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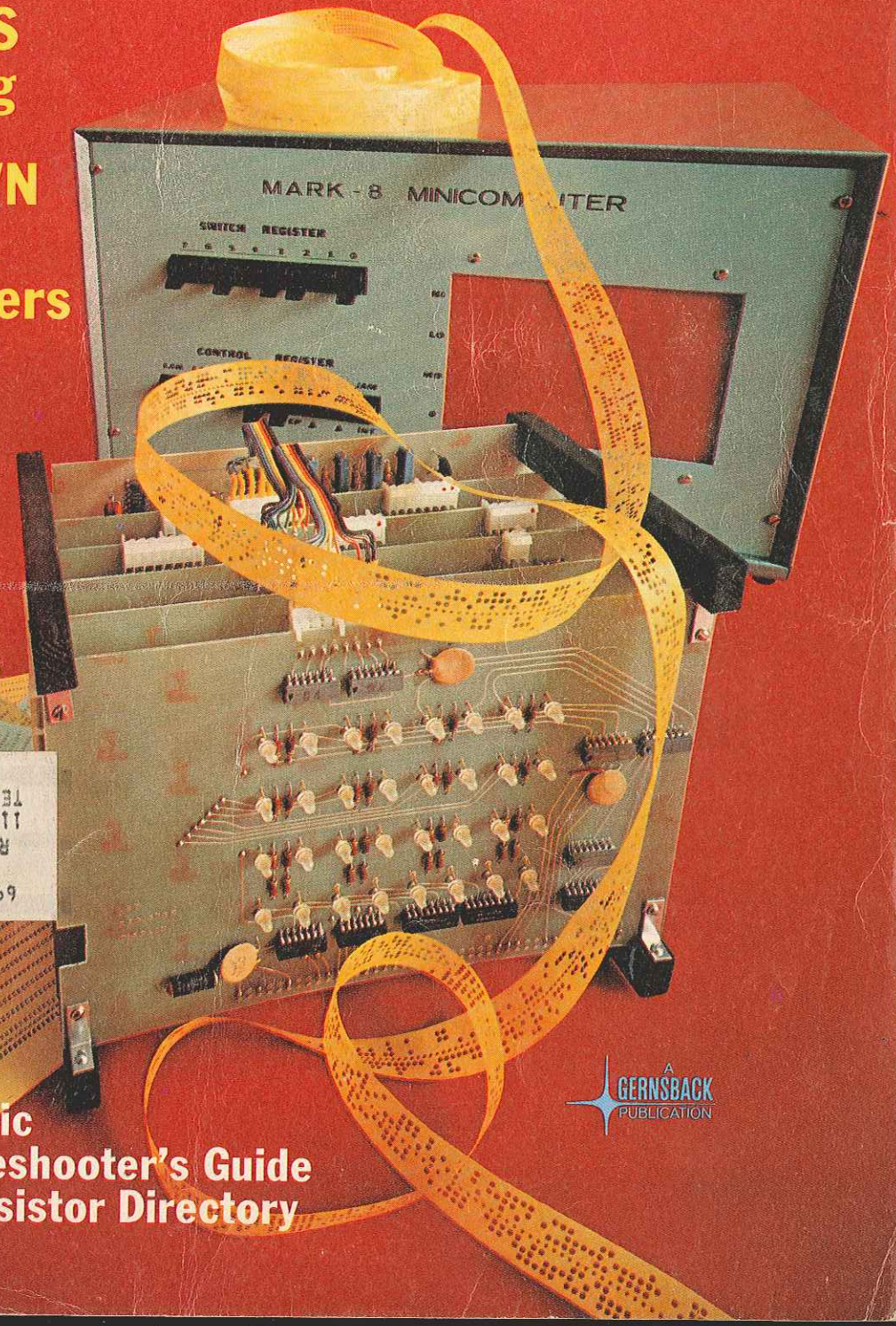

