

**MOTOROLA****8-BIT MICROPROCESSING UNIT**

The MC6809E is a revolutionary high performance 8-bit microprocessor which supports modern programming techniques such as position independence, reentrancy, and modular programming.

This third-generation addition to the M6800 family has major architectural improvements which include additional registers, instructions and addressing modes.

The basic instructions of any computer are greatly enhanced by the presence of powerful addressing modes. The MC6809E has the most complete set of addressing modes available on any 8-bit microprocessor today.

The MC6809E has hardware and software features which make it an ideal processor for higher level language execution or standard controller applications. External clock inputs are provided to allow synchronization with peripherals, systems or other MPUs.

MC6800 COMPATIBLE

- Hardware — Interfaces with All M6800 Peripherals
- Software — Upward Source Code Compatible Instruction Set and Addressing Modes

ARCHITECTURAL FEATURES

- Two 16-bit Index Registers
- Two 16-bit Indexable Stack Pointers
- Two 8-bit Accumulators can be Concatenated to Form One 16-bit Accumulator
- Direct Page Register Allows Direct Addressing Throughout Memory

HARDWARE FEATURES

- External Clock Inputs, E and Q, Allow Synchronization
- TSC Input Controls Internal Bus Buffers
- LIC Indicates Opcode Fetch
- AVMA Allows Efficient Use of Common Resources in A Multiprocessor System
- BUSY is a Status Line for Multiprocessing
- Fast Interrupt Request Input Stacks Only Condition Code Register and Program Counter
- Interrupt Acknowledge Output Allows Vectoring By Devices
- SYNC Acknowledge Output Allows for Synchronization to External Event
- Single Bus-Cycle **RESET**
- Single 5-Volt Supply Operation
- NMI Inhibited After **RESET** Until After First Load of Stack Pointer
- Early Address Valid Allows Use With Slower Memories
- Early Write-Data for Dynamic Memories

SOFTWARE FEATURES

- 10 Addressing Modes
 - M6800 Upward Compatible Addressing Modes
 - Direct Addressing Anywhere in Memory Map
 - Long Relative Branches
 - Program Counter Relative
 - True Indirect Addressing
 - Expanded Indexed Addressing:
 - 0, 5, 8, or 16-bit Constant Offsets
 - 8, or 16-bit Accumulator Offsets
 - Auto-Increment/Decrement by 1 or 2
- Improved Stack Manipulation
- 1464 Instructions with Unique Addressing Modes
- 8 x 8 Unsigned Multiply
- 16-bit Arithmetic
- Transfer/Exchange All Registers
- Push/Pull Any Registers or Any Set of Registers
- Load Effective Address

MC6809E

(1.0 MHz)

MC68A09E

(1.5 MHz)

MC68B09E

(2.0 MHz)

HMOS

(HIGH-DENSITY N-CHANNEL, SILICON-GATE)

**8-BIT
MICROPROCESSING
UNIT**

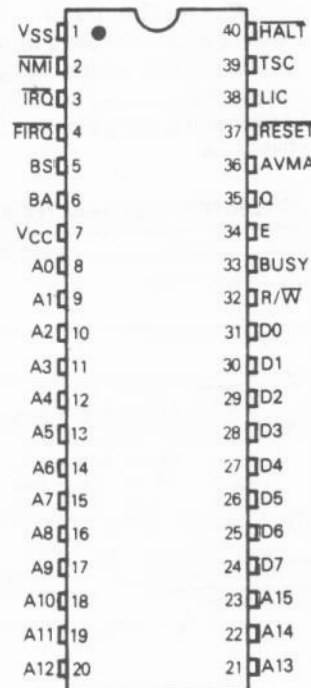
L SUFFIX
CERAMIC PACKAGE
CASE 715



P SUFFIX
PLASTIC PACKAGE
CASE 711



S SUFFIX
CERDIP PACKAGE
CASE 734

FIGURE 1 — PIN ASSIGNMENT

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 MC6809E, MC68A09E, MC68B09E	T _A	T _L to T _H 0 to +70	°C
Storage Temperature Range	T _{stg}	-55 to +150	°C

This 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.

Reliability of operation is enhanced if unused inputs are tied to an appropriate logic voltage level (e.g., either V_{SS} or V_{CC}).

THERMAL CHARACTERISTICS

Characteristic	Symbol	Value	Unit
Thermal Resistance	θ_{JA}		
Ceramic		50	
Cerdip		60	
Plastic		100	°C/W

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} × 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:

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

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 V ± 5%, V_{SS} = 0, T_A = T_L to T_H unless otherwise noted.)

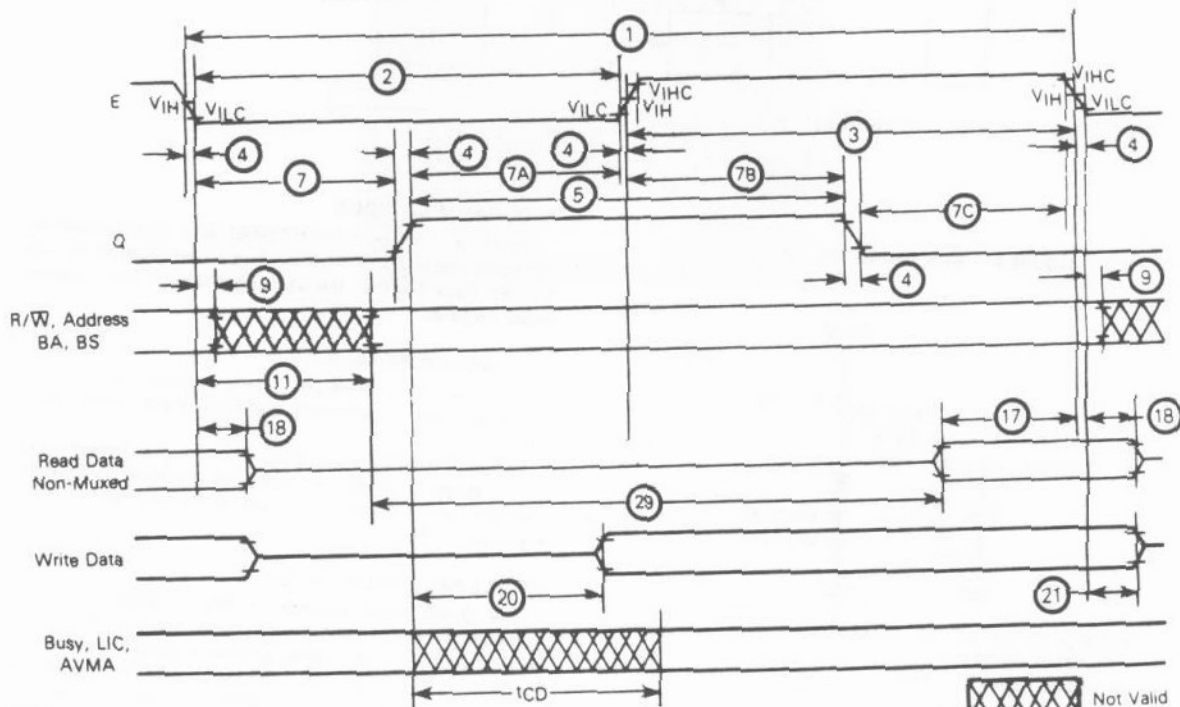
Characteristic		Symbol	Min	Typ	Max	Unit
Input High Voltage	Logic, Q, RESET E	V _{IH} V _{IHR} V _{IHC}	V _{SS} + 2.0 V _{SS} + 4.0 V _{CC} - 0.75	— — —	V _{CC} V _{CC} V _{CC} + 0.3	V
Input Low Voltage	Logic, Q, RESET E	V _{IL} V _{ILC}	V _{SS} - 0.3 V _{SS} - 0.3	— —	V _{SS} + 0.8 V _{SS} + 0.4	V
Input Leakage Current (V _{in} = 0 to 5.25 V, V _{CC} = max)	Logic, Q, RESET E	I _{in}	— —	— —	2.5 100	μA
DC Output High Voltage (I _{Load} = -205 μA, V _{CC} = min) (I _{Load} = -145 μA, V _{CC} = min) (I _{Load} = -100 μA, V _{CC} = min)	D0-D7 A0-A15, R/ $\overline{W}$ BA, BS, LIC, AVMA, BUSY	V _{OH}	V _{SS} + 2.4 V _{SS} + 2.4 V _{SS} + 2.4	— — —	— — —	V
DC Output Low Voltage (I _{Load} = 2.0 mA, V _{CC} = min)		V _{OL}	—	—	V _{SS} + 0.5	V
Internal Power Dissipation (Measured at T _A = T _L in Steady State Operation)		P _{INT}	—	—	1.0	W
Capacitance* (V _{in} = 0, T _A = 25°C, f = 1.0 MHz)	D0-D7, Logic Inputs, Q, RESET E A0-A15, R/ $\overline{W}$, BA, BS LIC, AVMA, BUSY	C _{in}	— —	10 30	15 50	pF
		C _{out}	—	10	15	pF
Frequency of Operation (E and Q Inputs)	MC6809E MC68A09E MC68B09E	f	0.1 0.1 0.1	— — —	1.0 1.5 2.0	MHz
Three-State (Off State) Input Current (V _{in} = 0.4 to 2.4 V, V _{CC} = max)	D0-D7 A0-A15, R/ $\overline{W}$	I _{TSI}	— —	2.0 —	10 100	μA

*Capacitances are periodically tested rather than 100% tested.

BUS TIMING CHARACTERISTICS (See Notes 1, 2, 3, and 4)

Ident. Number	Characteristics	Symbol	MC6809E		MC68A09E		MC68B09E		Unit
			Min	Max	Min	Max	Min	Max	
1	Cycle Time	t_{CYC}	10	10	0.667	10	0.5	10	μs
2	Pulse Width, E Low	PW_{EL}	450	9500	295	9500	210	9500	ns
3	Pulse Width, E High	PW_{EH}	450	9500	280	9500	220	9500	ns
4	Clock Rise and Fall Time	t_r, t_f	—	25	—	25	—	20	ns
5	Pulse Width, Q High	PW_{QH}	450	9500	280	9500	220	9500	ns
7	Delay Time, E to Q Rise	t_{EQ1}	200	—	130	—	100	—	ns
7A	Delay Time, Q High to E Rise	t_{EQ2}	200	—	130	—	100	—	ns
7B	Delay Time, E High to Q Fall	t_{EQ3}	200	—	130	—	100	—	ns
7C	Delay Time, Q High to E Fall	t_{EQ4}	200	—	130	—	100	—	ns
9	Address Hold Time	t_{AH}	20	—	20	—	20	—	ns
11	Address Delay Time from E Low (BA, BS, R/W)	t_{AD}	—	200	—	140	—	110	ns
17	Read Data Setup Time	t_{DSR}	80	—	60	—	40	—	ns
18	Read Data Hold Time	t_{DHR}	10	—	10	—	10	—	ns
20	Data Delay Time from Q	t_{DDQ}	—	200	—	140	—	110	ns
21	Write Data Hold Time	t_{DHW}	30	—	30	—	30	—	ns
29	Usable Access Time	t_{ACC}	695	—	440	—	330	—	ns
	Control Delay Time (Figure 2)	t_{CD}	—	300	—	250	—	200	ns
	Interrupts, HALT, RESET, and TSC Setup Time (Figures 7, B, 9, 10, 13, and 14)	t_{PCS}	200	—	140	—	110	—	ns
	TSC Drive to Valid Logic Level (Figure 14)	t_{TSV}	—	210	—	150	—	120	ns
	TSC Release MOS Buffers to High Impedance (Figure 14)	t_{TSR}	—	200	—	140	—	110	ns
	TSC Three-State Delay Time (Figure 14)	t_{TSC}	—	120	—	85	—	80	ns
	Processor Control Rise and Fall Time (Figure 8)	t_{PCr}, t_{PCf}	—	100	—	100	—	100	ns

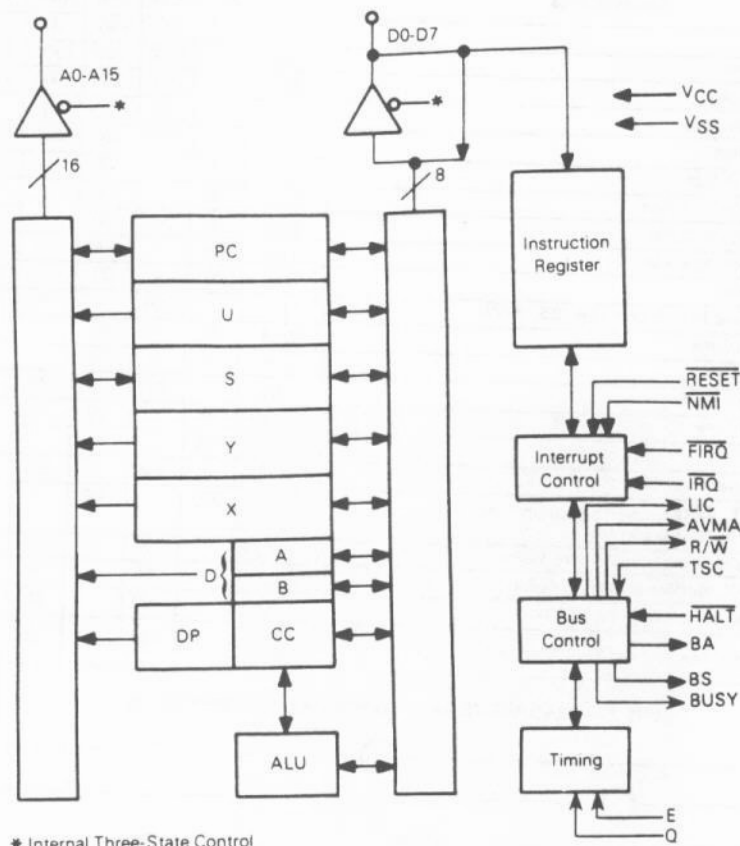
FIGURE 2 — READ/WRITE DATA TO MEMORY OR PERIPHERALS



NOTES:

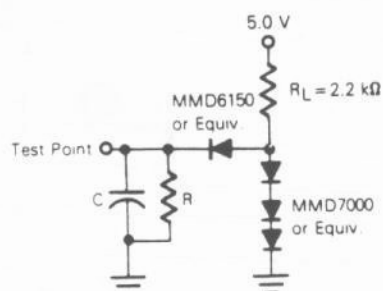
1. Voltage levels shown are $V_L \leq 0.4 V$, $V_{IH} \geq 2.4 V$, unless otherwise specified. 3. Hold time (t_{AH}) for BA and BS is not specified.
2. Measurement points shown are 0.8 V and 2.0 V, unless otherwise specified. 4. Usable access time is computed by: $1 - 4 - 11 \text{ max} - 17$.

FIGURE 3 — MC6809E EXPANDED BLOCK DIAGRAM



* Internal Three-State Control

FIGURE 4 — BUS TIMING TEST LOAD



$C = 30 \text{ pF}$ for BA, BS, LIC, AVMA, BUSY
 130 pF for D0-D7
 90 pF for A0-A15, R/W
 $R = 11.7 \text{ k}\Omega$ for D0-D7
 $16.5 \text{ k}\Omega$ for A0-A15, R/W
 $24 \text{ k}\Omega$ for BA, BS
 LIC, AVMA, BUSY

PROGRAMMING MODEL

As shown in Figure 5, the MC6809E adds three registers to the set available in the MC6800. The added registers include a Direct Page Register, the User Stack pointer and a second Index Register.

