together with the customized CHIP-8 language interpreter constitute a fresh and promising approach to personal computers.

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1. Getting Started

COSMAC VIP (Video Interface Processor) CDP18S711 is a complete computer on a single printed-circuit card. It includes the following:

*RCA CDP1802 Microprocessor (91 instructions)
*2048-byte RAM
*Built-in hex keyboard (modern reliable touchpad type)
*Graphic video display interface (standard video output)
*100-byte-per-second audio cassette interface
*Regulated power supply (wall-pack type)
*Crystal clock
*Sound circuits (for signal tones and games)
*512-byte ROM operating system
*Comprehensive documentation
*20 ready-to-use video game programs
*Unique CHIP-8 language (31 easy-to-use instructions)
*On-card RAM expansion up to 40% bytes
*On-card parallel 1/0 port
*Connector for extensive external expansion capability

COSMAC VIP was designed for home hobby use. Just add an inexpensive video display and an audio cassette recorder for program storage. You don't need expensive, hidden extras such as power supply, computer terminal, external keyboard, or additional RAM. COSMAC VIP provides everything needed for years of creative computer fun for the whole family. With COSMAC VIP you're immediately ready to play video games, experiment with computer art or animation, write your own programs with a new language called CHIP-8, or get hands-on experience using machine language.

With COSMAC VIP you can easily create pictures on the display screen and move them around. This feature is invaluable for video games and not usually available with computers costing several times as much. The software you need to use your computer is provided free instead of at added cost or not at all. Simplified operation was a primary design goal so that you don't have to waste a lot of time learning and remembering complex operating procedures. COSMAC VIP uses state-of-the-art devices coupled with an efficient design. Full expansion capability allows you to inexpensively tailor COSMAC VIP to specific applications such as model railroad control, music synthesis, or color graphics. You will soon.dis cover that COSMAC VIP provides a refreshingly new, lower-cost alternative to conventional computers which have been aimed more toward mathematics and business than fun.

What This Manual Covers

T'his manual serves several purposes. It lets you get started playing video games with minimum effort. just set up your system as described in this section and learn how to use the operating system and cassette interface as described in the next section. You can immediately use all the video games in Appendix D without going any further.

If you want to learn to write your own programs, Section III describes an easy language to start with called CHIP-8. Most of the programs in Appendix D were designed using this language. CHIP-8 looks somewhat like machine language but is quicker to learn and easier to use than many of the more common high-level languages. It also requires much less **RAM, which save8 you a lot of money.**

CHIP-8 includes a real time clock, random number generator, decimal conversion, and digit or graphic display capability. It only uses 512 bytes of RAM leaving over 1024 bytes for programs in a 2048-byte system. (You can get an additional 2048 bytes of RAM by plugging four more RAM chips into your card.)

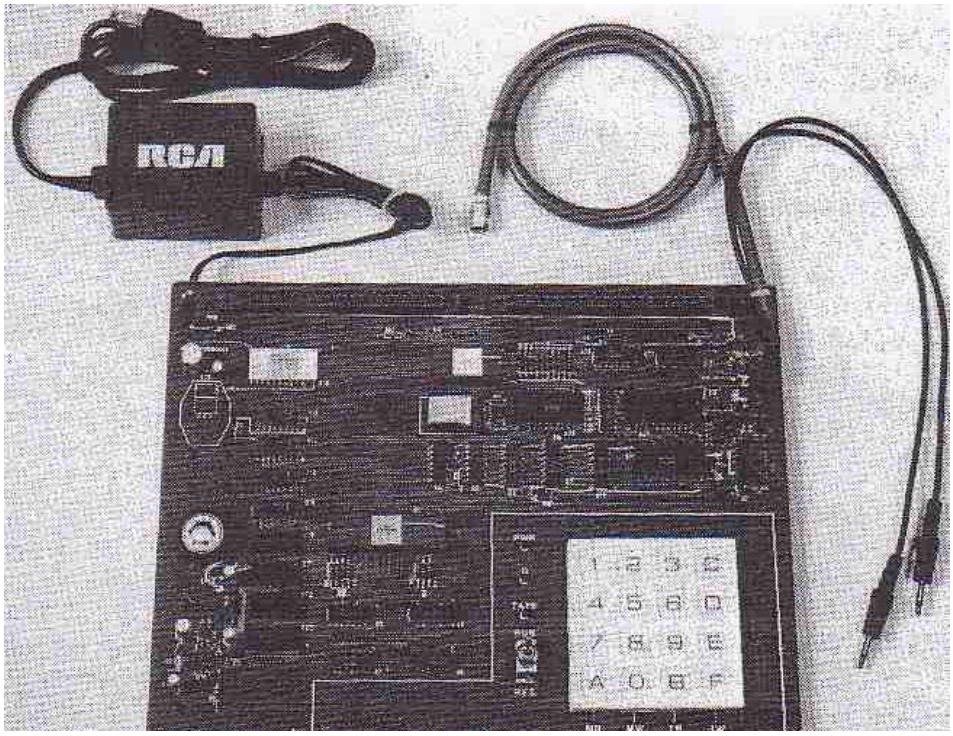
With the aid of the User Manual for the CDPI802 COSMAC Microprocessor, MPM-201, you can explore the fascinating world of machine language programming. You can even combine, machine language programs with CHIP-8 programs or develop your own interpretive languages.

For hardware hackers, COSMAC VIP provides complete external interface capabilities. Some suggestions for inexpensive external devices and applications are listed in Section VI. Logic diagrams, data sheets, trouble -shooting hints, and test programs are provided so that you can explore the hardware in as much detail as you want.

This manual assumes that you are familiar with computer basics from reading one or more of the excellent magazines devoted to home computing. You should understand RAM, ROM, memory addressing, instructions, bytes, etc. The use of a scope will facilitate setting up the cassette system and identifying hardware problems in the rare case where they occur. Hex notation is used in this manual unless noted otherwise. (One byte equals two hex digits.)

The Power Supply

The output wires of the internally regulated power converter supplied with the COSMAC VIP CDP18S711 are connected to the +V DC and GND pads at the back left comer of the PC card. The power converter output is regulated +5 V DC at 600 mA. If you wish to add more RAM to your system, however, you may need a higher-current power supply. A 2048-byte system requires about 350 mA (600 mA worst case). A 4096-byte system should require average current of about 600 mA. If, however, your RAM chips require above average power, you may need to supply as much as 900 mA at 5 V DC, regulated. You can also use your own unregulated 8 to 10 V DC power supply by adding voltage regulator U28 (plus heatsink) to your COSMAC VIP card and cutting the printed circuit link called LKI. Never apply more than +5 V DC to the card unless the U28 regulator has been added and link LKI cut.



Photograph of COSMAC VIP (Video Interface Processor) CDP18S711 The cables in the upper right are for the video display and for cassette operation. Cable on the upper left goes to the power converter.

What You See

You must now decide on the video display for your computer. The video pad at the back right comer of the COSMAC VIP card provides a video signal which you can connect directly to the high-impedance input of most standard video monitors. The horizontal sync frequency is 15,720 Hz and the vertical sync frequency is 60 Hz. One solution to your video display need is a commercial video monitor having a suitable input -- not rf or antenna input. Another option is your TV receiver used with a relatively inexpensive FCC-approved modulator. Do not use a standard TV receiver with the VIP output connected to the VHF or UHF antenna terminals. **Do not use transformerless TV receivers.**

Turning It On

After attaching a suitable video display, apply power. Make sure the RUN switch is in the down (or reset) position. Hold hex key C down while you flip the RUN switch up. You should hear a tone with key C pressed and the Q light should be on. When you release key C the tone and Q light should both go off. (The tone occurs whenever the Q light is on.) You should now see a random pattern of small square spots on the display. Push hex keys 8008 in sequence and you should see 8008 at the bottom left of the screen and 64 at the lower right. Adjust your display controls for the best picture (white spots on a-black background). You can experiment with changing the values of RI, R2, and R4 on the COSMAC VIP card to improve picture quality although this step shouldn't be necessary. Certain modulators work better with an R4 of 1 kilohm instead of 200 ohms. If you don't get a video picture refer to Section VII for troubleshooting hints.

After completing the above set-up procedure, you are ready to enter and run programs on your COSMAC VIP. The COSMAC VIP operating system, explained in the next section, permits you to load programs into memory from the hex keyboard, verify them, and record them on cassettes for later reuse.

11. COSMAC VIP Operation

COSMAC VIP is operated with the RUN switch and hex keyboard. The PWR light shows that power is on. The Q light is activated by various programs. A tone is sounded whenever the Q light is on. The TAPE light glows when cassette input data is present. When using COSMAC VIP, always start with the RUN switch in the down (or reset) position. Flipping the RUN switch up initiates execution of machine language programs beginning at memory location 0000. If you have previously stored the CHIP-8 Ian_ guage interpreter program at locations 0000-01FF, execution of a program written in this language will begin at 0200. To manually terminate execution of any program, flip RUN down.

Using the Operating System

With COSMAC VIP you can load programs into memory from the hex keyboard or cassette recorder, record the contents of memory on cassettes, show the contents of memory bytes in hex form on the display, and examine the contents of CDP1802 microprocessor registers. These functions are performed with the aid of a special program called an operating system. This operating system is contained in a ROM so that it's ready to use as soon as power is turned on. It is located at memory locations 8000-81FF. A machine code listing and summary of this operating system is provided in Appendix B.

To use the operating system hold key C down on the hex keyboard when you flip RUN up. You will hear a tone. Release key C and you're ready to use the operating system.

After selecting the operating system you can do four different operations as shown in the following table:

KEY	OPERATION
0	MW (Memory Write)
A	MR (Memory Read)
F	TW (Tape Write) TR
B	(Tape Read)

For any of these operations you must first enter a memory address. Enter the 4 hex digits of any memory address using the hex keyboard (most significant digit first). You will see the address at the lower left of the screen and the byte contained in that address at the lower right. Remember that addresses and bytes are always entered and shown in hex form. Suppose you entered 0200. You will see 0200 at the bottom left of the screen and the byte stored at 0200 at the lower right.

Memory Write

If you want to change this byte, press the 0 key. Now press two digits of the new byte (most significant digit first) and it will be stored at 0200 replacing the original byte. You will see this change on the screen. If you enter another byte it will be shown and stored at the next higher address in sequence (0201 in this example). You can load any, sequence of bytes directly from the hex keyboard in this manner. If you make a mistake, flip RUN down. With key C pressed, flip RUN back up. Enter the address at which you made the error. Press key 0 and resume entering your program.

Note the random bit pattern on the screen above the hex display. This pattern is the binary data

contained in the last 256-byte page of the on-card RAM. If you have a 2048-byte RAM, you are seeing locations 0700-7FF on the screen. Bit 7 of the byte at 0700 is in the upper left comer. Try storing a sequence of eight AA bytes followed by eight 55 bytes starting at location 0700. Keep repeating this sequence to draw a checkerboard pattern on the screen. There are 32 rows of spots on the screen. Each row represents 8 memory bytes (64 bits). Locations 0700-0707 are shown in the top row, 0708-07OF in the next row down. Draw a bit map on paper and you can construct pictures on the TV screen by entering the proper byte sequences. The byte pattern for displaying the word COSMAC is shown in Appendix A.

Memory Read

Suppose you wish to examine the contents of a memory location. Flip RUN up while pressing key C. Enter the address of the location you want to examine. Press key A for the Memory Read mode. You will see the memory address and the byte stored at that address on the screen. Press any hex key to step through memory and see the contents. Memory locations examined are left unchanged. If a program doesn't run properly you can use this mode to verify that it was stored correctly in memory.

You can now enter and run the short beeper program shown in Appendix A. Flip RUN up with key C pressed. Release key C and enter address 0000. Press key 0 to select the Memory Write mode. Now enter the beeper program one byte at a time using the hex keyboard. Flip RUN down to reset the computer. Flip RUN up to execute the beeper program you just loaded into locations 0000-OOOC. You can load and run any COSMAC VIP program in this manner. For most of the game programs you will first have to load the CHIP-8 interpreter (Appendix C) into locations 0000-OIFF followed by the game program starting at location 0200.

Tape Write

Any program you load into memory will be lost when you turn off power. Unless it is safely stored, you will have to key it in by hand again the next time you want to use it. The cassette interface is provided so that after keying in a program you can then record it on an audio cassette; and when you want to use the program again, all you have to do is play it back into the memory from the cassette. This playback usually takes less than 30 seconds.

The COSMAC VIP cassette interface was designed to work with most standard audio cassette recorders. Panasonic models RQ-309DS, RQ-212D, and RQ-413S have yielded satisfactory results as has the Sony TC-150. In general, better quality recorders provide more reliable operation.

Your tape recorder must have an 8-ohm earphone or external speaker jack and a microphone input jack. Connect the cassette recorder to the COSMAC VIP tape-in tape-out pads on the right-hand side of the card as shown in the cassette attachment diagram in Appendix A.

After properly connecting your cassette recorder you can try recording and playing back a cassette using the operating system as described below. Follow the cassette recording guidelines provided in Appendix A for best results. If you run into trouble, use the cassette phase and data test procedures described in Appendix A for troubleshooting.

The memory is divided into 256-byte pages for recording. You can record 1 to 15 consecutive pages on tape. The low-order byte of your starting address should be 00. Select the operating system by holding key C down while flipping RUN up. Enter the 4-digit address of the first page to be recorded on tape. Press key F and you're ready to record. Rewind a blank cassette and place your cassette unit in the record mode. Wait about 10 seconds and tap the hex key that represents the number of pages you want to record on tape. The screen will go blank and you'll hear a tone while recording. When the specified number of pages has been recorded on the cassette, the tone will end and the last memory byte recorded on tape will be shown on the screen.

Tape Read

To load memory from a previously recorded cassette, first select the operating system (RUN and key C). Enter the memory address of the first page to be loaded (usually 0000). Press key B to select the Tape Read mode. Rewind and play the cassette. Immediately press the hex key representing the number of pages you want to load into memory from the cassette. The tape recorder tone control should be set to maximum high. The volume control should be set for a steadily glowing tape light when data is being read from the tape. The screen will go blank while the program is loaded from the tape into memory. It will show the last byte loaded into memory at the end of loading.

