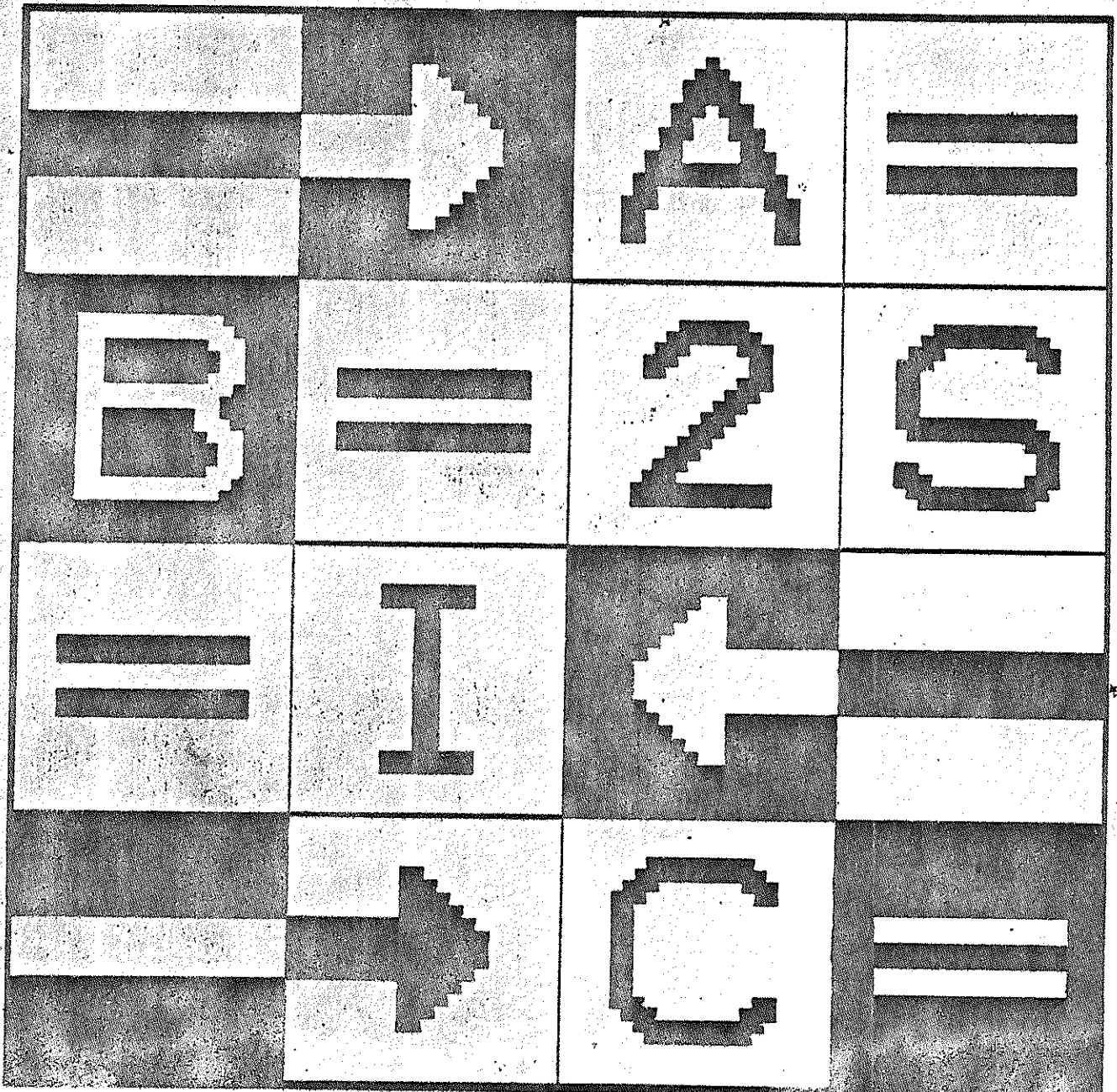




# Technical Data



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## TABLE OF CONTENTS

<u>SECTION</u>	<u>TITLE</u>	<u>PAGE</u>
	General Description	1
I	I/O Pin Description	3
II	Memory Allocation	5
III	CRU Allocation	6
IV	Interrupt Handling	6
V	Electrical Characteristics	8
VI	Glossary	13

## LIST OF ILLUSTRATIONS

<u>FIGURE</u>	<u>TITLE</u>	<u>PAGE</u>
A	99/4A System Block Diagram	2
B	I/O Read Timing	9
C	I/O Write Timing	10
D	CRU Timing	12
E	Connector Pin Identification Diagram	14
F	99/4A Logic Board Component Location Diagram	15
G	99/4A Schematic Diagram	16

## GENERAL DESCRIPTION

The concept for the Texas Instruments Home Computer 99/4 or 99/4A I/O bus is to provide maximum flexibility and good performance with a constraint of low cost for both mainframe and computer system. This concept is achieved by providing both memory and CRU I/O buses to the 99/4 or 99/4A peripherals. This brief description will give key details of this interface. Detailed information regarding the 9900 CRU is assumed. A source for this information is the 9900 Family Systems Design and Data Book. This manual may be obtained from TI Semiconductor Distributors. The memory bus (with data bus converted to eight bits wide) is used for instruction fetch from ROM in external peripherals and for data transfer to/from memory mapped portions of these devices. The CRU bus is used for peripheral enable/disable and for device control and data transfer to/from CRU mapped peripherals.