ACCUMULATORS (A, B, D)

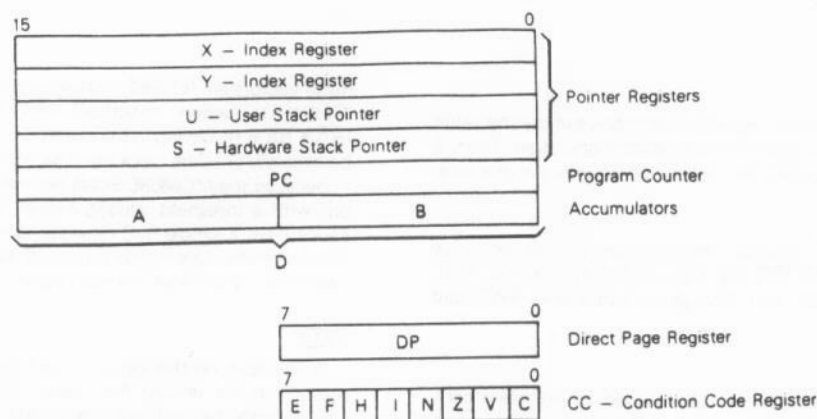
The A and B registers are general purpose accumulators which are used for arithmetic calculations and manipulation of data.

Certain instructions concatenate the A and B registers to form a single 16-bit accumulator. This is referred to as the D Register, and is formed with the A Register as the most significant byte.

DIRECT PAGE REGISTER (DP)

The Direct Page Register of the MC6809E serves to enhance the Direct Addressing Mode. The content of this register appears at the higher address outputs (A8-A15) during direct addressing instruction execution. This allows the direct mode to be used at any place in memory, under program control. To ensure M6800 compatibility, all bits of this register are cleared during Processor Reset.

FIGURE 5 — PROGRAMMING MODEL OF THE MICROPROCESSING UNIT

**INDEX REGISTERS (X, Y)**

The Index Registers are used in indexed mode of addressing. The 16-bit address in this register takes part in the calculation of effective addresses. This address may be used to point to data directly or may be modified by an optional constant or register offset. During some indexed modes, the contents of the index register are incremented or decremented to point to the next item of tabular type data. All four pointer register (X, Y, U, S) may be used as index registers.

STACK POINTER (U, S)

The Hardware Stack Pointer (S) is used automatically by the processor during subroutine calls and interrupts. The User Stack Pointer (U) is controlled exclusively by the programmer thus allowing arguments to be passed to and from subroutines with ease. The U-register is frequently used as a stack marker. Both Stack Pointers have the same indexed mode addressing capabilities as the X and Y registers, but also support **Push** and **Pull** instructions. This allows the MC6809E to be used efficiently as a stack processor, greatly enhancing its ability to support higher level languages and modular programming.

NOTE

The stack pointers of the MC6809E point to the top of the stack, in contrast to the MC6800 stack pointer, which pointed to the next free location on stack.

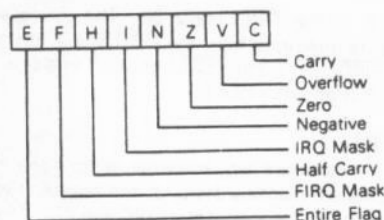
PROGRAM COUNTER

The Program Counter is used by the processor to point to the address of the next instruction to be executed by the processor. Relative Addressing is provided allowing the Program Counter to be used like an index register in some situations.

CONDITION CODE REGISTER

The Condition Code Register defines the state of the processor at any given time. See Figure 6.

FIGURE 6 — CONDITION CODE REGISTER FORMAT

**CONDITION CODE REGISTER
DESCRIPTION****BIT 0 (C)**

Bit 0 is the carry flag, and is usually the carry from the binary ALU. C is also used to represent a 'borrow' from subtract like instructions (CMP, NEG, SUB, SBC) and is the complement of the carry from the binary ALU.

BIT 1 (V)

Bit 1 is the overflow flag, and is set to a one by an operation which causes a signed two's complement arithmetic overflow. This overflow is detected in an operation in which the carry from the MSB in the ALU does not match the carry from the MSB-1.

BIT 2 (Z)

Bit 2 is the zero flag, and is set to a one if the result of the previous operation was identically zero.

BIT 3 (N)

Bit 3 is the negative flag, which contains exactly the value of the MSB of the result of the preceding operation. Thus, a negative two's-complement result will leave N set to a one.

BIT 4 (I)

Bit 4 is the $\overline{\text{IRQ}}$ mask bit. The processor will not recognize interrupts from the $\overline{\text{IRQ}}$ line if this bit is set to a one. $\overline{\text{NMI}}$, $\overline{\text{FIRQ}}$, $\overline{\text{IRQ}}$, $\overline{\text{RESET}}$, and SWI all set I to a one; SWI2 and SWI3 do not affect I.

BIT 5 (H)

Bit 5 is the half-carry bit, and is used to indicate a carry from bit 3 in the ALU as a result of an 8-bit addition only (ADC or ADD). This bit is used by the DAA instruction to perform a BCD decimal add adjust operation. The state of this flag is undefined in all subtract-like instructions.

BIT 6 (F)

Bit 6 is the $\overline{\text{FIRQ}}$ mask bit. The processor will not recognize interrupts from the $\overline{\text{FIRQ}}$ line if this bit is a one. $\overline{\text{NMI}}$, $\overline{\text{FIRQ}}$, SWI, and $\overline{\text{RESET}}$ all set F to a one. $\overline{\text{IRQ}}$, SWI2 and SWI3 do not affect F.

BIT 7 (E)

Bit 7 is the entire flag, and when set to a one indicates that the complete machine state (all the registers) was stacked, as opposed to the subset state (PC and CC). The E bit of the stacked CC is used on a return from interrupt (RTI) to determine the extent of the unstacking. Therefore, the current E left in the Condition Code Register represents past action.

PIN DESCRIPTIONS**POWER (VSS, VCC)**

Two pins are used to supply power to the part: VSS is ground or 0 volts, while VCC is +5.0 V $\pm 5\%$.

ADDRESS BUS (A0-A15)

Sixteen pins are used to output address information from the MPU onto the Address Bus. When the processor does not require the bus for a data transfer, it will output address FFFF₁₆, $\overline{\text{R/W}} = 1$, and BS = 0; this is a "dummy access" or VMA cycle. All address bus drivers are made high-impedance when output Bus Available (BA) is high or when TSC is asserted. Each pin will drive one Schottky TTL load or four LS TTL loads, and 90 pF.

DATA BUS (D0-D7)

These eight pins provide communication with the system bi-directional data bus. Each pin will drive one Schottky TTL load or four LS TTL loads, and 130 pF.

READ/WRITE (R/W)

This signal indicates the direction of data transfer on the data bus. A low indicates that the MPU is writing data onto the data bus. $\overline{\text{R/W}}$ is made high impedance when BA is high or when TSC is asserted.

 $\overline{\text{RESET}}$

A low level on this Schmitt-trigger input for greater than one bus cycle will reset the MPU, as shown in Figure 7. The

Reset vectors are fetched from locations FFFE₁₆ and FFFF₁₆ (Table 1) when Interrupt Acknowledge is true, ($\overline{\text{BA}} \cdot \text{BS} = 1$). During initial power-on, the Reset line should be held low until the clock input signals are fully operational.

Because the MC6809E Reset pin has a Schmitt-trigger input with a threshold voltage higher than that of standard peripherals, a simple R/C network may be used to reset the entire system. This higher threshold voltage ensures that all peripherals are out of the reset state before the Processor.

 $\overline{\text{HALT}}$

A low level on this input pin will cause the MPU to stop running at the end of the present instruction and remain halted indefinitely without loss of data. When halted, the BA output is driven high indicating the buses are high impedance. BS is also high which indicates the processor is in the Halt state. While halted, the MPU will not respond to external real-time requests ($\overline{\text{FIRQ}}$, $\overline{\text{IRQ}}$) although $\overline{\text{NMI}}$ or $\overline{\text{RESET}}$ will be latched for later response. During the Halt state Q and E should continue to run normally. A halted state ($\overline{\text{BA}} \cdot \text{BS} = 1$) can be achieved by pulling $\overline{\text{HALT}}$ low while $\overline{\text{RESET}}$ is still low. See Figure 8.

BUS AVAILABLE, BUS STATUS (BA, BS)

The Bus Available output is an indication of an internal control signal which makes the MOS buses of the MPU high impedance. When BA goes low, a dead cycle will elapse before the MPU acquires the bus. BA will not be asserted when TSC is active, thus allowing dead cycle consistency.

The Bus Status output signal, when decoded with BA, represents the MPU state (valid with leading edge of Q).

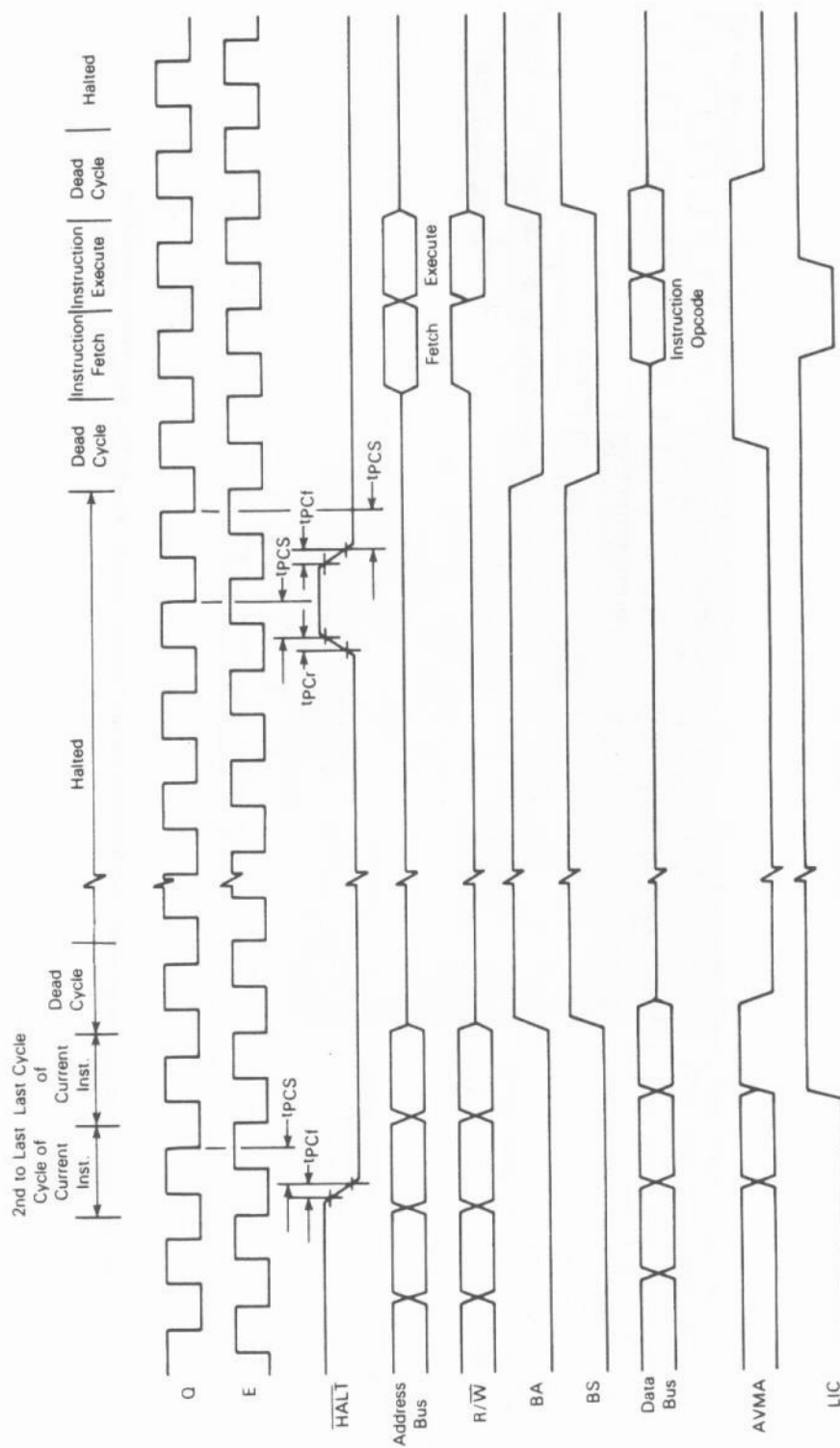
MPU State		MPU State Definition
BA	BS	
0	0	Normal (Running)
0	1	Interrupt or RESET Acknowledge
1	0	SYNC Acknowledge
1	1	HALT Acknowledge

Interrupt Acknowledge is indicated during both cycles of a hardware-vector-fetch ($\overline{\text{RESET}}$, $\overline{\text{NMI}}$, $\overline{\text{FIRQ}}$, $\overline{\text{IRQ}}$, SWI, SWI2, SWI3). This signal, plus decoding of the lower four address lines, can provide the user with an indication of which interrupt level is being serviced and allow vectoring by device. See Table 1.

TABLE 1 — MEMORY MAP FOR INTERRUPT VECTORS

Memory Map For Vector Locations		Interrupt Vector Description
MS	LS	
FFFE	FFFF	$\overline{\text{RESET}}$
FFFC	FFFD	$\overline{\text{NMI}}$
FFFA	FFFB	SWI
FFF8	FFF9	$\overline{\text{IRQ}}$
FFF6	FFF7	$\overline{\text{FIRQ}}$
FFF4	FFF5	SWI2
FFF2	FFF3	SWI3
FFF0	FFF1	Reserved

FIGURE 8 — HALT AND SINGLE INSTRUCTION EXECUTION TIMING FOR SYSTEM DEBUG



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.

Sync Acknowledge is indicated while the MPU is waiting for external synchronization on an interrupt line.

Halt/Acknowledge is indicated when the MC6809E is in a Halt condition.

NON MASKABLE INTERRUPT (NMI)*

A negative transition on this input requests that a non-maskable interrupt sequence be generated. A non-maskable interrupt cannot be inhibited by the program, and also has a higher priority than $\overline{\text{FIRQ}}$, $\overline{\text{IRQ}}$ or software interrupts. During recognition of an $\overline{\text{NMI}}$, the entire machine state is saved on the hardware stack. After reset, an $\overline{\text{NMI}}$ will not be recognized until the first program load of the Hardware Stack Pointer (S). The pulse width of $\overline{\text{NMI}}$ low must be at least one E cycle. If the $\overline{\text{NMI}}$ input does not meet the minimum set up with respect to Q, the interrupt will not be recognized until the next cycle. See Figure 9.

FAST-INTERRUPT REQUEST ($\overline{\text{FIRQ}}$)*

A low level on this input pin will initiate a fast interrupt sequence, provided its mask bit (F) in the CC is clear. This sequence has priority over the standard Interrupt Request ($\overline{\text{IRQ}}$), and is fast in the sense that it stacks only the contents of the condition code register and the program counter. The interrupt service routine should clear the source of the interrupt before doing an RTI. See Figure 10.

INTERRUPT REQUEST ($\overline{\text{IRQ}}$)*

A low level input on this pin will initiate an Interrupt Request sequence provided the mask bit (I) in the CC is clear. Since $\overline{\text{IRQ}}$ stacks the entire machine state it provides a slower response to interrupts than $\overline{\text{FIRQ}}$. $\overline{\text{IRQ}}$ also has a lower priority than $\overline{\text{FIRQ}}$. Again, the interrupt service routine should clear the source of the interrupt before doing an RTI. See Figure 9.

CLOCK INPUTS E, Q

E and Q are the clock signals required by the MC6809E. Q must lead E; that is, a transition on Q must be followed by a similar transition on E after a minimum delay. Addresses will be valid from the MPU, t_{AD} after the falling edge of E, and data will be latched from the bus by the falling edge of E. While the Q input is fully TTL compatible, the E input directly drives internal MOS circuitry and, thus, requires a high level above normal TTL levels. This approach minimizes clock skew inherent with an internal buffer. Timing and waveforms for E and Q are shown in Figure 2 while Figure 11 shows a simple clock generator for the MC6809E.

