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.

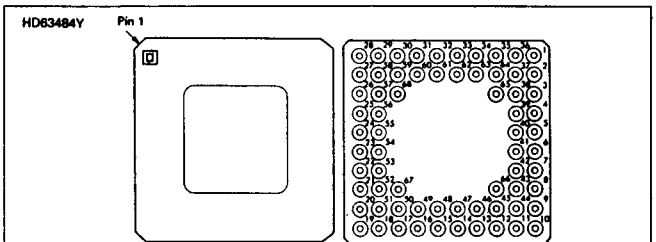
Features

- 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

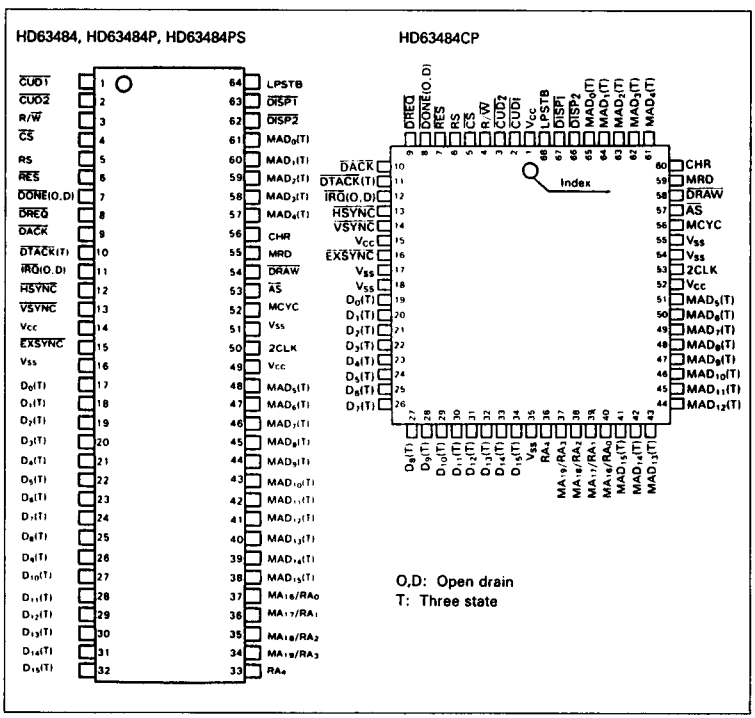
Part No.	Clock Frequency (2CLK)	Package
HD63484-4	4 MHz	DC-64
HD63484-6	6 MHz	(64-pin ceramic DIP)
HD63484-8	8 MHz	
HD63484-98	9.8 MHz	
HD63484P4	4 MHz	DP-64
HD63484P6	6 MHz	(64-pin plastic DIP)
HD63484P8	8 MHz	
HD63484P98	9.8 MHz	
HD63484CP4	4 MHz	CP-68
HD63484CP6*	6 MHz	(68-pin plastic PLCC)
HD63484CP8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

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



Pin No.	Pin Name	Pin No.	Pin Name	Pin No.	Pin Name	Pin No.	Pin Name
1	MAD_{14} (T)	18	RS	35	MA_{18}/RA_2	52	$\overline{DREQ}$
2	MAD_{11} (T)	19	$\overline{DTACK}$ (T)	36	MA_{19}/RA_0	53	$\overline{HSYNC}$
3	MAD_9 (T)	20	$\overline{IRQ}$ (O,D)	37	MAD_{13} (T)	54	$\overline{EXSYNC}$
4	MAD_8 (T)	21	$\overline{VSYNC}$	38	MAD_{10} (T)	55	D_0 (T)
5	MAD_6 (T)	22	V_{CC}	39	MAD_7 (T)	56	D_4 (T)
6	V_{CC}	23	V_{SS}	40	MAD_5 (T)	57	D_3 (T)
7	V_{SS}	24	V_{SS}	41	2CLK	58	D_8 (T)
8	V_{SS}	25	D_1 (T)	42	MCYC	59	D_9 (T)
9	$\overline{AS}$	26	D_2 (T)	43	$\overline{DRAW}$	60	D_{11} (T)
10	MRD	27	D_5 (T)	44	MAD_4 (T)	61	D_{14} (T)
11	MAD_3 (T)	28	D_6 (T)	45	MAD_2 (T)	62	RA_1
12	MAD_1 (T)	29	D_{10} (T)	46	MAD_0 (T)	63	MA_{17}/RA_1
13	$\overline{DISP_2}$	30	D_{12} (T)	47	$\overline{DISP_1}$	64	MAD_{15} (T)
14	LPSTB	31	D_{13} (T)	48	$\overline{CUD_1}$	65	MAD_{12} (T)
15	V_{CC}	32	D_{15} (T)	49	$\overline{CS}$	66	CHR
16	$\overline{CUD_2}$	33	V_{SS}	50	$\overline{RES}$	67	$\overline{DACK}$
17	R/W	34	MA_{16}/RA_3	51	$\overline{DONE}$ (O,D)	68	D_7

Pin Arrangement



Pin Description

Group	Mnemonic	Pin Number DIP	PLCC	PGA	I/O	Function
MPU Interface	$\overline{RES}$	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/$\overline{W}$	3	4	17	I	Read/write strobe
	$\overline{CS}$	4	5	49	I	Chip select
	RS	5	6	18	I	Register select
	$\overline{DTACK}$	10	11	19	O	Data transfer acknowledge (three state)
	$\overline{IRQ}$	11	12	20	O	Interrupt request (open drain)
DMAC Interface	$\overline{DREQ}$	8	9	52	O	DMA request
	$\overline{DACK}$	9	10	67	I	DMA acknowledge
	$\overline{DONE}$	7	8	51	I/O	DMA done (open drain)
CRT Interface	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
	$\overline{AS}$	53	57	9	O	Adress 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
	$\overline{MRD}$	55	59	10	O	Frame buffer memory read
	$\overline{DRAW}$	54	58	43	O	Draw/refresh signal
	$\overline{DISP1}$, $\overline{DISP2}$	63, 62	67, 66	47, 13	O	Display enable
	$\overline{CUD1}$, $\overline{CUD2}$	1,2	2,3	48,16		Cursor display
	$\overline{VSYNC}$	13	14	21	O	CRT vertical sync pulse
	$\overline{HSYNC}$	12	13	53		CRT horizontal sync pulse
	$\overline{EXSYNC}$	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 D_0-D_{15}, MAD_0-MAD_{15}, MA_{16}/RA_0-MA_{19}/RA_3. Please refer to the pin arrangement.

MPU Interface

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

D_0-D_{15} (Data Bus): D_0-D_{15} are the bidirectional data bus to/from the host MPU or DMAC. D_0-D_7 are used in 8-bit data bus mode.

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

$\overline{CS}$ (Chip Select): $\overline{CS}$ 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.

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

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

DMAC Interface

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

$\overline{DONE}$ (DMA Done): $\overline{DONE}$ 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.

MAD_0-MAD_{15} (Frame Memory Address/ Data Bus): MAD_0-MAD_{15} are the multiplexed frame buffer address/data bus.

$\overline{AS}$ (Address Strobe): The $\overline{AS}$ output demultiplexes the address/data bus (MAD_0-MAD_{15}).

MA_{16}/RA_0-MA_{19}/RA_3 (Memory Address/ Raster Address): MA_{16}/RA_0-MA_{19}/RA_3 are the upper bits of the graphics screen address multiplexed with the lower bits of the character screen raster address.

RA_4 (Raster Address): RA_4 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.

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

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

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

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

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

$\overline{EXSYNC}$ (External Sync): $\overline{EXSYNC}$ 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 × 808 dots, + 8 DA or + 4 SA
2. CRT monitor from 800 × 480 to 960 × 720 dots, + 4 DA

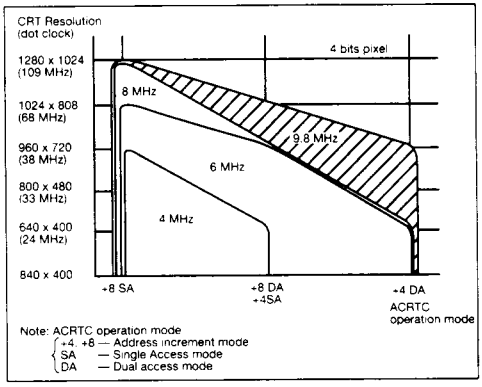


Figure A. ACRTC Operation Frequency and Supportable CRT Display Range

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.

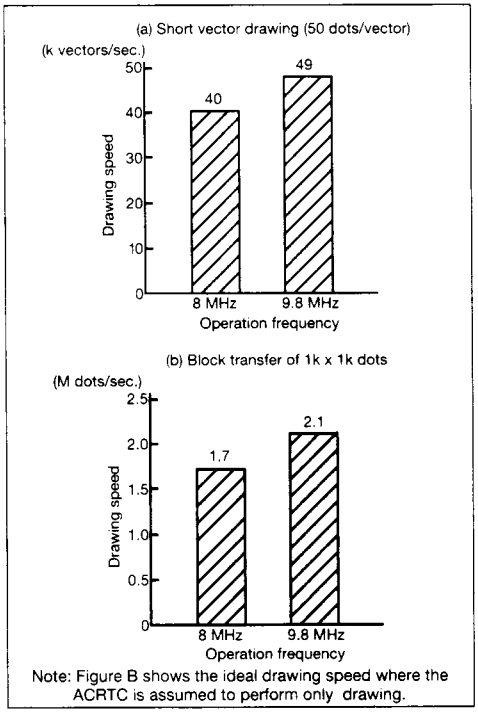


Figure B. Drawing Capability Comparison between 9.8-MHz and 8-MHz ACRTCs.

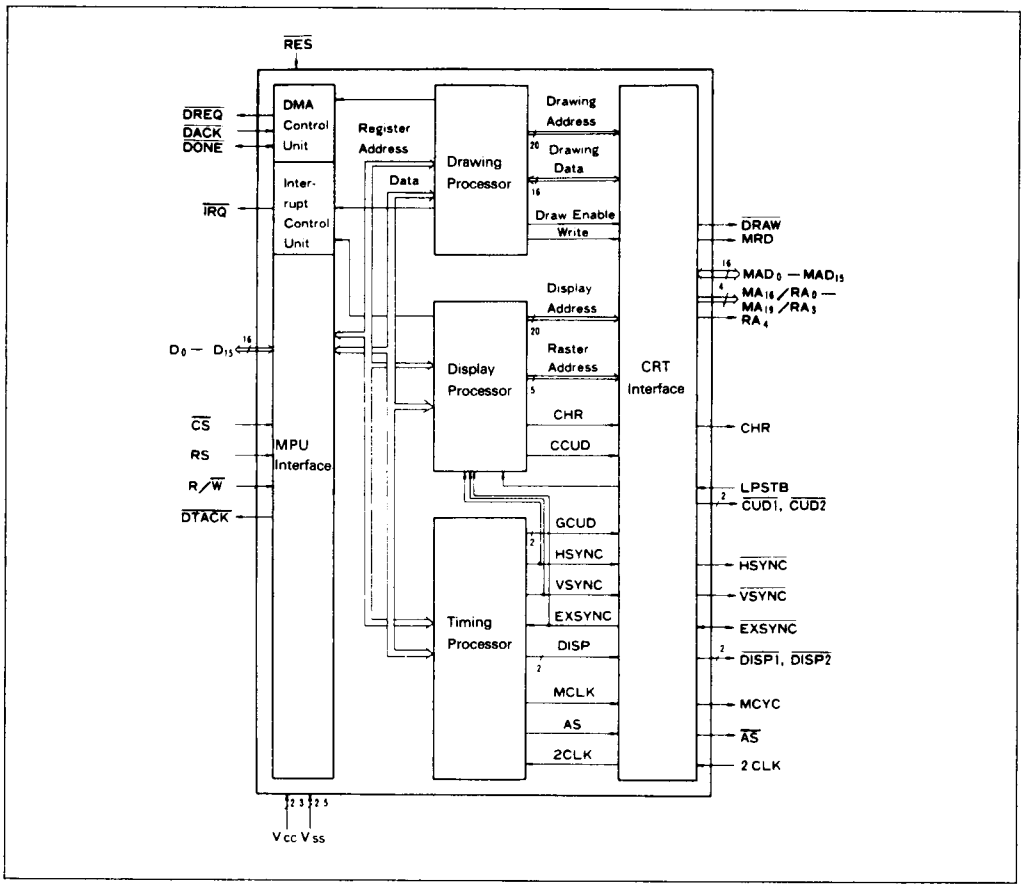


Figure 1 ACRTC Block Diagram

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.