A block diagram of the TI-99/4A electronics is shown in Figure A. The TMS 9900 microprocessor accesses each peripheral to obtain instructions from the device service routine (DSR) read only memory (ROM). Since each peripheral contains its own DSR, the 99/4A does not have to be designed to anticipate future peripheral requirements. The dual I/O bus capability, along with interrupt handling and external DSR's provide flexibility at low cost.



## I. I/O DESCRIPTION

<u>SIGNATURE</u>	<u>PIN</u>	<u>I/O</u>	<u>DESCRIPTION</u>
A0 (MSB)	31	Out	<u>ADDRESS BUS</u> A0 through A15 comprise the address bus. This bus provides the 16 bit memory address vector to the external memory system when <u>MEMEN</u> is active. Address bit 15 is also used for CRU DATA OUT on CRU output instructions.
A1	30	Out	
A2	20	Out	
	10	Out	
A4	7	Out	
A5	5	Out	
A6	29	Out	
A7	17	Out	
A8	14	Out	
A9	18	Out	
A10	6	Out	
A11	8	Out	
A12	11	Out	
A13	15	Out	
A14	16	Out	
A15/CRUOUT	19	Out	
D0 (MSB)	37	I/O	<u>DATA BUS</u> D0 through D7 comprise the bi-directional data bus. This bus transfers memory data to (when writing) and from (when reading) the external memory system when <u>MEMEN</u> is active.
D1	40	I/O	
D2	39	I/O	
D3	42	I/O	
D4	35	I/O	
D5	38	I/O	
D6	36	I/O	
D7	34	I/O	
			<u>BUS CONTROL</u>
<u>MEMEN</u>	32	Out	MEMory ENable. <u>MEMEN</u> indicates a memory access.
DBIN	9	Out	Data Bus IN. When active (high) the data buffers and 9900 are in the input mode.
<u>WE</u>	26	Out	Write Enable. <u>WE</u> indicates a memory write.
<u>MBE</u>	28	Out	Memory Block Enable. <u>MBE</u> indicates a memory access in memory block 4000-5FFF.
<u>CRUCLK</u>	22	Out	CRU CLOCK. Indicates data is available on the CRU OUT line.
CRUIN	33	In	CRU data IN. Input data line to the Home Computer.
READY/ <u>HOLD</u>	12	In	READY (when <u>MEMEN</u> is active) Indicates external memory is ready for a memory access. <u>HOLD</u> (when <u>MEMEN</u> is inactive) indicates request to use data buss.

I/O DESCRIPTION (CONTINUED)

<u>SIGNATURE</u>	<u>PIN</u>	<u>I/O</u>	<u>DESCRIPTION</u>
			<u>MEMORY CONTROL</u>
HOLD/IAQ	41	Out	<u>HOLD</u> Acknowledge goes true when <u>MEMEN</u> is inactive and indicates that the 9900 is in a HOLD state. <u>Instruction</u> <u>Acquisition</u> indicates (when <u>MEMEN</u> is active) the CPU is acquiring an instruction during a memory cycle.
			<u>TIMING AND CONTROL</u>
$\overline{\text{LOAD}}$	13	In	When active, $\overline{\text{LOAD}}$ causes the CPU to execute a nonmaskable interrupt; memory addresses FFFC and FFFE contain the new workspace and PC vectors respectively.
$\overline{\text{RESET}}$	3	Out	When active, $\overline{\text{RESET}}$ causes the Home Computer and the peripherals to be reset. <u>RESET</u> will be held active for a minimum of 5 clock cycles.
$\overline{\text{EXT INT}}$	4	In	<u>EXTernal</u> <u>INTerrupt</u> . When active, <u>EXT INT</u> causes the CPU to execute an interrupt.
$\overline{\phi 3}$	24	Out	CPU clock. Phase 3 of the CPU clock.
			<u>POWER</u>
GND	21,23 25,27		Ground reference.
			<u>SPEECH MODULE SIGNALS</u>
SBE	2	Out	Speech Block Enable. SBE indicates a memory access in the speech memory.
AUDIO IN	44	In	Input for the audio from the speech module.
	+5	1	Supply voltage (+5V Nom) for speech module (50ma Max)
	-5	43	Supply voltage (-5 Nom) for speech module (50ma Max)

11.

MEMORY ALLOCATION

The memory address space is broken into 8 blocks of 8K bytes of memory. The third block (addresses 4000 - 5FFF) is predecoded and made available at the I/O port for the peripherals. The second, sixth, seventh, and eighth blocks (address 2000-3FFF and A000-FFFF) are in the memory expansion peripheral. For the speech module, (addresses 9000-97FF), a predecoded line is available at the I/O port.

SYSTEM MEMORY MAP

HEX ADDRESS

0 - 1FFF	Console ROM Space
2000 - 3FFF	Memory Expansion
4000 - 5FFF	Peripheral Expansion (predecoded to I/O Connector).
6000 - 7FFF	Command Module ROM/RAM (predecoded to GROM Connector.
8000 - 9FFF	Microprocessor RAM, VDP, GROM, SOUND and SPEECH select.
A000 - BFFF	Memory Expansion
C000 - DFFF	" "
E000 - FFFF	" "

MEMORY MAPPED DEVICES

<u>ADDRESSES</u>	<u>A0</u>	<u>A1</u>	<u>A2</u>	<u>A3</u>	<u>A4</u>	<u>A5</u>	<u>A14</u>	<u>USE</u>
8000	1	0	0	0	0	0	0	Internal RAM (8300-83FF)
8400	1	0	0	0	0	1	0	Sound
8800	1	0	0	0	1	0	0	VDP Read Data
8802	1	0	0	0	1	0	1	VDF Read Status
8C00	1	0	0	0	1	1	0	VDP Write Data
8C02	1	0	0	0	1	1	1	VDP Write ADDR.
9000	1	0	0	1	0	0	0	Speech Read
9400	1	0	0	1	0	1	0	Speech Write
9800	1	0	0	1	1	0	0	GROM Read Data
9802	1	0	0	1	1	0	1	GROM Read ADDR.
9C00	1	0	0	1	1	1	0	GROM Write Data
9C02	1	0	0	1	1	1	1	GROM Write ADDR.