BUSY

Busy will be high for the read and modify cycles of a read-modify-write instruction and during the access of the first byte of a double-byte operation (e.g., LDX, STD, ADDD). Busy is also high during the first byte of any indirect or other vector fetch (e.g., jump extended, SWI indirect etc.).

In a multi-processor system, busy indicates the need to

defer the re-arbitration of the next bus cycle to insure the integrity of the above operations. This difference provides the indivisible memory access required for a "test-and-set" primitive, using any one of several read-modify-write instructions.

Busy does not become active during PSH or PUL operations. A typical read-modify-write instruction (ASL) is shown in Figure 12. Timing information is given in Figure 13. Busy is valid t_{CD} after the rising edge of Q.

AVMA

AVMA is the Advanced VMA signal and indicates that the MPU will use the bus in the following bus cycle. The predictive nature of the AVMA signal allows efficient shared-bus multiprocessor systems. AVMA is LOW when the MPU is in either a HALT or SYNC state. AVMA is valid t_{CD} after the rising edge of Q.

LIC

LIC (Last Instruction Cycle) is HIGH during the last cycle of every instruction, and its transition from HIGH to LOW will indicate that the first byte of an opcode will be latched at the end of the present bus cycle. LIC will be HIGH when the MPU is Halted at the end of an instruction, (i.e., not in CWA! or RESET) in SYNC state or while stacking during interrupts. LIC is valid t_{CD} after the rising edge of Q.

TSC

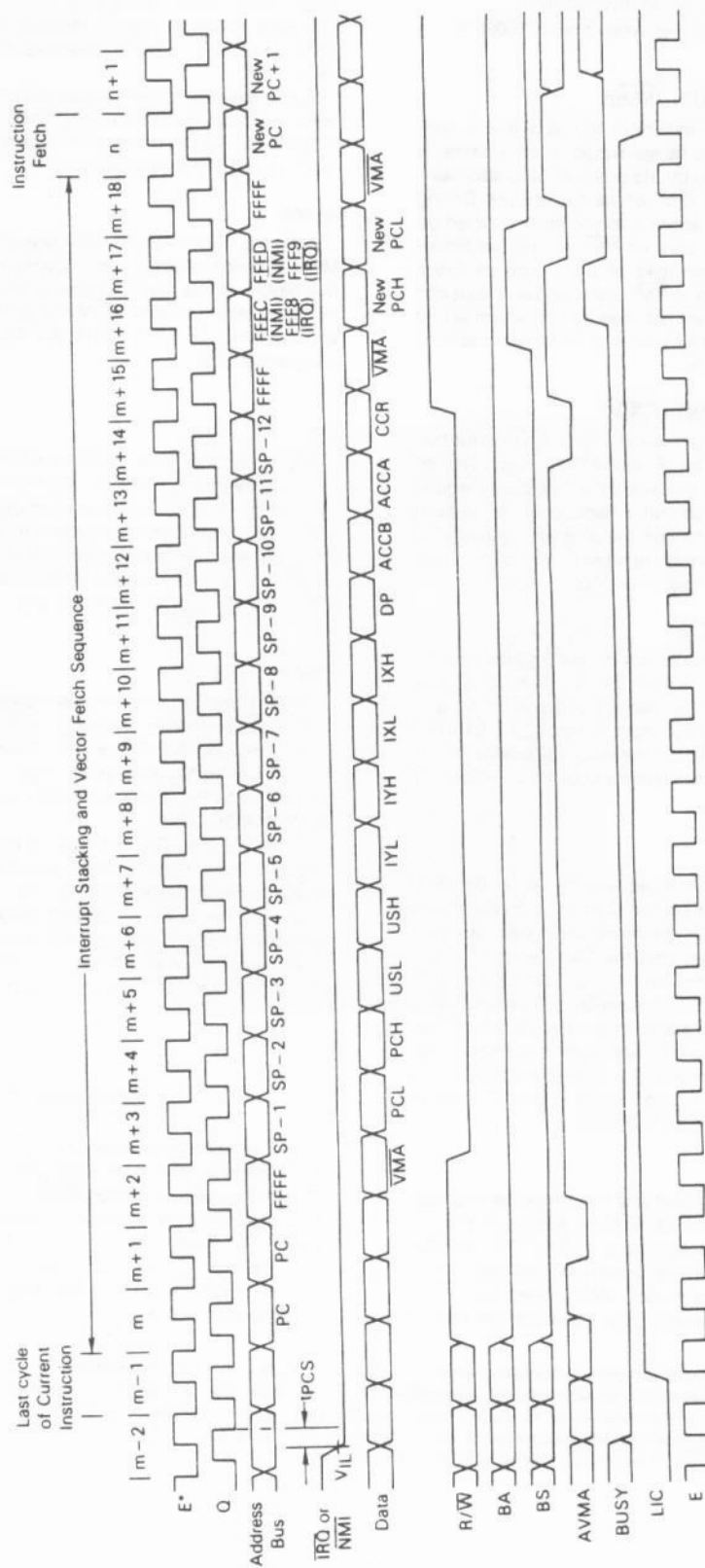
TSC (Three-State Control) will cause MOS address, data, and R/ $\overline{\text{W}}$ buffers to assume a high-impedance state. The control signals (BA, BS, BUSY, AVMA and LIC) will not go to the high-impedance state. TSC is intended to allow a single bus to be shared with other bus masters (processors or DMA controllers).

While E is low, TSC controls the address buffers and R/ $\overline{\text{W}}$ directly. The data bus buffers during a write operation are in a high-impedance state until Q rises at which time, if TSC is true, they will remain in a high-impedance state. If TSC is held beyond the rising edge of E, then it will be internally latched, keeping the bus drivers in a high-impedance state for the remainder of the bus cycle. See Figure 14.

MPU OPERATION

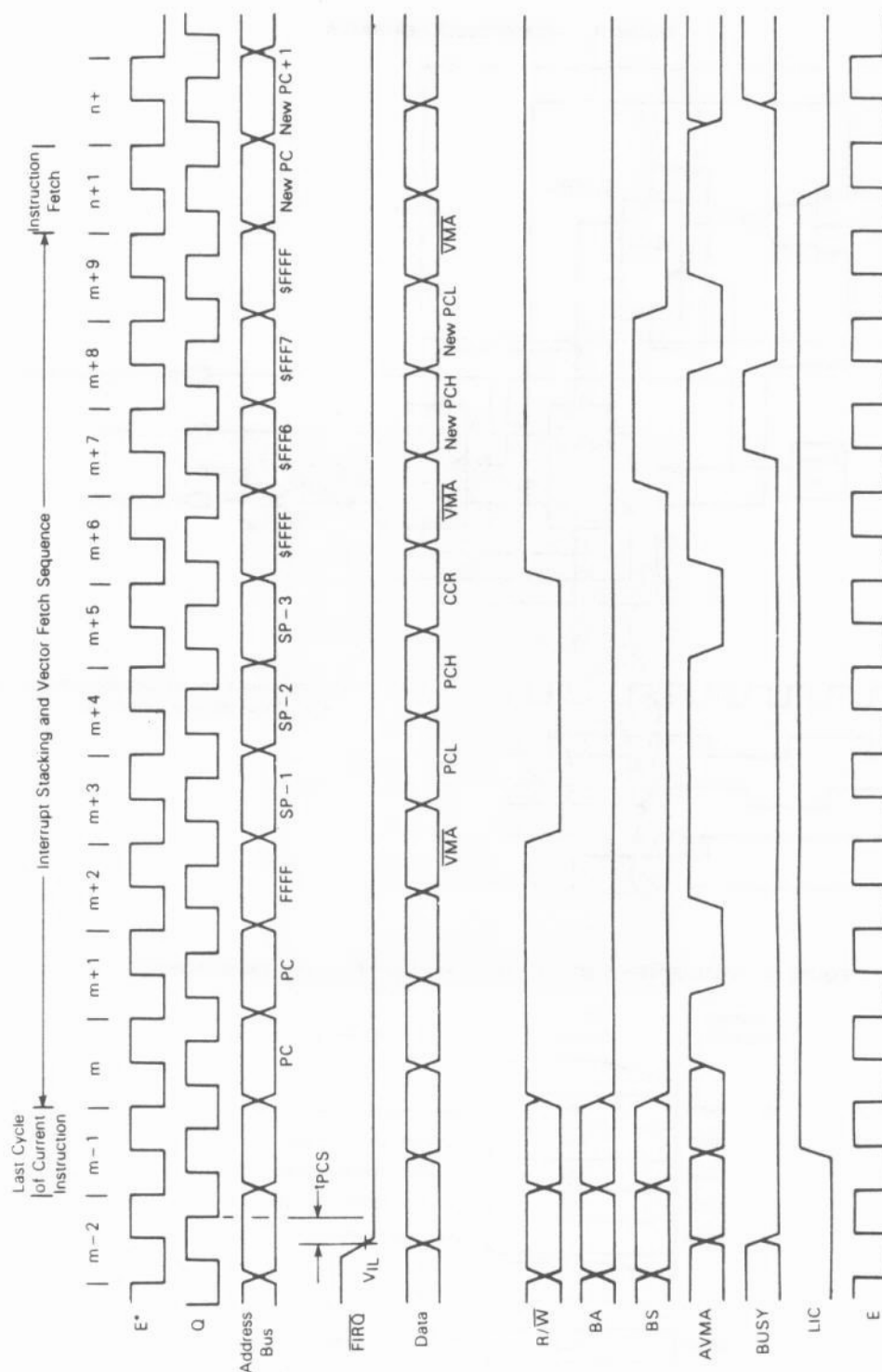
During normal operation, the MPU fetches an instruction from memory and then executes the requested function. This sequence begins after RESET and is repeated indefinitely unless altered by a special instruction or hardware occurrence. Software instructions that alter normal MPU operation are: SWI, SWI2, SWI3, CWA!, RTI and SYNC. An interrupt or HALT input can also alter the normal execution of instructions. Figure 15 is the flow chart for the MC6809E.

* $\overline{\text{NMI}}$, $\overline{\text{FIRQ}}$, and $\overline{\text{IRQ}}$ requests are sampled on the falling edge of Q. One cycle is required for synchronization before these interrupts are recognized. The pending interrupt(s) will not be serviced until completion of the current instruction unless a SYNC or CWA! condition is present. If $\overline{\text{IRQ}}$ and $\overline{\text{FIRQ}}$ do not remain low until completion of the current instruction they may not be recognized. However, $\overline{\text{NMI}}$ is latched and need only remain low for one cycle. No interrupts are recognized or latched between the falling edge of RESET and the rising edge of BS indicating RESET acknowledge. See RESET sequence in the MPU flowchart in Figure 15.

FIGURE 9 – $\overline{\text{IRQ}}$ AND $\overline{\text{NMI}}$ INTERRUPT TIMING

*E clock shown for reference only.

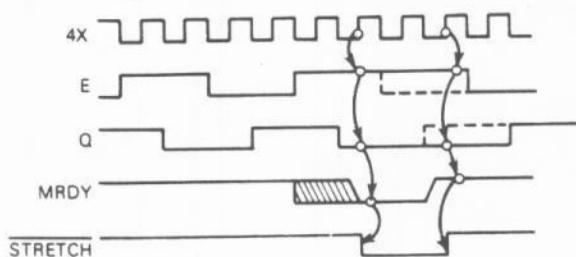
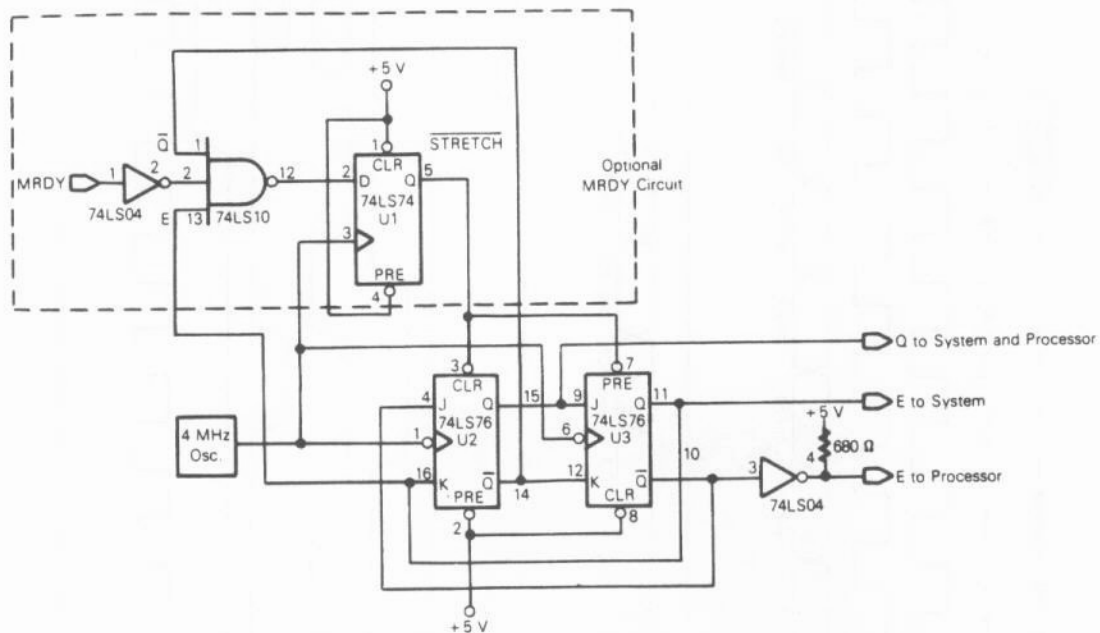
NOTE: Timing measurements are referenced to and from a low voltage of 0.8 volts and a high voltage of 2.0 volts, unless otherwise noted.

FIGURE 10 – $\overline{\text{FIRQ}}$ INTERRUPT TIMING

*E clock shown for reference only.

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.