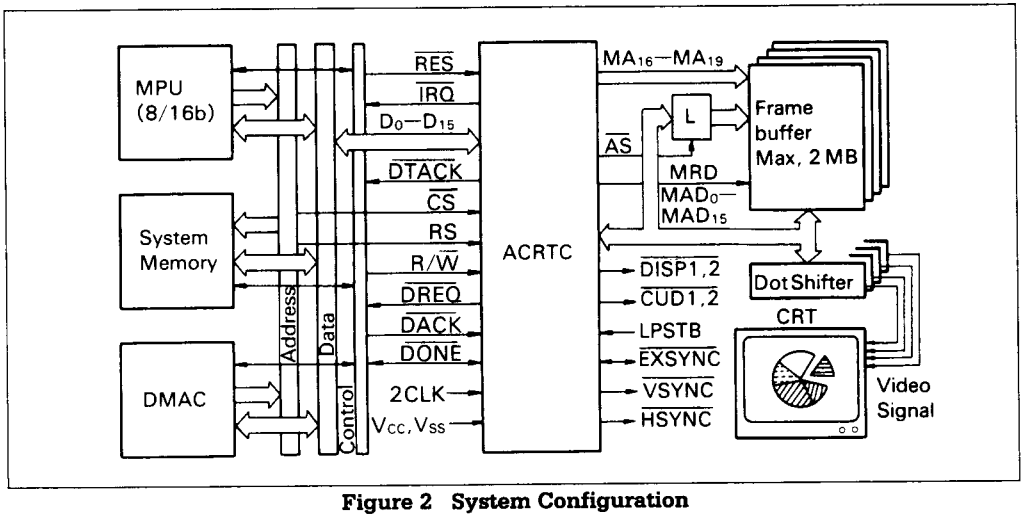


Figure 2 System Configuration

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

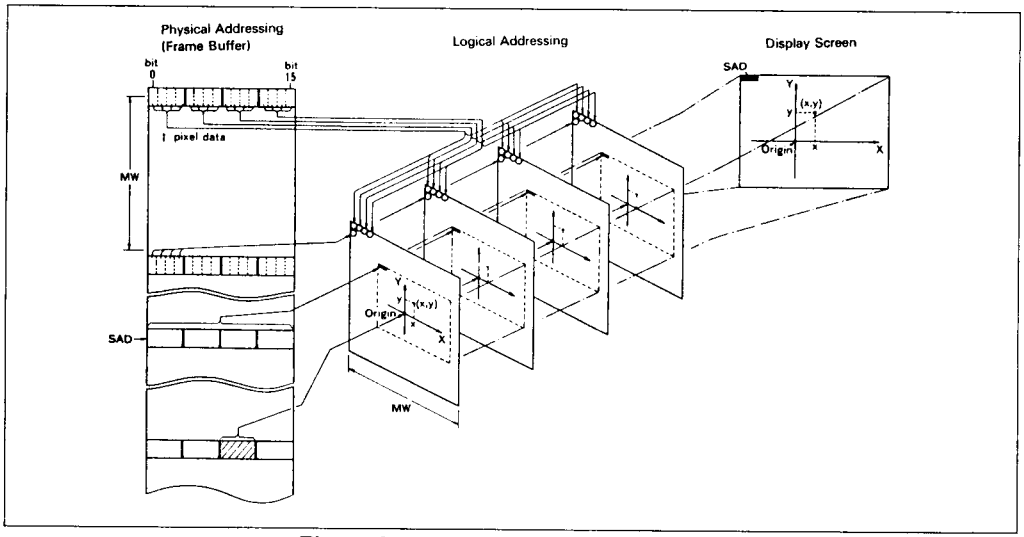


Figure 3. Logical/Physical Addressing

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 ($\overline{\text{HSYNC}}$, $\overline{\text{VSYNC}}$, 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 automaticaly 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.

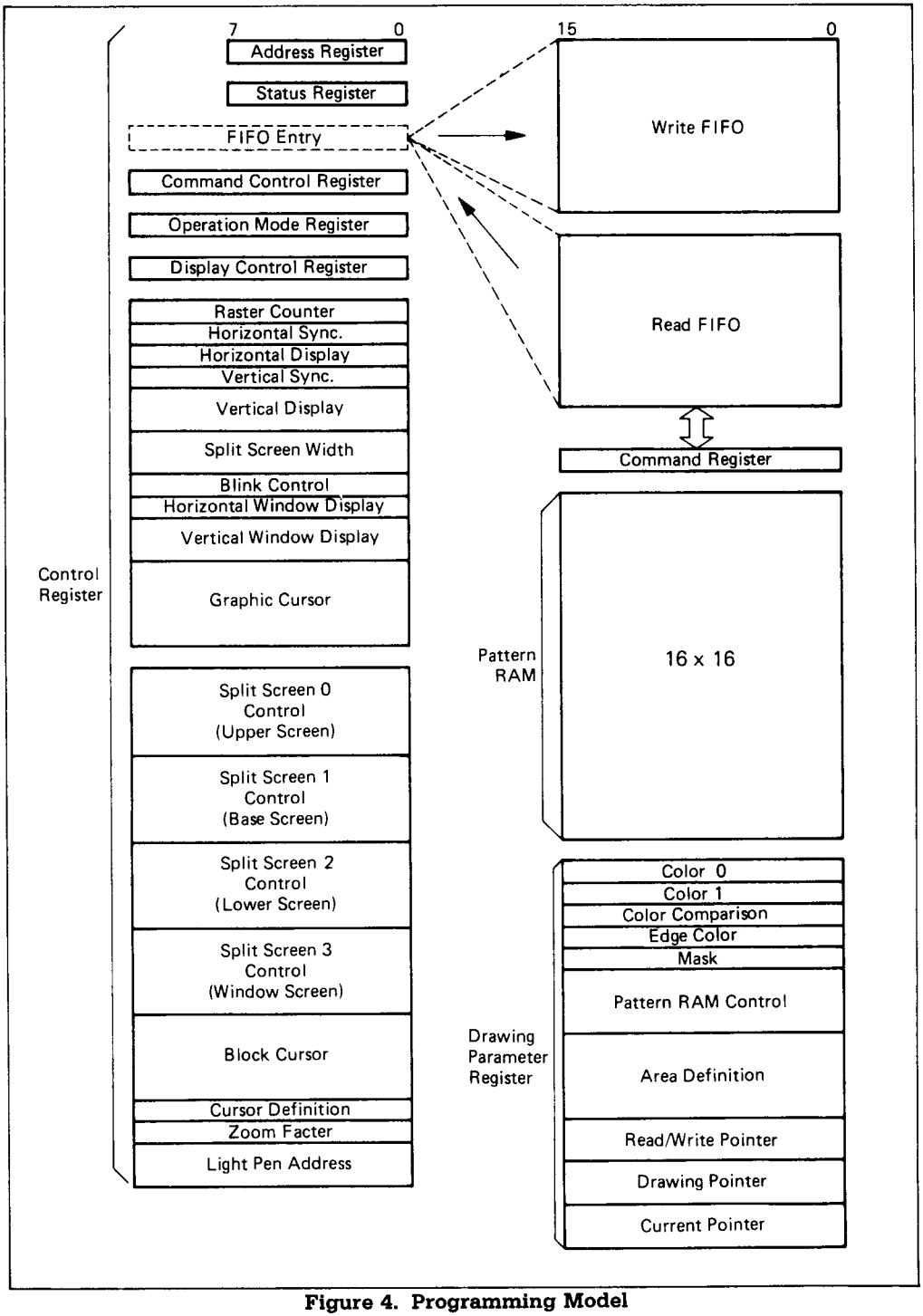


Figure 4. Programming Model

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	$\overline{CSK}$	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)

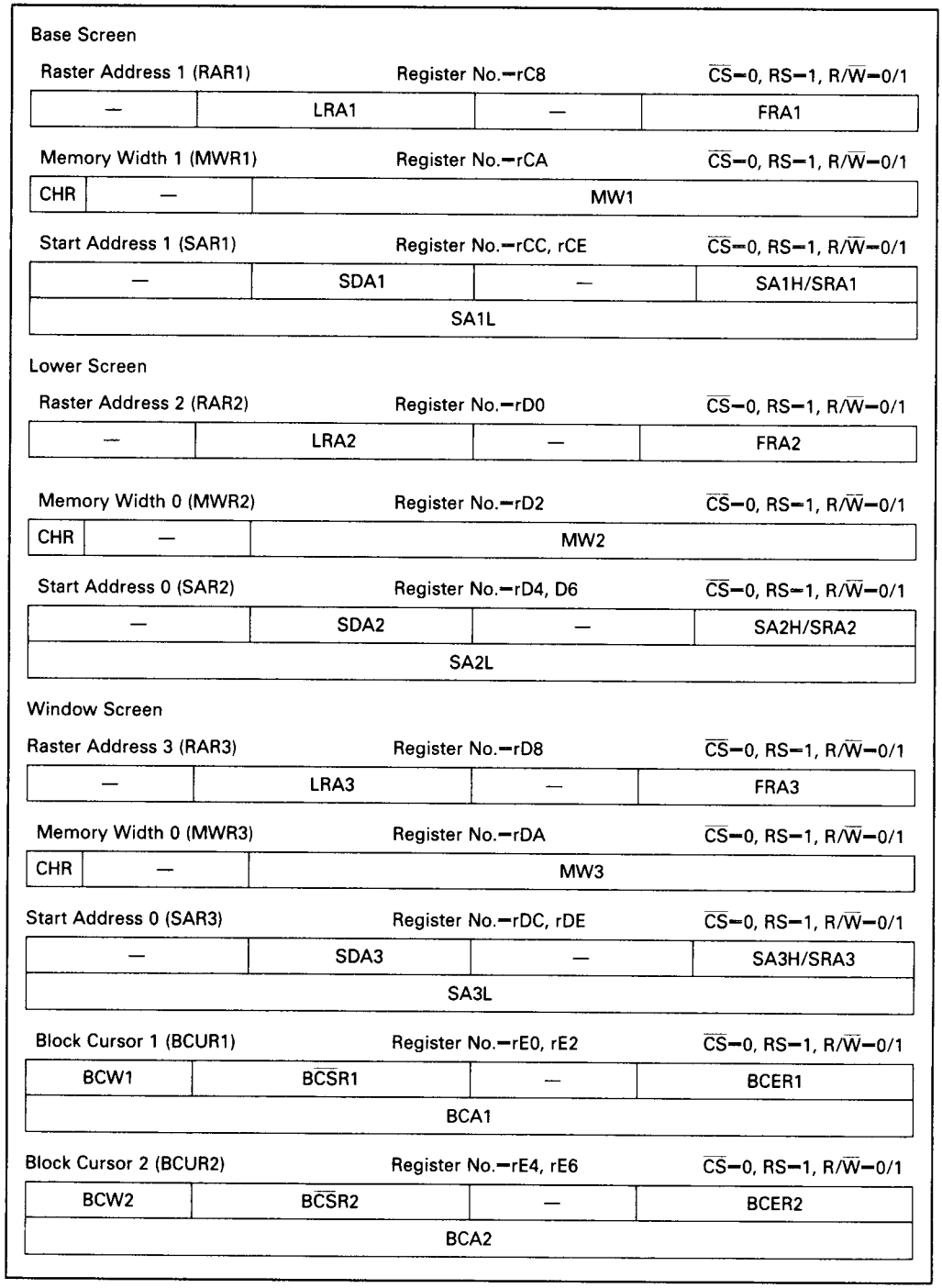


Figure 5. Hardware Access and Direct Access Registers (cont)

Cursor Definition (CDR) Register No.=rE8 $\overline{CS}$=0, RS=1, R/$\overline{W}$=0/1

CM	CON1	COFF1	—	CON2	COFF2

Zoom Factor (ZFR) Register No.=rEA $\overline{CS}$=0, RS=1, R/$\overline{W}$=0/1

HZF	VZF	—

Lightpen Address (LPAR) Register No.=rEC, rEE $\overline{CS}$=0, RS=1, R/$\overline{W}$=0/1

—	CHR	—	LPAH
LPAL			

(Underfined) Register No.=rF0-rFE $\overline{CS}$=0, RS=1, R/$\overline{W}$=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: $\overline{DMA}$ Request Control
DSK: $\overline{DISP}$ Skew
DSP: $\overline{DISP}$ 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 Facter, Vertical Zoom Factor
LPAH: Light Pen Address High
LPAL: Light Pen Address Low

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

Table 1. Drawing Parameter Registers

Register No.	Read/ Write	Name of Register	Abbr.	Data (H) 15	14	13	12	11	10	9	8	Data (L) 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 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 coodinate

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 interaction, 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.

Table 2. Logical Screen

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

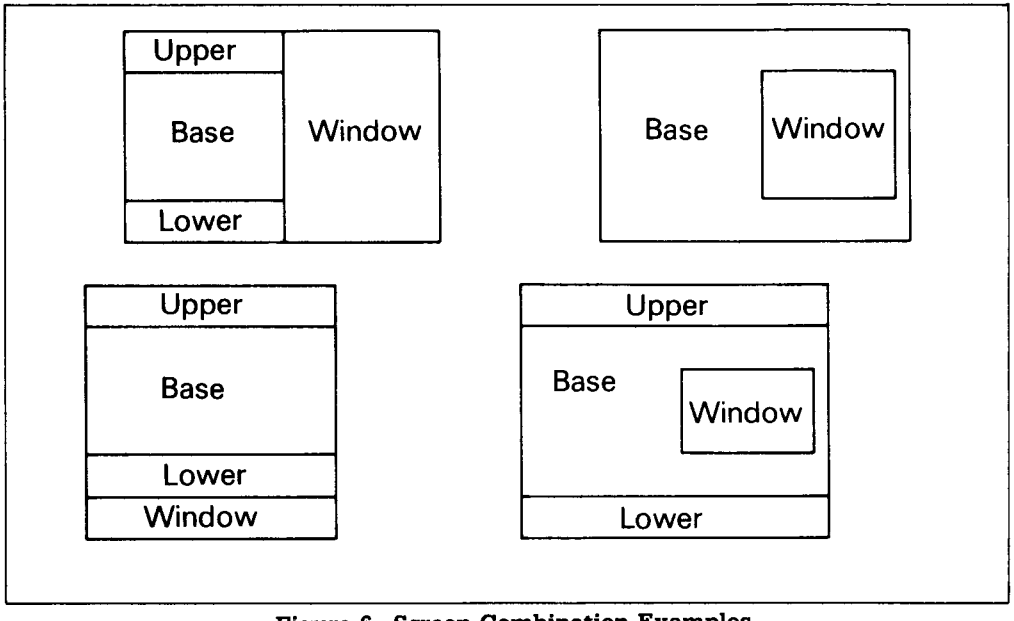


Figure 6. Screen Combination Examples

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).

