The MIL MF7114 Microprocessor

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The MF7114 was an early 4-bit single-chip microprocessor designed and built by Microsystems International between 1970 and 1972. The MF7114's genesis is the design work on Intel's first microprocessor, the 4004. Exploring the MF7114 microprocessor's development helps to gain a more complete historical perspective on the formation of the microprocessor and microcomputing industries.

The Microsystems MF7114 microprocessor, designed and built between 1970 and 1972, has its roots in the development of Intel's first single-chip central processing unit (CPU), the 4004.[1] Before it was given the MF7114 designation, the chip's general architecture was called the Intel 4005, and it was designed to back up the 4004 project by fabricating a simpler general-purpose microprocessor in case the 4004's development ran into severe difficulties.

The 4004 was one of the four devices constituting the MCS-4 chipset that Intel developed between 1969 and 1971 for Business Computer Corporation (Busicom), a Japanese manufacturer of desktop electronic calculators. By the late 1960s, calculator companies were taking advantage of medium-scale bipolar and metal-oxide semiconductor (MOS) devices to manufacture smaller, more portable, and less expensive products. Some, such as Sharp, Texas Instruments, and Busicom, were aiming at further savings by implementing calculator logic circuits using large-scale integration (LSI) MOS technology. When it signed the agreement with Busicom in 1969, Intel was one of only two semiconductor manufacturers in possession of MOS silicon-gate technology that, compared with metal-gate MOS, was capable of delivering fast, reliable, cost-effective, and low-power-consuming LSI devices. (The other company with MOS silicon-gate technology was Fairchild.)

The MCS-4 chipset's general architecture was the work of Marcian E. (Ted) Hoff Jr., the manager of Intel's Applications Research Group and the engineering liaison to the Busicom project. In his work on the Busicom calculator chipset, Hoff collaborated with Stanley Mazor, who joined Intel from Fairchild in September 1969.[2] Although the designers originally intended to make the Busicom calculator set more cost effective, as opposed to developing a general-purpose single-chip CPU, "when the design was done, we realized that this chipset could do a lot more than just make calculators."[3]

The 4004 chip was a high-risk project that tested the limits of Intel's MOS silicon-gate process technology. Did Hoff and Mazor have a plan to salvage their "computer on a chip" concept in case the 4004's circuit complexity and the economics of the chip's manufacturing called for transistor density that Intel's silicon gate process could not deliver? In fact, they did devise such a plan before Intel hired Federico Faggin in April of 1970 to lead the MCS-4 chipset design work. The plan called for a "minimum circuitry" single-chip CPU architecture and standard RAM and ROM memories. The 4005 CPU chip and the memories were to be designed in collaboration with Microsystems International Limited (MIL), a semiconductor company in Ottawa.

In early 1971, when Faggin and Masatoshi Shima's design work resulted in silicon wafers with a sufficient number of fully functional 4004 CPUs on them to permit the chips' fabrication at the target cost, Intel abandoned the 4005 project. MIL, on the other hand, continued the 4005's development and, by mid-1972, had its own 4-bit microprocessor—the MF7114.

In the end, the MF7114 did not secure the vast applications markets enjoyed by the 4004 and other early 4-bit CPUs such as Rockwell's PPS-4. It didn't capture the attention of a larger electronics engineering audience, either. However, the MF7114's historical significance lies elsewhere. Although it might have

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been just an episode in the history of the 4004's development, the 4005/MF7114 project at MIL turned out to be a rich source of historical data on the early development of the microprocessor and microcomputing industries. The project illustrates patterns of technology transfer and ways of gaining systems knowledge inside the early 1970s semiconductor industry. The MF7114's history provides evidence that Intel was sharing its single-chip CPU ideas with other companies even before the work on its first single-chip CPU was completed. It also shows that even at the earliest stages in the microprocessor technology development systems engineers considered (and built) general-purpose digital computers as one of the ground-breaking applications for the microprocessor. Finally, the annals of the MIL MF7114 project represent a case study on the dissemination of LSI knowledge outside of the electronics industry reaching the North American computer hobbyists' movement, which would play such a significant role in the creation of the microcomputing industry and in the social acceptance of personal computing.

