

CRT Controller (CRTC)

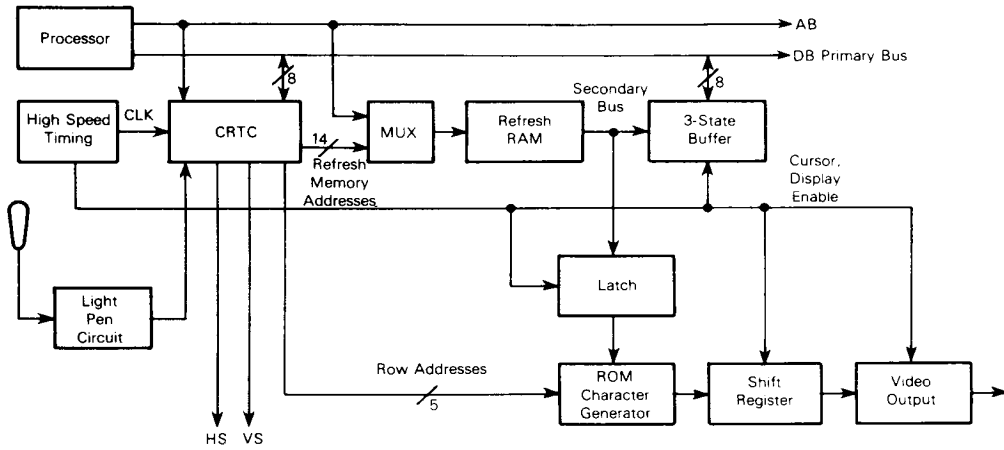
The MC6845 CRT controller performs the interface between an MPU and a raster-scan CRT display. It is intended for use in MPU-based controllers for CRT terminals in stand-alone or cluster configurations.

The CRTC is optimized for the hardware/software balance required for maximum flexibility. All keyboard functions, reads, writes, cursor movements, and editing are under processor control. The CRTC provides video timing and refresh memory addressing.

- Useful in Monochrome or Color CRT Applications
- Applications Include "Glass-Teletype," Smart, Programmable, Intelligent CRT Terminals; Video Games; Information Displays
- Alphanumeric, Semi-Graphic, and Full-Graphic Capability
- Fully Programmable Via Processor Data Bus. Timing May Be Generated for Almost Any Alphanumeric Screen Format, e.g., 80 × 24, 72 × 64, 132 × 20
- Single +5 V Supply
- M6800 Compatible Bus Interface
- TTL-Compatible Inputs and Outputs
- Start Address Register Provides Hardware Scroll (by Page or Character)
- Programmable Cursor Register Allows control of Cursor Format and Blink Rate
- Light Pen Register
- Refresh (Screen) Memory May be Multiplexed Between the CRTC and the MPU Thus Removing the Requirements for Line Buffers or External DMA Devices
- Programmable Interlace or Non-Interlace Scan Modes
- 14-Bit Refresh Address Allows Up to 16K of Refresh Memory for Use in Character or Semi-Graphic Displays
- 5-Bit Row Address Allows Up to 32 Scan-Line Character Blocks
- By Utilizing Both the Refresh Addresses and the Row Addresses, a 512K Address Space is Available for Use in Graphics Systems
- Refresh Addresses are Provided During Retrace, Allowing the CRTC to Provide Row Addresses to Refresh Dynamics RAMs
- Pin Compatible with the MC6835

This document contains information on a new product. Specifications and information herein are subject to change without notice.

FIGURE 1 — TYPICAL CRT CONTROLLER APPLICATION



MAXIMUM RATINGS

Rating	Symbol	Value	Unit
Supply Voltage	V _{CC}	-0.3 to +7.0	V
Input Voltage	V _{in}	-0.3 to +7.0	V
Operating Temperature Range MC6845, MC68A45, MC68B45 MC6845C, MC68A45C	T _A	T _L to T _H 0 to 70 -40 to +85	C
Storage Temperature Range	T _{stg}	-55 to +150	C

The device contains circuitry to protect the inputs against damage due to high static voltages or electric fields; however, it is advised that normal precautions be taken to avoid application of any voltage higher than maximum rated voltages to this high-impedance circuit. For proper operation it is recommended that V_{in} and V_{out} be constrained to the range V_{SS} ≤ V_{in} or V_{out} ≤ V_{CC}.

THERMAL CHARACTERISTICS

Characteristic	Symbol	Value	Unit
Thermal Resistance Plastic Package Cerdip Package	θ _{JA}	100 60	°C/W

RECOMMENDED OPERATING CONDITIONS

Characteristics	Symbol	Min	Typ	Max	Unit
Supply Voltage	V _{CC}	4.75	5.0	5.25	V
Input Low Voltage	V _{IL}	-0.3	-	0.8	V
Input High Voltage	V _{IH}	2.0	-	V _{CC}	V

POWER CONSIDERATIONS

The average chip-junction temperature, T_J , in °C can be obtained from:

$$T_J = T_A + (P_D \cdot \theta_{JA}) \quad (1)$$

where:

- T_A = Ambient Temperature, °C
- θ_{JA} = Package Thermal Resistance, Junction-to-Ambient, °C/W
- P_D = $P_{INT} + P_{PORT}$
- P_{INT} = $I_{CC} \times V_{CC}$, Watts — Chip Internal Power
- P_{PORT} = Port Power Dissipation, Watts — User Determined

For most applications $P_{PORT} < P_{INT}$ and can be neglected. P_{PORT} may become significant if the device is configured to drive Darlington bases or sink LED loads.

An approximate relationship between P_D and T_J (if P_{PORT} is neglected) is:

$$P_D = K \div (T_J - 273^\circ\text{C}) \quad (2)$$

Solving equations (1) and (2) for K gives:

$$K = P_D \cdot (T_A - 273^\circ\text{C}) - \theta_{JA} \cdot P_D^2 \quad (3)$$

where K is a constant pertaining to the particular part, K can be determined from equation (3) by measuring P_D (at equilibrium) for a known T_A . Using this value of K, the values of P_D and T_J can be obtained by solving equations (1) and (2) iteratively for any value of T_A .

DC ELECTRICAL CHARACTERISTICS ($V_{CC} = 5.0 \text{ Vdc} \pm 5\%$, $V_{SS} = 0$, $T_A = 0$ to 70°C unless otherwise noted, see Figures 2-4)

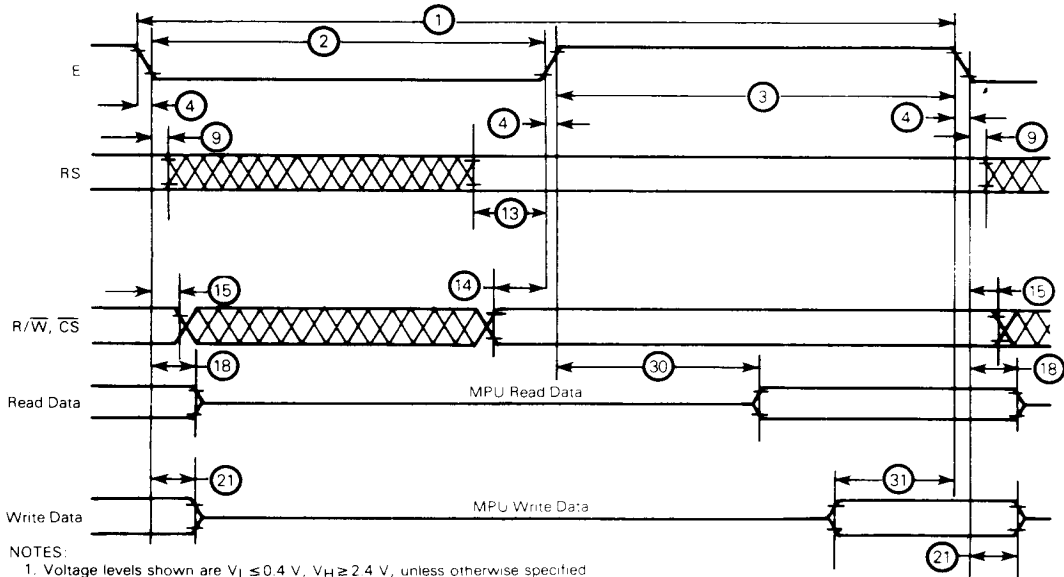
Characteristic	Symbol	Min	Typ	Max	Unit
Input High Voltage	V_{IH}	2.0	--	V_{CC}	V
Input Low Voltage	V_{IL}	-0.3	--	0.8	V
Input Leakage Current	I_{in}	--	0.1	2.5	μA
Hi-Z State Input Current ($V_{CC} = 5.25 \text{ V}$) ($V_{in} = 0.4$ to 2.4 V)	I_{TSI}	-10	--	10	μA
Output High Voltage ($I_{Load} = -205 \mu\text{A}$) ($I_{Load} = -100 \mu\text{A}$)	V_{OH}	2.4 2.4	3.0 3.0	-- --	V
Output Low Voltage ($I_{Load} = 1.6 \text{ mA}$)	V_{OL}	--	0.3	0.4	V
Internal Power Dissipation (Measured at $T_A = 0^\circ\text{C}$)	P_{INT}	--	600	750	mW
Input Capacitance	C_{in}	--	--	12.5 10	pF
Output Capacitance	C_{out}	--	--	10	pF

