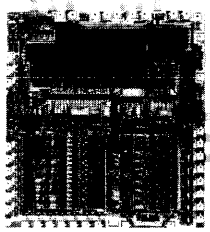
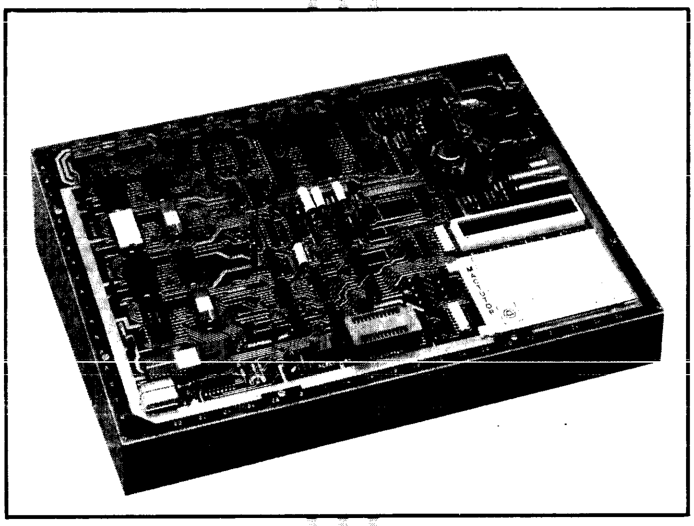
PA-800515
Issue 2, July 1979
AT&T Co Provisional



MAC-8



1A MICROPROCESSOR TRAINING AID MAC TUTOR REFERENCE MANUAL

Bell Laboratories

NOTICE

Prepared and published for the
Microprocessor Systems Development Department
by the
Technical Documentation Department
Bell Laboratories

Printed in U.S.A.

CONTENTS	PAGE NUMBER	ISSUE NUMBER AND DATE 4-1-79	7-1-79										
PAGE INDEX	A1	1	2										
	A2	1	2										
	A3	1	2										
	A4	1	2										
	A5	1	2										
	A6	Blank											
TITLE PAGE, FRONT	-	1	2										
TITLE PAGE, REAR	-	1	-										
FOREWORD, FRONT	-	-	2										
FOREWORD, REAR	-	Blank											
CONTENTS	i	1	2										
	ii	1	2										
CHAPTER 1 TITLE PAGE													
FRONT	-	1	-										
REAR	-	Blank											

PAGE INDEX NOTES

1. WHEN CHANGES ARE MADE IN THIS DOCUMENT, ONLY THOSE PAGES AFFECTED WILL BE REISSUED.
2. THIS PAGE INDEX WILL BE REISSUED AND BROUGHT UP TO DATE EACH TIME ANY PAGE OF THE DOCUMENT IS REISSUED, OR A NEW PAGE IS ADDED.
3. THE ISSUE NUMBER ASSIGNED TO A CHANGED OR NEW PAGE WILL BE THE SAME ISSUE NUMBER AS THAT OF THE PAGE INDEX.
4. PAGES THAT ARE NOT CHANGED WILL RETAIN THEIR EXISTING ISSUE NUMBER.
5. THE LAST ISSUE NUMBER OF THE PAGE INDEX IS RECOGNIZED AS THE LATEST ISSUE NUMBER OF THE DOCUMENT AS A WHOLE.

SUPPORTING INFORMATION

CATEGORY	NUMBER

Bell Laboratories

MAC TUTOR
REFERENCE MANUAL

AT&T Co.
Provisional

PA-800515-A1

CONTENTS	PAGE NUMBER	ISSUE NUMBER 1	2
1. SYSTEM OVERVIEW	1-1	1	2
	1-2	1	2
	1-3	1	2
	1-4	Blank	
	1-5	1	2
	1-6	Blank	
	1-7	1	2
	1-8	Blank	
	1-9	1	2
	1-10	Blank	
CHAPTER 2 TITLE PAGE			
FRONT	-	1	-
REVERSE	-	Blank	
2. MAC-TUTOR HARDWARE	2-1	1	2
	2-2	1	2
	2-3	1	2
	2-4	-	2
	2-5	1	2
	2-6	Blank	
	2-7	1	2
	2-8	Blank	
	2-9	1	-
	2-10	Blank	
	2-11	1	2
	2-12	1	2
	2-13	1	2
	2-14	1	2
	2-15	1	2
	2-16	1	2
	2-17	1	2
	2-18	1	2
	2-19	1	2
	2-20	Blank	

CONTENTS	PAGE NUMBER	ISSUE NUMBER 1	2
5. SOFTWARE	5-1	12	2
	5-2	1	2
	5-3	1	2
	5-4	1	2
	5-5	1	2
	5-6	1	2
APPENDIX TITLE PAGE			
FRONT	-	-	2
REAR	-	Blank	
APPENDIX, RESIDENT EXECUTIVE SOFTWARE	A-1	-	2
	A-2	-	2
	A-3	-	2
	A-4	-	2
	A-5	-	2
	A-6	-	2
	A-7	-	2
	A-8	-	2
	A-9	-	2
	A-10	-	2
	A-11	-	2
	A-12	-	2
	A-13	-	2
	A-14	-	2
	A-15	-	2
	A-16	-	2
	A-17	-	2
	A-18	-	2
	A-19	-	2
	A-20	-	2
	A-21	-	2
	A-22	-	2
	A-23	-	2
	A-24	-	2
	A-25	-	2

CONTENTS	PAGE NUMBER	ISSUE NUMBER 1	2
APPENDIX, Cont.	A-26	-	2
	A-27	-	2
	A-28	-	2
A-29	A-29	-	2
	A-30	-	2
	A-31	-	2
	A-32	-	2
	A-33	-	2
	A-34	-	2

FOREWORD

MAC-Tutor has been coded by the Western Electric Company as the No. 1A Microprocessor Training Aid (component code 103180717), but will be called MAC-Tutor throughout this manual.

The following manuals are shipped with the No. 1A Microprocessor Training Aid:

PA-800515 MAC-TUTOR REFERENCE MANUAL
PA-800516 MAC-TUTOR SELF-TRAINING MANUAL
PA-800517 MAC-8 HEXADECIMAL CODING CHART

For questions or comments concerning MAC-Tutor usage, repairs, documentation, and/or to be placed on distribution for future documentation updates, dial the MAC-Phone on CORNET 233, extension MAC8 (6228).

MAC TUTOR REFERENCE MANUAL

CONTENTS

Chapter 1

SYSTEM OVERVIEW

1. SYSTEM OVERVIEW

1.1 Introduction

The MAC Tutor is a low cost, self-contained, microprocessor-based system developed to familiarize users with microprocessor basics and, in particular, with MAC-8 microprocessor operation.

1.2 System Features

The MAC Tutor contains an on-board keypad and an 8-digit display whereby MAC-8 programs can be entered, executed, and debugged. In addition, the necessary interface is available for various peripheral equipment, such as a teletypewriter (TTY) terminal, a time-sharing computer, or a cassette tape recorder. Figure 1-1 shows the MAC Tutor sections.

MAC Tutor features include:

- MAC-8 microprocessor
- 2K bytes of random-access memory (RAM)
- 2K read-only memory (ROM) executive program to control hardware features
- Sockets for three 1K-byte programmable read-only memories (PROMs)
- Eight 7-segment light-emitting diode (LED) displays
- 28-button, calculator-type keypad
- PROM programming socket capable of creating and verifying Intel 2708-type, 1K-byte PROMs
- Audio cassette interface for storing and retrieving data at a rate of 166 baud
- 32 input/output (I/O) lines with a socket to add another 24 lines
- RS232C interface for TTY-compatible terminals capable of running at rates from 0 to 2400 baud
- Data set interface with software-controlled data direction switch
- Address and data buses available on 16-pin connectors for addition of memory or peripherals
- Ability to single-step program instructions
- On-board power supply (110-volt ac, 60-Hz input required)

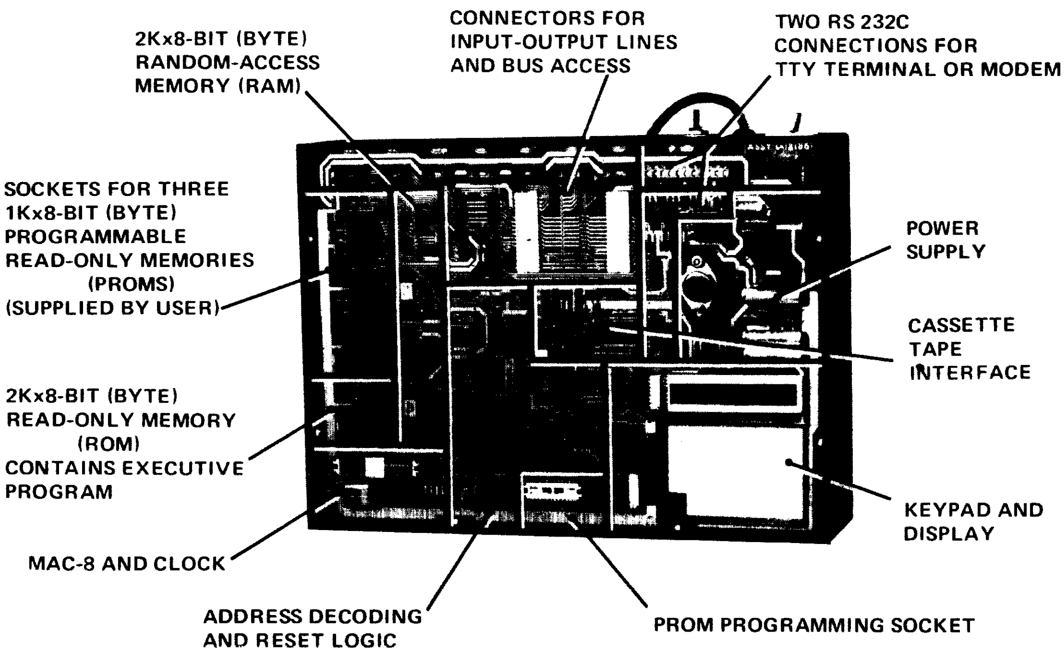


Figure 1-1. MAC Tutor Sections

Note: The material in this manual pertains to ISSUE 4 models (prototype version). ISSUE 4 schematic diagrams are shown in Figures 1-2 and 1-3. ISSUE 3 schematic diagrams, Figures 1-4 and 1-5, are included for reference only.

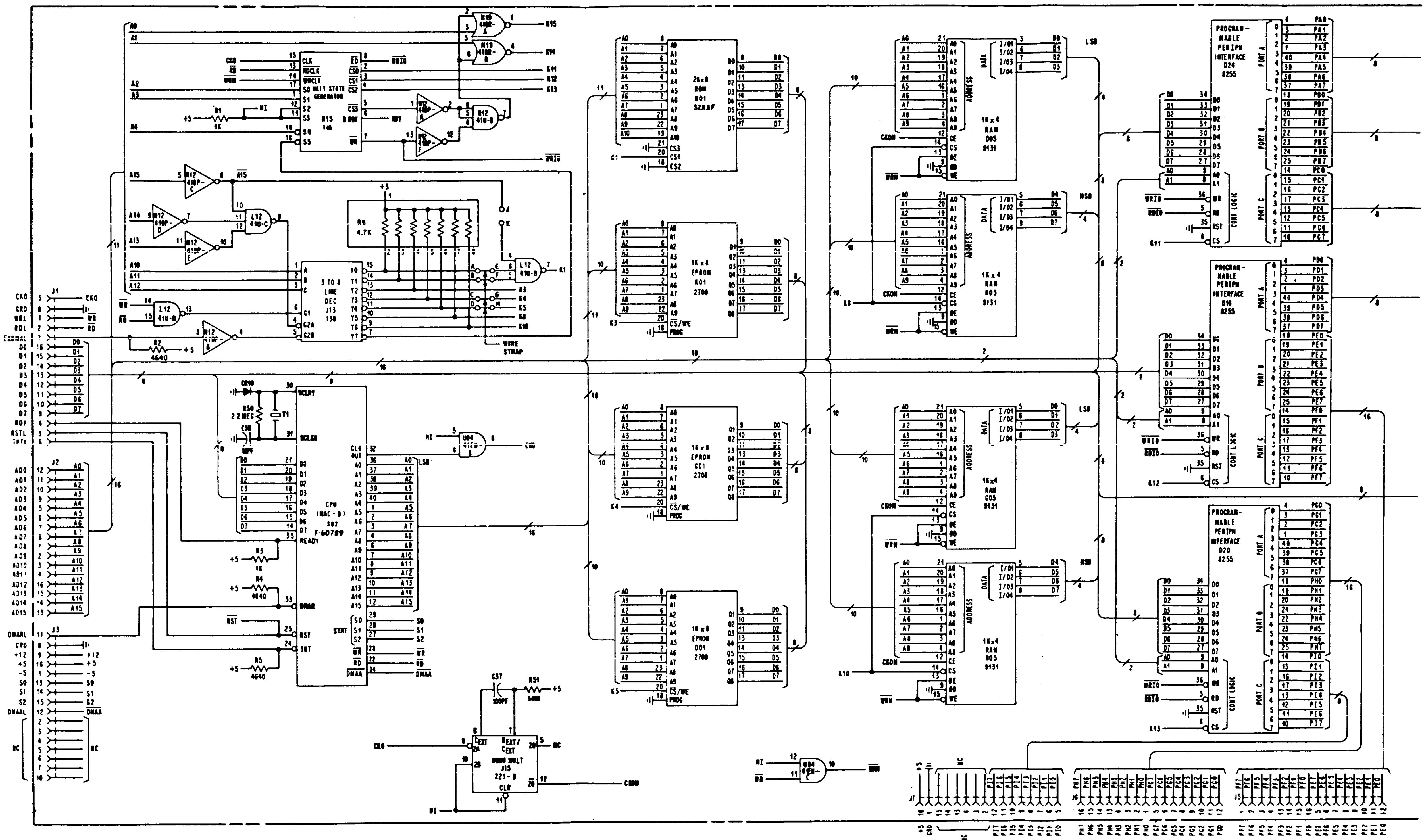


Figure 1-2. MAC Tutor Schematic Diagram
Issue 4, Sheet 1

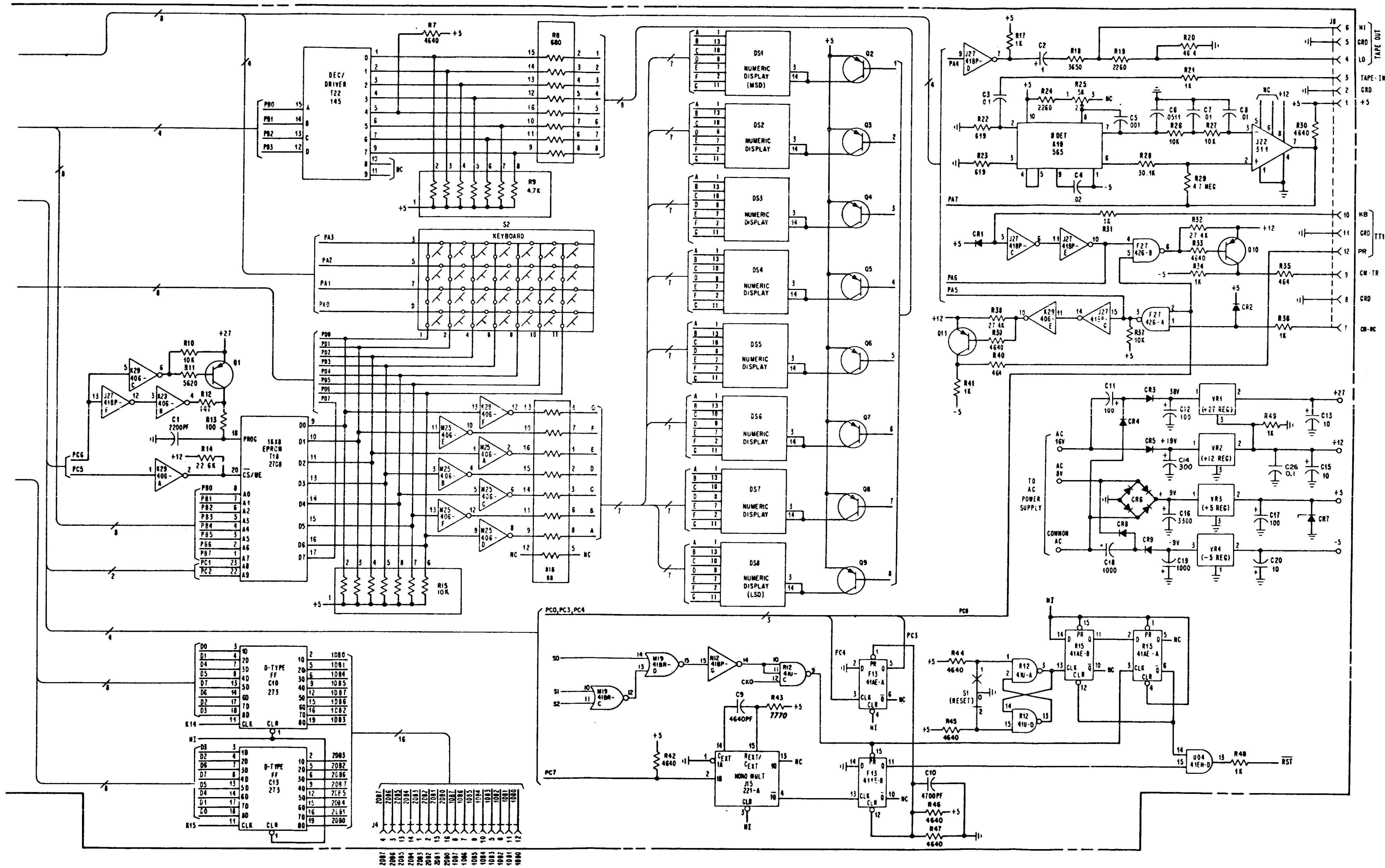


Figure 1-3. MAC Tutor Schematic Diagram
Issue 4, Sheet 2

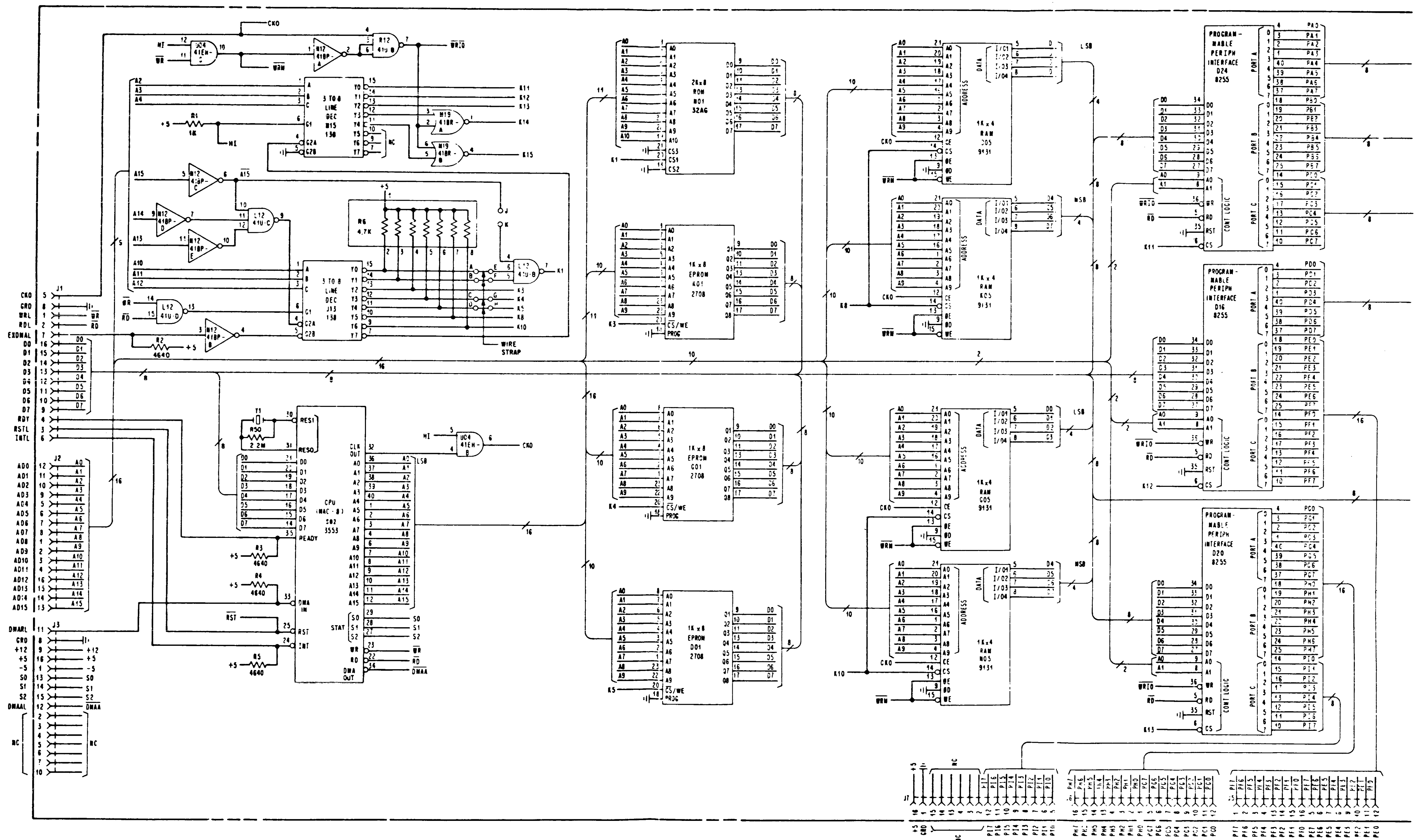


Figure 1-4. MAC Tutor Schematic Diagram
Issue 3, Sheet 1

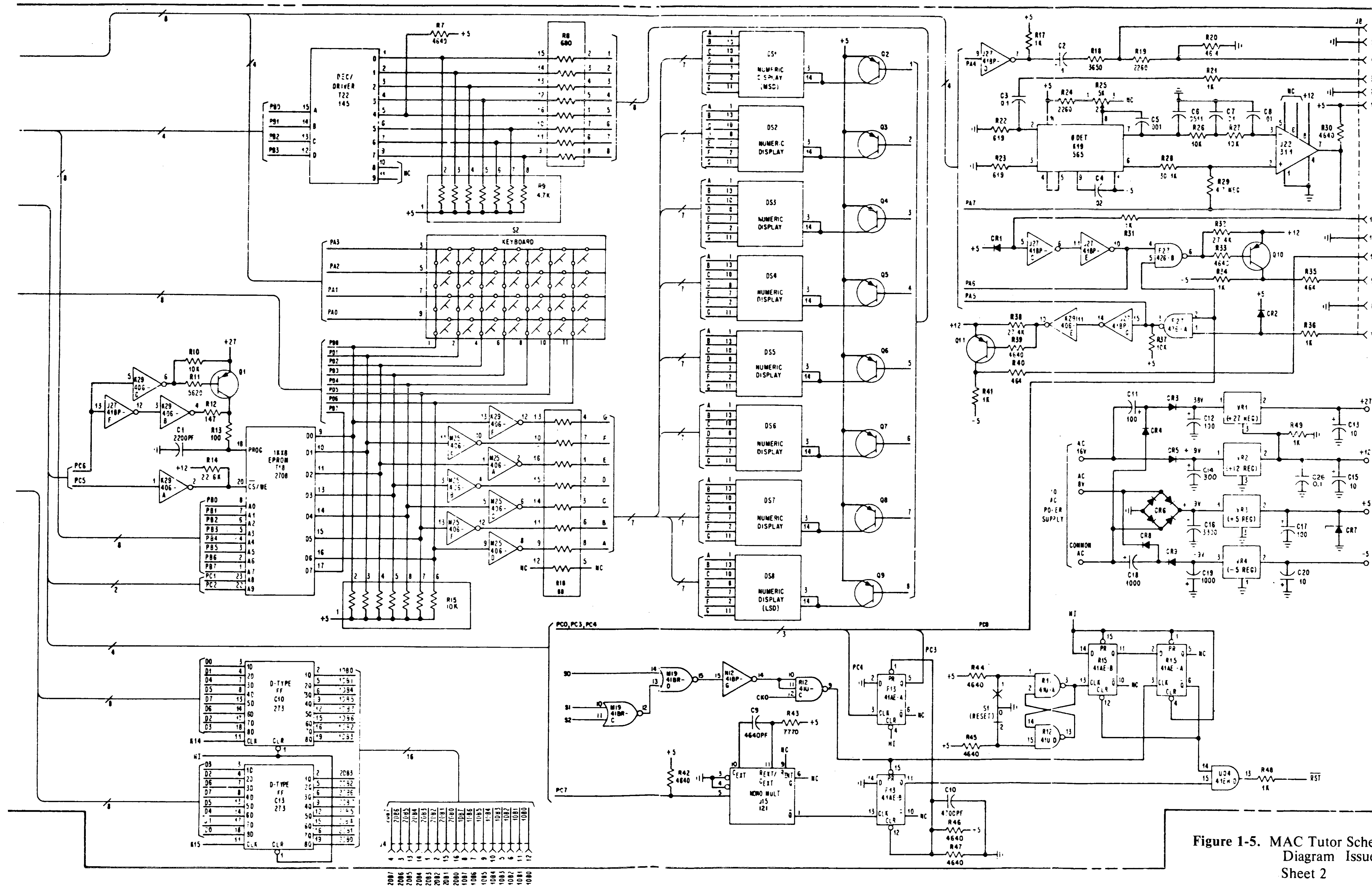


Figure 1-5. MAC Tutor Schematic Diagram Issue 3, Sheet 2

Chapter 2

MAC TUTOR HARDWARE

2. MAC TUTOR HARDWARE

2.1 Functional Description

The MAC Tutor contains a MAC-8 microprocessor and the associated control circuitry to perform the computing and controlling functions for the entire MAC Tutor. Figure 2-1 is a block diagram of the MAC Tutor hardware.