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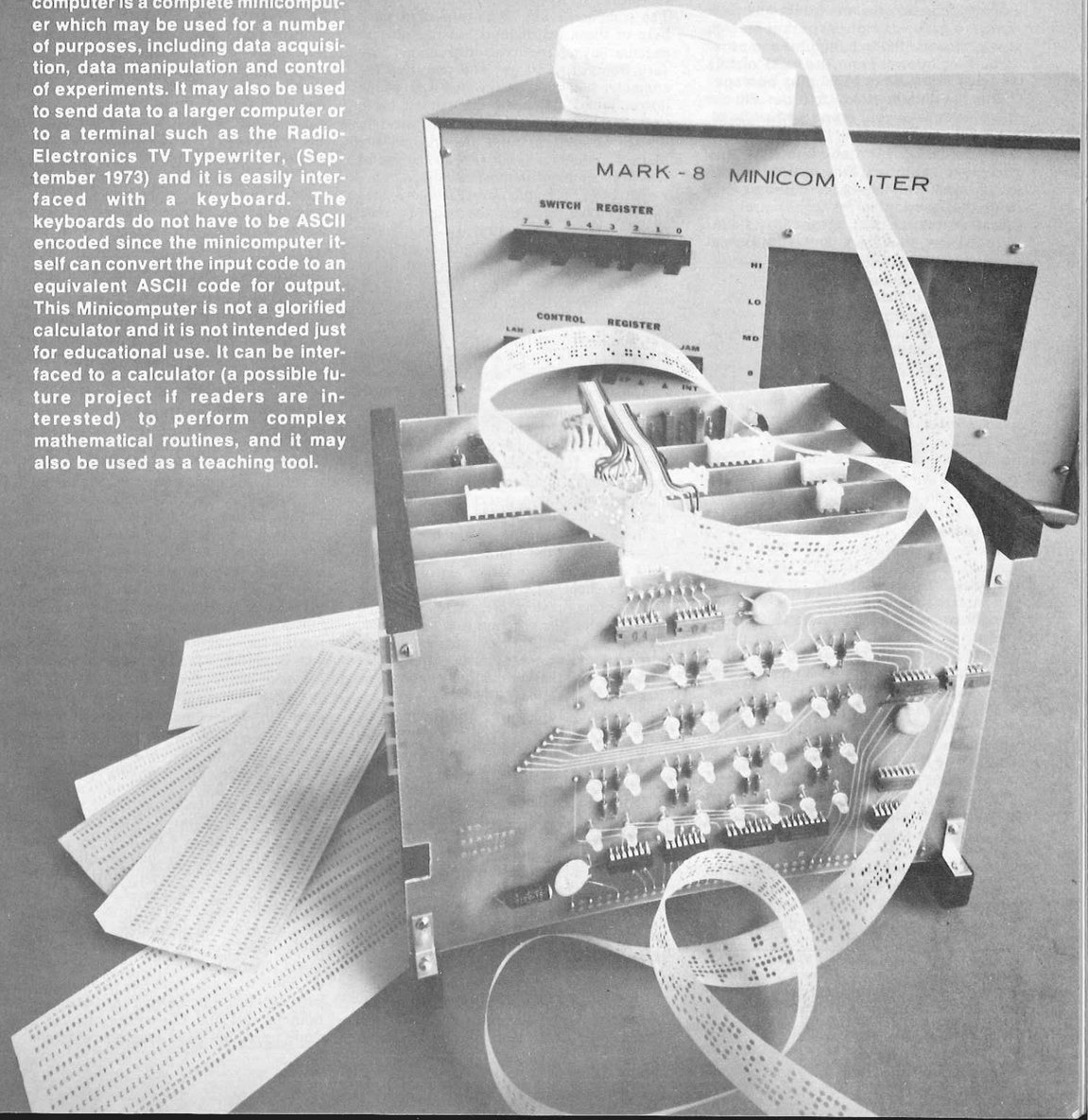
COMPUTER!