BUS TIMING CHARACTERISTICS (See Notes 1 and 2) (Reference Figures 2 and 3)

Ident. Number	Characteristic	Symbol	MC6845		MC68A45		MC68B45		Unit
			Min	Max	Min	Max	Min	Max	
1	Cycle Time	t_{cyc}	1.0	10**	0.67	10	0.5	10**	μ s
2	Pulse Width, E Low	PWEL	430	-	280	-	210	-	ns
3	Pulse Width, E High	PWEH	450	-	280	-	220	-	ns
4	Clock Rise and Fall Time	t_r, t_f	-	25	-	25	-	20	ns
9	Address Hold Time (RS)	t_{AH}	10	-	10	-	10	-	ns
13	RS Setup Time Before E	t_{AS}	80	-	60	-	40	-	ns
14	R/ \bar{W} and \bar{CS} Setup Time Before E	t_{CS}	80	-	60	-	40	-	ns
15	R/ \bar{W} and \bar{CS} Hold Time	t_{CH}	10	-	10	-	10	-	ns
18	Read Data Hold Time	t_{DHR}	20	50*	20	50*	20	50*	ns
21	Write Data Hold Time	t_{DHW}	10	-	10	-	10	-	ns
30	Peripheral Output Data Delay Time	t_{DDR}	-	290	-	180	0	150	ns
31	Peripheral Input Data Setup Time	t_{DSW}	165	-	80	-	60	-	ns

- * The data bus output buffers are no longer sourcing or sinking current by t_{DHR} maximum; high impedance.
- ** The E clock may be low for extended periods provided the CLK input is active.

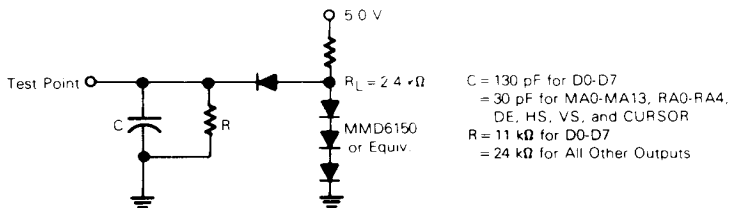
FIGURE 2 — MC6845 BUS TIMING



NOTES:

1. Voltage levels shown are $V_L \leq 0.4$ V, $V_H \geq 2.4$ V, unless otherwise specified.
2. Measurement points shown are 0.8 V and 2.0 V, unless otherwise specified.

FIGURE 3 — BUS TIMING TEST LOAD



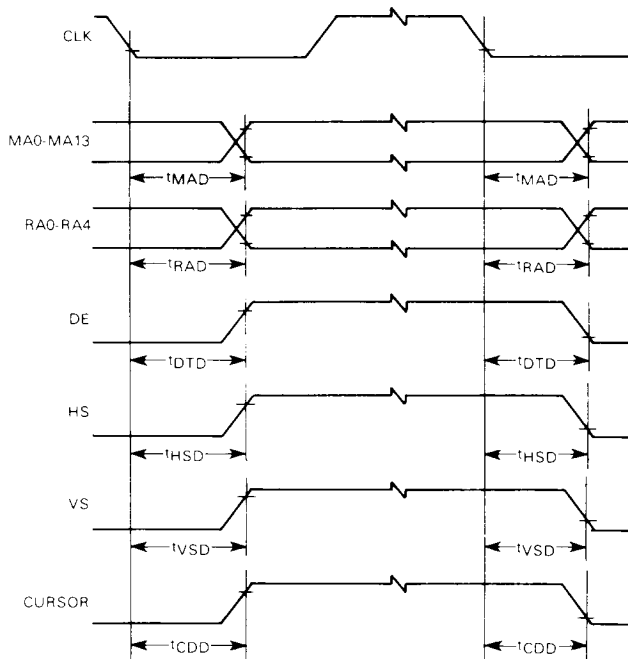
CRTC TIMING CHARACTERISTICS (Reference Figures 4 and 5)

Characteristic	Symbol	Min	Max	Unit
Minimum Clock Pulse Width, Low	P _{WCL}	150	—	ns
Minimum Clock Pulse Width, High	P _{WCH}	150	—	ns
Clock Frequency	f _c	—	3.0	MHz
Rise and Fall Time for Clock Input	t _{cr} , t _{cf}	—	20	ns
Memory Address Delay Time	t _{MAD}	—	160	ns
Raster Address Delay Time	t _{RAD}	—	160	ns
Display Timing Delay Time	t _{DTD}	—	250	ns
Horizontal Sync Delay Time	t _{HSD}	—	250	ns
Vertical Sync Delay Time	t _{VSD}	—	250	ns
Cursor Display Timing Delay Time	t _{CDD}	—	250	ns
Light Pen Strobe Minimum Pulse Width	PW _{LPH}	80	—	ns
Light Pen Strobe Disable Time	t _{LPD1}	—	80	ns
	t _{LPD2}	—	10	ns

NOTE: The light pen strobe must fall to low level before VS pulse rises

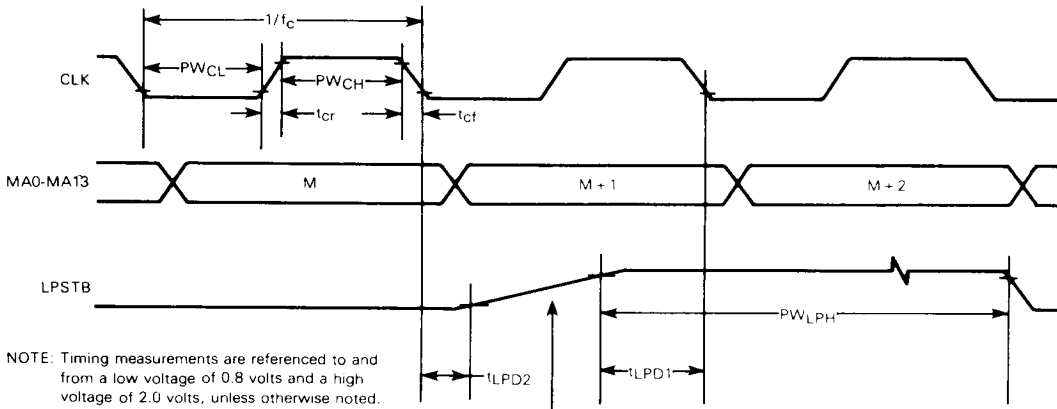
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FIGURE 4 — CRTC TIMING CHART



NOTE: Timing measurements are referenced to and from a low voltage of 0.8 volts and a high voltage of 2.0 volts unless otherwise noted

FIGURE 5 — CRTC-CLK, MA0-MA13, AND LPSTB TIMING DIAGRAM



When the CRTC detects the rising edge of LPSTB in this period, the CRTC sets the Refresh Memory Address 'M + 2' into the LIGHT PEN REGISTER.
 tLPD1, tLPD2: Period of uncertainty for the Refresh Memory Address



CRTC INTERFACE SYSTEM DESCRIPTION

The CRT controller generates the signals necessary to interface a digital system to a raster scan CRT display. In this type of display, an electron beam starts in the upper left hand corner, moves quickly across the screen and returns. This action is called a horizontal scan. After each horizontal scan the beam is incrementally moved down in the vertical direction until it has reached the bottom. At this point one frame has been displayed, as the beam has made many horizontal scans and one vertical scan.

Two types of raster scanning are used in CRTs, interlace and non-interlace, shown in Figures 6 and 7. Non-interlace scanning consists of one field per frame. The scan lines in Figure 6 are shown as solid lines and the retrace patterns are indicated by the dotted lines. Increasing the number of frames per second will decrease the flicker. Ordinarily, either a 50 or 60 frame per second refresh rate is used to minimize beating between the CRT and the power line frequency. This prevents the displayed data from weaving.

Interlace scanning is used in broadcast TV and on data monitors where high density or high resolution data must be displayed. Two fields, or vertical scans are made down the screen for each single picture or frame. The first field (even field) starts in the upper left hand corner; the second (odd field) in the upper center. Both fields overlap as shown in Figure 7, thus interlacing the two fields into a single frame.