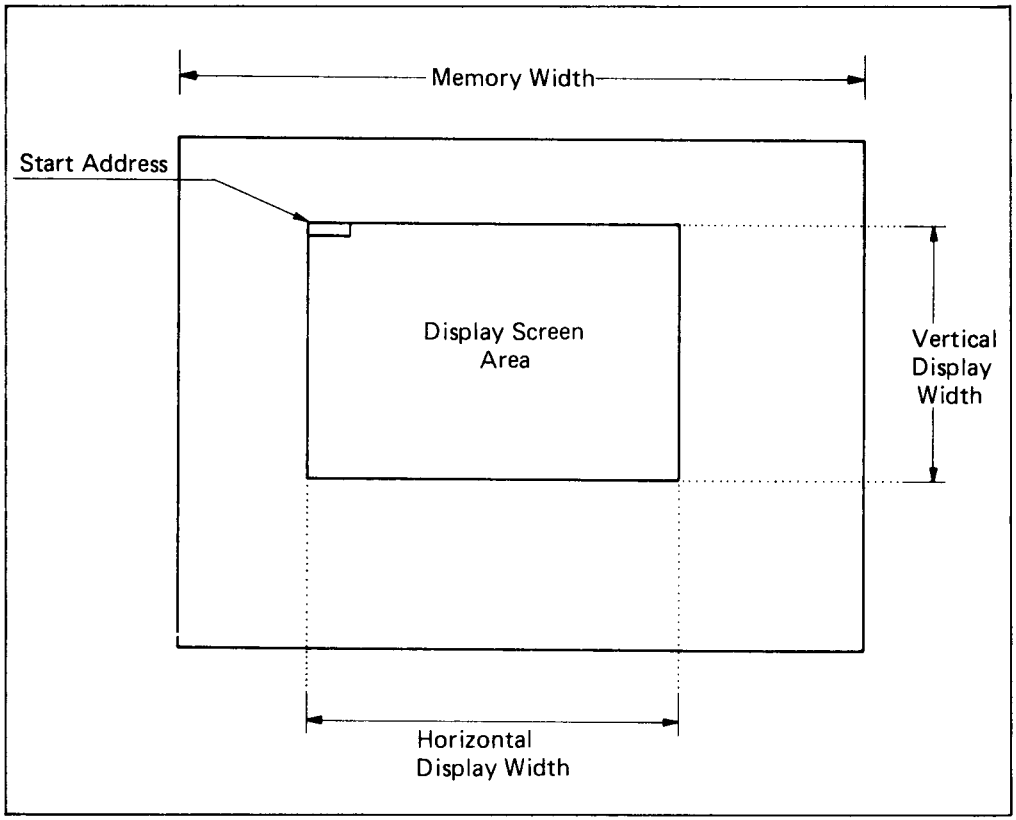


Figure 7. Frame Memory and Display Screen Area

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:

(Display width) = (Register value) + 1 memory cycles

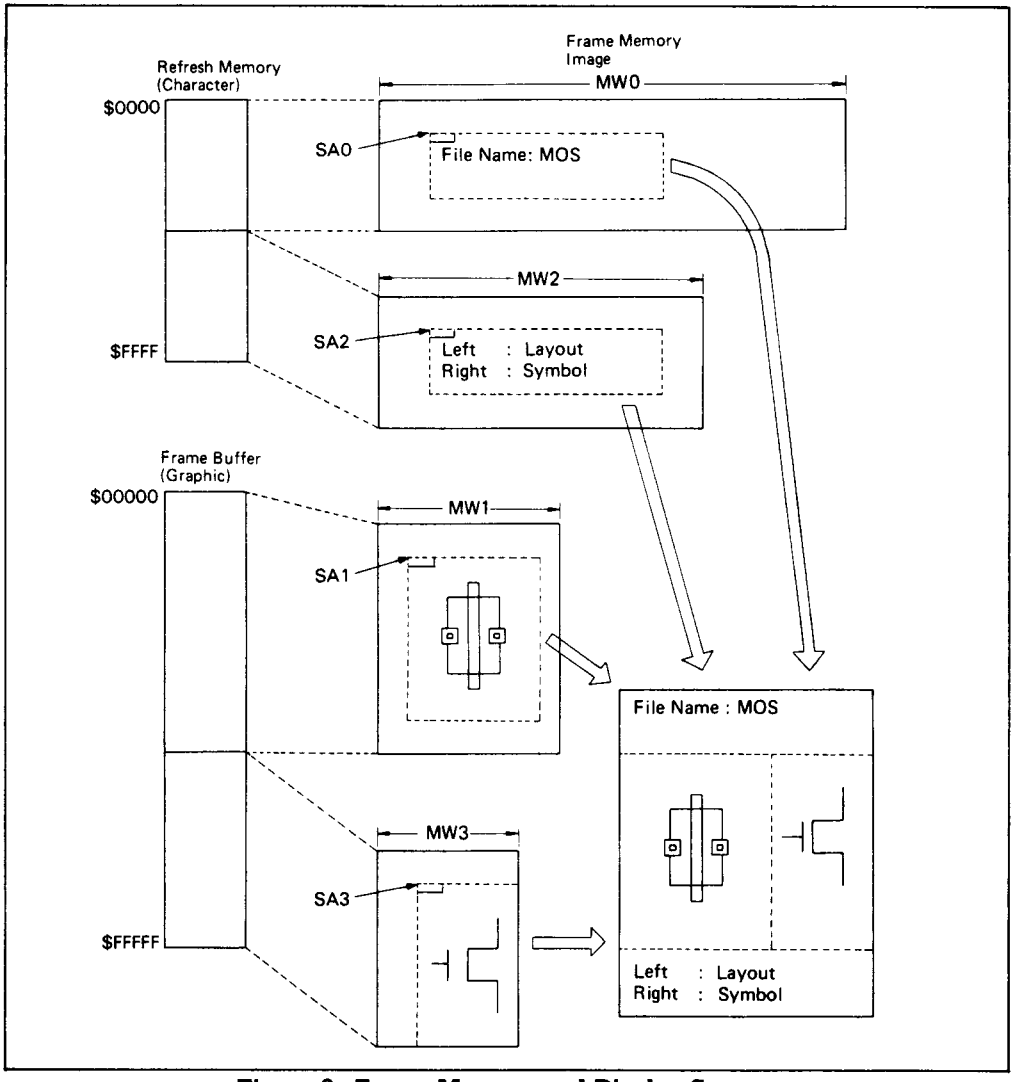


Figure 8. Frame Memory and Display Screens

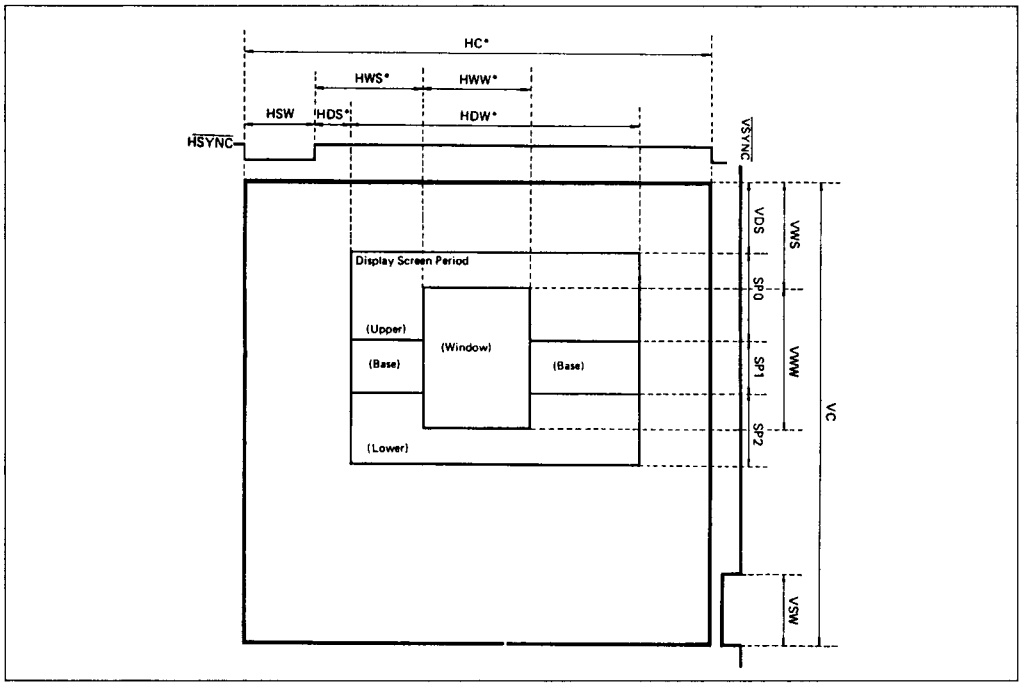


Figure 9. Display Screen Specification

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 trasnferred 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 initilizing 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 Access Command	ORG	Origin	3	8
	WPR	Write Parameter Register	2	6
	RPR	Read Parameter Register	1	6
	WPTN	Write Pattern RAM	n+2	4n+8
	RPTN	Read Pattern RAM	2	4n+10
Data Transfer Command	DRD	DMA Read	3	(4x+8)y+12[x·y/8↑]+(62~68)
	DWT	DMA Write	3	(4x+8)y+16[x·y/8↑]+34
	DMOD	DMA Modify	3	(4x+8)y+16[x·y/8↑]+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 Drawing Command	AMOVE	Absolute Move	3	56
	RMOVE	Relative Move	3	56
	ALINE	Absolute Line	3	P·L+18
	RLINE	Relative Line	3	P·L+18
	ARCT	Absolute Rectangle	3	2P(A+B)+54
	RRCT	Relative Rectangle	3	2P(A+B)+54
	APLL	Absolute Polyline	2n+2	Σ[P·L+16]+8
	RPLL	Relative Polyline	2n+2	Σ[P·L+16]+8
	APLG	Absolute Polygon	2n+2	Σ[P·L+16]+P·Lo+20
	RPLG	Relative Polygon	2n+2	Σ[P·L+16]+P·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·A+8)B+18
	RFRCT	Relative Filled Rectangle	3	(P·A+8)B+18
	PAINT	Paint	1	(18A+102)B-58 *2
	DOT	Dot	1	8
	PTN	Pattern	2	(P·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 RN	D
	RPR	0 0 0 0 1 1 0 0 0 0 0 RN	
	WPTN	0 0 0 1 1 0 0 0 0 0 0 0 PRA	n $D_1, \ldots, D_n$
	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 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 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 MM	D AX AY
	CPY	0 1 1 0 S DSD 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 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 X1, Y1, . . Xn, Yn
	RPLL	1 0 0 1 1 1 0 0 AREA COL OPM	n dX1, dY1, . . dXn, dYn
	APLG	1 0 1 0 0 0 0 0 AREA COL OPM	n X1, Y1, . . Xn, Yn
	RPLG	1 0 1 0 0 1 0 0 AREA COL OPM	n dX1, dY1,...dXn, dYn
	CRCL	1 0 1 0 1 0 0 C AREA COL OPM	r
	ELPS	1 0 1 0 1 1 0 C AREA COL OPM	a b DX
	AARC	1 0 1 1 0 0 0 C AREA COL OPM	Xc Yc Xe Ye
	RARC	1 0 1 1 0 1 0 C AREA COL OPM	dXc dYc dXe dYe
	AEARC	1 0 1 1 1 0 0 C AREA COL OPM	a b Xc Yc Xe Ye
	REARC	1 0 1 1 1 1 0 C AREA COL OPM	a b dXc dYc dXe dYe
	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 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	Xs Ys DX DY
	RGCPY	1 1 1 1 S DSD AREA 0 0 OPM	dXs dYs 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 = dX^2:dY^2
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/$\overline{W}$, $\overline{CS}$ = 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 initially 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 $\overline{DONE}$ signal. $\overline{DONE}$ 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 coordenates 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 throught 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 corrdinates
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 a ellipse whose shape is specifed 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 specifed 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 specifed 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 specifed by the current point (CP) and by the pattern size (rotation angle: 45°)
AGCPY	Copy a rectangular area specifed by the absolute coordinates to the address specifed 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.