The instructions to be executed by the MAC-8 are contained in the ROM and RAM. The ROM can be mask programmed at the factory or field programmed by inserting a blank PROM into the PROM programmer. The RAM can be read or written directly with the microprocessor.

The 2K-byte ROM (mask programmed) contains an executive program that includes the routines required to drive the display, read the keypad, and communicate with a terminal.

The 1K-byte RAM is used for MAC-8 registers, stack memory, and a user's program. Because this memory is volatile, it must be recorded into a PROM or cassette tape for retention.

Three sockets are provided for 2708-type PROMs, each having a capacity of 1K bytes. These PROMs can be programmed with the on-board programmer, using the separate 24-pin socket. Programs are erased by exposing the PROMs to ultraviolet light.

Users enter and debug their MAC-8 programs by interfacing with the 28-button keypad and eight 7-segment LED displays. Commands to the executive program are issued through the keypad and acknowledged through the display.

Sixty-four I/O lines, with a socket to add another 24 lines, are provided. Thirty-two I/O lines are used for internal operation and the remaining lines terminate at the 16-pin periphery sockets. Sixteen of these lines are transistor-transistor logic (TTL) outputs with an 8-mA current drive. The others that can be programmed as I/O lines are also TTL compatible, but have a 1.6-mA current drive (4 LSTTL Loads).

The computer/TTY data switch allows a remote computer or TTY terminal to communicate with the MAC Tutor.

A commercial quality cassette tape recorder can be used to store and retrieve files by connecting the microphone input and earphone output to the MAC Tutor.

A conventional 110-volt input connects to the on-board power supply, which generates the required voltage levels of ± 5, +12, and +27 volts dc.

2.2 Electrical Characteristics

The electrical sections of the MAC Tutor are: the MAC-8 and reset circuitry, ROM and RAM, I/O, keypad and display, PROM programmer, TTY terminal and data set interface, cassette tape interface, power supply circuitry, and timing.

2.2.1 MAC-8 Microprocessor and Reset Circuitry (See Figure 2-2.)

Conventionally, the reset input to a CPU resets the program counter to zero and a program begins to execute. However, the MAC-8 CPU also handles the reset input as a nonmaskable interrupt. That is, the status of the CPU is saved before resetting. As a result, the MAC Tutor uses the reset input for a power-on reset, single stepping, and nonmaskable interrupt. The **reset** button then allows the user to stop the execution of a program and monitor the location and status at that point. This unique feature requires the reset circuit to clock-in on only one reset request.

When the **reset** button is depressed, the first operation code (opcode) fetch generates the reset and the succeeding opcode fetch disables the reset.

A power-on detect flip-flop (F13-A) serves to distinguish between the reset function and the nonmaskable interrupt. Multivibrator J15 applies the reset signal 25 μs after a low to high signal transition to provide the single-stepping capability.

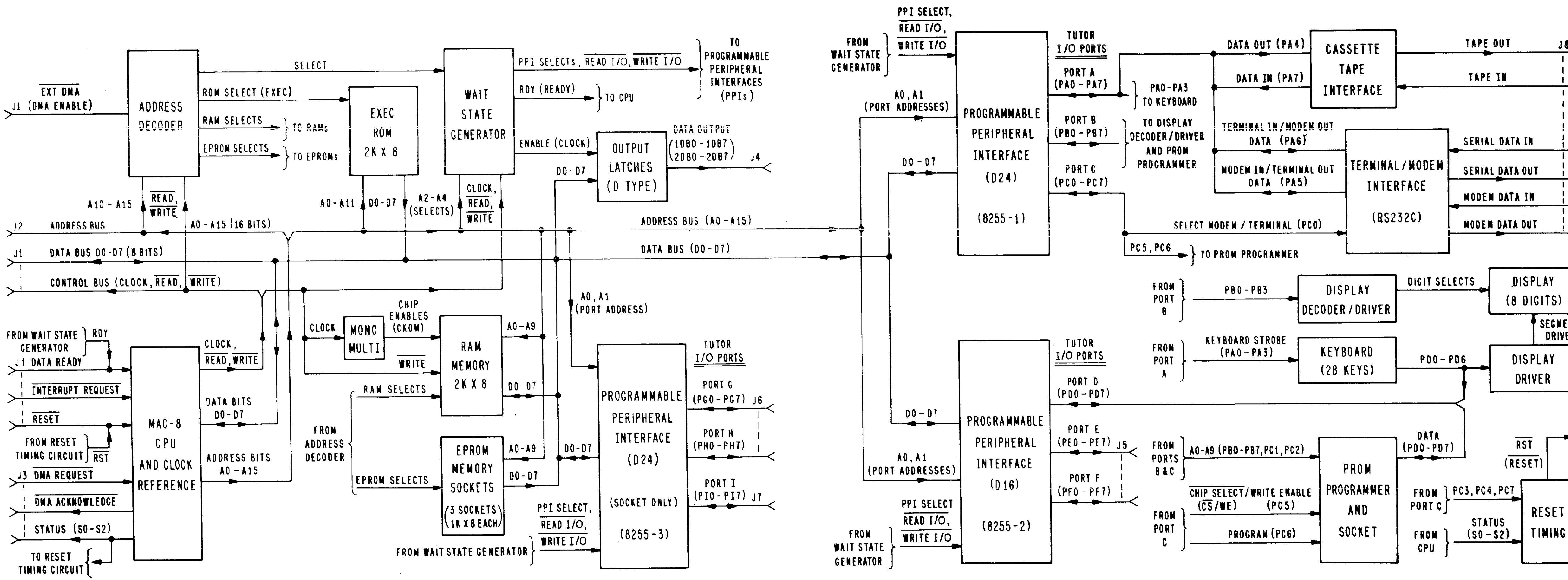
The basic controlling signals for remote access or system expansion are available at connectors J1, J2, and J3. These signals include the address and data buses as well as the +12, +5, and -5 volt dc buses. The 1-kilohm resistor (R48) allows the reset pin to be externally driven.

2.2.2 ROM and RAM (See Figure 2-3.)

The MAC Tutor circuitry is capable of driving one 2K by 8 ROM, three 1K by 8 PROMs, and four 1K by 4 RAMs. The chip-select lines are decoded from the address space through a 3- to 8-line decoder (J13 138). Table 2-1 lists the address assignments provided through these decoders.

The AMD 9131 clocked static RAMs do not need refreshing, but require a clock transition to latch in the address and chip-select signals. The required clock pulse edge is generated by a monostable multivibrator (J15 221-B, one-half of the 74221). The multivibrator is triggered by the falling edge of the clock-out pulse (CKO). Then, after a 400-ms delay, a positive going clock pulse (CKOM) is generated. For 2-MHz operation, a faster clock pulse edge is required.

PA-800515
Issue 2, July 1979



NOTE
Pin information for connectors J1 through J8 is shown in Table 2-2. MAC Tutor Pinouts.

Figure 2-1. Functional Block Diagram of MAC-Tutor

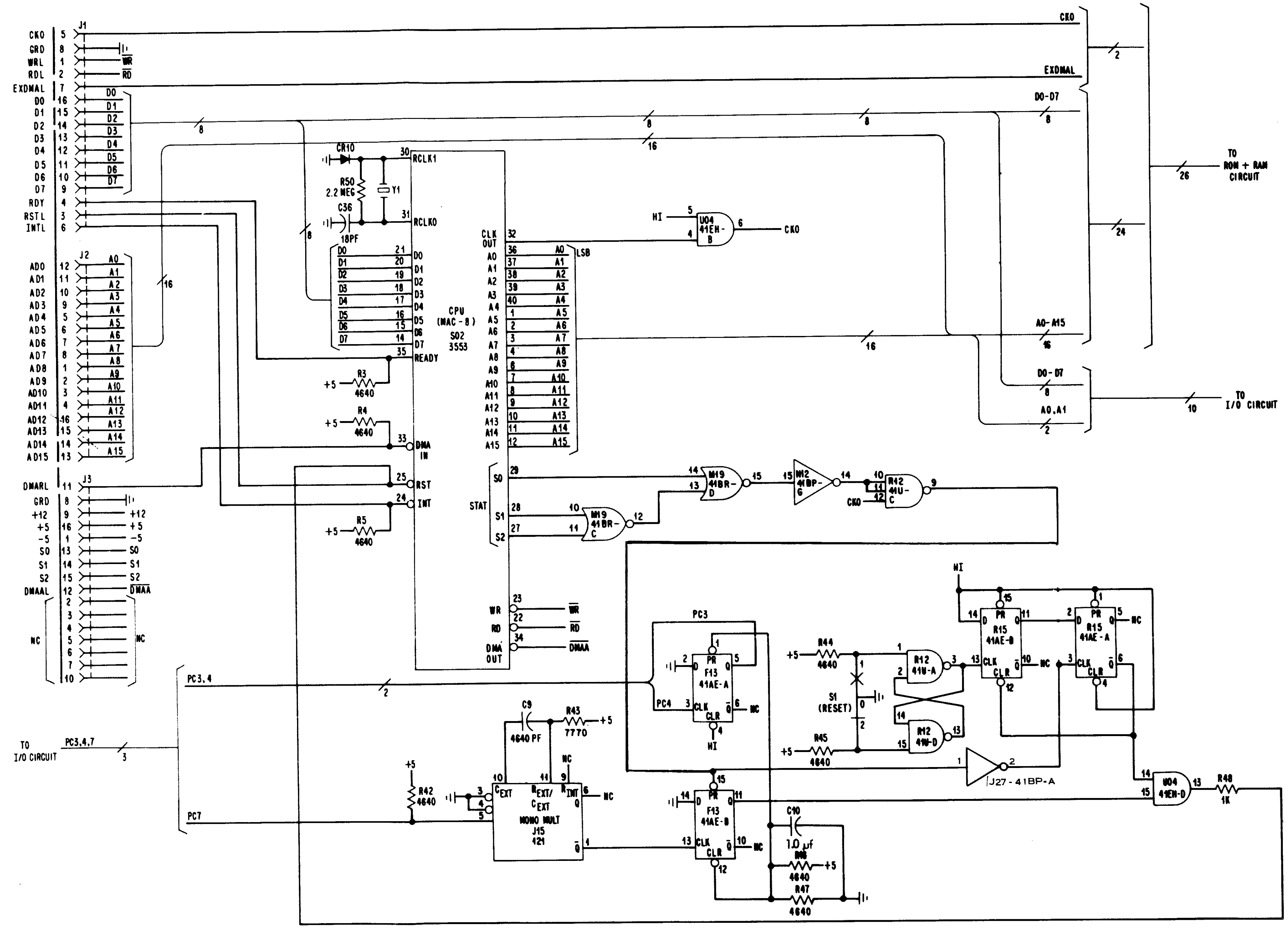


Figure 2-2. MAC-8 Microprocessor and Reset Circuitry Schematic Diagram

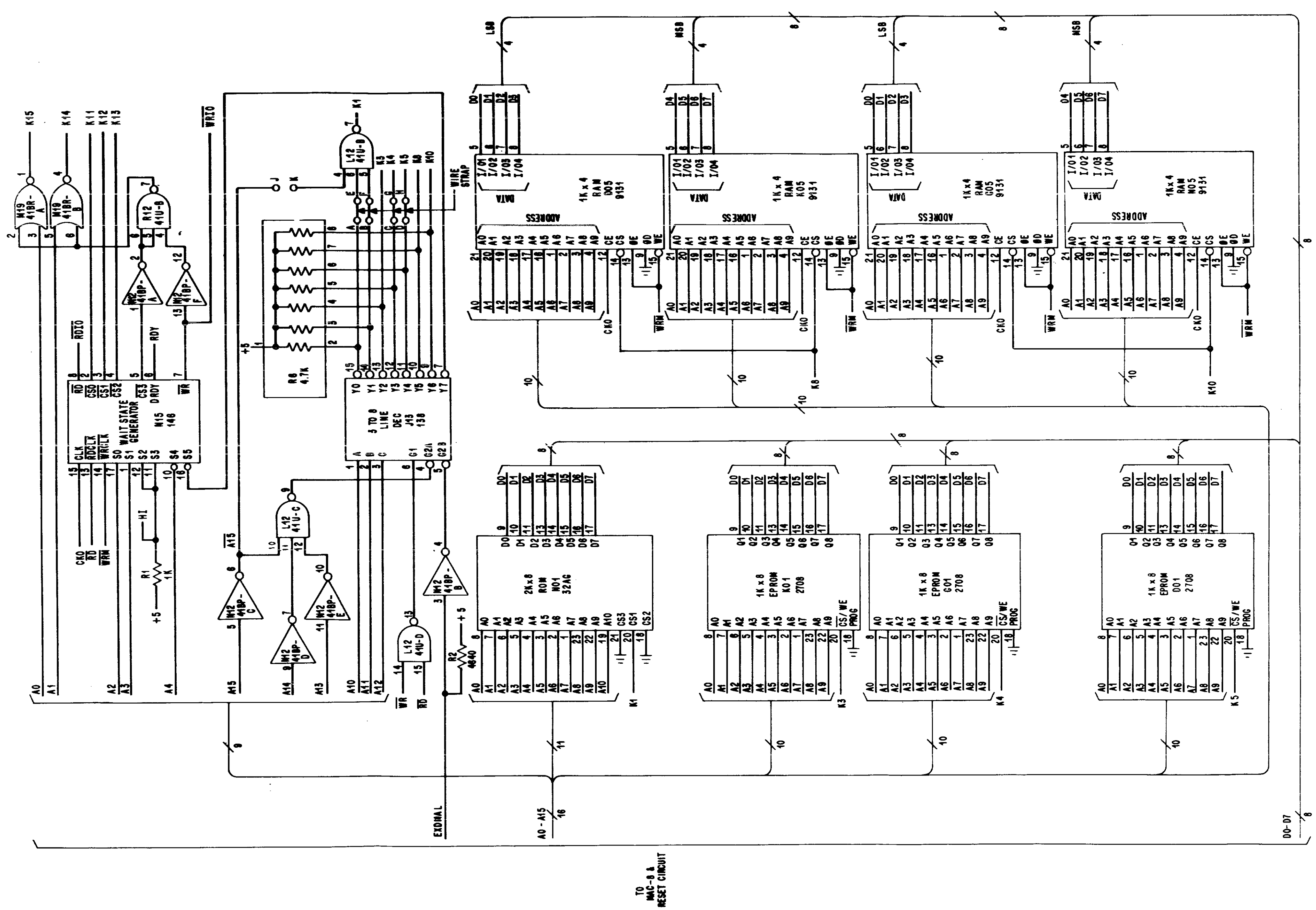


Figure 2-3. ROM and RAM Schematic Diagram

TABLE 2-1. ADDRESS ASSIGNMENTS/MEMORY MAP

Device	Physical Location	A15	A14	A13	A12	A11	A10	A4	A3	A2	A1	A0	Hex Addresses
32AG ROM 32AAF ROM	N01	0	0	0	0	0	X						0000-07FF
2708 PROM	K01	0	0	0	0	1	0						0800-OBFF
2708 PROM	G01	0	0	0	0	1	1						0C00-OFFF
2708 PROM	D01	0	0	0	1	0	0						1000-13FF
9131 RAM	D05-K05	0	0	0	1	0	1						1400-17FF
9131 RAM	G05-N05	0	0	0	1	1	0						1800-1BFF
8255 I/O	D24	0	0	0	1	1	1	0	0	0			1F00-1F03
8255 I/O	D16	0	0	0	1	1	1	0	0	1			1F04-1F07
8255 I/O	D20	0	0	0	1	1	1	0	1	0			1F08-1F0B
74LS273 I/O	C10	0	0	0	1	1	1	0	1	1	0	1	1F0D
74LS273 I/O	C13	0	0	0	1	1	1	0	1	1	1	0	1F0E

Table Notes: 1. X designates either logical 1 or 0. Blank areas indicate future expansion.

2. Unit comes equipped with one of the two listed ROMs.

Four wire straps connecting points A through D to E through H provide memory assignment flexibility. By interchanging points A and B with C and D, the address of executive ROM is interchanged with that of PROM 2 and PROM 3. This allows the user's PROM to have immediate control under a power-on or reset condition.

A wire strap between points J and K allows an interrupt to the MAC-8 to cause control of the program to transfer to the first location in PROM 1.

The memory configuration can be expanded or replaced by connecting external address signals to the two 16-pin dual in-line package (DIP) connectors, J1 and J2, located at the periphery. The entire memory can be deactivated by keeping EXDMAL (J1, pin 7) low.

2.2.3 I/O (See Figure 2-4.)

The MAC Tutor circuitry is capable of driving three Intel 8255 programmable peripheral interface (PPI) integrated circuits and two 74LS273 octal latches.

Each 8255 PPI has three I/O ports (eight lines per port) that can be programmed as either inputs or outputs. In the output configuration, they can only drive one medium-power TTL load. However, the two output ports provided by the 74LS273 latches have a drive fanout of 10 Low Power Schottky TTL (LSTTL) loads.

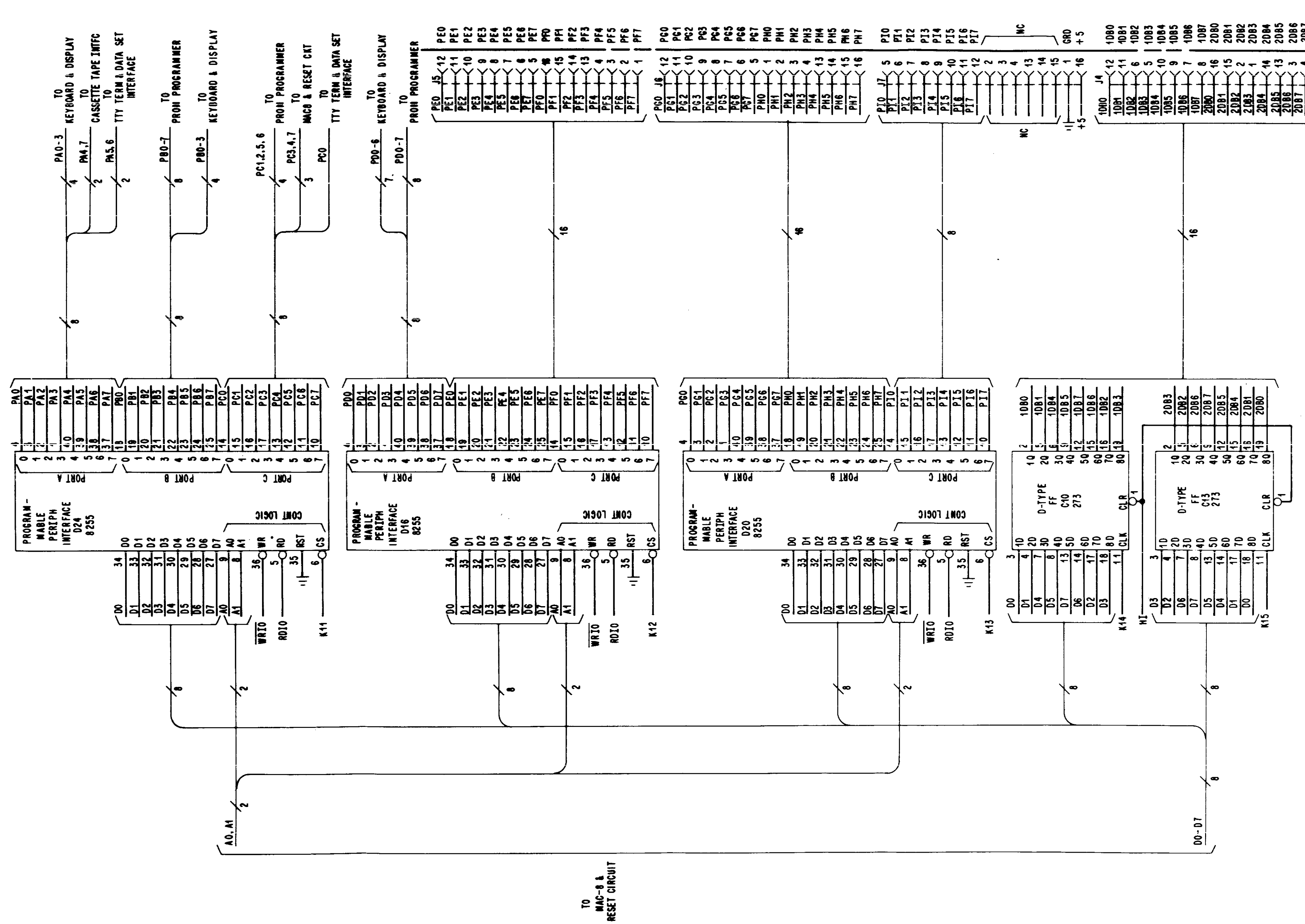


Figure 2-4. I/O Port Schematic Diagram

Four of the I/O ports are used mainly to drive the keypad display, and PROM. Additionally, two 8255 I/O ports, or five 8255 I/O ports when fully equipped, are available at connectors J5 through J7. The remaining two 74LS273 ports are available at connector J4.