If the Q light and tone come on while a tape is being read, an error occurred. Flip RUN down, rewind the cassette, and try again. You may h ' ave to readjust the cassette volume control. Be sure that the cassette contains at least as many pages as you specify to be loaded. For most of the game programs, load the CHIP-8 interpreter program (Appendix C) into 0000-

01FF, then load the game program starting at 0200. Record a cassette from 0000 to the end of the game program. When you load this tape, starting at 0000, you will be ready to play the game.

Testing Your Cassette System

Test your cassette system by entering the beeper program at 0000 (Appendix A). Store 25 at 06FF. Now record 7 pages on a cassette starting at 0000. Load these 7 pages back into memory from the cassette starting at 0000. If no errors occur you should see "06FF 25" on the screen after loading is complete. Flip RUN down, then up, and the beeper program should be running.

After recording and checking a program cassette, you can break out the tabs at the top of the cassette to prevent accidental erasure. In the event you wish to record on a cassette after you have broken out the tabs, you can do so simply by pasting tape over the tab holes. You can record and keep your own cassette software library starting with the game programs in Appendix D. Cassette recording or playback should require 5 + 2.5N seconds. N is the number of pages recorded on tape. Recording or loading the entire 2048-byte RAM (8 pages) will require less than 30 seconds. Ile next section describes how you can design your own programs using a unique easy-to-learn programming language called CHIP-8.

III. CHIP-8 Language Programming

CHIP-8 is an easy-to-learn programming language that lets you write your own programs. To use the CHIP-8 language, you must first store the 512-byte CHIP-8 language program at memory locations 0000 to 01FF. The CHIP-8 language program is shown in Appendix C in hex form so you can enter it directly in memory using the hex keyboard. You can then record it on a memory cassette for future use. Each CHIP-8 instruction is a two-byte (4-hex-digit) code. There are 31, easy-to-use CHIP-8 instructions as shown in Table L

When using CHIP-8 instructions your program must always begin at location 0200. There are 16 one-byte variables labeled 0-F. VX or VY refers to the value of one of these variables. A 63FF instruction sets variable 3 to the value FF (V3=FF). I is a memory pointer that can be used to specify any location in RAM. An A232 instruction would set I= 0232. 1 would then address memory location 0232.

Branch Instructions

There are several types of jump or branch instructions in the CHIP-8 language. Instruction 1242 would cause an unconditional branch to the instruction at memory location 0242. Instruction BMMM lets you index the branch address by adding the value of variable 0 to it before branching. Eight conditional skip instructions let you test the values of the 16 one-byte variables or determine if a specific hex key is being pressed. This latter capability is useful in video game programs. (Only the least significant hex digit of VX is used to specify the key.)

A 2570 instruction would branch to a subroutine starting at location 0570. 00EE at the end of this subroutine will return program execution to the instruction following the 2570. The subroutine itself could use another 2MMM instruction to branch to (or call) another subroutine. This technique is known as subroutine nesting. Note that all subroutines called (or branched to) by 2MMM instructions must end with 00EE. **Ignoring this rule will cause hard-to-find program bugs.**

How to Change and Use the Variables

The CXKK instruction sets a random byte value into VX. This random byte would have any bits matching 0 bit positions in KK set to 0. For example, a C407 instruction would set V4 equal to a random byte value between 00 and 07.

A timer (or real-time clock) can be set to any value between 00 and FF by a FX15 instruction. This timer is automatically decremented by one, 60 times per second until it reaches 00. Setting it to FF would require about 4 seconds for it to reach 00. This timer can be examined with a FX07 instruction. A FX18 instruction causes a tone to be sounded for the time specified by the value of VX. A value of FF would result in a 4-second tone. The minimum time that the speaker will respond to is that corresponding to the variable value 02.

A FX33 instruction converts the value of VX to decimal form. Suppose 1=0422 and V9=A7. A F933 instruction would cause the following bytes to be stored in memory:

0422	**01**
0423	**06**
0424	**07**

Since A7 in hex equals 167 in decimal, we see that the

Table I - CHIP-8 Instructions

Instruction	Operation
1MMM	Go to 0MMM
BMMM	Go to 0MMM + V0
2MMM	Do subroutine at 0MMM (must end with 00EE)
00EE	Return from subroutine
3XKK	Skip next instruction if VX = KK
4XKK	Skip next instruction if VX n.e. KK
5XY0	Skip next instruction if VX = VY
9XY0	Skip next instruction if VX n.e. VY
EX9E	Skip next instruction if VX = Hex key (LSD)
EXAl	Skip next instruction if VX n.e. Hex key (LSD)
6XKK	Let VX = KK
CXKK	Let VX = Random Byte (KK = Mask)
7XKK	Let VX=VX+ KK
8XY0	Let VX = VY
8XY1	Let VX = VX/VY (VF changed)
8XY2	Let VX = VX & VY (VF changed)
8XY4	Let VX=VX +VY(VF=00 if VX+VY l.e. FF,VF=01 if VX +VY>FF)
8XY5	Let VX = VX - VY (VF = 00 if VX < VY, VF = 01 if VX g.e. VY)
FX07	Let VX = current timer value
FX0A	Let VX = hex key digit (waits for any key pressed)
FX15	Set timer = VX (01 = 1/60 second)
FX18	Set tone duration = VX (01 = 1/60 second)
AMMM	Let I = 0MMM
FX1E	Let I = I + VX
FX29	Let I = 5-byte display pattern for LSD of VX
FX33	Let MI = 3-decimal digit equivalent of VX (I unchanged)
FX55	Let MI = V0:VX (I = I + X + 1)
FX65	Let V0: VX MI (I = I + X + 1)
00E0	Erase display (all 0's)
DXYN	Show n-byte MI pattern at VX-VY coordinates. I unchanged. MI pattern is combined with existing display via EXCLUSIVE-OR function. VF = 01 if a 1 in MI pattern matches 1 in existing display.
0MMM	Do machine language subroutine at 0MMM (subroutine must end with D4 byte)

three RAM bytes addressed by I contain the decimal equivalent of the value of V9.

If 1 =0327, a F355 instruction will cause the values of VO, V1, V2, and V3 to be stored at memory locations 0327, 0328, 0329, and 032A. If 1=0410, a F265 instruction would set V0, V1, and V2 to the values of the bytes stored at RAM locations 0410, 0411, and 0412. FX55 and FX65 let you store the values of variables in RAM and set the values of variables to RAM bytes. A sequence of variables (V0 to VX) is always transferred to or from RAM. If X = 0, only VO is transferred.

The 8XYI, 8XY2, and 8XY4, and 8XY5 instructions perform logic and binary arithmetic operations on two 1-byte variables. VF is used for overflow in the arithmetic operations.

Using the Display Instructions

An 00E0 instruction erases the screen to all 0's. When the CHIP-8 language is used, 256 bytes of RAM are displayed on the screen as'an array of spots 64 wide by 32 high. A white spot represents a I bit in RAM, while a dark (or off) spot represents a 0 bit in RAM. Each spot position on th ' e screen can be located by a pair of coordinates as shown in Fig. 1.

The VX byte value specifies the number of horizontal spot positions from the upper left corner of the display. The VY byte value specifies the number of vertical spot positions from the upper left corner of the display.

The DXYN instruction is used to show a pattern of spots on the screen. Suppose we wanted to form the

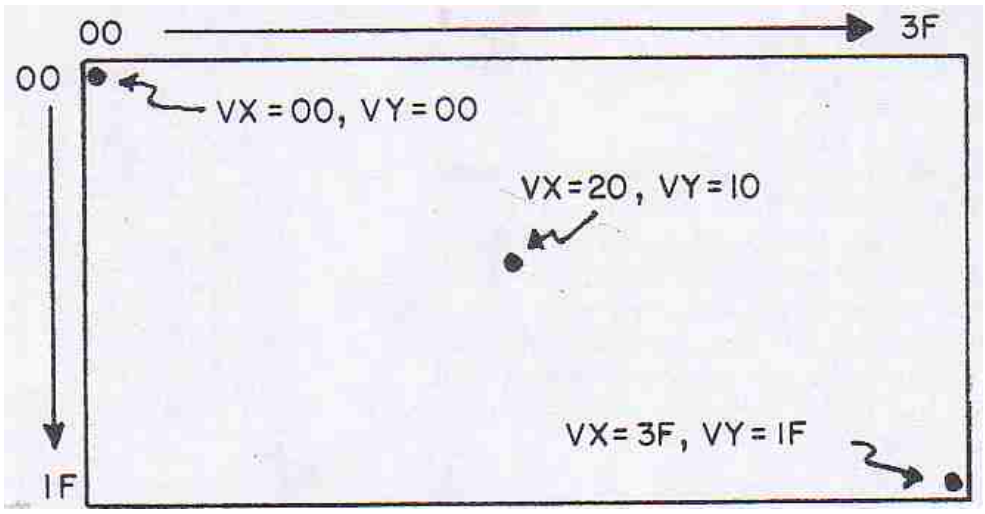


Fig. 1 - Display screen coordinate structure.

pattern for the digit "8" on the screen. First we make up a pattern of bits to form "8" as shown in Fig. 2.

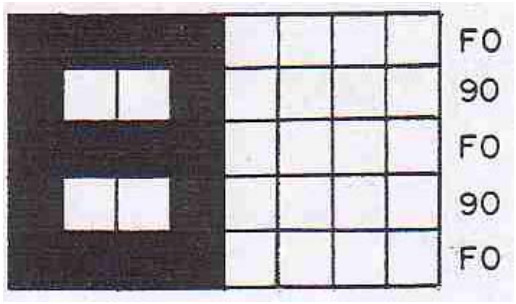


Fig. 2 - Patternof bitsjorming digit 8.

In this example we made the "8" pattern five spots high by four spots wide. Patterns to be shown on the screen using the DXYN instruction must always be one byte wide and no more than fifteen bytes high. (Several small patterns can be combined to form larger ones on the screen when required). To the right of the."8" pattern in Fig. 2 are the equivalent byte values in hex form. We could now store this pattern as a list of five bytes at RAM location 020A as follows:

020A	F0
020B	90
020C	F0
020D	90
020E	F0

Suppose we now want to show this pattern in the upper left corner of the screen. Well assign V I= VX and V2=VY. Now we let VI=V2=00 and set I=020A. If we now do a D125 instruction, the "8" pattern will be shown on the screen in the upper left corner.

You can write a program to show the "8" pattern on the screen as follows:

```
0200 A20A I=020A
0202 6100 V1=00
0204 6200 V2=00
0206 D125 SHOW 5MI@VlV2
0208 1208 GO 0208
020A F090
020C F090
020E F000
```

The first column of this program shows the memory locations at which the instruction bytes in the second column are stored. The third column indicates the function performed by each instruction in shorthand form. Only the bytes in the second column are actually stored in memory.

With the CHIP-8 interpreter stored at 0000-OIFF, you can load the above program in memory and run it. Set VI and V2 to different values to relocate the “8" pattern on the screen. The VX-VY coordinates always specify the screen position of the upper lefthand bit of your pattern. This bit can be either 0 or 1. The last digit of the DXYN instruction specifies the height of your patterns or the number of bytes in your pattern list.

When a pattern is displayed, it is compared with any pattern already on the screen. If a 1 bit in your ,pattern matches a I bit already on the screen, then a 0 bit will be shown at this spot position and VF will be set 1,6 it value of 01. You can test VF following a DXTN instruction to determine if your pattern

touched any part of a previously displayed pattern. This feature permits programming video games which require knowing if one moving pattern touches or hits another pattern.

Because trying to display two I spots at the same position on the screen results in a 0 spot, you can use the DXYN instruction to erase a previously displayed pattern by displaying it a second time in the same position. (The entire screen can be erased with a single 00E0 instruction.) The following program shows the "8" pattern, shows it again to erase it, and then changes VX and VY coordinates to create a moving pattern:

```
0200 A210 I=0210
0202 6100 V1=00
0204 6200 V2=00
0206 D125 SHOW 5MI@VlV2
0208 D125 SHOW 5MI@VlV2
020A 7101 V1+01
020C 7201 V2+01
020E 1206 GO 0206
0210 F090
0212 F090
0214 F000
```

The "8" pattern byte list was moved to 0210 to make room for the other instructions. Try changing the values that VI and V2 are incremented by for different movement speeds and angles. A delay could be inserted between the two DXYN instructions for slower motion.

The FX29 instruction sets I to the RAM address of a five-byte pattern representing the least significant hex digit of VX. If VX =07, then I would be set to the address of a "7" pattern which could then be shown on the screen with a DXYN instruction. N should always be 5 for these built-in hex-digit patterns. Appendix C shows the format for these standard hex patterns. The following program illustrates the use of the FX29 and FX33 instructions:

```
0200 6300 V3=00
0202 A300 I=0300
0204  F333 MI=V3 (3DD)
0206  F265 VO:V2=MI
0208  6400 V4=00
020A  6500 V5=00
020C  F029 I =VO (LSDP)
020E  D455 SHOW 5MI@V4V5
0210  7405 V4+05
0212  F129 I=Vl(LSDP)
0214  D455 SHOW 5MI@V4V5
0216 7405  V4+05
0218   F229 I =V2 (LSDP)
021A   D455 SHOW 5MI@V4V5
021C   6603 V6=03
021E   F618 TONE=V6
0220   6620 V6=20
0222   F615 TIME=V6
0224   F607 V6=TIME
0226   3600 SKIP;V6 EQ 00
0228   1224 GO 0224
022A   7301 V3+01
022C   00E0 ERASE
022E  1202 GO 0202
```

This program continuously increments V3, converts it to decimal form, and displays it on the screen.

The FX0A instruction waits for a hex key to he pressed, VX is then set to the value of the pressed key, and program execution continues when the key is released. (If key 3 is pressed, VX=03). A tone is heard while the key is pressed. This instruction is used to wait for keyboard input.