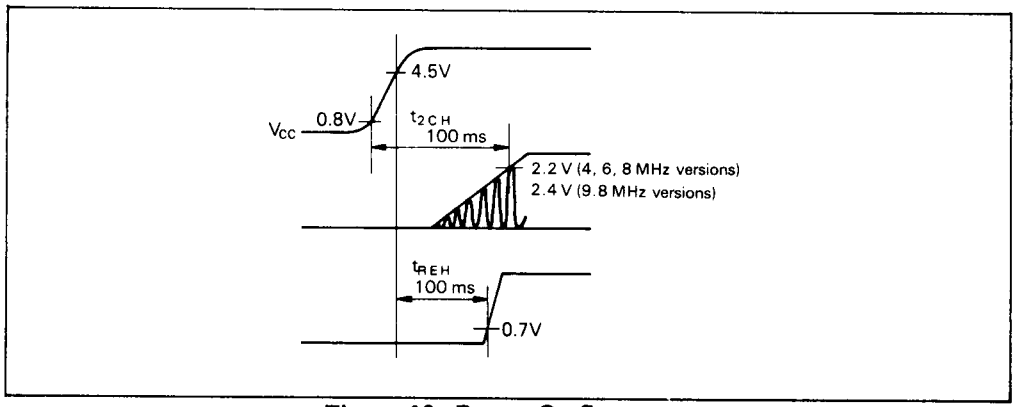


Figure 10. Power-On Sequence

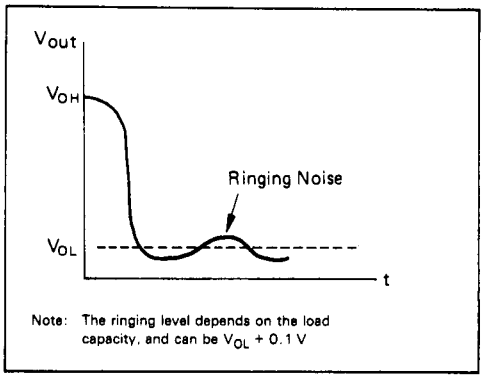


Figure 11. Ringing Noise

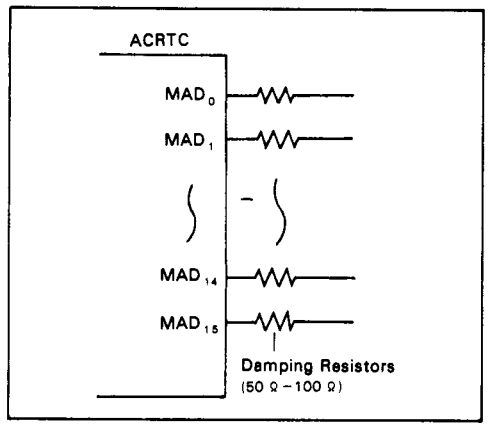


Figure 12. Damping Resistors

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).

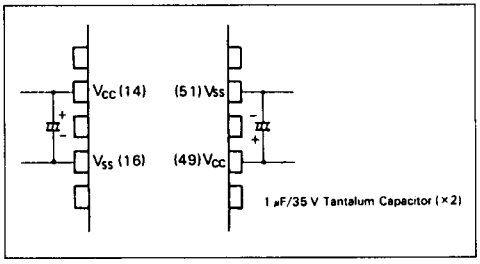


Figure 13. Power Supply Circuit Example, 64-Pin DIP

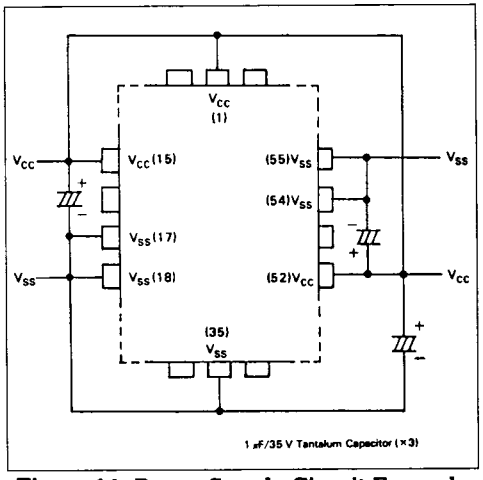


Figure 14. Power Supply Circuit Example, 68-Pin PLCC

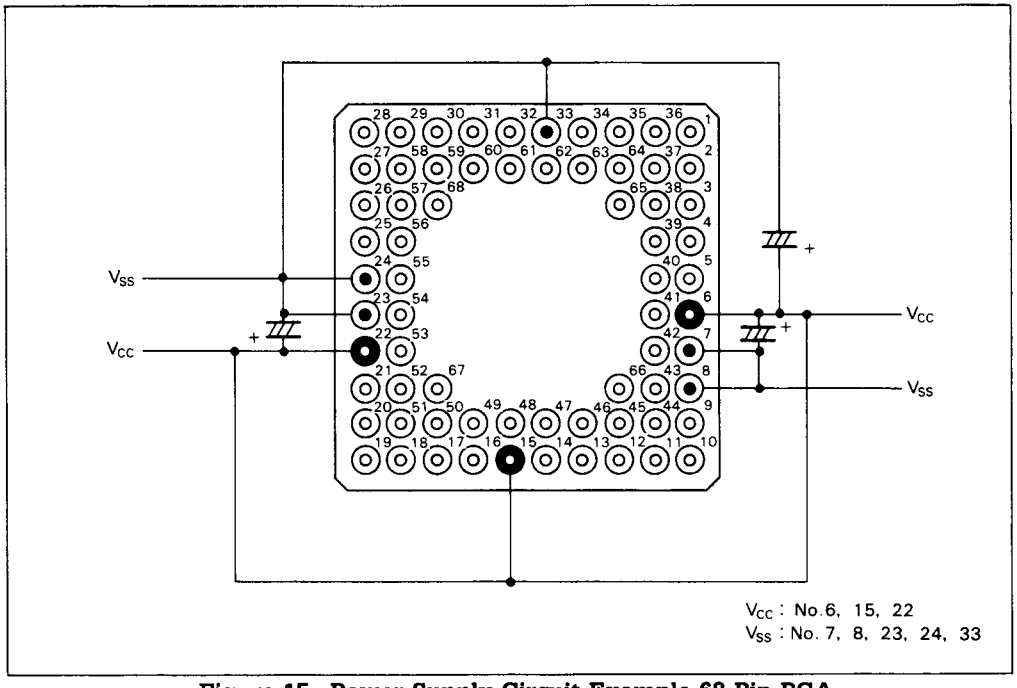


Figure 15. Power Supply Circuit Example 68-Pin PGA

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	$\|I_O\|$ (Note 2)	5	mA
Total Allowable Output Current	$\|\Sigma I_O\|$ (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/$\overline{W}$, $\overline{CS}$, RS, $\overline{RES}$, $\overline{DACK}$, 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}, $\overline{EXSYNC}$	I_{TSI}	−10	10	µA	V_{in}=0.4 to V_{CC}
Output High Level Voltage	D_0-D_{15}, MAD_0-MAD_{15}, $\overline{CUD1}$, $\overline{CUD2}$, $\overline{DREQ}$, $\overline{DTACK}$, $\overline{HSYNC}$, $\overline{VSYNC}$, $\overline{EXSYNC}$, $\overline{MRD}$, $\overline{DRAW}$, $\overline{AS}$, $\overline{DISP1}$, $\overline{DISP2}$, CHR, MCYC, RA_4, MA_{16}/RA_0-MA_{19}/RA_3	V_{OH}	V_{CC} −1.0		µA	I_{OH}=−400µA
Output Low Level Voltage	D_0-D_{15}, MAD_0-MAD_{15}, $\overline{CUD1}$, $\overline{CUD2}$, $\overline{DREQ}$, $\overline{DTACK}$, $\overline{HSYNC}$, $\overline{VSYNC}$, $\overline{EXSYNC}$, $\overline{MRD}$, $\overline{DRAW}$, $\overline{AS}$, $\overline{DISP1}$, $\overline{DISP2}$, CHR, MCYC, RA_4, MA_{16}/RA_0-MA_{19}/RA_3	V_{OL}		0.5	V	I_{OL}=2.2mA
	$\overline{IRQ}$, $\overline{DONE}$	VO_L		0.5	V	I_{OL}=2.5 mA
Output Leak Current (Hi-Z)	$\overline{IRQ}$, $\overline{DONE}$	I_{LOD}		10	µA	V_{OH}=V_{CC}
Input Capacitance	D_0-D_{15}, MAD_0-MAD_{15}, $\overline{EXSYNC}$, R/$\overline{W}$, $\overline{CS}$, RS, $\overline{RES}$, $\overline{DACK}$, 2CLK, LPSTB	C_{in}		17	pF	V_{in}=0 V, Ta=25°C, f=1.0 MHz
Output Capacitance	$\overline{IRQ}$, $\overline{DONE}$	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

2

AC Characteristics (V_{CC}=5.0V ± 5%, V_{SS}=0V, Ta=0 to +70°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	tcr	–	10	–	10	–	10	–	5	ns	
5	Clock Fall Time	tcf	–	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/$\overline{W}$ Setup Time	tRWS	70	–	60	–	50	–	50	–	ns	18—20
7	R/$\overline{W}$ 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	tRWAI	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	$\overline{DTACK}$ Delay Time (Z to L)	tDTKZL	–	90	–	80	–	70	–	70	ns	18—20
18	$\overline{DTACK}$ Delay Time (D to L)	tDTKDL	0	–	0	–	0	–	0	–	ns	18, 20
19	$\overline{DTACK}$ Release Time (L to H)	tDTKLH	–	100	–	90	–	80	–	80	ns	18—20
20	$\overline{DTACK}$ Turn Off Time (H to Z)	tDTKZ	–	100	–	100	–	100	–	100	ns	
21	Data Bus 3-State Recovery Time 1	tDBRT1	0	–	0	–	0	–	0	–	ns	18, 20
22	Write Wait Time	tWWAI	0	–	0	–	0	–	0	–	ns	19,20
23	Write Data Setup Time	tWDS	80	–	60	–	40	–	40	–	ns	
24	Write Data Hold Time	tWDH	10	–	10	–	10	–	10	–	ns	

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	$\overline{DREQ}$ Delay Time 1	tDRQD1	–	150	–	130	–	110	–	110	ns	21—24
26	$\overline{DREQ}$ Delay Time 2	tDRQD2	–	90	–	80	–	70	–	70	ns	
27	DMA R/$\overline{W}$ Setup Time	tDMRWS	70	–	60	–	50	–	50	–	ns	
28	DMA R/$\overline{W}$ Hold Time	tDMRWH	0	–	0	–	0	–	0	–	ns	
29	$\overline{DACK}$ Setup Time	tDAKS	50	–	40	–	40	–	40	–	ns	
30	$\overline{DACK}$ High Level Width	tWDAKH	80	–	70	–	60	–	60	–	ns	
31												
32	DMA Read Wait Time	tDRW	0	–	0	–	0	–	0	–	ns	21, 22
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	
36	DMA $\overline{DTACK}$ Delay Time (Z to L)	tDDTZL	–	90	–	80	–	70	–	70	ns	21—24
37	DMA $\overline{DTACK}$ Delay Time (D to L)	tDDTDL	0	–	0	–	0	–	0	–	ns	21, 22
38	DMA $\overline{DTACK}$ Release Time (L to H)	tDDTLH	–	100	–	90	–	80	–	80	ns	21—24
39	DMA $\overline{DTACK}$ Turn Off Time (H to Z)	tDDTHZ	–	100	–	100	–	100	–	100	ns	
40	$\overline{DONE}$ Output Delay Time	tDND	–	90	–	80	–	70	–	70	ns	
41	$\overline{DONE}$ Output Turn Off Time (L to Z)	tDNLZ	–	100	–	90	–	80	–	80	ns	
42	Data Bus 3-State Recovery Time 2	tDBRT2	0	–	0	–	0	–	0	–	ns	21, 22
43	$\overline{DONE}$ Input Pulse Width	tDNPW	2	–	2	–	2	–	2	–	tcyc	23, 24
44	DMA Write Wait Time	tDWW	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												

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	$\overline{AS}$ "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	$\overline{AS}$ Delay Time 1	tASD1	–	90	–	75	–	60	–	50	ns	
51	$\overline{AS}$ 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	$\overline{DRAW}$ Delay Time	tDRWD	–	90	–	80	–	70	–	50	ns	
63	$\overline{DRAW}$ 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	$\overline{\text{HSYNC}}$ Delay Time	tHSD	–	90	–	80	–	70	–	50	ns	28—30
68	$\overline{\text{VSYNC}}$ Delay Time	tVSD	–	90	–	80	–	70	–	50	ns	29
69	$\overline{\text{DISP1}}$, $\overline{\text{DISP2}}$ Delay Time	tDSPD	–	90	–	80	–	70	–	50	ns	
70	$\overline{\text{CUD1}}$, $\overline{\text{CUD2}}$ Delay Time	tCUDD	–	90	–	80	–	70	–	50	ns	
71	$\overline{\text{EXSYNC}}$ 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												

$\overline{\text{EXSYNC}}$ 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	$\overline{\text{EXSYNC}}$ Input Pulse Width	tEXSW	3	–	3	–	3	–	3	–	tcyc	30
76	$\overline{\text{EXSYNC}}$ Input Setup Time	tEXS	60	–	60	–	50	–	30	–	ns	
77	$\overline{\text{EXSYNC}}$ 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	

$\overline{\text{RES}}$ and $\overline{\text{DACK}}$ 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	$\overline{\text{DACK}}$ Setup Time for $\overline{\text{RES}}$	tDAKSR	100	–	100	–	100	–	100	–	ns	33
83	$\overline{\text{DACK}}$ Hold Time for $\overline{\text{RES}}$	tDAKHR	0	–	0	–	0	–	0	–	ns	
84	$\overline{\text{RES}}$ Input Pulse Width	tRES	10	–	10	–	10	–	10	–	tcyc	