A wait state generator integrated circuit (WE-146D) provides the required decoding and timing for the I/O devices. Refer to Figure 2-3 for circuit details.

Table 2-2 contains a listing of all the I/O pinouts. (This information is also included on Figures 1-2 and 1-3.)

TABLE 2-2. MAC Tutor Pinouts

Pin Number/Connector								Connector J8	
J1 A00	J2 A04	J3 A08	J4 A12	J5 A16	J6 A20	J7 A24	Pin No.	Designation	Pin No.
WRL	AD8	-5	2DB3	PF7	PH0	GRD	1	+5 VOLTS	1
RDL	AD9	NC	2DB2	PF6	PH1	NC	2	GRD	2
RSTL	AD10	NC	2DB6	PF5	PH2	NC	3	TAPE-IN	3
RDY	AD11	NC	2DB7	PF4	PH3	NC	4	TAPE-OUT-LO	4
CKO	AD4	NC	1DB3	PE7	PG7	PI0	5	GRD	5
INTL	AD5	NC	1DB2	PE6	PG6	PI1	6	TAPE-OUT-HI	6
EXDMAL	AD6	NC	1DB6	PE5	PG5	PI2	7	CM-RC	7
GRD	AD7	GRD	1DB7	PE4	PG4	PI3	8	GRD	8
D7	AD3	+12	1DB5	PE3	PG3	PI4	9	CM-TR	9
D6	AD2	NC	1DB4	PE2	PG2	PI5	10	TTY-KB	10
D5	AD1	DMARL	1DB1	PE1	PG1	PI6	11	GRD	11
D4	AD0	DMAAL	1DB0	PE0	PG0	PI7	12	TTY-PR	12
D3	AD15	S0	2DB5	PF3	PH4	NC	13		
D2	AD14	S1	2DB4	PF2	PH5	NC	14		
D1	AD13	S2	2DB1	PF1	PH6	NC	15		
D0	AD12	+5	2DB0	PF0	PH7	+5	16		

2.2.4 Keypad (See Figure 2-5.)

The keypad includes a 4 by 7 array of switches that is read with a strobing algorithm. Each row is strobed with a logical 0 signal and the state of the seven columns is read. Since the column outputs are converted to logic highs by a set of resistors (R15), a keypad depression in a particular column will cause a logical 0 reading at that input line. Strobing is repeated for the four rows so the MAC-8 can determine the state of the keypad.

The display contains eight 7-segment LED displays where digits are multiplexed in time and driven by common segment drivers. The same lines (PD0 through PD6) that are used to read the keypad also drive the segments. Output lines PB0 through PB3 are decoded to select the appropriate digit.

2.2.5 PROM Programmer (See Figure 2-6.)

The programming procedure for 2708 PROMs requires the following:

- Initiate write enable by applying 12 volts to $\overline{CS}$/WE pin.
- Sequence the address space of the 2708 PROM and apply data to be programmed for each address.
- When the address and data are valid, apply a 27-volt pulse of 1-ms duration to PROGRAM pin throughout the address sequence.
- Repeat address sequence 100 times.

A mix of software and hardware is used to implement the preceding procedure. High-level timing and control are done in software. The hardware has the 12-volt driver for the write enable signal and the 27-volt driver for the program pulse. This program pulse is generated by the resistance-capacitance (RC) circuit (R12, R13, C1) to produce a 1-μs rise and fall time level. level.

The PROM address and data lines are driven directly from the I/O ports so the MAC-8 can sequence through the address and data, and control the high-voltage drivers. After device programming, the MAC-8 is able to read the PROM if a low-level signal is coupled to the $\overline{CS}$ pin. This allows the PROM to be verified prior to programming for an erased condition (all 1s) and after programming for programmed contents.

2.2.6 TTY Terminal and Data Set Interface (See Figure 2-7.)

When a TTY terminal is connected to the MAC Tutor, all operations provided from the onboard keypad/display can be controlled from the TTY terminal. The interface to the TTY terminal is through a serial I/O line under direct control of the MAC-8. The MAC Tutor adapts to the baud rate of the terminal (up to 300 baud automatically and manually to 2400). Data can also be accepted from a remote computer through a telephone line when a modem is connected. A built-in, software-controlled data switch allows one of two configurations to be selected. In one configuration, the TTY terminal is fully connected to the modem with the MAC Tutor in the listening mode. In the other configuration, the TTY terminal is connected to the MAC Tutor and the modem is switched out. Both configurations are selected from the TTY terminal. Table 2-3 lists the TTY terminal and data set interface connections.

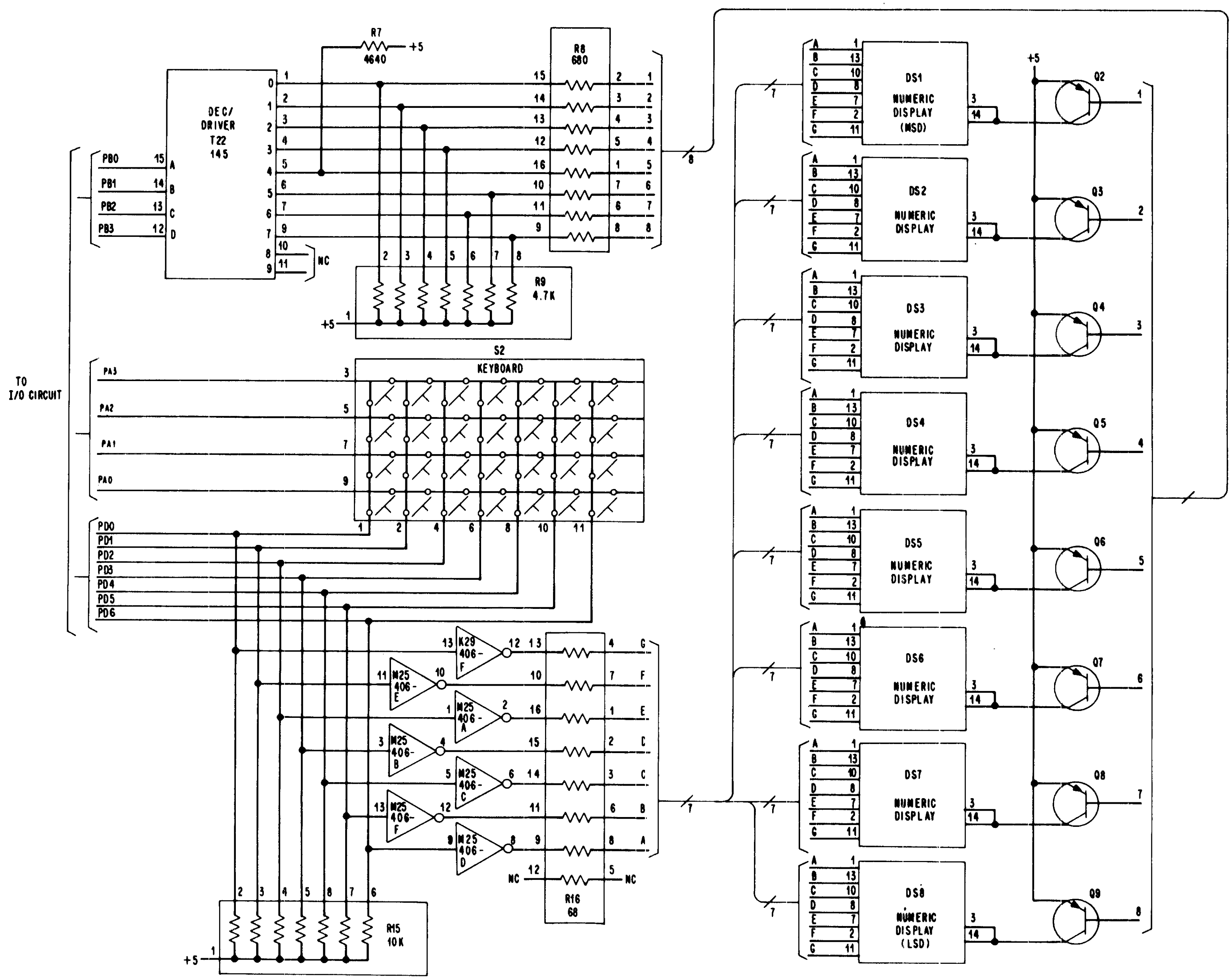


Figure 2-5. Keypad and Display Schematic Diagram

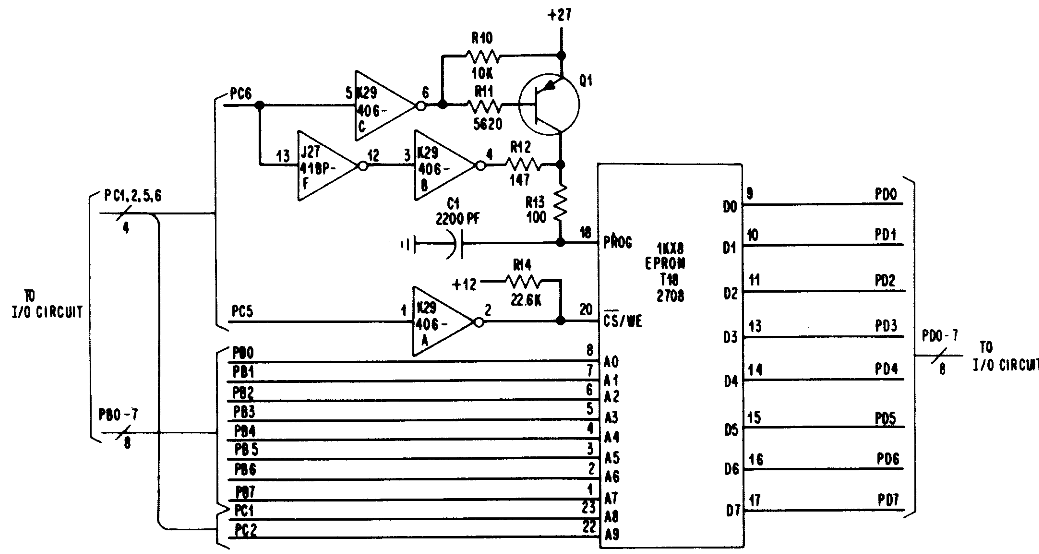


Figure 2-6. PROM Programmer Schematic Diagram

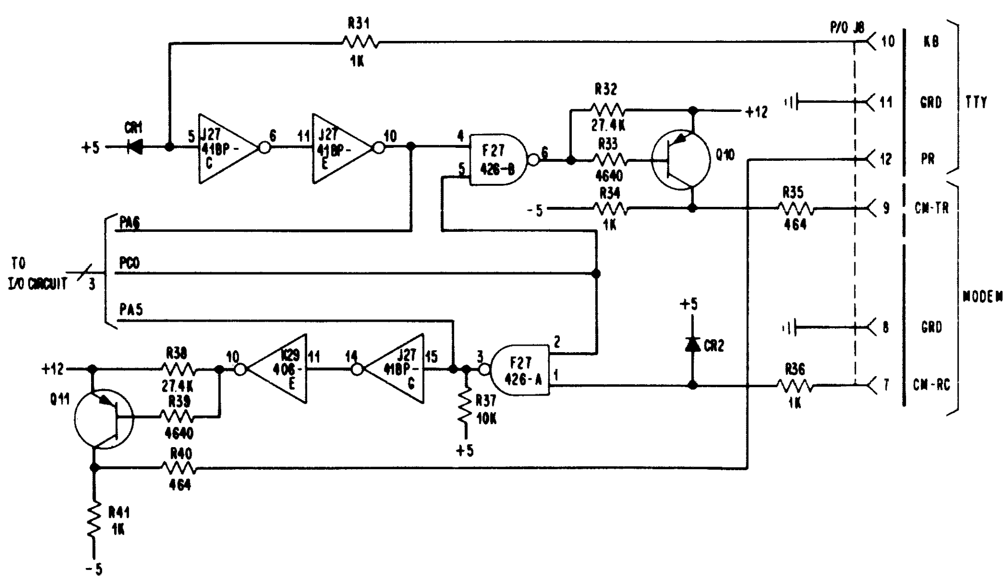


Figure 2-7. TTY Terminal and Data Set Interface Schematic Diagram

TABLE 2-3. TTY TERMINAL AND DATA SET INTERFACE CONNECTIONS

MAC Tutor Connector	**TTY Terminal Connector**
J8 (RS-232C level compatible)	25-pin interface connector (RS-232C level compatible)
Pin 10 - Terminal/Keypad Pin 12 - Terminal/Printer Pin 11 - Ground	Pin 2 - Terminal/Keypad Pin 3 - Terminal/Printer Pin 7 - Ground
MAC Tutor Connector	**Modem Connector**
J8 (RS-232C level compatible)	25-pin interface connector (RS-232C level compatible)
Pin 9 - Modem Transmitter Pin 7 - Modem Receiver Pin 8 - Ground	Pin 2 - Transmitter Pin 3 - Receiver Pin 7 - Ground

Table Note: In addition, some of the pins on the TTY terminal connector may be required to be strapped together for proper operation. Typically, pins 4, 5, 6, and 8 should be strapped together.

2.2.7 Cassette Tape Interface (See Figure 2-8.)

A cassette tape recorder microphone input and earphone output can be connected to the MAC Tutor to read and write data.

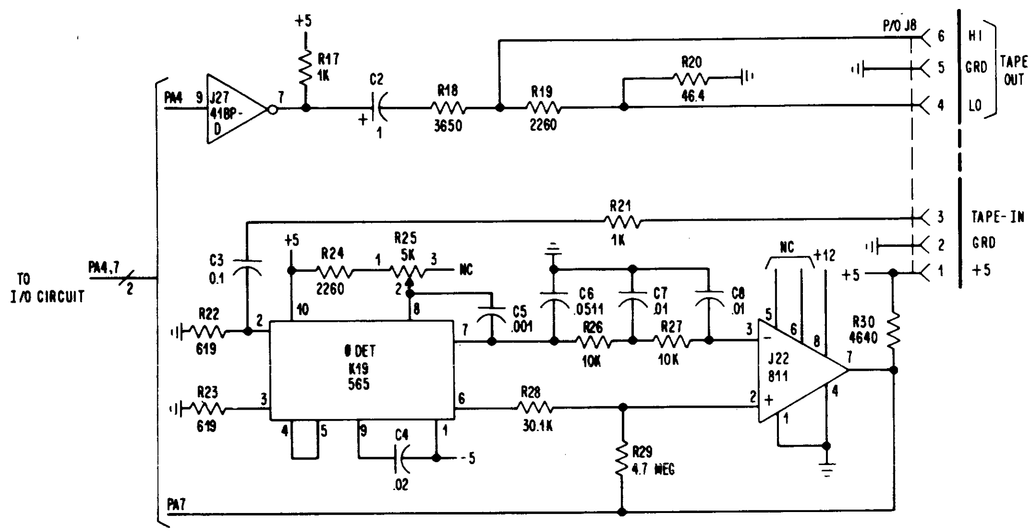


Figure 2-8. Cassette Tape Interface Schematic Diagram

To write data, the MAC Tutor generates a frequency shift keying (FSK) signal that alternates between 2000 and 4000 Hz. When a logical 0 is written on the tape, 2000 Hz appears for two-thirds of the bit time and 4000 Hz for one-third of the bit time. When a logical 1 is written, 2000 Hz appears for one-third of the bit time and 4000 Hz for two-thirds of the bit time.

To read data, an LM565 phase-lock loop integrated circuit (IC) with a free-running frequency of 3000 Hz locks on the input signal. The input voltage to the voltage-controlled oscillator

(VCO), which is available from the LM565 IC, indicates what frequency is being received. This signal is then passed through an RC filter to eliminate the carrier frequencies, while retaining the modulating signal. A comparator converts this low-level signal to a TTL signal for MAC-8 input. The MAC-8 synchronizes to the bit pattern by detecting the negative transition (from 4000 to 2000 Hz) and determines the state of the bit transmitted by the incoming waveform duty cycle.

The operating baud rate is 166 bits per second to ensure low error rates and portability of tape cassettes from one recorder/MAC Tutor to another recorder with a different MAC Tutor. The cassette tape recorder interface connections are listed in Table 2-4.

TABLE 2-4. CASSETTE TAPE RECORDER INTERFACE CONNECTIONS

MAC Tutor Connector	Cassette Tape Recorder Connector
J8, Pin 6 - TAPE-OUT-HI	MICROPHONE JACK
J8, Pin 5 - GROUND	MICROPHONE JACK GROUND
J8, Pin 3 - TAPE IN	EARPHONE JACK
J8, Pin 2 - GROUND	EARPHONE JACK GROUND

Table Note: An additional pin designated TAPE-OUT-LO (pin 4) is provided for cassette tape recorders that require a low-level input to the microphone jack.

2.2.8 Power Supply Circuitry (See Figure 2-9.)

The 117-volt ac line is stepped down by a 16-volt ac center-tapped transformer and four dc voltage outputs are generated, as indicated in Table 2-5.

Two voltage doubler circuits are used to generate the +27 and -5 voltage levels. The +27 voltage doubler circuit operates by charging capacitor C11 through diode CR4 on the negative half-cycle. On the positive half-cycle, CR4 becomes reverse-biased and the conducting path is through C11, CR3, and C12. Therefore, the voltage on C11 gets added to the ac voltage to effectively double the dc output voltage. Regulator VR1 is a 3-terminal, -15 volt regulator that uses the 12-volt supply as a reference. By adding this 15-volt supply to the 12-volt supply, the required 27-volt supply is obtained.

The 5-volt supply uses a full-wave bridge rectifier due to the high current requirement.

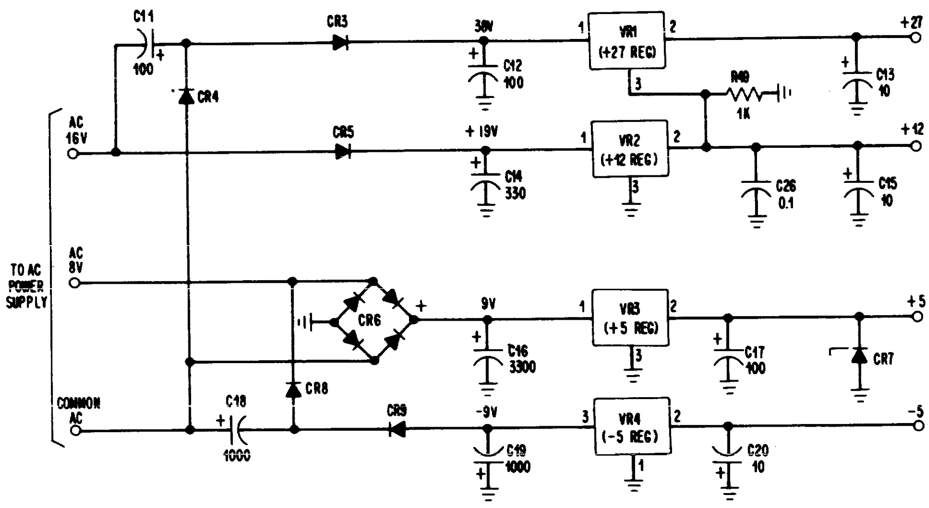


Figure 2-9. Power Supply Schematic Diagram

TABLE 2-5. POWER SUPPLY VOLTAGE AND CURRENT RATINGS

Voltage	Current Rating
+5Vdc	1.5A
-5Vdc	120 mA
+12Vdc	250 mA
+27Vdc	20 mA

Table Note: The 5-volt supply has 350 mA of spare current available at J8, pin 1 to drive the external logic.

2.2.9 Timing

Several factors are involved in the execution time (as defined in terms of microprocessor clock cycles) of an instruction. In one clock cycle a byte can be read from memory, a byte can be written into memory, or some internal function can be accomplished. To minimize requirements on the memory response time, there is a pipeline processor internal to the MAC-8 that imposes a lower bound on the total execution time of any instruction. A simple no outpulsing (NOP) instruction requires four cycles for completion and most instructions are multibyte to ensure that minimum time is used effectively. Timing detail diagrams include the following:

- Fast Memory Accessing, Figure 2-10
- Slow Memory Accessing, Figure 2-11
- A Wait State Generator, Figure 2-12.