Applying CHIP-8

You should now be able to write some simple CHIP-8 programs of your own. Here are some things to try:

1. Wait for a key to be pressed and show it on the display in decimal form.

2. Show an 8-bit by 8-bit square on the screen and make it move left or right when keys 4 or 6 are held down.

   Show an 8-bit square on the screen. Make it move randomly around the screen.

4. Show a single bit and make it move randomly around the screen leaving a trail.

   Program a simple number game. Show 100 (decimal) on the screen. Take turns with another player. On each turn you can subtract 1-9 from the number by pressing key 1-9. The first player to reach 000 wins. The game is more interesting if you are only allowed to press a key which is horizontally or vertically adjacent to the last key pressed.

If you are unsure of the operation of any CHIP-8 instruction, just write a short program using it. This step should clear up any questions regarding its operation. In your CHIP-8 programs be careful not to write into memory locations 0000-01FF or you will

lose the CHIP-8 interpreter and will have to reload it. You can insert stopping points in your program for debugging purposes. Suppose you want to stop and examine variables when your program reaches the instruction at 0260. Just write a 1260 instruction at location 0260. Flip RUN down and use operating system mode A to examine variables V0-VF. The memory map in Appendix C shows where you can find them.

After the above practice you are ready to design more sophisticated CHIP-8 programs. **Always prepare a flowchart before actually writing a program.** The last 352 bytes of on-card RAM are used for variables and display refresh. In a 2048-byte RAM system you can use locations 0200-069F for your programs. This area is enough for 592 CHIP-8 instructions (1184 bytes). In a 4096-byte RAM system you can use locations 0200-0E8F. This area is equal to 1608-CHIP-8 instructions (3216 bytes).

Some Program Ideas

Here are a few ideas for programs to write using the CHIP-8 language:

1. INTOXICATION TESTER - Display a six digit random number on the screen for several seconds. You must remember this number and enter it from the keyboard within ten seconds after the screen goes blank to prove that you're sober and score.

2. NUMBER BASE QUIZ - Display numbers in binary or octal on the screen. You must enter their decimal equivalent to score points.

3. DICE - Push any key to simulate rolling dice displayed on the screen.

4. PUPPETS - Show large face on the screen. Let small children move mouth and roll eyes by pushing keys.

r BUSY BOX - Let small children push keys to make different object appear on the screen, move, and make sounds.

6. SHUFFLEBOARD - Simulate shuffleboard type games on the screen.

7. COMPUTER ART - Design new programs to generate pleasing geometric moving patterns on the screen.

8. INVISIBLE MAZE - Try to move a spot through an invisible maze. Tones indicate when you bump into a wall.

9. LUNAR LANDING - Program a graphic lunar landing game.

10. COLLIDE - Try to maneuver a spot from one edge of the screen to the other without hitting randomly moving obstacles.

Il. CAPTURE - Try to chase and catch randomly moving spots within a specified time limit.

12. LEARNING EXPERIENCES - Program graphic hand and eye coordination exercises for young children or those with learning disabilities.

13. NUMBER RECOGNITION - Show groups of objects or spots on the screen. Young child must press key representing number of objects shown to score.

WALL BALL - Program a wall-ball-type paddle game for one player.

15. FOOTBALL - Each player enters his play via the hex keyboard and the computer moves the ball on the screen.

16. BLACKJACK - Play "21" against the com puter dealer.

17. HOLIDAY DISPLAYS - Design custom, animated displays for birthdays, Halloween, Christmas, etc.

18. METRIC CONVERSION - Help children learn metric by showing lengths on screen in inches and requiring centimeter equivalent to be entered to score.

19. TURING MACHINE - Simulate a simplifed Turing machine on the screen.

20. TIMER - Use the computer to time chess games, etc.

21. HEXAPAWN - Program Hexapawn so that the computer learns to play a perfect game.

22. NIM - Program Nim with groups of spots shown on the screen.

23. BLOCK PUZZLES - You can simulate a variety of sliding block-type puzzles on the screen.

24. BOMBS AWAY - Show a moving ship at the bottom of the screen. Try to hit the ship by releasing bombs from a moving plane at the top of the screen.

25. PROGRAMMED SPOT - Introduce children to programming concepts by letting them preprogram the movements of a spot or object on the screen.

The next section will discuss machine language programming. You can even combine machine language subroutines with CHIP-8 programs if desired.

IV. Machine Language Programming

VIP Machine Coding

For a complete description of machine language instructions, refer to the User **Manual for the CDP1802 COSMAC Microprocessor MPM201A**. Your COSMAC VIP computer incorporates the following special machine-language input and output instructions:

CODE	OPERATION
69	Turn display on (Bus -> MX,D)
6B	Input port byte + MX,D (Optional)
61	Turn display off (MX -> Bus,RX+1)
62	MX(LSD) -> Hex keyboard latch, RX+1
63	MX -> Output port, RX+1 (Optional)
64	MX -> Bus,RX+l

One 64 instruction is always executed by the Operating System. It can also be used in expanded systems if desired. Instructions 65, 66, 67, 6A, 6C, 6D, 6E, and 6F are also available for use in expanded systems.

The External Flag lines are used as follows:

FLAG	USE
EF1	Generated by the video interface (CDPI861)
EF2	Serial data from cassette player
EF3	Hex key pressed signal
EF4	Not used in basic system

EF4 can be used for system expansion. EF3 can also be used in expanded systems if no key will be depressed at the same time that an external device is using EF3. EF1 can only be used by an external device when the display is turned off. EF2 should not be used in expanded systems.

The latched Q line output performs several functions in the COSMAC VIP system. When set, it holds the Q light on and generates a continuous speaker tone. Ile Q line is also used for serial output data to a cassette recorder. You can use the Q output line as a control signal in an expanded system if you avoid conflicts with its normal functions.

You can store a machine language program starting at location 0000. It will be executed when you flip the RUN switch up. Initially P=0, X=0, R0=0000, Q=0, and R1=0XFF, where 0X= last page of on-card RAM. (0X = 07 in 2048-byte RAM system). The operating system uses the last 84 bytes of on-card RAM. You should avoid using these last 84 RAM bytes when writing machine language programs. With a 2048-byte RAM, locations 07AC-07FF would be reserved for use by the operating system. Note that Rl initially contains the address of the last on-card RAM byte. Your machine language program can use Rl to determine the amount of RAM in your system when required.

Putting Machine Coding and CHIP-8 Language Together

The operating system and the CHIP-8 language interpreter use a video display format that is 64 bits wide by 32 bits high. This 256-byte display can easily be modified by writing your own video refresh interrupt routine as explained in the CDP1861 data sheet provided in Appendix G. Display formats up to 64 bits wide by 128 bits high are possible with no hardware modification. The 4096-bit picture program in Appendix D uses a machine language refresh interrupt routine that provides a format 64 bits wide by 64 bits high.

The CHIP-8 language described in the previous section, permits machine language subroutines to be called with a 0MMM instruction. A D4 machine language instruction at the end of the machine language subroutine returns control to the CHIP-8 instruction following the 0MMM instruction. In Appendix C, the CDP1802 register use for the CHIP8 language is provided. R5 is used as the CHIP-8 program counter. When you call a machine language subroutine with a 0MMM instruction, R5 will be addressing the CHIP-8 instruction following the 0MMM. The machine language subroutine could retrieve the next two CHIP-8 program bytes as parameters by addressing with R5 and incrementing it by 2 before returning control to the CHIP-8 program with a D4 instruction. RC, RD, RE, and RF are available for use in machine language subroutines. RA is the CHIP-8 memory pointer (1). Changing the high-order byte of RB will cause any desired RAM page to be displayed. R3 is the machine language subroutine program counter.

CHIP-8 uses the operating system refresh interrupt routine contained in ROM for display. You can use this ROM interrupt routine for 256-byte display in your own machine language programs. First initialize R1 to 8146 and R2 as a stack pointer before turning on the video interface with a 69 instruction. Set the desired display page into RB.1. This interrupt routine uses R0 as the display refresh pointer and modifies RB.0. R8.1 and R8.0 are decremented by 1 during each interrupt unless they are equal to 00. Interrupts occur 60 times per second when the video interface is turned on. This rate is controlled by a crystal clock so that R8.0 and R8.1 can be used as real-time clocks when needed. -

While the video interface is turned on, you should not use any of the 3-machine-cycle CDP1802 instructions (except those used for sync in the refresh interrupt routine itself). If you are not using the video interface, then you can use the CDP1802 3-cycle instructions in your machine language programs. When you initiate a machine language program at 0000 by flipping RUN up, the video interface will be off. You must turn it on with a 69 instruction to use the COSMAC VIP graphic display capability.

Machine Language Programming Summed Up

In summary, COSMAC VIP provides you with an easy-to-use language called CHIP-8. You can insert machine language subroutines in CHIP-8 programs for greater flexibility or expanded I/0 capability. You can write complete machine language programs to fully utilize CDP1802 capabilities. The operating svstem facilitates debugging machine language programs by permitting you to examine general registers R3-RF. (See operating system register table in Appendix B). Advanced programmers can even develop their own, interpretive language tailored to special requirements. Direct execution of machine language code starting at location 0000 together with the expansion interface permits the COSMAC VIP system to be used as a low-cost development system as well as a personal recreational or educational computer.

V. Logic Description

A complete set of logic diagrams is provided in Appendix E. Power requirements for a system with 2048 bytes of RAM is 5 V DC at 350 mA. If you wish to expand the system you can use your own higher current power supply.

This system is designed around the CDP1802 microprocessor Wfl. Refer to the CDP1802 data sheet and **User Manual for the CDPI802 COSMAC Microprocessor MPM-201A** for a complete description of its operation. The CDP1802 requires a square-wave clock input at pin 1 for operation. This system uses a 1.7609-MHz clock. One half of U3 is connected as a free-running crystal-controlled oscillator. A 3.52180-MHz crystal is used in this circuit. The output of this 3.52180-MHz oscillator is then divided by 2 using U4 to provide the 1.7609MHz input clock for the CDP1802. Because each CDP1802 machine cycle equals 8 clock cycles, each machine cycle is about 4.54 *u*s in duration. TPA and TPB are timing pulses generated once each machine cycle by the CDP 1802 microprocessor.

How Memory Is Addressed

A debounced RUN level goes high when the RUN switch is flipped up. This signal causes the CDP1802 to begin fetching instructions from memory. When the RUN switch is down, the CDP1802 is held in a reset state and U6A (in Fig. E-2) is reset. U6B is held set by U6A. The CDP1802 starts fetching instructions from the ROM (U10) at location 8000 since UOB is being held set. The ROM contains the operating system program which uses a 64 instruction to generate an N2 pulse. This-N2 pulse sets U6A so it no longer holds U6B in its set state. From this point on, the selection,of RAM or ROM locations is controlled by the most significant address bit latched into U6B each cycle by TPA.

U8 latches an additional 4 address bits to provide the 1-9-bit address required in a 4096-byte RAM system. U9A decodes 2 of these address bits into 4 lines which are used to select up to four 1024-byte RAM sections. Each 1024-byte section of RAM consists of two 4 x 1024-bit RAM IC's (U16-U23 in Fig. E-4). Only the first two sections of RAM (U16-U19) are used in a 2048-byte system. U9B in Fig. E-2 is wired as a simple gate that inhibits selecting any section of RAM when either the ROM is selected or a positive RAM inhibit signal is generated on pin 19 of the expansion interface by external circuits.

Memory read (MRD) and write (MWR) signals are supplied to the RAM at appropriate times by the CDP1802. Data is transferred between memory, CDP1802, input, or output via an 8-bit data bus. Pull-up resistors are provided on this bus for compatibility with TTL signal swings provided by some RAMs.

How the Input/Output Works

Ull and U12 in Fig. E-3 are used to decode the input/output instruction codes used in the system.

U13 provides the hex keyboard interface. This interface permits a program to determine which key is

pressed. A 62 machine instruction causes the least significant 4 bits of memory byte to be latched into U13. These 4 bits are decoded to bring one of the 16 U13 output lines low. If the key that corresponds to this output line is pressed, the CDPI802 EF3 input will go low. The 4-bit codes latched into U13 correspond to the equivalent key positions. After the program send8 a 4-bit code to U13, it subsequently examines the EF3 line to see if the key corresponding to this code is pressed or not. In this manner, a program can determine when any specific key is pressed or can sequentially scan all keys while waiting for any one to be pressed. Key debounce delays must be provided in the program when required. A program can also cause a speaker tone to occur when a key is pressed. Only one key at a time should be pressed with this method of interfacing the keyboard.

U15 generates an audible tone when pin 4 is high. The output on pin 3 drives a small speaker. The 10 ohm resistor R48 in series with the speaker output can be raised in value to lower the volume if desired. The CDP1802 latched Q-line output drives the tone generator and also turns on the Q light. Q can be set high (1) or low (0) by machine language instructions. The RC network connected to pins 2, 6, and 7 of U15 determines the frequency of the tone. You can increase or decrease the value of R to adjust this frequency to suit your taste.

Q is also shaped by U14A in Fig. E-3 to form a signal suitable for recording on an audio cassette. Audio cassette recorders can't cope with square waves. Tle divider on the output of U 14A reduces the signal to about 50 mV which is suitable for the microphone input of most recorders. During recording, the operating system program in ROM converts memory bytes into bit serial form and transmits them to the recorder via the Q line. See the cassette data test page of Appendix A for the cassette data code used.

In playback, bit serial data from the cassette drives the tape light. The serial data is amplified and shaped into 5-volt pulses by U14B. The output of U14B is connected to the CDP1802 EF2 input line. The operating system reads tape data by examining the timing of the transitions on the EF2 input line. Cassette read and record timing is derived from the crystal-controlled clock so that no adjustments are necessary.

Video output is provided by the unique CDP1861 video display interface IC (U2 in Fig. E-1). Refer to the CDP1861 data sheet. in Appendix G for a description of its operation. This chip provides one of the lowest cost and most useful display interface capabilities available for any microcomputer. The values of the resistors RI and R4 in Fig. E-1 of Appendix E connected to output pins 6 and 7 of U2 can be adjusted for best results with your video display. 61 and 69 machine language instructions are used to generate the required on and off pulses for U2. The down position of the RUN switch resets the internal U2 circuits. When a program is initiated, by flipping RUN up, U2 will remain off until a 69 instruction is executed. No CDP1802 interrupt or DMA requests are generated by U2 until it is turned on by a 69 instruction. U I and U2 are both driven by the same clock. They must remain in sync to provide proper operation of the display.