Build this minicomputer yourself. Add it to the TV Typewriter for a complete computer system of your own

by JONATHAN A. TITUS

The Radio-Electronics Mark-8 Minicomputer is a complete minicomputer which may be used for a number of purposes, including data acquisition, data manipulation and control of experiments. It may also be used to send data to a larger computer or to a terminal such as the Radio-Electronics TV Typewriter, (September 1973) and it is easily interfaced with a keyboard. The keyboards do not have to be ASCII encoded since the minicomputer itself can convert the input code to an equivalent ASCII code for output. This Minicomputer is not a glorified calculator and it is not intended just for educational use. It can be interfaced to a calculator (a possible future project if readers are interested) to perform complex mathematical routines, and it may also be used as a teaching tool.



GET THE COMPLETE STORY

The Minicomputer is a very special story. Complete instruction information, including full-size circuit board patterns, would require a long multi-part article in Radio-Electronics.

To make it possible for interested readers to get full details of the unit and to start construction immediately, we are making available a special package of additional data. This includes complete construction details, more data on how it works, a group of eight experiments you can perform with the computer and other important information. The cost of this 52-page package is $5.00 plus postage.

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The heart of the Mark-8 Minicomputer is an Intel 8008 microprocessor IC that contains all of the arithmetic registers, subroutine registers and most of the control logic necessary to interface the microprocessor with semiconductor memories as well as input and output registers. Standard TTL type IC's are used throughout and commonly available 1101, 1101A and 1101A1 type memories are used for the central storage. The microprocessor with its associated logic will be refered to as the central processor unit, or CPU.

The central processor unit is an 8-bit parallel processor. A string of eight binary bits, D_7 through D_0 , is used to indicate the instruction data or memory locations. Rather than repeat, "eight bits of binary data", we refer to the eight bits as a byte. As you will note, some of the instructions take up to three bytes of data and they are, therefore, called three-byte instructions. The computer takes 20 μs to execute each byte of these instructions, so the time to execute any of the basic instructions may vary from 20 to 60 μs. The time that the computer takes to execute one byte of the instruction is called the computer's cycle time. Most minicomputers have a cycle time that is about ten times faster than the Mark-8, but this will not restrict the use of this Minicomputer in most situations. *

The Intel 8008 microprocessor provides us with some sophisticated features, only found on larger, more costly computers. These include a pointer register, interrupt pointers and a stack register for multiple subroutines.

The Mark-8 is programmed in assembly or machine language, the basic language of all computers which consists of 1's and 0's grouped into bytes. While it may seem cumbersome at first, this is one of the most flexible ways to program while keeping down the cost of added storage or memory. The use of just the 1's and 0's to represent the binary numbers can become tedious after a short while. It becomes much easier to convert the binary numbers to their octal equivalent and use these direct equivalents instead.

There are 48 program instructions to use in programs on the Mark-8. Each program must consist of an orderly, logical chain of steps in successive memory locations. If data or program steps are not loaded in the correct order, the program won't work correctly and is said to have a bug in it. Those not familiar with the basic operations of a computer and the various number systems used will find *Computer Architecture*, by Caxton Foster, Van Nostrand-Reinhold, New York, New, York 1970, $12.50 an easy to read and understand introduction that should be read before attempting to build or use the Mark-8.

The basic Minicomputer consists of six modules:

1. Main CPU module.
2. Memory Address/Manual Control module.
3. Input Multiplexer module.
4. Memory module.
5. Output module.
6. Readout module.

These modules provide the experimenter with the basic minicomputer configuration. Two 8-bit input ports are provided for getting data into the computer and four 8-bit output ports are provided to output data to external devices. The memory module can accommodate up to 1024 bytes or words of storage, although only 256 words are required to start. Manual controls are provided for the user and a readout of some of the important registers is provided on the Readout module.