Banks 1-7 available at other addresses, with external decode logic.



III.

CRU ALLOCATION

Of the available 4K of CRU bits, the first 1K (addresses 0000-07FE) are used internally in the console. The second 1K (addresses 0800-0FFE) are reserved for future use. The last 1.9K (addresses 1000-1FFE) are reserved for the peripherals to be plugged in the I/O port. A block of 128 CRU bits is assigned to each peripheral as listed below.

CRU ASSIGNMENTS

CRU ADDRESS	A3	A4	A5	A6	A7	USE
0000-0FFE	0	X	X	X	X	Internal Use
1000-10FE	1	0	0	0	0	Hard Disk Controller
1100-11FE	1	0	0	0	1	Disk Controller
1200-12FE	1	0	0	1	0	Modems
1300-13FE	1	0	0	1	1	RS232 (I)
1400-14FE	1	0	1	0	0	Reserved
1500-15FE	1	0	1	0	1	RS232 (II)
1600-16FE	1	0	1	1	0	Reserved
1700-17FE	1	0	1	1	1	Reserved
1800-18FE	1	1	0	0	0	Thermal Printer
1900-19FE	1	1	0	0	1	Unassigned
1A00-1AFE	1	1	0	1	0	Reserved
1B00-1BFE	1	1	0	1	1	Debugger
1C00-1CFE	1	1	1	0	0	VCR Controller
1D00-1DFE	1	1	1	0	1	IEEE 488 Bus Controller
1E00-1EFE	1	1	1	1	0	Reserved
1F00-1FFE	1	1	1	1	1	P-Code

IV.

INTERRUPT HANDLING

The interrupt available on the I/O port is one of the maskable interrupts of the TMS 9901 Programmable System Interface.

9900 INTERRUPTS

INTERRUPT LEVEL	VECTOR LOC. (MEMORY ADDR. IN HEX)	CPU PIN	DEVICE ASSIGNMENT
(Highest Priority)	0000-WSP	RESET	RESET
0	0002-PC		
	FFFC-WSP	LOAD	LOAD
	FFFE-PC		
1	0004-WSP	--	EX DEV (9901)
	0006-PC		

Lower priority CPU interrupts are not used. The additional interrupts are implemented on the 9901. Interrupt Level 1 is decoded by software to be either (1) VDP vertical sync. (2) 9901 internal timer or (3) I/O bus-generated.

9901 INTERRUPT MAPPING

<u>ADDRESS</u>	<u>CRU BIT</u>	<u>9901</u>	<u>PIN</u>	<u>FUNCTION</u>
0000	0	<u>Control</u>		Control
0002	1	<u>INT1</u>	17	External Interrupt
0004	2	<u>INT2</u>	18	Video Display Processor Vertical Sync
0006	3	<u>INT3</u>	9	9901 Internal Timer, Keyboard "=" line, Joystick "FIRE"
0008	4	<u>INT4</u>	8	Keyboard "Space" line, Joy- stick "LEFT"
000A	5	<u>INT5</u>	7	Keyboard "RETURN" line, Joy- stick "RIGHT"
000C	6	<u>INT6</u>	6	Keyboard "O" line, Joystick "DOWN"
000E	7	<u>INT7 (P15)</u>	34	Keyboard "FCTN" line, Joy- stick "UP"
0010	8	<u>INT8 (P14)</u>	33	Keyboard "SHIFT" line
0012	9	<u>INT9 (P13)</u>	32	Keyboard "CTRL" line
0014	10	<u>INT10 (P12)</u>	31	Keyboard "Z" line
0016	11	<u>INT11 (P11)</u>	30	Not Used As Interrupt
0018	12	<u>INT12 (P10)</u>	29	Reserved
001A-1E	13-15	<u>INT13-INT15</u>	28,27 & 23	Not Used As Interrupt

9901 I/O MAPPING

<u>ADDRESS</u>	<u>CRU BIT</u>	<u>9901</u>	<u>PIN</u>	<u>FUNCTION</u>
0020	16	P0	38	Reserved
0022	17	P1	37	Reserved
0024	18	P2	26	Bit2 of Keyboard Select
0026	19	P3	22	Bit1 of Keyboard Select
0028	20	P4	21	Bit0 (MSB) of Keyboard Select
002A	21	P5	20	Keyboard (ALPHA LOCK)
002C	22	P6	19	Cassette Control 1
002E	23	P7 ( <u>INT15</u> )	23	Cassette Control 2
0030	24	P8 ( <u>INT14</u> )	27	Audio Gate
0032	25	P9 ( <u>INT13</u> )	28	Mag Tape Out
0034	26	P10 ( <u>INT12</u> )	29	Reserved
0036	27	P11 ( <u>INT11</u> )	30	Mag Tape Input
0038-003E	28-31	P12-15	31-34	Not Used In I/O Mapping