In general, the logic of this system has been kept simple and straight-forward by the use of software to replace hardware. This design not only yields a low cost system, but one that should prove extremely reliable because of the reduced number of components that can cause failures. This system will not become obsolete for a long time. RAM, ROM, and microprocessor are all state-of-the-art devices and not obsolescent types that are about to be replaced by better ones. The cassette and video interfaces are optimum for long life. Also designed into the system are full expansion capability for added RAM, ROM, input, output, and full color graphics.

V1. Expansion Considerations and Connections

The COSMAC VIP was designed primarily as a self-contained graphic system for home use. Enough RAM and input/output features are provided for years of computer fun without adding anything to your system. If, however, you do want to expand your system, a variety of features have been included to make expansion as easy and inexpensive as possible. You can easily increase RAM to 4096 bytes by adding U20-U23 to your PC card. Use the same type or a compatible type of RAM as used for U16-U19. You may, however, have to add a higher-current power supply when expanding RAM.

Using the Byte Input/Output

First, you may wish to add some external computer-controlled devices such as relays, input sensing switches, or even a low-cost printer. The printer will require an 8-bit parallel input or output port and some "hand-shaking" signals. One parallel input port and one parallel output port are available on the PC card as shown in Fig. E-5 in Appendix E. These ports are provided by U24, U25, U26, and U27 along with the associated resistors and two IN914 diodes. The 22 input/output port connection pads (A-Z) along the back right edge of the PC card are connected to a standard 44-pin card socket on the COSMAC VIP board. You can plug your external circuits or devices into this socket. Table II gives the input/output port terminal connections.

The 8 buffered output signals (M,N,P,R,S,T,U,V) will each drive up to 2 TTL loads. A 63 machine language instruction will latch a memory byte into U24 for output. The 8 latched output lines can be used to drive individual relay driver circuits, power amplifiers, lights, battery motor drivers, etc. The buffered Q output line (W) can be used as an output strobe for transferring the latched output byte to an external device such as a printer. The EF3 (X) and EF4 (L) input fines can be used to indicate the status of an external device. Don't forget that EF3 is shared with the hex keyboard.

Table 11 - Input/Output Port Terminal Connections
(See Fig. E-5, Appendix E)

Pin	Signal	Description
A	IN 0	8-bit input bus
B	IN 1	
C	IN 2	
D	IN 3	
E	IN 4	
F	IN 5	
H	IN 6	
J	IN 7	
K	$\overline{\text{INST}}$	Input byte strobe to latch U25
L	$\overline{\text{EF4}}$	Input flag line #4
M	OUT 0	8-bit output bus
N	OUT 1	
P	OUT 2	
R	OUT 3	
S	OUT 4	
T	OUT 5	
U	OUT 6	
V	OUT 7	
W	$\overline{\text{Q}}$	Q flip-flop output line
X	$\overline{\text{EF3}}$	Input flag line #3 (also used for hex keyboard)
Y	+5 V	Optional power for external logic
Z	GND	

A single photocell input could be provided via the buffered EF4 line. You can attach the photocell directly between the L and Z pads. Experimentally adjust the pull-up resistor on pad L for best operation. No photocell amplifier should be required to drive the COS/MOS input. An, externally supplied positive pulse- on. Pins 2_and 14 of U25,can be used as an input,byte- strobe when yow want to latch an input byte into U25. A 68 can be used to store this input byte in RAM.

Using the Expansion Interface

The 44-pin card socket for the expansion interface pads along the back left edge of the PC board permits extensive expansion. If you expand beyond the capabilities of the power converter provided with the VIP, you will, of course, have to provide your own power supply. Output signals should only drive COS/MOS loads, and must be externally buffered with a. CD4050 or CD4049 IC to drive TTL loads. Keep any wires connected to the expansion pad signals as short as possible. Excessive stray capacitance on these signal lines can interfere with proper operation of the computer. Input signals should also be buffered with COS/MOS circuits. Refer to the. machine language programming section (Section IV) and the logic diagrams (Appendix E) to avoid conflicts with normal COSMAC VIP use of these signals. The external option terminal connections are given in Table III.

You can latch up the required high order address bits with the trailing edge of TPA when adding external memory. You must provide a Positive level on pad 19 to disable internal RAM when external RAM is addressed. The operating system will always use the highest page of internal (on-card) RAM, even when you add external RAM.

If you wish to substitute an external ROM or battery-powered COS/MOS RAM for U10, you can use the signal on pad X to select it. Remove U10 when substituting an external ROM. If you do use an external ROM for your own operating system you may no longer be able to use the CHIP-8 interpreter because it requires some of the operating system subroutines.

The expansion interface pads provide access to all CDP1802 signals so that you can add any desired external circuits.

Only 5 out of the possible 14 CDP1802 input/output instructions are used internally, so that you can externally decode the N0, N1, and N2 lines and use them with MRD to obtain the use of the remaining 9 input/output instruction codes. You can also latch high-order address bits to select external devices if desired. When using external circuits to generate DMA requests, interrupt requests, or input flag signals, isolate these signals with 1N914 diodes as shown for EF3 and EF4 in the optional parallel input/ output port logic. Refer to the **User Manual for the CDPI802 COSMAC Microprocessor, MPM-201A**, for specific examples of input/output attachment techniques.

Some Expansion Ideas

The August and September 1976 issues **of Popular Electronics** contain descriptions of a COSMAC ELF microcomputer using the CDP1802. These articles illustrate some input/output attachment techniques.

The following lists some things that with some exercise of your ingenuity could be added to your system at relatively low cost:

1. Manually operated photoelectric paper-tape strip reader. Only requires a tape guide and 8 photocells.
2. Scanning circuit for multiple input lines from sensing devices using CD4515 IC.
3. Full alphanumeric keyboard.
4. Low-cost printer.
5. Multi-digit numeric display.
6. Calculator chip.
7. Individual photocells or switches.
8. Output relays to control solenoids, bells, whistles, sirens, lights, or motors.
9. Sound-generating circuits that can be controlled by program.
10. Analog-to-digital input circuits.
11. Read-Only Memory for fixed program.
12. Digital-to-analog output circuits.
13. Alpha wave monitor input to control pictures on TV or output devices.
14. Temperature- or pressure-sensing devices.
15. Computer terminal.
16. A second hex keyboard for multi-player video games.

Table III - External Option Terminal Connections
(See Fig. E-2, Appendix E)

Pin	Signal	Description
A	$\overline{MWR}$	Negative-going memory-write pulse Early
B	TPA	timing pulse for M address clocking, etc.
C	MA0	Memory address lines. High-order address byte
D	MA1	appears on these lines during TPA time.,
E	MA2	followed by low-order address byte
F	MA3	
H	MA4	
J	MA5	
K	MA6	
L	MA7	
M	BUS 0	8-bit, 2-way tri-state data bus
N	BUS 1	
P	BUS 2	
R	BUS 3	
S	BUS 4	
T	BUS 5	
U	BUS 6	
V	BUS 7	
W	$\overline{MRD}$	Low for memory read machine cycles
X	CS	Chip select for operating system
Y	+5 V	Optional power for external logic
Z	GND	
1	CLOCK	CDP1802 clock output
2	$\overline{EF4}$	Flag input lines #3 and #4
3	$\overline{EF3}$	(Flag 3 also used for hex keyboard)
4	XTAL	Crystal frequency
5	$\overline{EF1}$	Flag input line #1
6	N0	Low-order 3 bits of N during
7	N1	6N instruction
8	N2	
9	SPOT	Video spot output
10	$\overline{SYNC}$	Video sync output
11	TPB	Timing pulse for clocking memory byte out, etc.
12	SC0	State code bit (+5 V for SI /S3, GND for SO/S2)
13	$\overline{INTERRUPT}$	Pulling to GND causes interrupt (22-KE2 input)
14	SC1	State code bit (+5 V for S2/S3, GND for SO/Sl)
15	$\overline{DMA\text{-}OUT}$	Pull to GND for DMA-OUT cycles
16	Q	Q flip-flop output line
17	$\overline{DMA\text{-}IN}$	Pull to GND for DMA-IN cycles
18	RUN	+5 V when running, GND when RUN switch down
19	INDIS	Internal RAM-disable input
20	$\overline{CDEF}$	GND when RAM pages C, D, E, and F selected
21	+5 V	Optional power for external logic (same as **Y-Z)**
22	GND	

Some possible applications for expanded systems include:

1. Counting packages, parts, cars, or people via photocell or switch input.
2. Composing poetry or pictures with printer output.
3. Video target games using photocell light gun.
4. Monitor burglar alarm switches.
5. Monitor water level and temperature in fish tank and regulate automatically.
6. Measure motor speed with photocell.
7. Monitor and control experiments in home, school, or lab. Use video display for real time bar graphs of multiple variables.
8. Provide a crystal-controlled, programmable pulse generator, clock, or timer.
9. Provide a programmable sequencer for light shows, advertising displays, holiday lighting, etc.
10. Automatic telephone dialer.
11. Model railroad controller.
12. Battery-operated toy or robot controller.
13. Detect tape-player tones and control slide projector.

You will soon discover that the potential applications of a computer such as the COSMAC VIP are only limited by your imagination and the ability to develop appropriate interface circuits.

VIL Troubleshooting Hints

This section is aimed at helping you diagnose and fix hardware problems should they occur. First, check all IC's to make sure they are properly inserted in the PC card. An IC inserted in the wrong direction can be permanently damaged. Check that the +5 V DC supply voltage ripple does not exceed 0.2 volt. Visually inspect the PC card for solder shorts or bad solder joints. Try to avoid zapping your PC card with static electricity charges. Discharge youself, if necessary, by touching a grounded object before touching any IC's or PC card wiring.

No Sound

If everything works but you don't hear any sound from the speaker you probably have a bad U15, bad speaker, or bad connection. Flip RUN up with key C down. Hold any key down and the Q light should come on. Check the Q line if it doesn't. The Q line should be at +5 V with a key held. If the Q light is on, but with no tone, check U15 and your speaker connections.

No Display

If you get no display but do get operating system key tones, check the video output signal. First, select the operating system to make sure video should be present. The video signal should be 0.5 volt peak to peak or higher. You should see negative-going vertical and horizontal sync pulses and positive-going video pulses. The sync pulses should be about 25% of the total swing. Check your display system and interconnections if you have the video signal present. Make sure you are using the correct high-impedance input setting, for example.

Other Problems

Using operating system mode 0, load bytes into RAM using all 16 hex keys. If a key doesn't work or shows the wrong value on the display screen, check the keyboard and U13.

If everything except the cassette interface works, check U14. Review the cassette recording guidelines in Appendix A. Use the cassette phase and data test procedures described in Appendix A to find out what's wrong.

If you can run some programs but not others, you may have a bad RAM bit. Load and use the memory test program provided in Appendix A. Try changing RAM chips, one at a time.

If nothing seems to work and you can't run the operating system, check your power supply and PC card wiring for shorts again. If everything still seems OK you will have to start signal tracing.

Signal Tracing

Check the U3 oscillator output. If not present, replace U3. If the 3.521280-MHz signal is present, check the U4 divider. Replace U4 if it isn't toggling. Make sure you use a 7474 type. With RUN up, you should see TPA and TPB pulses being generated at pins 33 and 34 of U1 If they are not present, check the RUN level to make sure the switch is working, then replace U1.

Check the output of U6B to make sure that the ROM is initially selected when RUN is first flipped

up with key C down. With RUN up, check bus and address lines to see if any look different from the others. They will, of course, be at different levels or bouncing around but you might spot something suspicious that would indicate a short or open for one of these lines.

Try operating with only a 1024-byte RAM (U16 and U17). Try the other two RAM chips in these sockets. Check U5 inputs and outputs to verify that all stages are inverting properly.

If you don't get a pulse at pin 10 of U2 when you flip RUN up with key C down, U12 may he bad. This pulse is a difficult pulse to see and you might have to breadboard a latch or use a latching logic probe to catch it. If you get the display on pulse at pin 10 of U2, you should then see U2 output pulses on pins 2, 3, and 9. If you don't, try replacing U2.

Last Resorts

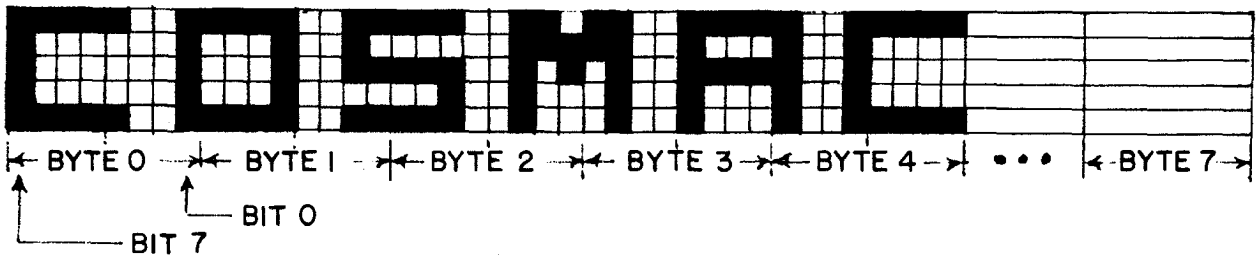
As a last resort, try replacing Ul and the ROM. Check the supply voltage at all chips. Examine the PC card for hairline breaks in the printed conductors. Fill up plated-through holes with solder to insure continuity. Check all signals. They should swing between ground and +4 or 5 volts. If you see a logic signal at some intermediate voltage, like +1 or 2 volts, check the source IC.

Once you get the operating system running, over 90% of the hardware will be operating properly. There are no critical adjustments to be made or maintained. All system timing is controlled by the crystal clock. With reasonable care your COSMAC VIP system should run for years without any problems.

Appendix A - Test and Operating Data

Byte Pattern for Displaying "COSMAC"

The following figure shows how the word "COSMAC" would be formed by spots (or bits) on the display screen.