In order to display the characters on the CRT screen the frames must be continually repeated. The data to be displayed is stored in the refresh (screen) memory by the MPU controlling the data processing system. The data is usually written in ASCII code, so it cannot be directly displayed as characters. A character generator ROM is typically used to convert the ASCII codes into the "dot" pattern for every character.

The most common method of generating characters is to create a matrix of dots "x" dots (columns) wide and "y" dots (rows) high. Each character is created by selectively filling in

FIGURE 6 — RASTER SCAN SYSTEM (NON-INTERLACE)

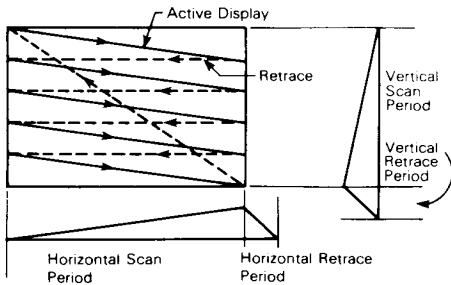
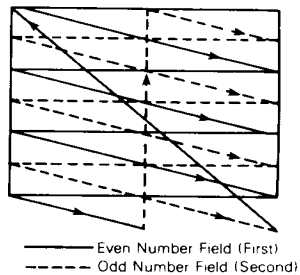


FIGURE 7 — RASTER SCAN SYSTEM (INTERLACE)



the dots. As "x" and "y" get larger a more detailed character may be created. Two common dot matrices are 5×7 and 7×9 . Many variations of these standards will allow Chinese, Japanese, or Arabic letters instead of English. Since characters require some space between them, a character block larger than the character is typically used, as shown in Figure 8. The figure also shows the corresponding timing and levels for a video signal that would generate the characters.

Referring to Figure 1, the CRT controller generates the refresh addresses (MA0-MA13), row addresses (RA0-RA4), and the video timing (vertical sync — VS, horizontal sync — HS, and display enable — DE). Other functions include an internal cursor register which generates a cursor output when its contents compare to the current refresh address. A light pen strobe input signal allows capture of the refresh address in an internal light pen register.

All timing in the CRT is derived from the CLK input. In alphanumeric terminals, this signal is the character rate. The video rate or "dot" clock is externally divided by high-speed logic (TTL) to generate the CLK input. The high-speed logic must also generate the timing and control signals necessary for the shift register, latch, and MUX control.

The processor communicates with the CRTC through an 8-bit data bus by reading or writing into the 19 registers.

The refresh memory address is multiplexed between the processor and the CRTC. Data appears on a secondary bus separate from the processor's bus. The secondary data bus concept in no way precludes using the refresh RAM for other purposes. It looks like any other RAM to the processor. A number of approaches are possible for solving contentions for the refresh memory:

1. Processor always gets priority. (Generally, "hash:" occurs as MPU and CRTC clocks are not synchronized.)
2. Processor gets priority access anytime, but can be synchronized by an interrupt to perform accesses only during horizontal and vertical retrace times.
3. Synchronize the processor with memory wait cycles (states).
4. Synchronize the processor to the character rate as shown in Figure 9. The M6800 processor family works very well in this configuration as constant cycle lengths are present. This method provides no overhead for the processor as there is never a contention for a memory access. All accesses are transparent.

FIGURE 8 — CHARACTER DISPLAY ON THE SCREEN AND VIDEO SIGNAL

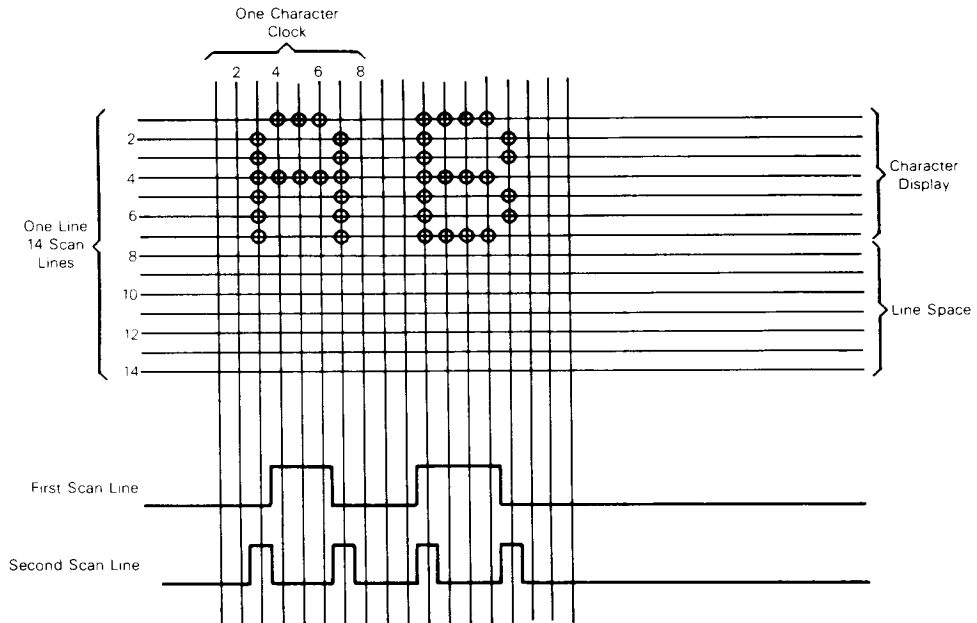
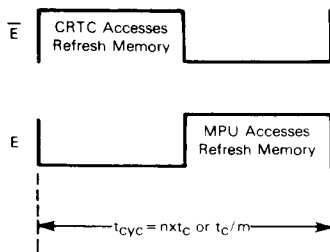


FIGURE 9 — TRANSPARENT REFRESH MEMORY
CONFIGURATION TIMING USING M6800 FAMILY MPU



Where: m, n are integers; t_c is character period

PIN DESCRIPTION

PROCESSOR INTERFACE

The CRTC interfaces to a processor bus on the bidirectional data bus (D0-D7) using \overline{CS} , RS, E, and R/\overline{W} for control signals.

Data Bus (D0-D7) — The bidirectional data lines (D0-D7) allow data transfers between the internal CRTC register file and the processor. Data bus output drivers are in the high-impedance state until the processor performs a CRTC read operation.

Enable (E) — The enable signal is a high-impedance TTL/MOS compatible input which enables the data bus input/output buffers and clocks data to and from the CRTC. This signal is usually derived from the processor clock. The high-to-low transition is the active edge.

Chip Select (\overline{CS}) — The \overline{CS} line is a high-impedance TTL/MOS compatible input which selects the CRTC, when low, to read or write to the internal register file. This signal should only be active when there is a valid stable address being decoded from the processor.

Register Select (RS) — The RS line is a high-impedance TTL/MOS compatible input which selects either the address register (RS = 0) or one of the data register (RS = 1) or the internal register file.

Read/Write (R/\overline{W}) — The R/\overline{W} line is a high-impedance TTL/MOS compatible input which determines whether the internal register file gets written or read. A write is defined as a low level.

CRT CONTROL

The CRTC provides horizontal sync (HS), vertical sync (VS), and display enable (DE) signals.

NOTE

Care should be exercised when interfacing to CRT monitors, as many monitors claiming to be "TTL compatible" have transistor input circuits which require the CRTC or TTL devices buffering signals from the CRTC/video circuits to exceed the maximum-rated drive currents.

Vertical Sync (VS) and Horizontal Sync (HS) — These TTL-compatible outputs are active high signals which drive the monitor directly or are fed to the video processing circuitry to generate a composite video signal. The VS signal determines the vertical position of the displayed text while the HS signal determines the horizontal position of the displayed text.

Display Enable (DE) — This TTL-compatible output is an active high signal which indicates the CRTC is providing addressing in the active display area.

REFRESH MEMORY/CHARACTER GENERATOR ADDRESSING

The CRTC provides memory addresses (MA0-MA13) to scan the refresh RAM. Row addresses (RA0-RA4) are also provided for use with character generator ROMs in a graphics system, both the memory addresses and the row addresses would be used to scan the refresh RAM. Both the memory addresses and the row addresses continue to run during vertical retrace thus allowing the CRTC to provide the refresh addresses required to refresh dynamic RAMs.

Refresh Memory Addresses (MA0-MA13) — These 14 outputs are used to refresh the CRT screen with pages of data located within a 16K block of refresh memory. These outputs are capable of driving one standard TTL load and 30 pF.

Row Addresses (RA0-RA4) — These five outputs from the internal row address counter are used to address the character generator ROM. These outputs are capable of driving one standard TTL load and 30 pF.