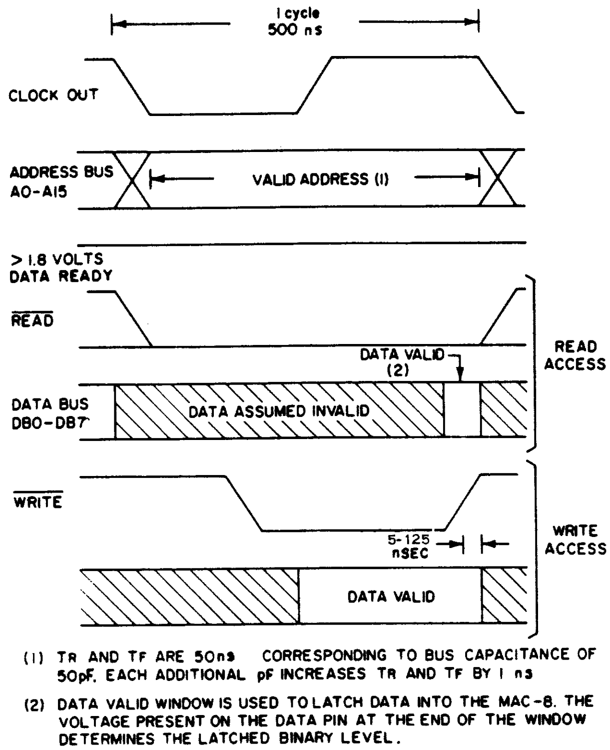


Figure 2-10. Fast Memory Accessing

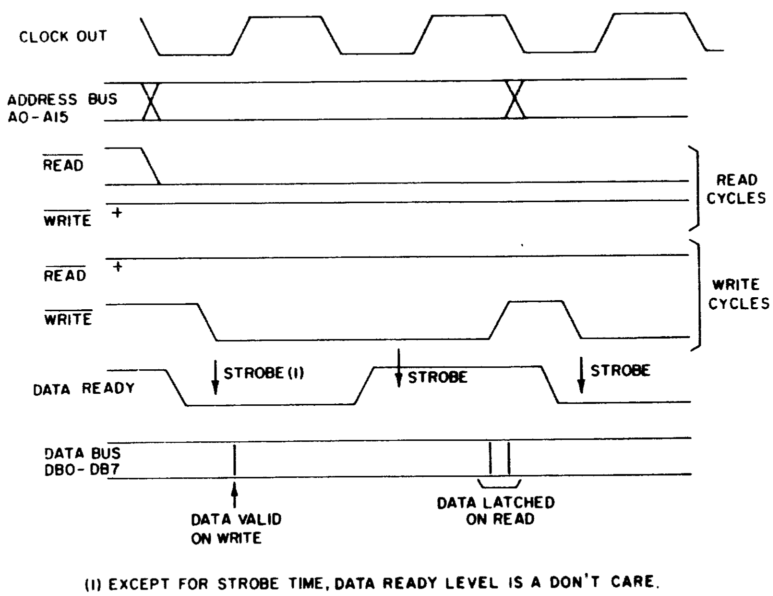


Figure 2-11. Slow Memory Accessing

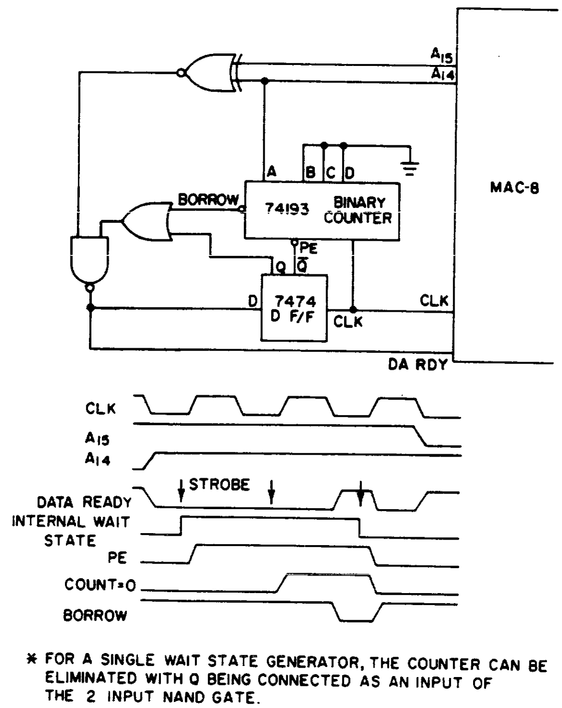


Figure 2-12. A Wait State Generator

Chapter 3

MAC-8 ARCHITECTURE

3. MAC-8 ARCHITECTURE

The MAC-8 is a byte-oriented, general purpose microprocessor in which the instruction repertoire emphasizes Boolean logical and integer arithmetic operations on 8-bit quantities. These instructions are supplemented by 16-bit operations chosen to facilitate address arithmetic.

Because the MAC-8 is a 2-address microprocessor, typical instructions for dyadic operations such as addition specify only two operands, the augend and addend. By convention, one of the operands is also the destination of the result. To distinguish the operands, one is called the source and the other is the destination, even though both are operand sources for dyadic operations. For monadic operations such as incrementing, there is only one operand, called the destination, which is also the source.

A set of memory-addressing modes is available for accessing up to the maximum of 65,536 bytes of storage. These modes, together with a set of identical general purpose registers, are used to form a highly symmetrical set of operand combinations for the instructions. The same memory-addressing modes are used to specify the destinations of control transfer instructions.

A pushdown stack is used as the subroutine call/return mechanism and allows dynamic storage management. Interrupts allow the processor to respond to unusual events in periphery.

3.1 General Registers

There are 16 general registers available to the MAC-8 at any given time that can be accessed in two different ways:

- As a 16-bit base register (b register) used primarily to hold memory addresses.
- As a low-order, 8-bit accumulator (a register) for arithmetic and logical operations.

When the register is used as an a register, only the low-order byte participates. Some operations, such as addition, can be performed with either the 8-bit or 16-bit register set. Certain operations, such as negation, can be performed only with an a register.

3.2 Register Pointer

The MAC-8 general purpose registers, unlike those of most computers, are not special hardware registers located in the microprocessor. A 32-byte section of regular memory is used as the register set. The first two bytes of this section are register 0, the next two are register 1, etc. The starting address of this section (which must be in writable memory) is contained in a 16-bit, on-chip register called the register pointer (rp). By changing the address in the rp, under program control, the user can locate the general registers anywhere in the memory space. The rp can be thought of as pointing to a movable 32-byte window in the memory space (a window through which the MAC-8 "sees" the register set).

The three low-order bits of the rp are always zero. For each instruction that accesses a general register, the complete effective address of the register is computed from the current value in the rp and the source or destination qualifier field of the instruction. Also included is a bit supplied by the MAC-8 designated as the HI/LO bit. The HI/LO bit determines whether the high-or low-order byte of the 16-bit register is being addressed. The formation of the effective address is shown in Table 3-1. Notice that the three quantities are aligned as shown and added, each being treated as an unsigned integer.

TABLE 3-1. EFFECTIVE REGISTER ADDRESS

BIT:	F	E	D	C	B	A	9	8	7	6	5	4	3	2	1	0
REGISTER POINTER	x	x	x	x	x	x	x	x	x	x	x	x	x	0	0	0
+								+								
S or D FIELD												x	x	x	x	
+								+								
HI/LO BIT																x
=																
EFFECTIVE REGISTER ADDRESS	y	y	y	y	y	y	y	y	y	y	y	y	y	x	x	x

The bump and debump instructions can be used to add or subtract a 1 to bit 3 or 4 of the rp. The effect is to move the general register window up or down in memory by 8 or 16 bytes, respectively, corresponding to a change of four or eight 16-bit registers. The effect is to introduce a new set of registers that partially overlaps the previous set. This makes it possible to save and restore the contents of the register set without actually moving any data.

3.3 Pushdown Stack

The stack pointer (sp) can be used to implement a last-in, first-out queue or "pushdown stack." The sp points to the top of the stack (the last item pushed on or the next item to be popped off). Since only the top item and those under it are valid, items above the top of the stack should not be used. An item is pushed onto the stack by decrementing the sp by 1 or 2, depending on the length of the item, and storing the item at the new address. Conversely, an item is popped off the stack by incrementing the sp by 1 or 2, depending on the length of the item. The item may or may not be moved somewhere before the sp is incremented.

In purely software terms, it does not matter whether pushing something onto the stack increments or decrements the sp, as long as pushes and pops are complementary. In the MAC-8, a push decrements and a pop increments, i.e., the stack grows downward in memory because this arrangement often facilitates systemwide memory allocation. In any case, the term "top of the stack" always refers to the *logical* top of the stack, whether or not this represents the highest absolute address.

The most common use for the pushdown stack is in calling subroutines. Since the dynamic nature of nested subroutine calls corresponds exactly to the action of a stack, a call is a push and a return is a pop. The MAC-8 uses the stack to save and restore the program counter (pc) when subroutines are called and when interrupts are accepted. In the latter case, the condition register (cr) is also saved on the stack. The depth of nesting of subroutines, plus interrupts, is limited only by the amount of memory allocated to the stack. In addition to these automatic uses of the stack, the executing program can use explicit push and pop instructions to place subroutine parameters and temporary variables on the stack. This use is facilitated by several special addressing modes that allow easy access to items at or near the top of the stack.

3.4 Addressing Modes

The addressing modes of an instruction are the different ways in which the effective addresses of the operands of the instruction are formed. Some instructions do not address memory and therefore have no modes.

Generation of a memory address usually involves one of the b registers. The b register (0 through 15) is specified in a 4-bit field of the instruction, called the s field for the source and d field for the destination. There are eight modes, with each mode representing a way of determining a source operand address and a destination operand address. To extend the MAC-8 addressing capability, s and d fields of register 15 often have special interpretations. In addition, mode 4 (memory-to-memory mode) is presently implemented only for 8-bit operations.

In summary, the three factors that determine how an operand address is calculated are as follows:

- The mode number (0 through 7).
- Whether the operand is the source or the destination.
- Whether or not the specified register is 15.

Refer to Table 3-2 for a list of addressing modes.

TABLE 3-2. ADDRESSING MODES

Addressing Mode	Source		Destination	
	s!=15	s==15	d!=15	d==15
0	Rs	*pc	Rd	R15
1	Rs	*pc	*Bd	**pc
2	Rs	*pc	*(Bd+n)	(SP+n) [*pc+n)]
3	Rs	*pc	*Bd++	*B15++
4	*(Bs+n1)	*(sp+n1)	*Bd+n2)	*(sp+n2)
5	*Bs	**pc	Rd	R15
6	*(Bs+n)	*(sp+n)	Rd	R15
7	*Bs++	*B15++	Rd	R15

Table Key:

- B - The contents of a 16-bit base register
- d - The destination operand qualifier (d field)
- n, n1, n2 - An 8-bit signed displacement
- pc - The contents of the program counter
- R - A 16-bit b register for 16-bit operations or an 8-bit a register for 8-bit operations
- s - The source operand qualifier (s field)
- sp - The contents of the stack pointer
- ++ - Indicates a post increment of the b register
- [] - Special interpretation for transfer instructions

3.5 Conditions

The 16 conditions in the MAC-8 are logical indicators that can be tested by the conditional instructions. A 4-bit condition field in these instructions selects one of the 16 conditions. Each instruction uses two opcodes representing, for example, **jump on condition true** and **jump on condition false**. Refer to Table 3-3 for a list of the 16 conditions and description of the 16 condition register bits.

TABLE 3-3. MAC-8 CONDITIONS

<table>
<tr><th>BIT</th><th>CLEARED</th><th>SET</th><th>DESCRIPTION</th><th>REMARKS</th></tr>
<tr><td>0</td><td>!neg</td><td>neg</td><td>Sign bit of result</td><td rowspan="8">ACTUAL CONDITION REGISTER BITS</td></tr>
<tr><td>1</td><td>!zero</td><td>zero</td><td>Indicates all zero result</td></tr>
<tr><td>2</td><td>!ovfl</td><td>ovfl</td><td>Indicates arithmetic overflow</td></tr>
<tr><td>3</td><td>!carry</td><td>carry</td><td>Indicates carry or borrow</td></tr>
<tr><td>4</td><td>!ones</td><td>ones</td><td>Indicates result is all ones</td></tr>
<tr><td>5</td><td>!odd</td><td>odd</td><td>Lower-order (LSB) of result</td></tr>
<tr><td>6</td><td>!enable</td><td>enable</td><td>Interrupts are enabled</td></tr>
<tr><td>7</td><td>!flag</td><td>flag</td><td>User-designated flag</td></tr>
<tr><td>8</td><td>!lt</td><td>lt</td><td>Arithmetically less than zero (bit 0∧bit 2)</td><td rowspan="8">DERIVED FROM CONDITION REGISTER BITS 0-7 (PHYSICALLY NON EXISTENT)</td></tr>
<tr><td>9</td><td>!lteg</td><td>lteg</td><td>Arithmetically less than or equal to zero [(bit 0∧bit 2)|bit 1]</td></tr>
<tr><td>10</td><td>!llteg</td><td>llteg</td><td>Logically less than or equal to zero (bit 3 |bit 1)</td></tr>
<tr><td>11</td><td>!homog</td><td>homog</td><td>Logically homogeneous (all zeros or all ones) (bit 4|bit 1)</td></tr>
<tr><td>12</td><td>!shovfl</td><td>shovfl</td><td>Arithmetic left-shift overflow (bit 0∧bit 3)</td></tr>
<tr><td>13</td><td>—</td><td>—</td><td>(Unused,Unassignable)</td></tr>
<tr><td>14</td><td>—</td><td>—</td><td>(Unused,Unassignable)</td></tr>
<tr><td>15</td><td>—</td><td>always</td><td>Condition always true (set) (unconditional jump, call, return)</td></tr>
</table>

! nontrue condition   ∧ bit-by-bit exclusive OR | bit-by-bit inclusive OR

Conditions 0 through 5 describe the results of the most recent arithmetic or logical instructions that are implicitly altered by many MAC-8 instructions. Condition 6 determines whether or not the MAC-8 can be interrupted and condition 7 is available as a user flag. These first eight conditions are known collectively as the cr. They can be explicitly altered by the set conditions and clear conditions instructions. The cr is automatically pushed onto the stack when an interrupt is accepted and the saved value is popped back into the cr when a return from interrupt instruction is executed.

The second group of eight conditions, 8 through F, is comprised of read-only indicators. Most of them represent useful logical combinations of the first eight. Since these conditions are derived from the first eight, it is unnecessary to save and restore them (they are effectively saved and restored whenever the first eight are).

3.6 Interrupts

Exceptional events (such as interrupt, trap, and reset) alter the course of the program running in the MAC-8. They have a common association with a fixed memory location (each different) to which control is transferred when the event occurs.

An external device requests an interrupt by setting the MAC-8 interrupt request pin. If the enable condition in the MAC-8 is 0, it will ignore the request because it is in a masked condition. If interrupts are enabled and a request is received, the following sequence occurs at the completion of the instruction being executed:

- The cr is pushed into the stack.
- The pc, which contains the address of the instruction that would have been next executed, is pushed onto the stack.
- The enable condition is set to 0.
- The MAC-8 performs a normal read operation, addressing location X(FFFF). In most applications, this address will not represent regular memory, but will serve as an interrupt acknowledgment to the interrupting device. The data byte read by the MAC-8 is supplied by the device and is used in the next step.
- The data byte read is right-adjusted with leading zeros placed in the pc. The next instruction is then taken from that location.

The value placed on the data bus by the interrupting device is effectively a pointer to an instruction in the first 256 bytes of memory. This should be the first instruction of the routine to process that particular type of interrupt. Depending on the application, there can be one or many interrupt handling routines.

It is the responsibility of the interrupt handler to save other registers (if necessary) before processing the interrupt. At completion of the routine, saved registers are restored and a return from interrupt instruction is executed, causing resumption of the program that was executing when the interrupt was accepted. Except for possible changes made by the interrupt handler, the state of the microprocessor will be identical to that before the interrupt was accepted.

3.7 Traps

A trap occurs when the MAC-8 controller has no valid transition defined for the present state and present inputs. This situation can develop when the MAC-8 attempts to execute an invalid opcode, when electrical transients disrupt the controller, or when a fault develops in the controller. However, not all transients and faults will cause a trap. Also, traps cannot be masked.

When a trap condition is recognized, the sequence occurs as follows:

- The cr is pushed onto the stack.
- The pc, which points two bytes beyond an invalid opcode byte, is pushed onto the stack.
- The enable condition is set to 0.
- The pc is set to X(0008) and the next instruction is taken from that location.

Location X(0008) should contain the first instruction of a routine to handle traps. The address of the interrupted instruction (which may have an invalid opcode) can be calculated from the saved pc.

3.8 Reset

An external device resets the MAC-8 by setting the reset pin. When this signal (which cannot be masked) is applied, the sequence occurs as follows:

- The cr is pushed onto the stack.
- The pc, which contains the address of the instruction that would have been the next one executed, is pushed onto the stack.

- The enable condition is set to 0.
- The MAC-8 performs what appears to be a normal read operation, addressing location X(FFFF), but the data byte read is ignored. The operation serves only to acknowledge the reset.
- The pc is set to X(0000) and the next instruction is taken from that location.

Location X(0000) should contain the first instruction of the routine to handle resets. If a reset occurs immediately after power-up, the values of the sp and rp are unpredictable.

Since the dedicated memory locations are associated with interrupts (traps and resets overlap), it is possible to simulate traps and resets by appropriate interrupt signals, as well as by direct jumps or calls from other routines.

Chapter 4

MAC TUTOR SOFTWARE

4. MAC TUTOR SOFTWARE

4.1 Functional Description

A resident executive program is supplied (see Appendix) to allow the user to access the hardware components. The primary purpose of this executive program is to enable the user to store programs in memory and then execute them. In addition, the executive program provides the following:

- Supplies the necessary interface routines to store information permanently on cassette tapes or PROMs.
- Allows program debugging with single-stepping, breakpoints, or nonmaskable interrupts.
- Allows communication between a TTY terminal and a time-sharing computer.

The executive program is divided into three major sections:

- *Keypad and Display* — Commands and directives are given with the keypad and the results appear on the LED displays.
- *TTY* — All of the capabilities of the executive keypad are available through a TTY terminal and communication with a time-sharing computer is possible at the same time.
- *Utilities* — Programs are available for such functions as writing PROMs, verifying PROMs, and writing/reading magnetic cassette tape information.

4.2 Operation

4.2.1 Keypad/Display

The keypad consists of a standard calculator-type button-pad with four rows, each containing seven keys. Each key is marked with two labels, one in blue and the other in yellow. The blue labels are presently in use and the yellow labels are intended for future system expansion requirements.

The eight 7-segment LED displays are used mainly to display memory addresses and contents of memory locations. The standard arrangement uses the left four digits for memory address and the next two digits show the contents of that memory address plus one. The right two digits show the contents of that memory location. For example, the number 18001234 indicates that memory location 1800 contains hexadecimal number 34 and location 1801 contains 12. The left four digits are the address, the next two digits are the high contents, and the last two digits are the low contents.

4.2.2 Keypad Button Control

There are 16 keypad buttons labeled 0 through F that represent hexadecimal digits 0 through F. A is the decimal number 10, B is the decimal number 11, and so on through F, which is the decimal number 15. These keys are used in conjunction with the other function keys to specify exactly what will be done.

Initialize — init

The purpose of the **init** button is to reinitialize memory to recover from some abnormal condition. When this button is pressed, operations are performed as follows:

- The executive registers are set to the last 32 bytes of RAM, locations 1BE0 through 1BFF.
- The user program registers are assigned to the preceding 32 bytes of RAM, locations 1BC0 through 1BDF. These are the registers that are examined with the **/a** and **/b** buttons.
- User register b11 is set to the address of the I/O page, location 1F00. This is done so that a user program can call subroutines in the executive program without setting this register beforehand.
- User register b12 is set to the constant FF02. This enables a user program to easily use the executive subroutines to display numbers on the LEDs.
- The stack is set to just below the user registers. The stack will then grow down toward lower addresses.
- The return address into the executive program is pushed onto the stack. This is to enable a user program to make a normal return to the executive program on termination.
- A zero byte, representing an empty user condition register, is pushed onto the stack.
- The default value of the program counter (1800 is the first location of RAM) is pushed onto the stack.
- The address of the user registers is pushed onto the stack and becomes the user register pointer.

TTY — ⓐ

The button with the Bell System logo allows a TTY terminal keyboard to enter commands and directives.

Memory Address — *

This button is used to specify a memory address. After the * button is pressed and as each succeeding button is pressed, the memory address is shifted one place to the left (the last button pressed becomes the rightmost digit). For example, if the current memory address is 19AB and we wish to look at location 03FD, refer to Table 4-1.

Register Pointer — /d

When the **/d** button is pressed, the display address is set to that location in memory which contains the register pointer and the right four display digits will indicate the register pointer value.

This enables the following:

- Manual change of register pointer. By pressing the = button and changing the two memory locations containing the register pointer, operating registers can be set to any memory position.
- Since the register pointer is stored on the stack, the address field will now indicate where the bottom of the stack is located. This makes it possible to examine what the program has pushed onto the stack.

TABLE 4-1. MEMORY ADDRESS EXAMPLE STEPS

Key Pressed	Display Reading
	19AB1234*
*	1800ABCD*
3	8003FFFF
F	003F5498
D	03FDAFED

Table Notes:

1. Although memory addresses consist of four digits, the immediacy of the executive program required only three digits to be entered. Whatever memory address is displayed, whether by chance or design, the digits to the right will display the contents of those two addresses.
2. It is a good idea to specify all four digits of a memory address, otherwise leftover digits from the previous address could produce unexpected results.
3. The content of nonexistent memory, in this example 8003, is *always* FF.

Display a Register — /a

The **/a** button allows examination of the contents of the sixteen 8-bit registers that have been assigned for use. After this button is pressed, the display changes to indicate an a register and not memory. The left two digits of the address and the digits indicating the high contents are blanked out. The right two digits of the address change to the letter **a**, indicating that the display is showing an a register, followed by a digit representing the particular register displayed. Register a10 is displayed as AA, a11 is AB, and on through a15, which is AF. By default, the register a0 is displayed when **/a** is pressed. The low contents then show what is contained in the register indicated by the address. Since an a register contains eight bits, only the two digits of low contents are required (that is why the high contents display is blanked out). Once the **/a** is pressed, the displayed register can be specified as follows:

- Pressing any of the digit buttons from 0 to F will cause that register (0 to 15) to be displayed.
- The **+** button will cause the next higher numbered register to be displayed. If the register displayed is 15, AF in the address digits, the **+** button will cause register a0 to appear.
- The - button will cause the next lower numbered register to be displayed. If the register displayed is a0, the - button will cause register a15 to appear.

For example, to assume that registers a9, a8, a15, and a1 are to be displayed in that order, refer to Table 4-2.

TABLE 4-2. REGISTER DISPLAY EXAMPLE STEPS

Key Pressed	Display Reading	
	1800	ACED
/a	A0	10
9	A9	34
-	A8	AA
F	AF	E0
+	A0	98
+	A1	BA

Table Notes:

1. The **/a** button causes the display format to change. This allows determination of whether the display refers to memory or registers.
2. The last digit pressed determines which register will be displayed.
3. Digit, +, and - buttons can be mixed at will to specify which register to display.

Display b Register — /b

The **/b** button allows examination of the contents of the sixteen 16-bit registers that have been assigned for use. When this button is pressed, the display is changed to a format indicating that b registers are being shown. The left two digits of the address are blanked out and the right two digits change to the letter b, followed by a digit that indicates the register being displayed. The right four digits of the display are then used to show the 16-bit contents of the b register being examined. The **/b** button operates in the same fashion as the **/a** button.

Display Next Location — +

The + button allows examination of successive locations in memory. When this button is pressed, the current memory address is incremented by one and the contents of the new memory locations are displayed.

For example, it is possible to step through memory looking at successive locations, one after another. Refer to Table 4-3.

TABLE 4-3. MEMORY LOCATION EXAMPLE STEPS

Key Pressed	Display Reading
	18002211
+	18013322
+	18024433

Table Note: The standard display has the low contents showing whatever is in the memory location pointed to by the address, and the high contents showing whatever is in the following location. This explains why every time + is pressed, whatever was showing in high contents is now displayed in low contents.