The following bytes when loaded into memory will cause the word "COSMAC" to be shown on the display in a 2048-byte RAM system. Start pattern of bytes at location OFOO in a 4096-byte system.

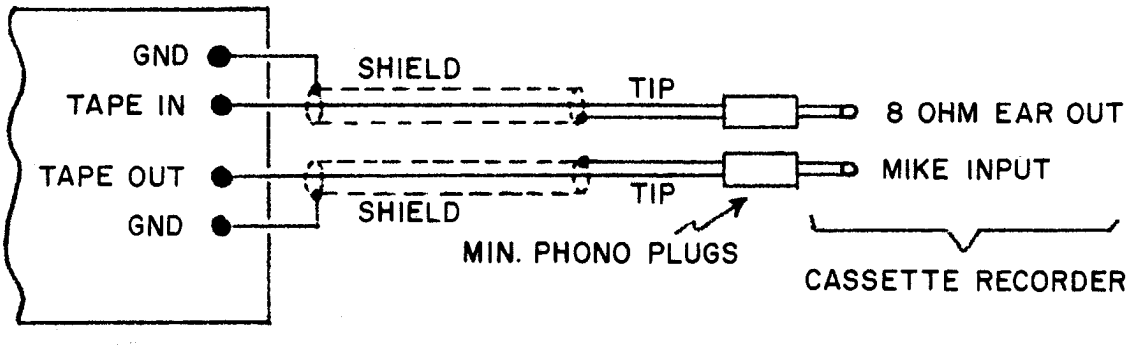
```
0700    F9  F3  E6  CF  9F  00  00  00
0708    81  12  07  C8  90  00  00  00
0710    81  13  E5  4F  90  00  00  00
0718    81  10  24  48  90  00  00  00
0720    F9  F3  E4  48  9F  00  00  00
0728    00  00  00  00  00  00  00  00
```

Beeper Program

This machine- language program flashes the Q light and beeps at a rate determined by the byte at location 0002. Change this byte for faster or slower rates.

```
0000    7A F8 0F BF 2F 9F 3A 04
0008    31 00 7B 30 01 00 00 00
```

Cassette Attachment Diagram



Cassette Phase Test

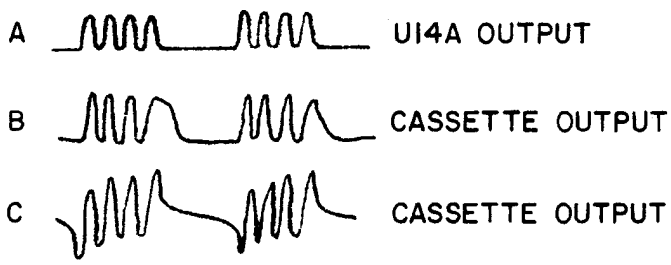
For best results your cassette recorder should not reverse the phase of an input signal on playback. When playing back a tape recorded on another recorder, it should not reverse the phase of the output signal. You may have to reverse the internal head connections on some cassette recorders to eliminate unwanted phase reversals.

To check for phase reversals, load the machine language test program, given below, into memory. Run this program to generate a phase test signal on the tape out line. Record one minute of this test signal, then play it back and observe the cassette recorder output on a scope. It should appear as shown in B or C below. Save this tape to test new recorders on which you want to play tapes you have recorded on a previously tested machine. If the playback signal appears upside down from that shown in B or C, you will have to reverse the internal head connection leads on the out-of-phase recorder.

Test Program

0000	F8	04	AA	7B	F8	0C	FF	01
0008	3A	06	7A	F8	0C	FF	01	3A
0010	0D	2A	8A	3A	03	F8	60	FF
0018	01	3A	17	30	00	00	00	00

Signals

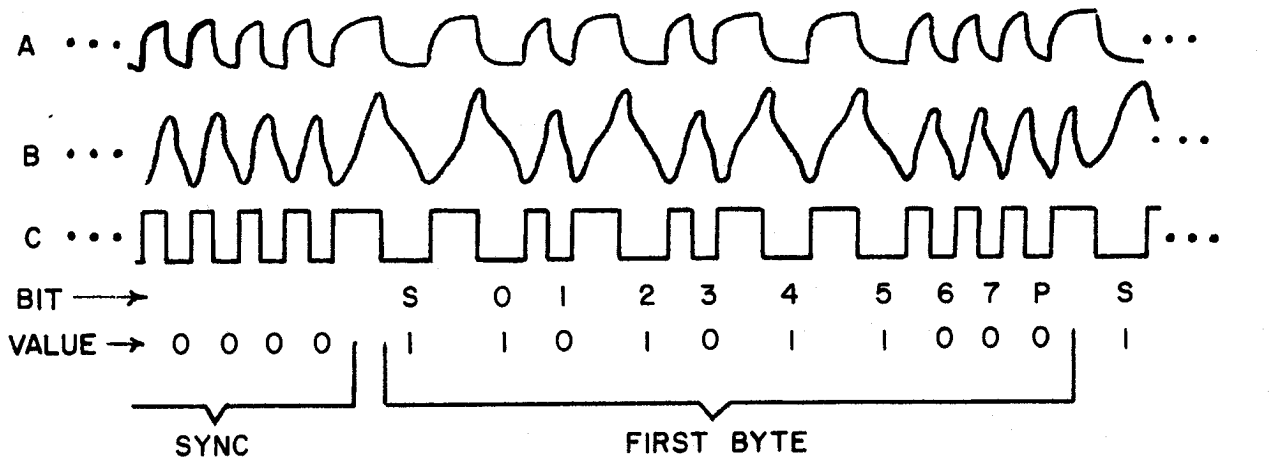


Cassette Data Test

Load the following machine language program into memory:

```
0000   90 B6 B3 F8 33 A6 F8 OA
0008   A3 D3 F8 6F AC F8 40 B9
0010   93 F6 DC 29 99 3A 10 F8
0018   10 A7 F8 08 A9 06 B7 F8
0020   80 FE DC 97 F6 B7 DC 29
0028   89 3A 23 17 87 F6 DC 30
0030   17 30 31 35 00 00 00 00
```

Rewind a blank cassette and put recorder into record mode. Wait 10 seconds and flip RUN up to initiate the program. The byte at location 0033 will be continuously recorded on tape. Flip RUN down to stop recording after a minute or so. You can play this tape to check the signals shown below. You can also load the tape into memory for testing purposes. Load 7 pages starting at 0100. You can use this tape to determine the proper volume control setting for your recorder. You can change the recorded byte at 0033 if desired. Bits on tape consist of one cycle at 2 kHz for "0" or one cycle at 0.8 kHz for "1". Data format is 4 seconds of continuous "0's" for sync followed by the specified number of data bytes. Bytes always begin with a "1" start bit (S) followed by 8 data bits (0-7), and end with a parity bit (P). Odd byte parity is used in this code. The waveforms below show how a 35 byte would appear on tape. The operating system translates memory bytes to bit serial output via the Q output line. Bit serial input from tape is received via input flag 2 and translated into parallel form for storage in memory by the operating system software.



A-OUTPUT OF U14A
B-OUTPUT FROM CASSETTE (TAP IN PAD ON CARD)
C-OUTPUT OF U14B

* WAVEFORMS SHOWN FOR PANASONIC MODEL RO-413S RECORDER.

Cassette Recording Guidelines

1. Use high quality tape (Maxell UD or equivalent).
2. Use shortest tapes possible. You can shorten tapes to several minutes in length if you enjoy splicing.
3. Keep heads and pinch rollers clean.
4. Keep heads aligned for tape interchangeability.
5. Avoid recording too close to beginning of tape.
6. Make sure cassette is properly seated in recorder.
7 If you have trouble with a cassette try others. You can have a had spot on tape or a warped cassette.
8. Highest setting of tone control is usually best.
9. Set recorder volume control so that TAPE light glows steadily on playback. This setting should be lower than highest-volume setting. Excessive TAPE light flickering indicates a bad tape or misaligned heads.
10. A dirty recorder volume control can cause tape dropouts.
11. Make sure cassette connection plugs make good contact.
12. Rewind cassettes before removing them from recorder.
13. Store cassettes in dust-proof containers.
14. Avoid exposing cassettes to heat or magnetic fields.
15. Before recording, wind cassette to one end and fully rewind.
16. Cassette recorders will give you problems once in a while (they don't like certain cassettes, etc.). If one gives you problems most of the time replace it.
17. Make sure that MIKE plug is connected before recording. You will hear a tone even if MIKE plug is out. On most recorders the TAPE light will glow while recording.
18. When recording give the page key a short tap to start.
19. Use the last byte of a tape block as a program identification and check code. It will appear on the display screen after the tape is loaded.
20. When loading a cassette into memory, the tape must contain as many pages as you specify to be loaded. If you try to load 8 pages from a 7-page tape the loading operation won't terminate properly.
21. You may have to record with the EAR plug out for some tape recorders.
22. Always use AC adaptor with recorder for best results.

Memory Test Program

This machine language program should be loaded into 0000-007F. It checks RAM locations 0000-07FF (UI8 and U19) for proper data storage. Flip RUN up to start test. Beeps sound during test. Entire 1024 byte section of RAM being tested is shown on screen. Program stops with tone on if a bad RAM bit is found. Error byte is at 007F. This byte should be 00 or FF for no error. For example, if byte is 01 or FE then bit 0 was bad. The error byte is also shown on the screen.

Set location 0020=00 and location 0023=80 to test RAM locations 0080-03FF (U16 and U17).

```
0000   90 B1 B2 B3 F8 17 A3 D3
0008   42 70 22 78 22 52 C4 C4
0010   C4 94 80 91 AO 30 08 F8
0018   0A Al F8 7F A2 E2 69 F8
0020   04 B4 F8 00 A4 94 B7 84
0028   A7 7A E2 F8 00 A5 F8 FF
0030   A6 85 57 94 BA 84 AA 8A
0038   52 87 F3 3A 45 9A 52 97
0040   F3 3A 45 30 47 86 5A 1A
0048   9A 52 94 FC 04 F3 3A 37
0050   07 52 85 F3 3A 6C F8 FF
0058   A5 93 A6 31 60 7B 30 31
0060   17 97 52 94 FC 04 F3 3A
0068   29 7A 30 6A 7B 30 6D 00
0070   00 00 00 00 00 00 00 00
0078   00 00 00 00 00 00 00 00
```

Appendix B - Operating System

Operating System Listing

The following shows the machine language code for the ROM operating system. ROM is addressed at 8000-81FF. This listing can be used to verify the contents of the ROM if required.

```
8000 F8 80 B2 F8 08 A2 E2 D2
8008 64 00 62 0C F8 FF Al F8
8010 0F B1 F8 AA 51 01 FB AA
8018 32 22 91 FF 04 3B 22 B1
8020 30 12 36 28 90 A0 E0 D0
8028 El F8 00 73 81 FB AF 3A
8030 29 F8 D2 73 F8 9F 51 81
8038 A0 91 B0 F8 CF Al D0 73
8040 20 20 40 FF 01 20 50 FB
8048 82 3A 3E 92 B3 F8 51 A3
8050 D3 90 B2 BB BD F8 81 BI
8058 B4 B5 B7 BA BC F8 46 Al
8060 F8 AF A2 F8 DD A4 F8 C6
8068 A5 F8 BA A7 F8 Al AC E2
8070 69 DC D7 D7 D7 B6 D7 D7
8078 D7 A6 D4 DC BE 32 F4 FB
8080 0A 32 EF DC AE 22 61 9E
8088 FB 0B 32 C2 9E FB 0F 3A
8090 8F F8 6F AC F8 40 B9 93
8098 F6 DC 29 99 3A 97 F8 10
80A0 A7 F8 08 A9 46 B7 93 FE
80A8 DC 86 3A AD 2E 97 F6 B7
80B0 DC 29 89 3A AD 17 87 F6
80B8 DC BE 3A 9E DC 69 26 D4
80C0 30 C0 F8 83 AC F8 0A B9
80C8 DC 33 C5 29 99 3A C8 DC
80D0 3B CF F8 09 A9 A7 97 76
80D8 B7 29 DC 89 3A D6 87 F6
80E0 33 E3 7B 97 56 16 86 3A
80E8 CF 2E BE 3A CF 30 BD DC
80F0 16 D4 30 EF D7 D7 D7 56
80F8 D4 16 30 F4 00 00 00 00
<eom>
```

```
8100 30 39 22 2A 3E 20 24 34
8108 26 28 2E 18 14 1C 10 12
8110 F0 80 F0 80 F0 80 80 80
8118 F0 50 70 50 F0 50 50 50
8120 F0 80 F0 10 F0 80 F0 90
8128 F0 90 F0 10 F0 10 F0 90
8130 F0 90 90 90 F0 10 10 10
8138 10 60 20 20 20 70 A0 A0
8140 F0 20 20 7A 42 70 22 78
8148 22 52 C4 19 F8 00 A0 9B
8150 B0 E2 E2 80 E2 E2 20 A0
8158 E2 20 A0 E2 20 A0 3C 53
8160 98 32 67 AB 2B 8B B8 88
8168 32 43 7B 28 30 44 D3 F8
8170 0A 3B 76 F8 20 17 7B BF
8178 FF 01 3A 78 39 6E 7A 9F
8180 30 78 D3 F8 10 3D 85 3D
8188 8F FF 01 3A 87 17 9C FE
8190 35 90 30 82 D3 E2 9C AF
8198 2F 22 8F 52 62 E2 E2 3E
81A0 98 F8 04 A8 88 3A A4 F8
81A8 04 A8 36 A7 88 31 AA 8F
81B0 FA 0F 52 30 94 00 00 00
81B8 00 D3 DC FE FE FE FE AE
81C0 DC BE F1 30 B9 D4 AA 0A
81C8 AA F8 05 AF 4A 5D 8D FC
81D0 08 AD 2F 8F 3A CC 8D FC
81D8 D9 AD 30 C5 D3 22 06 73
81E0 86 73 96 52 F8 06 AE F8
81E8 D8 AD 02 F6 F6 F6 F6 D5
81F0 42 FA 0F D5 BE F6 AE 32
81F8 DC 3B EA 1D 1D 30 EA 01
<eom>
```

Operating System Register Table

Memory Address	Register Byte	Memory Address	Register Byte,
0XB0		0XC0	
0XB1		0XC1	
0XB2		0XC2	
0XB3	R3.0	0XC3	R3.1
0XB4	R4.0	0XC4	R4.1
0XB5	R5.0	0XC5	R5.1
0XB6	R6.0	0XC6	R6.1
0XB7	R7.0	0XC7	R7.1
0XB8	R&0	0XC8	R8.1
0XB9	R9.0	0XC9	R9.1
0XBA	RA.0	0XCA	RA.1
0XBB	RB.0	0XCB	RB.1
0XBC	RC.0	0XCC	RC.1
0XBD	RD.0	0XCD	RD.1
0XBE	RE.0	0XCE	RE.1
0XBF	RF.0	0XCF	RF.1

0X = 07 for 2048-byte RAM
0X = 0B for 3072-byte RAM
0X = 0F for 4096-byte RAM
R5 = CHIP-8 language program counter
RA = CHIP-8 language I pointer
R3 = Machine Language Subroutine Program Counter

Operating System Summary

1. RUN up with key C pressed selects operating system at 8000.

2. Enter four-digit address followed by mode digit:

A MR (Memory Read)
0 MW (Memory Write)
B TR (Tape Read)
F TW (Tape Write)

3. CDP1802 microprocessor registers are stored as shown in table above. They may be examined after a program is run by using operating system mode A.