OTHER PINS

Cursor — This TTL-compatible output indicates a valid cursor address to external video processing logic. It is an active high signal.

Clock (CLK) — The CLK is a TTL/MOS-compatible input used to synchronize all CRT functions except for the processor interface. An external dot counter is used to derive this signal which is usually the character rate in an alphanumeric CRT. The active transition is high-to-low.

Light Pen Strobe (LPSTB) — A low-to-high transition on this high-impedance TTL/MOS-compatible input latches the current Refresh Address in the light pen register. The latching of the refresh address is internally synchronized to the character clock (CLK).

VCC and VSS — These inputs supply +5 Vdc \pm 5% to the CRTC.

RESET — The RESET input is used to reset the CRTC. A low level on the RESET input forces the CRTC into the following state:

- All counters in the CRTC are cleared and the device stops the display operation.
- All the outputs are driven low.

NOTE

The horizontal sync output is not defined until after R2 is programmed.

- The control registers of the CRTC are not affected and remain unchanged.

Functionality of RESET differs from that of other M6800 parts in the following functions:

- The RESET input and the LPSTB input are encoded as shown in Table 1.

TABLE 1 — CRTC OPERATING MODE

RESET	LPSTB	Operating Mode
0	0	Reset
0	1	Test Mode
1	0	Normal Mode
1	1	Normal Mode

The test mode configures the memory addresses as two independent 7-bit counters to minimize test time.

- After RESET has gone low and (LPSTB=0), MA0-MA13 and RA0-RA4 will be driven low on the falling edge of CLK. RESET must remain low for at least one cycle of the character clock (CLK).
- The CRTC resumes the display operation immediately after the release of RESET. DE and the CURSOR are not active until after the first frame has been displayed.

CRTC DESCRIPTION

The CRTC consists of programmable horizontal and vertical timing generators, programmable linear address register, programmable cursor logic, light pen capture register, and control circuitry for interface to a processor bus. A block diagram of the CRTC is shown in Figure 10.

All CRTC timing is derived from the CLK, usually the output of an external dot rate counter. Coincidence (CO) circuits continuously compare counter contents to the contents of the programmable register file, R0-R17. For horizontal timing generation, comparisons result in: 1) horizontal sync pulse (HS) of a frequency, position, and width determined by the registers; 2) horizontal display signal of a frequency, position, and duration determined by the registers.

The horizontal counter produces H clock which drives the scan line counter and vertical control. The contents of the raster counter are continuously compared to the maximum scan line address register. A coincidence resets the raster counter and clocks the vertical counter.

Comparisons of vertical counter contents and vertical registers result in: 1) vertical sync pulse (VS) of a frequency and position determined by the registers; 2) vertical display of a frequency and position determined by the registers.

The vertical control logic has other functions.

- Generate row selects, RA0-RA4, from the raster count for the corresponding interlace or non-interlace modes.
- Extend the number of scan lines in the vertical total by the amount programmed in the vertical total adjust register.

The linear address generator is driven by the CLK and locates the relative positions of characters in memory with their positions on the screen. Fourteen lines, MA0-MA13, are available for addressing up to four pages of 4K characters, eight pages of 2K characters, etc. Using the start address register, hardware scrolling through 16K characters is possible. The linear address generator repeats the same sequence of addresses for each scan line of a character row.

The cursor logic determines the cursor location, size, and blink rate on the screen. All are programmable.

The light pen strobe going high causes the current contents of the address counter to be latched in the light pen

register. The contents of the light pen register are subsequently read by the processor.

Internal CRTC registers are programmed by the processor through the data bus, D0-D7, and the control signals — R/W, CS, RS, and E.

REGISTER FILE DESCRIPTIONS

The nineteen registers of the CRTC may be accessed through the data bus. Only two memory locations are required as one location is used as a pointer to address one of the remaining eighteen registers. These eighteen registers control horizontal timing, vertical timing, interlace operation, row address operation, and define the cursor, cursor address, start address, and light pen register. The register addresses and sizes are shown in Table 2.

ADDRESS REGISTER

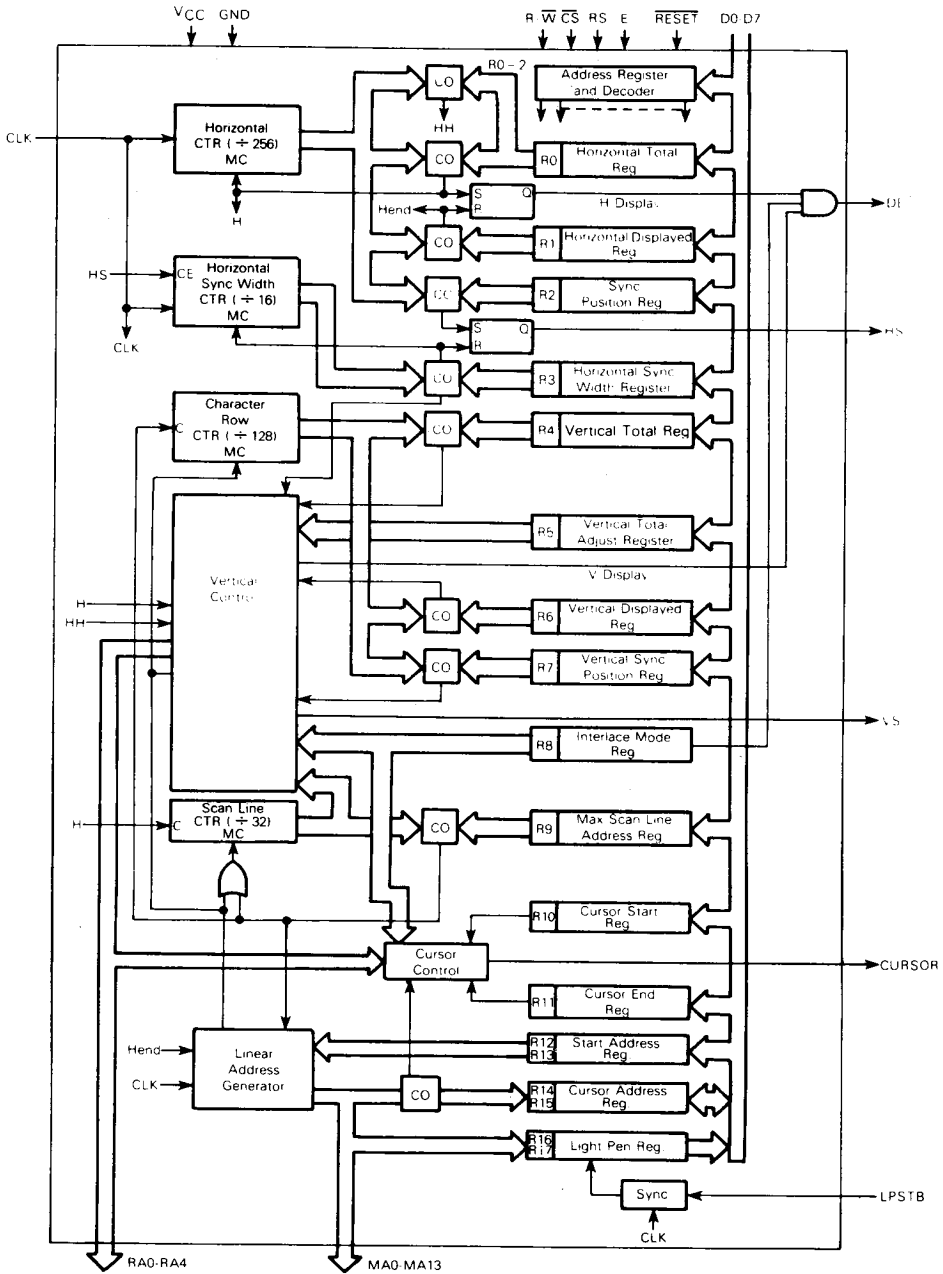
The address register is a 5-bit write-only register used as an "indirect" or "pointer" register. It contains the address of one of the other eighteen registers. When both RS and CS are low, the address register is selected. When CS is low and RS is high, the register pointed to by the address register is selected.

TIMING REGISTERS R0-R9

Figure 11 shows the visible display area of a typical CRT monitor giving the point of reference for horizontal registers as the left-most displayed character position. Horizontal registers are programmed in character clock time units with respect to the reference as shown in Figure 12. The point of reference for the vertical registers is the top character position displayed. Vertical registers are programmed in scan line times with respect to the reference as shown in Figure 13.

Horizontal Total Register (R0) — This 8-bit write-only register determines the horizontal sync (HS) frequency by defining the HS period in character times. It is the total of the displayed characters plus the non-displayed character times (retrace) minus one.