Display Previous Location — -

The - button performs a function similar to the + button, but in the opposite direction. Every time the - button is pressed, the address is decremented by one, which makes it possible to go backward in memory and look at different locations one at a time.

Change Contents — =

The = button makes it possible to change memory. Normally, any digit button depressed causes a change in the address. However, after the = button is pressed, any digit button pressed causes a change to the low contents. The low contents are shifted left by one digit, losing the leftmost digit, and the button pressed becomes the rightmost digit. Also, after every digit is pressed, the new value of the low contents is stored into the location pointed to by the address. For example, to assume that the numbers 1, 2, and 3 are stored into the locations 1900, 1902, and 1A00, refer to Table 4-4.

TABLE 4-4. LOW CONTENTS LOCATION EXAMPLE STEPS

Key Pressed	Display Reading
	1 8 0 0 0 0 0 0
*	1 8 0 0 0 0 0 0
1	8 0 0 1 F F F F
9	0 0 1 9 1 3 2 4
0	0 1 9 0 A C E D
0	1 9 0 0 2 2 1 1
=	1 9 0 0 2 2 1 1
=	1 9 0 0 2 2 1 1
0	1 9 0 0 2 2 1 0
1	1 9 0 0 2 2 0 1
+	1 9 0 1 3 4 2 2
+	1 9 0 2 F 8 3 4
0	1 9 0 2 F 8 4 0
2	1 9 0 2 F 8 0 2
*	1 8 0 0 0 0 0 0
1	8 0 0 1 F F F F
A	0 0 1 A F A C E
0	0 1 A 0 D 8 9 A
0	1 A 0 0 E D C 0
=	1 A 0 0 E D C 0
4	1 A 0 0 E D 0 4
0	1 A 0 0 E D 4 0
3	1 A 0 0 E D 0 3

Table Notes:

1. The low contents are the ones affected and only one memory location can be changed at a time.
2. Pressing the = button more than once makes no difference (additional button pressing is ignored).
3. To correct an error, keep pressing buttons until the proper number is obtained.

The a and b registers can be changed in a similar fashion. The only difference to keep in mind is the operation of b registers. Since the b registers contain 16-bit numbers, all of the rightmost *four* digits in the display are affected when a b register is changed, instead of the rightmost *two* digits. For example, to set a8 to 88, a7 to 77, b14 to 00EE, b15 to 00FF, and b0 to 00, refer to Table 4-5.

TABLE 4-5. A AND B REGISTER CHANGE EXAMPLE STEPS

Key Pressed	Display Reading
	1 8 0 0 F E C D
/a	A 0 3 4
8	A 8 1 2
=	A 8 1 2
8	A 8 2 8
8	A 8 8 8
-	A 7 6 7
7	A 7 7 7
/b	B 0 1 2 3 4
E	B E 3 4 0 0
=	B E 3 4 0 0
E	B E 4 0 0 E
E	B E 0 0 E E
+	B F 0 5 5 0
0	B F 5 5 0 0
F	B F 5 0 0 F
F	B F 0 0 F F
+	B 0 1 2 3 4
0	B 0 2 3 4 0
0	B 0 3 4 0 0
0	B 0 4 0 0 0
0	B 0 0 0 0 0

Table Notes:

1. It is only necessary to key in the number of digits to obtain the required number. Two digits were sufficient for b14, whereas all four were necessary for b0.
2. Once the = button is pressed, it does not need to be pressed again if the format of the display remains the same.
3. When the display went from **/a** format to **/b** format, the = was necessary to indicate that the b registers were to be changed. However, when going from a8 to a7, the executive program remained in a change register mode.
4. When changing registers or memory, the + and - buttons are used to go to a new register or memory location. After examining a specific register or memory location, the = button can be pressed to make necessary changes.

Program Execution — go

After a program is placed in memory with the = button, the **go** button is pressed to start the program running. This is an unconditional start and control will not return to the executive program unless one of three things happens:

- The user's program relinquishes control. (If the program executes a return instruction with no preceding subroutine call, the program will return to the executive program.)
- Illegal instructions will cause the executive program to regain control. To set a breakpoint, just place an illegal instruction (FF is a good choice) where the program breakpoint is desired.
- The **reset** button will also cause the MAC Tutor executive program to take over.

Single Step — sst

The **sst** button operates in the same manner as the **go** button, but with one difference. Every time the **sst** button is pressed and immediately released, one instruction from the user's program is executed. The executive program then takes control and displays the address of the next instruction that would have been executed. This allows successive execution of one instruction at a time from the user's program merely by pressing the **sst** button.

If the **sst** button is pressed and held down, instructions will be executed at a rate of approximately two per second. The address display will contain the address of the next instruction to be executed (used to view the program in operation).

4.2.3 TTY Control

If a TTY-compatible terminal is available, the MAC Tutor has the capability of using this device for the user interface instead of the on-board keypad/display. When the Bell System logo button is pressed, initialization functions are performed as follows:

- If there is no TTY connection or if the TTY is turned off, control will immediately return to the keypad/display portion of the MAC Tutor executive program.
- The executive program pauses, waiting for the user to type in a carriage return (cr). This key is used by the executive program to determine the terminal operating baud rate.
- A header is typed out to indicate what version of the executive program is being used. Currently the header looks like this: MAC Tutor Exec 1.0.
- The executive program displays a 4-digit memory address followed by a space and the 2-digit contents of that memory address. The memory address displayed will be the current value of the program counter, which on initial start-up will be 1800, the first address of RAM.

Operation from the TTY keyboard is the same as from the executive program keypad/display, except for the following differences.

Half Duplex — h

Normally the TTY executive program assumes that the terminal is running in full-duplex mode, therefore the executive program prints out each character as it is typed in. In the half-duplex mode, characters that are typed in will not be printed out. However, every time the **h** key is typed, the executive program switches from either half- or full-duplex to full- or half-duplex operation.

Initialize — i

The **i** key causes the memory to be set up and the header message and location 1800 are displayed.

Terminate TTY — Break Key

Pressing the **break** key, turning off the terminal, or unplugging the terminal will stop TTY operation and return control to the keypad/display.

Memory Address — *

Pressing the * key causes the executive program to set up to start displaying memory locations, and the memory address is set to the current value of the program counter.

After typing in the * followed by an optional address, a carriage return causes that memory address and its contents to be displayed at the terminal. For example, to examine locations 8003, 1900, and 1800 (in that order), refer to Table 4-6.

TABLE 4-6. MEMORY ADDRESS LOCATION (TTY) EXAMPLE STEPS

User Type Input	Output
	1800 DC
*3'cr'	8003 FF
*1234123111900'cr'	1900 8F
*'cr'	1800 DC

Table Notes:

1. It is required to only type in as few digits as are necessary to generate the proper address. (The digit **3** was sufficient to convert the address 1800 into 8003.)
2. The TTY executive program requires (at most) the last four digits to be typed. If a mistake is made, it can be corrected simply by typing in all the proper digits.
3. An * alone is sufficient to bring back the current value of the program counter.

Register Pointer — r

This key operates in a manner similar to the *. The difference is that the memory address is set to the bottom of the stack, which is where the register pointer is stored. As soon as the **r** key is typed, the address of the bottom of the stack is displayed, along with the contents of that location, the low byte of the register pointer. Refer to Table 4-7.

TABLE 4-7. REGISTER POINTER (TTY) EXAMPLE STEPS

User Type Input	Output
	1800 DC
r	1BB9 C0
'cr'*	1BBA 1B

Register Display — /

This key sets up the executive program to display the contents of one of the operating registers. After pressing the / key, either the character a or b must be typed, indicating whether examination of the 8-bit a registers or 16-bit b registers is desired. Next, one of the digits 0 through F should be typed to indicate which particular register is to be examined. If more than one digit is typed, the executive program will use the last one to specify which register is desired. After the type is entered and the proper register is selected, a carriage return will cause that register to be displayed. For example, to examine registers a10, b15, a0, and a9, refer to Table 4-8.

TABLE 4-8. REGISTER DISPLAY (TTY) EXAMPLE STEPS

User Type Input	Output
	1800 DC
/aA'cr'	AA 01
/Bf'cr'	BF 56D4
/'cr'	A0 FD
/A0123456789'cr'	A9 99

Display Next Location — Carriage Return

In order to examine a successive location, a carriage return (cr) key typed alone on a line will cause either the next higher memory location or register to be displayed. If the current register number is 15, the cr key will cause register 0 to be displayed. For example, to examine memory locations 1900 through 1903, registers a15 through a3, and registers b15 and b0, refer to Table 4-9.

TABLE 4-9. DISPLAY NEXT LOCATION (TTY) EXAMPLE STEPS

User Type Input	Output
	1800 DC
*1900'cr'	1900 00
'cr'	1901 11
'cr'	1902 22
'cr'	1903 33
/af'cr'	AF FF
'cr'	A0 00
'cr'	A1 11
'cr'	A2 22
'cr'	A3 33
/BF'cr'	BF 0FFF
'cr'	B0 1200

Display Previous Location — Line Feed

In contrast to the carriage return, the line feed (lf) key causes the next lower memory location or register to be displayed. Otherwise, the lf and cr keys operate in the same manner. For example, to display memory locations 1800 through 17FE, registers a1 through a14, and registers b14 through b1, refer to Table 4-10.

TABLE 4-10. DISPLAY PREVIOUS LOCATION (TTY) EXAMPLE STEPS

User Type Input	Output
	2FCD FF
*1800'cr'	1800 DC
'lf'	17FF FF
'lf'	17FE FF
/A1'cr'	A1 11
'lf'	A0 00
'lf'	AF 11
/BE'cr'	BE 0EEE
'cr'	BF 0FFF
'cr'	B0 0000
'cr'	B1 0111

Change Contents

If an input line consists of nothing but hexadecimal digits followed by either a cr or lf key, the digits are collected into one number. Then when the cr or lf key is typed, the rightmost two digits are stored into the currently displayed memory location or a register, or the rightmost four digits are stored into the currently displayed b register. If fewer digits than necessary to fill up a memory location or register are typed, the leftmost digits are assumed to be zero. For example, to store 59, 00, and 18 into memory locations 1800, 1802, and 1804; FF, 0, and 1 into registers a15 to a1; and 1, 1000, and FACE into registers b8 through b10, refer to Table 4-11.

TABLE 4-11. CHANGE CONTENTS (TTY) EXAMPLE STEPS

User Type Input	Output	
	BADD	FF
*1800'cr'	1800	DC
59 'cr'	1801	11
'cr'	1802	22
0'cr'	1802	33
18*1803'cr'	1803	33
'cr'	1804	44
18'cr'	1805	55
/AF'cr'	AF	FF
'cr'	A0	FF
0'cr'	A1	11
1'cr'	A2	22
/B8'cr'	B8	0888
1'cr'	B9	0999
1000'cr'	BA	0AAA
01234FACE'cr'	BB	0BBB

Table Notes:

1. Something has to be currently displayed before it can be changed.
2. The change does not take effect until the cr or lf key is depressed. This gives the ability to check the input for errors before making a change. If a mistake is made, start typing the desired number from scratch until the proper number is in the rightmost digit position.
3. If it is not desired to change a displayed value, type in a cr or lf key to skip over that location without affecting it.

Program Execution — g

The **g** key signals that the current memory location is the first address of some executable code. When the cr key is typed, the executive program starts execution at this address. The current memory location can be specified on the same line as the **g** command, so that the sequence *1800gcr would cause the MAC Tutor to start executing the program at location 1800. In order to avoid trying to execute a register address or other strange problems, it is recommended that program execution start with *, followed by a 4-digit starting address, followed by **g** command, and terminated with cr.

Single Step — s

The **s** key operates in the same manner as the **g** key, except that it only executes one instruction.

The **s** key also causes one instruction to be executed without waiting for a cr to be typed. After the instruction is completed, the header message is typed out, followed by the address of the next instruction to be executed and the contents of that memory location.

Since the address of the next instruction is the current address, a program can be single-stepped many times by merely using the **s** key. Since the * key sets the current memory location to the value of the program counter, it is easy to single-step a program for a while, look at memory locations or registers, then continue single-stepping or executing the program. Refer to Table 4-12 for an example that will single-step a program through two instructions, look at some registers and memory locations, and then restart execution at the third instruction of the program.

TABLE 4-12. SINGLE-STEP (TTY) EXAMPLE

User Type Input	Output
	2000 FF
*1900s	MAC Tutor Exec 1.0
	1902 7F
s	MAC Tutor Exec 1.0
	1903 59
/b0'cr'	B0 0000
'lf'	BF FFFF
/AF'cr'	AF FF
*1904'cr'	1904 00
'cr'	1905 18
*g'cr'	

Table Note: Although the last memory location displayed was 1905, the **g** command caused execution to resume at location 1903. Recall that the * key causes the current memory address to be set to the current value of the program counter, which in this example was left at 1903.

Talk to Host Computer — !

When the ! key is pressed, the TTY executive program connects a modem interface to allow communication with a time-sharing computer. If another ! is typed, the connection between the terminal and modem is broken and the connection is once again made with the MAC Tutor. (This sequence can be repeated as many times as desired.)

Load Hex File — l

If access to a time-sharing computer is available, the TTY executive program has the ability to load programs developed on that computer into the MAC Tutor memory. When the **l** key is typed, the TTY executive program will load a standard hex. file.

4.2.4 System Utilities

Certain routines have been created that utilize MAC Tutor features. All of these routines are executed as if they were user programs that were loaded into memory. However, because these routines are part of the ROM executive, they are always available and unmodifiable. These routines are invoked by setting certain registers to indicate what is desired, then executed with the keypad **go** button or terminal **g** key. Refer to 4.4 for routine details.

4.3 Programming

There are basically three ways to create programs for the MAC-8:

- *Hand Coding.* Pencil and paper are used to create each byte of each instruction in the program.
- *Assembler.* Assembly language programs can be created on a UNIX* time-sharing system. These programs can then be loaded into memory and executed on the MAC Tutor.
- *C Compiler.* A UNIX system can be used to create programs in the C programming language.

* UNIX is a trademark of Bell Laboratories.

4.4 Available Programs

The following descriptions include the starting address on the title line, input parameters, constraints, and abnormal conditions.

4.4.1 Move Memory - *022F

This routine moves a copy of a block of memory from one place to another. The input consists of setting registers b8, b9, and b10 as follows:

- b8 The address of where to move the block of memory.
- b9 The address of the first location to move.
- b10 One more than the last address that is to be moved.

For example, to move a copy of everything in locations 1900 through 19FF to locations 1800 through 18FF, refer to Table 4-13.

TABLE 4-13. MOVE MEMORY EXAMPLE STEPS

User Type Input	Output	
	1800	DC
/B8'cr'	B8	0888
1800'cr'	B9	0999
1900'cr'	BA	0AAA
1A00'cr'	BB	0BBB
*022Fg'cr'	MAC Tutor Exec 1.0 (cr)	
	1800	00

Table Note: If the "to" address is greater than the "from" address and the blocks overlap, only the locations between these two addresses will be moved properly. All the rest of the destination block will consist of repetitions of this small block.

4.4.2 Write a PROM - *0541

This program writes the contents of any contiguous 1024-byte block of memory into a 2708 PROM. The program that writes the PROM uses register and stack space in the upper 1024-byte block of RAM (starting address 1800); therefore, it is not possible to successfully program an entire 2708 PROM unless the lower 1024-byte block of RAM (starting address 1400) is used to contain the program to be written. This restriction is not too severe, since approximately the first 950 bytes in the upper 1024-bytes of RAM (starting address 1800) can be written into the PROM.

The only input required consists of setting register b9 to the starting address of the block of 1024-bytes of RAM to be written into the 2708 PROM. It takes approximately two minutes to write the PROM.

When the program is complete, it indicates whether or not the PROM is correctly written by setting registers b13 and b14 to the following values:

b13 If the lower 1024-bytes of RAM (starting address 1400) were used, this register contains 400 if the PROM is written correctly. If incorrectly written, b13 will contain a number from 0000 to 03FF, indicating the first location in the PROM that is in error. If the upper 1024-bytes of RAM (starting address 1800) were used, b13 should contain at least 03b9.

b14 If b13 does not contain 400, then the left two digits in b14 are what should have been stored in the PROM at the location specified by b13. The right two digits in b14 show what is actually there.

To write locations 1000 to 1400 into a PROM that has been placed in the PROM programming socket, refer to Table 4-14.

TABLE 4-14. WRITE PROM LOCATIONS EXAMPLE STEPS

User Type Input	Output
	1800 DC
/B9'cr'	B9 1234
1000'cr'	BA 5678
*0541g'cr'	

4.4.3 Verify a PROM - *057B

This program verifies that the contents of the PROM match what is in a block of memory. The only input is to set register b9 to the beginning address of a 1024-byte block of memory. (Since a blank PROM and nonexistent memory both contain FF, a PROM can be zero verified by specifying a nonexistent block of memory, such as 2000.)

When complete, the program indicates the results of the verification operation by setting registers b13 and b14 as follows:

- b13 If this register contains 400, the 1024 bytes in the PROM are the same as the 1024 bytes in memory. If the register does not contain 400, it will contain a number from 0 to 3FF, indicating the first location in the PROM that did not match.
- b14 If register b13 does not contain 400, the left two digits of register b14 indicate what was stored in the PROM. The right two digits are in memory.

To check whether the contents of locations 1800 to 1BFF are the same as what is in the PROM, refer to Table 4-15.

TABLE 4-15. VERIFY PROM CONTENTS EXAMPLE STEPS

User Type Input	Output
	1800 DC
/B9'cr'	B9 1234
1800'cr'	BA 5678
*057Bg'cr'	

4.4.4 Dump to Audio Tape - *06C6

This routine dumps a block of memory to an audio tape file. The input consists of:

- a8 File ID, a unique number from 1 through FE identifying this file. It is recommended that IDs O and FF not be used.
- b9 The address of the first location to be stored on the tape.

- b10 One more than the last address to be written onto the tape.

The sequence of events necessary to write a file out to tape is:

- Set registers a8, b9, and b10.
- Start tape recorder and set to record mode.
- Wait until tape leader has been skipped.
- Execute the tape dump program.
- Stop the tape recorder when the program is completed.

Note: While the program is executing, the leftmost digit of the LED display indicates what is happening. For the first 5 seconds it will show two vertical bars, the right bar being one-half the height of the left bar (this indicates that the 100 sync characters which begin every file are being written out). After this is completed, the right two vertical segments should be lighted, the top horizontal segment should be off, and all other segments should flicker (this indicates that data is being written out to the tape). If the display indicates a pattern of bars with none of the segments varying, one of two things has happened:

- All the data to be stored on tape is the same. This situation is possible, but rather unlikely.
- The data being written out are all Fs. This was probably caused by putting the wrong starting address in b9 and writing out a nonexistent program.

To store locations 1000 to 13FF on tape using the file ID 10, refer to Table 4-16.

TABLE 4-16. TAPE STORE LOCATION EXAMPLE STEPS

User Type Input	Output		User Action
	1800	DC	
/B8'cr'	B8	1234	
0010'cr'	B9	5678	
1000'cr'	BA	9ABC	
1400'cr'	BB	DEF0	
*06C6g'cr'	MAC Tutor Exec 1.0		Start tape recorder.
	1800	DC	Skip leader.
			Stop tape recorder.

4.4.5 Read from Audio Tape - *05EE

This routine reads information stored on tape back into MAC Tutor memory. The input consists of:

- a8 File ID of data to be read in from tape.
- b9 Address of the first location to be stored in memory. (This parameter is used only if the file ID is FF.)

Since special meanings have been assigned to certain file IDs, actions will take place as follows:

- 0 The next file on the tape will be read into the address stored as part of the file.
- 1-FE The first file with the same ID as this will be read into the address stored as part of the file.

- FF The next file on the tape will be read into the address specified in register b9.

The following steps are required to read in a file from tape:

- Set register a8 and possibly register b9.
- Start execution of the tape load program.
- Start tape recorder.
- Upon completion of program, stop tape recorder.

As with the dump program, the leftmost digit of the LED display gives some indication of what the program is doing. If the display is a random pattern that does not change or only changes very slowly every one or two seconds, the program is waiting for the next data file to appear. If there are two vertical bars (the right one half the height of the left one), the 100 sync characters that begin a data file are being read. The data file is actually being loaded when the right two vertical segments are lighted, the top horizontal segment is off, and all other segments are flickering too fast to be understood.

The program can detect the following types of errors:

- *Vertical parity error.* A parity bit is stored with each character in the data file to enable detection of a change in one bit of the character.
- *Longitudinal checksum error.* The last character of a file, called a checksum, gives the tape load program one more way of checking that a file is read in properly.

When the tape load program terminates, register b14 contains the number of vertical parity errors in the upper two digits. The lower two digits contain the computed checksum for the file. If register b14 contains all zeros, no errors were detected. If register b14 has no zeros, data that was read in should be viewed with suspicion. An error has occurred but there is no way to determine where it has occurred.

The tape read program will ignore anything on the tape that it does not recognize as a data file. As a result, a short voice description of a data file can precede that file on the tape without causing any problems for the load program.

For example, if a data file with file ID 53 has been stored on tape, refer to Table 4-17 to read that file back.

TABLE 4-17. TAPE READ EXAMPLE STEPS

User Type Input	Output	User Action
	1800 DC	
/A8'cr'	A8 12	
53'cr'	A9 34	
*05EEg'cr'	MAC Tutor Exec 1.0	Start tape recorder.
	1800 DC	
		Stop tape recorder.
/BE'cr'	BE 0000	

Table Note: The tape can be started from the very beginning and the program will skip everything until it comes to the right file. It is also possible to manually position the tape with the fast forward and rewind controls to just before the desired file. If the position of the file is known, either through voice information on the tape or tape recorder counter, this technique can be used to speed up tape file processing.

4.5 Testing and Diagnosing

MAC Tutor testing and diagnosing approaches consist of:

- Self-test program
- Truth table excitation
- Manual logic analyzer

The self-test approach consists of running a program that checks out each portion of the MAC Tutor. This program requires that a set of straps be plugged into the I/O and PROM programming sockets. Then, by feeding the outputs to the inputs of the various elements, the program verifies the operation.

The truth table excitation approach makes use of a logic tester to excite the various elements in the MAC Tutor and to logically compare the appropriate outputs. This test requires that the MAC-8 be removed from the socket and the logic tester be connected to the MAC-8 and I/O sockets.

The third approach for testing and diagnosing the MAC Tutor is through the use of a logic analyzer (e.g., Hewlett-Packard Model 1600A or equivalent). The address and data buses are available for monitoring purposes at connectors J1 and J2. Through the use of the memory map shown in Table 4-18, the read and write cycles for the various memory devices can be monitored and verified. Typically, the first items that are checked out involve the integrity of the control signals to and from the MAC-8. These include the reset, memory read, memory write, and clock signals. If these signals check out, the ROM, RAM, and I/O follow in sequence. These are checked out by determining the integrity of the chip select signal of these devices and the data bus contents.