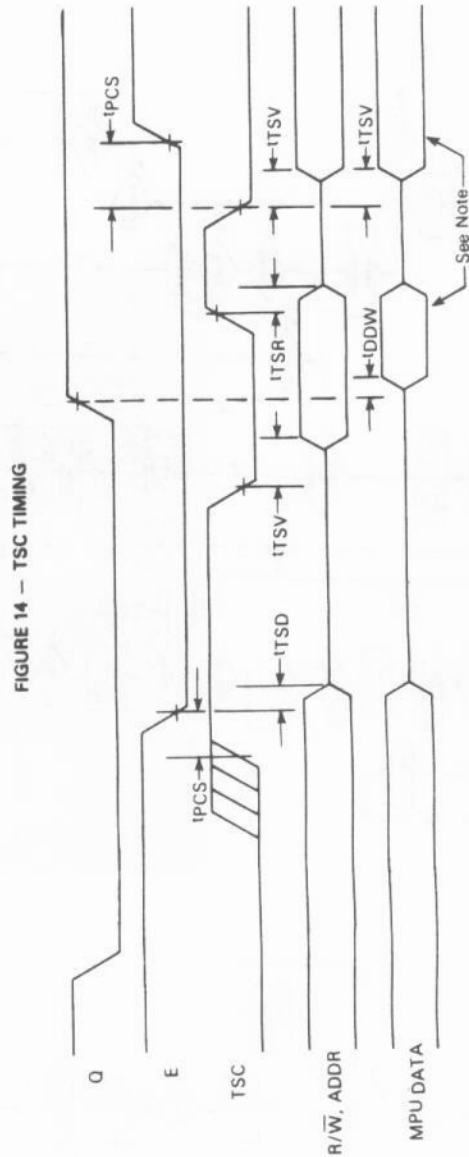
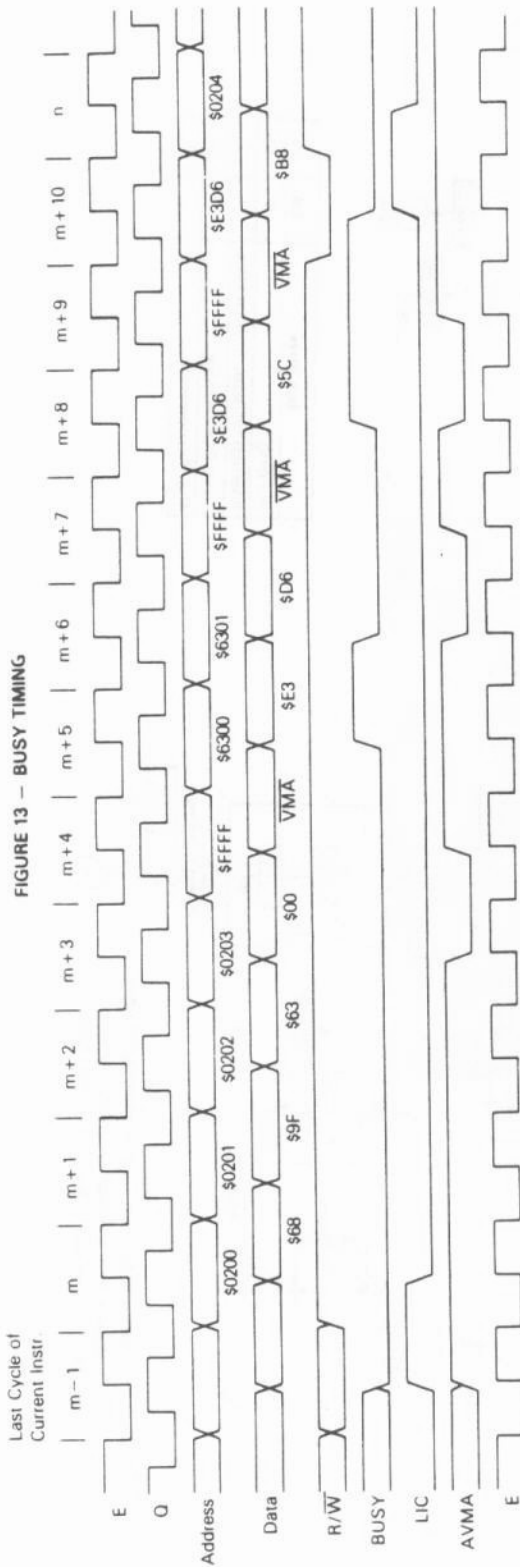
FIGURE 11 — MC6809E CLOCK GENERATOR



NOTE: If optional circuit is not included the CLR and PRE inputs of U2 and U3 must be tied high.

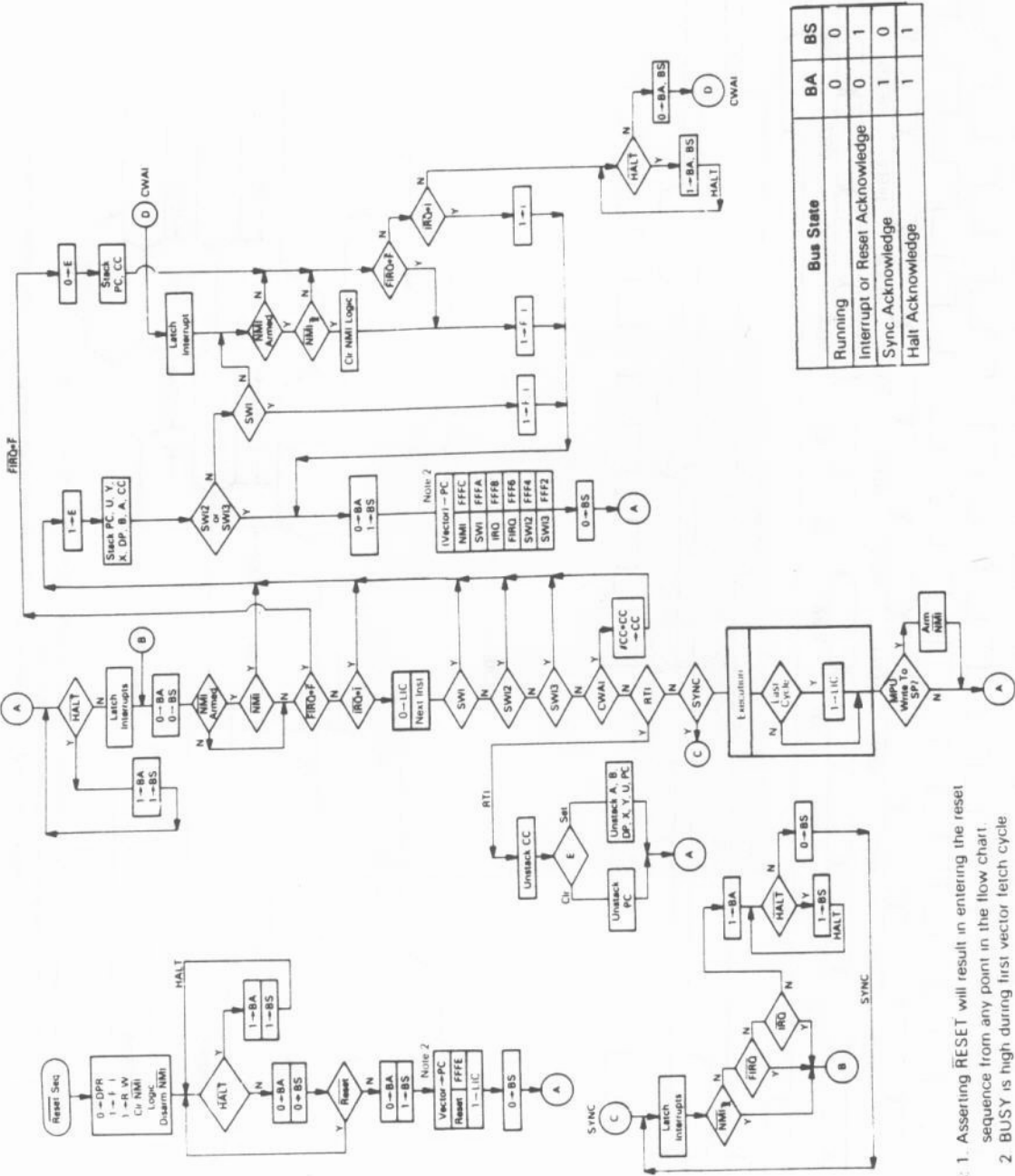
FIGURE 12 — READ-MODIFY-WRITE INSTRUCTION EXAMPLE (ASL EXTENDED INDIRECT)

Memory Location	Memory Contents	Contents Description
PC — \$0200	\$68	ASL Indexed Opcode
\$0201	\$9F	Extended Indirect Postbyte
\$0202	\$63	Indirect Address Hi-Byte
\$0203	\$00	Indirect Address Lo-Byte
\$0204		Next Main Instruction
\$6300	\$E3	Effective Address Hi-Byte
\$6301	\$D6	Effective Address Lo-Byte
\$E3D6	\$5C	Target Data



NOTE: Data will be asserted by the MPU only during the interval while R/W is low and (E or Q) is high.
A composite bus cycle is shown to give most cases of timing.
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 15 — FLOWCHART FOR MC6809E INSTRUCTIONS



Notes: 1. Asserting RESET will result in entering the reset sequence from any point in the flow chart.
2. BUSY is high during first vector fetch cycle

ADDRESSING MODES

The basic instructions of any computer are greatly enhanced by the presence of powerful addressing modes. The MC6809E has the most complete set of addressing modes available on any microcomputer today. For example, the MC6809E has 59 basic instructions; however, it recognizes 1464 different variations of instructions and addressing modes. The addressing modes support modern programming techniques. The following addressing modes are available on the MC6809E:

- Inherent (Includes Accumulator)
- Immediate
- Extended
 - Extended Indirect
- Direct
- Register
- Indexed
 - Zero-Offset
 - Constant Offset
 - Accumulator Offset
 - Auto Increment/Decrement
 - Indexed Indirect
- Relative
 - Short/Long Relative Branching
 - Program Counter Relative Addressing

INHERENT (INCLUDES ACCUMULATOR)

In this addressing mode, the opcode of the instruction contains all the address information necessary. Examples of Inherent Addressing are: ABX, DAA, SWI, ASRA, and CLRB.

IMMEDIATE ADDRESSING

In Immediate Addressing, the effective address of the data is the location immediately following the opcode (i.e., the data to be used in the instruction immediately follows the opcode of the instruction). The MC6809E uses both 8 and 16-bit immediate values depending on the size of argument specified by the opcode. Examples of instructions with Immediate Addressing are:

```
LDA #$20
LDX #$F000
LDY #CAT
```

NOTE: # signifies Immediate addressing, \$ signifies hexadecimal value to the MC6809 assembler.

EXTENDED ADDRESSING

In Extended Addressing, the contents of the two bytes immediately following the opcode fully specify the 16-bit effective address used by the instruction. Note that the address generated by an extended instruction defines an absolute address and is not position independent. Examples of Extended Addressing include:

```
LDA CAT
STX MOUSE
LDD $2000
```

EXTENDED INDIRECT

As a special case of indexed addressing (discussed below), one level of indirection may be added to Extended Addressing. In Extended Indirect, the two bytes following the postbyte of an Indexed instruction contain the address of the data.

```
LDA [CAT]
LDX [$FFFE]
STU [DOG]
```

DIRECT ADDRESSING

Direct addressing is similar to extended addressing except that only one byte of address follows the opcode. This byte specifies the lower 8 bits of the address to be used. The upper 8 bits of the address are supplied by the direct page register. Since only one byte of address is required in direct addressing, this mode requires less memory and executes faster than extended addressing. Of course, only 256 locations (one page) can be accessed without redefining the contents of the DP register. Since the DP register is set to \$00 on Reset, direct addressing on the MC6809E is upward compatible with direct addressing on the M6800. Indirection is not allowed in direct addressing. Some examples of direct addressing are:

```
LDA    where DP = $00
LDB    where DP = $10
LDD    < CAT
```

NOTE: < is an assembler directive which forces direct addressing.

REGISTER ADDRESSING

Some opcodes are followed by a byte that defines a register or set of registers to be used by the instruction. This is called a postbyte. Some examples of register addressing are:

```
TFR    X, Y    Transfers X into Y
EXG    A, B    Exchanges A with B
PSHS   A, B, X, Y Push Y, X, B and A onto S
                    stack
PULU   X, Y, D  Pull D, X, and Y from U stack
```

INDEXED ADDRESSING

In all indexed addressing, one of the pointer registers (X, Y, U, S, and sometimes PC) is used in a calculation of the effective address of the operand to be used by the instruction. Five basic types of indexing are available and are discussed below. The postbyte of an indexed instruction specifies the basic type and variation of the addressing mode as well as the pointer register to be used. Figure 16 lists the legal formats for the postbyte. Table 2 gives the assembler form and the number of cycles and bytes added to the basic values for indexed addressing for each variation.

FIGURE 16 — INDEXED ADDRESSING POSTBYTE REGISTER BIT ASSIGNMENTS

Post-Byte Register Bit								Indexed Addressing Mode
7	6	5	4	3	2	1	0	
0	R	R	d	d	d	d	d	EA = ,R + 5 Bit Offset
1	R	R	0	0	0	0	0	,R +
1	R	R	i	0	0	0	1	,R ++
1	R	R	0	0	0	1	0	, - R
1	R	R	i	0	0	1	1	, - - R
1	R	R	i	0	1	0	0	EA = ,R + 0 Offset
1	R	R	i	0	1	0	1	EA = ,R + ACCB Offset
1	R	R	i	0	1	1	0	EA = ,R + ACCA Offset
1	R	R	i	1	0	0	0	EA = ,R + 8 Bit Offset
1	R	R	i	1	0	0	1	EA = ,R + 16 Bit Offset
1	R	R	i	1	0	1	1	EA = ,R + D Offset
1	x	x	i	1	1	0	0	EA = ,PC + 8 Bit Offset
1	x	x	i	1	1	0	1	EA = ,PC + 16 Bit Offset
1	R	R	i	1	1	1	1	EA = [,Address]

Addressing Mode Field

Indirect Field
(Sign bit when b7 = 0)

Register Field: RR
00 = X
01 = Y
10 = U
11 = S

x = Don't Care
d = Offset Bit
0 = Not Indirect
1 = Indirect

Zero-Offset Indexed — In this mode, the selected pointer register contains the effective address of the data to be used by the instruction. This is the fastest indexing mode.

Examples are:

```
LDD 0, X
LDA ,S
```

Constant Offset Indexed — In this mode, a two's-complement offset and the contents of one of the pointer registers are added to form the effective address of the operand. The pointer register's initial content is unchanged by the addition.

Three sizes of offsets are available:

5-bit (–16 to +15)
8-bit (–128 to +127)
16-bit (–32768 to +32767)

The two's complement 5-bit offset is included in the postbyte and, therefore, is most efficient in use of bytes and cycles. The two's complement 8-bit offset is contained in a single byte following the postbyte. The two's complement 16-bit offset is in the two bytes following the postbyte. In most cases the programmer need not be concerned with the size of this offset since the assembler will select the optimal size automatically.

Examples of constant-offset indexing are:

```
LDA 23,X
LDX -2,S
LDY 300,X
LDU CAT,Y
```

TABLE 2 — INDEXED ADDRESSING MODE

Type	Forms	Non Indirect				Indirect			
		Assembler Form	Postbyte OP Code	+	+	Assembler Form	Postbyte OP Code	+	+
Constant Offset From R (2's Complement Offsets)	No Offset	,R	1RR00100	0	0	[,R]	1RR10100	3	0
	5 Bit Offset	n, R	0RRnnnnn	1	0	defaults to 8-bit			
	8 Bit Offset	n, R	1RR01000	1	1	[n, R]	1RR11000	4	1
	16 Bit Offset	n, R	1RR01001	4	2	[n, R]	1RR11001	7	2
Accumulator Offset From R (2's Complement Offsets)	A Register Offset	A, R	1RR00110	1	0	[A, R]	1RR10110	4	0
	B Register Offset	B, R	1RR00101	1	0	[B, R]	1RR10101	4	0
	D Register Offset	D, R	1RR01011	4	0	[D, R]	1RR11011	7	0
Auto Increment/Decrement R	Increment By 1	,R +	1RR00000	2	0	not allowed			
	Increment By 2	,R ++	1RR00001	3	0	[,R ++]	1RR10001	6	0
	Decrement By 1	, - R	1RR00010	2	0	not allowed			
	Decrement By 2	, - - R	1RR00011	3	0	[, - - R]	1RR10011	6	0
Constant Offset From PC (2's Complement Offsets)	8 Bit Offset	n, PCR	1xx01100	1	1	[n, PCR]	1xx11100	4	1
	16 Bit Offset	n, PCR	1xx01101	5	2	[n, PCR]	1xx11101	8	2
Extended Indirect	16 Bit Address	—	—	—	—	[n]	10011111	5	2

R = X, Y, U or S
x = Don't Care

RR:
00 = X
01 = Y
10 = U
11 = S

⁺ and ⁺ indicate the number of additional cycles and bytes respectively for the particular indexing variation.

Accumulator-Offset Indexed — This mode is similar to constant offset indexed except that the two's-complement value in one of the accumulators (A, B or D) and the contents of one of the pointer registers are added to form the effective address of the operand. The contents of both the accumulator and the pointer register are unchanged by the addition. The postbyte specifies which accumulator to use as an offset and no additional bytes are required. The advantage of an accumulator offset is that the value of the offset can be calculated by a program at run-time.