## V. ELECTRICAL CHARACTERISTICS

### DRIVE CAPABILITY OF I/O SIGNALS

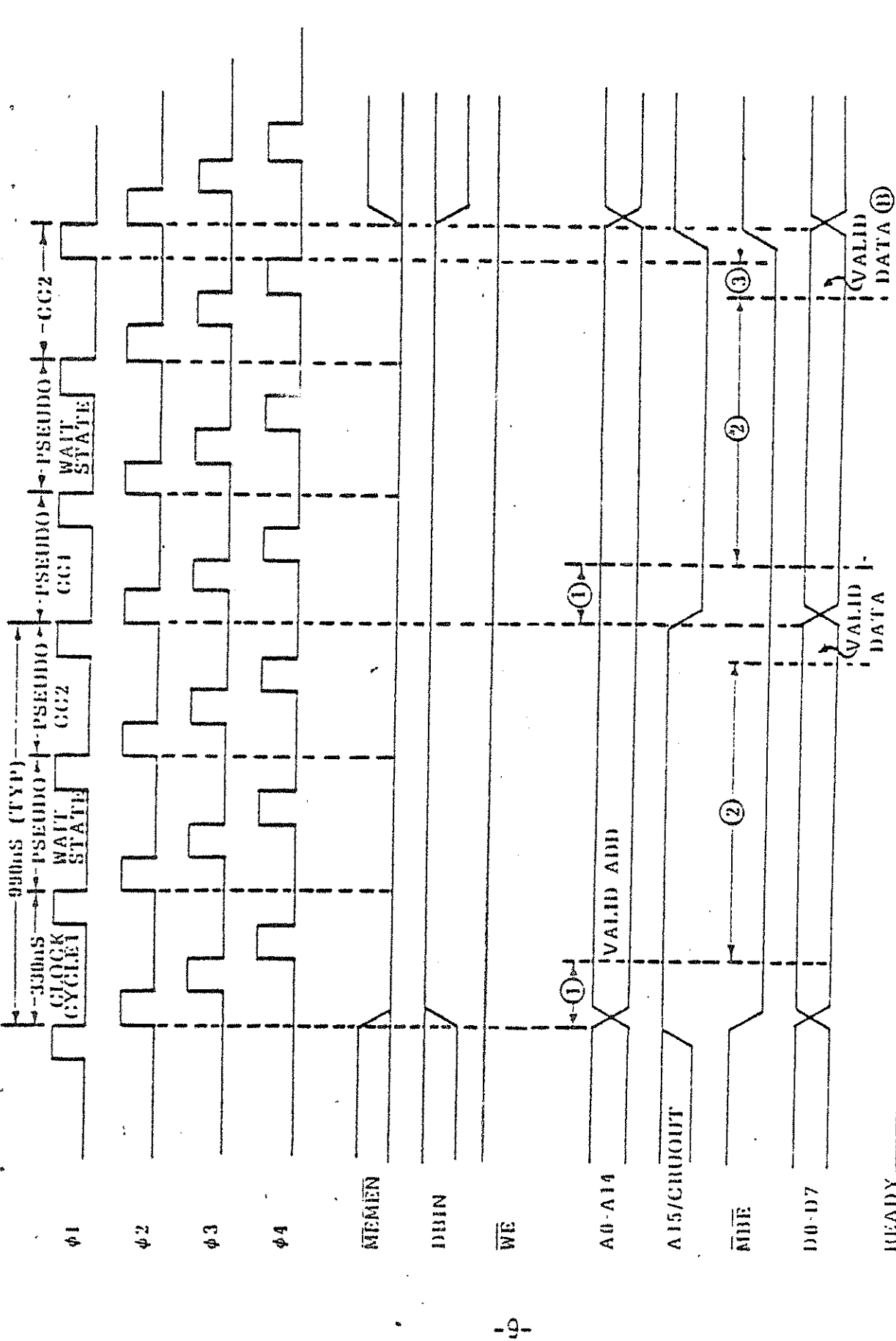
<u>SIGNAL NAME</u>	<u>DRIVER</u>
<u>Ø3</u>	74LS244
<u>CRUCLK</u>	74LS244
<u>WE</u>	74LS244
<u>A0</u>	74LS244
<u>A1</u>	74LS244
<u>A2</u>	74LS244
<u>DBIN</u>	74LS04
<u>MBE</u>	74LS244
<u>MEMEN</u>	74LS32
<u>A3-A14</u>	74LS367
<u>D0-D7</u>	74LS245
<u>A15/CRUOUT</u>	74LS244
<u>SBE</u>	74LS03
<u>HOLD/IAQ</u>	74LS32
<u>RESET</u>	74LS04

#### I/O READ

A CPU Read cycle for the external device consists of two 8-bit read cycles (Fig.B). The 2 bytes read are assembled as a 16 bit word before they are presented to the 9900. Shown in Fig. B are two 8 bit read cycles with one wait state inserted in each to work with slow memories. MEMEN goes low true at the beginning of clock cycle 1. At the same time DBIN goes high true. WE stays high false during the entire cycle. At the same time that MEMEN goes true, the address bus goes active. In order for the noise and the glitches (associated with crosstalk and simultaneous switching) to go away a minimum of 100nS should be allowed for the address lines to settle. MBE (predecoded from A0, A1, A2 and MEMEN) goes true during the leading edge of Ø2 of clock cycle 1. Data read from the peripherals will be valid 750nS after the start of clock cycle 1. The CPU will look at the full 16 bit data bus during the leading edge of Ø1, of clock cycle 2. Under worse-case conditions, data must be valid 100nS before that time.