TABLE 4-18. ADDRESS ASSIGNMENTS/MEMORY MAP

Device	Physical Location	A15	A14	A13	A12	A11	A10	A4	A3	A2	A1	A0	Hex Addresses
32AG ROM } 32AAF ROM }	N01	0	0	0	0	0	X						0000-07FF
2708 PROM	.K01	0	0	0	0	1	0						0800-OBFF
2708 PROM	G01	0	0	0	0	1	1						0C00-OFFF
2708 PROM	D01	0	0	0	1	0	0						1000-13FF
9131 RAM	D05-K05	0	0	0	1	0	1						1400-17FF
9131 RAM	G05-N05	0	0	0	1	1	0						1800-1BFF
8255 I/O	D24	0	0	0	1	1	1	0	0	0			1F00-1F03
8255 I/O	D16	0	0	0	1	1	1	0	0	1			1F04-1F07
8255 I/O	D20	0	0	0	1	1	1	0	1	0			1F08-1F0B
74LS273 I/O	C10	0	0	0	1	1	1	0	1	1	0	1	1F0D
74LS273 I/O	C13	0	0	0	1	1	1	0	1	1	1	0	1F0E

Table Notes: 1. X designates either logical 1 or 0. Blank areas indicate future expansion.

2. Unit comes equipped with one of the two listed ROMs.

Chapter 5

GLOSSARY

5. GLOSSARY

Addend	A number to be added to another.
Addressing Mode	A way of forming the effective memory address(es) for the operand(s) in an instruction.
Architecture	A design or orderly arrangement of a microprocessor.
Augend	A quantity to which an addend is added.
Autobaud	To automatically adjust to a given baud rate.
Baud Rate	A measure of data flow. The number of signal elements per second based on the duration of the shortest element. When each element carries one bit, the the baud rate is numerically equal to bits per second (bps).
Bit	A binary digit (logical 1 or 0).
Byte	A sequence of adjacent binary digits (usually shorter than a word) operated on as a unit. Sometimes referred to an 8-bit byte.
C Compiler	A unit that translates C language source programs into machine language codes.
Central Processing Unit (CPU)	The heart of any computer system. A basic CPU consists of an arithmetic and logic unit, control block register array, and input/output.

Checksum	The last character of a data file that is used for error detection purposes.
Clock	A pulse generator that controls the timing of microprocessor switching circuits.
Command	The portion of an instruction that specifies the operation to be performed.
C Program	An organized set of instructions written in the C programming language.
CPU	See *Central Processing Unit.*
Data Bus	A group of lines each capable of transferring one bit of data. It is bidirectional and can transfer data to and from the CPU, memory storage, and peripheral devices.
Debug	To search for and eliminate errors in a computer program.
Decrement	A programming instruction that decreases the contents of a storage location.
DIP Connector	Dual In-line package connector.
Dump	To transfer the contents of memory to an output device.
Dyadic Operation	An operation performed using two operands, the source and destination.
EPROM	See *Erasable Programmable Read-Only Memory.*
Erasable Programmable Read-Only Memory (EPROM)	Usually consists of a mosaic of undifferentiated cells that is electrically reprogrammable and erasable by ultraviolet irradiation.

Fetch

To obtain data from a memory location. Reading an instruction from memory and entering it in the instruction register is often referred to as an instruction fetch.

Frequency Shift Keying (FSK)

A form of frequency modulation in which the modulating wave shifts the output frequency between predetermined values (usually called a mark and space).

FSK

See *Frequency Shift Keying.*

Hardware

The electrical, mechanical, electronic, and magnetic components of a computer.

Hexadecimal

Whole numbers and letters in positional notation using the decimal number 16 as a base. The least significant hexadecimal digits read: 0,1,2,3,4,5,6,7,8,9,A,B,C,D,E,F.

Increment

A programming instruction that increases the contents of a storage location.

Input/Output (I/O)

Package pins connect directly to the internal bus network to interface the microprocessor with the "outside world."

Interface

A common boundary between adjacent component circuits or systems enabling the devices to yield or acquire information from one another. (Buffer, handshake, and adapter are used interchangeably with interface.)

Interrupt

Suspension of the normal programming routine of a microprocessor in order to handle a sudden request for service.

I/O

See *Input/Output.*

LED

Light-emitting diode.

Memory	Core, disk, drum, or semiconductor systems into which information can be inserted and held for future use. (Memory and storage are interchangeable terms.)
Microprocessor	A central processing unit fabricated on one or two chips consisting of arithmetic and logic unit, control block, and register array. The inputs and outputs of the associated sections are joined to a memory storage system.
Modem	An acronym for modulator-demodulator. A device that converts data to a form that is compatible between data processing and transmission equipment.
Monadic Operation	An operation performed using only one operand.
Opcode	An acronym for operation code; that part of the coded instruction designating the operation to be performed.
Operand	A quantity of data in which an operation is performed; usually one of the instruction fields in an addressing statement.
Peripheral	Auxiliary function (devices not under direct computer control).
PPI	See *Programmable Peripheral Interface.*
Program	A procedure for solving a problem. Frequently referred to as software.
Programmable Peripheral Interface (PPI)	An integrated circuit that can be programmed to interface with a variety of peripheral equipment.
Programmable Read-Only Memory (PROM)	A programmable mosaic of undifferentiated cells. Program data is stored in the PROM.

PROM	See *Programmable Read-Only Memory.*
Pushdown Stack	A register array used for storing and retrieving data on a last-in, first-out basis.
RAM	See *Random-Access Memory.*
Random-Access Memory (RAM)	Memory in which access to any storage location is provided immediately by means of vertical and horizontal coordination. Information can be "written in" or "read out" in the same rapid manner.
Read-Only Memory (ROM)	A storage device in which stored data cannot be altered by computer instructions (sometimes called firmware).
Register	A device for temporary storage of one or more bits involved in arithmetical, logical, or transferral operations. The number of registers in a microprocessor is considered one of the most important architecture features.
ROM	See *Read-Only Memory.*
Routine	A sequence of instructions for performing a particular task.
Single-Step	A command that executes only one instruction at a time.
Software	The internal programs or routines prepared to simplify computer operations. Software permits the programmer to use a language such as C or mathematics to communicate with a computer.
Storage	Any device that retains information. The word storage is used interchangeably with memory.

Subroutine
: Part of a master routine that can be used at will to accomplish a specific task (the object of a branch or jump command).

Teletypewriter (TTY)
: The teletypewriter uses electromechanical functions to generate codes (Baudot) in response to manual inputs from a typewriter keyboard.

Transistor-Transistor Logic (TTL)
: A logic-circuit design method that uses inputs from multiple emitter transistors. Sometimes referred to as multiemitter transistor logic.

TTL
: See *Transistor-Transistor Logic.*

TTY
: See *Teletypewriter.*

Word
: A number of bits that are treated as one unit, where the number depends on the CPU.