The 4005 alternative

The rapid advancements in the semiconductor process technologies in the second half of the 1960s opened up the possibility of depositing the complete circuitry of a simple CPU on a single integrated circuit (IC) and economically manufacturing such a CPU. Hoff's proposal to implement the Busicom chipset around a single-chip CPU was based on his conviction that Intel's MOS silicon-gate process could deliver devices of the 4004's complexity cost effectively. He expressed his view explicitly in March 1970 during the IEEE International Convention in New York:

> An entirely new approach to design of very small computers is made possible by the vast circuit complexity possible with MOS technology. With from 1000 to 6000 MOS devices per chip, an entire central processor may be fabricated on a single chip. By combining central processor chips with LSI ROM's and RAM's, a computer of modest size and performance can be constructed.[4]

However, in 1969, Intel's MOS silicon-gate process was still unproven for circuits of the 4004's complexity. As the cost of early LSI devices depended critically on the area of silicon used to implement them, it was unclear whether the 4004's die size would end up too large, preventing Intel from manufacturing the 4004s economically. According to Mazor, during the architectural work on the MCS-4 chipset, Hoff estimated the transistor count of each of the chips. The estimation for the 4004 CPU was approximately 2,000 transistors.

> The ROM/RAM memory chips were somewhat predictable, and since they are regular the die size estimate can be reasonably made. On the other hand, although [Hoff] had a transistor count estimate of the 4004, because of the wiring complexity of a CPU, we were unsure of the die size.[5]

Mazor further explained, "the yield varies inversely with (nearly the cube of the area), so if the 4004 die would end up too large, the yield would be miserably low, and our project would fail." That failure would most likely have put an end to the Busicom contract.

There was no easy way to overcome the uncertainties about the impact of the CPU's complexity on its fabrication yield. In early 1970, neither Hoff, Mazor, nor anybody else at Intel had any experience in designing random logic of the 4004's complexity in silicon gate. The manufacturing difficulties with Intel's first 1-Kbit dynamic RAM (DRAM) chip—the 1103—provided some indications of what the 4004's development might face. The design of the 1103 chip that called for 1024 3-transistor memory cells was putting Intel's MOS silicon-gate process to the test. The initial results were not encouraging—the first 1103 chips were nonfunctional and of low yield.

Therefore, a logical decision for Hoff and Mazor was to come up with an alternative design of a single-chip bare-bones CPU much simpler than the 4004. "After defining the MCS-4 family architecture," said Mazor, "we looked for a 'hedge' in case the project failed due to the 4004 die size being too large and having a poor yield." They named the chip the 4005.

According to Mazor, the general 4005's architecture that he and Hoff sketched was inspired by the processor architectures of minicomputers, specifically of the successful PDP-8 minicomputer Digital Equipment developed in the mid-1960s. The chip was to be simpler, but faster than the 4004, and it would not require any specialized memories. The 4004's architecture was based on 16 registers and a push-down stack. The 4005 was to be much simpler with only two memory pointer registers and an accumulator register but no stack, relying on main memory instead. The 4004 microprocessor was designed to work with specialized 4001 ROM chips, and it required some interface circuitry to allow the use of other types of ROMs (such as erasable programmable read-only memory (Eprom)) in place of the 4001s. The 4005's design didn't call for specialized ROM memory. In short, the 4005 was to represent a smaller, cautious step into the emerging LSI world.

There was also another incentive to work on an alternative microprocessor. The success of the MCS-4 chipset might well induce other calculator companies to shop for single-chip CPUs for their calculators. Until May 1971, the rights to the MCS-4 still resided with Busicom. Mazor explained,

> even if we succeeded [with the 4004] we might not be able to sell it to any other company; so why not develop, yet, another 4-bit family. . . . We were seeking other business from calculator companies beyond the Busicom deal. I visited a calculator company in Chicago, Victor Comptometer, and left a copy of our preliminary (4005) specification with them.