Six different modules

The Central Processor Unit (CPU) module contains the microprocessor IC and the extra circuitry used to interface with the rest of the computer. It is important to note that the 8008 microprocessor has been fabricated as an MOS circuit and the outputs will only drive one low-power circuit of the 74L series. Each output is buffered with a 74L04 inverter before it is used. The main, 8-line input/output bus, or I/O bus is also buffered by two 7404 circuits to give the TTL signals a high fan-out.

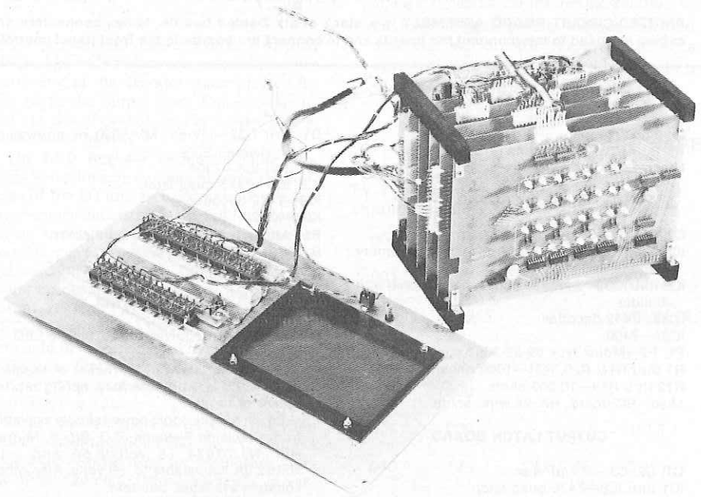
The computer is controlled by a 2-phase clock supplied by a crystal oscillator which controls the pulse widths and frequency. The clock and the synchronization signal supplied by the microprocessor are used to control some of the logical operations of the computer interface circuits. The synchronization signal synchronizes the operation of the very fast TTL circuits and the slower, clocked, MOS circuits in the microprocessor. The microprocessor also has three, state-output signals, S_0, S_1, and S_2 which are used to drive a decoder. The eight possible states are then used to control other functions in the interface logic. A complete description of the generation and use of these state outputs is included in the Intel User's Manual

Since the CPU uses a parallel 8-bit I/O bus for input and output of data there must be some control of when the bus is sending data from the CPU to an external device or when it is taking data in. Two lines are present on the CPU module, $\overline{IN}$ and $\overline{OUT}$. These lines are used by the other modules to regulate the flow of data in the correct direction at the correct time. The control of the $\overline{IN}$ and $\overline{OUT}$ lines is governed by the additional logic on the CPU module.

The Memory Address/Manual Control module is used to hold data which is to be used as the memory address. Two 8-bit latches are provided since the computer will use one set of eight bits for a memory address and the other set of eight bits for control functions. Since the microprocessor can directly address up to 16,424 words of memory, commonly noted as 16K, we will need 14 binary bits for the complete address. The complete memory address of any location is given by a 16-bit binary number; X X B_3 B_3 B_3 B_3 B_3 B_3 / B_2 B_2 B_2 B_2 B_2 B_2 B_2 B_2, where the X's represent bits that are not used. The computer specifies any address by first sending out the B_2 bits to one of the eight-bit latches, followed by the six B_3 bits and two X bits. Control of the correct latch is supplied from the CPU module.

The B_3 bits have the most significance or value in the complete digit, while the B_2 bits have the least significance. This is like comparing $1000 and $1. The further to the left the digit, in any numbering system, the more value it has. For this reason the B_3 bits are called the most significant or the HI part of the address, while the B_2 bits are called the least significant or LO part of the address. Both the HI and LO address latches are made up of SN74193 programmable counters, since the address held in them may be incremented, by counting up by one. The usefulness of this will be seen later. The HI and LO latches are also used for temporary data storage when they are not being used to store a memory address.

COMPUTER WITH ASCII KEYBOARD makes a complete working computer system. You can use the computer without the keyboard, but it is more difficult.



THE WORKING HEART of the computer is relatively simple. The six primary circuit boards and the front-panel controls are shown here. If additional memory is needed, more circuits boards are required.

