

HD63484

Advanced CRT Controller (ACRTC)

The advanced CRT controller (ACRTC) CMOS VLSI microcomputer peripheral device can display both graphics and characters on raster-scan displays. It is a new generation CRT controller based on bitmapped technology. It executes high-level commands, like Line, Ellipse, Paint, Pattern, and Copy, issued by the MPU in screen X-Y coordinates, and performs the address translation necessary to draw into frame memory. It can draw in up to 64k colors, on three split screens and an independent window, and perform area clipping and hitting.

The ACRTC controls a CRT in one of three modes: character only, graphics only, and multiplexed character/graphics modes. Therefore, the ACRTC has many applications, from character-only displays to large full-graphics systems.

The ACRTC reduces CPU software overhead and enhances system throughput.

Features

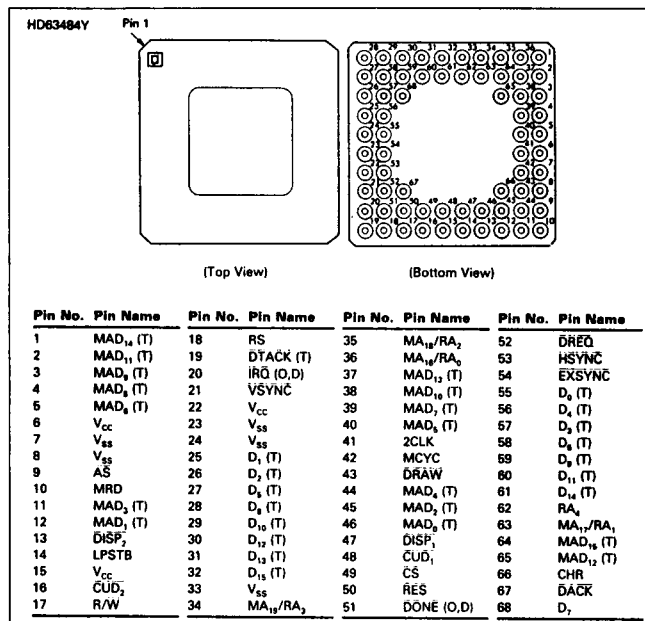
- High-speed graphics
 - Drawing rate: 408 ns/pixel max (color drawing)
 - Commands: 38 commands including 23 graphic drawing commands
Dot, Line, Rectangle, Poly-line, Polygon, Circle, Ellipse, Paint, Copy, etc.
- Colors: 16 bits/word
1, 2, 4, 8, 16 bits/pixel (5 types)
Monochrome to 64k colors max
- Pattern RAM: 32 bytes
- Converts logical X-Y coordinates to physical address
- Color operation and conditional drawing
- Drawing area control for hardware clipping and hitting
- Large frame-memory space
 - Maximum 2 Mbytes graphic memory and 128 kbytes character memory separate from the MPU memory
 - Maximum resolution: 4096×4096 pixels (1 bit/pixel mode)
- CRT display control
 - Split screens: three displays and one window
 - Zoom: 1 to 16 times
 - Scroll: vertical and horizontal
- Interleaved access mode for flashless display and superimposition
- External synchronization between ACRTCs or between ACRTC and external device (TV system or other controller)
- DMA interface
- Two programmable cursors
- Three scan modes
 - Non-interlaced
 - Interlace sync
 - Interlace sync and video
- Interrupt request to MPU
- 256 characters/line 32 raster/line, 4096 rasters/screen
- Maximum clock frequency: 9.8 MHz
- CMOS, single +5 V power supply

Ordering Information

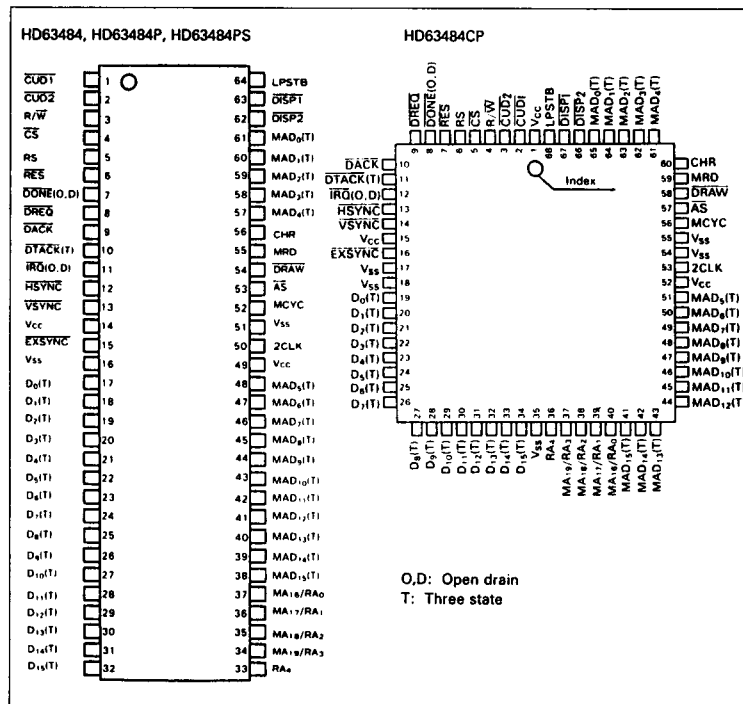
Part No.	Clock Frequency (2CLK)	Package
HD63484-4	4 MHz	DC-64 (64-pin ceramic DIP)
HD63484-6	6 MHz	
HD63484-8	8 MHz	
HD63484-98	9.8 MHz	
HD63484P4	4 MHz	DP-64 (64-pin plastic DIP)
HD63484P6	6 MHz	
HD63484P8	8 MHz	
HD63484P98	9.8 MHz	
HD63484CP4	4 MHz	CP-68 (68-pin plastic PLCC)
HD63484CP6*	6 MHz	
HD63484CP8	8 MHz	
HD63484CP98	9.8 MHz	
HD63484Y4	4 MHz	PC-68 (68-pin PGA)
HD63484Y6	6 MHz	
HD63484Y8	8 MHz	
HD63484Y98	9.8 MHz	
HD63484PS4	4 MHz	DP-64S (64-pin plastic shrink DIP)
HD63484PS6	6 MHz	
HD63484PS8	8 MHz	
HD63484PS98	9.8 MHz	

Note: Wide temperature range (−40°C to +80°C) version is available.





Pin Arrangement



Pin Description

Group	Mnemonic	Pin Number			I/O	Function
		DIP	PLCC	PGA		
MPU Interface	RES	6	7	50	I	ACRTC reset
	D ₀ -D ₁₅ *	17-32	19-34	25-32 55-61 68	I/O	Data bus (three state)
	R/W	3	4	17	I	Read/write strobe
	CS	4	5	49	I	Chip select
	RS	5	6	18	I	Register select
	DTACK	10	11	19	O	Data transfer acknowledge (three state)
DMAC Interface	IRQ	11	12	20	O	Interrupt request (open drain)
	DREQ	8	9	52	O	DMA request
	DACK	9	10	67	I	DMA acknowledge
CRT Interface	DONE	7	8	51	I/O	DMA done (open drain)
	2CLK	50	53	41	I	ACRTC clock
	MAD ₀ -MAD ₁₅ *	61-57, 48-38	65-61, 51-41	1-5, 11,12 37-40,44- 46, 64, 65	I/O	Multiplexed frame buffer address/data bus
	AS	53	57	9	O	Address strobe
	MA ₁₆ /RA ₀ -* MA ₁₉ /RA ₃	37-34	40-37	34-36	O	Higher-order address bits/ character screen raster address
	RA ₄	33	36	62	O	High-order character screen raster address bit
	CHR	56	60	66	O	Graphic or character screen access
	MCYC	52	56	42	O	Frame buffer memory access timing signal
	MRD	55	59	10	O	Frame buffer memory read
	DRAW	54	58	43	O	Draw/refresh signal
	DISP1, DISP2	63, 62	67, 66	47, 13	O	Display enable
	CUD1, CUD2	1,2	2,3	48,16		Cursor display
	VSYSN	13	14	21	O	CRT vertical sync pulse
	HSYSN	12	13	53		CRT horizontal sync pulse
	EXSYN	15	16	54	I/O	External sync
	LPSTB	64	68	14	I	Lightpen strobe
Power Supply	V _{cc}	14, 49	1, 15, 52	6, 15, 22		+5 V
	V _{ss}	16, 51	17, 18, 35, 54, 55	7, 8, 23 24, 33		Ground

*: PGA pin numbers don't correspond to D₀-D₁₅, MAD₀-MAD₁₅, MA₁₆/RA₀-MA₁₉/RA₃.
Please refer to the pin arrangement.

MPU Interface

RES (Reset): $\overline{\text{RES}}$ is the MPU hardware reset.

D₀-D₁₅ (Data Bus): D₀-D₁₅ are the bidirectional data bus to/from the host MPU or DMAC. D₀-D₇ are used in 8-bit data bus mode.

R/ $\overline{\text{W}}$ (Read/Write): R/ $\overline{\text{W}}$ input controls the direction of host/ACRTC transfers.

CS (Chip Select): $\overline{\text{CS}}$ input enables transfers between the host and the ACRTC.

RS(Register Select): RS input selects the ACRTC register to be accessed. It is usually connected to the least significant bit of the host address bus.

DTACK (Data Transfer Acknowledge): DTACK output provides asynchronous bus cycle timing. It is compatible with the HD68000 MPU DTACK output.

IRQ (Interrupt Request): $\overline{\text{IRQ}}$ output generates interrupt service requests to the host MPU.

DMAC Interface

DREQ (DMA Acknowledge): $\overline{\text{DACK}}$ receives DMA acknowledge timing from the host DMAC.

DONE (DMA Done): $\overline{\text{DONE}}$ terminates DMA transfer. It is compatible with the HD68450 DMAC DONE signal.

CRT Interface

2CLK (Dot Clock): 2CLK is the basic ACRTC operating clock, twice the frequency of the dot clock.

MAD₀-MAD₁₅ (Frame Memory Address/Data Bus): MAD₀-MAD₁₅ are the multiplexed frame buffer address/data bus.

AS (Address Strobe): The $\overline{\text{AS}}$ output demultiplexes the address/data bus (MAD₀-MAD₁₅).

MA₁₆/RA₀-MA₁₉/RA₃ (Memory Address/Raster Address): MA₁₆/RA₀-MA₁₉/RA₃ are the upper bits of the graphics screen address multiplexed with the lower bits of the character screen raster address.

RA₄ (Raster Address): RA₄ is the high bit

of the character screen raster address (up to 32 rasters).

CHR (Character): CHR output indicates whether a graphic or character screen is being accessed.

MCYC (Memory Cycle): MCYC is the frame buffer memory access timing output, one-half the frequency of 2CLK.

MRD (Memory Read): MRD output controls the frame buffer data bus direction.

DRAW (Draw): $\overline{\text{DRAW}}$ output differentiates between drawing and CRT display refresh cycles.

DISP1, DISP2 (Display 1, 2): The $\overline{\text{DISP1}}$ and $\overline{\text{DISP2}}$ programmable display enable outputs can enable, disable, and blank logical screens.

CUD1, CUD2 (Cursor Display 1, 2): CUD1 and CUD2 outputs provides cursor timing programmed by ACRTC parameters such as cursor definition, cursor mode, cursor address, etc.

VSYNC (Vertical Sync): $\overline{\text{VSYNC}}$ outputs the CRT vertical synchronization pulse.

HSYNC (Horizontal Sync): $\overline{\text{HSYNC}}$ outputs the CRT horizontal synchronization pulse.

EXSYNC (External Sync): $\overline{\text{EXSYNC}}$ allows synchronization between multiple ACRTCs and other video signal generators.

LPSTB (Lightpen Strobe): LPSTB is the lightpen input.

Block Diagrams

ACRTC Functions

The ACRTC consists of 5 major functional blocks (figure 1). They operate in parallel to achieve maximum performance.

MPU Interface: The MPU interface interfaces asynchronously with the host MPU. Its functions include programmable interrupts handling, and DMA handshaking control.

CRT Interface: The CRT interface manages the frame buffer bus and the CRT timing input and output control signals. It also selects display refresh or drawing address outputs.

Drawing Processor: The drawing processor interprets commands and command parameters issued by the host bus (MPU and/or DMAC) and performs drawing operations on the frame buffer memory. It executes ACRTC drawing algorithms and converts logical X-Y addresses to physical frame buffer addresses.

It communicates with the host bus via separate 16-byte read and write FIFOs.

Display Processor: The display processor manages frame buffer refresh addressing based on the user-specified display screen organization. It combines and displays as many as 4 independent screen segments (3 horizontal split screens and 1 window) using an internal high-speed address calculation unit. It controls display refresh outputs in graphic (physical frame buffer address) or character (physical refresh memory address + row address) modes.

Timing Processor: The timing processor generates the CRT synchronization signals and signals used internally by the ACRTC.

Registers: The ACRTC registers that are visible to software are partitioned in the same way. They reside in the internal processor appropriate to their function. The registers in the display and timing processors are loaded with the basic display parameters during system initialization. During operation, the host communicates primarily with the ACRTC's drawing processor via the on-chip FIFOs.

High-Speed (= 9.8 MHz) Version of ACRTC

To keep up with the demand for improvements in the quality and resolution of CRT monitors, Hitachi has introduced a 9.8 MHz version of the HD63484 (ACRTC).

It can be used for:

1. High-resolution displays such as in office workstations, business personal computers, and CAD/CAM displays.
2. Applications requiring faster drawing than the current ACRTC with an 8-MHz 2CLK operation frequency.

High-Resolution Display

As shown in figure A, the 9.8-MHz allows the following configurations for a 4-bit/pixel system:

1. CRT monitor with 1024 x 808 dots, +8 DA or +4 SA
2. CRT monitor from 800 x 480 to 960 x 720 dots, +4 DA

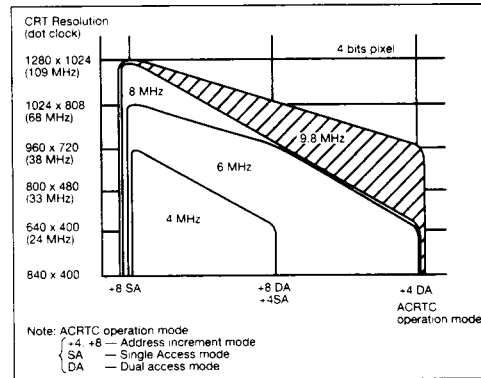


Figure A. ACRTC Operation Frequency and Supportable CRT Display Range

High-Speed Drawing Support

The ACRTC drawing speed depends on its operation frequency. Consequently it takes less time to draw with a 9.8-MHz clock than with an 8-MHz clock. Figure B compares drawing capabilities of the 9.8-MHz ACRTC and the 8-MHz ACRTC.

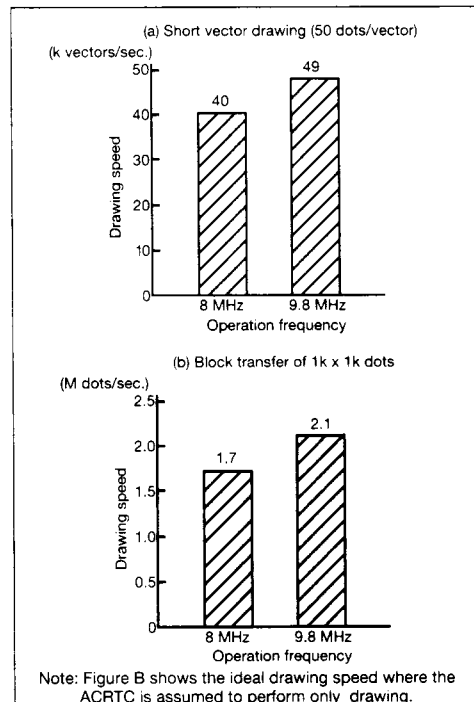


Figure B. Drawing Capability Comparison between 9.8-MHz and 8-MHz ACRTCs.

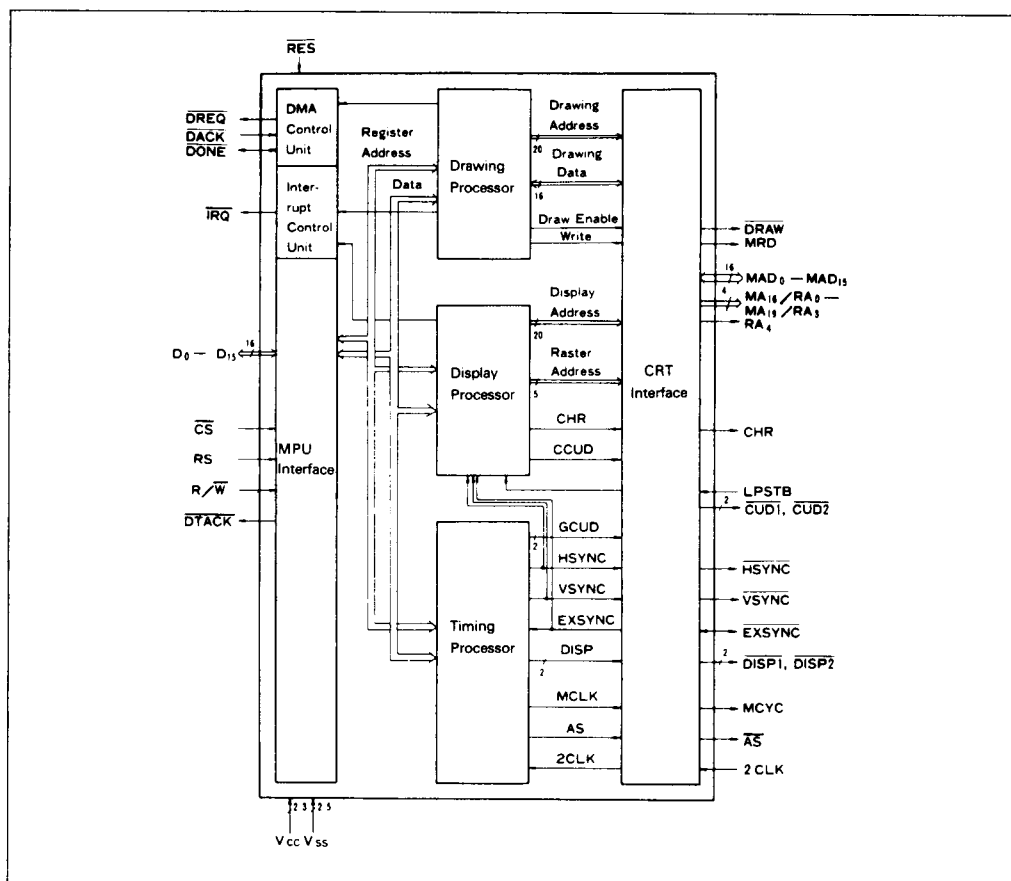


Figure 1 ACRTC Block Diagram

System Configuration

Current CRT controllers provide a single bus interface to the frame buffer that must be shared with the host MPU. However, refreshing large frame buffers, and accessing the frame buffer for drawing operations can quickly saturate the shared bus.