#### I/O WRITE

Figure C shows a 16 bit I/O write cycle. As described earlier it is composed of two 8-bit writes. A write cycle will always be preceded by an ALU cycle. MEMEN and DBIN go true at the start of the cycle. A settling time of 100nS (min) is allowed for the address lines to settle. down. WE goes true (low) on the leading edge of Ø2, during the wait states, and stays true for 660nS (TYP). Both during a Read or a Write the odd byte is accessed first, followed by the even byte. A15/CRU OUT changes its state 900nS (TYP) after the cycle is initiated. The second 8-bit write cycle is identical to the first 8-bit write. MBE stays true (low) during the entire (1.8us) cycle.



- ① - SETTLING TIME - 100ns (MIN)
- ② - ACCESS TIME FOR DSB ROM + DATA TS + DATA BUFF DELAY (PERIPHERAL + MAINFRAME) - 650ns (MAX)
- ③ - SETUP TIME FOR 9900 - 60ns (MIN)

FIGURE B  
I/O READ TIMING

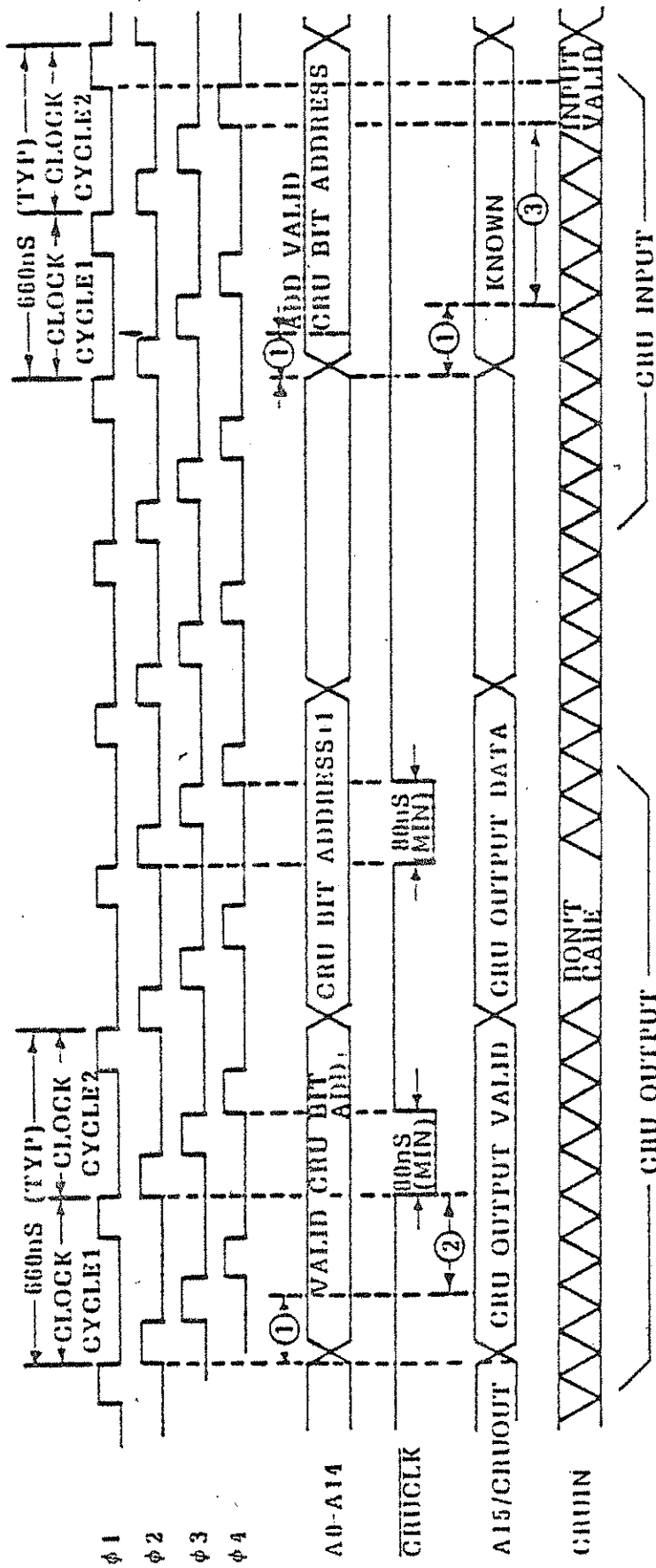
### CRU TIMING

CRU interface timing is shown in figure D. The CRU OUT cycle is composed of 2 clock cycles. The CRU bit address when placed on the address bus A0 through A14 is allowed to settle for 100nS (min). CRUCLK is 63nS (max) low true signal which occurs on the trailing edge of 01 of clock cycle 2. CRUOUT data is valid at the state of clock cycle 1, and is latched by CRUCLK in the respective peripheral.

CRUIN also consists of 2 clock cycles 660nS (TYP). Again we allow 100nS for the address bus to settle down. The CPU samples the CRUIN line on the leading edge of 01 of clock cycle 2. Data must be valid 40nS (min) before that. This implies less than 500nS for CRUIN.