In an interview for the IEEE History Center in 2004, Federico Faggin explained that while Busicom had the exclusive rights to the use of the MCS-4 chipset,

> they did not have any rights to the 4004 intellectual property. It's a critical distinction, and some people don't put it all together. Basically, Intel could have designed another CPU, just a bit different, and it would have been fine.[6]

This hedging strategy with the 4005 shows that even at the early stages of the 4004's development, some engineers at Intel considered the emerging microprocessor technology an important business opportunity for Intel.

Enter Microsystems International

In 1966, the Canadian Department of Industry estimated that Canada's trade imbalance in the computer industry reached C$60 million that year alone and projected the imbalance to increase steadily in future years.[7] The department also concluded that the lack of computer manufacturing, research, and development in Canada was damaging the Canadian economy in a number of ways: from lost employment and under-utilization of skilled human resources to unnecessary support of foreign R&D activities, estimated at C$10 million in 1966. The Department of Industry viewed computer, data processing, and telecommunications industries as the key to a modern and successful Canadian economy. That economy could not properly develop and stay competitive on the world's market without creating the domestic semiconductor research and production infrastructure.

In the end, the Department of Industry teamed up with Northern Electric Company, Bell Canada's wholly owned manufacturing arm that was already developing and manufacturing electronic devices (such as transistors and ICs) at its Advanced Devices Center in Ottawa. In March 1969, with a C$48 million package from the Canadian Treasury Board, Northern Electric transformed its entire Advanced Devices Center into a new company—Microsystems International Limited (MIL). In support of its choice, the Canadian government argued that

> The Northern Electric Company, has the product ''know-how'', the research capability, the user relationship, the market access, the management competence, the need and the corporate commitment which when combined with adequate Government assistance provides an excellent opportunity for the development of an efficient, internationally competitive and self-sustaining production facility in the microelectronics area for Canada.[8]

In a short time, MIL acquired state-of-the-art IC manufacturing technologies and second-source rights to several semiconductor devices. The company grew quickly, opening a new assembly plant in Malaysia and subsidiaries in Germany, Malaysia, and the US. MIL sold various computer components as well as linear and telecom ICs through its worldwide extensive chain of distribution, marketing, and sales centers. The company financed its operations using the federal government's C$48 million package, funds raised from the public (C$20 million by the end of 1970), Northern Electric's cash subscription, and a bank line of credit (C$10 million by the end of 1970).[9]

On 2 July 1970, MIL concluded one of its most important deals with Intel. Under the terms of the agreement, the Canadian company was getting an access to Intel's MOS silicon-gate technology and the second-source rights to the 1103 DRAM memory.[10] Intel was to set up a production line for MOS ICs at MIL's Ottawa facility and guarantee the critically important quality performance. In return, Intel was getting much-needed cash to weather the economic contraction of the December 1969 to November 1970 recession and a second-source partner for some of its products.

While shopping at Intel, MIL learned about and expressed an interest in the 4004 microprocessor. Because the chip was Busicom's and not Intel's property at that time, MIL was offered the opportunity to collaborate on the 4005 development instead. According to Mazor,

> The deal was MIL would design and build the CPU to our 4005 specification, and Intel would convert our general-purpose RAM and ROM to work with the CPU with minimum circuitry. MIL and Intel would have joint ownership of the products and both sell all three of these chips CPU/ROM/RAM.

MIL agreed and assigned the task of the 4005's design to one of its engineers, Kenneth Au. Mazor acted as Intel's principal technical liaison to MIL on the 4005 project, reporting to Hoff, and shared his office with Au, who did most of the 4005's design at Intel. This was a convenient arrangement for Intel as its business was focused on semiconductor memories and it could barely staff the development of its first two microprocessors—the 4004 and the 8-bit 8008. ''We felt that this was a great tradeoff,'' said Mazor, ''since the 'expensive' chip design and layout would be done by MIL (our specification), and we would reap the rewards of making and selling their chip design with our memory chips.''