As shown in figure 2, the ACRTC uses separate host MPU and frame buffer interfaces. This allows the ACRTC full access to the frame buffer for display refresh and drawing operations and minimizes the ACRTC's use of the MPU system bus. A related benefit is that a large frame buffer (2 Mbyte for each ACRTC) can be used, even if the host MPU has a smaller address space or segment size restriction.

The ACRTC can use an external DMA controller. A DMA controller increases system throughput when many commands, parameters, and data must be transferred to the ACRTC. Advanced DMAC features, such as the HD68450 "chaining" modes can be used to develop powerful graphics system architectures.

However, more cost-sensitive or less performance-sensitive applications do not require a DMAC. The interface to the ACRTC can be handled under MPU software control.

While both ACRTC bus interfaces (host MPU and frame buffer) are 16 bits wide, the ACRTC also offers an 8-bit MPU mode for easy connection to popular 8-bit busses.

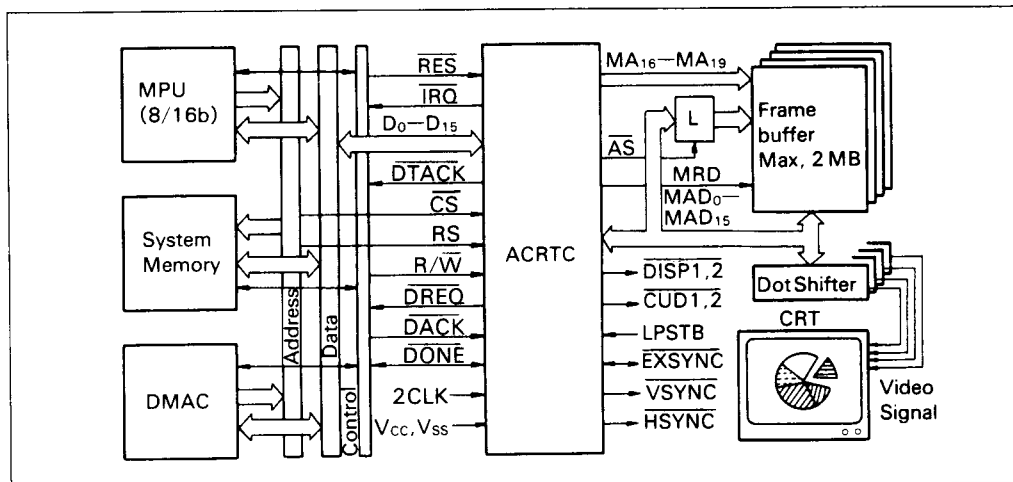


Figure 2 System Configuration

Programming Model

Address Space

The ACRTC allows the host to issue commands in logical X-Y coordinates. The ACRTC converts these physical linear word addresses with bit field offsets in the frame buffer. Figure 3 shows the relationship between the logical X-Y screen address and the frame buffer memory, which is organized as sequential 16-bit words. The host may specify logical pixels of 1, 2, 4, 8, or 16 physical bits in the frame buffer. The system in figure 3 uses 4-bit logical pixels, allowing 16 colors or tones to be selected.

Up to four logical screens (upper, base, lower, and window) are mapped onto the ACRTC physical address space. The host specifies a logical screen physical start address, logical screen physical memory width (memory words per raster), logical pixel physical memory width (bit per pixel), and the logical origin physical address. Then the ACRTC converts logical pixel X-Y addresses issued by the host MPU or the ACRTC drawing processor to physical frame buffer addresses. The ACRTC also performs bit extraction and masking to map logical pixel

operations (for example, 4 bits), to 16-bit word frame buffer addresses.

Registers

The ACRTC has over 200 bytes of accessible registers (figures 4, 5 and table 1). They are organized as hardware access, direct access, and FIFO access.

Hardware Access: The ACRTC is connected to the host MPU as a standard memory-mapped peripheral that occupies two word locations of the host's address space. The RS (register select) pin selects one of these two locations. When RS = 0 (low), read operations access the status register, and write operations access the address register.

The status register summarizes the ACRTC state. It monitors the overall state of the ACRTC for the host MPU.

When the MPU wants to access a direct access register, it puts the register's address

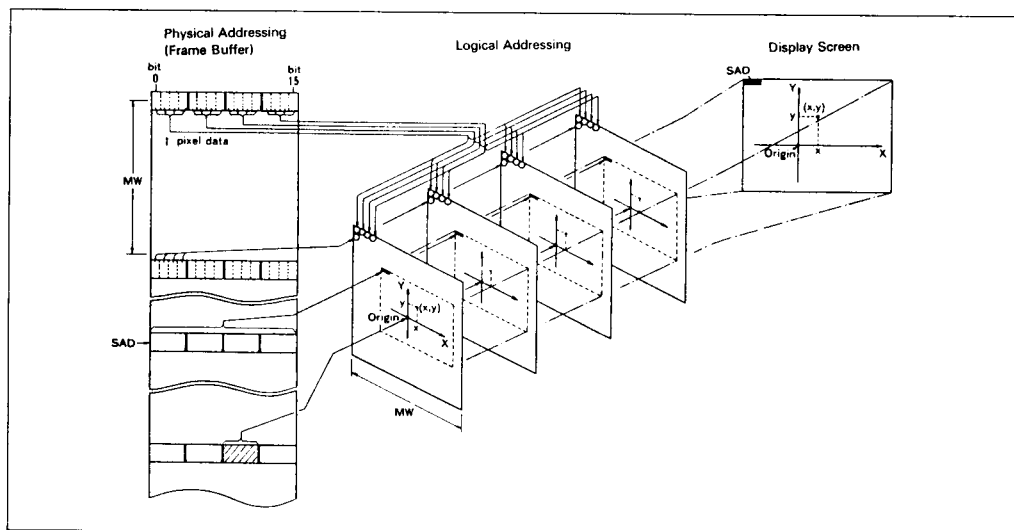


Figure 3. Logical/Physical Addressing

into the ACRTC address register.

Direct Access: The MPU accesses the direct access registers by first loading the register address into the address register. Then, when the MPU accesses the ACRTC with RS = 1 (high), the chosen register is accessed.

The FIFO entry register enables the MPU to access FIFO access registers using the ACRTC read and write FIFOs.

The command control register controls overall ACRTC operations, such as aborting or pausing commands, defining DMA protocols, and enabling/disabling interrupt sources.

The operation mode register defines basic parameters of ACRTC operation, such as frame buffer access mode, display or drawing priority, cursor and display timing skew factors, and raster scan mode.

The display control register independently enables and disables the four ACRTC logical address screens (upper, base, lower, and window). It also contains 8 user-defined video attribute bits.

The timing control RAM registers define ACRTC timing, including timing specifications for CRT control signals (HSYNC, VSYNC, etc), logical display screen size and

display period, and blink period.

The display control RAM contains registers which define logical screen display parameters, such as start address, raster address, and memory width. It also includes the cursor(s) definition, zoom factor, and lightpen registers.

FIFO Access: For high-performance drawing, key drawing processor registers are coupled to the host MPU via the ACRTC's 16-byte read and write FIFOs.

ACRTC commands are sent from the MPU via the write FIFO to the command register. As the ACRTC completes a command, the next command is automatically fetched from the write FIFO and put into the command register.

The pattern RAM defines drawing and painting patterns. It is accessed with the ACRTC's Read Pattern RAM (RPTN) and Write Pattern RAM (WPTN) register access commands.

The drawing parameter registers define detailed parameters of the drawing process, such as color data, area control (hitting/clipping), and pattern RAM pointers. The drawing parameter registers are accessed using the ACRTC's Read Parameter Register (RPR) and Write Parameter Register (WPR) commands.

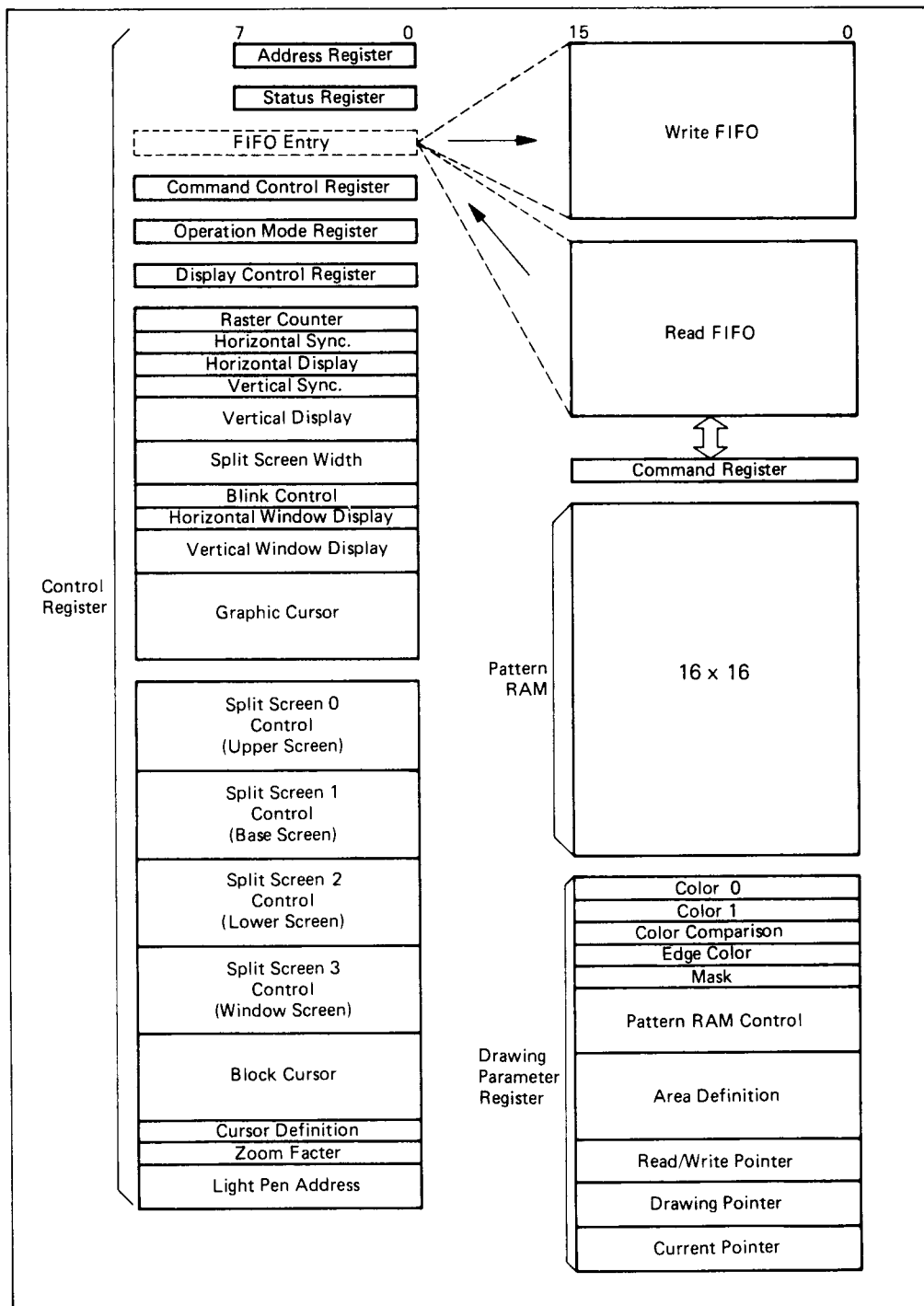


Figure 4. Programming Model

Data High								Data Low							
15	14	13	12	11	10	9	8	7	6	5	4	3	2	1	0

Address Register					Register No.—AR					$\overline{CS}=0$, RS=0, R/ $\overline{W}=0$				
—					Address									

Status Register					Register No.—AR					$\overline{CS}=0$, RS=0, R/ $\overline{W}=0$				
					CER	ARD	CED	LPD	RFF	RFR	WFR	WFE		

FIFO Entry (FE)					Register No.—r00					$\overline{CS}=0$, RS=1, R/ $\overline{W}=0/1$				
FIFO Entry														

Command Control (CCR)					Register No.—r02					$\overline{CS}=0$, RS=1, R/ $\overline{W}=0/1$				
ABT	PSE	DDM	CDM	DRC	GBM		CRE	ARE	CEE	LPE	RFE	RRE	WRE	WEE

Operation Mode (OMR)					Register No.—r04					$\overline{CS}=0$, RS=1, R/ $\overline{W}=0/1$				
M/S	STR	ACP	WSS	CSK	DSK	RAM	GAI		ACM		RSM			

Display Control (DCR)					Register No.—r06					$\overline{CS}=0$, RS=1, R/ $\overline{W}=0/1$				
DSP	SE1	SE0		SE2	SE3	ATR								

(Undefined)					Register No.—r08-R7E					$\overline{CS}=0$, RS=1, R/ $\overline{W}=0/1$				
—														

Raster Count (RCR)					Register No.—r80					$\overline{CS}=0$, RS=1, R/ $\overline{W}=1$				
—					RC									

Horizontal Sync (HSR)					Register No.—r82					$\overline{CS}=0$, RS=1, R/ $\overline{W}=0/1$				
HC					—					HSW				

Horizontal Display (HDR)					Register No.—r84					$\overline{CS}=0$, RS=1, R/ $\overline{W}=0/1$				
HDS					HDW									

Vertical Sync (VSR)					Register No.—r86					$\overline{CS}=0$, RS=1, R/ $\overline{W}=0/1$				
—					VC									

Vertical Display (VDR)					Register No.—r88					$\overline{CS}=0$, RS=1, R/ $\overline{W}=0/1$				
VDS					—					VSW				

Figure 5. Hardware Access and Direct Access Registers

Split Screen Width (SSW)		Register No.—8A, 8C, 8E		$\overline{CS}=0$, RS=1, R/ $\overline{W}=0/1$	
—	SP1				
—	SP0				
—	SP2				
Blink Control (BCR)		Register No.—r90		$\overline{CS}=0$, RS=1, R/ $\overline{W}=0/1$	
BON1	BOFF1	BON2	BOFF2		
Horizontal Window Display (HWR)		Register No.—r92		$\overline{CS}=0$, RS=1, R/ $\overline{W}=0/1$	
HWS		HWW			
Vertical Window Display (VDR)		Register No.—r94, 96		$\overline{CS}=0$, RS=1, R/ $\overline{W}=0/1$	
—	VWS				
—	VWW				
Graphic Cursor (GCR)		Register No.—r98, 9A, 9C		$\overline{CS}=0$, RS=1, R/ $\overline{W}=0/1$	
CXE		CXS			
—	CYS				
—	CYE				
(Underfined)		Register No.—r9E-BE		$\overline{CS}=0$, RS=1, R/ $\overline{W}=0/1$	
—					
Upper Screen					
Raster Address 0 (RAR0)		Register No.—rC0		$\overline{CS}=0$, RS=1, R/ $\overline{W}=0/1$	
—	LRA0	—	FRA0		
Memory Width 0 (MWR0)		Register No.—C2		$\overline{CS}=0$, RS=1, R/ $\overline{W}=0/1$	
CHR	—	MW0			
Start Address 0 (SAR0)		Register No.—rC4, C6		$\overline{CS}=0$, RS=1, R/ $\overline{W}=0/1$	
—	SDA0	—	SA0H/SRA0		
SA0L					

Figure 5. Hardware Access and Direct Access Registers (cont)

Base Screen			
Raster Address 1 (RAR1)		Register No.—rC8	$\overline{CS}=0, RS=1, R/\overline{W}=0/1$
—	LRA1	—	FRA1
Memory Width 1 (MWR1)		Register No.—rCA	$\overline{CS}=0, RS=1, R/\overline{W}=0/1$
CHR	—	MW1	
Start Address 1 (SAR1)		Register No.—rCC, rCE	$\overline{CS}=0, RS=1, R/\overline{W}=0/1$
—	SDA1	—	SA1H/SRA1
SA1L			
Lower Screen			
Raster Address 2 (RAR2)		Register No.—rD0	$\overline{CS}=0, RS=1, R/\overline{W}=0/1$
—	LRA2	—	FRA2
Memory Width 0 (MWR2)		Register No.—rD2	$\overline{CS}=0, RS=1, R/\overline{W}=0/1$
CHR	—	MW2	
Start Address 0 (SAR2)		Register No.—rD4, D6	$\overline{CS}=0, RS=1, R/\overline{W}=0/1$
—	SDA2	—	SA2H/SRA2
SA2L			
Window Screen			
Raster Address 3 (RAR3)		Register No.—rD8	$\overline{CS}=0, RS=1, R/\overline{W}=0/1$
—	LRA3	—	FRA3
Memory Width 0 (MWR3)		Register No.—rDA	$\overline{CS}=0, RS=1, R/\overline{W}=0/1$
CHR	—	MW3	
Start Address 0 (SAR3)		Register No.—rDC, rDE	$\overline{CS}=0, RS=1, R/\overline{W}=0/1$
—	SDA3	—	SA3H/SRA3
SA3L			
Block Cursor 1 (BCUR1)		Register No.—rE0, rE2	$\overline{CS}=0, RS=1, R/\overline{W}=0/1$
BCW1	B $\overline{CS}$ R1	—	BCER1
BCA1			
Block Cursor 2 (BCUR2)		Register No.—rE4, rE6	$\overline{CS}=0, RS=1, R/\overline{W}=0/1$
BCW2	B $\overline{CS}$ R2	—	BCER2
BCA2			