$\overline{IRQ}$ 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	$\overline{IRQ}$ Delay Time 1	tIRQ1	–	250	–	200	–	150	–	150	ns	34, 35
86	$\overline{IRQ}$ 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	$\overline{CS}$ Cycle Time	tCSC	4	–	4	–	4	–	4	–	tcyc	18, 19
101	$\overline{CS}$ Low Level Width	tWCSL	2	–	2	–	2	–	2	–	tcyc	
102	$\overline{CS}$ High Level Width	tWCSH	2	–	2	–	2	–	2	–	tcyc	
104	$\overline{DACK}$ Cycle Time	tDACKC	4	–	4	–	4	–	4	–	tcyc	22, 24
105	$\overline{DACK}$ Low Level Width	tWDACKL	2	–	2	–	2	–	2	–	tcyc	
106	$\overline{DACK}$ High Level Width	tWDACKH	2	–	2	–	2	–	2	–	tcyc	

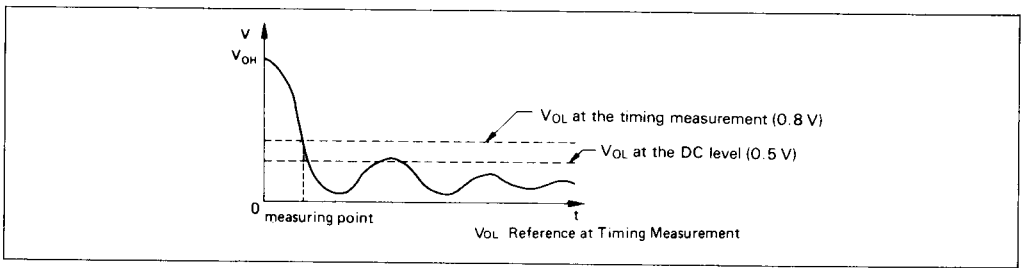
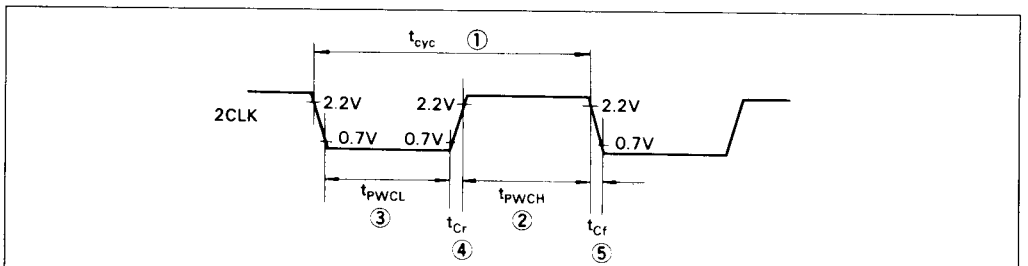
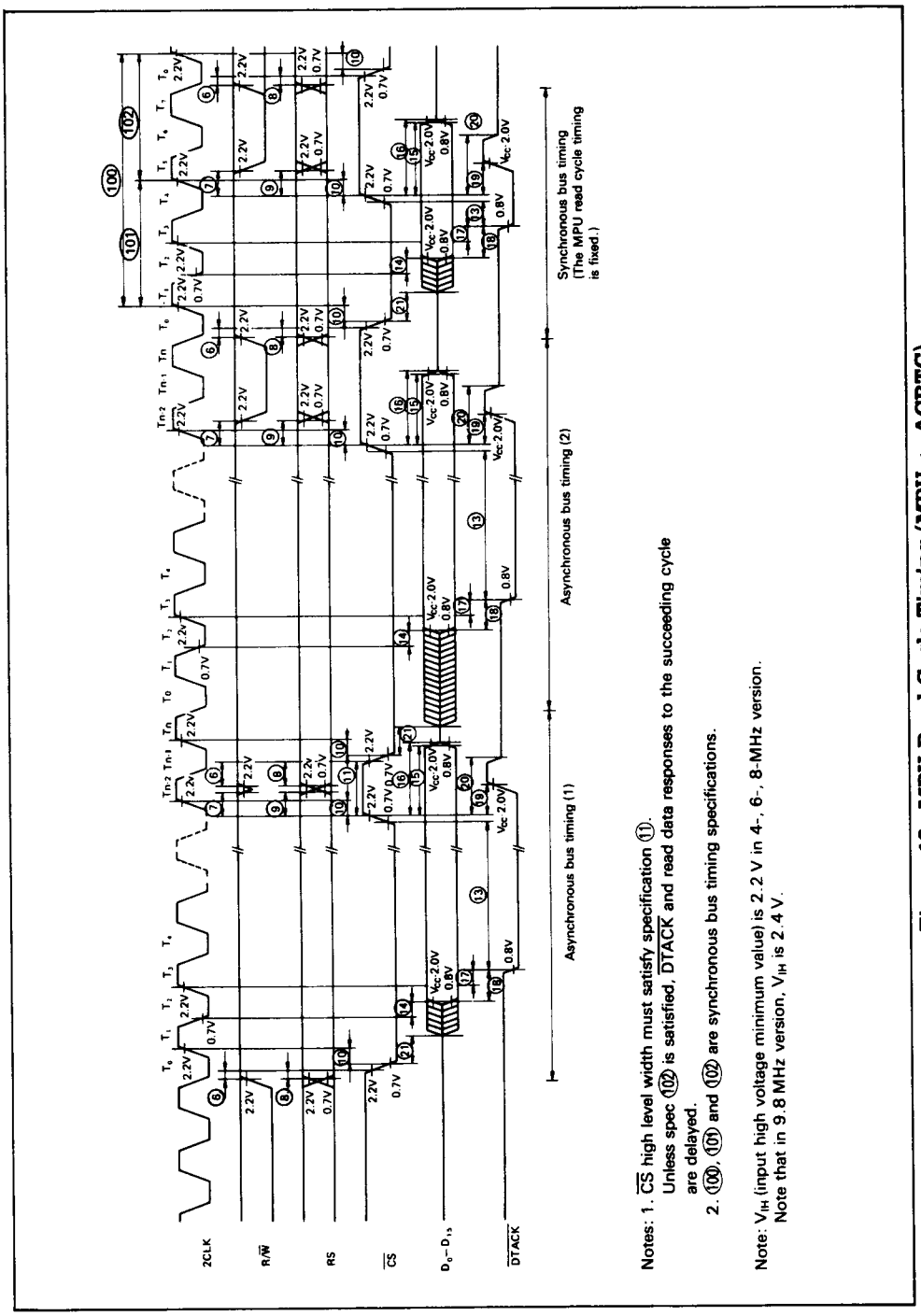


Figure 16. Test Points



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.

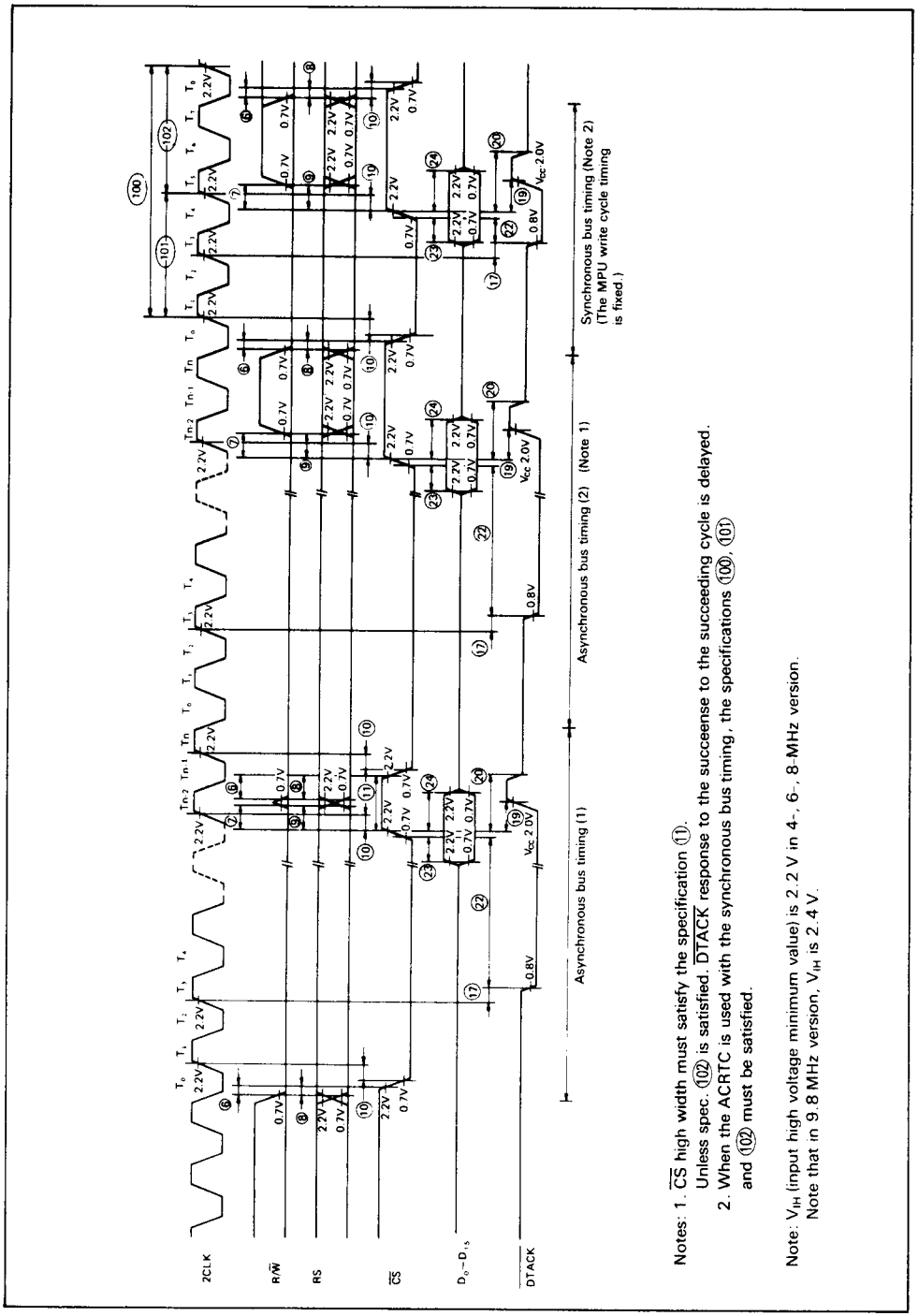
Figure 17. 2CLK Waveform



Notes: 1. $\overline{CS}$ high level width must satisfy specification (11).
Unless spec (102) is satisfied, $\overline{DTACK}$ and read data responses to the succeeding cycle are delayed.
2. (100), (101) and (102) are synchronous 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.

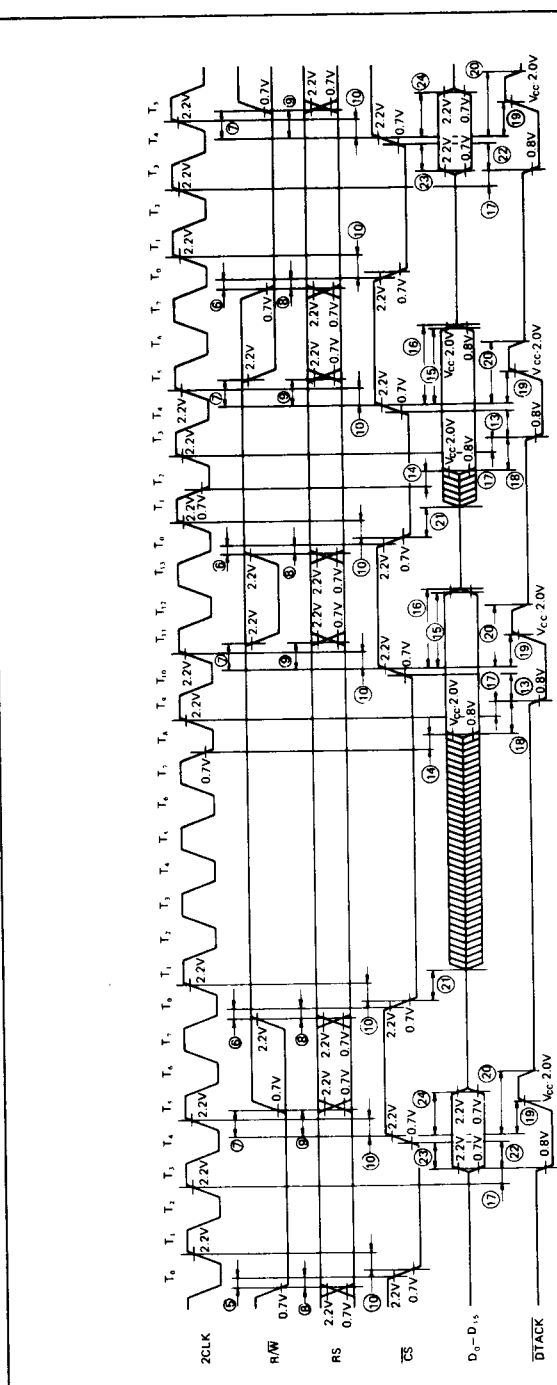
Figure 18. MPU Read Cycle Timing (MPU ← ACRTC)



Notes: 1. $\overline{CS}$ high width must satisfy the specification ①.
Unless spec. ⑩② is satisfied. $\overline{DTACK}$ response to the succeense to the succeeding cycle is delayed.
2. When the ACRTC is used with the synchronous bus timing, the specifications ⑩⓪, ⑩①
and ⑩② must be 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 19. MPU Write Cycle Timing (MPU → ACRTC)