From the 4005 to MF7114

In April 1970, just weeks before Intel agreed to share its MOS silicon-gate process with MIL, Intel hired Federico Faggin—formerly of Fairchild Camera and Instrument—to head the design of the MCS-4 chipset. In just nine months of relentless work, Faggin, assisted by Busicom's Masatoshi Shima, had a working 4004 chip on a tiny 3×4 mm piece of silicon. Faggin's success not only confirmed Hoff's assessment of MOS silicon-gate technology's potential for the realization of single-chip CPU devices but also put an abrupt end to the collaboration between Intel and MIL on the 4005 chipset. ''When the MCS-4 family worked, we didn't need our 'insurance policy,''' commented Mazor, ''and [Intel] dropped out of the deal ... not making the special ROM or RAM, and MIL failed to make the 4005 ... at that point, anyway.''

The MF7114 was a single-chip 4-bit parallel CPU implemented using the p-channel silicon-gate process.

As far as Intel was concerned, the 4005 project was dead. Au returned to MIL with a mostly completed chip design, while Mazor geared up for the MCS-4's promotional work, beginning with the official introduction of the chipset during the November 1971 Fall Joint National Computer Conference in Las Vegas.

MIL, however, didn't want to waste the opportunity to have a single-chip CPU of its own. The company was rapidly gaining expertise in designing and manufacturing semiconductor memories—thanks to the engineering expertise and creativity of people such as Richard (Dick) C. Foss and Robert Harland—so picking up Intel's end of the 4005 project wasn't a big problem. MIL decided to develop its own three-chip microcomputer set consisting of the 4005 CPU, one ROM, and one RAM device. The 4005 chip was first renamed the MF4005 and, finally, the MF7114.

The work on the MF7114 continued at MIL through the first half of 1972, with the first tests scheduled for 1 July. Unfortunately, Au left MIL before the first round of tests was completed. His job was taken over by John Freeman, who came from Marconi UK and became the manager of MIL's MOS Products Development in 1970. Later he managed MIL's Systems Application Group. The tests Freeman performed on Au's design determined that although the chip ''showed some signs of life,'' it was too noisy and, hence, nonfunctional. According to Freeman, the redesign work was difficult because, as Freeman put it, Au was known to use ''unproven'' design solutions.[11] Mazor concurred,

> Although I wasn't a chip designer, I considered Ken Au to be a bit immature in MOS chip

Figure 1. The MIL MP-1 chipset consisted of the MF7114 CPU, the MF1601 ROM, and the MF7115 RAM. This image features a MIL MP-1 promotional paper weight. (Courtesy of York University Computer Museum.)

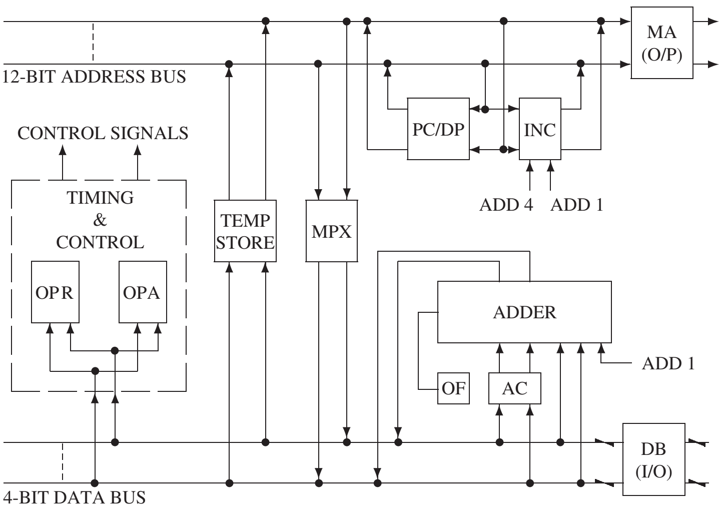

Figure 2. MF7114 block diagram showing accumulator (AC), adder (ADDER), data buffer (DB), data storage (OPA), incrementer (INC), instruction storage (OPR), memory address buffer (MA), the overflow register (OF), program counter pointer (PC), temporary storage (TEMP STORE), and data pointer (DP). DB and MA denote data and memory address buffers, respectively.[13]