### I/O BUS LOADING

<u>SIGNAL</u>	<u>TOTAL SWITCHING LOAD (pf)</u>	<u>MAXIMUM PERIPHERAL LOAD (pf)</u>
DO-D7	210	90
A0-A2	100	90
A3-A14	100	90
A15/CRUOUT	110	100
O3	110	100
RESET	100	90
READY/HOLD	80	70
CRUIN	125	90
CRUCLK	100	90
MBE	100	90
WE	100	90
SBE	35	25
DBIN	100	90
MEMEN	100	90
HOLD/IAQ	80	70



- ① - SETTLING TIME 100ns (MIN)
- ② - ADD VALID TO CRUCLK = 220ns (TYP)
- ③ - ADD VALID TO VALID CRUIN = 400ns (MAX)

FIGURE D  
CRU TIMING

## VI.

## GLOSSARY

CPU	Central Processing Unit
CRU	Communication Register Unit (I/O technique for TMS 9900 Microprocessor)
DSR	Device Service Routine (TMS 9900 Machine language for Device Interface).
GROM	Graphics Read Only Memory (TMC 0430). This memory device is a 6144 byte read only memory with on board 13 bit program counter. The program counter can be written or read through an eight bit interface and will automatically increment.
I/O	Input/Output
VDP	Video Display Processor (TMS 9918A).
ROM	Read Only Memory.
RAM	Random Access Memory
MSB	Most Significant Bit
BIT	Smallest unit of memory, Binary digit
BYTE	8 Bits of Memory
WORD	16 Bits/2 Bytes of Memory
ALU	Arithmetic Logic Unit

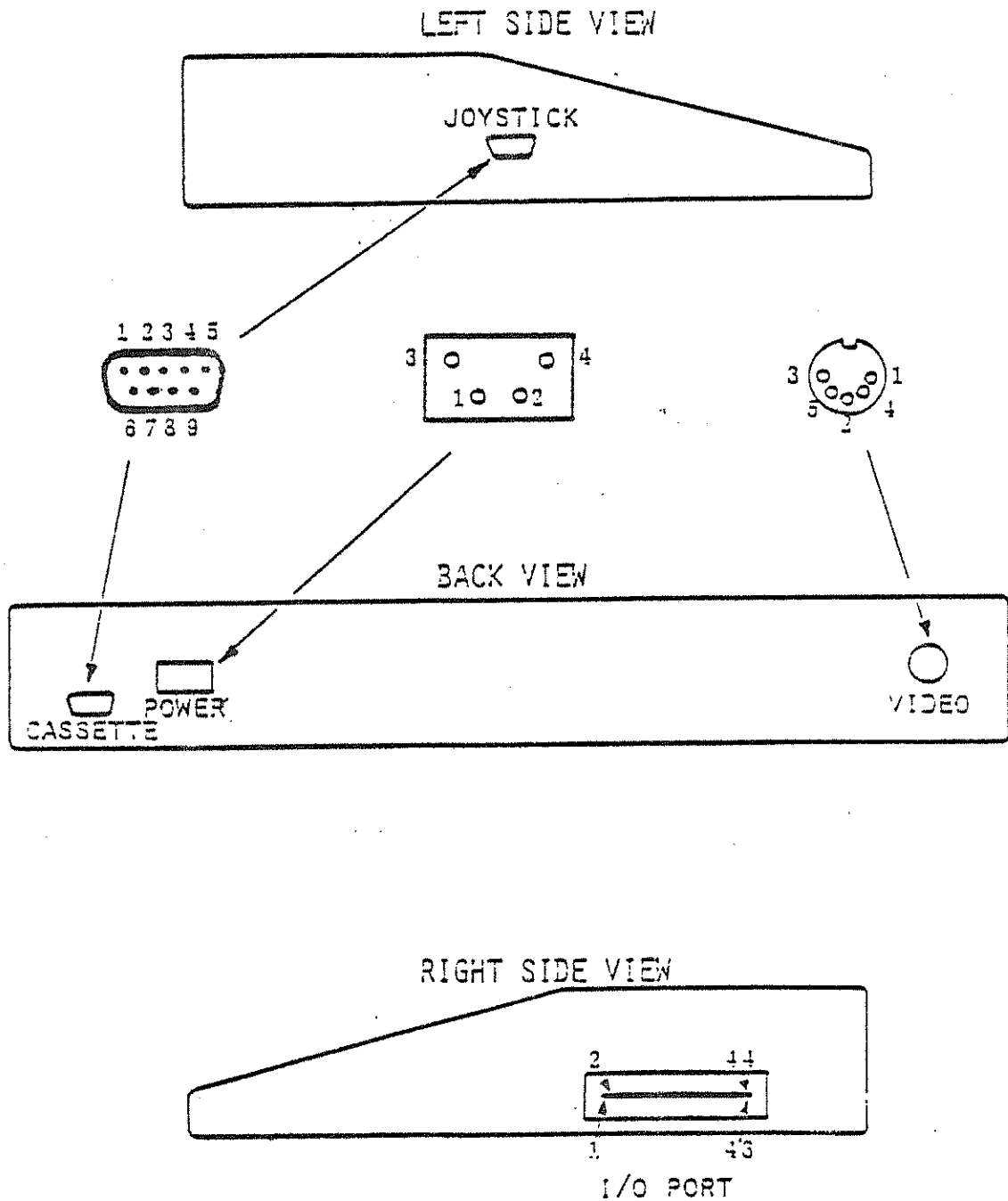
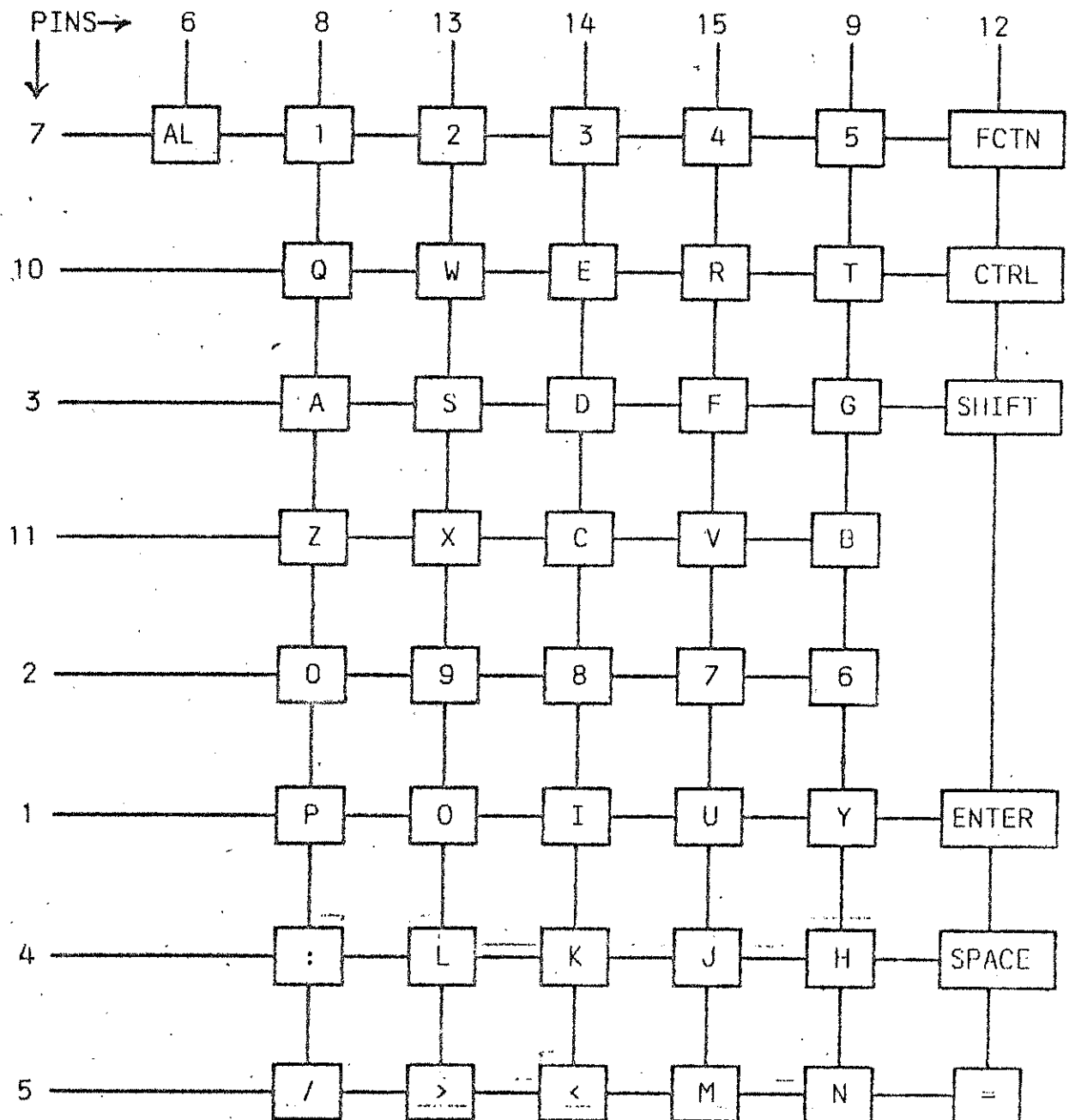