APPENDIX

RESIDENT EXECUTIVE PROGRAM

```
#define IOPAGE  017400
#define PCNTRL  *(b11+3)
#define QCNTRL  *(b11+7)
#define PAIO    *b11
#define PBIO    *(b11+1)
#define PCIO    *(b11+2)
#define PDIO    *(b11+4)

#define SETMOD  0200
#define AINP    020
#define BINP    02
#define CINP    011
#define CLINP   01
#define CUINP   010
#define DINP    010

#define SSTKEY  24
#define NOKEY   28
#define OFFDIG  15
#define ALLDIG  0177400
#define KDOWN   2

#define BAUD    *015776

#define NUMDEL  3
#define SSTDEL  0x7f

#define RAMORG  0x1800
#define RAMLEN  04000
#define SYSREG  0x1be0
#define USERRG  0x1bc0
#define USERB11 *015726 /* 0x1bd6 */
#define USERB12 *015730 /* 0x1bd8 */
#define USERB13 *015732 /* 0x1bda */
#define USERB14 *015734 /* 0x1bdc */

#define NBIT    50

#define A       10
#define B       11

#define STARTCH '*'
#define ENDCH   '/'
#define CHECKSUM 0x2a   /* '*' */
#define EOT     004
#define SYNC    026

#define BIT1    24<<8 | 12
#define BIT0    12<<8 | 12
#define CYCLE0  13
#define CYCLE1  6
#define NOISE   040

int USERB11;
int USERB12;
```

```
                                  int USERB13;
                                  int USERB14;

                                  int BAUD;
                                  _ASSEM "BAUD = 15776";

                                  _ASSEM "PCNTRL = 17403";
                                  _ASSEM "QCNTRL = 17407";
                                  _ASSEM "PAIO = 17400";
                                  _ASSEM "PBIO = 17401";
                                  _ASSEM "PCIO = 17402";
                                  _ASSEM "PDIO = 17404";

77A  7E 30 6D 79                  char tfmt[]     { 0176, 0060, 0155, 0171 }
77E  33 5B 5F 70                                  { 0063, 0133, 0137, 0160 }
782  7F 73 77 1F                                  { 0177, 0163, 0167, 0037 }
786  0D 3D 4F 47                                  { 0015, 0075, 0117, 0107 };


78A  18 14 10 0C                  char tnum[]     { 24, 20, 16, 12 }
78E  0D 0E 0F 19                                  { 13, 14, 15, 25 }
792  15 11 08 09                                  { 21, 17,  8,  9 }
796  0A 0B 1A 16                                  { 10, 11, 26, 22 }
79A  12 04 05 06                                  { 18,  4,  5,  6 }
79E  07 1B 17 13                                  {  7, 27, 23, 19 }
7A2  00 01 02 03                                  {  0,  1,  2,  3 };


7A6  65 01 E2 01 F0 01            int tfnc[]      { &numb, &plus, &minus, &star }
7AC  D1 01
7AE  DE 01 0E 02 A7 01                            { &equal, &exec, &areg, &breg }
7B4  C3 01
7B6  FE 01 15 02 15 02                            { &rptr, &sst, &sst, &init0 }
7BC  29 00
7BE  44 02                                        { &tty };

                                  /*  Mac8 Tutor Executive
                                   *
                                   *  Global memory allocation
                                   *
                                   *           +---------------+
                                   *  1BFE     |--   b15     --|      BAUD rate counter
                                   *           +---------------+
                                   *           |--   b14     --|      contents of (b13)
                                   *           +---------------+
                                   *           |--   b13     --|      current address
                                   *           +---------------+
                                   *           |_______________+      on digits flags
                                   *           |     a12       |      exec state flags
                                   *           +---------------+
                                   *           |--   b11     --|      address of IO page
                                   *           +---------------+
                                   *                  .
                                   *                  .
                                   *                  .
```

```
                                        *        +---------------+
                                        *  1BE0  |--    b0     --|
                                        *        +---------------+  <- rp
                                        *  1BDE  |--    b15    --|
                                        *        +---------------+
                                        *                .
                                        *                .            user registers
                                        *                .
                                        *        +---------------+
                                        *  1BC0  |--    b0     --|
                                        *        +---------------+  <- user rp
                                        *        |--   init0   --|     return address to exec
                                        *        +---------------+
                                        *        |      cr       |
                                        *        +---------------+
                                        *        |--  User pc  --|
                                        *        +---------------+
                                        *        |--  User rp  --|
                                        *        +---------------+  <- sp
                                        *                .
                                        *                .            Stack
                                        *                .
                                        *        +---------------+
                                        *  1400  |               |    Origin of RAM
                                        *        +---------------+
                                        *
                                        */
                                       main()
                                       {
 0  7F                                          nop();
 1  7F                                          nop();
 2  7F                                          nop();
 3  58 03                                       goto 1f;
 5  59 00 08                                    goto *0x800;
 8  47                                 1:       push(rp);
 9  4D 0F E0 1B                                 rp = SYSREG;
 D  C0 BF 00 1F                                 b11 = IOPAGE;
11  82 BF 07 8B                                 QCNTRL = 0213;
15  82 BF 04 FF                                 PDIO = 0377;
19  82 BF 03 93                                 PCNTRL = 0223;
1D  86 0B 02                                    a0 = PCIO;
20  52 03 31                                    if (!bit(3,a0)) goto 1f;
23  7F                                          nop();
24  59 F4 07                                    goto powon;
27  60 F0                              reset:   b15 = 0;
29  C1 FF D6 1B 00 1F                  init0:   USERB11 = IOPAGE;
2F  C1 FF D8 1B 02 FF                           USERB12 = ALLDIG | KDOWN;
35  4D 0F E0 1B                        init:    rp = SYSREG;
39  C0 BF 00 1F                                 b11 = IOPAGE;
3D  0D 0F B9 1B                                 sp = USERRG - 2 - 1 - 2 - 2;
41  C2 FF 05 35 00                              *(dsp + 5) = &init;
46  22 F0 04                                    *(sp + 4) = 0;
49  C2 FF 02 00 18                              *(dsp + 2) = RAMORG;
4E  C2 FF 00 C0 1B                              *(dsp + 0) = USERRG;
53  82 BF 03 90                        1:       PCNTRL = 0220;
57  82 BF 02 10                                 PCIO = 020;
```

```
5B   C6 DF 02                   b13 = *(dsp + 2);
5E   C5 ED                      b14 = *d13;
60   C0 CF 00 FF       man2:    b12 = ALLDIG;
64   01 02                      set(zero);        /* mac7 hardware error */
66   C5 0F FE 1B                b0 = BAUD;
6A   61 F1 44 02                if (!zero) tty();
6E   79 AC 00                   rdkey();
71   B0 0F 18                   a0 - SSTKEY;
74   48 F1 04                   if (zero) goto 1f;
77   80 CF 02                   a12 = KDOWN;
7A   79 DF 00          1:       disp();
7D   79 AC 00                   rdkey();
80   B0 0F 1C                   if (a0 == NOKEY) {
83   40 F1 06
86   98 CF FD                           a12 =& 0375;
89   58 EF                              goto 1b;
                                }
8B   5A C1 ED                   if (bit(1,a12)) goto 1b;
8E   90 CF 02                   a12 =¦ KDOWN;
91   B0 0F 0F                   if (a0 <= 15) {
94   40 F9 07
97   C0 20                              b2 = b0;
99   C0 0F 0F 00                        b0 = 15;
                                }
9D   A0 0F 0F                   a0 =- 15;
A0   30 01                      a0 =* 2;
A2   E8 0F A6 07                b0 =+ &tfnc;
A6   C5 30                      b3 = *d0;
A8   69 3F                      *b3();
AA   58 CE                      goto 1b;
                       }
                       /*   rdkey - read keyboard
                        *
                        *   entry - entry - none.
                        *
                        *   uses - a 0,1,3
                        *          b 0,1
                        *
                        *   calls - none.
                        *
                        *   exit - a0 = number from 0 to 27 indicating
                        *               which key was pressed.
                        *
                        */
                       rdkey()
                       {
AC   82 BF 03 82                PCNTRL = 0202;
B0   82 BF 07 9B                QCNTRL = 0233;
B4   C0 0F F9 00                b0 = (-7)&0377;
B8   80 3F EF                   a3 = 0357;
BB   A8 0F 07          1:       a0 =+ 7;
BE   34 3F                      a3 =>>> 1;
C0   65 00                      if (!neg) return;
C2   81 B3                      PAIO = a3;
C4   86 4B 04                   a4 = PDIO;
C7   98 4F 7F                   a4 =& 0177;
```

```
CA   88 4F 7F                  a4 =^ 0177;
CD   48 F1 EC                  if (zero) goto 1b;
D0   0C 14                     a1 = flo(a4);
D2   28 18                     --a1;
D4   A8 01                     a0 =+ a1;
D6   C0 1F 8A 07               b1 = &tnum;
DA   75 10                     b1 =+ logical(a0);
DC   85 01                     a0 = *b1;
DE   66                        return;
                       }
                       /*  disp - display numbers in 7-segment displays
                        *
                        *  entry - a12(15-8) = bit mask indicating on
                        *                        digits.
                        *          b13 = first four digits to display
                        *          b14 = last four digits
                        *
                        *  uses - a 0,2,5
                        *         b 0,5
                        *
                        *  calls - dsp4, delay.
                        *
                        *  exit - 7-segment displays refreshed.
                        *
                        */
                       disp()
                       {
DF   7F                        nop();          /* historical allignment */
E0   82 BF 07 8B               QCNTRL = 0213;
E4   22 B0 04                  PDIO = 0;
E7   82 BF 03 90               PCNTRL = 0220;
EB   6A C0                     swap(b12);
ED   20 20                     a2 = 0;
EF   C0 0D                     b0 = b13;
F1   79 07 01                  dsp4();
F4   C0 0E                     b0 = b14;
F6   79 07 01                  dsp4();
F9   C0 5F 03 00               b5 = NUMDEL;
FD   79 5D 01                  delay();
100  82 BF 01 0F               PBIO = OFFDIG;
104  6A C0                     swap(b12);
106  66                        return;
                       }
                       /*  dsp4 - display 4 digits
                        *
                        *  entry - b0 = 16-bit number to display
                        *
                        *  uses - a none.
                        *         b 0
                        *
                        *  calls - dsp2.
                        *
                        *  exit - next 4 digits displayed.
                        *
                        */
                       dsp4()
```

```
                                {
107   6A 00                             swap(b0);
109   79 12 01                          dsp2();
10C   6A 00                             swap(b0);
10E   79 12 01                          dsp2();
111   66                                return;
                                }
                                /*  dsp2 - display 2 digits
                                 *
                                 *  entry - a0 = 8-bit number to display
                                 *
                                 *  uses - a 0,1,2,3,5
                                 *         b 3,5
                                 *
                                 *  calls - delay.
                                 *
                                 *  exit - next 2 digits displayed.
                                 *
                                 */
                                dsp2()
                                {
112   80 10                             a1 = a0;
114   38 1F                             a1 =>> 1;
116   38 1F                             a1 =>> 1;
118   38 1F                             a1 =>> 1;
11A   38 1F                             a1 =>> 1;
11C   C0 3F 7A 07                       b3 = &tfmt;
120   75 31                             b3 =+ logical(a1);
122   85 33                             a3 = *b3;
124   82 BF 01 0F                       PBIO = OFFDIG;
128   34 C1                             a12 =<<< 1;
12A   40 F5 0E                          if (!odd) goto dp21;
12D   82 B3 04                          PDIO = a3;
130   82 B2 01                          PBIO = a2;
133   C0 5F 03 00                       b5 = NUMDEL;
137   79 5D 01                          delay();
13A   28 20                     dp21:   ++a2;
13C   98 0F 0F                          a0 =& 017;
13F   C0 3F 7A 07                       b3 = &tfmt;
143   75 30                             b3 =+ logical(a0);
145   85 33                             a3 = *b3;
147   82 BF 01 0F                       PBIO = OFFDIG;
14B   34 C1                             a12 =<<< 1;
14D   40 F5 07                          if (!odd) goto dp22;
150   82 B3 04                          PDIO = a3;
153   82 B2 01                          PBIO = a2;
156   28 20                     dp22:   ++a2;
158   66                                return;
                                }
                                /*  bitime, delay - delay specified time
                                 *
                                 *  entry - b5 = delay count (picked up from
                                 *                   BAUD by bitime)
                                 *
                                 *  uses - a 5
                                 *         b 5
```

```
                         *
                         *  calls - none.
                         *
                         *  exit - eventually.
                         *
                         */
                        bitime()
                        {
159  C5 5F FE 1B                b5 = BAUD;
15D  01 02              delay:  set(zero);
15F  68 58                      --b5;
161  64 00                      if (neg) return;
163  58 F8                      goto delay;
                        }
                        /*  numb = process hex number
                         *
                         *  entry - a2 = number keyed in
                         *
                         *  uses - a 0,1,13,14
                         *         b 0,13,14
                         *
                         *  calls - none.
                         *
                         *  exit - number shifted into the current
                         *         address or data field as required.
                         *
                         */
                        numb()
                        {
165  52 C0 12                   if (bit(0,a12)) {
168  5A C2 21                           if (bit(2,a12)) goto chreg;
16B  38 E1                              a14 =<< 1;
16D  38 E1                              a14 =<< 1;
16F  38 E1                              a14 =<< 1;
171  38 E1                              a14 =<< 1;
173  90 E2                              a14 =¦ a2;
175  81 DE                              *b13 = a14;
177  58 11                      } else {
179  5A C2 3A                           if (bit(2,a12)) goto reg2;
17C  C0 0D                              b0 = b13;
17E  79 3B 02                           shift4();
181  C0 D0                              b13 = b0;
183  98 DF F0                           a13 =& 0360;
186  90 D2                              a13 =¦ a2;
188  C5 ED                              b14 = *d13;
                                }
18A  66                         return;
18B  52 C3 0A           chreg:  if (bit(3,a12)) {
18E  C0 0E                              b0 = b14;
190  79 3B 02                           shift4();
193  C0 E0                              b14 = b0;
195  58 08                      } else {
197  38 E1                              a14 =<< 1;
199  38 E1                              a14 =<< 1;
19B  38 E1                              a14 =<< 1;
19D  38 E1                              a14 =<< 1;
```

```
                                            }
19F   90 E2                                 a14 =¦ a2;
1A1   79 33 04                              regad();
1A4   C1 0E                                 *d0 = b14;
1A6   66                                    return;
                                    }
                                    /*  areg - set a register mode
                                     *
                                     *  entry - none.
                                     *
                                     *  uses - a 0,2,12,13,14
                                     *         b 0,12,13
                                     *
                                     *  calls - none.
                                     *
                                     *  exit - display set up for a-register dispiay
                                     *
                                     */
                                    areg()
                                    {
1A7   D0 CF 04 FF                           b12 =¦ ALLDIG¦04;
1AB   D8 CF F6 33                           b12 =& 031766;
1AF   C0 DF A0 00                           b13 = A<<4;
1B3   20 20                         reg1:   a2 = 0;
1B5   98 2F 0F                      reg2:   a2 =& 017;
1B8   98 DF F0                              a13 =& 0360;
1BB   90 D2                                 a13 =¦ a2;
1BD   79 33 04                              regad();
1C0   C5 E0                                 b14 = *d0;
1C2   66                                    return;
                                    }
                                    /*  breg - set b register mode
                                     *
                                     *  entry - none.
                                     *
                                     *  uses - a 12,13
                                     *         b 12,13
                                     *
                                     *  calls - areg.
                                     *
                                     *  exit - display set up for b-register display.
                                     *
                                     */
                                    breg()
                                    {
1C3   D0 CF 0C FF                           b12 =¦ ALLDIG¦014;
1C7   D8 CF FE 3F                           b12 =& 037776;
1CB   C0 DF B0 00                           b13 = B<<4;
1CF   58 E2                                 goto reg1;
                                    }
                                    /*  star - set address mode
                                     *
                                     *  entry - none.
                                     *
                                     *  uses - a 12,13,14
                                     *         b 12,13,14
```

```
                                 *
                                 *  calls - none.
                                 *
                                 *  exit - display set up for memory display and
                                 *          all further numbers keyed into the
                                 *          address field.  Address is set to
                                 *          current user pc.
                                 *
                                 */
                                star()
                                {
1D1   98 CF F2                          a12 =& 0362;
1D4   D0 CF 00 FF                       b12 =| ALLDIG;
1D8   C6 DF 04                          b13 = *(dsp + 4);
1DB   C5 ED                             b14 = *d13;
1DD   66                                return;
                                }
                                /*  equal - set data mode
                                 *
                                 *  entry - none.
                                 *
                                 *  uses - a 12
                                 *         b none.
                                 *
                                 *  calls - none.
                                 *
                                 *  exit - all further numbers keyed in get
                                 *          stored at the current address.
                                 *
                                 */
                                equal()
                                {
1DE   90 CF 01                          a12 =| 1;
1E1   66                                return;
                                }
                                /*  plus - increment the current address
                                 *
                                 *  entry - b13 = current address
                                 *
                                 *  uses - a 2,13,14
                                 *         b 2,13,14
                                 *
                                 *  calls - none.
                                 *
                                 *  exit - current address incremented and
                                 *          address/data mode unchanged.
                                 *
                                 */
                                plus()
                                {
1E2   52 C2 07                          if (!bit(2,a12)) goto 1f;
1E5   80 2D                             a2 = a13;
1E7   28 20                             ++a2;
1E9   58 CA                             goto reg2;
1EB   68 D0                     1:      ++b13;
1ED   C5 ED                             b14 = *d13;
```

```
1EF  66                         return;
                        }
                        /*  minus - decrement the current address
                         *
                         *  entry - b13 = current address
                         *
                         *  uses - a 2,13,14
                         *         b 2,13,14
                         *
                         *  calls - none.
                         *
                         *  exit - current address decremented and
                         *           address/data mode unchanged.
                         *
                         */
                        minus()
                        {
1F0  52 C2 07                   if (!bit(2,a12)) goto 1f;
1F3  80 2D                      a2 = a13;
1F5  28 28                      --a2;
1F7  58 BC                      goto reg2;
1F9  68 D8              1:      --b13;
1FB  C5 ED                      b14 = *d13;
1FD  66                         return;
                        }
                        /*  rptr - display user rp
                         *
                         *  entry - none.
                         *
                         *  uses - a 12,13,14
                         *         b 12,13,14
                         *
                         *  calls - none.
                         *
                         *  exit - current address set to location
                         *           containing the user rp.
                         *
                         */
                        rptr()
                        {
1FE  6F DF 00                   b13 = &*(sp+0);
201  7D DF 02                   b13 =+ 2;
204  C5 ED              rpt1:   b14 = *d13;
206  D0 CF 00 FF                b12 =¦ ALLDIG;
20A  98 CF F2                   a12 =& 0362;
20D  66                         return;
                        }
                        /*  exec - execute user program
                         *
                         *  entry - b13 = starting address
                         *
                         *  uses - a 0
                         *         b 0
                         *
                         *  calls - none.
                         *
```

```
                             *  exet - to user program.
                             *
                             */
                            exec()
                            {
20E   44 00                         b0 = pop();
210   C2 FD 02                      *(dsp+2) = b13;
213   45                            rp = pop();
214   67                            ireturn();
                            }
                            /*  sst - single step user program
                             *
                             *  entry - b13 = current address to execute
                             *
                             *  uses - none.
                             *
                             *  calls - none.
                             *
                             *  exit - None.  Interrupt will automatically
                             *           occure before one user instruction
                             *           can complete.
                             *
                             */
                            sst()
                            {
215   80 AF 7F                      a10 = SSTDEL;
218   79 DF 00              1:      disp();
21B   28 A8                         --a10;
21D   40 F0 F9                      if (!neg) goto 1b;
220   44 00                 sst0:   b0 = pop();
222   80 CF 12                      a12 = 022;
225   C2 FD 02                      *(dsp+2) = b13;
228   82 BF 02 80                   PCIO = 0200;
22C   7F                            nop();
22D   45                            rp = pop();
22E   67                            ireturn();
                            }
                            /*  move - move block of memory
                             *
                             *  entry - b8 = fwa of destination
                             *          b9 = fwa of source
                             *          b10 = lwa+1 of source
                             *
                             *  uses - a 0,8,9
                             *         b 8,9
                             *
                             *  calls - none.
                             *
                             *  exit - (b9) to (b10-1) moved to b8.
                             *
                             */
                            move()
                            {
22F   01 02                         set(zero);
231   F0 9A                         b9 - b10;
233   64 01                         if (zero) return;
```

```
235  87 09                a0 = *b9++;
237  83 80                *b8++ = a0;
239  58 F4                goto move;
                  }
                  /*  shift4 - shift b0 left by 4
                   *
                   *  entry - b0 = 16-bit number to be shifted
                   *               logically.
                   *
                   *  uses - a 0,1
                   *         b 0,1
                   *
                   *  calls - none.
                   *
                   *  exit - b0 shifted left 4.
                   *
                   */
                  shift4()
                  {
23B  E8 00                b0 =+ b0;
23D  E8 00                b0 =+ b0;
23F  E8 00                b0 =+ b0;
241  E8 00                b0 =+ b0;
243  66                   return;
                  }
7C0  4D 63 54 75 74 6F    char header[] "McTutor Exec 1.0\n\r";
7C6  72 20 45 78 65 63
7CC  20 31 2E 30 0A 0D
7D2  00

7D3  68 2A 67 73          char ttty[]      { 'h', '*', 'g', 's' }
7D7  0D 0A 21 6C                           { '\r', '\n', '!', 'l' }
7DB  2F 69 72                              { '/', 'i', 'r' };

7DE  99 03 8D 02 A9 02    int ttyf[]       { &half, &addr, &run, &sst0 }
7E4  20 02
7E6  9D 03 EB 03 08 03                     { &retrn, &linefd, &unix, &load }
7EC  22 03
7EE  83 02 29 00 99 02                     { &raddr, &init0, &rpoint };


                  /*  tty - main teletype controler
                   *
                   *  entry - none.
                   *
                   *  uses - a 0,7,10,13,14
                   *         b 0,10,13
                   *  calls - baud, prstring, rdtty, prtty, ktype
                   *
                   *  exit - none.  (it doesn't)
                   *
                   */
                  tty()
```

```
                        {
244   44 00                     b0 = pop();
246   79 A1 04                  baud();
249   80 7F 40                  a7 = 0100;
24C   80 CF 02                  a12 = 02;
24F   79 76 04                  lfcr();
252   C0 DF C0 07               b13 = &header;
256   79 91 04                  prstring();
259   C6 DF 02                  b13 = *(dsp + 2);
25C   79 05 04                  prloc();
25F   79 C6 04          1:      rdtty();
262   98 EF 7F                  a14 =& 0177;
265   49 F1 27 00               if (zero) goto reset;
269   5A C4 04                  if (bit(4,a12)) goto 2f;
26C   79 14 05                  prtty();
26F   B0 EF 41          2:      a14 - 'A';
272   48 F8 0A                  if (lt) goto 3f;
275   B0 EF 5A                  a14 - 'Z';
278   40 F9 04                  if (!lteq) goto 3f;
27B   90 EF 20                  a14 =¦ 040;
27E   79 3F 04          3:      ktype();
281   58 DC                     goto 1b;
                        }
                        /*  raddr - set register mode
                         *
                         *  entry - none.
                         *
                         *  uses - a 12,13
                         *         b none.
                         *
                         *  calls - none.
                         *
                         *  exit - state bits set up for register
                         *            operations.
                         *
                         */
                        raddr()
                        {
283   98 CF 12                  a12 =& 022;
286   90 CF 68                  a12 =¦ 0150;
289   80 DF A0                  a13 = A<<4;
28C   66                        return;
                        }
                        /*  addr - `*' key => set up to input address
                         *
                         *  entry - none
                         *
                         *  uses - a 12
                         *         b 10,13
                         *
                         *  calls - none.
                         *
                         *  exit - current address set to origin of ram
                         *            and ready to be changed.
                         *
                         */
```

```
                        addr()
                        {
28D  C6 AF 04                   b10 = *(dsp + 4);
290  C0 DA                      b13 = b10;
292  98 CF 12                   a12 =& 022;
295  90 CF 20                   a12 =¦ 040;
298  66                         return;
                        }
                        /*  rpoint - set address to rp
                         *
                         *  entry - none.
                         *
                         *  uses - a 12,13
                         *         b 13
                         *
                         *  calls - lfcr, prloc
                         *
                         *  exit - current address set to base of stack
                         *             which contains the user rp.
                         *
                         */
                        rpoint()
                        {
299  6F DF 00                   b13 = &*(sp + 0);
29C  7D DF 02                   b13 =+ 2;
29F  98 CF 12                   a12 =& 022;
2A2  79 76 04                   lfcr();
2A5  79 05 04                   prloc();
2A8  66                         return;
                        }
                        /*  run - set execute bit in status byte
                         *
                         *  entry - none.
                         *
                         *  uses - a 12
                         *         b none.
                         *
                         *  calls - none.
                         *
                         *  exit - execute bit set so next return
                         *             will start execution.
                         *
                         */
                        run()
                        {
2A9  90 CF 80                   a12 =¦ 0200;
2AC  66                         return;
                        }
                        /*  prnum - print 8-bit number on tty
                         *
                         *  entry - a9 = number to be printed
                         *
                         *  uses - none.
                         *
                         *  calls - prn1.
                         *
```

```
                  *  exit - number printed as two hex digits.
                  *
                  */
                 prnum()
                 {
2AD  79 B4 02            prn1();
2B0  79 B4 02            prn1();
2B3  66                  return;
                 }
                 /*  prn1 - print 4-bit number as hex digit
                  *
                  *  entry - a9 = upper 4 bits is number to be
                  *               printed.
                  *
                  *  uses - a 9,14
                  *         b none.
                  *
                  *  calls - prtty.
                  *
                  *  exit - digit printed and a9 shifted left
                  *         by 4.
                  *
                  */
                 prn1()
                 {
2B4  34 91               a9 =<<< 1;
2B6  34 91               a9 =<<< 1;
2B8  34 91               a9 =<<< 1;
2BA  34 91               a9 =<<< 1;
2BC  80 E9               a14 = a9;
2BE  98 EF 0F            a14 =& 017;
2C1  80 EF 09            a14 - 9;
2C4  48 F9 04            if (lteq) goto 1f;
2C7  A8 EF 07            a14 =+ 'A' - '0' - 10;
2CA  A8 EF 30    1:      a14 =+ '0';
2CD  79 14 05            prtty();
2D0  66                  return;
                 }
                 /*  tnumb - number input from tty
                  *
                  *  entry - b10 = current number being built up
                  *          a14 = character input
                  *
                  *  uses - a 0,10,12,13,14
                  *         b 0,10,13
                  *
                  *  calls - shift4.
                  *
                  *  exit - new digit shifted into the right
                  *         of b10.
                  *
                  */
                 tnumb()
                 {
2D1  98 EF 0F            a14 =& 017;
2D4  52 C3 1C            if (!bit(3,a12)) goto 2f;
```

```
2D7    52 C6 10                   if (!bit(6,a12)) goto 1f;
2DA    98 CF BF                   a12 =& 0277;
2DD    B0 EF 0B                   a14 - 11;
2E0    65 01                      if (!zero) return;
2E2    90 CF 04                   a12 =| 04;
2E5    80 DF B0                   a13 = B<<4;
2E8    66                         return;
2E9    52 C5 07           1:      if (!bit(5,a12)) goto 2f;
2EC    98 DF F0                   a13 =& 0360;
2EF    90 DE                      a13 =| a14;
2F1    66                         return;
2F2    C0 0A              2:      b0 = b10;
2F4    79 3B 02                   shift4();
2F7    C0 A0                      b10 = b0;
2F9    98 AF F0                   a10 =& 0360;
2FC    90 AE                      a10 =| a14;
2FE    5A C5 05                   if (bit(5,a12)) goto 1f;
301    90 CF 01                   a12 =| 1;
304    66                         return;
305    C0 DA              1:      b13 = b10;
307    66                         return;
                          }
                          /*  unix - listen to modem
                           *
                           *  entry - none.
                           *
                           *  uses - a 14.
                           *         b none.
                           *
                           *  calls - rdtty.
                           *
                           *  exit - when a '!' is received from the modem.
                           *
                           */
                          unix()
                          {
308    82 BF 02 01                PCIO = 01;
30C    79 C6 04           1:      rdtty();
30F    98 EF 7F                   a14 =& 0177;
312    B0 EF 21                   a14 - '!';
315    40 F1 F5                   if (!zero) goto 1b;
318    22 B0 02                   PCIO = 0;
31B    79 14 05                   prtty();
31E    79 76 04                   lfcr();
321    66                         return;
                          }
                          /*  load - load hex file from modem
                           *
                           *  entry - none.
                           *
                           *  uses - a 7,8,9,13,14
                           *         b 13
                           *
                           *  calls - rdmod, lfcr, prloc, getbyt.
                           *
                           *  exit - next location that would have been
```

```
                              *            load is printed.  Only ':00' is
                              *            printed from the last line of the
                              *            hex file if the load is successfull.
                              *            Otherwise there was a checksum error
                              *            in the last line listed.
                              *
                              */
                             load()
                             {
322   82 BF 02 01                    PCIO = 01;
326   80 7F 20                       a7 = 040;
329   20 80                          a8 = 0;
32B   79 0D 05               1:      rdmod();
32E   98 EF 7F                       a14 =& 0177;
331   B0 EF 3A                       a14 - ':';
334   40 F1 F5                       if (!zero) goto 1b;
337   79 71 03                       getbyt();
33A   80 9A                          a9 = a10;
33C   40 F1 10                       if (!zero) goto 3f;
33F   22 B0 02               2:      PCIO = 0;
342   80 7F 40                       a7 = 0100;
345   81 D8                          *b13 = a8;
347   79 76 04                       lfcr();
34A   79 05 04                       prloc();
34D   66                             return;
34E   79 71 03               3:      getbyt();
351   80 DA                          a13 = a10;
353   79 71 03                       getbyt();
356   6A D0                          swap(b13);
358   80 DA                          a13 = a10;
35A   79 71 03                       getbyt();
35D   28 98                  3:      --a9;