design. Case in point, Faggin added logic to the 4004 CPU to make it more testable, whereas Ken's comment to me was that testing wasn't his problem ... (not my job).... I've come to learn that testability is a major issue in chip architecture and chip logic design.

In the end, the work of Freeman's group resulted in a well-performing chip. MIL released its MF7114-based microcomputer chipset in the second half of 1972. Named the MP-1 Microprocessor, the chipset consisted of the MF7114 CPU, the MF1601 ROM (2,048 bits), and the MF7115 RAM (see Figure 1). MIL advertised the MP-1 as a "basic microprocessor set for complete microcomputer systems."

To support its MF7114 customers, MIL published the "How to Use the CPS/1 Micro-Computer System" bulletin,[12] which described the CPU's architecture and instruction set as well as its applications, programming, and program development software.

The 7114 CPU

The MF7114 was a single-chip 4-bit parallel CPU implemented using the p-channel silicon-gate process. Similar to the Intel 4004, it was designed to operate with 4-bit data words, it could directly address 4,096 4-bit words of memory, and featured the 4-bit accumulator. But this is where the similarities end. The MF7114 CPU was designed around a 21-line bus called Combus. All communication between the CPU and external devices (e.g., memory or I/O devices) was done on this bus using 12 lines for addressing, four lines for data, and the remaining five lines for carrying control signals such as clock phase, system reset, data direction, or instruction fetch (see Figure 2). In comparison, the Intel 4004's address bus had only four lines, which meant that each address had to be sent over the bus in three 4-bit bytes in three CPU cycles. Provisions were made to increase the number of address lines and to expand the MF7114's addressing capabilities to 256 Kbytes, which let an MF7114-based system handle larger volumes of data.

The most distinct feature of the MF7114's design was the use of RAM to implement the CPU's working registers and I/O ports. There were eight 4-bit data registers and eight 12-bit address registers that did not reside on the MF7114 chip itself but in the first 32 bytes of RAM. These RAM-implemented registers provided a fast-access scratch pad for the CPU to hold such items as intermediate results and loop counts. These working registers could be conveniently addressed as normal memory locations.

The interfacing of I/O devices was also simplified by implementing the I/O ports in

RAM. Each external device connected to an MF7114-based system was assigned and was responding to one or more addresses in the memory space. For instance, if an analog-to-digital converter was assigned the address 6000, then each time this address was sent down the Combus address lines the converter placed the 4-bit binary representation of its analog input on the data bus.[14] This is analogous to normal memory read instruction: sending out a memory address results in data stored at this address to be placed on the data bus destined for the CPU's accumulator.

Apart from the accumulator (AC in Figure 2), there were only three other registers residing on the MF7114 chip. These were the program counter (12 bit, to store the address of the next instruction), the data pointer (12 bit, to store the address of data to be operated on), and the 1-bit overflow register (see PC, DP, and OF in Figure 2).

The MF7114's instruction set consisted of 58 instructions that the chip executed in three to five cycles with the speed of 0.9 microseconds per cycle. The chip was packaged in 24-pin dual inline package (DIP). The 4004 had 45 instructions executable in eight to 16 CPU cycles with the speed of 1.33 microseconds per cycle. It was housed in a smaller 16-pin DIP.