FIGURE 10 — CRTC BLOCK DIAGRAM



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Horizontal Displayed Register (R1) — This 8-bit write-only register determines the number of displayed characters per line. Any 8-bit number may be programmed as long as the contents of R0 are greater than the contents of R1.

Horizontal Sync Position Register (R2) — This 8-bit write-only register controls the HS position. The horizontal sync position defines the horizontal sync delay (front porch) and the horizontal scan delay (back porch). When the programmed value of this register is increased, the display on the CRT screen is shifted to the left. When the programmed value is decreased the display is shifted to the right. Any 8-bit number may be programmed as long as the sum of the contents of R2 and R3 are less than the contents of R0. R2 must be greater than R1.

Sync Width Register (R3) — This 8-bit write-only register determines the width of the horizontal sync (HS) pulse. The vertical sync pulse width is fixed at 16 scan-line times.

The HS pulse width may be programmed from 1-to-15 character clock periods thus allowing compatibility with the HS pulse width specifications of many different monitors. If zero is written into this register then no HS is provided.

Horizontal Timing Summary (Figure 12) — The difference between R0 and R1 is the horizontal blanking interval. This interval in the horizontal scan period allows the beam to return (retrace) to the left side of the screen. The retrace time is determined by the monitor's horizontal scan components. Retrace time is less than the horizontal blanking interval. A good rule of thumb is to make the horizontal blanking about 20% of the total horizontal scanning period for a CRT. In inexpensive TV receivers, the beam overscans the display screen so that aging of parts does not result in underscanning. Because of this, the retrace time should be about one third the horizontal scanning period. The horizontal sync delay, HS pulse width, and horizontal scan delay are typically programmed with a 1:2:2 ratio.

Vertical Total Register (R4) and Vertical Total Adjust Register (R5) — The frequency of VS is determined by both R4 and R5. The calculated number of character row times is usually an integer plus a fraction to get exactly a 50 or 60 Hz vertical refresh rate. The integer number of character row times minus one is programmed in the 7-bit write-only vertical total register (R4). The fraction of character line times is programmed in the 5-bit write-only vertical total adjust register (R5) as the number of scan lines required.

Vertical Displayed Register (R6) — This 7-bit write-only register specifies the number of displayed character rows on the CRT screen, and is programmed in character row times. Any number smaller than the contents of R4 may be programmed into R6.

Vertical Sync Position (R7) — This 7-bit write-only register controls the position of vertical sync with respect to the reference. It is programmed in character row times. When the programmed value of this register is increased, the display position of the CRT screen is shifted up. When the programmed value is decreased the display position is shifted down. Any number equal to or less than the vertical total (R4) and greater than or equal to the vertical displayed (R6) may be used.

Interlace Mode and Skew Register (R8) — The MC6845 only allows control of the interlace modes as programmed by the low order two bits of this write-only register. Table 3 shows the interlace modes available to the user. These modes are selected using the two low order bits of this 6-bit write-only register.

TABLE 3 — INTERLACE MODE REGISTER

Bit 1	Bit 0	Mode
0	0	Normal Sync Mode (Non-Interlace)
1	0	
0	1	Interlace Sync Mode
1	1	Interlace Sync and Video Mode

In the normal sync mode (non-interlace) only one field is available as shown in Figures 6 and 14a. Each scan line is refreshed at the VS frequency (e.g., 50 or 60 Hz).

Two interlace modes are available as shown in Figures 7, 14b, and 14c. The frame time is divided between even and odd alternating fields. The horizontal and vertical timing relationship (VS delayed by one half scan line time) results in the displacement of scan lines in the odd field with respect to the even field.

In the interlace sync mode the same information is painted in both fields as shown in Figure 14b. This is a useful mode for filling in a character to enhance readability.

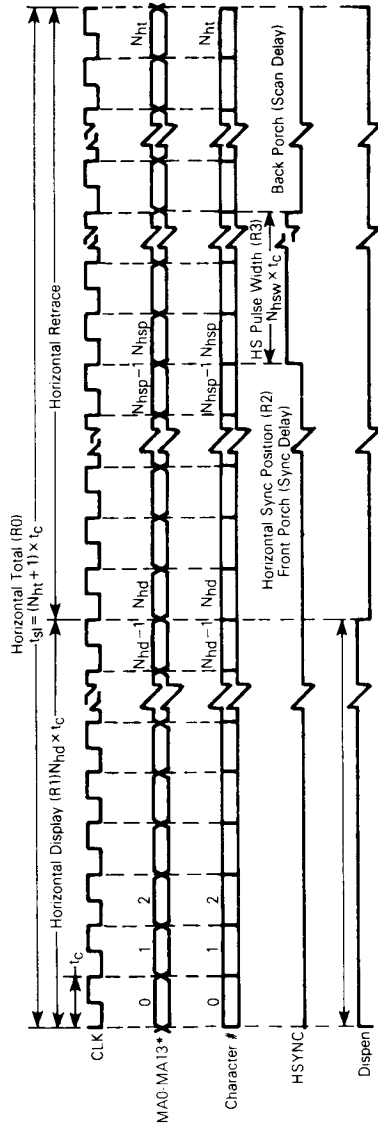
In the interlace sync and video mode, shown in Figure 14c, alternating lines of the character are displayed in the even field and the odd field. This effectively doubles the given bandwidth of the CRT monitor.

Care must be taken when using either interlace mode to avoid an apparent flicker effect. This flicker effect is due to the doubling of the refresh time for all scan lines since each field is displayed alternately and may be minimized with proper monitor design (e.g., longer persistence phosphors).

In addition, there are restrictions on the programming of the CRT registers for interlace operation:

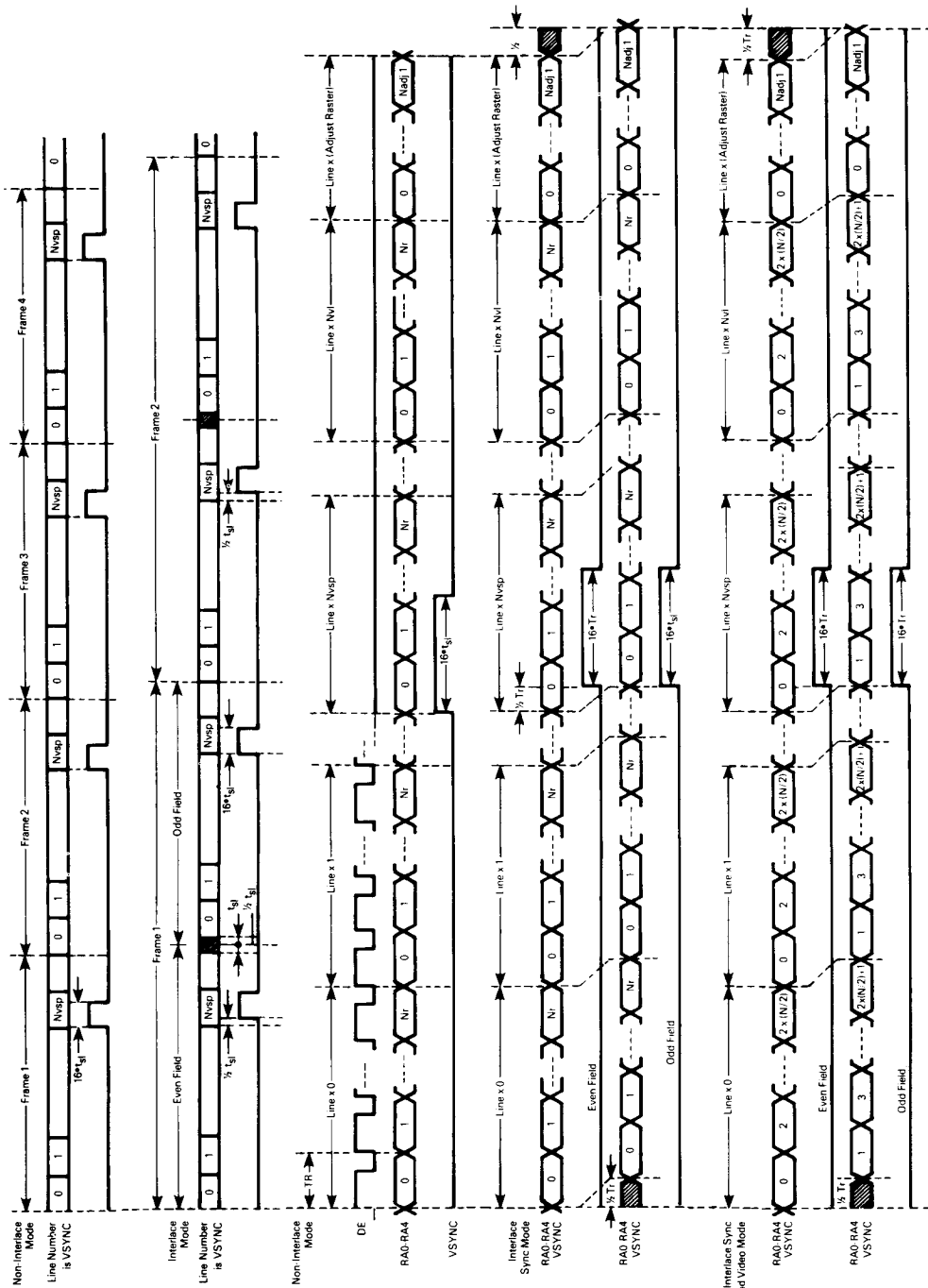
1. The horizontal total register value, R0, must be odd (i.e., an even number of character times).
2. For interlace sync and video mode only, the maximum scan-line address, R9, must be odd (i.e., an even number of scan lines).
3. For interlace sync and video mode only, the number (Nvd) programmed into the vertical display register (R6) must be one half the actual number required. The even numbered scan lines are displayed in the even field and the odd numbered scan lines are displayed in the odd field.
4. For interlace sync and video mode only, the cursor start register (R10) and cursor end register (R11) must both be even or both odd depending on which field the cursor is to be displayed in. A full block cursor will be displayed in both the even and the odd field when the cursor end register (R11) is programmed to a value greater than the value in the maximum scan line address register (R9).