4. Mode 0 can be used to insert temporary stops in a program for debugging purposes. Insert a "branch-to-itself" instruction at the desired stopping point.

5. The operating system uses the top 84 bytes of RAM (0XAC-0XFF). Avoid using these byte locations in your programs.

6. The operating system searches for and uses the top (highest) 256-byte page of on-card RAM. When RUN is flipped up to execute a program, beginning at 0000, the following initial conditions exist:

P=0, Q=0, R0=0000, and R1 =0XFF where 0X highest page of on-card RAM.

Appendix C - CHIP-8 Interpreter

CHIP-8 Interpreter Listing

To use the CHIP-8 language you must first load the following interpreter program into memory locations 0000-0IFF (2 pages). This interpreter will allow you to run the games in Appendix D or write your own programs using the CHIP-8 instruction set described in section III.

```
0000  91  BB  FF  01  B2  B6  F8  CF
0008  A2  F8  81  B1  F8  46  A1  90
0010  B4  F8  1B  A4  F8  01  B5  F8
0018  FC  A5  D4  96  B7  E2  94  BC
0020  45  AF  F6  F6  F6  F6  32  44
0028  F9  50  AC  8F  FA  0F  F9  F0
0030  A6  05  F6  F6  F6  F6  F9  F0
0038  A7  4C  B3  8C  FC  0F  AC  0C
0040  A3  D3  30  1B  8F  FA  0F  B3
0048  45  30 40  22  69  12  D4  00
0050  00  01  01  01  01  01  01  01
0058  01  01  01  01  01  00  01  01
0060  00  7C  75  83  88  95  B4  87
0068  BC  91  EB  A4  D9  70  99  05
0070  06  FA  07  BE  06  FA  3F  F6
0078  F6  F6  22  52  07  FA  1F  FE
0080  FE  FE  F1  AC  9B  BC  45  FA
0088  0F  AD  A7  F8  D0  A6  93  AF
0090  87  32  F3  27  4A  BD  9E  AE
0098  8E  32  A4  9D  F6  BD  8F  76
00A0  AF  2E  30  98  9D  56  16  8F
00A8  56  16  30  8E  00  EC  F8  D0
00B0  A6  93  A7  8D  32  D9  06  F2
00B8  2D  32  BE  F8  01  A7  46  F3
00C0  5C  02  FB  07  32  D2  1C  06
00C8  F2  32  CE  F8  01  A7  06  F3
00D0  5C  2C  16  8C  FC  08  AC  3B
00D8  B3  F8  FF  A6  87  56  12  D4
00E0  9B  BF  F8  FF  AF  93  5F  8F
00E8  32  DF  2F  30  E5  00  42  B5
00F0  42  A5  D4  8D  A7  87  32  AC
00F8  2A  27  30  F5  00  00  00  00
<e0m>
```

```
0100  00  00  00  00  00  45  A3  98
0108  56  D4  F8  81  BC  F8  95  AC
0110  22  DC  12  56  D4  06  B8  D4
0118  06  A8  D4  64  0A  01  E6  8A
0120  F4  AA  3B  28  9A  FC  01  BA
0128  D4  F8  81  BA  06  FA  0F  AA
0130  0A  AA  D4  E6  06  BF  93  BE
0138  F8  1B  AE  2A  1A  F8  00  5A
0140  0E  F5  3B  48  56  0A  FC  01
0148  5A  30  40  4E  F6  3B  3C  9F
0150  56  2A  2A  D4  00  22  86  52
0158  F8  F0  A7  07  5A  87  F3  17
0160  1A  3A  5B  12  D4  22  86  52
0168  F8  F0  A7  0A  57  87  F3  17
0170  1A  3A  6B  12  D4  15  85  22
0178  73  95  52  25  45  A5  86  FA
0180  0F  B5  D4  45  E6  F3  3A  82
0188  15  15  D4  45  E6  F3  3A  88
0190  D4  45  07  30  8C  45  07  30
0198  84  E6  62  26  45  A3  36  88
01A0  D4  3E  88  D4  F8  F0  A7  E7
01A8  45  F4  A5  86  FA  0F  3B  B2
01B0  FC  01  B5  D4  45  56  D4  45
01B8  E6  F4  56  D4  45  FA  0F  3A
01C0  C4  07  56  D4  AF  22  F8  D3
01C8  73  8F  F9  F0  52  E6  07  D2
01D0  56  F8  FF  A6  F8  00  7E  56
01D8  D4  19  89  AE  93  BE  99  EE
01E0  F4  56  76  E6  F4  B9  56  45
01E8  F2  56  D4  45  AA  86  FA  0F
01F0  BA  D4  00  00  00  00  00  00
01F8  00  00  00  00  00  E0  00  4B
<eom>
```

CHIP-8 Memory Map

Location	Use
0000 • • • 01FF	CHIP-8 LANGUAGE INTERPRETER
0200 • • •	User programs using CHIP-8 instruction set (1184 bytes available in 2048-byte system)
0YA0 • • • 0YCF	CHIP-8 stack (48 bytes max. for up to 12 levels of subroutine nesting)
0YD0 • • • 0YEF	Reserved for CHIP-8 INTERPRETER work area
0YF0	V0
0YF1	V1
0YF2	V2
0YF3	V3
0YF4	V4
0YF5	V5
0YF6	V6
0YF7	V7
0YF8	V8
0YF9	V9
0YFA	VA
0YFB	VB
0YFC	VC
0YFD	VD
0YFE	VE
0YFF	VF
0X00 • • • 0XFF	256-byte RAM area for display refresh

0X = Highest on-card RAM page (07 for 2048-byte system)
0Y = 0X – 1 (06 for 2048-byte system)

CDP1802 Register Use for CHIP-8 Interpreter

R0 = DMA pointer (page 0X for display refresh)
R1 = INTERRUPT routine program counter
R2 = Stack pointer
R3 = INTERPRETER subroutine program counter
R4 = CALL subroutine program counter
R5 = CHIP-8 instruction program counter
R6 = VX pointer (R6.1 must not be changed)
R7 = VY pointer (available for machine-language subroutines)
R8 = Timers (R8.1 = timer, R8.0 = tone duration)
R9 = Random number (+1 in INTERRUPT routine)
RA = I pointer
RB = Display page pointer (RB.1 = 0X)
RC =Available
RD = Available
RE = Available
RF = Available

CHIP-8/Operating System Standard Digit Display Format

HEX DIGIT	ROM ADDRESS	BYTE	BITS 7 6 5 4 3 2 1 0
E-	8110	F0	
	11	80	
F-	8112	F0	
	13	80	
C-	8114	F0	
	15	80	
	16	80	
	17	80	
B-	8118	F0	
	19	50	
	1A	70	
	1B	50	
D-	811C	F0	
	1D	50	
	1E	50	
	1F	50	
5-	8120	F0	
	21	80	
2-	8122	F0	
	23	10	
6-	8124	F0	
	25	80	
8-	8126	F0	
	27	90	
9-	8128	F0	
	29	90	
3-	812A	F0	
	2B	10	
	2C	F0	
	2D	10	
A-	812E	F0	
	2F	90	
0-	8130	F0	
	31	90	
	32	90	
	33	90	
7-	8134	F0	
	35	10	
	36	10	
	37	10	
	38	10	
1-	8139	60	
	3A	20	
	3B	20	
	3C	20	
	3D	70	
4-	813E	A0	
	3F	A0	
	40	F0	
	41	20	
	42	20	

CHIP-8 User Notes

1 Do not use any of the CDP1802 three-cycle machine language instructions in CHIP-8 programs.

2. CDP1802 R5 is used as the CHIP-8 instruction counter. It will he addressing the byte following a 0MMM instruction for machine language subroutines and can be used to pass 2-byte parameters. Refer to the operating system register table in Appendix B to examine this register during CHIP-8 program debugging.

3. .....

4. .....

5. R7, RC, RD, RE, and RF can be used as working registers in machine language subroutines. Changing other registers can cause the CHIP-8 interpreter to malfunction.

6.....

7. Program bugs can destroy the CHIP-8 interpreter at locations 0000-01FF. If you suspect that this has happened, reload the interpreter.

8. The CHIP-8 interpreter uses subroutines and digit patterns contained in the operating system ROM. If you modify this operating system, the CHIP-8 interpreter should not be used.

A

This Appendix contains program listings for twenty video games. These games, which illustrate entertainment applications of COSMAC VIP, were developed by Joe Weisbecker (games, 1 through 8), Joyce Weisbecker (games 9 and 10), Jef Winsor (games 11, 12, and 13), Tom Chen (games 14,15, and 16), and Phil Baltzer (games 17 through 20).

In the listing for each game, the first column is the memory location at which the instruction bytes in the second column are stored. The comments in the third column indicate the function of the instruction byte. The comments are not stored in memory.

The game titles are listed below:

Game Title .....

1. VIP Kaleidoscope .....
2. VIP Video Display Drawing Game .....
3. VIP Wipe Off .....
4. VIP Space Intercept .....
5. VIP 4096-Bit Picture .....
6. VIP Figure Shooting at Moving Target .....
7. VIP Tick-Tack-Toe Game .....
8. VIP Spooky Spot .....
9. VIP Jackpot .....
10. VIP Snake Race .....
11. VIP Card Matching Game .....
12. VIP Armored Vehicle Clash .....
13. VIP Hi-Lo .....
14. VIP Hex Reflex.....
15. VIP Dot-Dash .....
16. VIP A-Mazing .....
17. VIP Deduce .....
18. VIP Shooting Stars .....
19. VIP Strike-9 .....
20. VIP Card Game (like the well-known acey-

1. VIP Kaleidoscope

This program uses the CHIP-8 INTERPRETER at 0000-01FF. Four spots appear in a group at the center of the screen. Press keys 2, 4, 6, or 8 to create a pattern. Keep your pattern smaller than 138 key depressions. Push key 0 to terminate pattern entry. Pushing key 0 causes your pattern to be continuously repeated forming a fascinating, changing kaleidoscope display on the screen. A "44444442220" key sequence provides a very nice effect Experiment to find other nice patterns. The subroutine at 0232-0274 causes your pattern to be duplicated in the four quadrants of the screen.

```
0200 6000 V0=00
0202 6380 V3=80
0204 611F V1=1F
0206 620F V2=0F
0208 2232 DO 0232
020A A200 I=0200
020C F31E I=I+V3
020E F00A V0=KEY
0210 F055 MI-V0:V0
0212 4000 SKIP;V0 NE 00
0214 121C GO 021C
0216 7301 V3+01
0218 3300 SKIP;V3 EQ 00
021A 1208 GO 0208
021C 6380 V3=80
021E A200 I=0200
0220 F31E I=I+V3
0222 F065 VO:VO=MI
0224 4000 SKIP;VO NE 00
0226 121C GO 021C
0228 7301 V3+01
022A 4300 SKIP;V3 NE 00
022C 121C GO 021C
022E 2232 DO 0232
0230 121E GO 021E
0232 4002 SKIP;V0 NE 02
0234 72FF V2+FF
0236 4004 SKIP;VO NE 04
0238 71FF VI+FF
023A 4006 SKIP;V0 NE 06
023C 7101 V1+01
023E 4008 SKIP;V0 NE 08
0240 7201 V2+01
0242 A277 I=0277
0244 6AEO VA=E0
0246 8A12 VA=VA&Vl
0248 6B1F VB=1F
024A 81B2 VI=Vl&VB
024C 3AOO SKIP;VA EQ 00
024E 7201 V2+01
0250 6AFO VA=FO
0252 8A22 VA=VA&V2
0254 6BOF VB=OF
0256 8282 V2=V2&VB
0258 3AOO SKIP; VAEQ 00
025A 7101 V1+01
025C 6BIF VB=1F
025E 81B2 Vl=Vl&VB
0260 D121 SHOW 1MI@VlV2
0262 8A10 VA=Vl
0264 6B1F VB=1F
0266 8B25 VB=VB-V2
0268 DAB1 SHOW 1MI@VAVB
026A 6A3F VA=3F
026C 8A15 VA=VA-VI
026E DABI SHOW 1MI@VAVB
0270 8B20 VB=V2
0272 DAB1 SHOW 1MI@VAVB
0274 00EE RET
0276 0180
0278 0000
```