The common electronic calculator was the origin of both the MF7114 and 4004 CPUs. However, by the time the process of morphing the 4005 concept into fully functional MF7114 microprocessor was completed in the second half of 1972, MIL considered and started marketing its chip as a CPU of a general-purpose microcomputer system. Concurrently with the development of the 7114, MIL was building a computer around its CPU to "serve applications where [a minicomputer such as] the PDP/8 has more computing power than is required."[15] On the other hand, it would be Intel's first 8-bit CPU—the 8008—and not the 4004, to initiate Intel's first-generation line of general-purpose computer-oriented CPUs.

MIL CPS/1 microcomputer

To support its microprocessor and Eprom products, Intel developed inexpensive microprocessor development systems and offered them to its customers in 1972. These systems were powered by Intel's 4-bit SIM4-0x and 8-bit SIM8-01 microcomputers.[16] MIL also needed similar hardware and software tools to support its MF7114 processor and the MF1701 and 1702 Eproms. Although Intel was aiming its SIM4 and SIM8 microprocessor prototyping aids at in-house development of the 4004- and 8008-based applications, MIL wanted to build general-purpose microprocessor-powered computers (or microcomputers).

In 1972, no general-purpose microcomputers were on the market, but a few were in the making, most notably the French R2E Micral and the Canadian MCM/70; both would be formally announced in the following year.[17]

MIL started its work on the MF7114-based computers in the first half of 1972. On 18 May, a group of engineers from various MIL departments met to form the CPS/1 Group with the purpose of designing a general-purpose computer based on the MF7114 CPU (CPS/1 stands for "chip processor system, first try"). The group was led by Juan Monico and Larry Schweizer and included, among other engineers, Ken Au, Richard Foss, and John Heckman. Monico joined MIL as an applications engineer in mid-1971 when the 4005 project had already been initiated. Soon after, he was appointed the manager of MIL's Systems Engineering Department. His first responsibility was to put together an extensive systems engineering team. He attracted, among other people, Schweizer and Heckman. Among the Systems Engineering Department's responsibilities were microprocessor products. "One of the things that we needed obviously to make was a development system for the 7114," recollected Monico.[18] The CPS/1 computer, however, "was intended to be more than just a demonstrator," explained Heckman.[19] In fact, it was intended as a cost-effective alternative to minicomputers in applications that did not require the full processing power of the minis.

During the 18 May CPS/1 Group meeting, Au reported on the 7114's design progress. The group aimed at the initial development of 10 complete prototypes of the CPS/1 computer by mid-September 1972. First software packages for the CPS/1 (such as the assembly language package) were to be ready by the end of May. The group also agreed to a naming convention for the CPS/1 software, according to which software products would be named "CPXX," where "XX" were the first letters of the named program.[20] "The emulator became the CPE, the assembler language CPAL, and then the system was dubbed the CPS. CPAL/1 was the first version

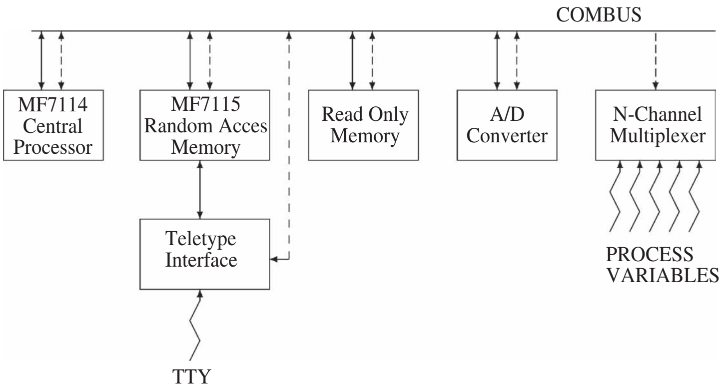

Figure 3. The block diagram of a small CPS/1 system. The diagram depicts a data logger with output to a standard teletype (TTY).[24]

of the assembler, CPS/1 became the first version of the system,'' Heckman recollected.