FIGURE 12 — CRTC HORIZONTAL TIMING



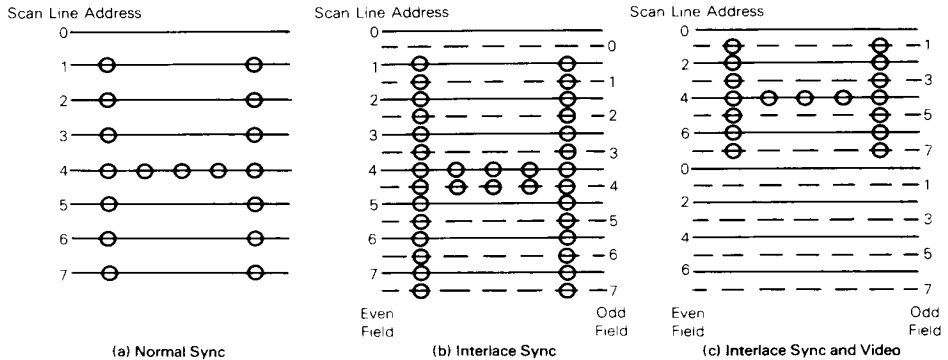
* Timing is shown for first displayed scan row only. See chart in Figure 15 for other rows. The initial MA is determined by the contents of start address register, R12/R13. Timing is shown for R12/R13=0.
NOTE: Timing values are described in Table 5.

FIGURE 13 — CRTC VERTICAL TIMING



NOTES: 1. In interface sync and video mode, maximum raster address (Nr) shall be odd.
 2. In interface mode, Nnt shall be odd.

FIGURE 14 — INTERLACE CONTROL



Maximum Scan Line Address Register (R9) — This 5-bit write-only register determines the number of scan lines per character row including the spacing; thus, controlling operation of the row address counter. The programmed value is a maximum address and is one less than the number of scan lines.

CURSOR CONTROL

Cursor Start Register (R10) and Cursor End Register (R11) — These registers allow a cursor of up to 32 scan lines in height to be placed on any scan line of the character block as shown in Figure 15. R10 is a 7-bit write-only register used to define the start scan line and the cursor blink rate. Bits 5 and 6 of the cursor start address register control the cursor operation as shown in Table 4. Non-display, display, and two blink modes (16 times or 32 times the field period) are available. R11 is a 5-bit write-only register which defines the last scan line of the cursor.

TABLE 4 — CURSOR START REGISTER

Bit 6	Bit 5	Cursor Display Mode
0	0	Non-Blink
0	1	Cursor Non-Display
1	0	Blink, 1/16 Field Rate
1	1	Blink, 1/32 Field Rate

Example of cursor display mode

When an external blink feature on characters is required, it may be necessary to perform cursor blink externally so that both blink rates are synchronized. Note that an invert/non-

invert cursor is easily implemented by programming the CRTC for a blinking cursor and externally inverting the video signal with an exclusive-OR gate.

Cursor Register (R14-H, R15-L) — This 14-bit read/write register pair is programmed to position the cursor anywhere in the refresh RAM area; thus, allowing hardware paging and scrolling through memory without loss of the original cursor position. It consists of an 8-bit low order (MA0-MA7) register and a 6-bit high order (MA8-MA13) register.

OTHER REGISTERS

Start Address Register (R12-H, R13-L) — This 14-bit write-only register pair controls the first address output by the CRTC after vertical blanking. It consists of an 8-bit low order (MA0-MA7) register and a 6-bit high order (MA8-MA13) register. The start address register determines which portion of the refresh RAM is displayed on the CRT screen. Hardware scrolling by character or page may be accomplished by modifying the contents of this register.

Light Pen Register (R16-H, R17-L) — This 14-bit read-only register pair captures the refresh address output by the CRTC on the positive edge of a pulse input to the LPSTB pin. It consists of an 8-bit low order (MA0-MA7) register and a 6-bit high order (MA8-MA13) register. Since the light pen pulse is asynchronous with respect to refresh address timing an internal synchronizer is designed into the CRTC. Due to delays (Figure 5) in this circuit, the value of R16 and R17 will need to be corrected in software. Figure 16 shows an interrupt driven approach although a polling routine could be used.

FIGURE 15 — CURSOR CONTROL

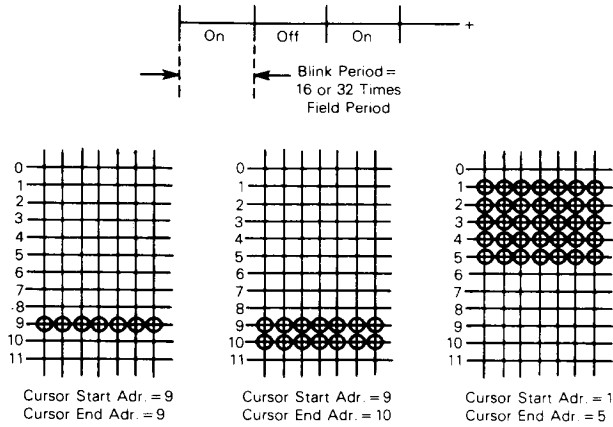
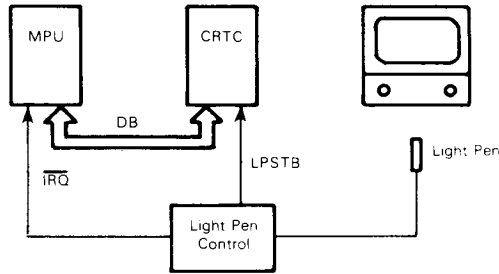


FIGURE 16 — INTERFACING OF LIGHT PEN



OPERATION OF THE CRTC

TIMING CHART OF THE CRT INTERFACE SIGNALS

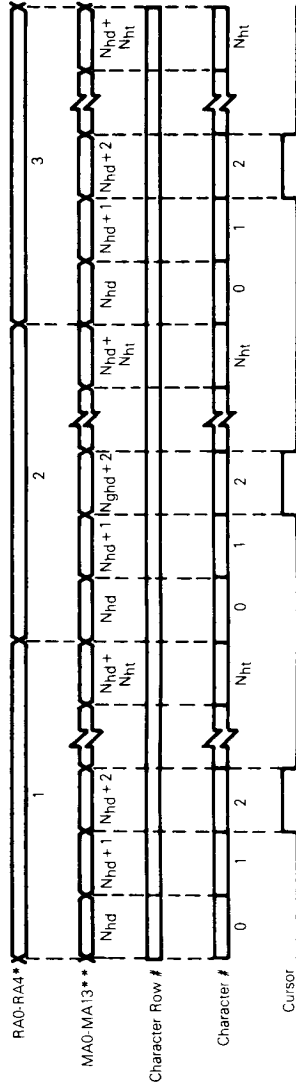
Timing charts of CRT interface signals are illustrated in this section. When values listed in Table 5 are programmed into CRTC control registers, the device provides the outputs as shown in the timing diagrams (Figures 12, 13, 17, and 18). The screen format is shown in Figure 11 which illustrates the relation between refresh memory address (MA0-MA13), raster address (RA0-RA4), and the position on the screen. In this example, the start address is assumed to be zero.