The manual control portion of this module allows us to program the computer and to control its operation from an operator's console. We are able to externally address any memory location and deposit data or instructions in it. We may also return to any location and check the data stored there. Controls are also provided to allow us to single-step the computer through a program, one instruction at a time and to interrupt the computer while it is executing a program. These controls will be described in detail later.

The Data Input Multiplexer module controls the flow of all data into the computer. All data going into the computer is placed on the I/O bus during the IN cycle signalled by the $\overline{IN}$ signal. Since data may be coming in from a number of different experiments or sources, we must have some means of selecting which data is fed into the CPU. Two basic multiplexers are used for this precise gating of data. The two 8263 quad, three-line to one-line multiplexers control which of three sets of input lines are selected. Note that two sets of these input lines are input ports 0 and 1. These are the two external data input ports. The third set of data input lines comes from the memory. Data or instructions in the memory, all go through the multiplexer and into the CPU.

This multiplexer is followed by a second set of multiplexers, 8267's. These are quad, two-line to one-line multiplexers with open-collector outputs which are compatible with the computer bus structure. This multiplexer switches between the data selected at the previous multiplexer and data from the Interrupt Instruction Port. The use of the Interrupt Instruction Port will be covered in the Interrupt section. This second multiplexer may also be in an off or unselected state which is used when data is not to be sent to the CPU module. Control lines SL_0 and SL_1 are sent directly from the CPU interface logic.

Remember that when the HI address is not being used to store a memory address, it is used for control signals. During an IN or OUT cycle these control signals are decoded and used to select the proper input or output lines for the I/O bus. The Multiplexer module decodes the control bits B, C, D, and D_{Enable} and OR's them with $\overline{IN}$ to select the proper external data input port. When the computer is instructed to get some data from memory it automatically selects the memory input section of the multiplexer. The INPUT instruction is only used when you wish to input data from some external source such as a digital voltmeter or keyboard, through one of the two input ports.

The Memory module uses the widely available 1101 type of semiconductor, integrated circuit memory. The 1101 random access memory or RAM is organized as a 256 x 1-bit memory, so eight of the 1101 type memories are used to give us 256, eight-bit words. This is the minimum configuration necessary for the operation of the Mark-8. Each memory module can hold 32 of the 1101 memories for a total of 1024 or 1K words of storage. Up to four Memory modules may be used with the Mark-8, giving us a maximum 4K of storage space. More than enough for most applications.

Each of the 256 words are addressed by the eight bits from the LO address latch. Since 2^8 = 256 we can only address 256 words using the LO address alone. Each memory also has an enable line so we may select blocks of 256 words, using this line. The HI address is, therefore, used and decoded with a standard decoder and the decoded outputs are used to enable or select the blocks. You do not have to be concerned about the particular block where data has been stored, just use the complete 14-bit address, since the memory does the complete decoding.

Each of the addressed memory locations may store one 8-bit word or byte of information. For 2 or 3-byte program steps, two or three successive memory locations are used for storage.

The 1101 type memories are volatile semiconductor memories and information stored in them will be altered or lost if the power is shut off. If you want to save a program, leave the power on.

A chart in the construction section shows how the memory jumpers are wired for each of the four possible boards. Boards must be added in numerical sequence; 1, 2, 3, and 4. Blocks of memory must be added in units of 256 words in the A, B, C, and D sequence, to prevent gaps in the memory.