Some examples are:

```
LDA  B,Y
LDX  D,Y
LEAX B,X
```

Auto Increment/Decrement Indexed — In the auto increment addressing mode, the pointer register contains the address of the operand. Then, after the pointer register is used it is incremented by one or two. This addressing mode is useful in stepping through tables, moving data, or for the creation of software stacks. In auto decrement, the pointer register is decremented prior to use as the address of the data. The use of auto decrement is similar to that of auto increment; but the tables, etc., are scanned from the high to low addresses. The size of the increment/decrement can be either one or two to allow for tables of either 8- or 16-bit data to be accessed and is selectable by the programmer. The pre-decrement, post-increment nature of these modes allow them to be used to create additional software stacks that behave identically to the U and S stacks.

Some examples of the auto increment/decrement addressing modes are:

```
LDA  ,X+
STD  ,Y++
LDB  , -Y
LDX  , --S
```

Care should be taken in performing operations on 16-bit pointer registers (X, Y, U, S) where the same register is used to calculate the effective address.

Consider the following instruction:

```
STX 0,X++ (X initialized to 0)
```

The desired result is to store a 0 in locations \$0000 and \$0001 then increment X to point to \$0002. In reality, the following occurs:

```
0→temp    calculate the EA; temp is a holding register
X+2→X      perform autoincrement
X→(temp)   do store operation
```

INDEXED INDIRECT

All of the indexing modes with the exception of auto increment/decrement by one, or a ± 5 -bit offset may have an additional level of indirection specified. In indirect addressing, the effective address is contained at the location specified by the contents of the Index Register plus any offset. In the example below, the A accumulator is loaded indirectly using an effective address calculated from the Index Register and an offset.

```
Before Execution
A = XX (don't
care)
X = $F000
```

```
$0100 LDA [$10,X] EA is now $F010
```

```
$F010 $F1      $F150 is now the
$F011 $50      new EA
```

```
$F150 $AA
```

After Execution

```
A = $AA (Actual Data Loaded)
X = $F000
```

All modes of indexed indirect are included except those which are meaningless (e.g., auto increment/decrement by 1 indirect). Some examples of indexed indirect are:

```
LDA  [,X]
LDD  [,10,S]
LDA  [B,Y]
LDD  [,X++]
```

RELATIVE ADDRESSING

The byte(s) following the branch opcode is (are) treated as a signed offset which may be added to the program counter. If the branch condition is true then the calculated address (PC + signed offset) is loaded into the program counter. Program execution continues at the new location as indicated by the PC; short (1 byte offset) and long (2 bytes offset) relative addressing modes are available. All of memory can be reached in long relative addressing as an effective address interpreted modulo 216. Some examples of relative addressing are:

```
BEQ  CAT      (short)
BGT  DOG      (short)
CAT  LBEQ     RAT      (long)
DOG  LBGT     RABBIT   (long)
•
•
•
RAT  NOP
RABBIT NOP
```

PROGRAM COUNTER RELATIVE

The PC can be used as the pointer register with 8 or 16-bit signed offsets. As in relative addressing, the offset is added to the current PC to create the effective address. The effective address is then used as the address of the operand or data. Program Counter Relative Addressing is used for writing position independent programs. Tables related to a particular routine will maintain the same relationship after the routine is moved, if referenced relative to the Program Counter. Examples are:

```
LDA  CAT, PCR
LEAX TABLE, PCR
```

Since program counter relative is a type of indexing, an additional level of indirection is available.

```
LDA  [CAT, PCR]
LDU  [DOG, PCR]
```

MC6809E INSTRUCTION SET

The instruction set of the MC6809E is similar to that of the MC6800 and is upward compatible at the source code level. The number of opcodes has been reduced from 72 to 59, but because of the expanded architecture and additional addressing modes, the number of available opcodes (with different addressing modes) has risen from 197 to 1464.

Some of the new instructions are described in detail below:

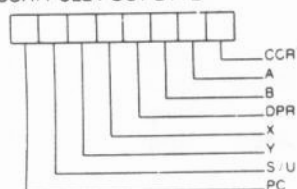
PSHU/PSHS

The push instructions have the capability of pushing onto either the hardware stack (S) or user stack (U) any single register, or set of registers with a single instruction.

PULU/PULS

The pull instructions have the same capability of the push instruction, in reverse order. The byte immediately following the push or pull opcode determines which register or registers are to be pushed or pulled. The actual PUSH/PULL sequence is fixed; each bit defines a unique register to push or pull, as shown below.

PUSH/PULL POST BYTE



STACKING ORDER

PULL ORDER



TFR/EXG

Within the MC6809E, any register may be transferred to or exchanged with another of like-size; i.e., 8-bit to 8-bit or 16-bit to 16-bit. Bits 4-7 of postbyte define the source register, while bits 0-3 represent the destination register. These are denoted as follows:

TRANSFER/EXCHANGE POST BYTE

SOURCE	DESTINATION
--------	-------------

REGISTER FIELD

0000	D (A, B)	1000	A
0001	X	1001	B
0010	Y	1010	CCR
0011	U	1011	DPR
0100	S		
0101	PC		

NOTE: All other combinations are undefined and INVALID.

LEAX/LEAY/LEAU/LEAS

The LEA (Load Effective Address) works by calculating the effective address used in an indexed instruction and stores that address value, rather than the data at that address, in a pointer register. This makes all the features of the internal addressing hardware available to the programmer. Some of the implications of this instruction are illustrated in Table 3.

The LEA instruction also allows the user to access data and tables in a position independent manner. For example:

```
LEAX MSG1, PCR
LBSR PDATA (Print message routine)
```

```
MSG1 FCC 'MESSAGE'
```

This sample program prints: 'MESSAGE'. By writing MSG1, PCR, the assembler computes the distance between the present address and MSG1. This result is placed as a constant into the LEAX instruction which will be indexed from the PC value at the time of execution. No matter where the code is located, when it is executed, the computed offset from the PC will put the absolute address of MSG1 into the X pointer register. This code is totally position independent.

The LEA instructions are very powerful and use an internal holding register (temp). Care must be exercised when using the LEA instructions with the autoincrement and autodecrement addressing modes due to the sequence of internal operations. The LEA internal sequence is outlined as follows:

LEAa, b+ (any of the 16-bit pointer registers X, Y, U or S may be substituted for a and b.)

1. b ← temp (calculate the EA)
2. b + 1 ← b (modify b, postincrement)
3. temp ← a (load a)

LEAa, -b

1. b - 1 ← temp (calculate EA with predecrement)
2. b - 1 ← b (modify b, predecrement)
3. temp ← a (load a)

TABLE 3 — LEA EXAMPLES

Instruction	Operation	Comment
LEAX 10, X	X + 10 → X	Adds 5-bit constant 10 to X
LEAX 500, X	X + 500 → X	Adds 16-bit constant 500 to X
LEAY A, Y	Y + A → Y	Adds 8-bit A accumulator to Y
LEAY D, Y	Y + D → Y	Adds 16-bit D accumulator to Y
LEAU -10, U	U - 10 → U	Subtracts 10 from U
LEAS -10, S	S - 10 → S	Used to reserve area on stack
LEAS 10, S	S + 10 → S	Used to 'clean up' stack
LEAX 5, S	S + 5 → X	Transfers as well as adds

Autoincrement-by-two and autodecrement-by-two instructions work similarly. Note that LEAX ,X+ does not change X, however LEAX , -X does decrement X. LEAX 1,X should be used to increment X by one.

MUL

Multiplies the unsigned binary numbers in the A and B accumulator and places the unsigned result into the 16-bit D accumulator. This unsigned multiply also allows multiple-precision multiplications.

Long And Short Relative Branches

The MC6809E has the capability of program counter relative branching throughout the entire memory map. In this mode, if the branch is to be taken, the 8 or 16-bit signed offset is added to the value of the program counter to be used as the effective address. This allows the program to branch anywhere in the 64K memory map. Position independent code can be easily generated through the use of relative branching. Both short (8-bit) and long (16-bit) branches are available.

SYNC

After encountering a Sync instruction, the MPU enters a Sync state, stops processing instructions and waits for an interrupt. If the pending interrupt is non-maskable (NMI) or maskable (FIRQ, IRQ) with its mask bit (F or I) clear, the processor will clear the Sync state and perform the normal interrupt stacking and service routine. Since FIRQ and IRQ are not edge-triggered, a low level with a minimum duration of three bus cycles is required to assure that the interrupt will be taken. If the pending interrupt is maskable (FIRQ, IRQ) with its mask bit (F or I) set, the processor will clear the Sync state and continue processing by executing the next inline instruction. Figure 17 depicts Sync timing.

Software Interrupts

A Software Interrupt is an instruction which will cause an interrupt, and its associated vector fetch. These Software Interrupts are useful in operating system calls, software debugging, trace operations, memory mapping, and software development systems. Three levels of SWI are available on this MC6809E, and are prioritized in the following order: SWI, SWI2, SWI3.

16-Bit Operation

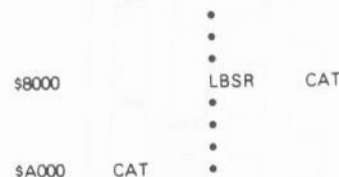
The MC6809E has the capability of processing 16-bit data. These instructions include loads, stores, compares, adds, subtracts, transfers, exchanges, pushes and pulls.

CYCLE-BY-CYCLE OPERATION

The address bus cycle-by-cycle performance chart illustrates the memory-access sequence corresponding to each possible instruction and addressing mode in the MC6809E. Each instruction begins with an opcode fetch. While that opcode is being internally decoded, the next program byte is always fetched. (Most instructions will use the next byte, so this technique considerably speeds throughput.) Next, the operation of each opcode will follow the flow chart. VMA is an indication of FFFF₁₆ on the ad-

dress bus, R/W = 1 and BS = 0. The following examples illustrate the use of the chart; see Figure 18.

Example 1: LBSR (Branch Taken) Before Execution SP = F000



CYCLE-BY-CYCLE FLOW

Cycle #	Address	Data	R/W	Description
1	8000	17	1	Opcode Fetch
2	8001	20	1	Offset High Byte
3	8002	00	1	Offset Low Byte
4	FFFF	*	1	VMA Cycle
5	FFFF	*	1	VMA Cycle
6	A000	*	1	Computed Branch Address
7	FFFF	*	1	VMA Cycle
8	EEEE	80	0	Stack High Order Byte of Return Address
9	EEEE	03	0	Stack Low Order Byte of Return Address

Example 2: DEC (Extended)



CYCLE-BY-CYCLE FLOW

Cycle #	Address	Data	R/W	Description
1	8000	7A	1	Opcode Fetch
2	8001	A0	1	Operand Address, High Byte
3	8002	00	1	Operand Address, Low Byte
4	FFFF	*	1	VMA Cycle
5	A000	80	1	Read the Data
6	FFFF	*	1	VMA Cycle
7	A000	7F	0	Store the Decrement Data

* The data bus has the data at that particular address.

MC6809E INSTRUCTION SET TABLES

The instructions of the MC6809E have been broken down into five different categories. They are as follows:

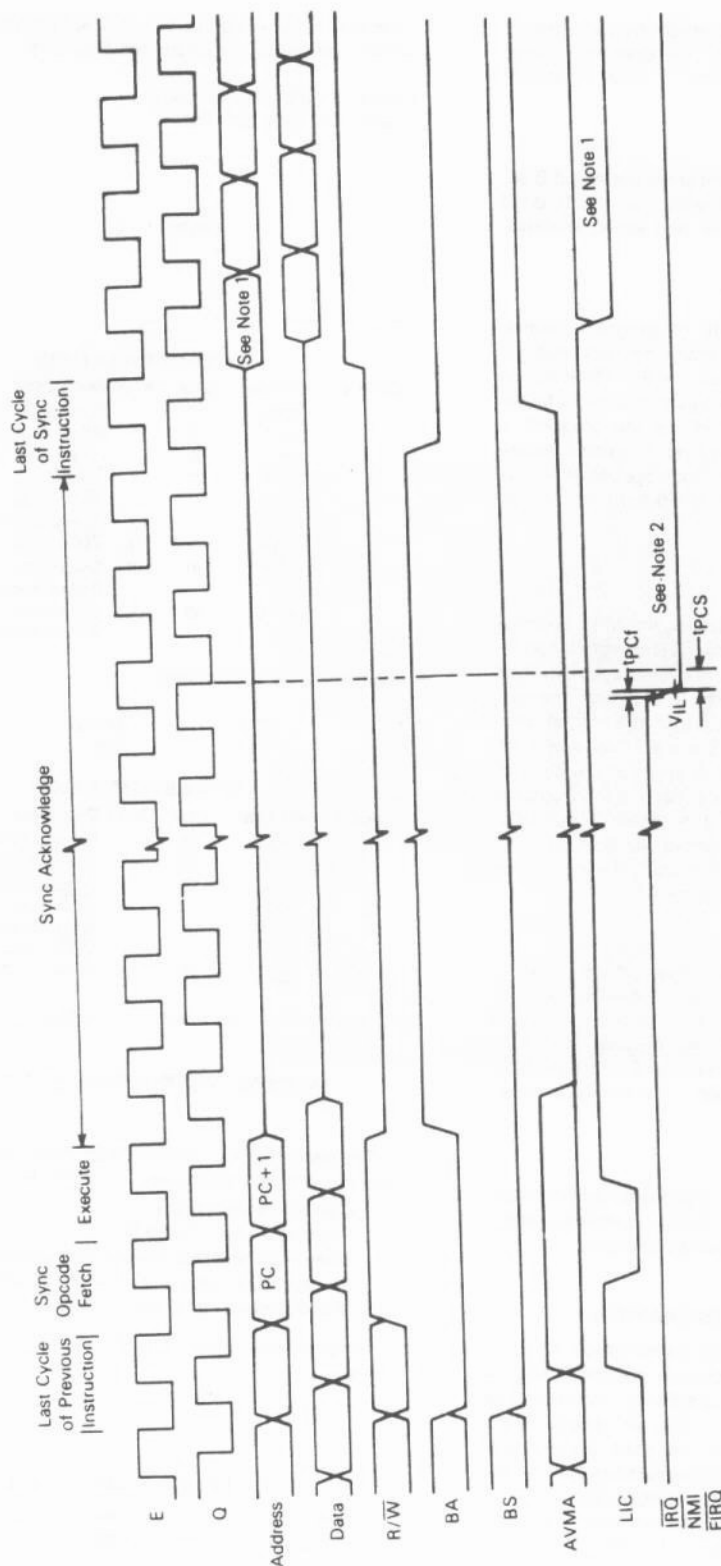
- 8-Bit operation (Table 4)
- 16-Bit operation (Table 5)
- Index register/stack pointer instructions (Table 6)
- Relative branches (long or short) (Table 7)
- Miscellaneous instructions (Table 8)

Hexadecimal values for the instructions are given in Table 9.

PROGRAMMING AID

Figure 18 contains a compilation of data that will assist you in programming the MC6809E.