35F   48 F0 08                       if (neg) goto 4f;
362   79 71 03                       getbyt();
365   83 DA                          *b13++ = a10;
367   58 F4                          goto 3b;
369   79 71 03               4:      getbyt();
36C   48 F1 BD                       if (zero) goto 1b;
36F   58 CE                          goto 2b;
                             }
                             /*  getbyt - accumulate 8-bit byte from hex file
                              *
                              *  entry - none.
                              *
                              *  uses - a 8,10
                              *         b none.
                              *
                              *  calls - digit.
                              *
                              *  exit - a10 = byte read
                              *         a8  = current value of check sum.
                              *
                              */
                             getbyt()
                             {
371   79 86 03                       digit();
```

```
374   80 AE                     a10 = a14;
376   79 86 03                  digit();
379   38 A1                     a10 =<< 1;
37B   38 A1                     a10 =<< 1;
37D   38 A1                     a10 =<< 1;
37F   38 A1                     a10 =<< 1;
381   90 AE                     a10 =| a14;
383   A8 8A                     a8 =+ a10;
385   66                        return;
                        }
                        /*  digit - read hex digit from hex file
                         *
                         *  entry -  none.
                         *
                         *  uses - a 14
                         *         b none.
                         *
                         *  calls - rdmod.
                         *
                         *  exit - a14 = binary value of hex digit read
                         *
                         */
                        digit()
                        {
386   79 0D 05                  rdmod();
389   98 EF 7F                  a14 =& 0177;
38C   B0 EF 39                  a14 - '9';
38F   48 F9 04                  if (lteq) goto 1f;
392   A8 EF 09                  a14 =+ 9;
395   98 EF 0F          1:      a14 =& 017;
398   66                        return;
                        }
                        /*  half - set half duplex mode
                         *
                         *  entry - none.
                         *
                         *  uses - a 12
                         *         b none.
                         *
                         *  calls - none.
                         *
                         *  exit - bit set in a12 to indicate no echoing
                         *           of input.
                         *
                         */
                        half()
                        {
399   88 CF 10                  a12 =^ 020;
39C   66                        return;
                        }
                        retrn()
                        {
39D   79 33 04                  regad();
3A0   79 1F 04                  store();
3A3   80 EF 0A                  a14 = '\n';
3A6   79 14 05                  prtty();
```

```
3A9   52 C7 04               if (!bit(7,a12)) goto 1f;
3AC   59 0E 02               goto exec;
3AF   52 C3 33      1:       if (!bit(3,a12)) goto 2f;
3B2   80 0D                  a0 = a13;
3B4   5A C5 03               if (bit(5,a12)) goto ret0;
3B7   28 00                  ++a0;
3B9   98 0F 0F      ret0:    a0 =& 017;
3BC   98 DF F0               a13 =& 0360;
3BF   90 D0                  a13 =| a0;
3C1   79 82 04               crdel();
3C4   80 9D                  a9 = a13;
3C6   79 AD 02               prnum();
3C9   79 11 05               prsp();
3CC   79 33 04               regad();
3CF   C5 90                  b9 = *d0;
3D1   52 C2 08               if (!bit(2,a12)) goto 1f;
3D4   6A 90                  swap(b9);
3D6   79 AD 02               prnum();
3D9   6A 90                  swap(b9);
3DB   79 AD 02      1:       prnum();
3DE   79 11 05               prsp();
3E1   60 A0                  b10 = 0;
3E3   66                     return;
3E4   5A C5 1C      2:       if (bit(5,a12)) goto lnf1;
3E7   68 D0                  ++b13;
3E9   58 17                  goto lnf1;
                    }
                    /*  linefd - print previous location
                     *
                     *  entry - b13 = current address
                     *          a10 = possible value to store in
                     *                current address.
                     *
                     *  uses - a 8,9,10,13,14
                     *         b 9,10,13
                     *
                     *  calls - store, prtty, prnum, prsp.
                     *
                     *  exit - any pending values are stored in
                     *          the location if necessary and
                     *          the previous location is displayed.
                     *
                     */
                    linefd()
                    {
3EB   79 33 04               regad();
3EE   79 1F 04               store();
3F1   80 EF 0D               a14 = '\r';
3F4   79 14 05               prtty();
3F7   52 C3 07               if (!bit(3,a12)) goto 1f;
3FA   80 0D                  a0 = a13;
3FC   28 08                  --a0;
3FE   58 B9                  goto ret0;
400   68 D8         1:       --b13;
402   79 82 04      lnf1:    crdel();
405   C0 9D         prloc:   b9 = b13;
```

```
407   6A 90                        swap(b9);
409   79 AD 02                     prnum();
40C   6A 90                        swap(b9);
40E   79 AD 02                     prnum();
411   79 11 05                     prsp();
414   85 9D                        a9 = *b13;
416   79 AD 02                     prnum();
419   79 11 05                     prsp();
41C   60 A0                        b10 = 0;
41E   66                           return;
                           }
                           /*  store - store value in current location
                            *
                            *  entry - b0 = register address if necessary
                            *          b13 = current address
                            *          a10 = value to be stored there
                            *
                            *  uses - a 10,12,13
                            *         b 10,13
                            *
                            *  calls - none.
                            *
                            *  exit - if necessary, value stored in current
                            *           location and status updated to
                            *           indicate no value to be stored.
                            *
                            */
                           store()
                           {
41F   52 C0 0F                     if (!bit(0,a12)) goto 2f;
422   52 C3 0A                     if (!bit(3,a12)) goto 1f;
425   81 0A                        *b0 = a10;
427   52 C2 07                     if (!bit(2,a12)) goto 2f;
42A   C1 0A                        *d0 = b10;
42C   58 02                        goto 2f;
42E   81 DA                1:      *b13 = a10;
430   60 A0                2:      b10 = 0;
432   66                           return;
                           }
                           /*  regad - calculate user register address
                            *
                            *  entry - a13(0-3) = register number
                            *          *(dsp+4) = user register pointer
                            *
                            *  uses - a 0
                            *         b 0
                            *
                            *  calls - none.
                            *
                            *  exit - b0 = address of desired register.
                            *
                            */
                           regad()
                           {
433   80 0D                        a0 = a13;
435   D8 0F 0F 00                  b0 =& 017;
```

```
439   38 01                        a0 =<< 1;
43B   EE 0F 04                     b0 =+ *(dsp + 4);
43E   66                           return;
                           }
                           /*  ktype - determine key type
                            *
                            *  entry - a14 = ascii character input
                            *
                            *  uses - a 0,1,2,14
                            *         b 1,2
                            *
                            *  calls - space, addr, go, retrn, linefd, unix,
                            *              load, tnumb.
                            *
                            *  exit - to appropriate processing routine.
                            *          In the case of 'tnumb' characters
                            *          'a' - 'f' are converted into easy
                            *          to convert values.
                            *
                            */
                           ktype()
                           {
43F   B0 EF 30                     a14 - '0';
442   48 F8 08                     if (lt) goto 1f;
445   B0 EF 39                     a14 - '9';
448   49 F9 D1 02                  if (lteq) goto tnumb;
44C   B0 EF 61             1:      a14 - 'a';
44F   48 F8 0D                     if (lt) goto 1f;
452   B0 EF 66                     a14 - 'f';
455   40 F9 07                     if (!lteq) goto 1f;
458   A8 EF 09                     a14 =+ 9;
45B   59 D1 02                     goto tnumb;
45E   C0 1F D3 07          1:      b1 = &ttty;
462   C0 2F DC 07                  b2 = &ttyf - 2;
466   7D 2F 02             1:      b2 =+ 2;
469   87 01                        a0 = *b1++;
46B   64 01                        if (zero) return;
46D   B0 0E                        a0 - a14;
46F   40 F1 F5                     if (!zero) goto 1b;
472   C5 22                        b2 = *d2;
474   49 2F                        goto *b2;
                           }
                           /*  lfcr - output linefeed and carriage return
                            *
                            *  entry - none.
                            *
                            *  uses - a 0,14
                            *         b none.
                            *
                            *  calls - prtty, bitime
                            *
                            *  exit - carriage moved to new line and delay
                            *          done to allow time for this.
                            *
                            */
                           lfcr()
```

```
                                {
476   80 EF 0A                          a14 = '\n';
479   79 14 05                          prtty();
47C   80 EF 0D                  prcr:   a14 = '\r';
47F   79 14 05                          prtty();
482   98 CF 9E                  crdel:  a12 =& 0236;
485   80 0F 32                          a0 = NBIT;
488   79 59 01                  1:      bitime();
48B   28 08                             --a0;
48D   40 F1 F9                          if (!zero) goto 1b;
490   66                                return;
                                }
                                /*  prstring - print out '\0' terminated string
                                 *
                                 *  entry - b13 = pointer to string.
                                 *
                                 *  uses - a 13,14
                                 *         b 13
                                 *
                                 *  calls - prtty, crdel.
                                 *
                                 *  exit - string printed out on terminal.
                                 *
                                 */
                                prstring()
                                {
491   87 ED                     1:      a14 = *b13++;
493   64 01                             if (zero) return;
495   79 14 05                          prtty();
498   B0 EF 0D                          a14 - '\r';
49B   69 F1 82 04                       if (zero) crdel();
49F   58 F0                             goto 1b;
                                }
                                /*  baud - determine baud rate of terminal
                                 *
                                 *  entry - BAUD = 0 => baud rate unknown
                                 *
                                 *  uses - a 0,5
                                 *         b 0
                                 *
                                 *  calls - none.
                                 *
                                 *  exit - BAUD contains delay count that enables
                                 *           bitime to wait one bit time.
                                 *
                                 */
                                baud()
                                {
4A1   82 BF 03 92                       PCNTRL = 0222;
4A5   C5 0F FE 1B                       b0 = BAUD;
4A9   65 01                             if (!zero) return;
4AB   5B B6 14                          if (bit(6,PAIO)) goto 3f;
4AE   53 B6 FE                  1:      if (!bit(6,PAIO)) goto 1b;
4B1   7D 0F 03                  1:      b0 =+ 3;
4B4   80 5F 02                          a5 = 2;
4B7   80 55                             a5 = a5;
```

```
4B9   28 58             2:      --a5;
4BB   40 F0 FC                  if (!neg) goto 2b;
4BE   5B B6 F1                  if (bit(6,PAIO)) goto 1b;
4C1   C1 F0 FE 1B       3:      BAUD = b0;
4C5   66                        return;
                        }
                        /*  rdtty - read character from tty
                         *
                         *  entry - none.
                         *
                         *  uses - a 0,1,5,6,14
                         *             b 5
                         *
                         *  calls - delay, bitime.
                         *
                         *  exit - a14 = character read
                         *
                         */
                        rdtty()
                        {
4C6   20 10                     a1 = 0;
4C8   20 E0             rdt0:   a14 = 0;
4CA   86 6B 02                  a6 = PCIO;
4CD   82 BF 03 92               PCNTRL = 0222;
4D1   82 B6 02                  PCIO = a6;
4D4   85 0B             1:      a0 = PAIO;
4D6   98 07                     a0 =& a7;
4D8   88 01                     a0 =^ a1;
4DA   48 F1 F8                  if (zero) goto 1b;
4DD   C5 5F FE 1B               b5 = BAUD;
4E1   03 08                     clear(carry);
4E3   6A 50                     swap(b5);
4E5   3C 5F                     a5 =>>$ 1;
4E7   6A 50                     swap(b5);
4E9   3C 5F                     a5 =>>$ 1;
4EB   79 5D 01                  delay();
4EE   80 6F 09                  a6 = 9;
4F1   28 68             1:      --a6;
4F3   48 F1 14                  if (zero) goto 2f;
4F6   79 59 01                  bitime();
4F9   38 EF                     a14 =>> 1;
4FB   85 0B                     a0 = PAIO;
4FD   98 07                     a0 =& a7;
4FF   88 01                     a0 =^ a1;
501   40 F1 EE                  if (!zero) goto 1b;
504   90 EF 80                  a14 =| 0200;
507   58 E8                     goto 1b;
509   79 59 01          2:      bitime();
50C   66                        return;
                        }
                        /*  rdmod - read character from modem
                         *
                         *  entry - none.
                         *
                         *  uses - a 1.
                         *         b none.
```

```
                              *
                              *  calls - rdtty.
                              *
                              *  exit - through rdtty.  a14 = character read.
                              *
                              */
                             rdmod()
                             {
50D   80 17                          a1 = a7;
50F   58 B7                          goto rdt0;
                             }
                             /*  prtty - print character to tty.
                              *
                              *  entry - a14 = character to be printed
                              *
                              *  uses - a 0,6,14
                              *         b none.
                              *
                              *  calls - bitime.
                              *
                              *  exit - character written out to terminal.
                              *
                              */
                             prsp()
                             {
511   80 EF 20                       a14 = ' ';
514   86 6B 02               prtty:  a6 = PCIO;
517   82 BF 03 82                    PCNTRL = 0202;
51B   82 B6 02                       PCIO = a6;
51E   21 B0                          PAIO = 0;
520   79 59 01                       bitime();
523   80 6F 08                       a6 = 8;
526   80 0F 20               1:      a0 = 040;
529   5A E0 03                       if (bit(0,a14)) goto 2f;
52C   20 00                          a0 = 0;
52E   34 EF                  2:      a14 =>>> 1;
530   81 B0                          PAIO = a0;
532   79 59 01                       bitime();
535   28 6B                          --a6;
537   40 F1 ED                       if (!zero) goto 1b;
53A   81 BF 20                       PAIO = 040;
53D   79 59 01                       bitime();
540   66                             return;
                             }

                             /*  prom - write a prom
                              *
                              *  entry - b9 = starting address
                              *
                              *  uses - a 1,7,12
                              *         b none.
                              *
                              *  calls - verify, zapall.
                              *
                              *  exit - 1024 bytes starting at b9 are written
                              *           out, then the prom is verified to
```

```
                                    *           see that everything was written out
                                    *           correctly.  If everything is OK the
                                    *           address displayed will be 400.
                                    *
                                    */
                                   prom()
                                   {
541   82 BF 03 90                          PCNTRL = SETMOD ¦ AINP;
545   82 BF 07 80                          QCNTRL = SETMOD;
549   80 7F 6E                             a7 = 110;
54C   79 BB 05                     1:      zapall();
54F   28 78                                --a7;
551   40 F1 F9                             if (!zero) goto 1b;
554   79 7B 05                             verify();
557   22 B0 02                     retd:   PCIO = 0;
55A   0D 0F BB 1B                          sp = USERRG - 2 - 1 - 2;
55E   C2 FF 03 35 00                       *(dsp + 3) = &init;
563   22 F0 02                             *(sp + 2) = 0;
566   C2 FF 00 00 18                       *(dsp + 0) = RAMORG;
56B   47                                   push(rp);
56C   4D 0F E0 1B                          rp = SYSREG;
570   C5 DF DA 1B                          b13 = USERB13;
574   C5 EF DC 1B                          b14 = USERB14;
578   59 60 00                             goto man2;
                                   }
                                   /*  verify - verify information in prom
                                    *
                                    *  entry - a12(4) = zero/data verify
                                    *          b9 = starting address for data verify
                                    *
                                    *  uses - a 0,1,3,4,9,13,14
                                    *         b 0,9,13
                                    *
                                    *  calls - none.
                                    *
                                    *  exit - if no errors then return.  If error
                                    *          then return one level up and set
                                    *          b13 to prom address in error,
                                    *          b14(15-8) to prom data, and
                                    *          b14(7-0) to expected data.
                                    *
                                    */
                                   verify()
                                   {
57B   60 D0                                b13 = 0;
57D   20 30                                a3 = 0;
57F   80 4F 20                             a4 = 040;
582   82 BF 03 90                          PCNTRL = 0220;
586   82 BF 07 9B                          QCNTRL = 0233;
58A   82 B4 02                             PCIO = a4;
58D   C0 5F FF 3F                          b5 = 0x3fff;
591   79 5D 01                             delay();
594   82 B3 01                     1:      PBIO = a3;
597   82 B4 02                             PCIO = a4;
59A   86 EB 04                             a14 = PDIO;
59D   87 19                                a1 = *b9++;
```

```
59F   B0 1E                  a1 - a14;
5A1   48 F1 07               if (zero) goto 2f;
5A4   6A E0                  swap(b14);
5A6   80 E1                  a14 = a1;
5A8   58 AD                  goto retd;
5AA   68 D0         2:       ++b13;
5AC   28 30                  ++a3;
5AE   40 F1 E4               if (!zero) goto 1b;
5B1   A8 4F 02               a4 =+ 02;
5B4   B0 4F 28               a4 - 050;
5B7   48 F8 DB               if (lt) goto 1b;
5BA   66                     return;
                    }
                    /*  zapall - write all locations in prom
                     *
                     *  entry - b9 = starting address to write
                     *
                     *  uses - a 0,3,4,5,13
                     *         b 5,13
                     *
                     *  calls - none.
                     *
                     *  exit - all locations of the prom hit with a
                     *          1 msec. write pulse.
                     *
                     */
                    zapall()
                    {
5BB   C0 D9                  b13 = b9;
5BD   20 30                  a3 = 0;
5BF   20 40                  a4 = 0;
5C1   87 0D         1:       a0 = *b13++;
5C3   82 B3 01               PBIO = a3;
5C6   82 B4 02               PCIO = a4;
5C9   82 B0 04               PDIO = a0;
5CC   88 4F 40               a4 =^ 0100;
5CF   82 B4 02               PCIO = a4;
5D2   C0 5F 1C 00            b5 = 28;
5D6   79 5D 01               delay();
5D9   88 4F 40               a4 =^ 0100;
5DC   82 B4 02               PCIO = a4;
5DF   28 30                  ++a3;
5E1   40 F1 DE               if (!zero) goto 1b;
5E4   A8 4F 02               a4 =+ 02;
5E7   B0 4F 08               a4 - 010;
5EA   48 F8 D5               if (lt) goto 1b;
5ED   66                     return;
                    }
                    /*  loadt - load file from tape
                     *
                     *  entry - a8 = file id
                     *          b9 = fwa of load
                     *
                     *  uses - a 1,3,7,8,9,12,13,14
                     *         b 13
                     *
```

```
                                 *   calls - rdbit, rdchar, rdbyte, rdnib
                                 *
                                 *   exit - file with matching id from tape
                                 *           loaded into ram.
                                 *
                                 */
                                loadt()
                                {
5EE   82 BF 03 90                         PCNTRL = SETMOD | AINP;
5F2   82 BF 07 80                         QCNTRL = SETMOD;
5F6   C0 D9                               b13 = b9;
5F8   98 CF 1F                            a12 =& 037;
5FB   80 98                               a9 = a8;
5FD   40 FB 0A                            if (!homog) goto 1f;
600   90 CF 20                            a12 =| 040;
603   48 F1 04                            if (zero) goto 1f;
606   90 CF 40                            a12 =| 0100;
609   82 BC 04                  1:        PDIO = a12;
60C   79 B2 06                  sync:     rdbit();
60F   38 1F                               a1 =>> 1;
611   90 10                               a1 =| a0;
613   B0 1F 16                            a1 - SYNC;
616   40 F1 F4                            if (!zero) goto sync;
619   80 3F 0A                            a3 = 10;
61C   79 8B 06                  1:        rdchar();
61F   B0 1F 16                            a1 - SYNC;
622   40 F1 E8                            if (!zero) goto sync;
625   28 38                               --a3;
627   40 F1 F3                            if (!zero) goto 1b;
62A   79 8B 06                  1:        rdchar();
62D   B0 1F 2A                            a1 - STARTCH;
630   48 F1 09                            if (zero) goto 1f;
633   B0 1F 16                            a1 - SYNC;
636   40 F1 D4                            if (!zero) goto sync;
639   58 EF                               goto 1b;
63B   C0 8F 2A 00               1:        b8 = CHECKSUM;  /* initialize check sum character */
63F   79 72 06                            rdbyte();
642   5A C5 06                            if (bit(5,a12)) goto 1f;        /* accept anything */
645   B0 79                               a7 - a9;
647   40 F1 C3                            if (!zero) goto sync;           /* wrong id */
64A   79 72 06                  1:        rdbyte();
64D   6A 70                               swap(b7);
64F   79 72 06                            rdbyte();
652   6A 70                               swap(b7);
654   5A C6 03                            if (bit(6,a12)) goto 1f;        /* ignore addr on tape */
657   C0 D7                               b13 = b7;
659   79 8B 06                  1:        rdchar();
65C   B0 1F 2F                            a1 - ENDCH;
65F   48 F1 08                            if (zero) goto 1f;
662   79 75 06                            rdnib();
665   83 D7                               *b13++ = a7;
667   58 F0                               goto 1b;
669   79 8B 06                  1:        rdchar();
66C   C0 E8                               b14 = b8;
66E   98 EF 7F                            a14 =& 0177;
671   66                                  return;
```

```
                         }
                         /*  rdbyte - read 8-bit byte from tape
                          *
                          *  entry - none.
                          *
                          *  uses - a 1,7
                          *         b none.
                          *
                          *  calls - rdchar.
                          *
                          *  exit - a7 = 8-bit byte assembled from 2 pseudo
                          *             ascii characters on the tape.
                          *
                          */
                         rdbyte()
                         {
672  79 8B 06                        rdchar();
675  98 1F 0F            rdnib:     a1 =& 017;
678  80 71                          a7 = a1;
67A  38 71                          a7 =<< 1;
67C  38 71                          a7 =<< 1;
67E  38 71                          a7 =<< 1;
680  38 71                          a7 =<< 1;
682  79 8B 06                       rdchar();
685  98 1F 0F                       a1 =& 017;
688  90 71                          a7 =¦ a1;
68A  66                             return;
                         }
                         /*  rdchar - read pseudo ascii character from tape
                          *
                          *  entry - none.
                          *
                          *  uses - a 1,2,8
                          *         b none.
                          *
                          *  calls - rdbit.
                          *
                          *  exit - a1 = character read from tape.
                          *
                          */
                         rdchar()
                         {
68B  80 2F 08                       a2 = 8;
68E  79 B2 06            1:         rdbit();
691  38 1F                          a1 =>> 1;
693  90 10                          a1 =¦ a0;
695  28 28                          --a2;
697  40 F1 F5                       if (!zero) goto 1b;
69A  82 B1 04                       PDIO = a1;
69D  88 81                          a8 =^ a1;
69F  80 01                          a0 = a1;
6A1  98 1F 7F                       a1 =& 0177;
6A4  0E 00                          a0 = bitsum(a0);
6A6  88 0F 01                       a0 =^ 1;
6A9  D8 0F 01 00                    b0 =& 1;
6AD  6A 00                          swap(b0);
```

```
6AF   E8 80                    b8 =+ b0;
6B1   66                       return;
                        }
                        /*  rdbit - read a bit from the tape
                         *
                         *  entry - none.
                         *
                         *  uses - a 0
                         *         b none.
                         *
                         *  calls - none.
                         *
                         *  exit - a0(7) = bit read.
                         *
                         *  note - the loop at '2' is very time critical
                         *          and dependant upon the way outbit puts
                         *          out bits.
                         *
                         */
                        rdbit()
                        {
6B2   20 00                    a0 = 0;
6B4   53 B7 FE          1:     if (!bit(7,PAIO)) goto 1b;
6B7   28 00             2:     ++a0;
6B9   5B B7 FC                 if (bit(7,PAIO)) goto 2b;
6BC   80 0F 20                 a0 - NOISE;
6BF   48 FA F1                 if (llteq) goto rdbit;
6C2   98 0F 80                 a0 =& 0200;
6C5   66                       return;
                        }
                        /*  dumpt - dump file to tape
                         *
                         *  entry - a8 = file id
                         *          b9 = fwa to dump
                         *          b10 = lwa+1 to dump
                         *
                         *  uses - a 1,4,7,9,10,13
                         *         b 7,13
                         *
                         *  calls - outch, outbyte
                         *
                         *  exit - fwa to lwa stored on tape
                         *
                         */
                        dumpt()
                        {
6C6   82 BF 03 80              PCNTRL = SETMOD;
6CA   82 BF 07 80              QCNTRL = SETMOD;
6CE   C0 D9                    b13 = b9;
6D0   C0 1F 64 16              b1 = SYNC<<8 | 100;
6D4   6A 10             1:     swap(b1);
6D6   79 31 07                 outch();
6D9   6A 10                    swap(b1);
6DB   28 18                    --a1;
6DD   40 F1 F5                 if (!zero) goto 1b;
6E0   20 90                    a9 = 0;
```

```
6E2   80 1F 2A                    a1 = STARTCH;
6E5   79 31 07                    outch();
6E8   80 78                       a7 = a8;
6EA   79 1A 07                    outbyte();
6ED   C0 7D                       b7 = b13;
6EF   79 1A 07                    outbyte();
6F2   6A 70                       swap(b7);
6F4   79 1A 07                    outbyte();
6F7   01 02               1:      set(zero);
6F9   F0 AD                       b10 - b13;
6FB   48 F1 08                    if (zero) goto 1f;
6FE   87 7D                       a7 = *b13++;
700   79 1A 07                    outbyte();
703   58 F2                       goto 1b;
705   80 1F 2F            1:      a1 = ENDCH;
708   79 31 07                    outch();
70B   80 19                       a1 = a9;
70D   79 33 07                    outchar();
710   80 1F 04                    a1 = EOT;
713   79 31 07                    outch();
716   79 31 07                    outch();
719   66                          return;
                          }
                          /*  outbyte - output one 8-bit byte to tape
                           *
                           *  entry - a7 = byte to be written
                           *
                           *  uses - none.
                           *
                           *  calls - out4.
                           *
                           *  exit - a7 written out as two pseudo ascii
                           *          characters and contents of a7 unchanged.
                           *
                           */
                          outbyte()
                          {
71A   79 21 07                    out4();
71D   79 21 07                    out4();
720   66                          return;
                          }
                          /*  out4 - output 4-bit nibble as pseudo ascii
                           *          character.
                           *  outch - output ascii character
                           *
                           *  entry - a7 = 4-bit nibble to be written out (out4)
                           *          a1 = ascii character to output (outch)
                           *
                           *  uses - a 0,1,2,4,7,9
                           *         b 0
                           *
                           *  calls - outbit.
                           *
                           *  exit - one ascii character written to tape.
                           *
                           */
```

```
                                out4()
                                {
721   34 71                              a7 =<<< 1;
723   34 71                              a7 =<<< 1;
725   34 71                              a7 =<<< 1;
727   34 71                              a7 =<<< 1;
729   80 17                              a1 = a7;
72B   98 1F 0F                           a1 =& 017;
72E   90 1F 30                           a1 =¦ '0';
731   88 91                     outch:   a9 =^ a1;
733   82 B1 04                  outchar:PDIO = a1;
736   0E 01                              a0 = bitsum(a1);
738   98 0F 01                           a0 =& 1;
73B   88 0F 01                           a0 =^ 1;
73E   34 0F                              a0 =>>> 1;
740   90 10                              a1 =¦ a0;
742   80 4F 08                           a4 = 8;
745   C0 0F 0C 18               1:       b0 = BIT1;
749   34 1F                              a1 =>>> 1;
74B   48 F0 05                           if (neg) goto 2f;
74E   C0 0F 0C 0C                        b0 = BIT0;
752   80 2F 0D                  2:       a2 = CYCLE0;
755   79 66 07                           outbit();
758   80 2F 06                           a2 = CYCLE1;
75B   6A 00                              swap(b0);
75D   79 66 07                           outbit();
760   28 48                              --a4;
762   40 F1 E1                           if (!zero) goto 1b;
765   66                                 return;
                                }
                                /*  outbit - output stream of bits to tape
                                 *
                                 *  entry - a0 = twice the number of 1 bits desired
                                 *          a2 = length of each 1 bit
                                 *
                                 *  uses - a 0,3,5
                                 *         b none.
                                 *
                                 *  calls - none.
                                 *
                                 *  exit - a square wave of proper frequency and
                                 *            length is written to the tape.
                                 *
                                 */
                                outbit()
                                {
766   20 30                              a3 = 0;
768   88 3F 10                  1:       a3 =^ 020;
76B   81 B3                              PAIO = a3;
76D   80 52                              a5 = a2;
76F   28 58                     2:       --a5;
771   40 F0 FC                           if (!neg) goto 2b;
774   28 08                              --a0;
776   40 F1 F0                           if (!zero) goto 1b;
779   66                                 return;
                                }
```

```
                                   /*  powon - delay for power on
                                    *
                                    *  entry - none.
                                    *
                                    *  uses - a 5
                                    *         b 5
                                    *
                                    *  calls - reset.
                                    *
                                    *  exit - Delay done to enable any transient
                                    *           interrupts caused by the noisy
                                    *           transformer to disappear.  This
                                    *           routine had to be encoded into
                                    *           the data section since it is a patch
                                    *           that must be at the very end of the
                                    *           executive.
                                    */

                                   char powon[]
7F4   C0 58                                { 0xc0, 0x5b }          /* b5 = b11; */
7F6   68 58                                { 0x68, 0x58 }          /* 1: --b5; */
7F8   40 F0 FC                             { 0x40, 0xf0, 0xfc }    /* if (!neg) goto 1b; */
7FB   59                                   { 0x59 };               /* goto reset; */

7FC   27 00                        int powr &reset;

                                   char unused[]
7FE   CD 05                                { 0xcd, 0x05};


  *** SYMBOL TABLE ***
1BFEa -       BAUD
1F03a -     PCNTRL
1F07a -     QCNTRL
1F00a -       PAIO
1F01a -       PBIO
1F02a -       PCIO
1F04a -       PDIO
 77AD -       tfmt
 78AD -       tnum
 7A6D -       tfnc
   0T -       main
  27t -      reset
  29t -      init0
  35t -       init
  60t -       man2
  8Bt - L...0001
  9Dt - L...0003
  ACT -      rdkey
  DFT -       disp
 107T -       dsp4
 112T -       dsp2
 13At -       dp21
 156t -       dp22
```

```
159T -    bitime
15DT -     delay
165T -      numb
179t - L...0005
18At - L...0006
18Bt -     chreg
197t - L...0007
19Ft - L...0008
1A7T -      areg
1B3t -      reg1
1B5t -      reg2
1C3T -      breg
1D1T -      star
1DET -     equal
1E2T -      plus
1F0T -     minus
1FET -      rptr
204t -      rpt1
20ET -      exec
215T -       sst
220t -      sst0
22FT -      move
23BT -    shift4
7C0D -    header
7D3D -      ttty
7DED -      ttyf
244T -       tty
283T -     raddr
28DT -      addr
299T -    rpoint
2A9T -       run
2ADT -     prnum
2B4T -      prn1
2D1T -     tnumb
308T -      unix
322T -      load
371T -    getbyt
386T -     digit
399T -      half
39DT -     retrn
3B9t -      ret0
3EBT -    linefd
402t -      lnf1
405T -     prloc
41FT -     store
433T -     regad
43FT -     ktype
476T -      lfcr
47Ct -      prcr
482T -     crdel
491T -  prstring
4A1T -      baud
4C6T -     rdtty
4C8t -      rdt0
50DT -     rdmod
511T -      prsp
```

514T	-	prtty
541T	-	prom
557t	-	retd
578T	-	verify
5BBT	-	zapall
5EET	-	loadt
60Ct	-	sync
672T	-	rdbyte
675T	-	rdnib
68BT	-	rdchar
6B2T	-	rdbit
6C6T	-	dumpt
71AT	-	outbyte
721T	-	out4
731T	-	outch
733T	-	outchar
766T	-	outbit
7F4D	-	powon
7FCD	-	powr
7FED	-	unused