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LAWRENCE LIVERMORE LABORATORY

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A STORES STOCK MICRO COMPUTER SYSTEM--
THE MCS-8 8-BIT PROCESSOR CONTROLLER

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Introduction

In the early days of computers each one was a huge, costly machine, usually bought on order with the appropriate combination of peripherals to suit the desired application. And usually the application was for computerizing a major industrial or commercial operation such as control of a refinery, automating the huge billing operations of a department store, or for untangling the complex reservations mess of an airline.

Later came the minicomputers, often a dedicated small computer which was a subsystem in a major functional system. For example, a dedicated minicomputer for control of a particular machine tool, a chemical process, etc.

Nowadays we have the "microcomputer", made possible by the advances in integrated circuit technology which make it possible to put a major functional subdivision of a computer system - such as the central processor and memory - each onto a single chip which is packaged as a dual-in-line that measures only 1/4 by 3/4 inches.

LLL's EE Department M & M Group, with design guidance from E. Fisher (General Chemistry Electronics Group), has taken advantage of this to develop "modules" of these major functional computer elements - processor, memories, I/O controls, etc. - each module comprising a small (2 1/2 x 4 1/2 inch) circuit board, plus a standard crate or chassis in which a number of these functional elements can be assembled into a desired computer system by merely "plugging in" the right circuit boards. Thus a desired microcomputer for a particular application can be custom made for that application by including (plugging in) the right combination of standard circuit boards into a single standard chassis (figure 1).

Furthermore, the desired microcomputer becomes immediately available because the standard functional modules (circuit boards), of which it is composed, and the standard chassis in which they are mounted, are all available as off-the-shelf items kept on hand in LLL Stores Stock.

This is a major turning point in the history of computers because the computer user can now get a computer custom made (tailored) to his application, can have it quickly, by combination of off-the-shelf elements; and at low cost (about \$500). The details of this revolutionary stage in computer technology, as developed at LLL, are described below under the following major headings:

I Functional integrated circuit elements
Processor and memory in "dual-in-line packages".

II Circuit board modules
Standard packaging (CPU, PROM, RAM, I/O)
Standard assembly (Card Frame, Chassis, Connectors, Power Supply)

FIGURE 1
BLOCK DIAGRAM OF BASIC
MCS-8 CONTROL PROCESSOR

- III MCS-8 System
 - Hardware, software combinations
- IV Major application areas
 - Machine tools, process and experiment control, graphic terminals, LLL applications
- V MCS-8 System's future
- VI Microcomputer resources available at LLL
 - a) System components in Stores Stock
(Loaded circuit boards, wiring frames, chassis, etc.)
 - b) Programming (software) available
(Microcomputer programs, tie-ins to minicomputers, etc.)
 - c) Programmed memory formation (PROM's)
(Write-in and erase facilities)
 - d) System try-out set-up
(M & M facilities for try-out of circuit board combinations)
 - e) Documentation
 - f) Design assistance
(Guide lines, consulting services, completed and pending microcomputer systems at LLL.)
- I Functional Integrated Circuit Elements

This modular computer system is made possible by several integrated circuit functional computer components, each produced on a single dual-in-line package for mounting on a circuit board. The principal one of these single integrated circuit functional elements is the processor, or "Central Processing Unit" (Intel 8008 CPU). It comprises mainly an arithmetic unit and a number of shift registers. (Fig. 2)

This processor controls the operation of the entire microcomputer system. It has a normal complement of 48 micro-instructions and operates on a single 3-inch x 5-inch circuit module. However, the combination of shift registers and arithmetic unit permits the processor far greater computer power than would normally be possible with such limited hardware. These features are described in detail in the article on "General-Purpose Micro-Controllers, Part II: Design and Applications", by William H. Davidow. COMPUTER DESIGN, August 1972, pages 69-75. See also Intel 8008 CPU Users Manual, page 3.

Another important computer system functional element, which is also produced on a single integrated circuit "chip", is the random access memory dual-in-line package. This was made possible by a special semiconductor memory cell design that eliminates a large amount of internal wiring within the chip, and thus makes it practical to construct so much memory in so small a space.