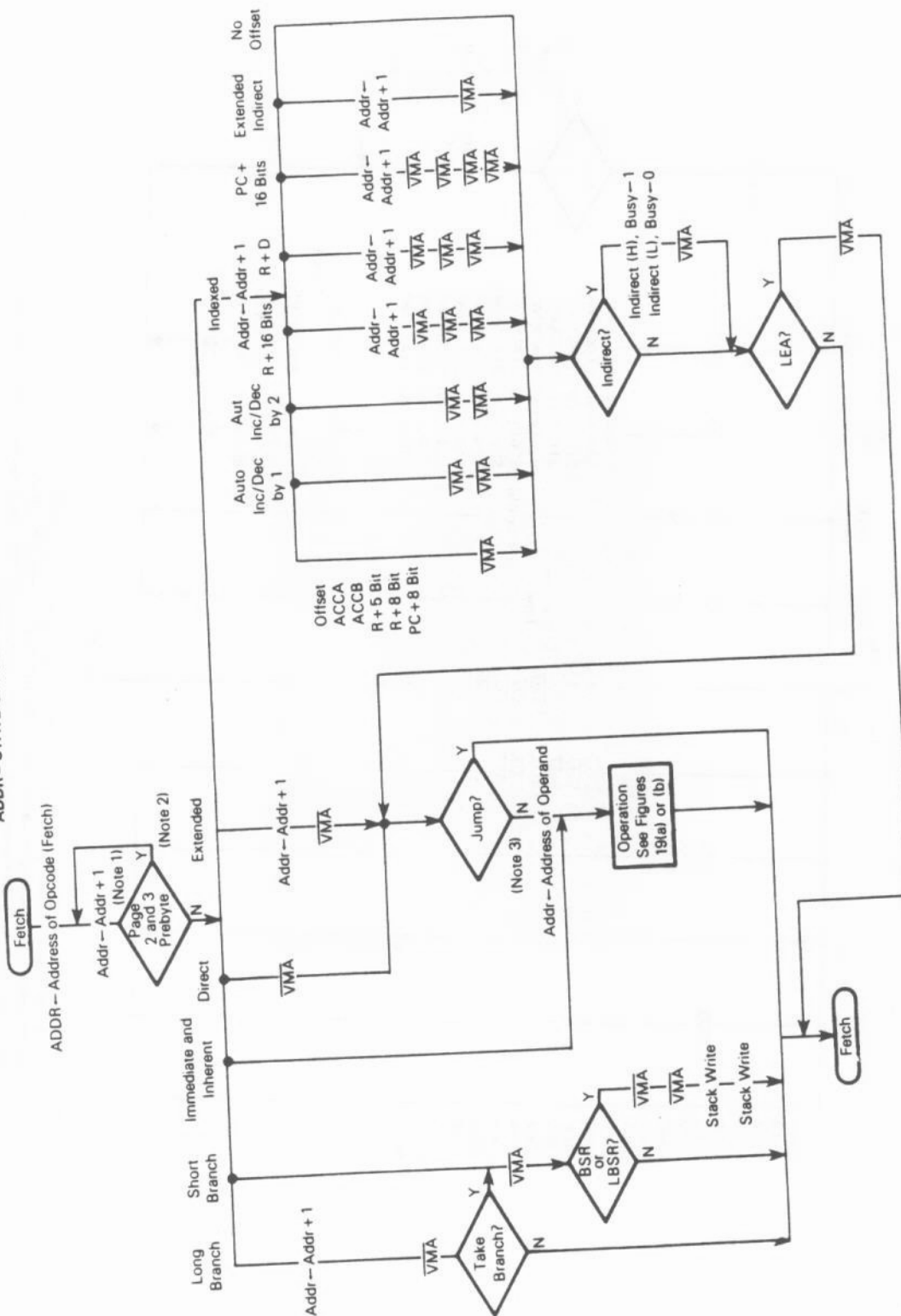
FIGURE 17 — SYNC TIMING



- Notes:
1. If the associated mask bit is set when the interrupt is requested, LIC will go low and this cycle will be an instruction fetch from address location PC+1. However, if the interrupt is accepted (NMI) or an unmasked **FIRO** or **IRQ**, LIC will remain high and interrupt processing will start with this cycle as (m) on Figures 9 and 10 (Interrupt Timing).
 2. If mask bits are clear, **IRQ** and **FIRO** must be held low for three cycles to guarantee that interrupt will be taken, although only one cycle is necessary to bring the processor out of SYNC.

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.

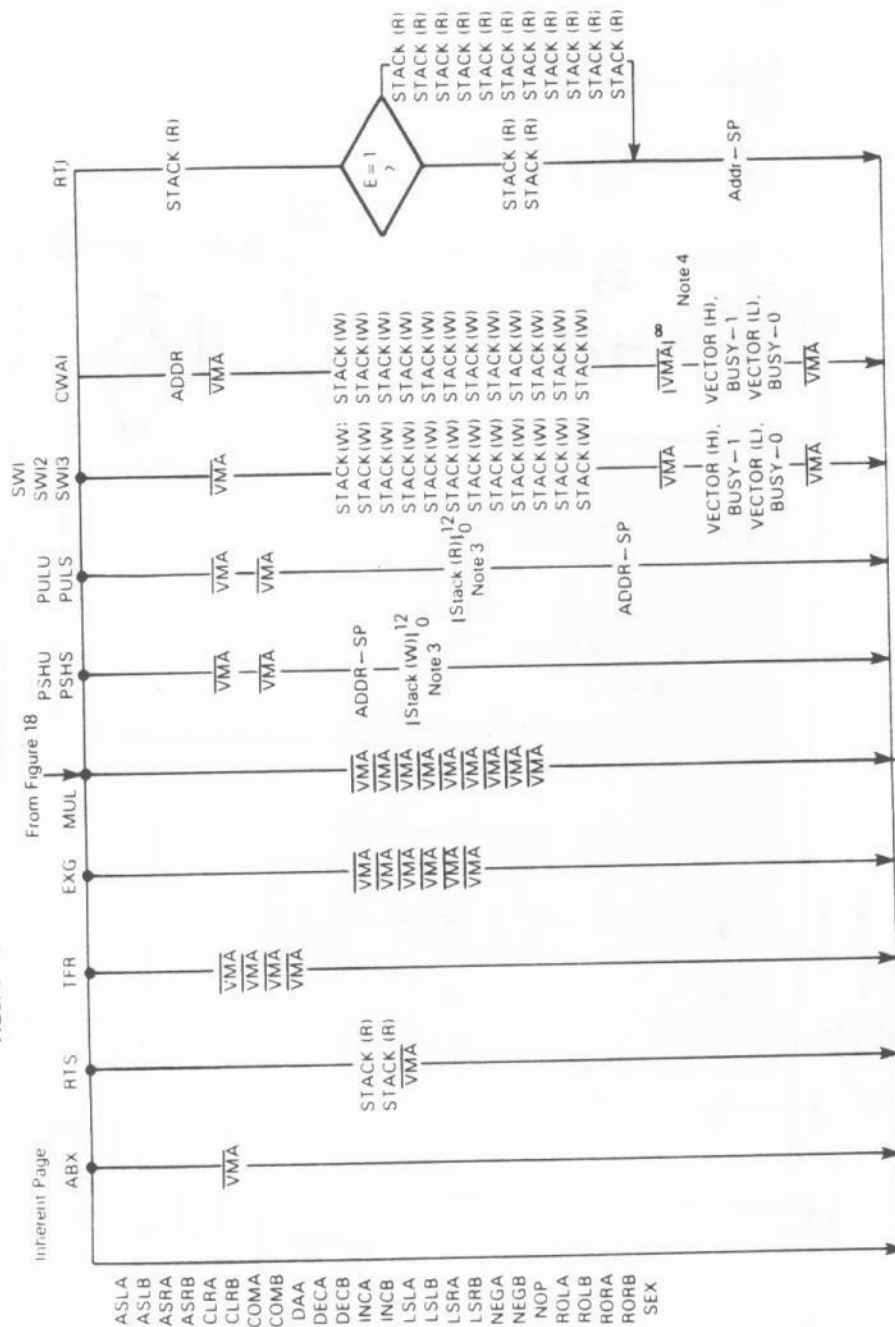
FIGURE 18 — ADDRESS BUS CYCLE-BY-CYCLE PERFORMANCE
ADDR = STATE OF ADDRESS BUS



NOTES:

1. Busy = 1 during access of first byte of double byte immediate load.
2. All subsequent Page 2 and Page 3 prebytes will be ignored after initial opcode fetch.
3. Write operation during store instruction. Busy = 1 during first two cycles of a double-byte access and the first cycle of read-modify-write access.
4. AVMA is asserted on the cycle before a VMA cycle.

FIGURE 19(a) -- OPERATIONS: ADDRESS BUS CYCLE-BY-CYCLE PERFORMANCE



▲ To Figure 18

NOTES

- NOTES
1. Stack (W) refers to the following sequence: $SP - SP - 1$, then $ADDR - SP$ with $R/W = 0$.
 2. Stack (R) refers to the following sequence: $ADDR - SP$ with $R/W = 1$, then $SP - SP + 1$.
 3. $PSHU$, $PULU$ instructions use the user stack pointer (i.e., $SP \equiv U$) and $PSHS$, $PULS$ use the hardware stack pointer (i.e., $SP \equiv S$).
 4. Vector refers to the address of an interrupt or reset vector (see Table 1).
 5. The number of stack accesses will vary according to the number of bytes saved.
 6. The number of stack accesses will vary according to the number of bytes saved.
 7. VMA cycles will occur until an interrupt occurs.

TABLE 4 — 8-BIT ACCUMULATOR AND MEMORY INSTRUCTIONS

Mnemonic(s)	Operation
ADCA, ADCB	Add memory to accumulator with carry
ADDA, ADDB	Add memory to accumulator
ANDA, ANDB	And memory with accumulator
ASL, ASLA, ASLB	Arithmetic shift of accumulator or memory left
ASR, ASRA, ASRB	Arithmetic shift of accumulator or memory right
BITA, BITB	Bit test memory with accumulator
CLR, CLRA, CLRB	Clear accumulator or memory location
CMPA, CMPB	Compare memory from accumulator
COM, COMA, COMB	Complement accumulator or memory location
DAA	Decimal adjust A accumulator
DEC, DECA, DECB	Decrement accumulator or memory location
EORA, EORB	Exclusive or memory with accumulator
EXG R1, R2	Exchange R1 with R2 (R1, R2 = A, B, CC, DP)
INC, INCA, INCB	Increment accumulator or memory location
LDA, LDB	Load accumulator from memory
LSL, LSLA, LSLB	Logical shift left accumulator or memory location
LSR, LSRA, LSRB	Logical shift right accumulator or memory location
MUL	Unsigned multiply ($A \times B \rightarrow D$)
NEG, NEGA, NEGB	Negate accumulator or memory
ORA, ORB	Or memory with accumulator
ROL, ROLA, ROLB	Rotate accumulator or memory left
ROR, RORA, RORB	Rotate accumulator or memory right
SBCA, SBCB	Subtract memory from accumulator with borrow
STA, STB	Store accumulator to memory
SUBA, SUBB	Subtract memory from accumulator
TST, TSTA, TSTB	Test accumulator or memory location
TFR R1, R2	Transfer R1 to R2 (R1, R2 = A, B, CC, DP)

NOTE: A, B, CC or DP may be pushed to (pulled from) either stack with PSHS, PSHU (PULS, PULU) instructions.

TABLE 5 — 16-BIT ACCUMULATOR AND MEMORY INSTRUCTIONS

Mnemonic(s)	Operation
ADDD	Add memory to D accumulator
CMPD	Compare memory from D accumulator
EXG D, R	Exchange D with X, Y, S, U or PC
LDD	Load D accumulator from memory
SEX	Sign Extend B accumulator into A accumulator
STD	Store D accumulator to memory
SUBD	Subtract memory from D accumulator
TFR D, R	Transfer D to X, Y, S, U or PC
TFR R, D	Transfer X, Y, S, U or PC to D

NOTE: D may be pushed (pulled) to either stack with PSHS, PSHU (PULS, PULU) instructions.

TABLE 6 — INDEX REGISTER/STACK POINTER INSTRUCTIONS

Instruction	Description
CMPS, CMPU	Compare memory from stack pointer
CMPX, CMPY	Compare memory from index register
EXG R1, R2	Exchange D, X, Y, S, U or PC with D, X, Y, S, U or PC
LEAS, LEAU	Load effective address into stack pointer
LEAX, LEAY	Load effective address into index register
LDS, LDU	Load stack pointer from memory
LDX, LDY	Load index register from memory
PSHS	Push A, B, CC, DP, D, X, Y, U, or PC onto hardware stack
PSHU	Push A, B, CC, DP, D, X, Y, S, or PC onto user stack
PULS	Pull A, B, CC, DP, D, X, Y, U or PC from hardware stack
PULU	Pull A, B, CC, DP, D, X, Y, S or PC from hardware stack
STS, STU	Store stack pointer to memory
STX, STY	Store index register to memory
TFR R1, R2	Transfer D, X, Y, S, U or PC to D, X, Y, S, U or PC
ABX	Add B accumulator to X (unsigned)

TABLE 7 — BRANCH INSTRUCTIONS

Instruction	Description
SIMPLE BRANCHES	
BEQ, LBEQ	Branch if equal
BNE, LBNE	Branch if not equal
BMI, LBMI	Branch if minus
BPL, LBPL	Branch if plus
BCS, LBCCS	Branch if carry set
BCC, LBCC	Branch if carry clear
BVS, LBVS	Branch if overflow set
BVC, LBVC	Branch if overflow clear
SIGNED BRANCHES	
BGT, LBGT	Branch if greater (signed)
BVS, LBVS	Branch if invalid 2's complement result
BGE, LBGE	Branch if greater than or equal (signed)
BEQ, LBEQ	Branch if equal
BNE, LBNE	Branch if not equal
BLE, LBLE	Branch if less than or equal (signed)
BVC, LBVC	Branch if valid 2's complement result
BLT, LBLT	Branch if less than (signed)
UNSIGNED BRANCHES	
BHI, LBHI	Branch if higher (unsigned)
BCC, LBCC	Branch if higher or same (unsigned)
BHS, LBHS	Branch if higher or same (unsigned)
BEQ, LBEQ	Branch if equal
BNE, LBNE	Branch if not equal
BLS, LBLS	Branch if lower or same (unsigned)
BCS, LBCCS	Branch if lower (unsigned)
BLO, LBLO	Branch if lower (unsigned)
OTHER BRANCHES	
BSR, LBSR	Branch to subroutine
BRA, LBRA	Branch always
BRN, LBRN	Branch never

TABLE 8 — MISCELLANEOUS INSTRUCTIONS

Instruction	Description
ANDCC	AND condition code register
CWAI	AND condition code register, then wait for interrupt
NOP	No operation
ORCC	OR condition code register
JMP	Jump
JSR	Jump to subroutine
RTI	Return from interrupt
RTS	Return from subroutine
SWI, SWI2, SWI3	Software interrupt (absolute indirect)
SYNC	Synchronize with interrupt line