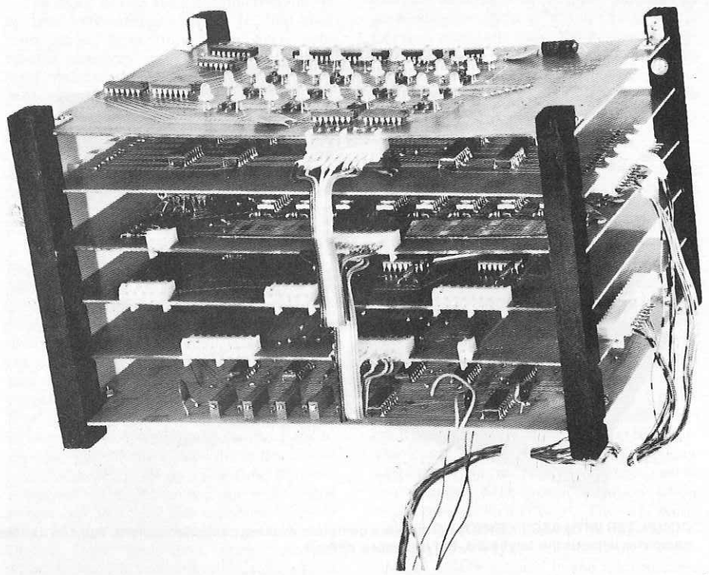
A read/write or R/W line is provided on the module so that data may either be read from, or written into a selected memory location. The CPU and the Manual Control module both control this line so that data may be entered under computer control or

so that we may insert our program data into the memory prior to use by the computer.

The eight data-output lines from the memory are sent to the CPU I/O bus through the Input Multiplexer module. When we ask for data from the memory with an LrM type of instruction (see Intel User's Manual), the CPU senses that the memory data is needed and it sets the input multiplexer so that the data is placed on the I/O bus at the proper time.

The Output Latch module is used to send data from the computer to some external device or instrument, such as a teletype or perhaps the **Radio-Electronics** TV Typewriter (**Radio-Electronics,** September 1973). Four output latches are provided on the Output Latch module and two of these modules may be used with the Mark-8. The second module may, however, only use three of the output latches.

Note that data is sent from the LO address latch to each output port and that these connections are in parallel. The computer decides which latch is activated according to the OUTPUT instruction that we have in our program. Here, again, the HI address latch holds the control bits B, C, and D which are decoded and NORed with $\overline{\text{OUT}}$ to activate the selected eight bit output port or latch. NOTE: The OUTPUT instruction in the Intel User's Manual has two RR bits shown in it. These bits must be set to RR = 01 for proper data output. OUT = 01 01M MM1. The MMM bits are set to the binary equivalent of the decoder state selected for that particular output port. For example 01 010 111 would output data at output port 3, since 011 = MMM = 3.



PRINTED-CIRCUIT BOARD ASSEMBLY is a stack of six 2-sided boards. Molex connectors and cables are used to interconnect the boards and to connect the boards to the front-panel controls.

The LED Register Display module provides you with a visual indication of the contents of the HI and LO address latches and the memory data in the selected memory location indicated by that address. Output port 0 is also located on the Readout module and it may be used in programming to give a visual output of a byte of data. Each of the output registers is represented by eight LED indicators, 1 = ON, 0 = OFF. As the data held in each register changes, so do the indicators. Data to be displayed at output port 0 must be sent with an OUT instruction 01 010 001 or 121_8.

Since the HI address latch is used for some control functions and the LO address latch may also be used for temporary storage of data going to the output ports, at various times in programs the data in these registers will change from a memory address to these control and output data and then back to an address. Checking this data visually in these registers during the debugging of a program is very helpful.

The power supply requirements of the Mark-8 are +5 Vdc at 3 amps and −9 Vdc at 1.5 amps. Since regulation at these high current levels is critical we suggest that the power supply or supplies are purchased. There are many good power supplies on the surplus market that may be used with the Mark-8. The type used with the prototype is listed in the complete parts List. A substitute, available from Wortek, 5971 Reseda Blvd., Tarzana, Calif. 91356 will work as well. Order part numbers PRS-1 and PRS-3, each $25.00 **R-E**

* For more detailed data on the Microprocessor IC write to Intel Corp., 3065 Bowers Ave., Santa Clara, Calif. 95051 - ask for a copy of *"8008, 8-Bit Parallel Central Processor Unit-Users Manual.* This manual was offered free at the time this article went to press.