Figure 5. Hardware Access and Direct Access Registers (cont)

Cursor Definition (CDR)		Register No.=rE8		CS=0, RS=1, R/W=0/1	
CM	CON1	COFF1	—	CON2	COFF2

Zoom Factor (ZFR)		Register No.=rEA		CS=0, RS=1, R/W=0/1	
HZF	VZF	—			

Lightpen Address (LPAR)		Register No.=rEC, rEE		CS=0, RS=1, R/W=0/1	
—		CHR	—	LPAH	
LPAL					

(Underfined)		Register No.=rF0-rFE		CS=0, RS=1, R/W=0/1	
—					

ABT: Abort ACM: Access Mode ACP: Access Priority Address: Control Register number ARD: Area Detect ARE: Area Detect Interrupt Enable ATR: Attribute Control CDM: Command DMA Mode CED: Command End CEE: Command End Interrupt Enable CER: Command Error CRE: Command Error Interrupt Enable CSK: Cursor Display Skew DDM: Data DMA Mode DRC: DMA Request Control DSK: DISP Skew DSP: DISP Signal Control FE: FIFO Entry GAI: Graphic Address Increment Mode GBM: Graphic Bit Mode HC: Horizontal Cycle HDS: Horizontal Display Start HDW: Horizontal Display Width HSW: Horizontal Sync Width LPD: Light Pen Strobe Detect LPE: Light Pen Strobe Interrupt Enable M/S: Master/Slave PSE: Pause RAM: RAM Mode RC: Raster Count RFE: Read FIFO Full Interrupt Enable RFF: Read FIFO Full RFR: Read FIFO Ready RRE: Read FIFO Ready Interrupt Enable RSM: Raster Scan Mode SE0: Split Enable 0 SE1: Split Enable 1 SE2: Split Enable 2 SE3: Split Enable 3 STR: Start	VC: Vertical Cycle VDS: Vertical Display Start VSW: Vertical Sync Width WEE: Write FIFO Empty Interrupt Enable WFE: Write FIFO Empty WFR: Write FIFO Ready WRE: Write FIFO Ready Interrupt Enable WSS: Window Smooth Scroll SP0, SP1, SP2: Split Screen 0 Width, Split Screen 1 Width, Split Screen 2 Width BON1, BON2: Blink On 1, Blink On 2 BOFF1, BOFF2: Blink Off 1, Blink Off 2 HWS: Horizontal Window Start HWW: Horizontal Window Width VWS: Vertical Window Start VWW: Vertical Window Width CXS, CYS: Cursor X Start, Cursor Y Start CXE, CYE: Cursor X End, Cursor Y End FRA: First Raster Address LRA: Last Raster Address CHR: Character MW: Memory Width SDA: Start Dot Address SAH/SRA: Start Address High/Start Raster Address SAL: Start Address Low BCW1, BCW2: Block Cursor Width 1, Block Cursor Width 2 BCSR1, BCSR2: Block Cursor Start Raster 1, Block Cursor Start Raster 2 BCER1, BCER2: Block Cursor End Raster 1, Block Cursor End Raster 2 BCA1, BCA2: Block Cursor Address 1, Block Cursor Address 2 CM: Cursor Mode CON1, CON2: Cursor On 1, Cursor On 2 COFF1, COFF2: Cursor Off 1, Cursor Off 2 HZF, VZF: Horizontal Zoom Factor, Vertical Zoom Factor LPAH: Light Pen Address High LPAL: Light Pen Address Low
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Figure 5. Hardware Access and Direct Access Registers (cont)

Table 1. Drawing Parameter Registers

Register Read/ No.	Write	Name of Register	Abbr.	Data (H)								Data (L)							
				15	14	13	12	11	10	9	8	7	6	5	4	3	2	1	0
Pr00	R/W	Color 0	CL0									CL0							
Pr01	R/W	Color 1	CL1									CL1							
Pr02	R/W	Color Comparison	CCMP									CCMP							
Pr03	R/W	Edge Color	EDG									EDG							
Pr04	R/W	Mask	MASK									MASK							
Pr05	R/W	Pattern RAM Control	PRC	PPY		PZCY		PPX		PZCX									
↓				PSY		—		PSX		—									
Pr07				PEY		PZY		PEX		PZX									
Pr08	R/W	Area Definition**	ADR	XMIN															
↓				YMIN															
				XMAX															
Pr08				YMAX															
Pr0C	R/W	Read Write Pointer	RWP	DN	—				RWPH										
Pr0D				RWPL				—											
Pr0E	—	Undefined	—	—															
Pr0F				—															
Pr010	R	Drawing Pointer	DP	DN	—				DPAH										
Pr11				DPAL				DPD											
Pr12	R	Current Pointer**	CP	X															
Pr13				Y															
Pr14	—	Undefined	—	—															
Pr15				—															

—: Always set to 0.

** : Set two's complements for negative values of X and Y axis.

Drawing Parameter Register

R: Register which can be read by Read Parameter Register Command (RPR)

W: Register which can be written into by Write Parameter Register Command (WPR)

—: Access is not allowed

CL0: Defines the color data used for the drawing when logical drawing data=0

CL1: Defines the color data used for the drawing when logical drawing data=1

CCMP: Defines the comparison color of the drawing operation

PSX, PSY: Pattern Start Point

PEX, PEY: Pattern End Point

PPX, PPY: Pattern Scan Start Point

PZX, PZY: Pattern Zoom

PZCX, PZCY: Pattern Zoom Count

XMIN, YMIN: Start point of Area definition

XMAX, YMAX: End point of Area definition

Dn: Screen Number

RWPH: High-order 8 bits of Read Write Pointer Address

RWPL: Low-order 12 bits of Read Write Pointer Address

DPAH: High-order 8 bits of Drawing Pointer Address

DPAL: Low-order 12 bits of Drawing Pointer Address

DPD: Drawing Pointer Dot Address

X, Y: Position indicated by Current Pointer on X-Y coordinate



Display Functions

Logical Display Screens

The ACRTC allows the frame buffer to be divided into four separate logical screens (table 2, figure 6).

In the simplest case, only the base screen parameters must be defined. Other screens may be selectively enabled, disabled, and blanked under software control.

The background screens (upper, base, and lower) split the screen into three horizontal partitions whose positions are fully programmable. A typical application might use the base screen for the bulk of user interac-

tion, using the lower screen for a "status line(s)" and the upper screen for "pulldown menus".

The window screen is unique, since the ACRTC usually gives it higher priority than the background screens. Thus, when the window, whose size and position is completely programmable, overlaps a background screen, the window is displayed. The exception is in the ACRTC superimposed mode, in which the window has the same priority as the background screens. In this mode, the window and background screens are "superimposed" on the display.

2

Table 2. Logical Screen

Screen Number	Screen Name	Screen Group
0	Upper screen	Background screens
1	Base screen	
2	Low screen	
3	Window screen	

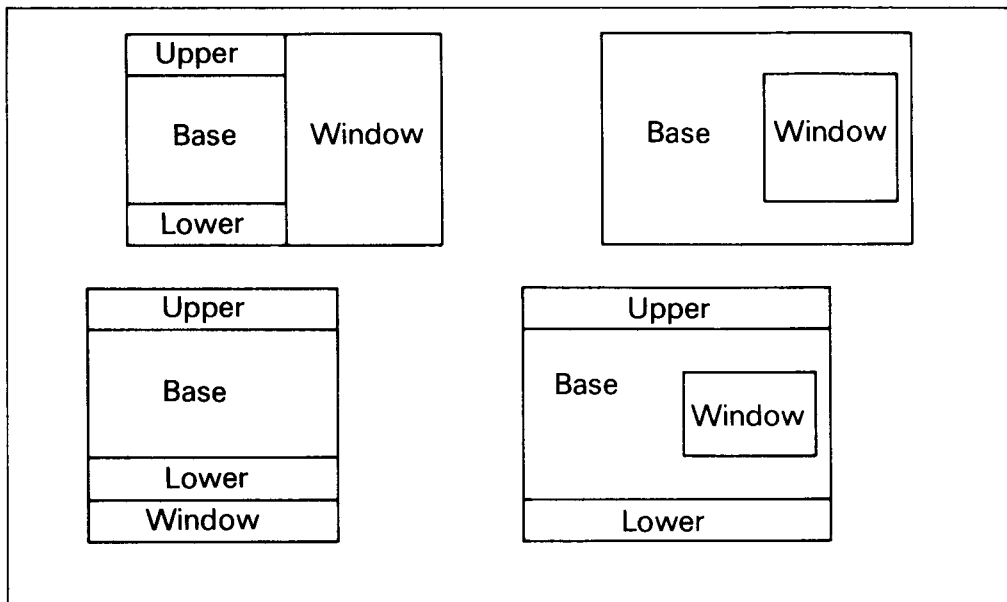


Figure 6. Screen Combination Examples

Frame Memory Setup

The ACRTC can have two independent frame memories, a 2-Mbyte frame buffer and a 128-kbyte refresh memory. The CHR output controls which memory is accessed.

Frame memory width is defined by setting up the memory width register (MWR). The horizontal width is independently defined by the horizontal display register (HDR). The memory area can therefore be specified bigger than the display area (figure 7).

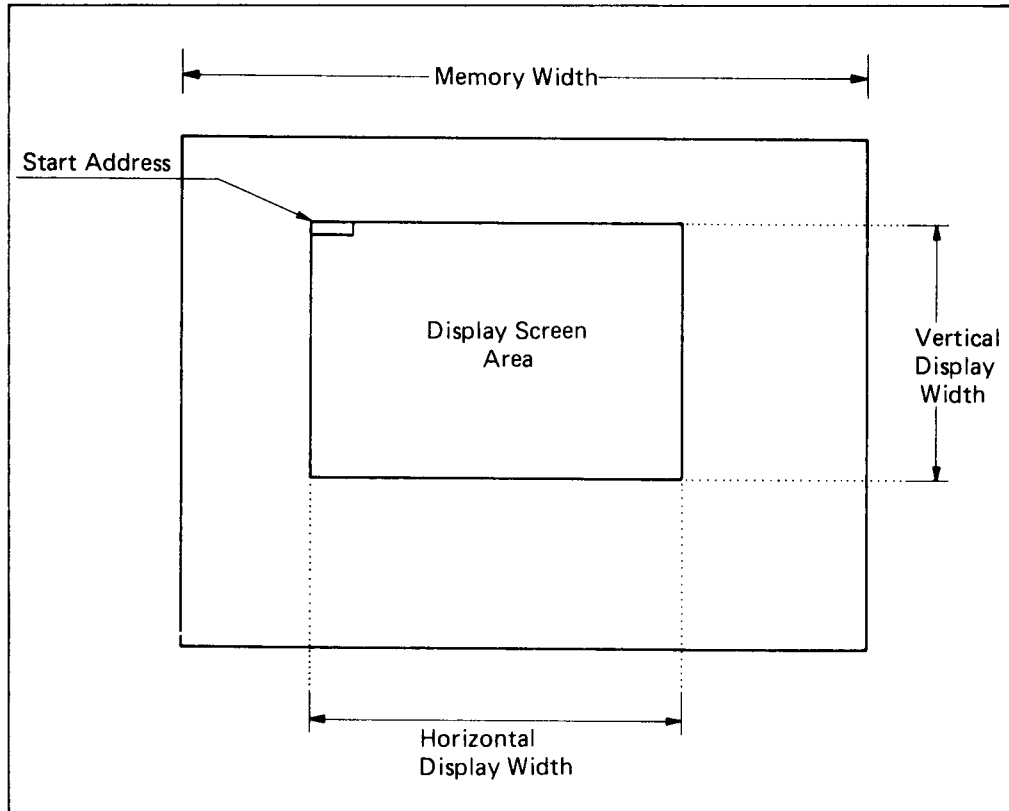


Figure 7. Frame Memory and Display Screen Area

Display Control

Figure 8 shows the relation between the frame memory and display screens. Each screen has its own memory width, vertical display width, and character/graphic attribution. These specifications are set by the control registers.

Horizontal display control registers are set in units of memory cycles. Vertical display control registers are set in units of rasters.

Note that display width of registers marked with an asterisk (*) in figure 9 is:

$$(\text{Display width}) = (\text{Register value}) + 1 \text{ memory cycles}$$

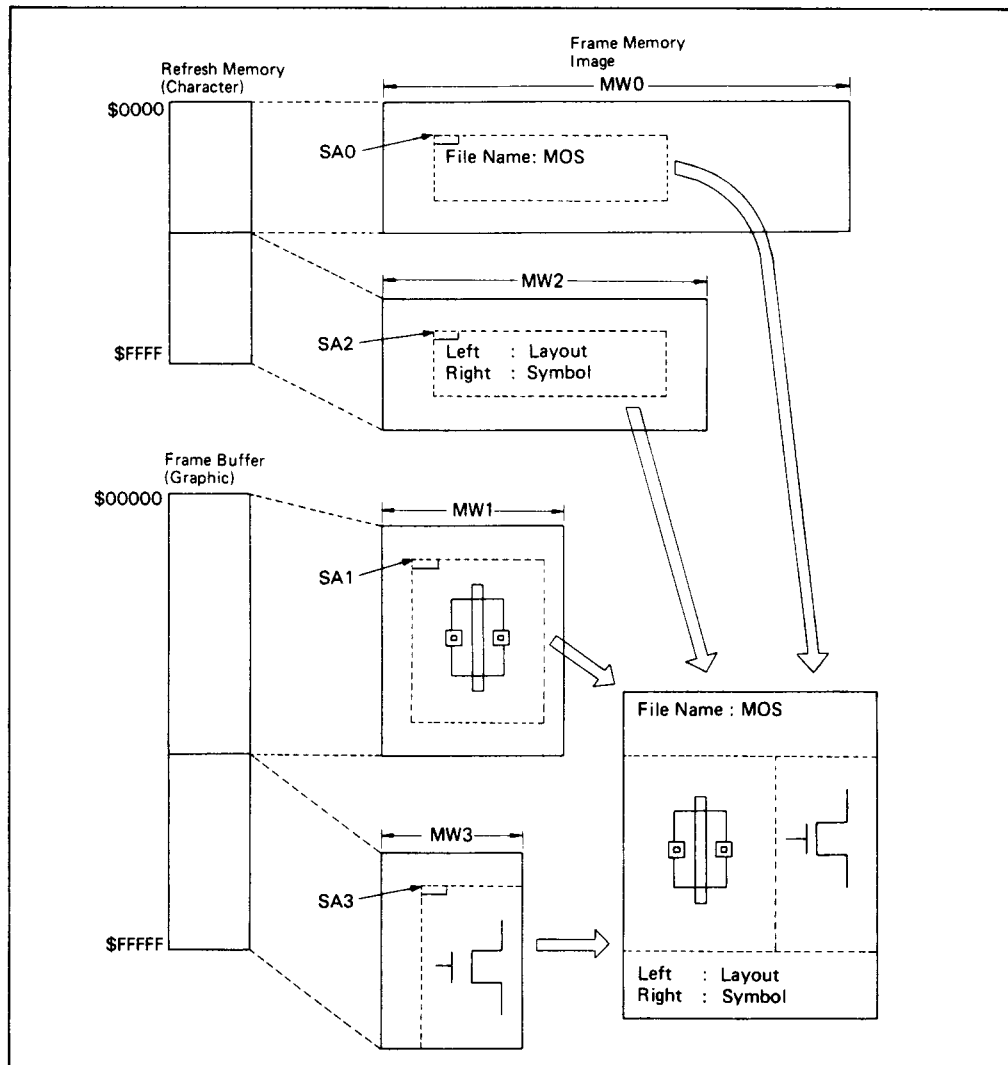


Figure 8. Frame Memory and Display Screens

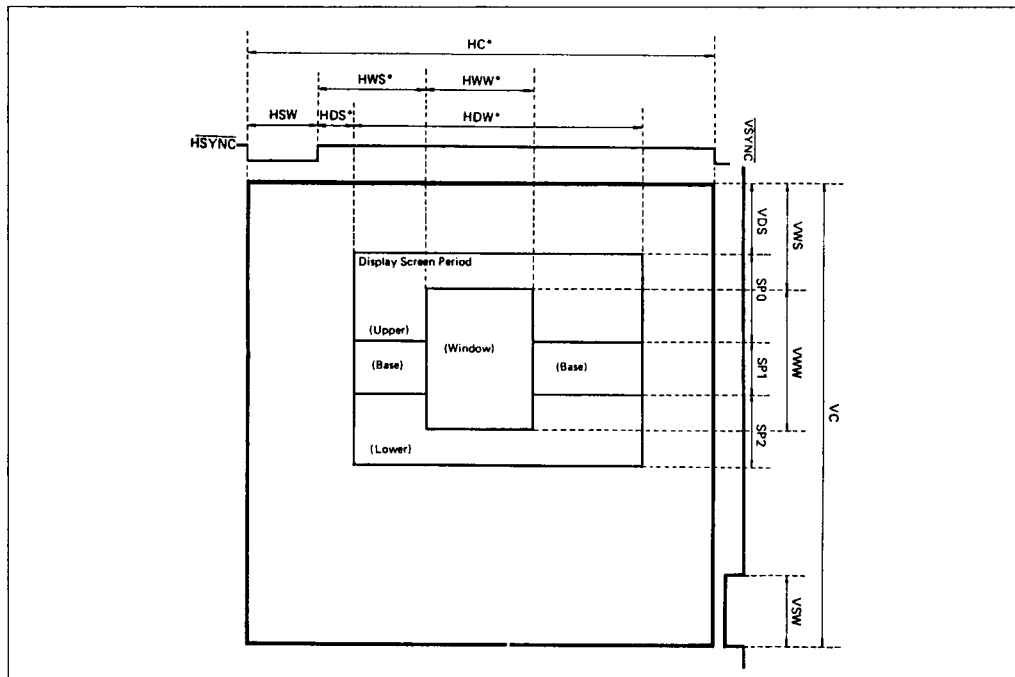


Figure 9. Display Screen Specification

Commands

The ACRTC has 38 commands classified into three groups (tables 3, 4):

- Register access
- Data transfer
- Graphic drawing

Five register access commands give the host MPU access to drawing processor drawing parameter registers and the pattern RAM.