TABLE 9 — HEXADECIMAL VALUES OF MACHINE CODES

OP	Mnem	Mode	-	#	OP	Mnem	Mode	-	#	OP	Mnem	Mode	-	#
00	NEG	Direct	6	2	30	LEAX	Indexed	4+	2+	60	NEG	Indexed	6+	2+
01	*				31	LEAY	Indexed	4+	2+	61	*			
02	*				32	LEAS	Indexed	4+	2+	62	*			
03	COM		6	2	33	LEAU	Indexed	4+	2+	63	COM		6+	2+
04	LSR		6	2	34	PSHS	Inherent	5+	2	64	LSR		6+	2+
05	*				35	PULS		5+	2	65	*			
06	ROR		6	2	36	PSHU		5+	2	66	ROR		6+	2+
07	ASR		6	2	37	PULU		5+	2	67	ASR		6+	2+
08	ASL, LSL		6	2	38	*				68	ASL, LSL		6+	2+
09	ROL		6	2	39	RTS		5	1	69	ROL		6+	2+
0A	DEC		6	2	3A	ABX		3	1	6A	DEC		6+	2+
0B	*				3B	RTI		6/15	1	6B	*			
0C	INC		6	2	3C	CWAI		≥20	2	6C	INC		6+	2+
0D	TST		6	2	3D	MUL		11	1	6D	TST		6+	2+
0E	JMP		3	2	3E	*				6E	JMP	Indexed	3+	2+
0F	CLR	Direct	6	2	3F	SWI	Inherent	19	1	6F	CLR	Indexed	6+	2+
10	Page 2	-	-	-	40	NEGA	Inherent	2	1	70	NEG	Extended	7	3
11	Page 3	-	-	-	41	*				71	*			
12	NOP	Inherent	2	1	42	*				72	*			
13	SYNC	Inherent	≥4	1	43	COMA		2	1	73	COM		7	3
14	*				44	LSRA		2	1	74	LSR		7	3
15	*				45	*				75	*			
16	LBRA	Relative	5	3	46	RORA		2	1	76	ROR		7	3
17	LBSR	Relative	9	3	47	ASRA		2	1	77	ASR		7	3
18	*				48	ASLA, LSLA		2	1	78	ASL, LSL		7	3
19	DAA	Inherent	2	1	49	ROLA		2	1	79	ROL		7	3
1A	ORCC	Immed	3	2	4A	DECA		2	1	7A	DEC		7	3
1B	*	-			4B	*				7B	*			
1C	ANDCC	Immed	3	2	4C	INCA		2	1	7C	INC		7	3
1D	SEX	Inherent	2	1	4D	TSTA		2	1	7D	TST		7	3
1E	EXG		8	2	4E	*				7E	JMP		4	3
1F	TFR	Inherent	6	2	4F	CLRA	Inherent	2	1	7F	CLR	Extended	7	3
20	BRA	Relative	3	2	50	NEGB	Inherent	2	1	80	SUBA	Immed	2	2
21	BRN		3	2	51	*				81	CMPA		2	2
22	BHI		3	2	52	*				82	SBCA		2	2
23	BLS		3	2	53	COMB		2	1	83	SUBD		4	3
24	BHS, BCC		3	2	54	LSRB		2	1	84	ANDA		2	2
25	BLO, BCS		3	2	55	*				85	BITA		2	2
26	BNE		3	2	56	RORB		2	1	86	LDA		2	2
27	BEQ		3	2	57	ASRB		2	1	87	*			
28	BVC		3	2	58	ASLB, LSLB		2	1	88	EORA		2	2
29	BVS		3	2	59	ROLB		2	1	89	ADCA		2	2
2A	BPL		3	2	5A	DECB		2	1	8A	ORA		2	2
2B	BMI		3	2	5B	*				8B	ADDA		2	2
2C	BGE		3	2	5C	INCB		2	1	8C	CMPX	Immed	4	3
2D	BLT		3	2	5D	TSTB		2	1	8D	BSR	Relative	7	2
2E	BGT		3	2	5E	*				8E	LDX	Immed	3	3
2F	BLE	Relative	3	2	5F	CLRB	Inherent	2	1	8F	*			

LEGEND

- Number of MPU cycles (less possible push pull or indexed-mode cycles)
- # Number of program bytes
- * Denotes unused opcode

TABLE 9 — HEXADECEMAL VALUES OF MACHINE CODES (CONTINUED)

OP	Mnem	Mode	—	#	OP	Mnem	Mode	—	#	OP	Mnem	Mode	—	#
90	SUBA	Direct	4	2	C0	SUBB	Immed	2	2					
91	CMPA	4	2		C1	CMPB	2	2						
92	SBCA	4	2		C2	SBCB	2	2						
93	SUBD	6	2		C3	ADDD	4	3						
94	ANDA	4	2		C4	ANDB	2	2						
95	BITA	4	2		C5	BITB	Immed	2	2					
96	LDA	4	2		C6	LDB	Immed	2	2					
97	STA	4	2		C7	*								
98	EORA	4	2		C8	EORB	2	2						
99	ADCA	4	2		C9	ADCB	2	2						
9A	ORA	4	2		CA	ORB	2	2						
9B	ADDA	4	2		CB	ADDB	2	2						
9C	CMPX	6	2		CC	LDD	3	3						
9D	JSR	7	2		CD	*								
9E	LDX	5	2		CE	LDU	Immed	3	3					
9F	STX	Direct	5	2	CF	*								
A0	SUBA	Indexed	4+	2+	D0	SUBB	Direct	4	2					
A1	CMPA	4+	2+		D1	CMPB	4	2						
A2	SBCA	4+	2+		D2	SBCB	4	2						
A3	SUBD	6+	2+		D3	ADDD	6	2						
A4	ANDA	4+	2+		D4	ANDB	4	2						
A5	BITA	4+	2+		D5	BITB	4	2						
A6	LDA	4+	2+		D6	LDB	4	2						
A7	STA	4+	2+		D7	STB	4	2						
A8	EORA	4+	2+		D8	EORB	4	2						
A9	ADCA	4+	2+		D9	ADCB	4	2						
AA	ORA	4+	2+		DA	ORB	4	2						
AB	ADDA	4+	2+		DB	ADDB	4	2						
AC	CMPX	6+	2+		DC	LDD	5	2						
AD	JSR	7+	2+		DD	STD	5	2						
AE	LDX	5+	2+		DE	LDU	5	2						
AF	STX	Indexed	5+	2+	DF	STU	Direct	5	2					
B0	SUBA	Extended	5	3	E0	SUBB	Indexed	4+	2+					
B1	CMPA	5	3		E1	CMPB	4+	2+						
B2	SBCA	5	3		E2	SBCB	4+	2+						
B3	SUBD	7	3		E3	ADDD	6+	2+						
B4	ANDA	5	3		E4	ANDB	4+	2+						
B5	BITA	5	3		E5	BITB	4+	2+						
B6	LDA	5	3		E6	LDB	4+	2+						
B7	STA	5	3		E7	STB	4+	2+						
B8	EORA	5	3		E8	EORB	4+	2+						
B9	ADCA	5	3		E9	ADCB	4+	2+						
BA	ORA	5	3		EA	ORB	4+	2+						
BB	ADDA	5	3		EB	ADDB	4+	2+						
BC	CMPX	7	3		EC	LDD	5+	2+						
BD	JSR	8	3		ED	STD	5+	2+						
BE	LDX	6	3		EE	LDU	5+	2+						
BF	STX	Extended	6	3	EF	STU	Indexed	5+	2+					
					F0	SUBB	Extended	5	3					
					F1	CMPB	5	3						
					F2	SBCB	5	3						
					F3	ADDD	7	3						
					F4	ANDB	5	3						
					F5	BITB	5	3						
					F6	LDB	5	3						
					F7	STB	5	3						
					F8	EORB	5	3						
					F9	ADCB	5	3						
					FA	ORB	5	3						
					FB	ADDB	Extended	5	3					
					FC	LDD	Extended	6	3					
					FD	STD	6	3						
					FE	LDU	6	3						
					FF	STU	Extended	6	3					

NOTE: All unused opcodes are both undefined and illegal

Page 2 and 3 Machine Codes

1021	LBRN	Relative	5	4
1022	LBHI	5(6)	4	
1023	LBLS	5(6)	4	
1024	LBHS, LBCC	5(6)	4	
1025	LBCS, LBLO	5(6)	4	
1026	LBNE	5(6)	4	
1027	LBEQ	5(6)	4	
1028	LBVC	5(6)	4	
1029	LBVS	5(6)	4	
102A	LBPL	5(6)	4	
102B	LBMI	5(6)	4	
102C	LBGE	5(6)	4	
102D	LBTL	5(6)	4	
102E	LBGT	5(6)	4	
102F	LBLE	5(6)	4	
103F	SWI2	Inherent	20	2
1083	CMPD	Immed	5	4
108C	CMPY	Immed	5	4
108E	LDY	Immed	4	4
1093	CMPD	Direct	7	3
109C	CMPY	Direct	7	3
109E	LDY	Direct	6	3
109F	STY	Direct	6	3
10A3	CMPD	Indexed	7+	3+
10AC	CMPY	Indexed	7+	3+
10AE	LDY	Indexed	6+	3+
10AF	STY	Indexed	6+	3+
10B3	CMPD	Extended	8	4
10BC	CMPY	Extended	8	4
10BE	LDY	Extended	7	4
10BF	STY	Extended	7	4
10CE	LDS	Immed	4	4
10DE	LDS	Direct	6	3
10DF	STS	Direct	6	3
10EE	LDS	Indexed	6+	3+
10EF	STS	Indexed	6+	3+
10FE	LDS	Extended	7	4
10FF	STS	Extended	7	4
113F	SWI3	Inherent	20	2
1183	CMPU	Immed	5	4
118C	CMPS	Immed	5	4
1193	CMPU	Direct	7	3
119C	CMPS	Direct	7	3
11A3	CMPU	Indexed	7+	3+
11AC	CMPS	Indexed	7+	3+
11B3	CMPU	Extended	8	4
11BC	CMPS	Extended	8	4

FIGURE 20 — PROGRAMMING AID

Instruction	Forms	Addressing Modes															Description	5	3	2	1	0
		Immediate			Direct			Indexed			Extended			Inherent				H	N	Z	V	C
		Op	~	#	Op	~	#	Op	~	#	Op	~	#	Op	~	#						
ABX														3A	3	1	B + X ← X (Unsigned)	*	*	*	*	*
ADC	ADCA	89	2	2	99	4	2	A9	4+	2+	B9	5	3				A + M ← A	1	1	1	1	1
	ADCB	C9	2	2	D9	4	2	E9	4+	2+	F9	5	3				B + M ← B	1	1	1	1	1
ADD	ADDA	8B	2	2	9B	4	2	AB	4+	2+	BB	5	3				A + M ← A	1	1	1	1	1
	ADDB	CB	2	2	DB	4	2	EB	4+	2+	FB	5	3				B + M ← B	1	1	1	1	1
	ADDD	C3	4	3	D3	6	2	E3	6+	2+	F3	7	3				D + M, M + 1 ← D	*	1	1	1	1
AND	ANDA	84	2	2	94	4	2	A4	4+	2+	B4	5	3				A ∧ M ← A	*	1	1	0	*
	ANDB	C4	2	2	D4	4	2	E4	4+	2+	F4	5	3				B ∧ M ← B	*	1	1	0	*
	ANDCC	1C	3	2													CC ∧ IMM ← CC	*	1	1	0	7
ASL	ASLA													48	2	1		8	1	1	1	1
	ASLB													58	2	1		8	1	1	1	1
	ASL				08	6	2	68	6+	2+	78	7	3					8	1	1	1	1
ASR	ASRA													47	2	1		8	1	1	*	1
	ASRB													57	2	1		8	1	1	*	1
	ASR				07	6	2	67	6+	2+	77	7	3					8	1	1	*	1
BIT	BITA	85	2	2	95	4	2	A5	4+	2+	B5	5	3				Bit Test A (M ∧ A)	*	1	1	0	*
	BITB	C5	2	2	D5	4	2	E5	4+	2+	F5	5	3				Bit Test B (M ∧ B)	*	1	1	0	*
CLR	CLRA													4F	2	1	0 ← A	*	0	1	0	0
	CLRB													5F	2	1	0 ← B	*	0	1	0	0
	CLR				0F	6	2	6F	6+	2+	7F	7	3				0 ← M	*	0	1	0	0
CMP	CMPA	81	2	2	91	4	2	A1	4+	2+	B1	5	3				Compare M from A	8	1	1	1	1
	CMPB	C1	2	2	D1	4	2	E1	4+	2+	F1	5	3				Compare M from B	8	1	1	1	1
	CMPD	10	5	4	10	7	3	10	7+	3+	10	8	4				Compare M, M + 1 from D	*	1	1	1	1
	CMPS	83			93			A3			B3						Compare M, M + 1 from S	*	1	1	1	1
		11	5	4	11	7	3	11	7+	3+	11	8	4									
	CMPU	8C			9C			AC			BC						Compare M, M + 1 from U	*	1	1	1	1
		11	5	4	11	7	3	11	7+	3+	11	8	4									
	CMPX	83			93			A3			B3						Compare M, M + 1 from X	*	1	1	1	1
		10	5	4	10	7	3	10	7+	3+	10	8	4									
	COM	COMA													43	2	1	A ← A	*	1	1	0
COMB														53	2	1	B ← B	*	1	1	0	1
CWAi	COM																M ← M	*	1	1	0	1
		3C	≥20	2													CC ∧ IMM ← CC Wait for Interrupt					7
DAA														19	2	1	Decimal Adjust A	*	1	1	0	1
DEC	DECA													4A	2	1	A ← A - 1	*	1	1	1	*
	DECB													5A	2	1	B ← B - 1	*	1	1	1	*
EOR	DECB				0A	6	2	6A	6+	2+	7A	7	3				M ← M - 1	*	1	1	1	*
	DEC																					
EOR	EORA	88	2	2	98	4	2	A8	4+	2+	B8	5	3				A ⊕ M ← A	*	1	1	0	*
	EORB	C8	2	2	D8	4	2	E8	4+	2+	F8	5	3				B ⊕ M ← B	*	1	1	0	*
EXG	R1, R2													1E	8	2	R1 ← R2	*	*	*	*	*
INC	INCA													4C	2	1	A ← A + 1	*	1	1	1	*
	INCB													5C	2	1	B ← B + 1	*	1	1	1	*
JMP	INC				0C	6	2	6C	6+	2+	7C	7	3				M ← M + 1	*	1	1	1	*
					0E	3	2	6E	3+	2+	7E	4	3				EA ³ ← PC	*	*	*	*	*
JSR					9D	7	2	AD	7+	2+	BD	8	3				Jump to Subroutine	*	*	*	*	*
LD	LDA	86	2	2	96	4	2	A6	4+	2+	B6	5	3				M ← A	*	1	1	0	*
	LDB	C6	2	2	D6	4	2	E6	4+	2+	F6	5	3				M ← B	*	1	1	0	*
	LDD	1C	3	3	DC	5	2	EC	5+	2+	FC	6	3				M, M + 1 ← D	*	1	1	0	*
	LDS	10	4	4	10	6	3	10	6+	3+	10	7	4				M, M + 1 ← S	*	1	1	0	*
	LDU	CE			DE			EE			FE						M, M + 1 ← U	*	1	1	0	*
		10	4	4	10	6	3	10	6+	3+	10	7	4									
	LDX	CE	3	3	DE	5	2	EE	5+	2+	FE	6	3				M, M + 1 ← X	*	1	1	0	*
		8E	3	3	9E	5	2	AE	5+	2+	BE	6	3									
	LDY	10	4	4	10	6	3	10	6+	3+	10	7	4				M, M + 1 ← Y	*	1	1	0	*
		8E			9E			AE			BE											
LEA	LEAS							32	4+	2+							EA ³ ← S	*	*	*	*	*
	LEAU							33	4+	2+							EA ³ ← U	*	*	*	*	*
	LEAX							30	4+	2+							EA ³ ← X	*	*	*	*	*
	LEAY								31	4+	2+							EA ³ ← Y	*	*	*	*

Legend

OP Operation Code (Hexadecimal)
~ Number of MPU Cycles
Number of Program Bytes
+ Arithmetic Plus
- Arithmetic Minus
• Multiply

M Complement of M
- Transfer Into
H Half-carry (from bit 3)
N Negative (sign bit)
Z Zero result
V Overflow, 2's complement
C Carry from ALU

! Test and set if true, cleared otherwise
• Not Affected
CC Condition Code Register
Concatenation
V Logical or
A Logical and
⊕ Logical Exclusive or

FIGURE 20 — PROGRAMMING AID (CONTINUED)