2. VIP Video Display Drawing Game

This program uses the CHIP-8 INTERPRETER at 0000-01FF. A flashing spot appears in the upper left corner of the screen. You can move the spot by holding key 2, 4, 6, or 8. Press key 5 and you can draw a picture with the spot. Press key 0 and the spot can be moved without drawing or used to erase a previously drawn line. 0245-024E is a list of initial values for VO-V9. In this program, locations 0300-03FF are used for the picture. After drawing a picture, you can change M(0208) from OOEO to 120A. Write locations 0000-03FF (4 pages) to tape to save your picture. When you load these four pages back into memory you will see your original picture. Changing the OOEO instruction in the program to 120A prevents your picture from being erased when the program is started.

```
0200 A245 I=0245
0202 F965 VO:V9=MI
0204 A24F I=024F
0206 0236 MLS@0236
0208 OOEO ERASE
020A F915 TIME-V9
020C FA07 VA=TIME
020E 3AOO SKIP;VA EQ 00
0210 120C GO 020C
0212 D121 SHOW 1MI@V1V2
0214 3FOO SKIP;VF EQ 00
0216 D121 SHOW 1MI@VIV2
0218 E3A1 SKIP;V3 NE KEY
021A 8030 VO=V3
021C E4AI SKIP;V4 NE KEY
O~U 8040 VO=V4
0220 4000 SK1P;VO NE 00
0222 123C GO 023C
0224 E5A1 SKIP;V5 NE KEY
0226 72FF V2+FF
0228 E6A1 SKIP;V6 NE KEY
022A 71FF V1+FF
022C E7AI S&IP;V7 NE KEY
022E 7101 V1+01
0230 E8A1 SKJP;V8 NE KEY
0232 7201 V2+01
0234 120A GO 020A
0236 OlF8
0238 03BB
023A E2D4
023C D121 SHOW 1MI@V1V2
023E 4FOO SKIP;VF NE 00
0240 D121 SHOW 1MI@V1V2
0242 1224 GO 0224
0244 0100
0246 0000
0248 0005
024A 0204
024C 0608
024E 0880
```

Appendix E - Logic Diagrams

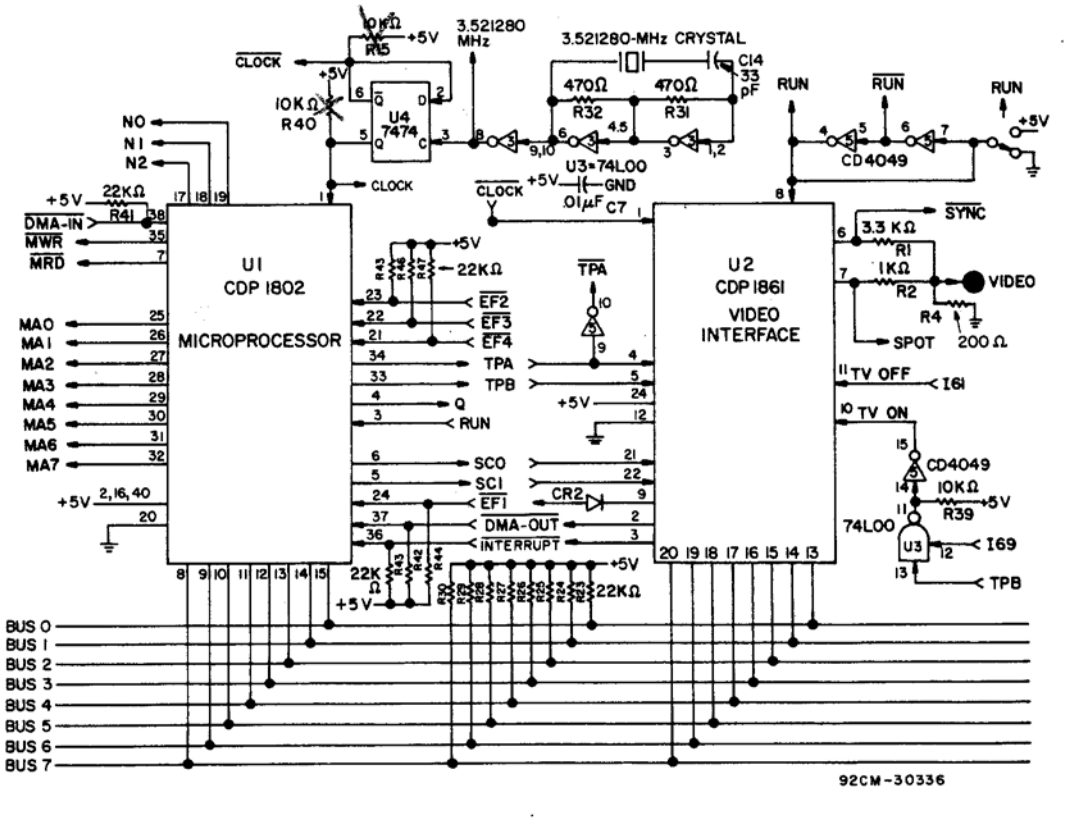


Fig. **E-1** - **Microprocessor and Display Interface Circuits**

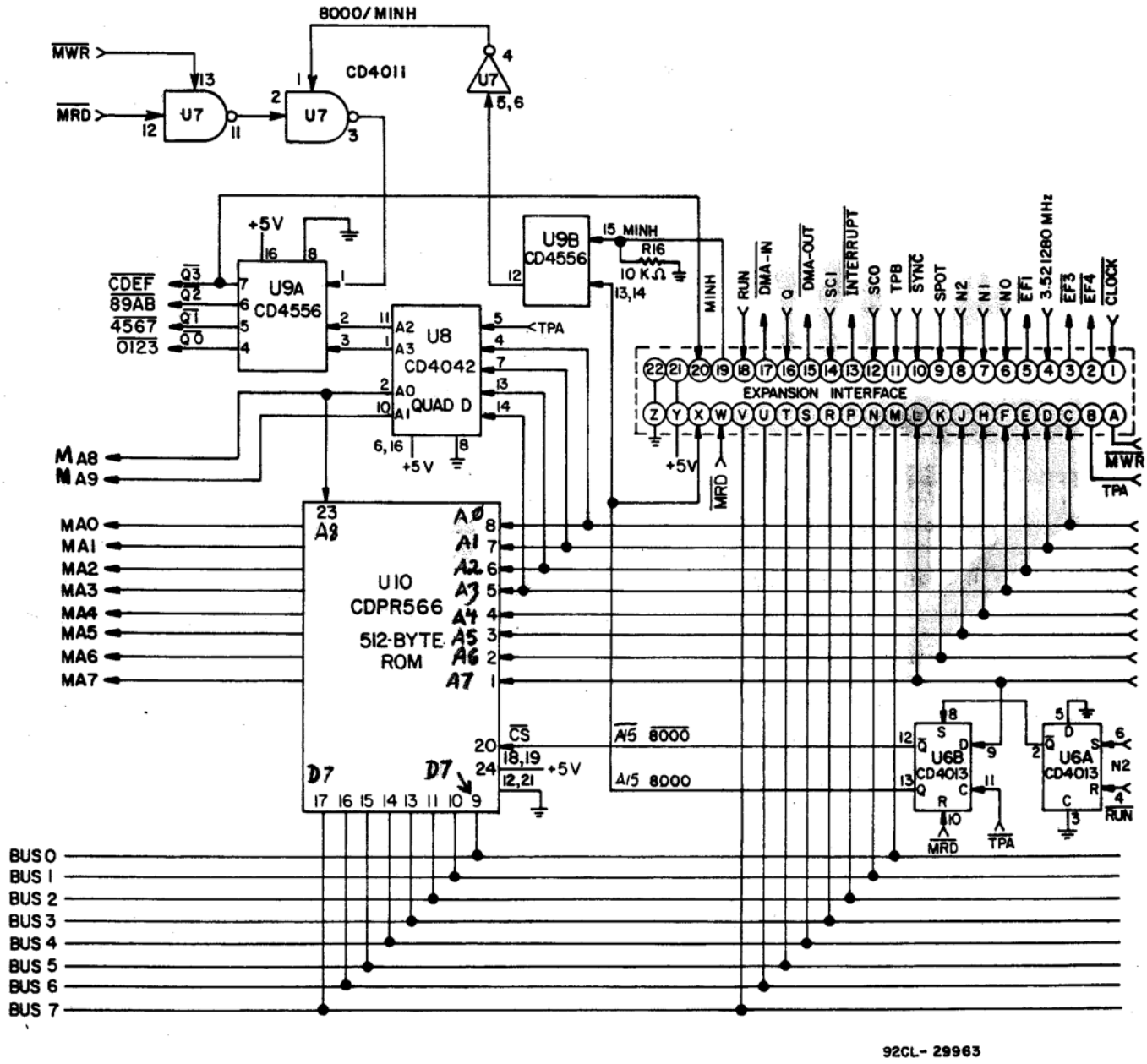


Fig. **E-2 - ROM Circuits and Expansion Interface**

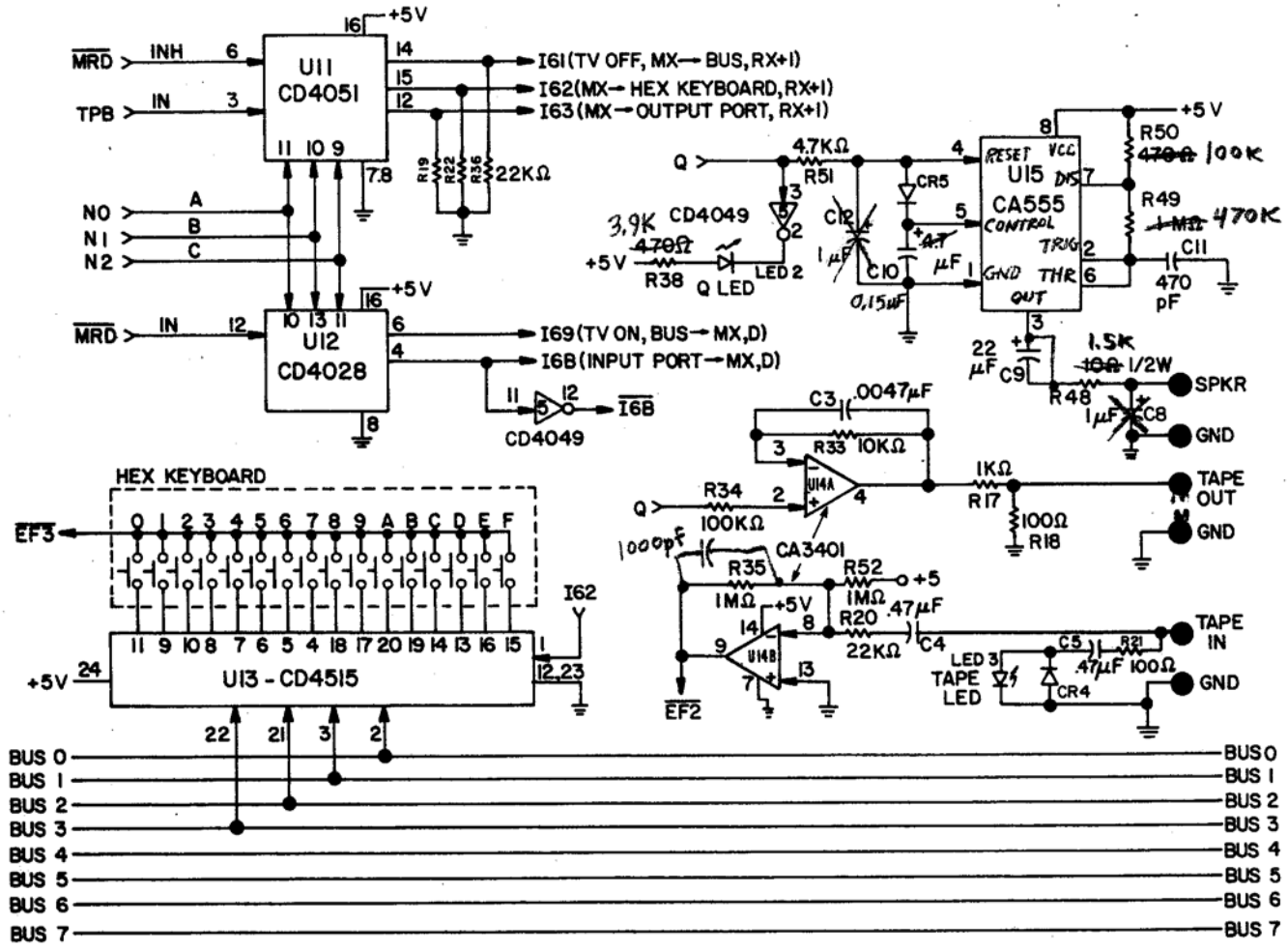


Fig. **E-3 - Keyboard, Decoding, Audio Oscillator, and Cassette Interface Circuits**