Ten data transfer commands move data between the host system memory and the frame buffer, or within the frame buffer.

Twenty-three graphic drawing commands cause the ACRTC to draw. Parameters for these commands are specified using logical X-Y addressing.

All commands, parameters, and data are transferred via the ACRTC read and write FIFOs.

Assuming the ACRTC has been properly initialized, the MPU must perform two

steps to make the ACRTC draw:

1. First the MPU must specify drawing parameters that define the details associated with the drawing. For example, to draw a figure or paint an area, the MPU must specify the drawing or painting pattern by initializing the ACRTC pattern RAM and related pointers. If clipping or hitting control are desired, the MPU must specify the area to be monitored during drawing by initializing the area definition registers. Other drawing parameters include color, edge definition, etc.
2. After the drawing parameters have been specified, the MPU issues a drawing command and any required command parameters, such as the CRCL (circle) command with a radius parameter.

The ACRTC then performs the specified drawing operation by reading, modifying, and rewriting the contents of the frame buffer.

Table 3. ACRTC Command Table

Type	Mnemonic	Command Name	# (words)	Operation Cycles *1
Register	ORG	Origin	3	8
Access	WPR	Write Parameter Register	2	6
Command	RPR	Read Parameter Register	1	6
	WPTN	Write Pattern RAM	n+2	4n+8
	RPTN	Read Pattern RAM	2	4n+10
Data	DRD	DMA Read	3	$(4x+8)y+12[x \cdot y/8\uparrow] + (62 \sim 68)$
Transfer	DWT	DMA Write	3	$(4x+8)y+16[x \cdot y/8\uparrow] + 34$
Command	DMOD	DMA Modify	3	$(4x+8)y+16[x \cdot y/8\uparrow] + 34$
	RD	Read	1	12
	WT	Write	2	8
	MOD	Modify	2	8
	CLR	Clear	4	$(2x+8)y+12$
	SCLR	Selective Clear	4	$(4x+6)y+12$
	CPY	Copy	5	$(6x+10)y+12$
	SCPY	Selective Copy	5	$(6x+10)y+12$
Graphic	AMOVE	Absolute Move	3	56
Drawing	RMOVE	Relative Move	3	56
Command	ALINE	Absolute Line	3	$P \cdot L + 18$
	RLINE	Relative Line	3	$P \cdot L + 18$
	ARCT	Absolute Rectangle	3	$2P(A+B)+54$
	RRCT	Relative Rectangle	3	$2P(A+B)+54$
	APLL	Absolute Polyline	2n+2	$\Sigma [P \cdot L + 16] + 8$
	RPLL	Relative Polyline	2n+2	$\Sigma [P \cdot L + 16] + 8$
	APLG	Absolute Polygon	2n+2	$\Sigma [P \cdot L + 16] + P \cdot Lo + 20$
	RPLG	Relative Polygon	2n+2	$\Sigma [P \cdot L + 16] + P \cdot Lo + 20$
	CRCL	Circle	2	8d+66
	ELPS	Ellipse	4	10d+90
	AARC	Absolute Arc	5	8d+18
	RARC	Relative Arc	5	8d+18
	AEARC	Absolute Ellipse Arc	7	10d+96
	REARC	Relative Ellipse Arc	7	10d+96
	AFRCT	Absolute Filled Rectangle	3	$(P \cdot A + 8)B + 18$
	RFRCT	Relative Filled Rectangle	3	$(P \cdot A + 8)B + 18$
	PAINT	Paint	1	$(18A+102)B-58$ *2
	DOT	Dot	1	8
	PTN	Pattern	2	$(P \cdot A + 10)B + 20$
	AGCPY	Absolute Graphic Copy	5	$((P+2)A+10)B+70$
	RGCPY	Relative Graphic Copy	5	$((P+2)A+10)B+70$

Notes: 1. 2CLK cycles.

2. Applies to rectangular figures. Time varies for other shapes.

3. Abbreviations

n: Number of read/write data words

x: Number of words in X direction

y: Number of words in Y direction

↑: Round up

P: Operation cycles—P=4 cycles when OPM=000—011;

P=6 cycles when OPM=100—111

L, Lo: Number of dots in a straight line

d: Total number of dots

A: Number of dots in main scan direction

B: Number of dots in sub scan direction

Table 4. Command Operation Codes and Parameters

Type	Mnemonic	Operation Code	Parameter
Register Access Command	ORG	0 0 0 0 0 1 0 0 0 0 0 0 0 0 0 0	DPH DPL
	WPR	0 0 0 0 1 0 0 0 0 0 0 0	RN D
	RPR	0 0 0 0 1 1 0 0 0 0 0 0	RN
	WPTN	0 0 0 1 1 0 0 0 0 0 0 0	PRA n D ₁ , ..., D _n
	RPTN	0 0 0 1 1 1 0 0 0 0 0 0	PRA n
Data Transfer Command	DRD	0 0 1 0 0 1 0 0 0 0 0 0 0 0 0 0	AX AY
	DWT	0 0 1 0 1 0 0 0 0 0 0 0 0 0 0 0	AX AY
	DMOD	0 0 1 0 1 1 0 0 0 0 0 0 0 0 0 0	MM AX AY
	RD	0 1 0 0 0 1 0 0 0 0 0 0 0 0 0 0	
	WT	0 1 0 0 1 0 0 0 0 0 0 0 0 0 0 0	D
	MOD	0 1 0 0 1 1 0 0 0 0 0 0 0 0 0 0	MM D
	CLR	0 1 0 1 1 0 0 0 0 0 0 0 0 0 0 0	D AX AY
	SCLR	0 1 0 1 1 1 0 0 0 0 0 0 0 0 0 0	D AX AY
	CPY	0 1 1 0 S DSD	0 0 0 0 0 0 0 0 0 0 SAH SAL AX AY
	SCPY	0 1 1 1 S DSD	0 0 0 0 0 0 0 0 0 0 MM SAH SAL AX AY
Graphic Drawing Command	AMOVE	1 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0	X Y
	RMOVE	1 0 0 0 0 1 0 0 0 0 0 0 0 0 0 0	dX dY
	ALINE	1 0 0 0 1 0 0 0	AREA COL OPM X Y
	RLINE	1 0 0 0 1 1 0 0	AREA COL OPM dX dY
	ARCT	1 0 0 1 0 0 0 0	AREA COL OPM X Y
	RRCT	1 0 0 1 0 1 0 0	AREA COL OPM dX dY
	APLL	1 0 0 1 1 0 0 0	AREA COL OPM n X ₁ , Y ₁ , ..., X _n , Y _n
	RPLL	1 0 0 1 1 1 0 0	AREA COL OPM n dX ₁ , dY ₁ , ..., dX _n , dY _n
	APLG	1 0 1 0 0 0 0 0	AREA COL OPM n X ₁ , Y ₁ , ..., X _n , Y _n
	RPLG	1 0 1 0 0 1 0 0	AREA COL OPM n dX ₁ , dY ₁ , ..., dX _n , dY _n
	CRCL	1 0 1 0 1 0 0 0	AREA COL OPM r
	ELPS	1 0 1 0 1 1 0 0	C AREA COL OPM a b DX
	AARC	1 0 1 1 0 0 0 0	C AREA COL OPM X _c Y _c X _e Y _e
	RARC	1 0 1 1 0 1 0 0	C AREA COL OPM dX _c dY _c dX _e dY _e
	AEARC	1 0 1 1 1 0 0 0	C AREA COL OPM a b X _c Y _c X _e Y _e
	REARC	1 0 1 1 1 1 0 0	C AREA COL OPM a b dX _c dY _c dX _e dY _e
	AFRCT	1 1 0 0 0 0 0 0	AREA COL OPM X Y
	RFRCT	1 1 0 0 0 1 0 0	AREA COL OPM dX dY
	PAINT	1 1 0 0 1 0 0 0	E AREA 0 0 0 0 0
	DOT	1 1 0 0 1 1 0 0	AREA COL OPM
	PTN	1 1 0 1 SL SD	AREA COL OPM SZ
	AGCPY	1 1 1 0 S DSD	AREA 0 0 OPM X _s Y _s DX DY
	RGCPY	1 1 1 1 S DSD	AREA 0 0 OPM dX _s dY _s DX DY

- Notes: 1. Register access commands abbreviations
 RN: Drawing parameter register number (\$0-\$13)
 PRA: Pattern RAM read/write operation starting address (\$0-\$F)
 DPH: Drawing pointer register high word (figure 29)
 DPL: Drawing pointer register low word (figure 29)
 DPAH: Higher 8 bits of drawing pointer address
 DPAL: Lower 12 bits of drawing pointer address
 DPD: Dot position in memory address
2. Data transfer commands abbreviations
 MM: Modify mode
 S: Source scan direction (figure 30)
 DSD: Destination scan direction (figure 31)
 AX: Number of words in X direction—1
 AY: Number of words in Y direction—1
 D: Write data
 SAH: Source start address high word (figure 32)
 SAL: Source start address low word
3. Graphic drawing commands abbreviations
 AREA: Area mode
 COL: Color mode
 OPM: Operation mode
 C: Circle drawing direction—C = 0 for counterclockwise;
 C = 1 for clockwise

E: Edge color definition—E = 0, edge color is data in edge color register;
E = 1, edge color is any color except data in color register

SL: Slant (figure 33)

SD: Scan direction (figure 33)

S: Source scan direction (figure 30)

DSD: Destination scan direction (figure 31)

4. Parameter abbreviations

X, X1, ..., Xn: Absolute X address from origin point

Y, Y1, ..., Yn: Absolute Y address from origin point

dX: Relative X address from current pointer

dY: Relative Y address from current pointer

n: Number of nodes

dX1, ..., dXn: Relative X address from each node

dY1, ..., dYn: Relative Y address from each node

r: Number of dots on radius

a, b: ratio of dX squared to dY squared in ellipse—a:b = dX²:dY²

DX: X-direction dot number

DY: Y-direction dot number

Xc: Absolute X address of center point of arc/ellipse

Yc: Absolute Y address of center point of arc/ellipse

dXc: Relative X address from current point to center point of arc/ellipse

dYc: Relative Y address from current point to center point of arc/ellipse

Xe: Absolute X address of end point of arc/ellipse

Ye: Absolute Y address of end point of arc/ellipse

dXe: Relative X address from current point to end point of arc/ellipse

dYe: Relative Y address from current point to end point of arc/ellipse

Xs: Absolute X address of start point of arc/ellipse

Ys: Absolute Y address of start point of arc/ellipse

dXs: Relative X address from current point to start point of arc/ellipse

dYs: Relative Y address from current point to start point of arc/ellipse

Program Transfer

For program transfer, the MPU specifies the FIFO entry address and then writes commands/parameters to the write FIFO under program control (RS = high, R/W, CS = low). The MPU writes are normally synchronized with FIFO status by software polling or interrupt.

Software Polling: WFR, WFE interrupts are disabled.

1. MPU program checks the SR (status register) for write FIFO ready flag (WFR) = 1, then writes 1 command/parameter word.
2. MPU program checks the SR (status register) for write FIFO empty flag (WFE) = 1, then writes 1 to 8 command/parameter words.

Interrupt Driven: WFR, WFE interrupts are enabled.

1. MPU WFR interrupt service routine writes 1 command/parameter word.
2. MPU WFE interrupt service routine writes 1 to 8 command/parameter words.

Register Access Commands: When writing register access commands to an in-

itially empty write FIFO, the MPU does not have to synchronize to write FIFO status. The ACRTC can fetch and execute these commands faster than the MPU can issue them.

Command DMA Transfer

Commands and parameters can be transferred from the MPU system memory by an external DMAC. The MPU initiates and terminates command DMA transfer under software control (CDM bit of CCR). Command DMA transfer can also be terminated by asserting the ACRTC DONE signal. DONE is an input in command DMA transfer mode.

In command DMA transfer mode, the ACRTC issues cycle stealing DMA requests to the DMAC when the write FIFO is ready. The DMA data is automatically sent from system memory to the ACRTC write FIFO regardless of the contents of the address register.

Make sure that the write FIFO is empty and all previous commands are terminated before starting the command DMA transfer.

Data DMA transfer cannot be executed in command DMA transfer mode.

Table 5. Register Access Commands

Command	Function
ORG	Initialize the relation between the origin point in the X-Y coordinates and the physical address
WPR	Write into parameter register
RPR	Read the parameter register
WPTN	Write into pattern RAM
RPTN	Read pattern RAM

Register Access Commands

Registers associated with the drawing processor (pattern RAM and drawing parameter registers) are accessed through the read and write FIFOs using register access commands (table 5).

Data Transfer Commands

Data transfer commands move blocks of data between the MPU system memory and the ACRTC frame buffer, or within the frame buffer itself (table 6). Before issuing these commands, a physical 20-bit frame buffer address must be specified in the

RWP (read/write pointer) drawing parameter register.

Graphic Drawing Commands

The ACRTC has 23 graphic drawing commands (table 7). Graphic drawing is performed by modifying the contents of the frame buffer based on microcoded drawing algorithms in the ACRTC drawing processor.

Most drawing coordinate parameters are specified by logical pixel X-Y addresses. The ACRTC high-speed hardware performs the complex task of translating a logical pixel address to a linear frame buffer word address, and further, selecting the proper subfield of the word (for example, a 4-bit logical pixel might reside in bits 8-11 of a certain frame buffer word).

Many instructions allow specification in either absolute or relative X-Y coordinates (for example, ALINE and RLINE). In both cases, two's complement numbers represent both positive and negative values.

Table 6. Data Transfer Commands

Command	Function
DRD	Transfer data, by DMA transfer, from the frame buffer to the MPU system memory
DWT	Transfer data, by DMA transfer, from the MPU system memory to the frame buffer
DMOD	Transfer data, by DMA transfer, from the MPU system to the frame buffer subject to logical modification (bit maskable)
RD	Read one word of data from the frame buffer specified by the read/write pointer (RWP), and load the word into read FIFO
WT	Write one word of data to the frame buffer specified by the read/write pointer (RWP)
MOD	Perform logical operation on one word in the frame buffer specified by the read/write pointer (RWP) (bit maskable)
CLR	Clear a rectangular area of the frame buffer with data in the command parameter
SCLR	Initialize a rectangular area of the frame buffer with 1-word data subject to logical operation (bit maskable)
CPY	Copy frame buffer data from one area (source area) to another area (destination area) specified by the read/write pointer (RWP)
SCPY	Copy frame buffer data from one area (source area) to another area (destination area) subject to logical modification by word. The source and destination areas must reside on the same screen (bit maskable)

Table 7. Graphic Drawing Commands

Command	Function
AMOVE	Move the current pointer (CP) to an absolute logical pixel X-Y address
RMOVE	Move the current pointer (CP) to a relative logical pixel X-Y address
ALINE	Draw a straight line from the current pointer (CP) to a command-specified end point in absolute coordinates
RLINE	Draw a straight line from the current pointer (CP) to a command-specified end point in relative coordinates
ARCT	Draw a rectangle defined by the current pointer (CP) and a command-specified diagonal point in absolute coordinates
RRCT	Draw a rectangle defined by the current pointer (CP) and a command-specified diagonal point in relative coordinates
APLL	Draw a polyline (multiple contiguous segments) from the current pointer (CP) through command-specified points in absolute coordinates
RPLL	Draw a polyline (multiple contiguous segments) from the current pointer (CP) through command-specified points in relative coordinates
APLG	Draw a polygon which connects the current pointer (CP) and command-specified points in absolute coordinates
RPLG	Draw a polygon which connects the current pointer (CP) and command-specified points in relative coordinates
CRCL	Draw a circle of radius R placing the current pointer (CP) at the center
ELPS	Draw an ellipse whose shape is specified by command parameters, placing the current pointer (CP) at the center
AARC	Draw an arc by using the current pointer (CP) as a start point with an end point and a center point in absolute coordinates
RARC	Draw an arc by using the current pointer (CP) as a start point with an end point and a center point in relative coordinates
AEARC	Draw an ellipse arc by using the current pointer (CP) as a start point with an end point and a center point in absolute coordinates
REARC	Draw an ellipse arc by using the current pointer (CP) as a start point with an end point and a center point in relative coordinates
AFRCT	Paint a rectangular area specified by the current pointer (CP) and command parameters (absolute coordinates) according to a figure pattern stored in the pattern RAM (tiling)
RFRCT	Paint a rectangular area specified by the current point (CP) and command parameters (relative coordinates) according to a figure pattern stored in the pattern RAM (tiling)
PAINT	Paint a closed area surrounded by edge color using a figure pattern stored in the pattern RAM (tiling)
DOT	Mark a dot on the coordinates indicated by the current pointer (CP)
PTN	Draw a graphic pattern defined in the pattern RAM onto a rectangular area specified by the current point (CP) and by the pattern size (rotation angle: 45°)
AGCPY	Copy a rectangular area specified by the absolute coordinates to the address specified by the current pointer (CP) (rotation angle: 90°/mirror reflection)
RGCPY	Copy a rectangular area specified by the relative coordinates to the address specified by the current pointer (CP) (rotation angle: 90°/mirror reflection)

Notes on System Design

Power-On Sequence

The conditions in figure 10 must be satisfied at power-on.

Output Waveform

If excessive ringing (figure 11) occurs on CRT data buses, (MAD_0 - MAD_{15} , MA_{16}/RA_0 - MA_{19}/RA_4), damping resistors may be required as shown in figure 12.