TABLE 5 — VALUES PROGRAMMED INTO CRTC REGISTERS

Reg. #	Register Name	Value	Programmed Value
R0	H. Total	N _{ht} + 1	N _{ht}
R1	H. Displayed	N _{hd}	N _{hd}
R2	H. Sync Position	N _{hsp}	N _{hsp}
R3	H. Sync Width	N _{hsw}	N _{hsw}
R4	V. Total	N _{vt} + 1	N _{vt}
R5	V. Scan Line Adjust	N _{adj}	N _{adj}
R6	V. Displayed	N _{vd}	N _{vd}
R7	V. Sync Position	N _{vsp}	N _{vsp}
R8	Interlace Mode		
R9	Max. Scan Line Address	N _{sl}	N _{sl}



FIGURE 17 -- CURSOR TIMING



* Timing is shown for non-interface and interface sync modes.

Example shown has cursor programmed as:

Cursor Register = Nhd + 2

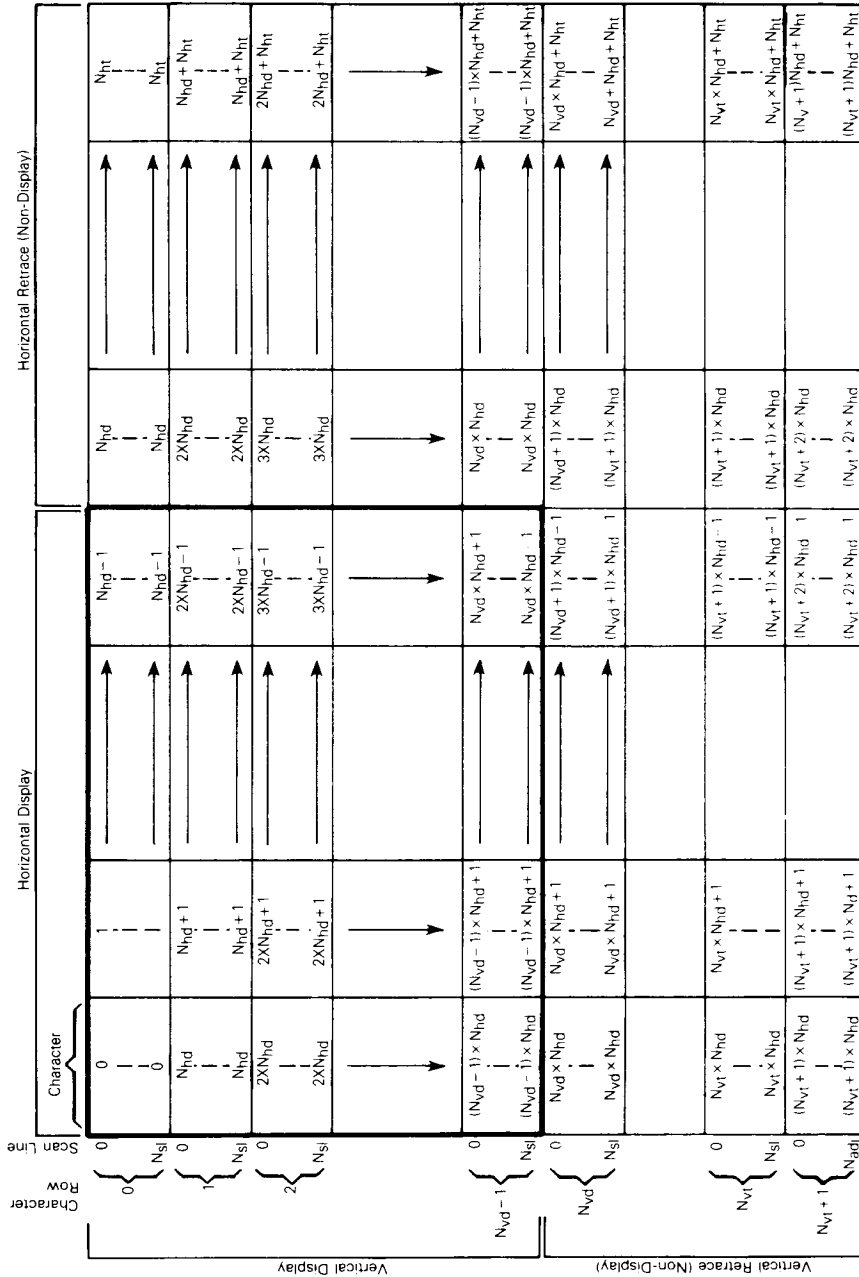
Cursor Start = 1

Cursor End = 3

** The initial MA is determined by the contents of start address register, R12/R13. Timing is shown for R12/R13 = 0.

NOTE 1: Timing values are described in Table 5.

FIGURE 18 — REFRESH MEMORY ADDRESSING (MA0-MA13) STAGE CHART



NOTE 1: The initial MA is determined by the contents of start address register, R12/R13. Timing is shown for R12/R13 = 0. Only non-interface and interface sync pulses are shown.



DETERMINING REGISTER CONTENTS

Some of the register contents are determined rather easily. They are:

Register	Name	Contents
R8	Interlace Mode Register	See Table 3
R10	Cursor Start	See Figure 15 and Table 4
R11	Cursor End	See Figure 15
R12	Start Address (H)	User programs first memory location to be displayed
R13	Start Address (L)	User programs desired cursor location
R14	Cursor (H)	Can be loaded via light-pen strobe only
R15	Cursor (L)	
R16	Light Pen (H)	
R17	Light Pen (L)	

The remaining register contents must be determined from some basic data related to the CRT monitor and from the user-desired display format. The CRTC reference sheet (see Figure 19) gives a set of formulas for calculating the register contents as well as other useful characteristics of the display. This type of data is summarized under basic parameters in Figures 20 and 21; most or all of this data must be supplied by the user before he can determine the contents for registers R0-R7 and R9. All variables B₁-B₁₀ are equal to basic parameters 1 through 10.

FIGURE 19 — CRTC REFERENCE SHEET

Register Function		Intermediate Calculations			Register Calculations	
		Symbol	Description	Calculation	Register	Calculation
R0	Horizontal Total					
R1	Horizontal Displayed	f'	Dot frequency (1st approx.)	$\frac{B_5 \cdot (B_7 + B_9)}{(17B_1) - B_3}$	R0	$\frac{f'}{B_1 \cdot (B_7 + B_9)} - 1$
R2	Horizontal Sync Position					
R3	Horizontal Sync Width	t _c	Character Time	$\frac{1}{((R0) + 1) \cdot B_1}$	R1	B ₅
R4	Vertical Total	f	Dot frequency	$\frac{B_7 + B_9}{t_c}$		
R5	Vertical Total Adjust				R2	$\frac{(R1) + (R3)}{2}$
R6	Vertical Displayed	t _{sl}	Scan line time	$((R0) + 1) \cdot t_c$	R3	$\frac{(R0) - (R1)}{3}$
R7	Vertical Sync Position	n	Total # of scan lines	$\frac{1}{B_2 \cdot t_{sl}}$		
R8	Interlace Mode				R4	N - 1
R9	Maximum Scan Line Address	N	Integer and	$\frac{n = N + R}{B_8 + B_{10}} \quad \frac{R}{B_8 + B_{10}}$	R5	R
R10	Cursor Start	R	Integer remainder			
R11	Cursor End				R6	B ₆
R12	Start Address (H)	t _{cr}	Character row time	$(B_8 + B_{10}) \cdot t_{sl}$	R7	$((R4) + 1) - \frac{16 - (R5) \geq (R7) \geq (R6)}{B_8 + B_{10}}$
R13	Start Address (L)	t _{hr}	Horizontal retrace time	$\leq \frac{((R0) + 1 - B_5) \cdot (B_7 + B_9)}{f}$		
R14	Cursor (H)				R9	$(B_8 + B_{10}) - 1$
R15	Cursor (L)	t _{vr}	Vertical retrace time	$\leq \frac{B_1}{B_2} - B_6(B_8 + B_{10}) \cdot t_{sl}$		
R16	Light Pen (H)					
R17	Light Pen (L)					



FIGURE 21 — CRT WORKSHEET EXAMPLE CALCULATION (80 × 24)