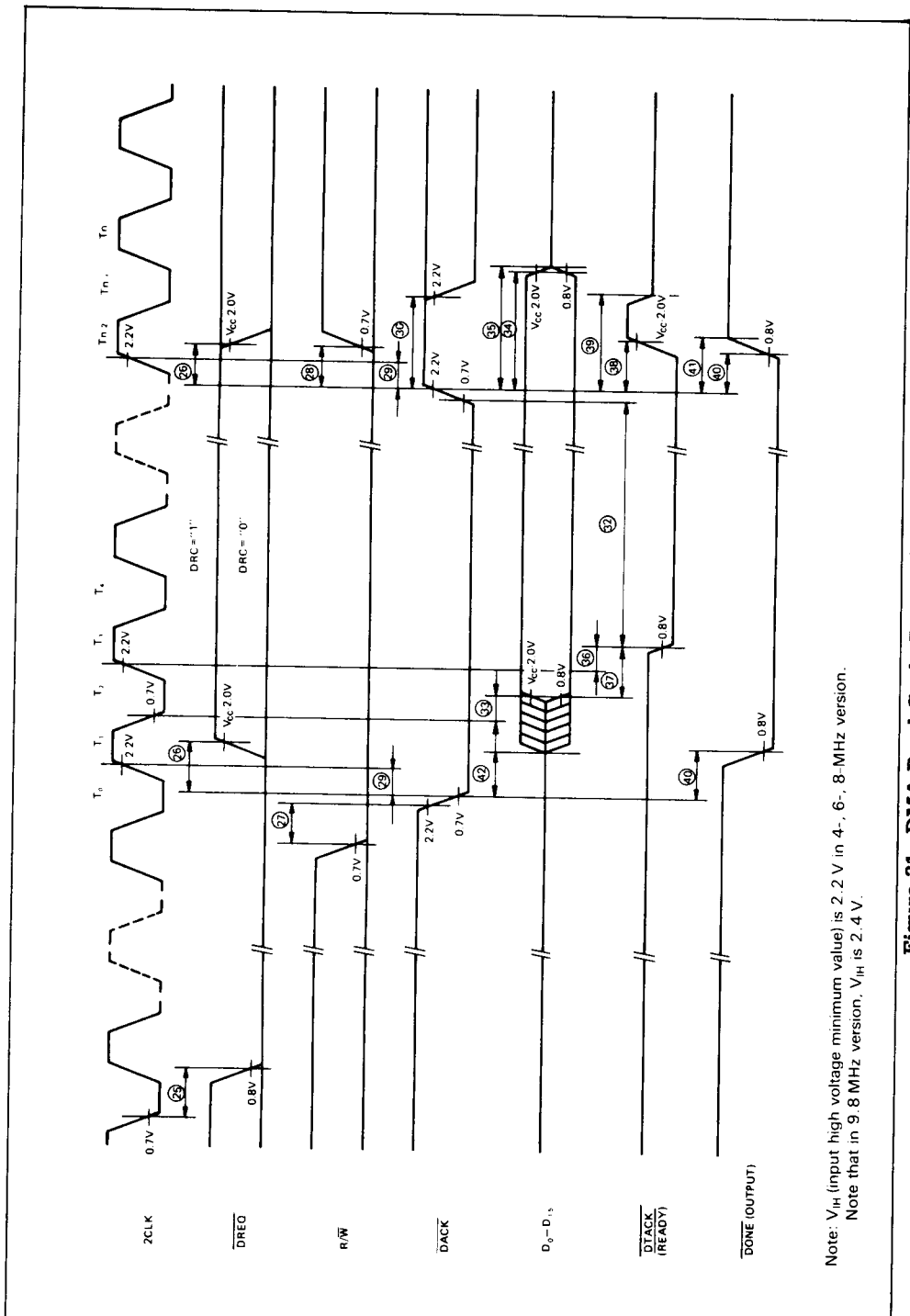


Note: When the MPU read cycle immediately follows the MPU wirte cycle execution, DTACK and the read data responses are delayed (by 3 cycles of 2CLK) even though spec. (102) is satisfied.

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.

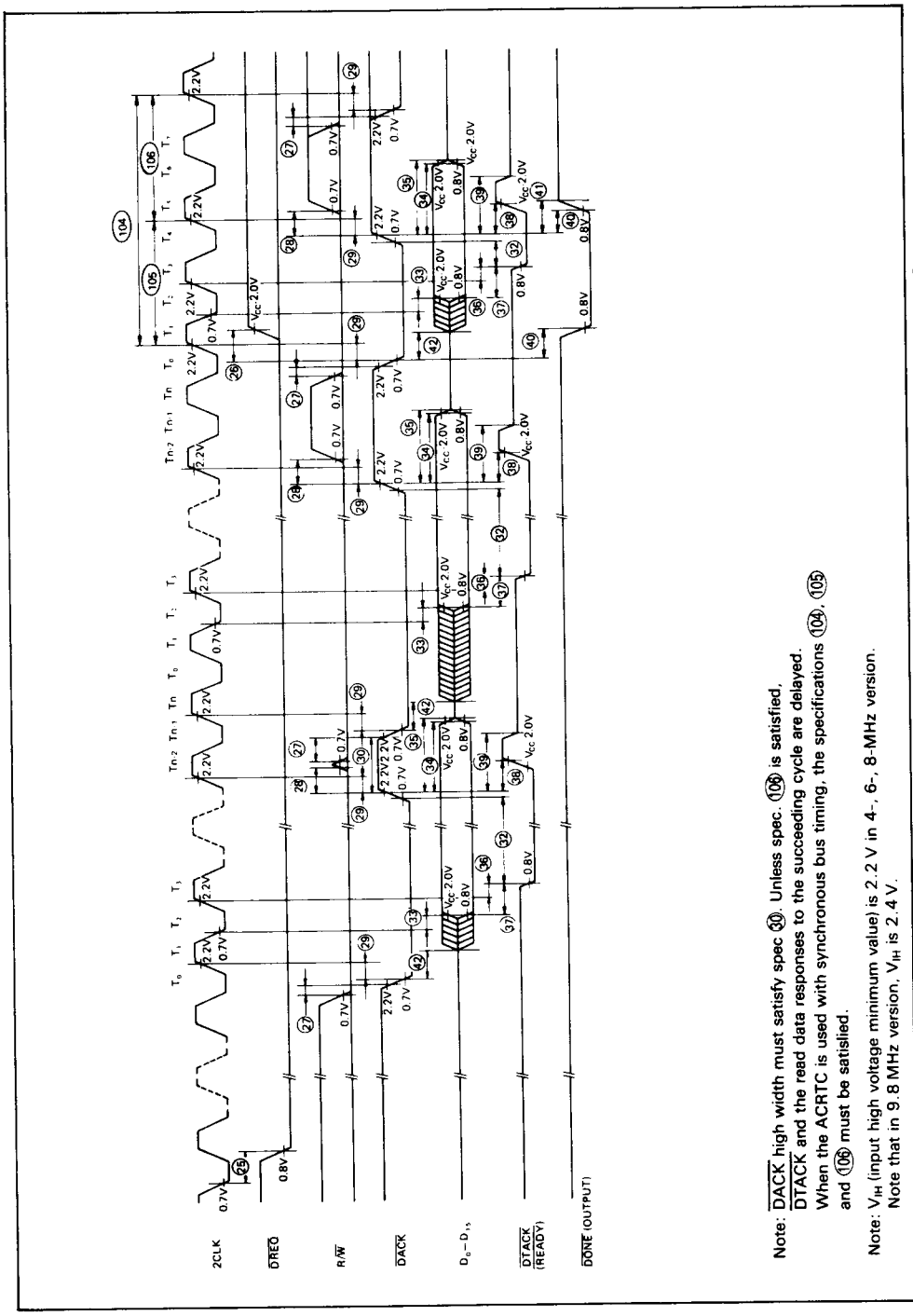
Figure 20. MPU Read/Write Cycle Timing (MPU → ACRTC)

2



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)



Note: DACK high width must satisfy spec (30). Unless spec. (106) is satisfied, DTACK and the read data responses to the succeeding cycle are delayed. When the ACRTC is used with synchronous bus timing, the specifications (104), (105), and (106) must be 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 22. DMA Ready Cycle Timing (Memory ← ACRTC): Burst Mode

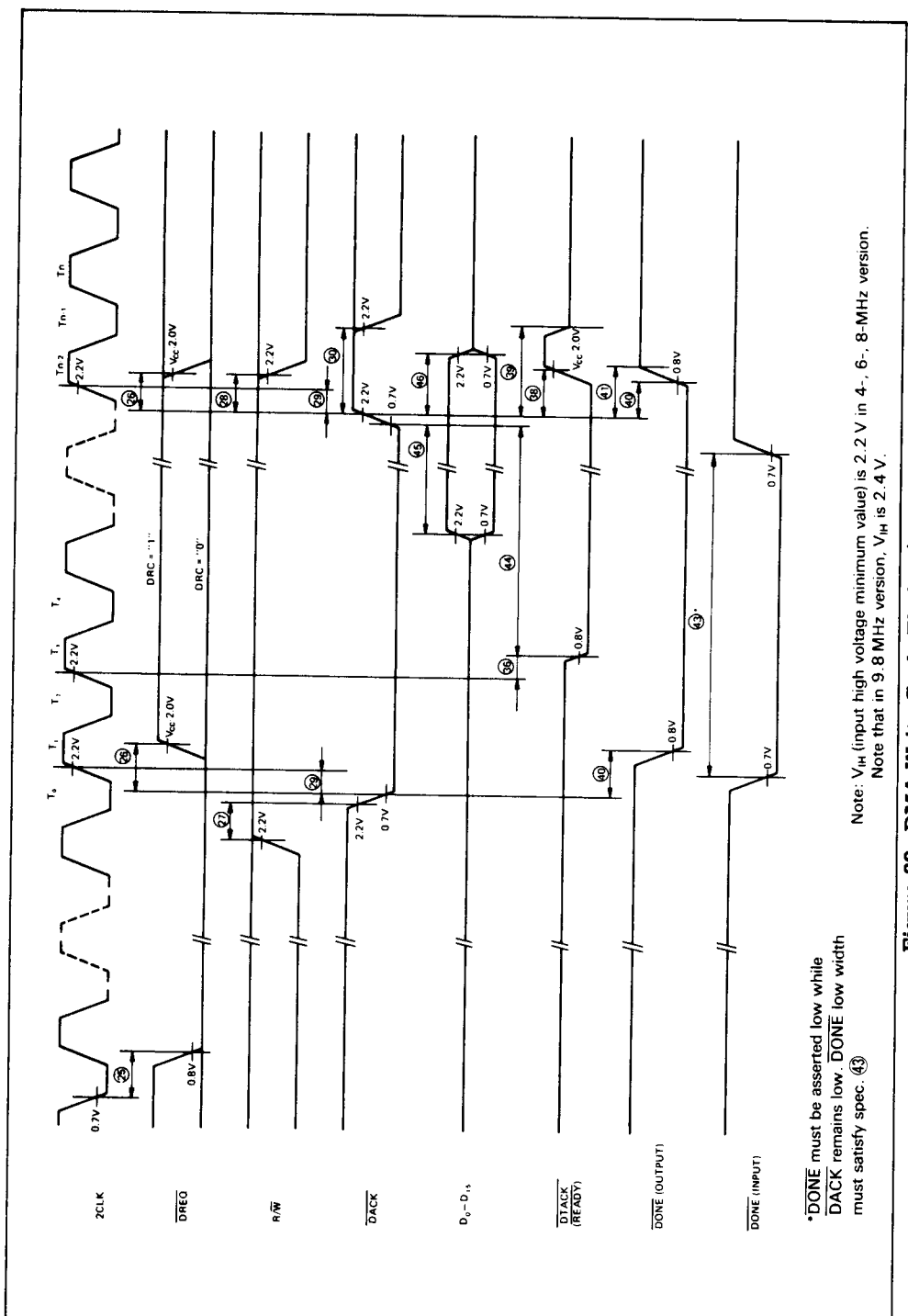
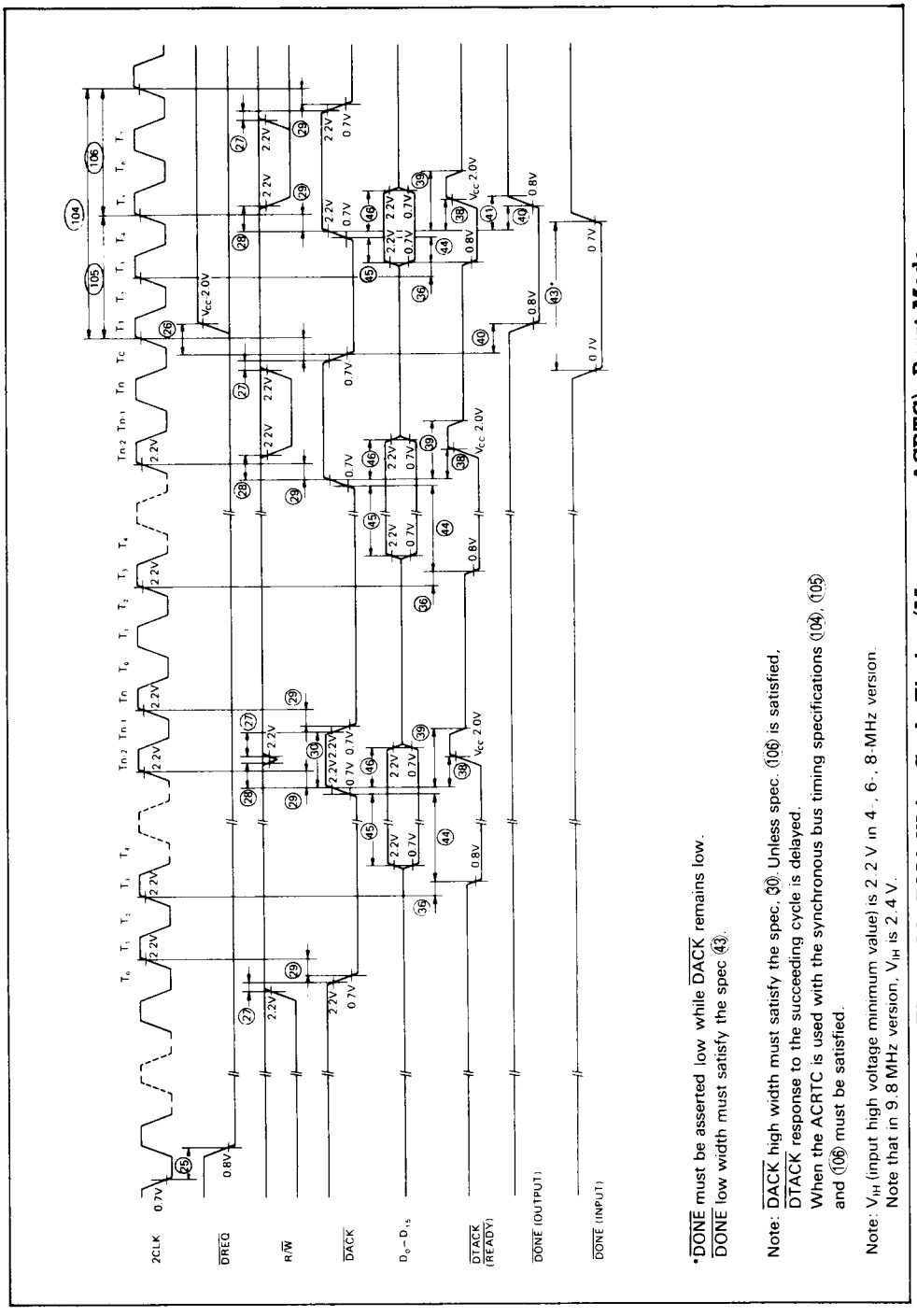