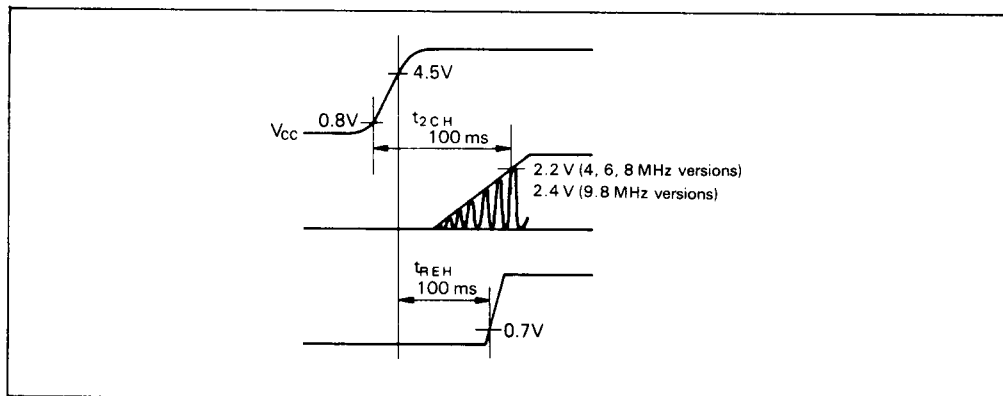


Figure 10. Power-On Sequence

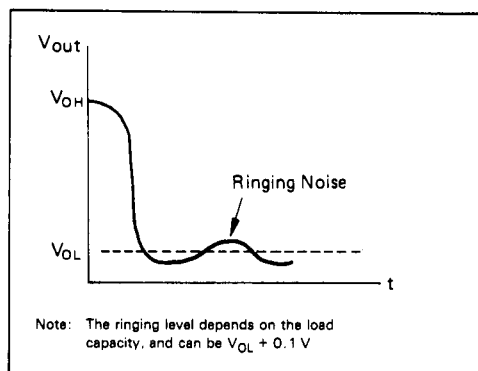


Figure 11. Ringing Noise

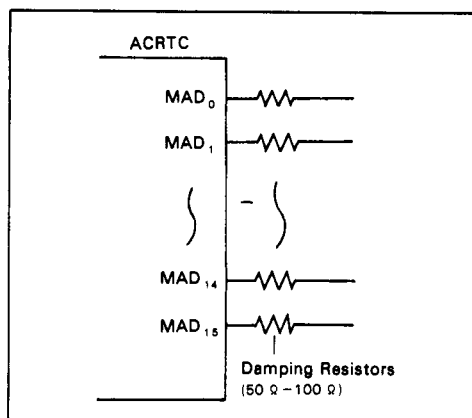


Figure 12. Damping Resistors

Power Supply Circuit

When laying out the V_{CC} and V_{SS} traces on

the circuit board, locate capacitors as close as possible to each power supply pin (figures 13, 14, 15).

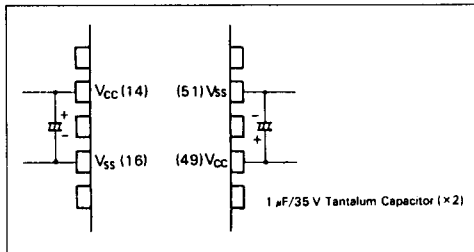


Figure 13. Power Supply Circuit Example, 64-Pin DIP

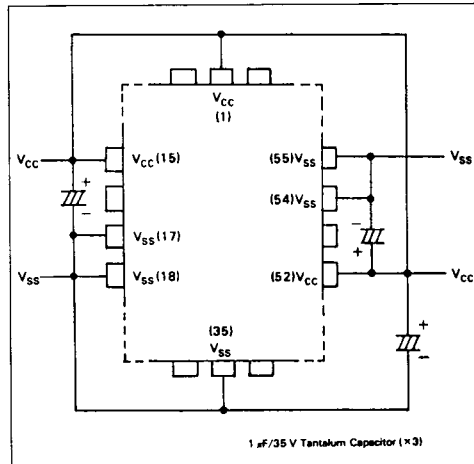


Figure 14. Power Supply Circuit Example, 68-Pin PLCC

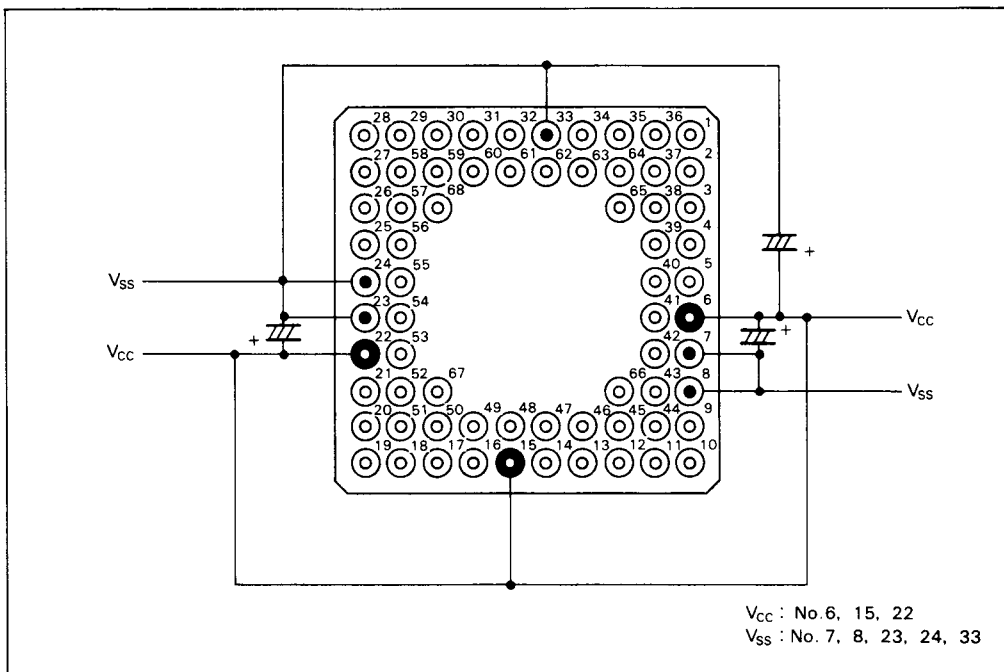


Figure 15. Power Supply Circuit Example 68-Pin PGA

Absolute Maximum Ratings

Item	Symbol	Rating	Unit
Supply Voltage	V_{CC} (Note 1)	-0.3 to +7.0	V
Input Voltage	V_{in} (Note 1)	-0.3 to $V_{CC} + 0.3$	V
Allowable Output Current	$ I_{O1} $ (Note 2)	5	mA
Total Allowable Output Current	$ \sum I_O $ (Note 3)	120	mA
Operating Temperature	T_{opr}	0 to +70	°C
Storage Temperature	T_{stg}	-55 to +150	°C

- Notes: 1. Referenced to $V_{SS} = 0$ V.
 2. The maximum current that may be drawn from, or flow out of, one output, or one common input/output terminal.
 3. The total sum of currents that may be drawn from, or flow out of, all output or common input/output terminals.
 4. Using an LSI beyond its maximum rating may result in its permanent destruction.
 LSIs should usually be used under recommended operating conditions. Exceeding any of these conditions may adversely affect reliability.

Recommended Operating Conditions

Item	Symbol	Min	Typ	Max	Unit
Supply Voltage	V_{CC} (Note)	4.75	5.0	5.25	V
Input Low Voltage	V_{IL} (Note)	0		0.7	V
Input High Voltage (4, 6, 8 MHz versions)	V_{IH} (Note)	2.2		V_{CC}	V
(9.8 MHz version)	V_{IH} (Note)	2.4		V_{CC}	V
Operating Temperature	T_{opr}	0	25	75	°C

Note: Referenced to $V_{SS} = 0$ V

Electrical Characteristics**DC Characteristics**(V_{CC}=5.0V ± 5%, V_{SS}=0V, Ta=0°C to +70°C unless otherwise noted)

Item		Symbol	Min	Max	Unit	Test Condition
Input High Level Voltage	All inputs	V _{IH}	2.2	V _{CC}	V	4, 6, 8 MHz versions
			2.4	V _{CC}	V	9.8 MHz version ★
Input Low Level Voltage	All inputs	V _{IL}	-0.3	0.7	V	
Input Leak Current	R/W, CS, RS, RES, DACK, 2CLK, LPSTB	I _{in}	-2.5	2.5	μA	V _{in} = -0.4 to V _{CC}
Hi-Z Input Current	D ₀ -D ₁₅ , MAD ₀ -MAD ₁₅ , EXSYNC	I _{TSI}	-10	10	μA	V _{in} = -0.4 to V _{CC}
Output High Level Voltage	D ₀ -D ₁₅ , MAD ₀ -MAD ₁₅ , CUD1, CUD2, DREQ, DTACK, HSYNC, VSYNC, EXSYNC, MRD, DRAW, AS, DISP1, DISP2, CHR, MCYC, RA ₄ , MA ₁₆ /RA ₀ -MA ₁₉ /RA ₃	V _{OH}	V _{CC} -1.0		μA	I _{OH} = -400 μA
Output Low Level Voltage	D ₀ -D ₁₅ , MAD ₀ -MAD ₁₅ , CUD1, CUD2, DREQ, DTACK, HSYNC, VSYNC, EXSYNC, MRD, DRAW, AS, DISP1, DISP2, CHR, MCYC, RA ₄ , MA ₁₆ /RA ₀ -MA ₁₉ /RA ₃	V _{OL}		0.5	V	I _{OL} = 2.2 mA
	IRQ, DONE	VO _L		0.5	V	I _{OL} = 2.5 mA
Output Leak Current (Hi-Z)	IRQ, DONE	I _{LOD}		10	μA	V _{OH} = V _{CC}
Input Capacitance	D ₀ -D ₁₅ , MAD ₀ -MAD ₁₅ , EXSYNC, R/W, CS, RS, RES, DACK, 2CLK, LPSTB	C _{in}		17	pF	V _{in} = 0 V, Ta = 25°C, f = 1.0 MHz
Output Capacitance	IRQ, DONE	C _{out}		15	pF	V _{in} = 0 V, Ta = 25°C, f = 1.0 MHz
Current Consumption		I _{CC}		60	mA	4 MHz version
				80	mA	6 MHz version
				100	mA	8 MHz version
				120	mA	9.8 MHz version

AC Characteristics ($V_{CC}=5.0V \pm 5\%$, $V_{SS}=0V$, $T_a=0$ to $+70^\circ C$ unless otherwise noted)

Clock Timing

No.	Item	Symbol	4 MHz Version		6 MHz Version		8 MHz Version		9.8 MHz Version		Unit	Reference Figure Number
			Min	Max	Min	Max	Min	Max	Min	Max		
	Operation Frequency of 2CLK	f	1	4	1	6	1	8	1	9.8	MHz	17
1	Clock Cycle Time	tcyc	250	1000	167	1000	125	1000	102	1000	ns	
2	Clock High Level Pulse Width	tPWCH	115	500	75	500	55	500	46	500	ns	
3	Clock Low Level Pulse Width	tPWCL	115	500	75	500	55	500	46	500	ns	
4	Clock Rise Time	tr	—	10	—	10	—	10	—	5	ns	
5	Clock Fall Time	tf	—	10	—	10	—	10	—	5	ns	

MPU Read/Write Cycle Timing

No.	Item	Symbol	4 MHz Version		6 MHz Version		8 MHz Version		9.8 MHz Version		Unit	Reference Figure Number
			Min	Max	Min	Max	Min	Max	Min	Max		
6	R/W Setup Time	tRWS	70	—	60	—	50	—	50	—	ns	18—20
7	R/W Hold Time	tRWH	0	—	0	—	0	—	0	—	ns	
8	RS Setup Time	tRSS	70	—	60	—	50	—	50	—	ns	
9	RS Hold Time	tRSH	0	—	0	—	0	—	0	—	ns	
10	$\overline{CS}$ Setup Time	tCSS	50	—	40	—	40	—	40	—	ns	
11	$\overline{CS}$ High Level Width	tWCSH	80	—	70	—	60	—	60	—	ns	18, 19
12												
13	Read Wait Time	tRWA	0	—	0	—	0	—	0	—	ns	18, 20
14	Read Data Access Time	tRDAC	—	120	—	100	—	80	—	80	ns	
15	Read Data Hold Time	tRDH	10	—	10	—	10	—	10	—	ns	
16	Read Data Turn Off Time	tRDZ	—	60	—	60	—	60	—	60	ns	
17	DTACK Delay Time (Z to L)	tDTKZL	—	90	—	80	—	70	—	70	ns	18—20
18	DTACK Delay Time (D to L)	tDTKDL	0	—	0	—	0	—	0	—	ns	18, 20
19	DTACK Release Time (L to H)	tDTKLH	—	100	—	90	—	80	—	80	ns	18—20
20	DTACK Turn Off Time (H to Z)	tDTKZ	—	100	—	100	—	100	—	100	ns	18, 20
21	Data Bus 3-State Recovery Time 1	tDBRT1	0	—	0	—	0	—	0	—	ns	
22	Write Wait Time	tWWA	0	—	0	—	0	—	0	—	ns	
23	Write Data Setup Time	tWDS	80	—	60	—	40	—	40	—	ns	
24	Write Data Hold Time	tWDH	10	—	10	—	10	—	10	—	ns	19, 20

DMA Read/Write Cycle Timing

No.	Item	Symbol	4 MHz Version		6 MHz Version		8 MHz Version		9.8 MHz Version		Unit	Reference Figure Number
			Min	Max	Min	Max	Min	Max	Min	Max		
25	DREQ Delay Time 1	tDRQD1	—	150	—	130	—	110	—	110	ns	21—24
26	DREQ Delay Time 2	tDRQD2	—	90	—	80	—	70	—	70	ns	
27	DMA R/W Setup Time	tDMRWS	70	—	60	—	50	—	50	—	ns	
28	DMA R/W Hold Time	tDMRWH	0	—	0	—	0	—	0	—	ns	
29	DACK Setup Time	tDAKS	50	—	40	—	40	—	40	—	ns	
30	DACK High Level Width	tWDAKH	80	—	70	—	60	—	60	—	ns	21, 22
31												
32	DMA Read Wait Time	tDRW	0	—	0	—	0	—	0	—	ns	
33	DMA Read Data Access Time	tDRDAC	—	120	—	100	—	80	—	80	ns	
34	DMA Read Data Hold Time	tDRDH	10	—	10	—	10	—	10	—	ns	
35	DMA Read Data Turn Off Time	tDRDZ	—	60	—	60	—	60	—	60	ns	21—24
36	DMA DTACK Delay Time (Z to L)	tDDTZL	—	90	—	80	—	70	—	70	ns	
37	DMA DTACK Delay Time (D to L)	tDDTDL	0	—	0	—	0	—	0	—	ns	21, 22
38	DMA DTACK Release Time (L to H)	tDDTLH	—	100	—	90	—	80	—	80	ns	21—24
39	DMA DTACK Turn Off Time (H to Z)	tDDTHZ	—	100	—	100	—	100	—	100	ns	
40	DONE Output Delay Time	tDND	—	90	—	80	—	70	—	70	ns	
41	DONE Output Turn Off Time (L to Z)	tDNLZ	—	100	—	90	—	80	—	80	ns	21, 22
42	Data Bus 3-State Recovery Time 2	tDBRT2	0	—	0	—	0	—	0	—	ns	
43	DONE Input Pulse Width	tDNPW	2	—	2	—	2	—	2	—	tcyc	23, 24
44	DMA Write Wait Time	tDWVW	0	—	0	—	0	—	0	—	ns	
45	DMA Write Data Setup Time	tDWDS	80	—	60	—	40	—	40	—	ns	
46	DMA Write Data Hold Time	tDWDH	10	—	10	—	10	—	10	—	ns	
47												

2

Frame Memory Read/Write Cycle Timing

No.	Item	Symbol	4 MHz Version		6 MHz Version		8 MHz Version		9.8 MHz Version		Unit	Reference Figure Number
			Min	Max	Min	Max	Min	Max	Min	Max		
48	AS "Low" Level Pulse Width	tPWASL	80	—	40	—	25	—	20	—	ns	25—28
49	Memory Address Hold Time 2	tMAH2	10	—	10	—	10	—	5	—	ns	
50	AS Delay Time 1	tASD1	—	90	—	75	—	60	—	50	ns	
51	AS Delay Time 2	tASD2	5	90	5	75	5	65	5	40	ns	
52	Memory Address Delay Time	tMAD	15	95	15	80	15	70	10	50	ns	
53	Memory Address Hold Time 1	tMAH1	25	—	25	—	25	—	15	—	ns	
54	Memory Address Turn Off Time (A to Z)	tMAAZ	—	50	—	50	—	50	—	35	ns	
55	Memory Read Data Setup Time	tMRDS	60	—	50	—	35	—	30	—	ns	26
56	Memory Read Data Hold Time	tMRDH	10	—	10	—	10	—	0	—	ns	
57	MA/RA Delay Time	tMARAD	—	100	—	90	—	80	—	60	ns	25—28
58	MA/RA Hold Time	tMARAH	10	—	10	—	10	—	5	—	ns	25—27
59	MCYC Delay Time	tMCYCD	5	60	5	50	5	50	5	40	ns	25—29
60	MRD Delay Time	tMRDD	—	90	—	80	—	70	—	50	ns	24—28
61	MRD Hold Time	tMRH	10	—	10	—	10	—	5	—	ns	
62	DRAW Delay Time	tDRWD	—	90	—	80	—	70	—	50	ns	
63	DRAW Hold Time	tDRWH	10	—	10	—	10	—	5	—	ns	
64	Memory Write Data Delay Time	tMWDD	—	90	—	80	—	70	—	50	ns	27
65	Memory Write Data Hold Time	tMWDH	10	—	10	—	10	—	5	—	ns	
110	Memory Address Setup Time 1	tMAS1	10	—	10	—	10	—	10	—	ns	25—28
112	Memory Address Setup Time 2	tMAS2	10	—	10	—	10	—	10	—	ns	

- Notes: 1. Characteristic No.52 is independent of the 2CLK operation frequency (f) and timing of No.51 and No.110.
2. New characteristics No.50 and No.52 shown above are applicable only to lot numbers 5M*, 6*, 7**, and greater (* means don't care).