Basic Parameters (B1-B10)		Intermediate Calculations			Register Calculations		
	Symbol		Value	Register	Decimal	Hex	
1. Horizontal frequency	= <u>18,600</u> (1) f'	$\frac{80 \cdot (7+2)}{18600 - 11 \times 10^{-6}}$	<u>16.836 × 10⁶</u>	(2) R0	$\frac{16.836 \times 10^6}{(18,600)(9)} - 1$	<u>100</u> <u>64</u>	
2. Vertical frequency	= <u>60</u> (6) t _c	$\frac{1}{(100+1) \cdot 18600}$	<u>532.31 × 10⁻⁹</u>	(3) R1	B5 = 80	<u>80</u> <u>50</u>	
3. Minimum Horizontal retrace time	= <u>11 × 10⁻⁶</u> (7) f	$\frac{7+2}{532.31 \times 10^{-9}}$	<u>16.907 × 10⁶</u>	(5) R2	$80 + \frac{7}{2}$	<u>84</u> <u>54</u>	
4. Minimum vertical retrace time	= <u>1 × 10⁻³</u> (8) t _{sl}	$(100+1)(532.31 \times 10^{-9})$	<u>53.76 × 10⁻⁶</u>	(4) R3	$\frac{R0 - R1}{3}$	<u>7</u> <u>07</u>	
5. # of displayed characters per row	= <u>80</u> (9) n	$\frac{1}{(60)(53.76 \times 10^{-6})}$	<u>310</u>	(11) R4	28 - 1	<u>27</u> <u>1B</u>	
6. # of displayed character rows	= <u>24</u> (10) N		<u>28</u>	(12) R5	R = 2	<u>02</u> <u>02</u>	
7. # of dots in character dot matrix row	= <u>7</u> R	$\frac{310}{11}$	<u>2</u>	(13) R6	B6 = 24	<u>24</u> <u>18</u>	
8. # of scan lines in character matrix column	= <u>9</u> (16) t _{cr}	$(9+2)(53.76 \times 10^{-6})$	<u>591.39 × 10⁻⁶</u>	(14) R7	(A)	<u>25</u> <u>19</u>	
9. Number of dots between horizontal adjacents	= <u>2</u> (17) t _{hr}	$\leq \frac{(101-80)(7+2)}{16.907 \times 10^6}$	<u>11.17 × 10⁻⁶</u>	(15) R9	$(9+2) - 1$	<u>10</u> <u>0A</u>	
10. Number of scan lines between vertical adjacents	= <u>2</u> (18) t _{vr}	$\leq \left[\frac{18600}{60} - 24(11) \right] 53.76 \times 10^{-6}$	<u>2.47 × 10⁻³</u>	R10		<u>00</u> <u>00</u>	
(A) $(27+1) - \frac{(16-2)}{11} \geq R7 \geq 24$ $26.72 \geq R7 \geq 24$		(B) $B2 = 1/[(t_{cr})(R4+1) + (t_{sl})(R5)]$ $= 1/[(591.39 \times 10^6)(28) + (53.76 \times 10^{-6})(2)]$ $= 1/16.667 \times 10^{-3}$ $= 60$		R11		<u>11</u> <u>0B</u>	
				R12		<u>00</u> <u>00</u>	
				R13		<u>128</u> <u>80</u>	
				R14		<u>128</u> <u>00</u>	
				R15		<u>80</u> <u>80</u>	

3

FIGURE 22 — CRTC WORKSHEET

Basic Parameters		Intermediate Calculations		Register Calculations			
		Symbol	Value	Register	Decimal	Hex	
1. Horizontal frequency	= _____	f'	_____	R0	_____	_____	
2. Vertical frequency	= _____	t _c	_____	R1	_____	_____	
3. Minimum Horizontal retrace time	= _____	f	_____	R2	_____	_____	
	_____			R3	_____	_____	
4. Minimum vertical retrace time	= _____	t _{sl}	_____	R4	_____	_____	
	_____			R5	_____	_____	
5. # of displayed characters per row	= _____	n	_____	R6	_____	_____	
	_____			R7	_____	_____	
6. # of displayed character rows	= _____	N	_____	R8	_____	_____	
	_____			R9	_____	_____	
7. # of dots in character dot matrix row	= _____	R	_____	R10	_____	_____	
	_____			R11	_____	_____	
8. # of scan lines in character * matrix column	= _____	t _{cr}	_____	R12	_____	_____	
	_____			R13	_____	_____	
9. Number of dots between horizontal adjacents	= _____	t _{hr}	_____	R14	_____	_____	
	_____			R15	_____	_____	
10. Number of scan lines between vertical adjacents	= _____	t _{vr}	_____	R16	_____	_____	
	_____			R17	_____	_____	
				R18	_____	_____	
				R19	_____	_____	

CRTC INITIALIZATION

Register R0-R15 must be initialized after the system is powered up. The processor will normally load the CRTC register file from a firmware table. The program required to initialize the CRTC for a 80 × 24 format (example calculation #2) is shown in Figure 23.

The CRTC registers will have an initial value at power up. When using a direct drive monitor (sans horizontal oscillator) these initial values may result in out-of-tolerance operation. CRTC programming should be done immediately after power up especially in this type of system.

ADDITIONAL CRTC APPLICATIONS

The foremost system function which may be performed by the CRTC controller is the refreshing of dynamic RAM. This

is quite simple as the refresh addresses continually run

Note that the LPSTB input may be used to support additional system functions other than a light pen. A digital-to-analog converter (DAC) and comparator could be configured to use the refresh addresses as a reference to a DAC composed of a resistive adder network connected to a comparator. The output of the comparator would generate the LPSTB input signifying a match between the refresh address analog level and the unknown voltage.

The light-pen strobe input could also be used as a character strobe to allow the CRTC refresh addresses to decode a keyboard matrix. Debouncing would need to be done in software.

Both the VS and HS outputs may be used as a real-time clock. Once programmed, the CRTC will provide a stable reference frequency.

FIGURE 23 - MC6800 PROGRAM FOR CRTC INITIALIZATION

PAGE 001 CRTCINIT.SA:0 MC6845 CRTC Initialization Program

```

00001          NAM      MC6845
00002          TTL      / MC6845-1 CRTC initialization program
00003          OPT      G,S,LLE=85 print FCB's, FDB's & XREF table
00004          *****
00005          * Assign CRTC addresses
00006          *
00007          9000 A CRTCAD EQU      $9000      Address Register
00008          9001 A CRTCRG EQU      CRTCAD+1  Data Register
00009          *****
00010          * Initialization program
00011          *
00012A 0000          ORG      0              a place to start
00013A 0000 5F          CLR      B          clear counter
00014A 0001 CE 1020 A   LD      X          table pointer
00015A 0004 F7 9000 A CRTC1 STAB     CRTCAD    load address register
00016A 0007 A6 00      A          LDAA     0,X      get register value from table
00017A 0009 B7 9001 A   STAA     CRTCRG    program register
00018A 000C 08          INX          INX          increment counters
00019A 000D 5C          INCB         INCB         increment counters
00020A 000E C1 10      A          CMPB     $10     finished?
00021A 0010 26 F2 0004 BNE      CRTC1    no: take branch
00022A 0012 3F          SWI          SWI          yes: call monitor
00023          *****
00024          * CRTC register initialization table
00025          * 80 x 24 non-interlaced format
00026A 1020          ORG      $1020     start of table
00027A 1020 65 A CRTTAB FCB $64,$50 R0, R1 - H total & H displayed
00028A 1022 56 A          FCB      $54,$07 R2, R3 - HS pos. & HS width
00029A 1024 18 A          FCB      $1B,$02 R4, R5 - V total & V total adj.
00030A 1026 18 A          FCB      $18,$19 R6, R7 - V displayed $ VS pos.
00031A 1028 00 A          FCB      $00,$0A R8, R9 - Interlace & Max scan line
00032A 102A 00 A          FCB      $00,$0B R10,R11- Cursor start & end
00033A 102C 0080 A        FDB      $0080 R12,R13- Start Address
00034A 102E 0080 A        FDB      $0080 R14,R15- Cursor Address
00035          END
TOTAL ERRORS 00000--00000

CRTC1 0004 CRTCAD 9000 CRTCRG 9001 CRTTAB 1020
    
```



MC6845

ORDERING INFORMATION

Package Type	Frequency (MHz)	Temperature	Order Number
Cerdip S Suffix	1.0	0°C to 70°C	MC6845S
	1.0	-40°C to +85°C	MC6845CS
	1.5	0°C to 70°C	MC68A45S
	1.5	-40°C to +85°C	MC68A45CS
	2.0	0°C to 70°C	MC68B45S
Plastic P Suffix	1.0	0°C to 70°C	MC6845P
	1.0	-40°C to +85°C	MC6845CP
	1.5	0°C to 70°C	MC68A45P
	1.5	-40°C to +85°C	MC68A45CP
	2.0	0°C to 70°C	MC68B45P

PIN ASSIGNMENT