Instruction	Forms	Addressing Modes															Description	5 H	3 N	2 Z	1 V	0 C
		Immediate			Direct			Indexed ¹			Extended			Inherent								
		Op	-	#	Op	-	#	Op	-	#	Op	-	#	Op	-	#						
LSL	LSLA LSLB LSL				08	6	2	68	6+	2+	78	7	3	48 58	2 2	1 1		•	•	•	•	•
LSR	LSRA LSRB LSR				04	6	2	64	6+	2+	74	7	3	44 54	2 2	1 1		•	•	•	•	•
MUL														3D	11	1	A × B → D (Unsigned)	•	•	•	•	•
NEG	NEGA NEGB NEG				00	6	2	60	6+	2+	70	7	3	40 50	2 2	1 1	A ← 1 - A B ← 1 - B M ← 1 - M	•	•	•	•	•
NOP														12	2	1	No Operation	•	•	•	•	•
OR	ORA ORB ORCC	8A CA 1A	2 2 3	2 2 2	9A DA	4 4	2 2	AA EA	4+ 4+	2+ 2+	BA FA	5 5	3 3				A V M ← A B V M ← B CC V IMM ← CC	•	•	•	•	•
PSH	PSHS PSHU	34 36	5+ 5+	4 4	2 2												Push Registers on S Stack Push Registers on U Stack	•	•	•	•	•
PUL	PULS PULU	35 37	5+ 5+	4 4	2 2												Pull Registers from S Stack Pull Registers from U Stack	•	•	•	•	•
ROL	ROLA ROLB ROL				09	6	2	69	6+	2+	79	7	3	49 59	2 2	1 1		•	•	•	•	•
ROR	RORA RORB ROR				06	6	2	66	6+	2+	76	7	3	46 56	2 2	1 1		•	•	•	•	•
RTI														3B	6/15	1	Return From Interrupt					•
RTS														39	5	1	Return from Subroutine	•	•	•	•	•
SBC	SBCA SBCB	82 C2	2 2	2 2	92 D2	4 4	2 2	A2 E2	4+ 4+	2+ 2+	B2 F2	5 5	3 3				A ← M - C - A B ← M - C - B	•	•	•	•	•
SEX														1D	2	1	Sign Extend B into A	•	•	•	•	•
ST	STA STB STD STS STU STX STY				97 D7 DD 10 DF DF 9F 10 9F	4 4 5 6 5 5 5 6 6	2 2 2 3 2 2 2 3 3	A7 E7 ED 10 EF EF AF 10 AF	4+ 4+ 5+ 6+ 5+ 5+ 5+ 6+ 6+	2+ 2+ 2+ 3+ 2+ 2+ 2+ 3+ 3+	B7 F7 FD 10 FF FF BF 10 BF	5 5 6 7 6 6 6 7 7	3 3 3 4 3 3 3 4 4				A ← M B ← M D ← M M + 1 S ← M M + 1 U ← M M + 1 X ← M M + 1 Y ← M M + 1	•	•	•	•	•
SUB	SUBA SUBB SUBD	80 C0 83	2 2 4	2 2 3	90 D0 93	4 4 6	2 2 2	A0 E0 A3	4+ 4+ 6+	2+ 2+ 2+	B0 F0 B3	5 5 7	3 3 3				A ← M - A B ← M - B D ← M M + 1 - D	•	•	•	•	•
SWI	SWI ⁶ SWI ⁶ SWI ⁶													3F 10 3F 11 3F	19 20 20 20 20	1 2 1 1 1	Software Interrupt 1 Software Interrupt 2 Software Interrupt 3	•	•	•	•	•
SYNC														13	≥4	1	Synchronize to Interrupt	•	•	•	•	•
TFR	R1, R2													1F	6	2	R1 ← R2 ²	•	•	•	•	•
TST	TSTA TSTB TST				0D	6	2	6D	6+	2+	7D	7	3	4D 5D	2 2	1 1	Test A Test B Test M	•	•	•	•	•

Notes:

- This column gives a base cycle and byte count. To obtain total count, add the values obtained from the INDEXED ADDRESSING MODE table, Table 2.
- R1 and R2 may be any pair of 8 bit or any pair of 16 bit registers.
The 8 bit registers are: A, B, CC, DP
The 16 bit registers are: X, Y, U, S, D, PC
- EA is the effective address.
- The PSH and PUL instructions require 5 cycles plus 1 cycle for each byte pushed or pulled.
- 5(6) means: 5 cycles if branch not taken, 6 cycles if taken (Branch instructions).
- SWI sets I and F bits. SWI2 and SWI3 do not affect I and F.
- Conditions Codes set as a direct result of the instruction.
- Value of half-carry flag is undefined.
- Special Case — Carry set if b7 is SET.

FIGURE 20 — PROGRAMMING AID (CONTINUED)

Branch Instructions

Instruction	Forms	Addressing Mode			Description					
		Relative								
		OP	-	#		5	3	2	1	0
BCC	BCC	24	3	2	Branch C = 0 Long Branch C = 0	*	*	*	*	*
	LBCC	10	5(6)	4		*	*	*	*	*
		24								
BCS	BCS	25	3	2	Branch C = 1 Long Branch C = 1	*	*	*	*	*
	LBCCS	10	5(6)	4		*	*	*	*	*
		25								
BEQ	BEQ	27	3	2	Branch Z = 1 Long Branch Z = 0	*	*	*	*	*
	LBEQ	10	5(6)	4		*	*	*	*	*
		27								
BGE	BGE	2C	3	2	Branch $\geq$ Zero Long Branch $\geq$ Zero	*	*	*	*	*
	LBGE	10	5(6)	4		*	*	*	*	*
		2C								
BGT	BGT	2E	3	2	Branch > Zero Long Branch > Zero	*	*	*	*	*
	LBGT	10	5(6)	4		*	*	*	*	*
		2E								
BHI	BHI	22	3	2	Branch Higher Long Branch Higher	*	*	*	*	*
	LBHI	10	5(6)	4		*	*	*	*	*
		22								
BHS	BHS	24	3	2	Branch Higher or Same Long Branch Higher or Same	*	*	*	*	*
	LBHS	10	5(6)	4		*	*	*	*	*
		24								
BLE	BLE	2F	3	2	Branch $\leq$ Zero Long Branch $\leq$ Zero	*	*	*	*	*
	LBLE	10	5(6)	4		*	*	*	*	*
		2F								
BLO	BLO	25	3	2	Branch lower Long Branch Lower	*	*	*	*	*
	LBLO	10	5(6)	4		*	*	*	*	*
		25								

Instruction	Forms	Addressing Mode				Description					
		Relative									
		OP	-	5	#		H	N	Z	V	C
BLS	BLS	23	3	2	Branch Lower or Same	*	*	*	*	*	
	LBLS	10 23	5(6)	4	Long Branch Lower or Same	*	*	*	*	*	
BLT	BLT	2D	3	2	Branch < Zero	*	*	*	*	*	
	LBLT	10 2D	5(6)	4	Long Branch < Zero	*	*	*	*	*	
BMI	BMI	2B	3	2	Branch Minus	*	*	*	*	*	
	LBMI	10 2B	5(6)	4	Long Branch Minus	*	*	*	*	*	
BNE	BNE	26	3	2	Branch Z = 0	*	*	*	*	*	
	LBNE	10 26	5(6)	4	Long Branch Z ≠ 0	*	*	*	*	*	
BPL	BPL	2A	3	2	Branch Plus	*	*	*	*	*	
	LBPL	10 2A	5(6)	4	Long Branch Plus	*	*	*	*	*	
BRA	BRA	20	3	2	Branch Always	*	*	*	*	*	
	LBRA	16 3	5	3	Long Branch Always	*	*	*	*	*	
BRN	BRN	21	3	2	Branch Never	*	*	*	*	*	
	LBRN	10 21	5	4	Long Branch Never	*	*	*	*	*	
BSR	BSR	8D	7	2	Branch to Subroutine	*	*	*	*	*	
	LBSR	17	9	3	Long Branch to Subroutine	*	*	*	*	*	
BVC	BVC	28	3	2	Branch V = 0	*	*	*	*	*	
	LBVC	10 28	5(6)	4	Long Branch V = 0	*	*	*	*	*	
BVS	BVS	29	3	2	Branch V = 1	*	*	*	*	*	
	LBVS	10 29	5(6)	4	Long Branch V = 1	*	*	*	*	*	

SIMPLE BRANCHES

	OP	-	#
BRA	20	3	2
LBRA	16	5	3
BRN	21	3	2
LBRN	1021	5	4
BSR	8D	7	2
LBSR	17	9	3

SIMPLE CONDITIONAL BRANCHES (Notes 1-4)

Test	True	OP	False	OP
N = 1	BMI	28	BPL	2A
Z = 1	BEQ	27	BNE	26
V = 1	BVS	29	BVC	28
C = 1	BCS	25	BCC	24

SIGNED CONDITIONAL BRANCHES (Notes 1-4)

Test	True	OP	False	OP
$r > m$	BGT	2E	BLE	2F
$r \geq m$	BGE	2C	BLT	2D
$r = m$	BEQ	27	BNE	26
$r \leq m$	BLE	2F	BGT	2E
$r < m$	BLT	2D	BGE	2C

UNSIGNED CONDITIONAL BRANCHES (Notes 1-4)

Test	True	OP	False	OP
$r > m$	BHI	22	BLS	23
$r \geq m$	BHS	24	BLO	25
$r = m$	BEQ	27	BNE	26
$r \leq m$	BLS	23	BHI	22
$r < m$	BLO	25	BHS	24

Notes:

1. All conditional branches have both short and long variations.
2. All short branches are 2 bytes and require 3 cycles.
3. All conditional long branches are formed by prefixing the short branch opcode with \$10 and using a 16-bit destination offset.
4. All conditional long branches require 4 bytes and 6 cycles if the branch is taken or 5 cycles if the branch is not taken.
5. 5(6) means: 5 cycles if branch not taken, 6 cycles if taken.

INDEXED ADDRESSING MODES

TYPE	FORMS	NON INDIRECT			INDIRECT		
		Assembler Form	Post-Byte OP Code	- #	Assembler Form	Post-Byte OP Code	- #
CONSTANT OFFSET FROM R	NO OFFSET	. R	1RR00100	0 0	[. R]	1RR10100	3 0
	5 BIT OFFSET	n. R	0RRnnnnn	1 0	defaults to 8-bit		
	8 BIT OFFSET	n. R	1RR01000	1 1	[n. R]	1RR11000	4 1
	16 BIT OFFSET	n. R	1RR01001	4 2	[n. R]	1RR11001	7 2
ACCUMULATOR OFFSET FROM R	A—REGISTER OFFSET	A. R	1RR00110	1 0	[A. R]	1RR10110	4 0
	B—REGISTER OFFSET	B. R	1RR00101	1 0	[B. R]	1RR10101	4 0
	D—REGISTER OFFSET	D. R	1RR01011	4 0	[D. R]	1RR11011	7 0
AUTO INCREMENT/DECREMENT R	INCREMENT BY 1	. R +	1RR00000	2 0	not allowed		
	INCREMENT BY 2	. R ++	1RR00001	3 0	[. R ++]	1RR10001	6 0
	DECREMENT BY 1	. - R	1RR00010	2 0	not allowed		
	DECREMENT BY 2	. -- R	1RR00011	3 0	[. -- R]	1RR10011	6 0
CONSTANT OFFSET FROM PC	8 BIT OFFSET	n. PCR	1XX01100	1 1	[n. PCR]	1XX11100	4 1
	16 BIT OFFSET	n. PCR	1XX01101	5 2	[n. PCR]	1XX11101	8 2
EXTENDED INDIRECT	16 BIT ADDRESS	—	—	—	[n]	10011111	5 2

R = X, Y, U, or S
X = DON'T CARE

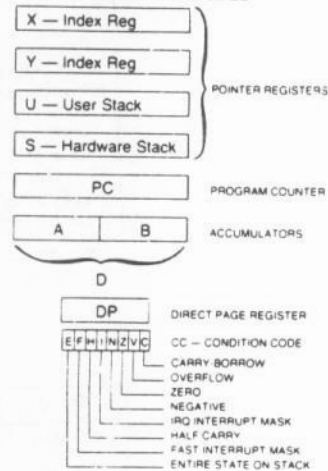
RR: 00 = X 10 = U
 01 = Y 11 = S

INDEXED ADDRESSING POSTBYTE
REGISTER BIT ASSIGNMENTS

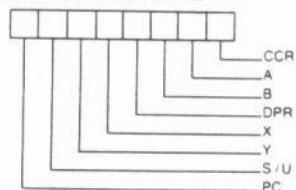
POST-BYTE REGISTER BIT	INDEXED ADDRESSING MODE
7 6 5 4 3 2 1 0	
0 R R x x x x x	EA = .R + 5 Bit Offset
1 R R 0 0 0 0 0	. R +
1 R R 1 0 0 0 1	. R ++
1 R R 0 0 0 1 0	. - R
1 R R 1 0 0 1 1	. -- R
1 R R 1 0 1 0 0	EA = .R + 0 Offset
1 R R 1 0 1 0 1	EA = .R + ACCB Offset
1 R R 1 0 1 1 0	EA = .R + ACCA Offset
1 R R 1 1 0 0 0	EA = .R + 8 Bit Offset
1 R R 1 1 0 0 1	EA = .R + 16 Bit Offset
1 R R 1 1 0 1 1	EA = .R + D Offset
1 x x 1 1 1 0 0	EA = PC + 8 Bit Offset
1 x x 1 1 1 0 1	EA = PC + 16 Bit Offset
1 R R 1 1 1 1 1	EA = [.Address]

Addressing Mode Field
Indirect Field
!Sign bit when b7 = 0!
Register Field RR
00 = X
01 = Y
10 = U
11 = S
x = Don't Care

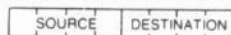
6809 PROGRAMMING MODEL



PUSH/PULL POST BYTE



TRANSFER/EXCHANGE POST BYTE



REGISTER FIELD

0000 D (A B)	1000 A
0001 X	1001 B
0010 Y	1010 CCR
0011 U	1011 DPR
0100 S	
0101 PC	

6809 STACKING ORDER

PULL ORDER



PUSH ORDER

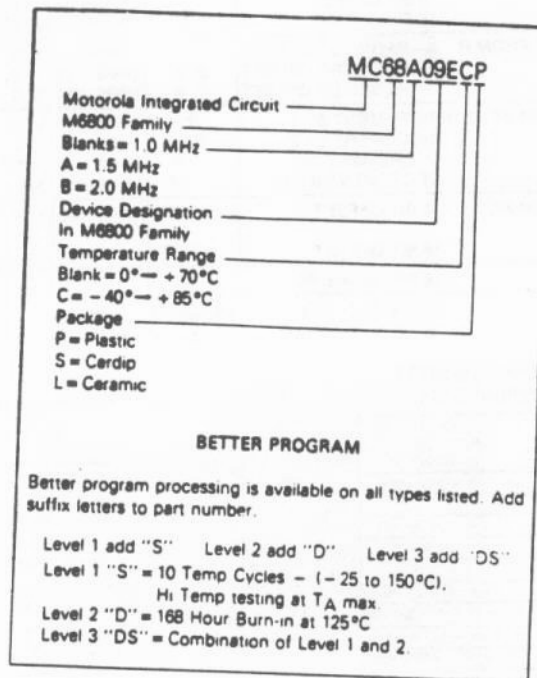
INCREASING
MEMORY



6809 VECTORS

FFFF	Restart
FFFC	NMI
FFFA	SWI
FFF8	IRQ
FFF6	FI/RQ
FFF4	SWI2
FFF2	SWI3
FFF0	Reserved

ORDERING INFORMATION



Speed	Device	Temperature Range
1.0 MHz	MC6809EP,L,S	0 to 70°C
1.5 MHz	MC68A09EP,L,S	0 to + 70°C
2.0 MHz	MC68B09EP,L,S	0 to + 70°C