For the other lot numbers, applicable characteristics are as follows:

No.	Symbol	4 MHz Version		6 MHz Version		8 MHz Version		Unit
		Min	Max	Min	Max	Min	Max	
50	tASD1	—	90	—	75	—	65	ns
52	tMAD	—	95	—	80	—	70	ns

Display Control Signal Output Timing

No.	Item	Symbol	4 MHz Version		6 MHz Version		8 MHz Version		9.8 MHz Version		Unit	Reference Figure Number
			Min	Max	Min	Max	Min	Max	Min	Max		
67	HSYNC Delay Time	tHSD	—	90	—	80	—	70	—	50	ns	28–30
68	VSYNC Delay Time	tVSD	—	90	—	80	—	70	—	50	ns	29
69	DISP1, DISP2 Delay Time	tDSPD	—	90	—	80	—	70	—	50	ns	
70	CUD1, CUD2 Delay Time	tCUDD	—	90	—	80	—	70	—	50	ns	
71	EXSYNC Output Delay Time	tEXD	20	90	20	80	20	70	15	50	ns	
72	CHR Delay Time	tCHD	—	90	—	80	—	70	—	50	ns	
73												
74												

EXSYNC Input Timing

No.	Item	Symbol	4 MHz Version		6 MHz Version		8 MHz Version		9.8 MHz Version		Unit	Reference Figure Number
			Min	Max	Min	Max	Min	Max	Min	Max		
75	EXSYNC Input Pulse Width	tEXSW	3	—	3	—	3	—	3	—	tcyc	30
76	EXSYNC Input Setup Time	tEXS	60	—	60	—	50	—	30	—	ns	
77	EXSYNC Input Hold Time	tEXH	15	—	15	—	15	—	10	—	ns	

LPSTB Input Timing

No.	Item	Symbol	4 MHz Version		6 MHz Version		8 MHz Version		9.8 MHz Version		Unit	Reference Figure Number
			Min	Max	Min	Max	Min	Max	Min	Max		
78	LPSTB Uncertain Time 1	tLPD1	70	—	70	—	70	—	45	—	ns	31, 32
79	LPSTB Uncertain Time 2	tLPD2	10	—	10	—	10	—	10	—	ns	
80	LPSTB Input Hold Time	tLPH	10	—	10	—	10	—	10	—	ns	
81	LPSTB Input Inhibit time	tLPI	4	—	4	—	4	—	4	—	tcyc	

RES and DACK Input Timing

No.	Item	Symbol	4 MHz Version		6 MHz Version		8 MHz Version		9.8 MHz Version		Unit	Reference Figure Number
			Min	Max	Min	Max	Min	Max	Min	Max		
82	DACK Setup Time for RES	tDAKSR	100	—	100	—	100	—	100	—	ns	33
83	DACK Hold Time for RES	tDAKHR	0	—	0	—	0	—	0	—	ns	
84	RES Input Pulse Width	tRES	10	—	10	—	10	—	10	—	tcyc	

IRQ and Attributes Output Cycle Timing

No.	Item	Symbol	4 MHz Version		6 MHz Version		8 MHz Version		9.8 MHz Version		Unit	Reference Figure Number
			Min	Max	Min	Max	Min	Max	Min	Max		
85	IRQ Delay Time 1	tIRQ1	—	250	—	200	—	150	—	150	ns	34, 35
86	IRQ Delay Time 2	tIRQ2	—	500	—	500	—	500	—	500	ns	
87	ATR Delay Time 1	tATRD1	—	100	—	90	—	80	—	60	ns	28
88	ATR Hold Time 1	tATRH1	10	—	10	—	10	—	5	—	ns	
89												
90	ATR Delay Time 2	tATRD2	—	100	—	90	—	80	—	60	ns	28
91	ATR Hold Time 2	tATRH2	10	—	10	—	10	—	5	—	ns	

Synchronous Bus Timing, MPU or DMA Read/Write Cycle

No.	Item	Symbol	4 MHz Version		6 MHz Version		8 MHz Version		9.8 MHz Version		Unit	Reference Figure Number
			Min	Max	Min	Max	Min	Max	Min	Max		
100	CS Cycle Time	tCSC	4	—	4	—	4	—	4	—	tcyc	18, 19
101	CS Low Level Width	tWCSL	2	—	2	—	2	—	2	—	tcyc	
102	CS High Level Width	tWCSH	2	—	2	—	2	—	2	—	tcyc	22, 24
104	DACK Cycle Time	tDACKC	4	—	4	—	4	—	4	—	tcyc	
105	DACK Low Level Width	tWDACKL	2	—	2	—	2	—	2	—	tcyc	
106	DACK High Level Width	tWDACKH	2	—	2	—	2	—	2	—	tcyc	

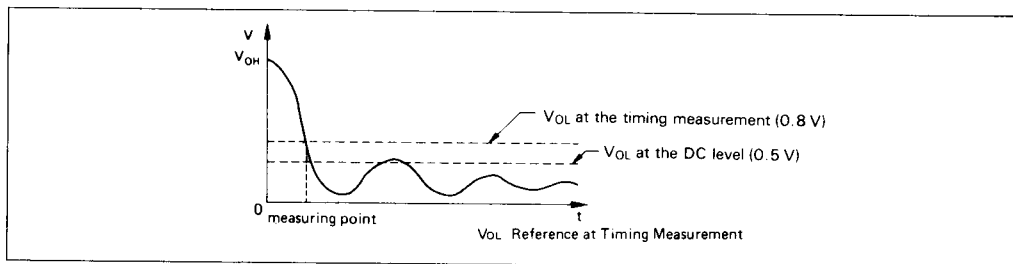


Figure 16. Test Points

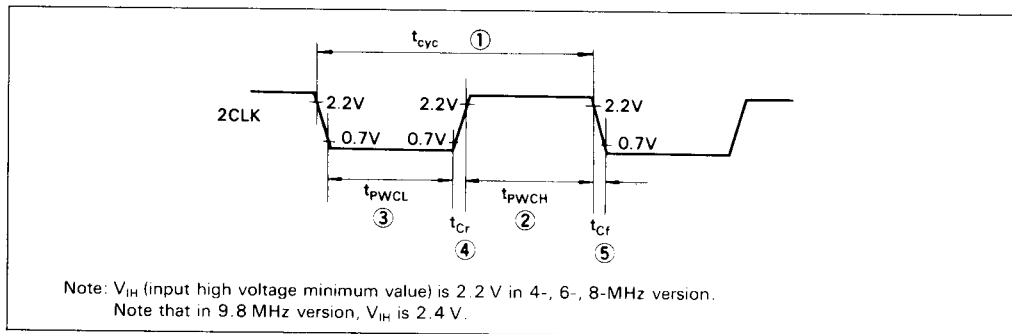
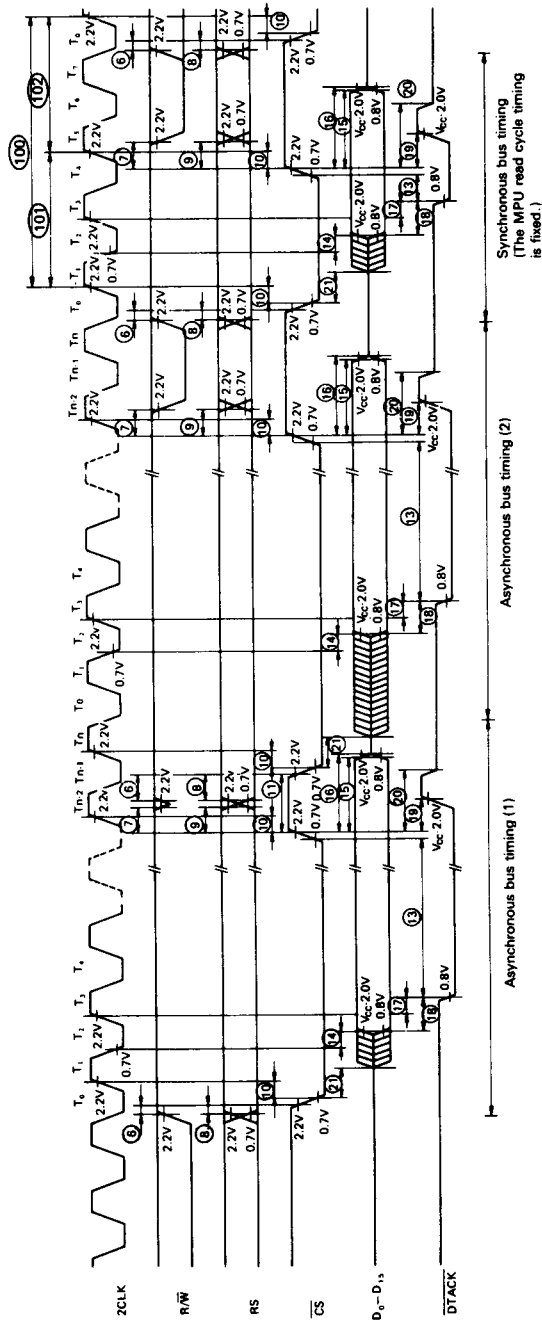


Figure 17. 2CLK Waveform



Notes: 1. $\overline{CS}$ high level width must satisfy specification (1).

Unless spec (12) is satisfied, $\overline{DTACK}$ and read data responses to the succeeding cycle are delayed.

2. (10), (15) and (12) are asynchronous bus timing specifications.

Note: V_{IH} (input high voltage minimum value) is 2.2 V in 4-, 6-, 8-MHz version.
Note that in 9.8 MHz version, V_{IH} is 2.4 V.

Figure 18. MPU Read Cycle Timing (MPU ← ACRTC)

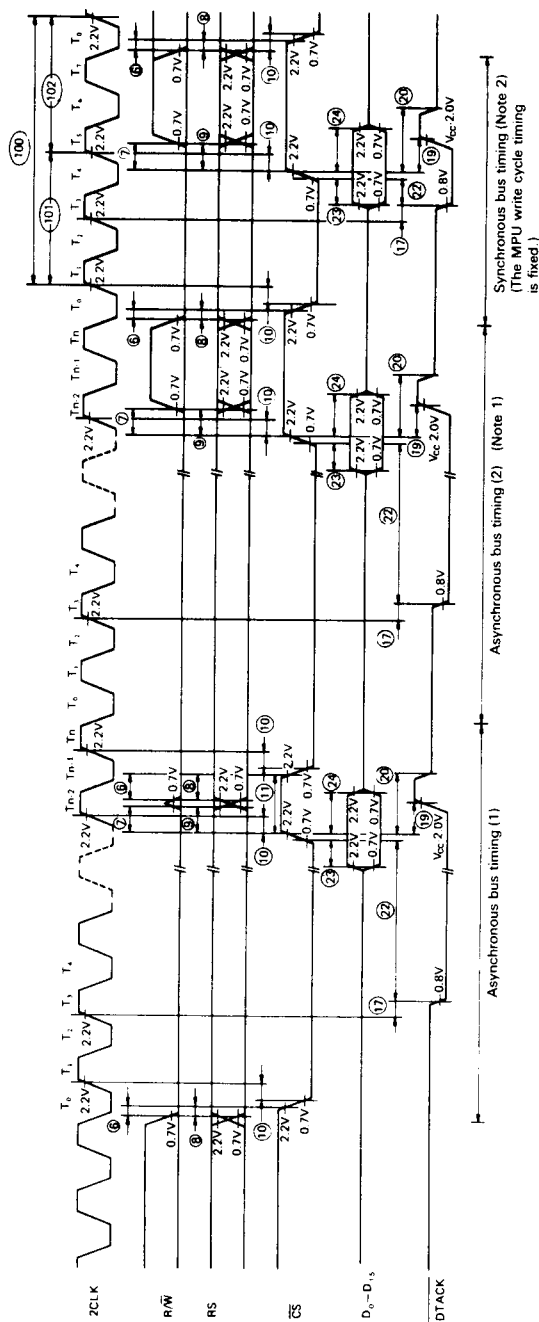
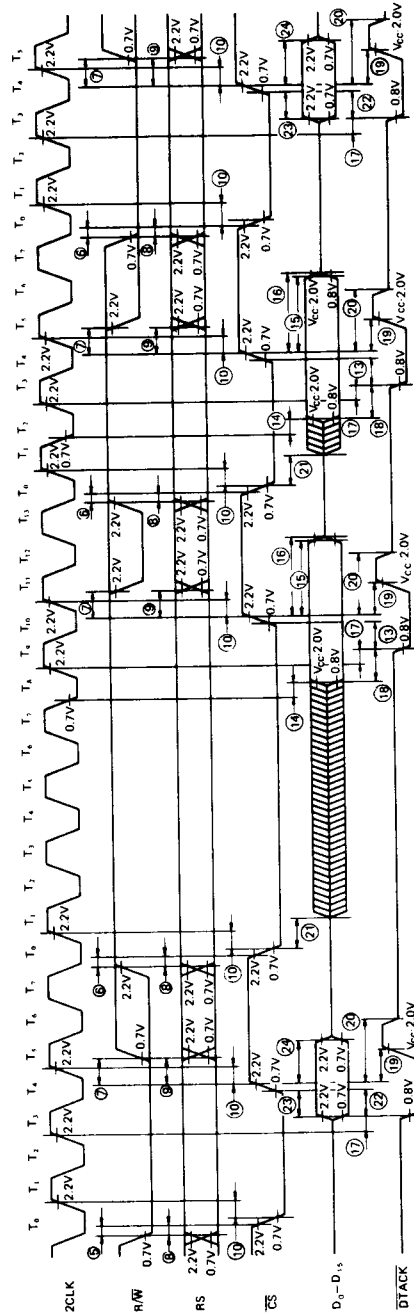


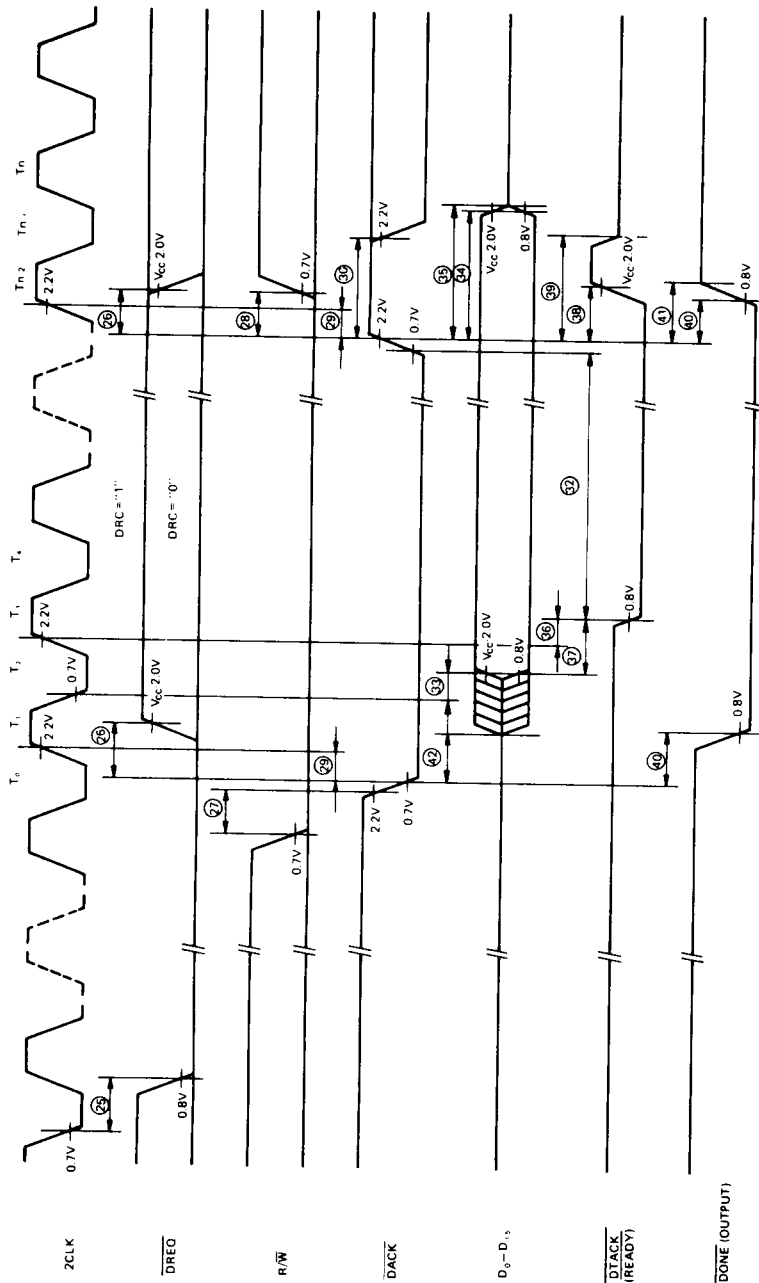
Figure 19. MPU Write Cycle Timing (MPU → ACRTC)



Note: When the MPU read cycle immediately follows the MPU write cycle execution, $\overline{DTACK}$ and the read data responses are delayed (by 3 cycles of 2CLK) even though spec. (100) is satisfied.

Note: V_{IH} (input high voltage minimum value) is 2.2 V in 4-, 6-, 8-MHz version.
Note that in 9.8 MHz version, V_{IH} is 2.4 V.

Figure 20. MPU Read/Write Cycle Timing (MPU → ACRTC)



Note: V_{IH} (input high voltage minimum value) is 2.2 V in 4-, 6-, 8-MHz version.
Note that in 9.8 MHz version, V_{IH} is 2.4 V.