Figure 23. DMA Write Cycle Timing (Memory → ACRTC)

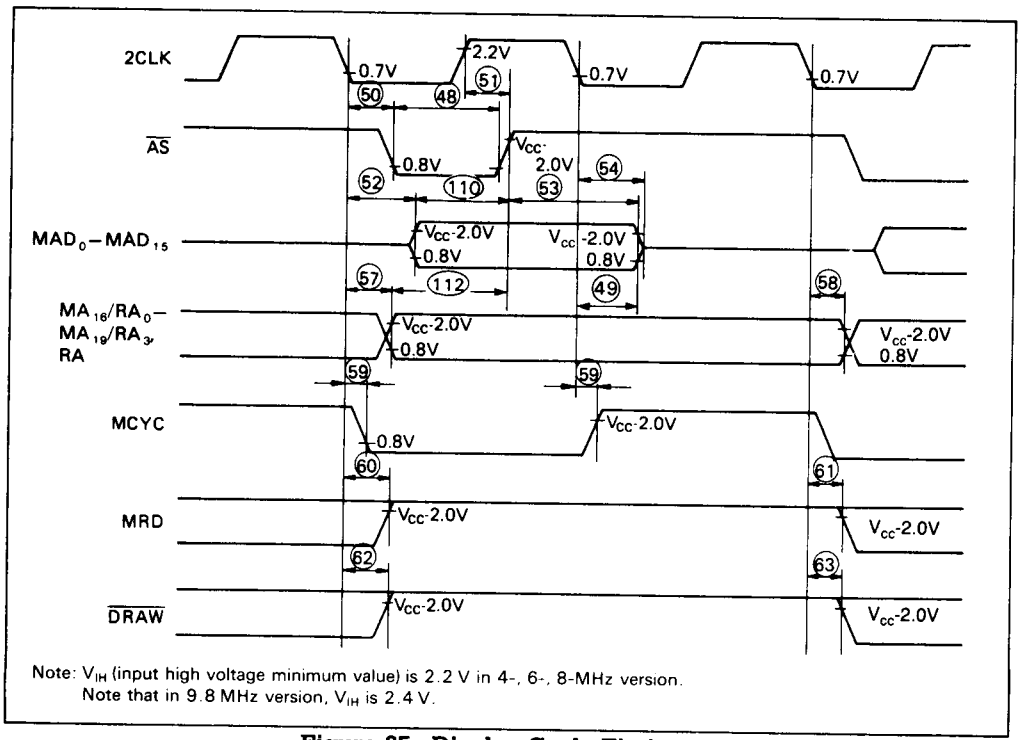


*DONE must be asserted low while DACK remains low.
DONE low width must satisfy the spec (43).

Note: DACK high width must satisfy the spec. (30). Unless spec. (106) is satisfied.
DTACK response to the succeeding cycle is delayed.
When the ACRTC is used with the synchronous bus timing specifications (104), (105) and (106) must be satisfied.

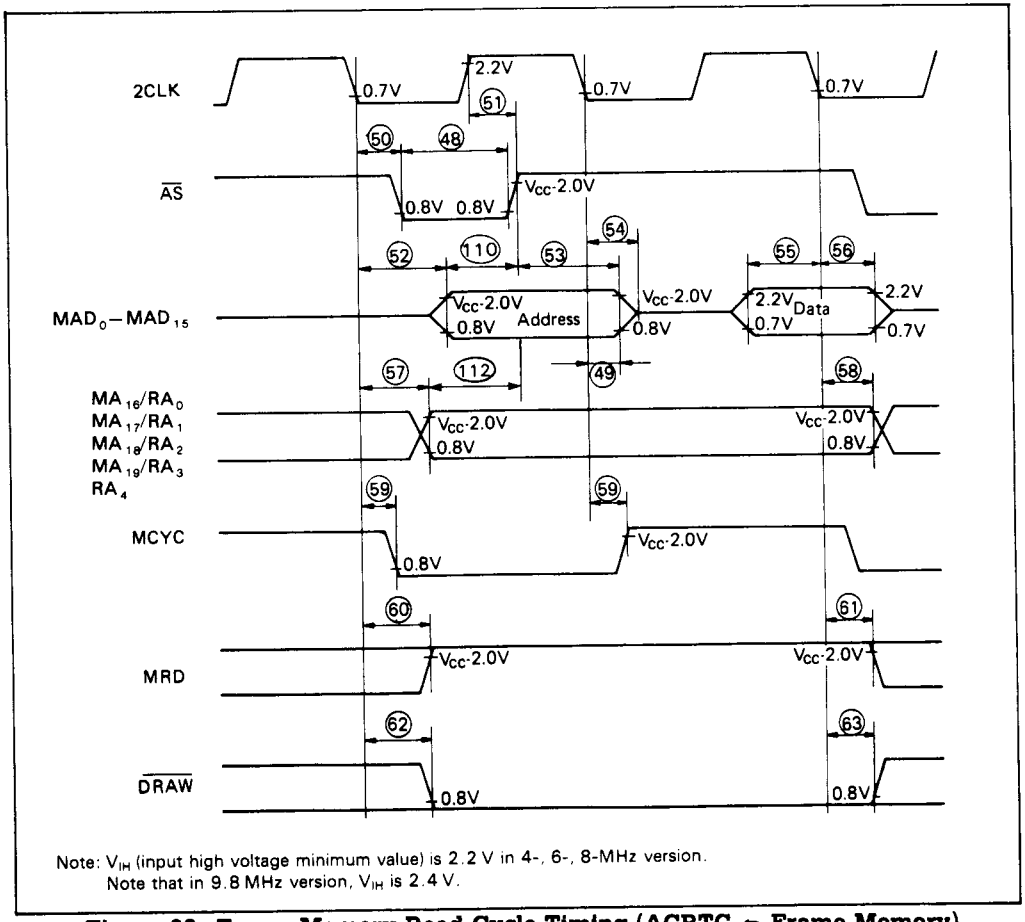
Note: V_{IH} (input high voltage minimum value) is 2.2 V in 4-, 6-, 8-MHz version.
Note that in 9.8 MHz version, V_{IH} is 2.4 V.

Figure 24. DMA Write Cycle Timing (Memory → ACRTC): Burst Mode



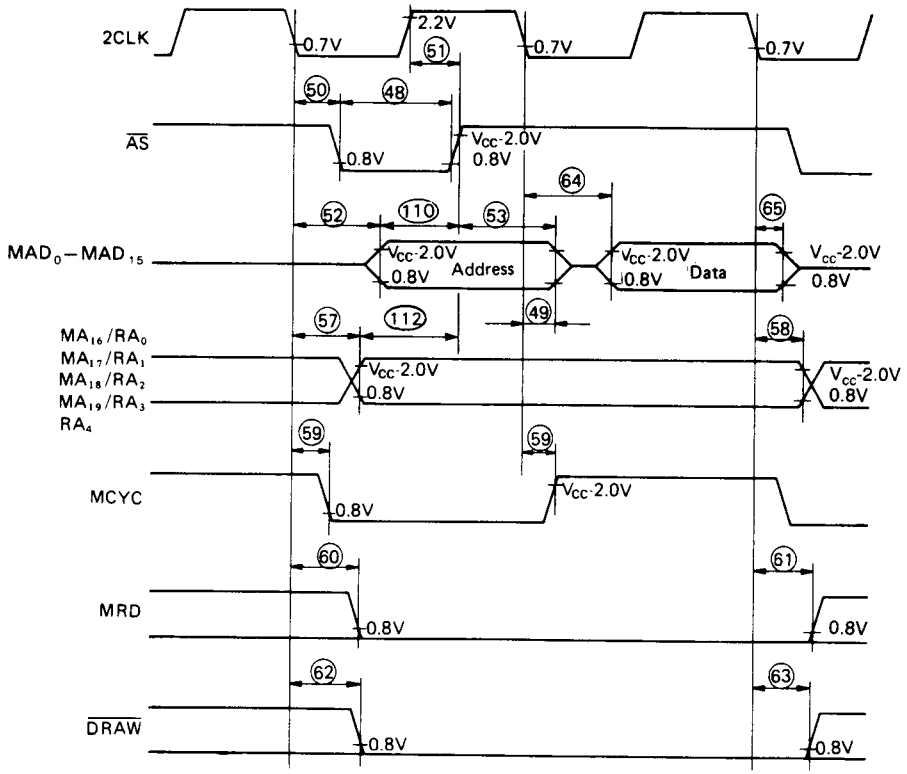
Note: V_{IH} (input high voltage minimum value) is 2.2 V in 4-, 6-, 8-MHz version.
Note that in 9.8 MHz version, V_{IH} is 2.4 V.

Figure 25. Display Cycle Timing



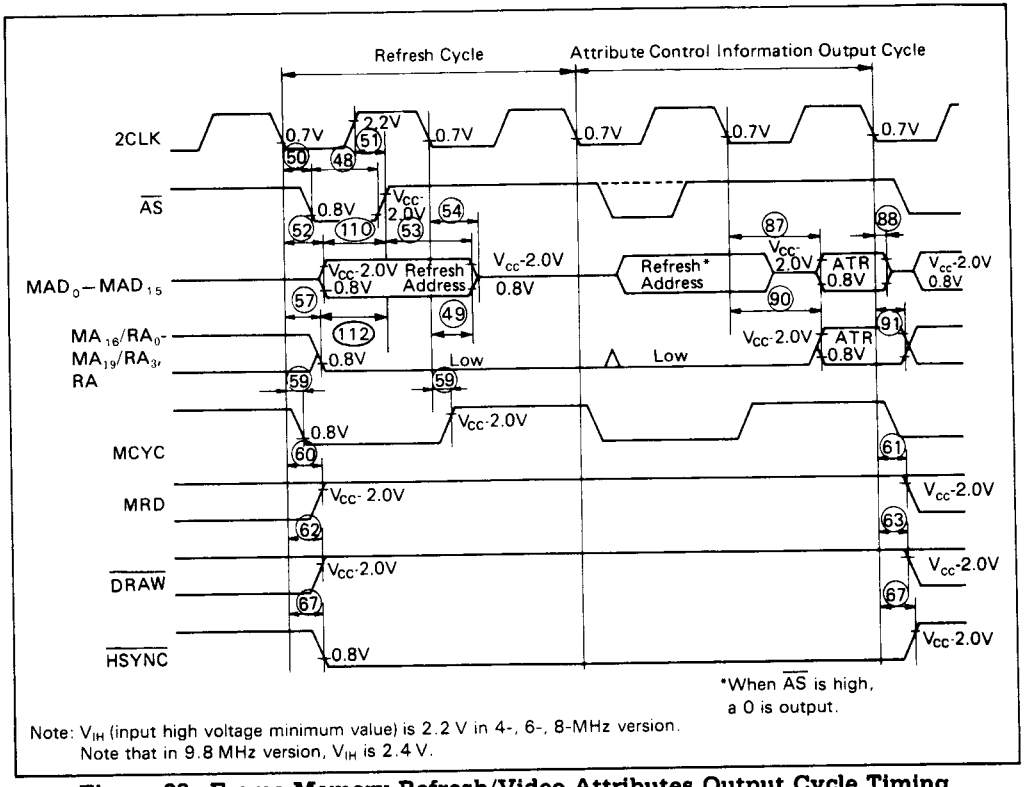
Note: V_{IH} (input high voltage minimum value) is 2.2 V in 4-, 6-, 8-MHz version.
Note that in 9.8 MHz version, V_{IH} is 2.4 V.