This random access memory (RAM) provides flexibility to the computer system by permitting changes in the computer characteristics through software changes of the program stored in the RAM. But the RAM also permits much greater extension of the computer system's power by acting as an expansion to fixed programs, stored in programmed read only memories (PROM's), which are also available as single integrated circuit packages. (Fig. 3).

The programmable read only memory chip (Intel ROM 1702A) provides a 256-word, 8-bit memory which can be permanently programmed electrically. It has a quartz lid which permits erasing the fixed program by use of ultra violet light. Needed programs stored in the PROM can therefore be changed as many times as desired.

The ROM permits storing microinstructions and data which can be quickly accessed by the processor and thus add greatly to the power of the processor in controlling operation of the entire microcomputer system. Combinations of a RAM, a PROCESSOR, and several ROM chips can be formed which provide micro-computer capabilities that come close to the capabilities provided by mini-computers.

II Circuit Board Modules and Standard Packaging

LLL Stores keeps in stock a considerable number of standard logic combinations on printed circuit boards (logic modules). These boards or modules can be used by EE Department engineers and designers to form desired microcomputer systems merely by suitable combination of standard items kept in stock. It was decided to incorporate the Intel MCS 8008 Central Processor Integrated Circuit chip into the standard logic boards (modules) stocked at LLL. This would permit LLL engineers to form, out of Stores Stock parts, microcomputers that are custom designed to the particular application.

The design goals were to provide circuit board cards which would supply a complete computer with the following characteristics.

- 1) Low cost - <\$500.00
- 2) Modular in design
- 3) Expandable memory
- 4) Compatibility with existing logic modules
- 5) Moderate speed
- 6) Minimum wiring required

The basic system which resulted provides an 8-bit microcomputer set, partitioned onto Control Logic Series Format Circuit Cards, and includes the following cards. (Figure 1.)

- 1) Central Processor - LEA68-9068-93
- 2) Input-Output Control - LEA 68-9068-94
- 3) Memory Address Buffer - LEA 68-9068-95
- 4) 512 x 8-Bit PROM - LEA68-9068-96
- 5) 256 x 8-Bit RAM - LEA68-9068-97
- 6) 1000 x 8-Bit RAM - LEA68-9068-98

Also provided are these input multiplexer and teletype interface cards. (Figure 1.)

- 1) Universal Asynchronous Receiver/Transmitter (UAR/T-LEA68-9068-99
- 2) 4 Bit-4 channel Multiplexer - LEA68-9068-33 (2 each)
- 3) 4 line-to-16 line decoders - LEA72-9068-03

These cards fit into a standard, prewired Card Frame Assembly unit (LEA72-900101) which is a large rectangular aluminium drawer (Figure 4) suitable for standard electronic equipment rack mounting. It comes in two sizes, one of which (Figure 4) provides one, and the other two, control logic bins (card frames) in which the control logic circuit cards are mounted by insertion into plug-in connectors. Besides the card frames, the assembly unit includes cooling fans and appropriate power supplies. The card frame has a central section for mounting the nine basic cards of the MCS-8 microcomputer system mentioned above, with additional slots prebussed (Figure 5) for additional memory cards, as required to expand the system. Details of all the hardware for this modular computer system available in Stores Stock are given in the EE Department's Bulletin 72-1, available from the M & M Group of EE, (X-8951).

III MCS-8 System

The 8008 is typical of most MOS devices in that, to interface with the TTL and operate from standard +5 V power supplies, a certain amount of IC overhead is required. This overhead is packaged on three logic modules considered the minimum system. These three cards - the central processor board, the I/O board, and the memory address board - supply all the clocks, bufferings, and time decoding to provide a computer system including 256 eight-bit words of memory.