Figure 21. DMA Read Cycle Timing (Memory - ACRTC)

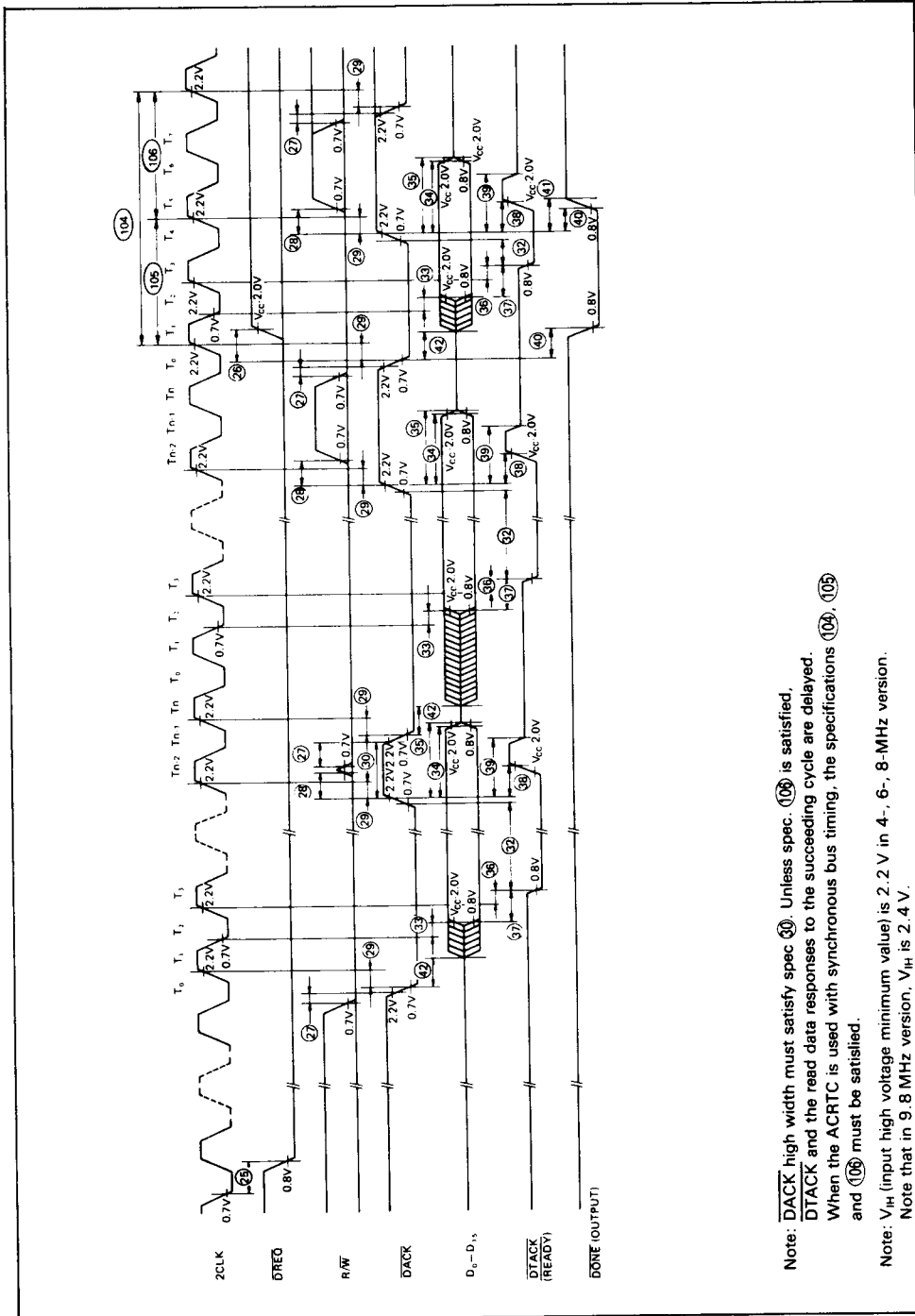


Figure 22. DMA Ready Cycle Timing (Memory - ACRTC): Burst Mode

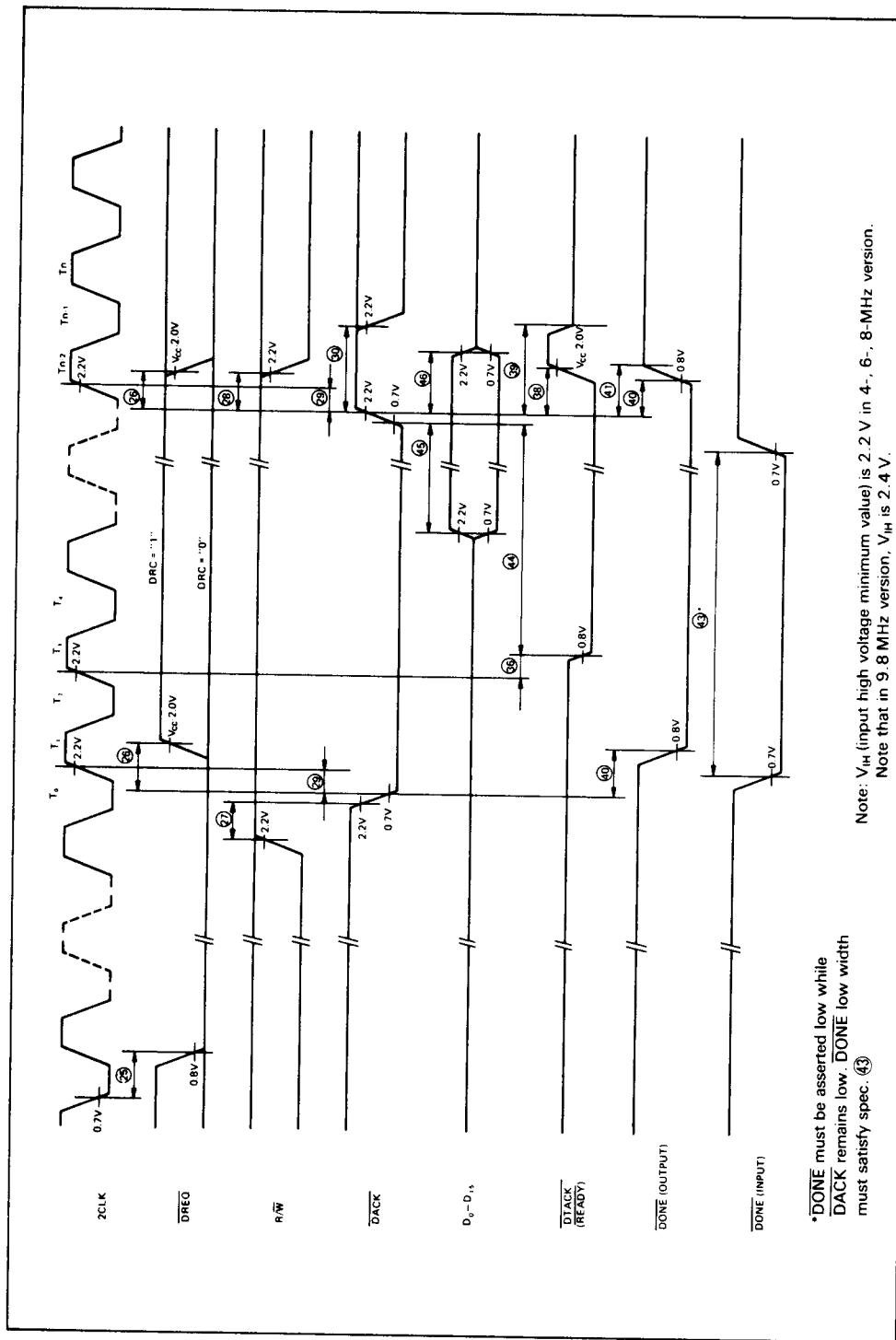
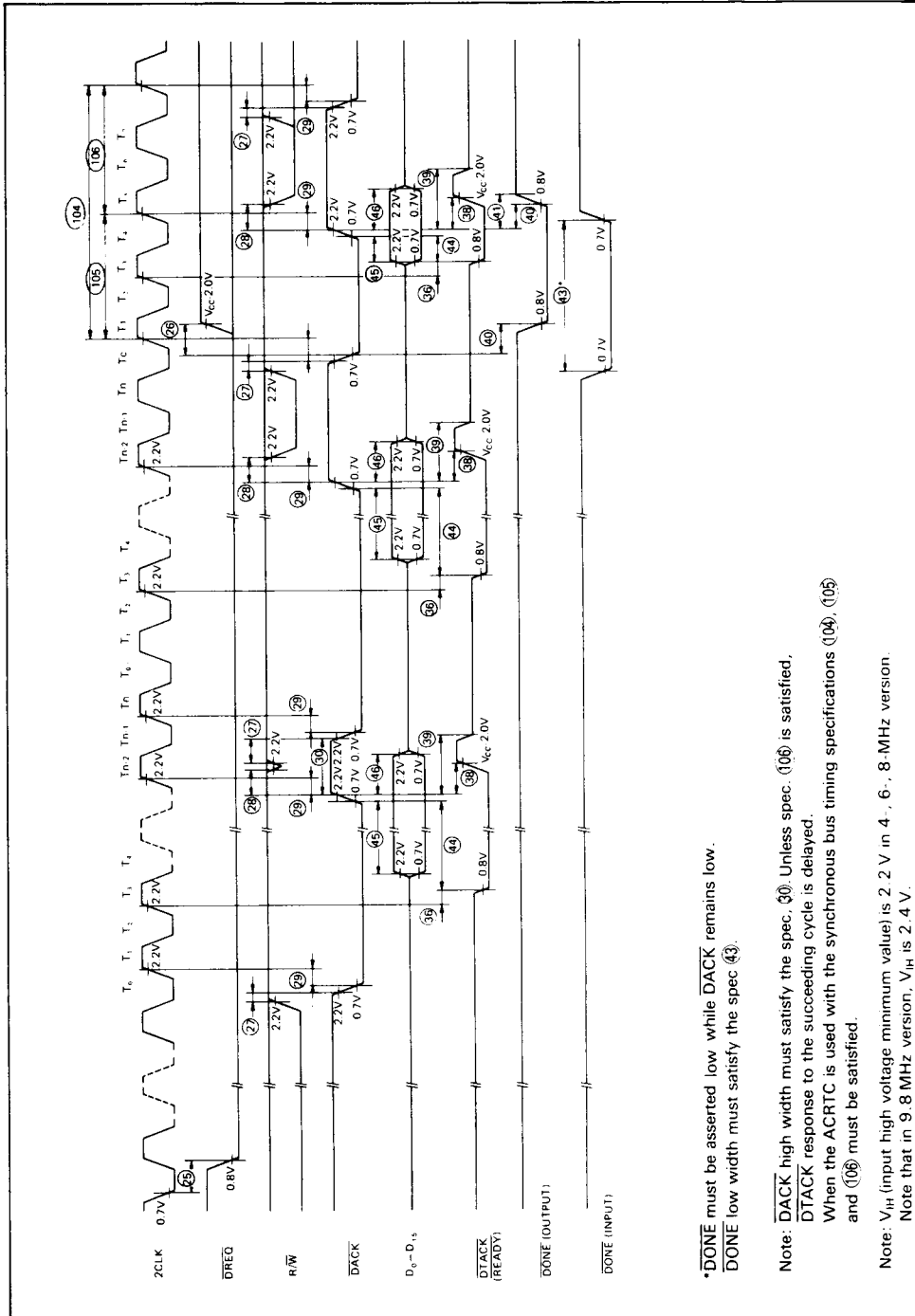


Figure 23. DMA Write Cycle Timing (Memory → ACRTC)

*DONE must be asserted low while DACK remains low. DONE low width must satisfy spec. (43)



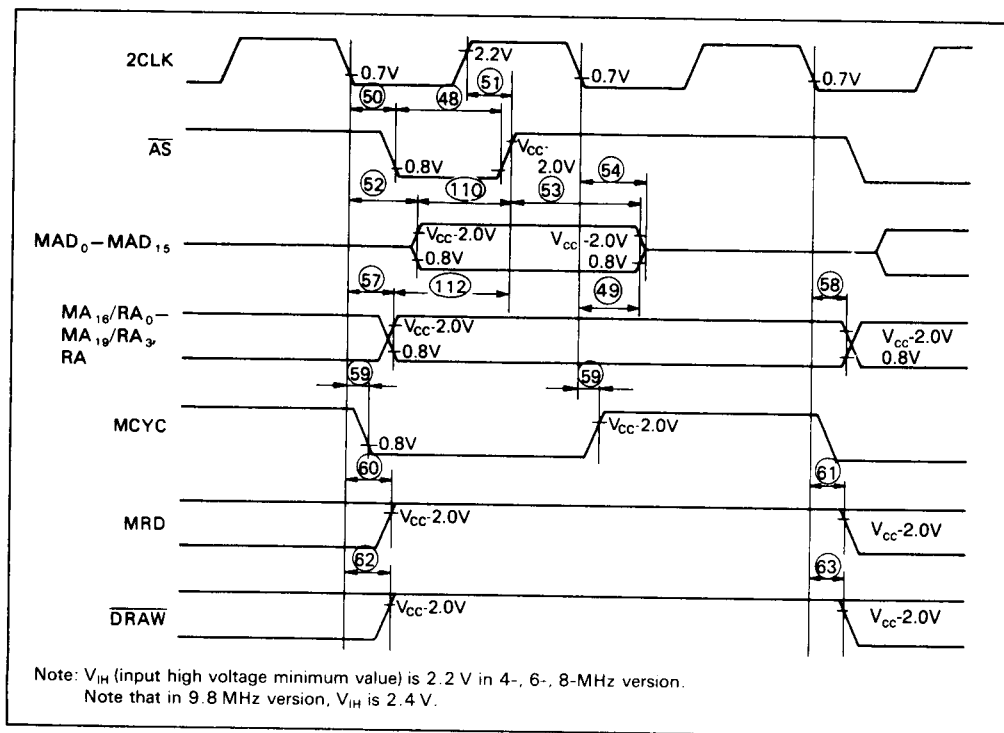


Figure 25. Display Cycle Timing

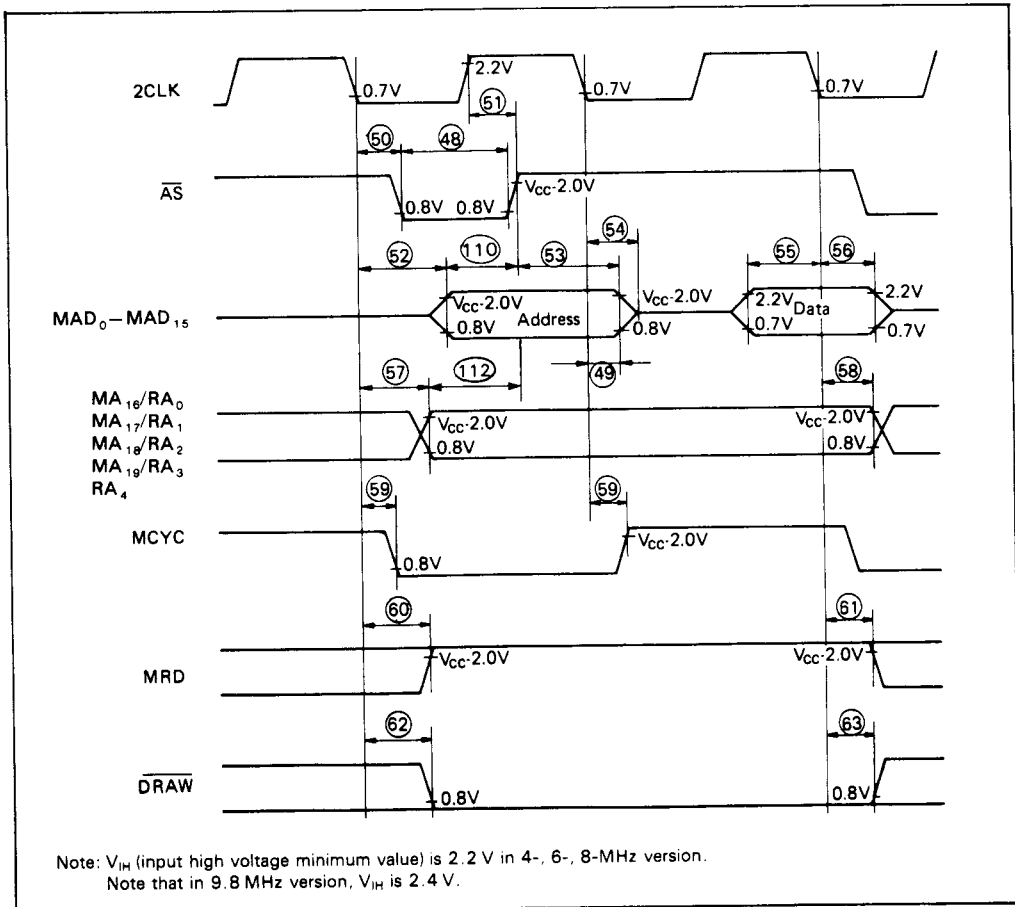


Figure 26. Frame Memory Read Cycle Timing (ACRTC - Frame Memory)

2

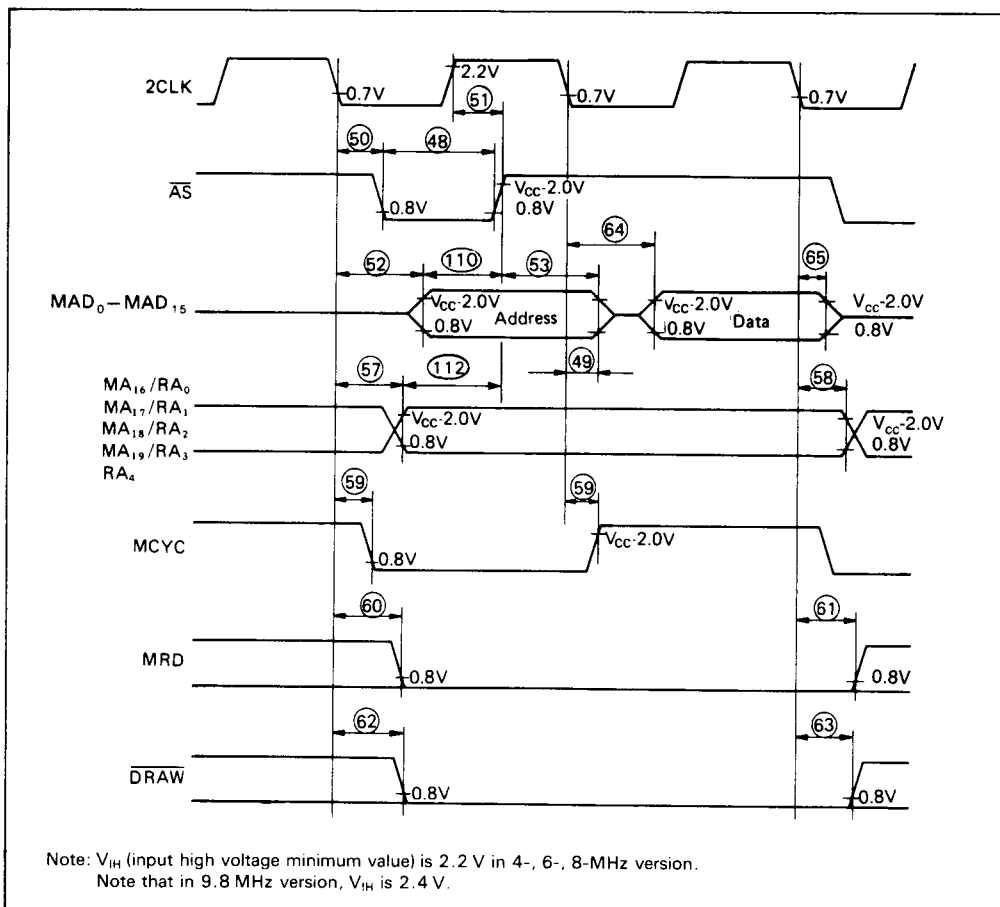


Figure 27. Frame Memory Write Cycle Timing (ACRTC → Frame Memory)