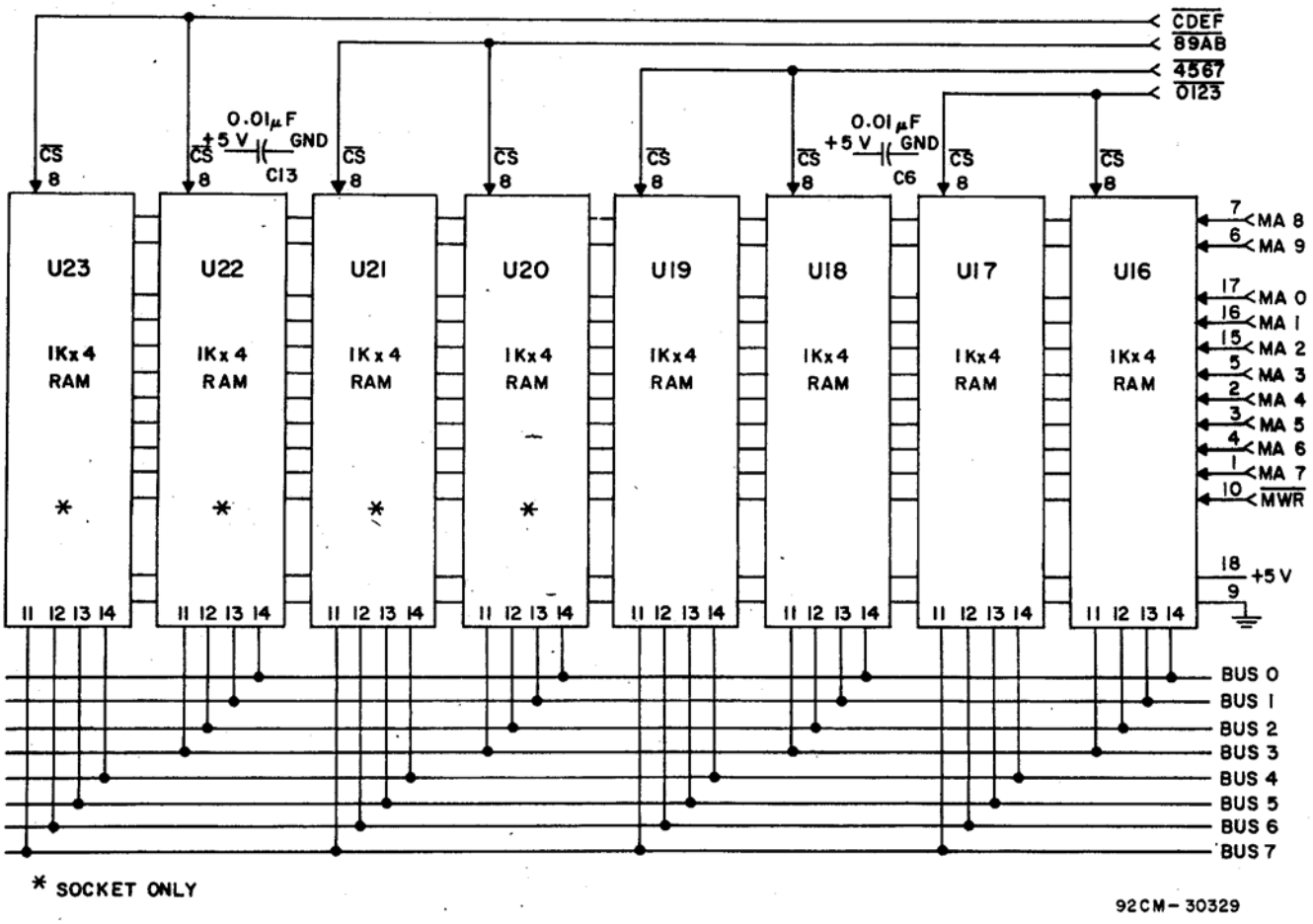


Fig. **E-4 - RAM Circuits**

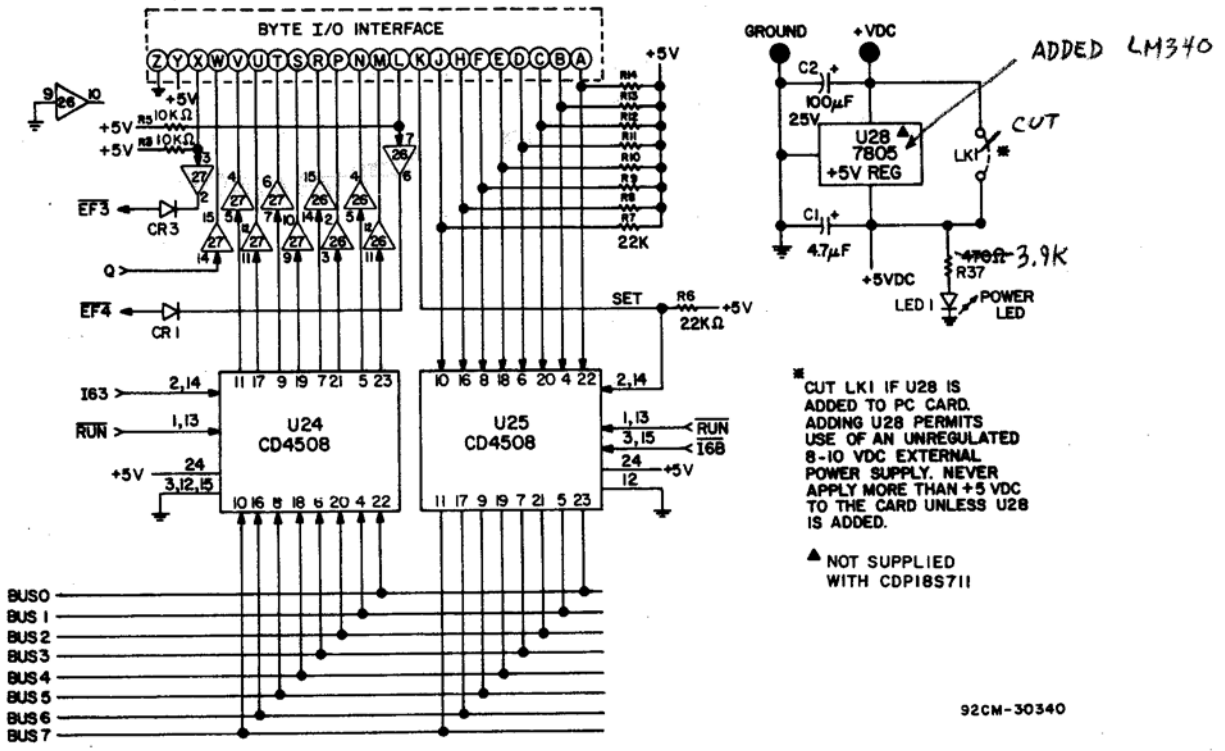


Fig. **E-5 - Power Supply Circuit and Byte Input/Output Interface**

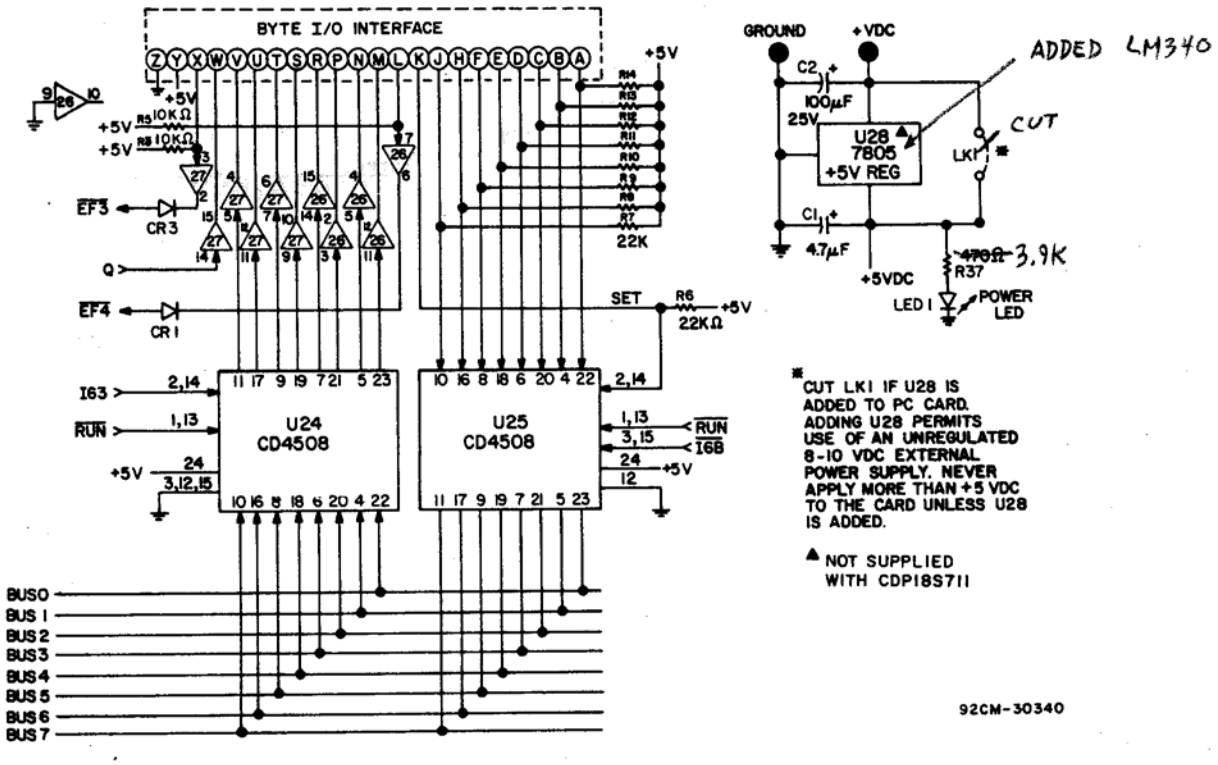


Fig. **E-5 - Power Supply Circuit and Byte Input/Output Interface**

Appendix F -
Board Layout, Parts List, and Expansion Notes

1. Printed Circuit Board Layout

2. Parts List for RCA COSMAC VIP CDP18S711

2. Parts List for RCA COSMAC VIP CDP18S711

Type	Number	Qty.	Description
Integrated Circuits - Supplied			
CDP1802	Ul	1	COSMAC Microprocessor
CDPI 861	U2	1	Video Interface
SN74L00N	U3	1	Quad NAND Low Power
SN7474N	U4	1	Dual D-Type Flip-Flop
CD4049	U5	1	Hex Inverting Buffer
CD4013	U6	1	Dual D-Type Flip-Flop
CD4011	U7	1	Quad 2-Input NAND Gate
CD4042	U8	1	Quad Clocked "D" Latch
CD4556	U9	1	Dual Binary 1 of 4 Decoder
CDPR566	U10	1	512 x 8-Bit Static ROM (Programmed CDP1832)
CD4051	Ull	1	Binary 1 of 8 Decoder
CD4028	U12	1	BCD-to-Decimal Decoder
CD4515	U13	1	4-Bit Latch/] of 16 Decoder
CA3401	U14	1	Quad Single-Supply Op-Amp
CA555CE	U15	1	Timer
2114 or TMS4045	U16-U19	4	1 K x 4-Bit Static RAM
CD4508	U24,U25	2	Dual 4-Bit Latch
CD4050	U26,U27	2	Hex Buffer
Integrated Circuits - Optional			
2114 or TMS4045	U20-U23	4	1 K x 4-Bit Static RAM
Capacitors - Supplied			
	Cl,Cl0	2	4.7 *u*F 35 V Electrolytic
	C2	1	100 *u*F 16 V Electrolytic
	C3	1	0.0047 *u*F 50 V Poly Film (472)
	C4,C5	2	0.47 *u*F 50 V
	C6,C7,C13	3	0.0 1 *u*F 50 V Poly Film (103)
	C8,C12	2	1 *u*F 50 V Electrolytic
	C9	1	22 *u*F 16 V Electrolytic
	C11	1	470 pF 500 V Disc
	C14	1	33 pF ± 10% 1 kV

(Continued on next page)

2. Parts List for RCA COSMAC VIP CDP18S711 (Continued)

Type	Number	Qty.	Description
Resistors - Supplied (1 /4 W except as noted)			
	RI	1	3.3 K ohm
	R3 R5 RIS		
	Rl6, R33	7	10 K ohm
	R39, R40		
	R2, R17	2	1 K ohm
	R6-RI4		
	R19, R20		
	R22-R30, R36	28	22 K ohm
	R41-R47		
	R18, R21	2	100 ohm
	R31, R32		
	R37, R38		470 ohm
	R50		
	R34	1	100 K ohm
	R35, R49	3	1 megohm
	R52		
	R48	1	10 ohm 1/2 W
	R51	1	4.7 K ohm
	R4	1	200 ohm
Miscellaneous - Supplied			
I N914	CR1 through	5	Diode
	CR5		
HP5082-4494		3	Red LED
		1	3.521280 MHz Crystal
7 101 -S-D-V30-B	Sl	1	SPDT Toggle Switch; C&K
E7807		1	Panel Dress Nut for Switch; C&K
18SO22		1	Printed Circuit Board
M-1651.0		1	Keyboard, Centralab
		1	Cover, Thermoplastic
		7	Rubber Feet
C931802		4	18-Pin IC Socket
C932402		1	24-Pin IC Socket
C934002		1	40-Pin IC Socket
CDP18S023		1	Power Supply, Regulated; 5 V dc, 600 mA; 110 V 50/60 Hz
		6	Cable Straps
		1	Speaker
	JI,J2	2	44-Pin Connector
MPM-201		1	User Manual for the CDP1802 COSMAC Microprocessor
MPM-920		1	Instruction Summary for the CDP 1802 COSMAC Microprocessor
VIP-311		1	RCA COSMAC VIP Instruction Manual
			Connectors, cables, hardware
Miscellaneous - Optional			
LAD66A2CD		1	Heat Sink; IERC
		2	4-40 1/4" Binder Hd. Machine Screws and Nuts
7805	U28	1	Voltage Regulator

3. COSMAC VIP Expansion Notes

a. **Soldering the PC Board**

In the event you wish to make some changes or add components requiring soldering, you should have some experience building electronic kits. The PC board pads are small and close together requiring extra caution when soldering to avoid shorts or solder bridges. Use a low-heat, small-tipped, grounded soldering iron. Keep it clean. Use small gauge, rosin core 60/40 solder. Preheat the connection and apply just enough solder to "wet" the connection. Avoid using excessive amounts of solder because it will flow through the plated-through holes and form "blobs" on the top of the card. Excessive or protracted heat from the soldering iron can damage some of the components.

b. **Voltage Regulator Option**

An unregulated 8-10 volt DC power supply can be used with the COSMAC VIP card if desired. Cut LK1 on the PC card. Add U28 (a 7805, 5-volt regulator IC) to the card together with an appropriate heat sink. Make sure the U28 lead pads on the PC DC card don't touch the heat sink. Disconnect the +5 V supply at the + V DC and GND pads and connect your unregulated 8-10 V DC power supply to these pads. This on-card regulator will handle up to I ampere of current and is useful for system expansion. Do not use a plastic cover for your PC card when this on-card regulator option is used. Air How is needed to permit the regulator to operate properly.

c. Additional 2048-Byte RAM Option

To increase your COSMAC VIP RAM to a total of 4096 bytes, add U20-U23 to the PC card by plugging units into the four sockets provided. Measure the power supply current to be sure it does not exceed the capacity of the +5 V DC power pack supplied with the VIP (600 mA). If you require additional power supply current use a regulated +5 V DC supply capable of supplying I ampere or use an unregulated 8-10 V DC supply with the voltage regulator option on the cards.