Memory is provided on additional logic boards in modular units. The Random Access Memory (RAM) has 256 or 1,024 8-bit words per board, and the Programmable Read Only Memory (PROM) is provided with 512 8-bit words per board. The memory boards each contain the necessary decoding for page addressing in the address structure and therefore allowing slot independence on the memory buss. This feature allows any form of memory to be plugged into any slot. As a result, a program may be dynamically debugged in RAM memory and then permanently cast into PROM cards which may then replace the RAM cards. All RAM is of the static variety in that no refreshing is required. The input-output (I/O) member of the cards was designed to simplify the external interfacing required.

The data transfers were designed so that the 8-bit parallel data transfers are always strobed at the receiving end regardless of the transfer direction.

Two I/O signals are provided other than the data; they are $\overline{\text{IN}}$ and $\overline{\text{OUT}}$. The instruction set of the 8008 dictates that there will be 8 input device codes and 24 output device codes. By gating one of these device codes with the $\overline{\text{IN}}$ or $\overline{\text{OUT}}$ signals, an 8-bit parallel data transfer is made.

Data transfers into the central processor are provided in two popular technologies, MOS and TTL. Because these two technologies require slightly different logic levels, a dual input port is provided into the MCS-8 with the decision of which one to use left to the discretion of the interface designer.

IV Major Application Areas

The MCS-8, as a tool for the logic designer, will probably find its most successful application as a logic element. As a logic element, the MCS-8 has the capability of reducing combinational logic designs up to 50%. Any logic decision, within the MCS-8 speed limitations, may now be programmed at a software level, and have all the capability of and versatility of a 48-instruction computer at the cost of 3 boards of logic. The possibilities of this element has already brought back logic designs that were heretofore not economically feasible with discrete MSI logic elements. I think it is fair to say the microcomputers will completely dominate the areas of computer interfacing, data terminals, and complex switching networks in future designs.

V The MCS-8 System's Future

The 8008 appears to be one-to-two years ahead of other microcomputers in terms of availability. Although somewhat slow, the 8008 has good capability in its instruction set. The 8008 is presently available with cycle times of 20 μ s or 12.4 μ s; a software compatible CPU IC with expanded capabilities is coming in late 1973 with a cycle time in the order of 2 μ s. Although other microcomputers have recently been announced, all of them are trying to fill the shoes of minicomputers, and therefore, may not be as attractive as the 8008 as a simple-to-use element. Therefore, it seems likely that the 8008 and its successors have at least two to three year future at LLL.

VI Microcomputer Resources Available at LLL

Besides the plug-in cards which can be built into a microcomputer system, the EE Department of LLL also provides the following related services and facilities that promote application of this modular microcomputer system by people at LLL.

a) Systems Components in Stores Stock

Any of the cards and the assembly to house them may be obtained by simply submitting a Job Order to the Manufacturing and Materials Engineering Group of the EE Department. Call Bob Goodman, X-8951. He will give you details on the cards, ordering numbers, costs, etc.

b) Programming (Software)

1) Octal Debug Technique (ODT)

A program called ODT has been written for the MCS-8 Central Processor. It performs the following functions via TTY Key-board interaction:

- . Examination and/or modification of any memory location
- . Start-up or execution of stored programs
- . Read-in of N-P format tapes for debug
- . Provides TTY subroutines for Program I/O

This program is provided as a basic operating system to allow MCS-8 users an easy way to exercise the system hardware and to debug software. A complete description of the program can be obtained in LER72-103402 by Gene Fisher/Jim English. PROM's programmed with ODT can be obtained from the M & M Engineering Group with a Job Order Request Form.

2) MCS-8 Software

To date, four LER's have been written pertaining to MCS-8 programming.

LER72-103401, "Assembler Program for the MCS-8 8008 CPU", by Waldo Magnuson, is a preliminary users' manual for a CDC-7600 computer program. The program accepts, as input, programs written in Intel 8008 CPU assembly language using mnemonic symbols for the instruction operations and creates these two output files:

- . A standard assembly output (symbol table, source and objective code).
- . A formatted object code output.

LER72-103001, "Adapting a Mini-computer Programming System to the MCS-4 and MCS-8 Microcomputer System", by Roger Peterson. This report describes the use of the Digital Equipment Corporation PDP-8 class processors, editors, assemblers and loaders as the basis for programming the MCS-8.