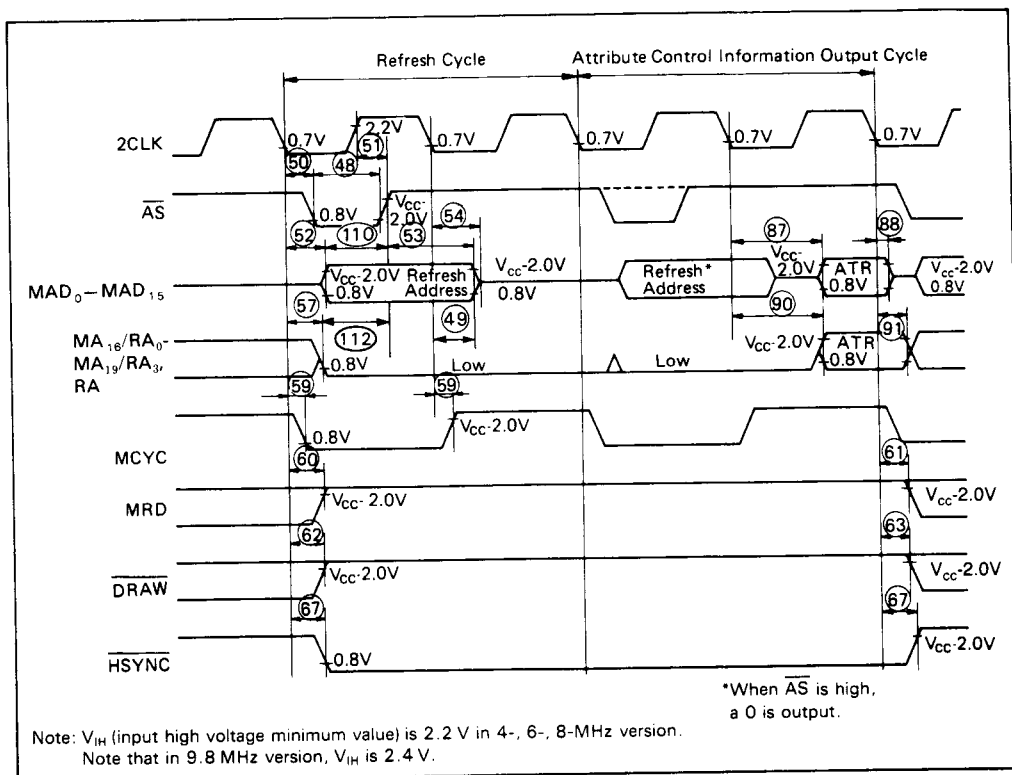


Figure 28. Frame Memory Refresh/Video Attributes Output Cycle Timing

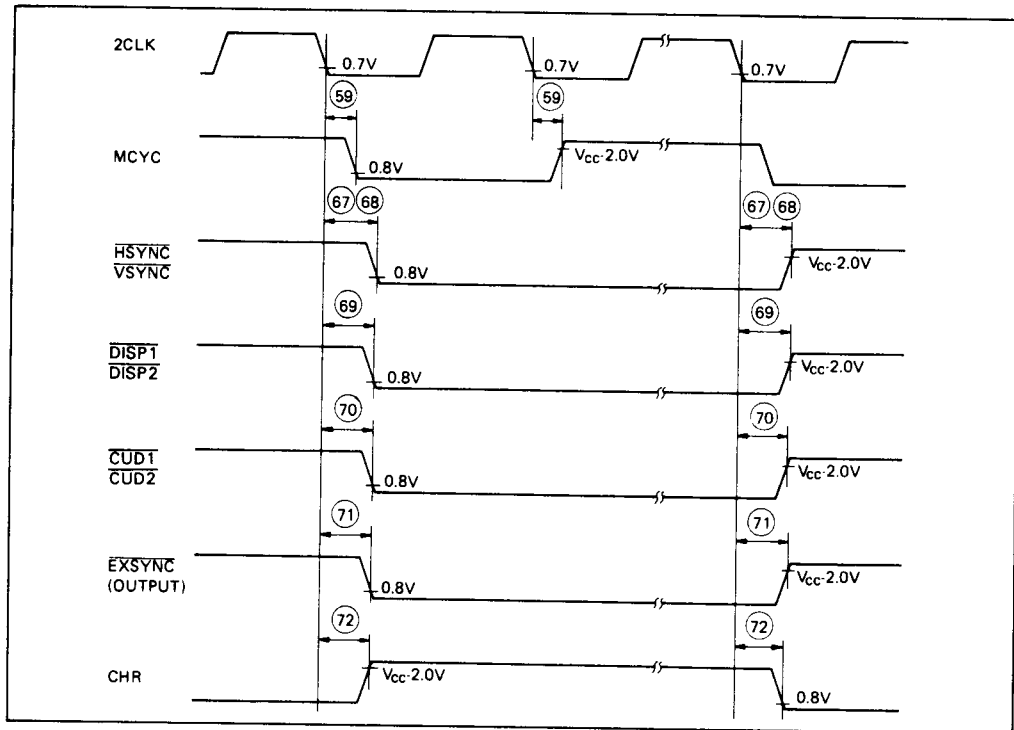


Figure 29. Display Control Signal Output Timing

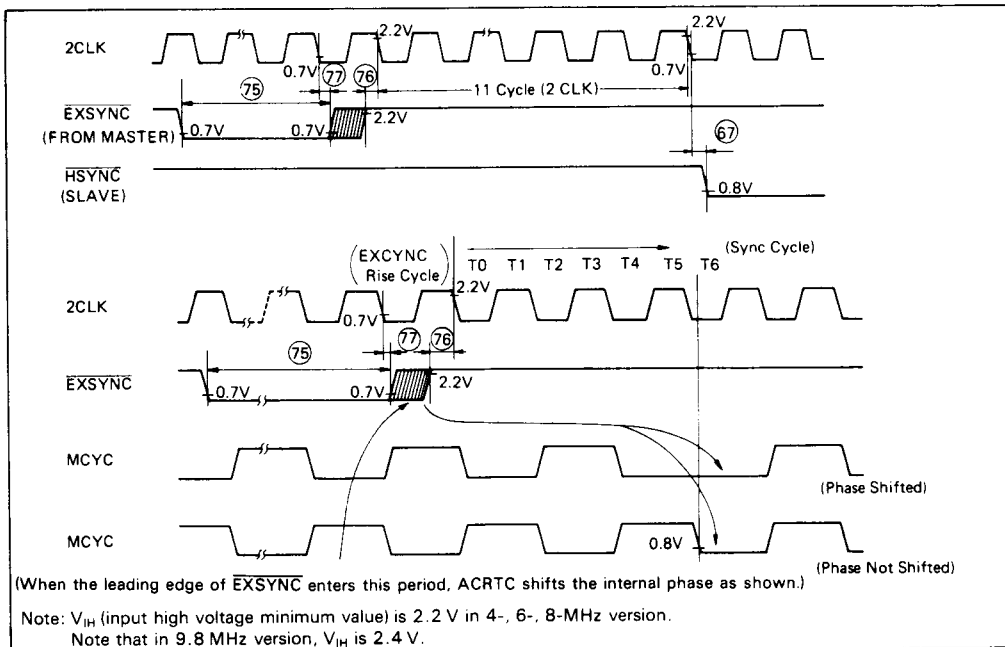


Figure 30. EXSYNC Input Timing

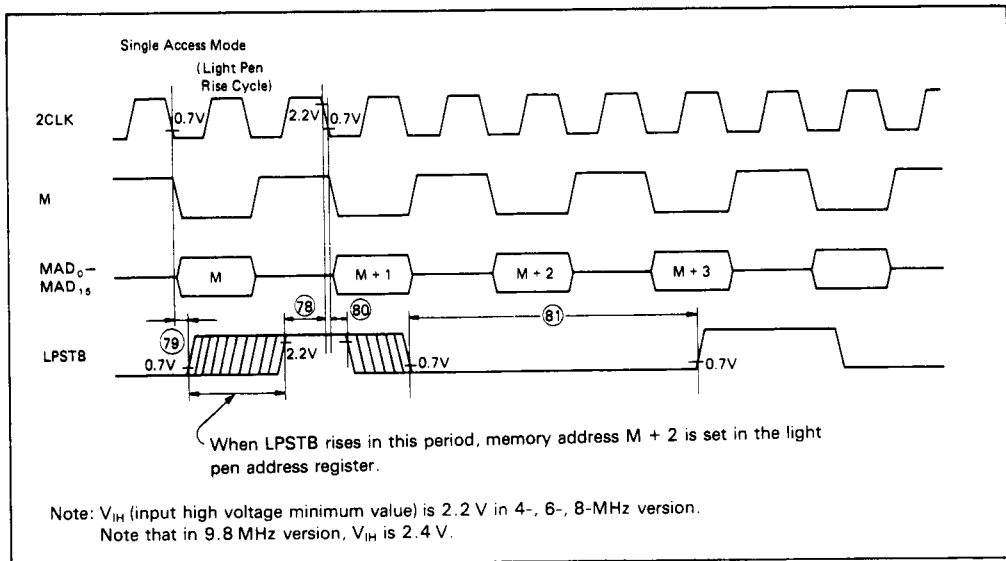


Figure 31. LPSTB Input Timing (Single Access Mode)

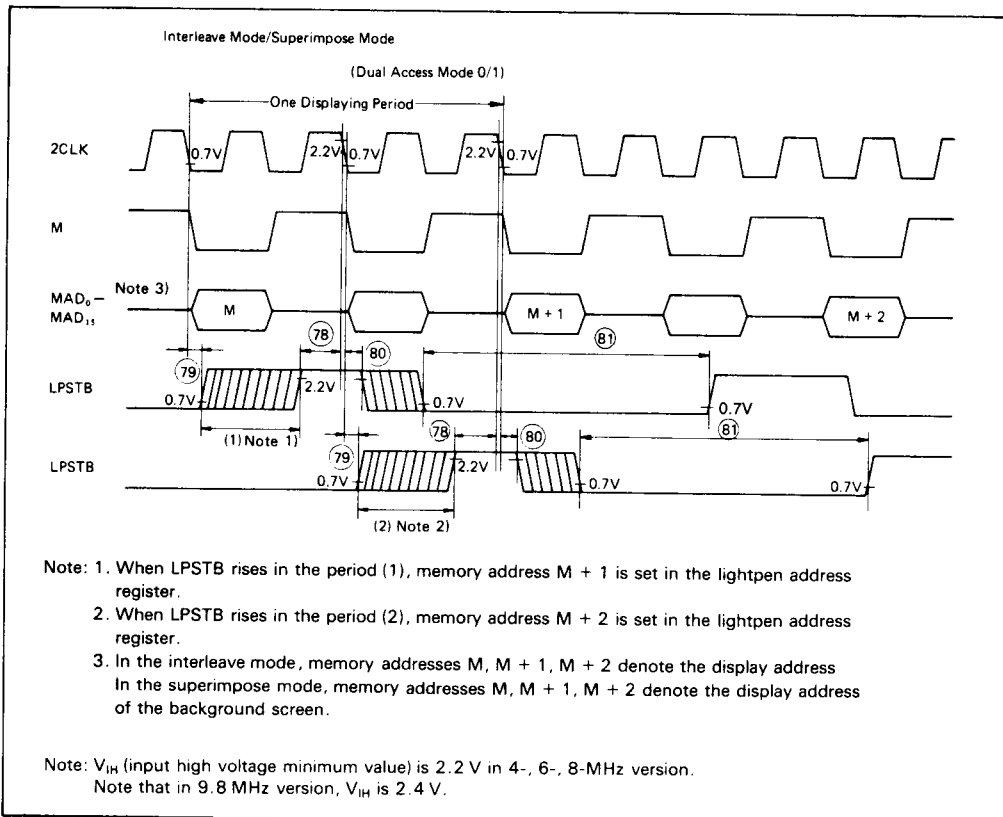


Figure 32. LPSTB Input Timing (Dual Access Mode)

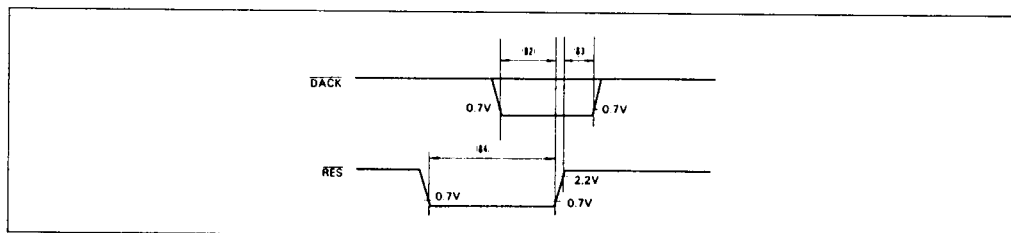


Figure 33. RES Input and DACK Input Timing (System Reset and 16-Bit/8-Bit Selection)

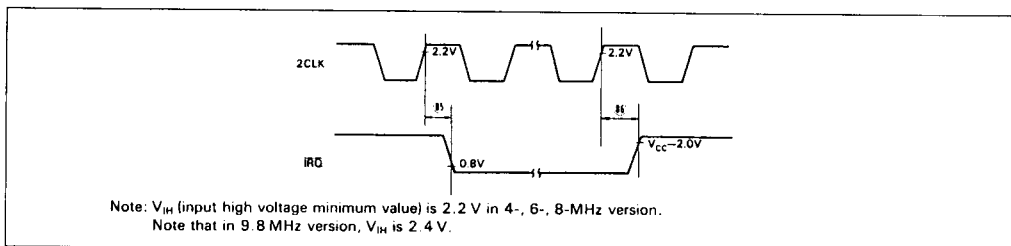


Figure 34. IRQ Output Timing

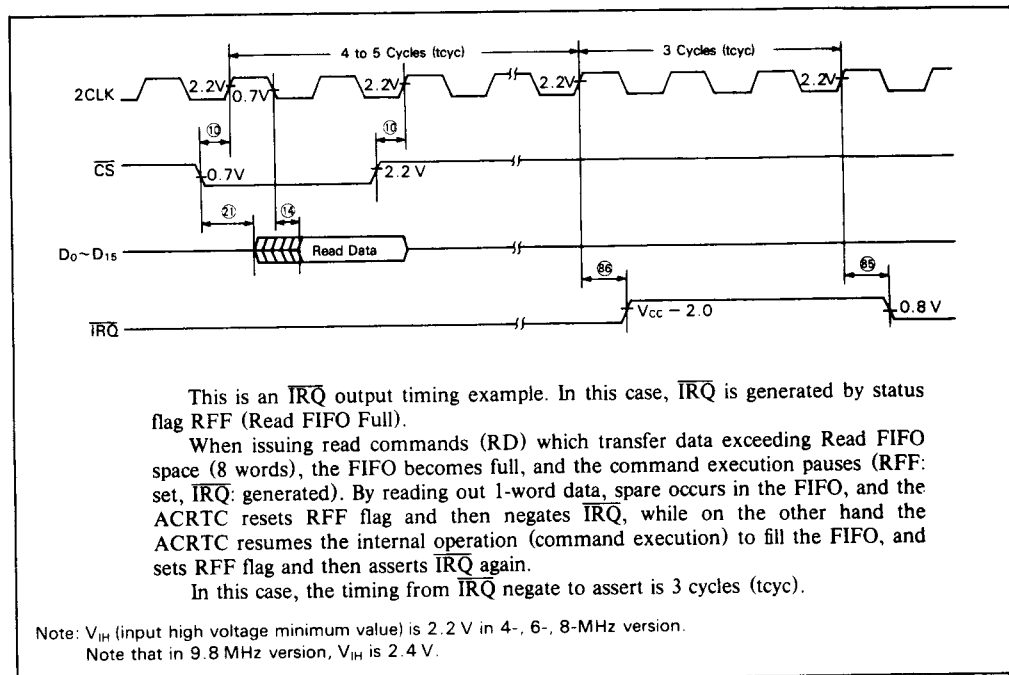


Figure 35. $\overline{\text{IRQ}}$ Output Timing (Example: Read FIFO Full Interrupt Enable)

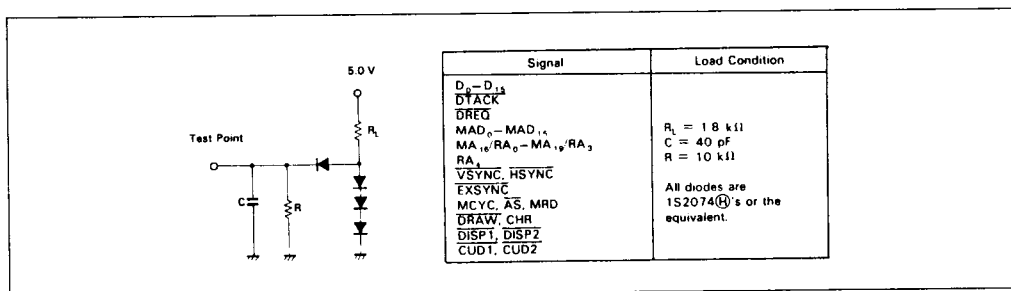


Figure 36. Test Load Circuit A

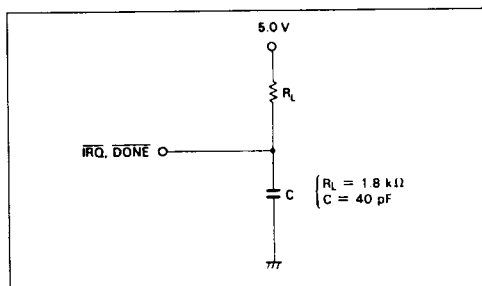


Figure 37. Test Load Circuit B