PARTS LIST

All resistors are ¼ Watt, 10%

CPU BOARD

C1—33-pF disc
C2 thru C6—0.1-µF disc
IC1, IC,4, IC6, IC7, IC9, IC13, IC17, IC19— 7400
IC2, IC,3, IC14—7476 Dual JK flip-flop
IC5, IC11, IC16, IC20, IC21—7404
IC8, IC12—7474 dual D flip-flop
IC22, IC23, IC25—74L04 hex inverter, low power
IC10, IC18—7410
IC15—7420
IC24—8008 Intel microprocessor
IC26—7442 decoder
R1, R2—220 ohms
R3—560 ohms
R4—1800 ohms
R5, R6, R7, R8, R17—1000 ohms
R9 thru R16—22,000 ohms
XTAL 1—4000.000-KHz crystal type EX ($3.95 from International Crystal, 10 N. Lee Street, Oklahoma City, OK)
Misc—PC Board, No. 24 wire, solder

INPUT MULTIPLEXER BOARD

C1, C2, C4—0.1-µF disc
C2—1 .0-µF 10 V electrolytic
IC1, IC2—8263 multiplexer (Signetics)
IC3—7400
IC4, IC5—8267 multiplexer (Signetics)
IC6—7402
IC7—7442 decoder
P1, P2, P3, P4—Molex type 09-52-3081 connectors
R1—1000 ohms
Misc—PC board, No. 24 wire, solder

ADDRESS LATCH BOARD

C1 thru C6—0.01-µF disc ceramic
C7—680-pF disc
IC1, IC2—74123 dual monostable
IC3, IC4, IC5, IC6, IC7—7400
IC8, IC9, IC10, IC11—74193 programmable counter
P1, P2, P3—Molex Type 09-52-3081 connectors
R1 thru R3—10,000 ohms
R4-22,000 ohms
R5 thru R16—1000 ohms
Misc—PC board, 324 wire, solder

MEMORY BOARD

C1, C2, C3—0.1-µF disc ceramic
IC1 thru IC8—1101, 1101A or 1101A1 memory circuits, 256 x 1
IC9 thru IC32—Same as above, but optional with builder
IC33—7442 decoder
IC34—7400
P1, P2—Molex type 09-52-3081 connector
R1 thru R11, R20, R21—1000 ohms
R12 thru R19—10,000 ohms
Misc—RC board, No. 24 wire, solder

OUTPUT LATCH BOARD

C1, C2, C3,—0.1-µF disc
IC1 thru IC8—7475 quad latch
IC9, IC10—7404
IC11—7402
IC12—7442
P1, P2, P3, P4—Molex type 09-52-3081 connector
Misc—PC board, No, 24 wire, solder

LED REGISTER DISPLAY BOARD

C1—100-µF electrolytic
C2, C3, C4—0.1-µF disc
D1 thru D32—MV-50, MV-5020 or equivalent Red, visible LED's
IC1 thru IC6—7404
IC7, IC8—7475 quad latch
IC9—7442 decoder
IC10—7402
P1—Molex type 09-52-3081 connector
R1 thru R32—220 ohms
Misc—PC board, No. 24 wire, solder

CONTROL PANEL

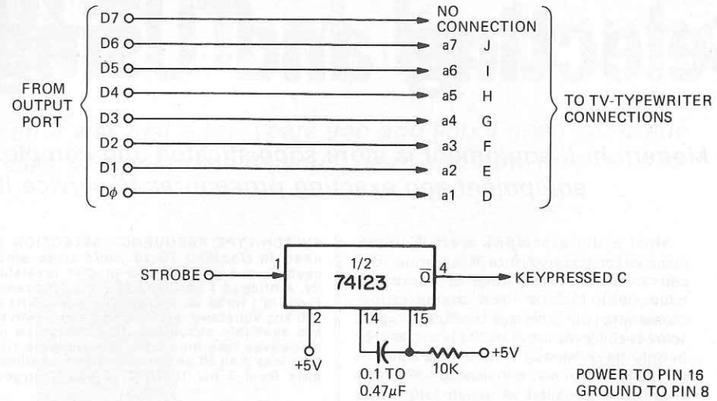
D1—MV-5020 or equivalent red, visible LED
R1—220 ohms
S1 thru S11—spdt switches, rocker or toggle
S13 thru S17—spdt momentary, spring return, rocker or toggle
PS—Power supply, logic power supply available from Precision Systems, P.O. Box 6, Murray Hill, NJ 07974. +5 volts/8.5A and −12 volts/2.0A, adjustable to −9 volts. Also other voltages available. See text.
Misc—Metal case, red plastic filter, line cord, hardware, hook-up wire, solder.