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



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



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 28. Frame Memory Refresh/Video Attributes Output Cycle Timing

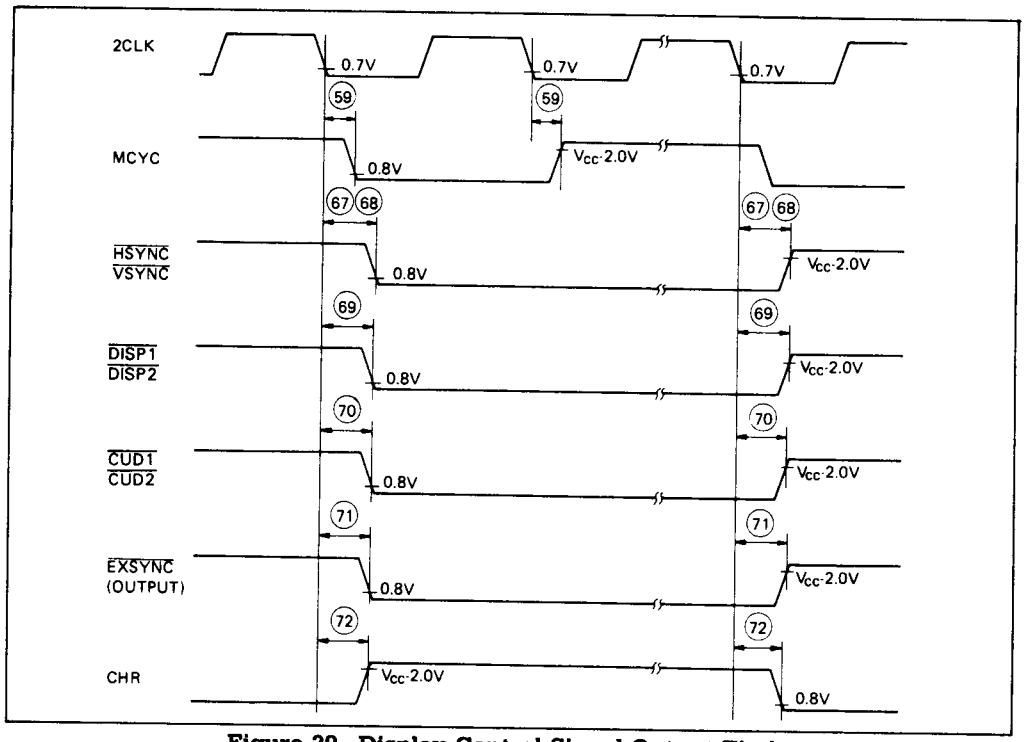


Figure 29. Display Control Signal Output Timing

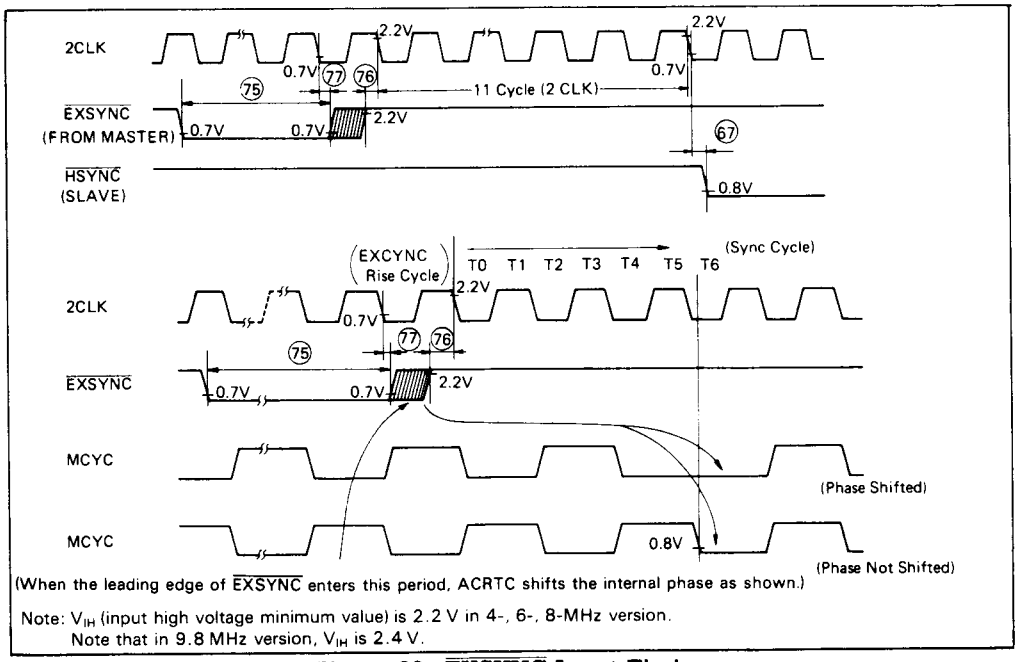


Figure 30. EXSYNC Input Timing

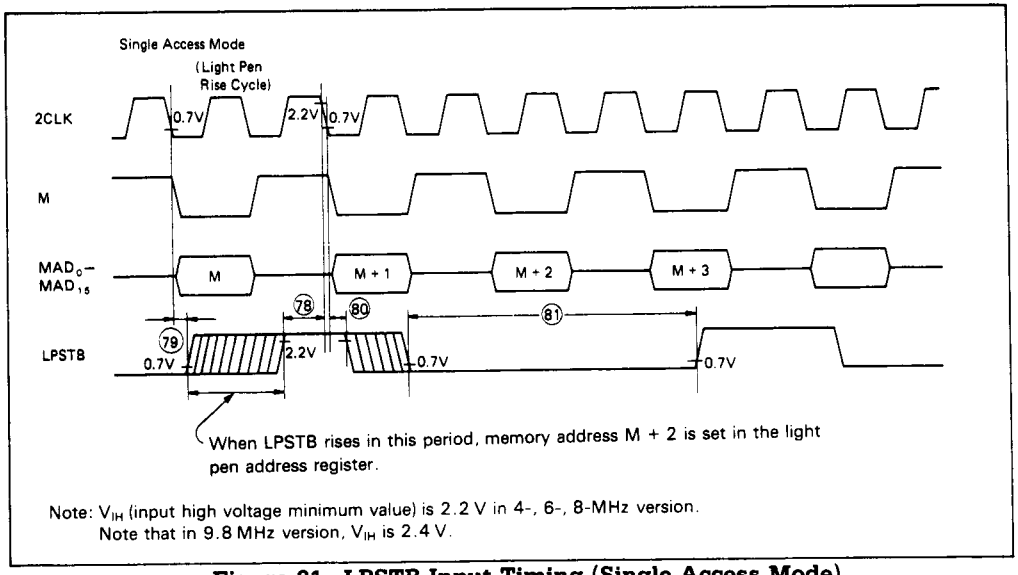
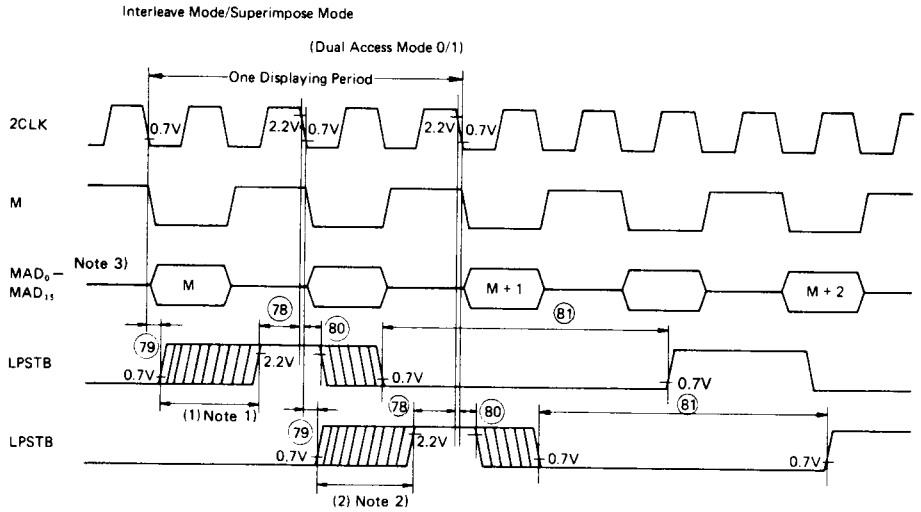


Figure 31. LPSTB Input Timing (Single Access Mode)



Note: 1. When LPSTB rises in the period (1), memory address M + 1 is set in the lightpen address register.
2. When LPSTB rises in the period (2), memory address M + 2 is set in the lightpen address register.
3. In the interleave mode, memory addresses M, M + 1, M + 2 denote the display address In the superimpose mode, memory addresses M, M + 1, M + 2 denote the display address of the background screen.

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 32. LPSTB Input Timing (Dual Access Mode)

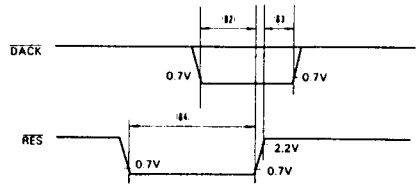
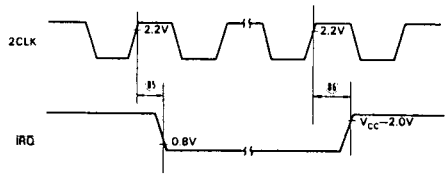
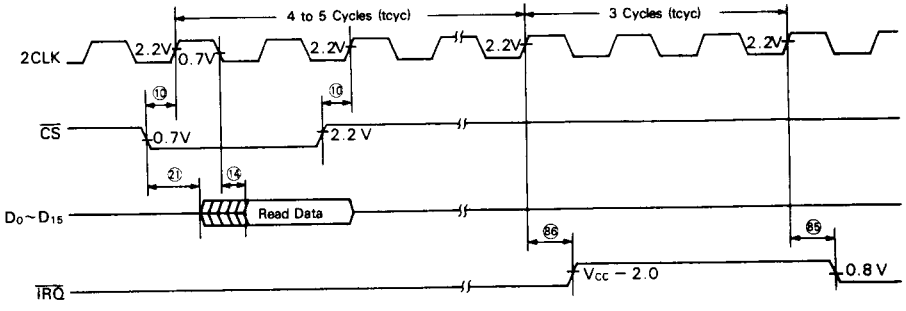


Figure 33. $\overline{RES}$ Input and $\overline{DACK}$ Input Timing (System Reset and 16-Bit/8-Bit Selection)



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 34. $\overline{IRQ}$ Output Timing



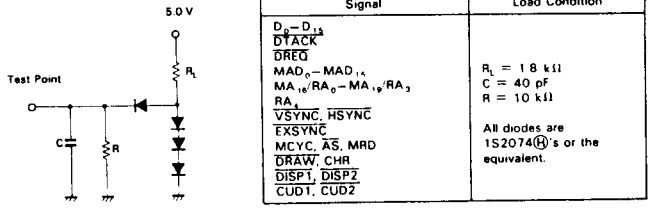
This is an $\overline{IRQ}$ output timing example. In this case, $\overline{IRQ}$ is generated by status flag RFF (Read FIFO Full).

When issuing read commands (RD) which transfer data exceeding Read FIFO space (8 words), the FIFO becomes full, and the command execution pauses (RFF: set, $\overline{IRQ}$: generated). By reading out 1-word data, spare occurs in the FIFO, and the ACRTC resets RFF flag and then negates $\overline{IRQ}$, while on the other hand the ACRTC resumes the internal operation (command execution) to fill the FIFO, and sets RFF flag and then asserts $\overline{IRQ}$ again.

In this case, the timing from $\overline{IRQ}$ negate to assert is 3 cycles (tcyc).

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



Signal	Load Condition
D_0-D_{15} $\overline{DTACK}$ $\overline{DREQ}$ MAD_0-MAD_{15} $MA_{16}/RA_0-MA_{19}/RA_3$ RA_4 $\overline{VSYNC}$, $\overline{HSYNC}$ $\overline{EXSYNC}$ MCYC, $\overline{AS}$, MRD $\overline{DRAW}$, CHR $\overline{DISP1}$, $\overline{DISP2}$ $\overline{CUD1}$, $\overline{CUD2}$	R_L = 1.8 kΩ C = 40 pF R = 10 kΩ All diodes are 1S2074Ⓗ's or the equivalent.

Figure 36. Test Load Circuit A

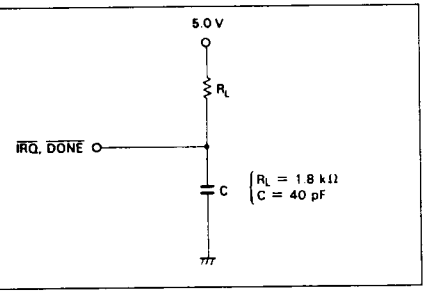


Figure 37. Test Load Circuit B