FIGURE E  
CONNECTOR PIN IDENTIFICATION DIAGRAM



# TI99/4A KEYBOARD WIRING MATRIX

PIN 1 IS NEAREST TO JOYSTICK PORT ON THE MOTHERBOARD.



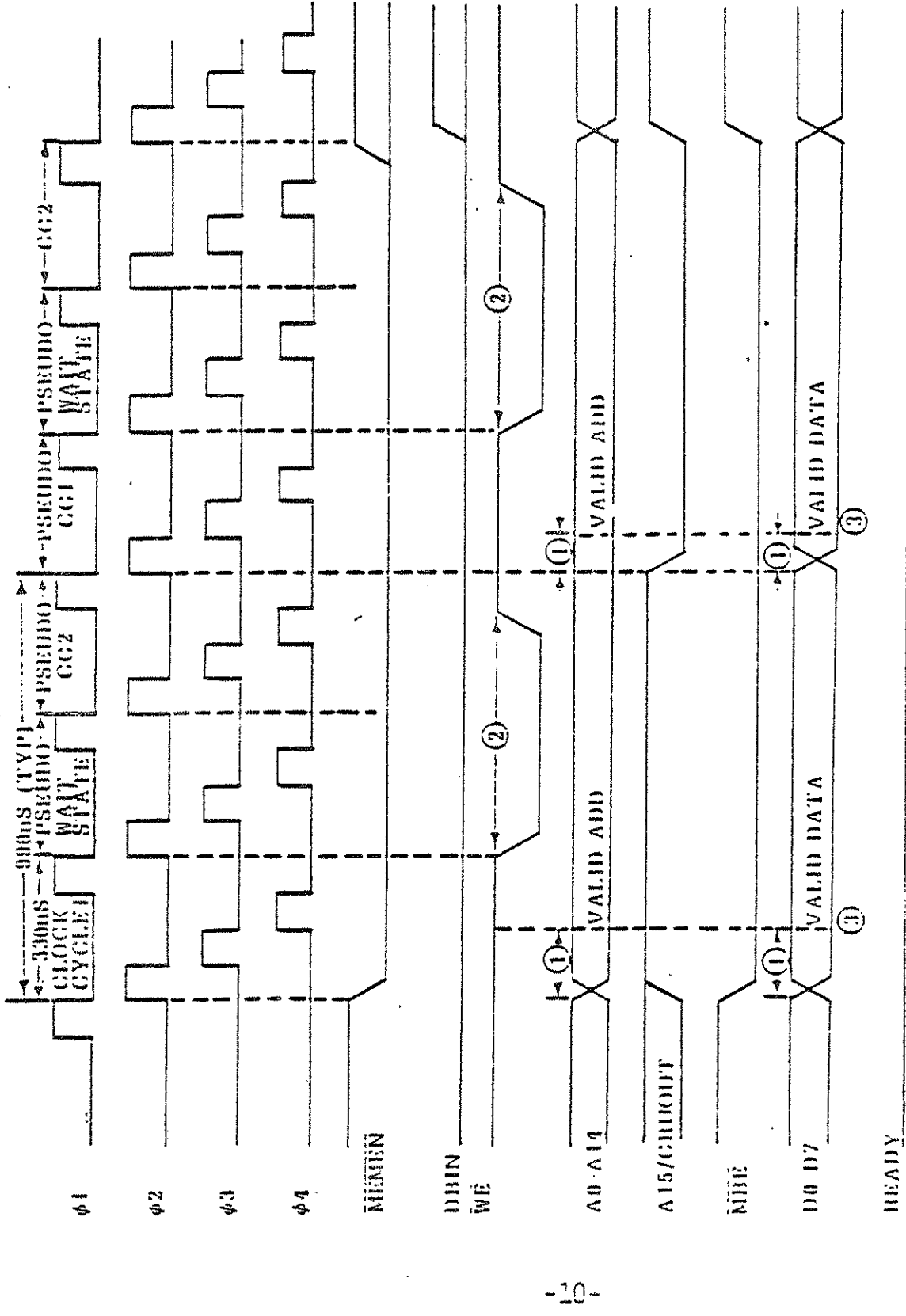


FIGURE C  
I/O WRITE TIMING

# POWER-UP ROUTINE

## Q & A

Over the past few months we have received some questions regarding the Power Up routine and its sequence of events.

The Power Up routine resides in console ROM and console GROM chip 0, with the majority of it in GROM. Listed below is the sequence of events, as we know it, that take place from the moment power is applied to the console.

1. When power is first applied to the 9900 microprocessor it executes a level 0 interrupt which is a reset. When this happens it knows to grab its workspace pointer from address >0000 and its program counter or instruction pointer from address >0002. In the 99/4A these addresses are burned into the console ROM. Once it has these addresses it begins to execute the code that is pointed to by address >0002.

2. The code pointed to by address >0002 loads R13 with >9800, the GROM read address, R14 with >0100, the status flag and R15 with >8C02, the VDP write address.

3. The balance of the Power Up routine is in GROM chip 0. First it clears out the sound list indicator at >83CE and then it turns off the Speech Synthesizer, if you have one, and turns off the sound generators.

4. Next it initializes the Data and subroutine GPL stacks in Scratch Pad RAM.

5. Then it loads the VDP registers with default values stored in a GROM table.

6. Most of the Scratch Pad RAM is then cleared out by writing zeros to it.

7. The keyboard interrupts are then disabled and the cassette audio gate is turned on, this allows you to hear the cassette through your monitor speaker.

8. Next the VDP and external interrupts are enabled.

9. The cassette motors are then enabled, this sets up the remote jack so the motors can run.

10. Next it generates a BEEP sound by calling the TONI routine in GROM chip 0.

11. And then it determines the size of VDP RAM, 4K or 16K, and sets bit 0 in VDP register 1 to 1 for 16K. I guess that TI thought they might produce a 4K console at one point in time.

12. The first 4K of VDP RAM is then cleared out and the default color and character tables are moved from GROM to VDP RAM.

13. Next the keyboards are initialized by scanning them. ie: CALL KEY(5.. , CALL KEY(4.. , CALL KEY(3.. etc.

14. Then it moves the data for the Title Screen into the screen image table. At this point the screen can not be seen because it is turned off. Bit 1 in VDP register 1 is set to zero.

15. The ROMs(DSR) and GROMs are then searched for power up headers and if they have one they are executed.

16. After the search and execution of power up headers is complete the Title Screen is displayed by writing a 1 to bit 1 of VDP register 1. This is the first time that you are able to see the Title Screen.

17. Next it initializes the Random Number Generator and then waits for you to 'PRESS ANY KEY'. After you press a key it generates another BEEP sound.

18. And then it searches through the cartridge ROM and GROM for application programs and builds a list of their names. ie: Editor/Assembler, Extended Basic, Basic etc. Note: some consoles, V2.0 (C) 1983, do not search ROM only GROM.

19. At this point the screen is once again turned off, VDP register 1, bit 1 is set to zero and then it sets up the menu screen with the application programs it found.

20. After the menu is set up it turns on the screen by writing a 1 to bit 1 of VDP register 1, and waits for you to make a selection.

21. If you make an illegal selection it generates a HONK sound, otherwise it sets up the starting address for the application program you selected and branches to it.