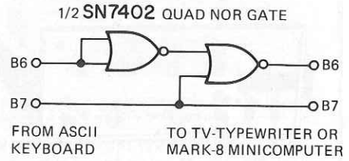
The microprocessor integrated circuit is available from Intel Corporation, 3065 Bowers Avenue, Santa Clara, CA 95051 at a cost of $120.00.

A complete set of circuit boards is available for the Mark-8 Minicomputer from Techniques Inc., 235 Jackson Stree, Englewood, N.J. 07631. Prices include shipping charges inside the United States.

Complete set of six boards (1 of each)	**$47.50**
CPU Board	**7.50**
Address Latch Board	**10.50**
Input Multiplexer Board	**9.50**
1K Memory Board	**8.45**
LED Register Display Board	**8.45**
Output Ports Board	**8.50**

Techniques had 100 sets of boards in stock when this issue went on sale. When these boards are sold, there will be a 6 to 8-week delay before additional boards become available.





HOOKUP THE MARK-8 COMPUTER TO YOUR TV TYPEWRITER using the circuits shown above and to the left. Wiring to the TV typewriter is just direct connections (above). The IC monostable (left) stretches the pulse width. Together, the TV Typewriter (Radio-Electronics, September 1973) and the Mark-8 make a powerful computer package.

Mark-8 Minicomputer to TV-Typewriter interface

The Mark-8 Minicomputer may be used with the TV-Typewriter to display computer generated information. The interface uses either the A or B Output Port strapped to the specific output code, 1-7, that you select. The A and B output ports have strobe lines which are pulsed during the output cycle. These two lines are found above the B output lines and below the A output lines on the printed circuit board. These strobe lines provide us with the Keypressed signal required to enter data into the TV Typewriter. A monostable is attached to this strobe line to stretch the pulse width and the 10 µF capacitor used for debouncing is removed from the TV-Typewriter. This is C17 shown in Fig. 8 of the TV-Typewriter booklet.

This is the second time that **Radio-Electronics** has presented a construction article in the fashion. We are doing so, only because of the special nature of this story and to make it possible for interested readers to get full details on the computer in a single package. These details include full-size printed circuit patterns and parts layout overlays. We do not intend to do an article this way as a regular practice. All conventional construction articles will be published, complete, within the regular pages of **Radio-Electronics.**—*Editor*

SOFTWARE EXAMPLE

Data in the A register is output to the TV-Typewriter as a complete ASCII character. The computer then enters a short timing loop so that it can not go faster than data may be entered to the TV-Typewriter memory.

000	006		LDAI	/Load A with data
001	177		177	/Data = 177 = ASCII "?"
002	106		JSUN OUTPUT	/Jump to OUTPUT subroutine
003	040			
004	000			
005	000		HALT	/Stop, end of program
040	123	OUTPUT,	OUT1	/Data from A to output port 1
041	026		LDCI	/Load C Immediate
042	004		004	/Data
043	031	LOOP,	DECD	/Decrement D
044	110		JPFZ, LOOP	/Jump on a false zero flag to LOOP
045	043			
046	000			
047	021		DECC	/Decrement C
050	110		JPFZ, LOOP	/Jump on a false zero flag to LOOP
051	043			
052	000			
053	007		RTUN	/Unconditional return to main program