LER72-103002, "Generating a Programmer Tape For The Intel MP7-02/SIM 4 Programming System", by Ron Casterson. This report describes how a binary tape is translated to the proper format required by the Intel Programming System. In addition, an assembly program which runs on the MCS-8 System itself will be available within approximately 30 days.

LER72-103403, "Simulator Program for the Intel MCS-8 8008 CPU", by Waldo Magnuson, Jr. The Intel 8008 CPU Simulator is now available on the LLL OCTOPUS CDC-7600 computer system. The program (MCS8SIM) provides a software simulation together with simulator execution commands to aid in program development for the MCS-8. Besides accepting 8008 machine code the simulator allows: Manipulation of the simulated memory and 8008 registers, breakpoint insertion, program tracing, symbolic and numeric

dumps, single stepping, and other operations during the simulation. This report states how the simulator (MCS8SIM) is accessed and how it is run on the OCTOPUS network.

c) Programmed Memory Formation

A PROM Programmer which writes programs electrically into ROM's is available for users' use from the Manufacturing & Materials Engineering Group, Bldg. 131, Room 1556. The Programmer accepts Intel's "N-P" format paper tapes only. (Tape is output of assembler.) In addition, a new PROM programmer will soon be available which will be capable of programming both MOS and bipolar PROMS stocked at LLL.

d) System Try-Out Set-Up

Anyone wishing to gain experience with the system, or to debug their MCS-8 program, can utilize the MCS-8 system tied to a TTY, (Figures 6, 7), which system is available in the Manufacturing & Materials Engineering Group area.

e) Documentation

A section of the Logic System Designers Manual is being dedicated to computer documentation. This section will be divided into three areas titled:

- Computer Systems
- Computer Applications
- Computer Software

A circuit description, electrical specifications, logic diagram and circuit diagram will be contained in the Computer Systems section. The Computer Applications Section will contain known system applications as well as new applications as they become available from users. The Computer Software Section will contain a brief description of the programs available from the Computer User's Library, L-152 Bldg. 131, Room 2631, Ext. 0060.

f) Design Assistance

Those interested in designing their own microcomputer from off-the-shelf elements can obtain guide lines, consulting services, and can see such systems already built at LLL. Call one of the following: Robert Goodman, X-8951, Jim Spann, X-8951 or Gene Fisher, X-7761.

Figure 3

MOS LSI Integrated circuit chips for MCS-8 microcomputer system.

Far Left: Programmable Read Only Memory

Second from Left: Central Processor Unit

Third from Left: 1000-word Random Access Memory

Right: 256-word Random Access Memory

Figure 4

Standard LLL card frame assembly unit (LEA 72-900101) for MCS-8 microcomputer system. Assembly unit is aluminum drawer which houses control logic bins (card frames), power supply, and cooling fans.

Figure 5

Backplane of logic bin (LEA 72-900111) in which computer system modules (circuit boards) are mounted. The card frame has a central section for mounting the nine basic cards of the MCS-8 microcomputer system with additional slots prebussed for additional memory cards, as required to expand the system.

Figure 6

Teletype (TTY) converted to a "smart" terminal by addition of MCS-8 computer in its base. Circuit boards (stack of horizontal boards, center) are plugged into a card frame assembly (column of connectors). Empty space to left of column provides room for additional frame assembly. Rectangular metal box which houses frame assemblies is hinged (at right) to permit swing out, thus provides easy access to wiring.

Figure 7

TTY "smart" terminal showing TTY at top with MCS-8 microcomputer in its base. Microcomputer is assembled on hinged frame (center) which swings out to permit easy access to card frame wiring.

Figure 8

Application of MCS-8 microcomputer system to self-contained display unit. Screen unit (black area) mounts on base below it, which houses the MCS-8 system. Keyboard unit (in foreground) permits operator input. Display unit permits graphic and text display. Keyboard, base and screen units are modular elements which are quickly assembled or disassembled by latching mechanism.

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