The main engineer behind the CPS/1 project was Larry R. Schweizer. In his May 1972 document entitled ''CPS/1 Concepts and Facilities,'' he wrote,

> CPS/1 is the first in a series of microcomputer systems from Microsystems International Limited. CPS/1 provides, for the first time, a truly general purpose computer system at a cost which is an order of magnitude smaller than the most inexpensive ''mini'' on the market. CPS/1 not only gives the digital system designer a real alternative to ''hard wired logic'' but gives him an alternative where a general purpose computer is required.[21]

The CPS/1 went through a number of transformations and name changes: from CPS/1 to MP-1 (microprocessor) and, finally, to MC-1. Still, the underlying architectural objective was to develop a modular microcomputer—that is, a partitioned system of interconnected and compatible system modules communicating with each other via system communication bus under control of the MF7114. Because all the modules (except for devices such as operator's consoles or I/O equipment) were to be built with compatible technologies, the system timing could be derived from the communication bus's clock lines.

The CPS/1's modular architecture was formulated to make a computer system more responsive to users' needs, maximize the system's versatility, and avoid waste. An application-oriented system must be able to be partitioned so that only the necessary modules were to be used in a given application. As Schweizer explained it informally in one of his technical documents, ''Traditionally, computers have been designed by hardware types or software types. This led to machines which pleased the builder or the programmer, not necessarily the user.''[22]

The ''CPS/1 Concepts and Facilities''[21] and ''CPS/1 Application Guide''[23] documents written in May and June 1972, respectively, provide insights into the CPS/1 computer's architecture and applications. All communication between a CPS/1 system's components was done on the Combus (see Figure 3). External devices (keyboards, digital displays, teletypes, cassette storage, and so on) were connected to a system through Combus connectors. The system was to handle applications that required interrupt, real-time, analog-to-digital, and digital-to-analog capabilities. A programmer could develop CPS/1 software on a mainframe or a minicomputer using a set of CPS/1 software development tools and utility packages written in Fortran and APL. The CPS/1 assembler CPAL/1 and the CPS/1 emulator CPE/1 were written by a group of software engineers that included Heckman. Among the utility programming packages, the group offered the arithmetic package (routines to perform arithmetic operations on variable precision binary and decimal numbers), math package (containing routines for functions such as sin, cos, exp, square root, or log), character package (a set of routines for input, output, and character string manipulation), and housekeeping package (containing routines to assist in programming including push and pop stacks of data or addresses, or subroutine calls). These packages were available on preprogrammed ROMs or as CPAL/1 listings.

Detailing the benefits of the CPS/1, Schweizer wrote,

> CPS/1 gives the digital system designer a new, powerful tool for implementing digital systems. The ease of using CPS/1 is enhanced by the availability of a complete range of support software and straightforward interfacing techniques. Thus we herald in a new era in digital computer systems applications.[21]

The boldness of Schweizer's proclamation should not be too surprising if one recalls a similar announcement from Intel that in fall 1971 proclaimed ''a new era in integrated electronics'' to be brought about by its novel ''microprogrammable computer on a chip''—the 4004.[25]

The first prototype of the CPS/1 was a single-board computer mounted in an aluminum box and sporting 2 Kbytes of ROM and 1 Kbyte of RAM. It resembled a minicomputer of the era and featured the front panel with lights and switches used to load and execute programs. MIL began to advertise its CPS/1 system in late 1972 with the publication of the ''How to Use the CPS/1 Micro-Computer System'' bulletin. According to Freeman, who in 1973 became MIL's Manager of Systems Applications and Marketing, only a few CPS/1 development systems were sold.

Dissemination of knowledge

The development of the CPS/1 ended in fall 1973, when in an effort to overcome its mounting financial difficulties, MIL moved to streamline its product portfolio and concentrate its managerial, research, and manufacturing efforts on fewer, high-volume products. Although 1973 sales were good and totaled C$20,475,000, compared to just C$12,303,000 in the previous year, the 1973 net loss of C$10,146,000 more than doubled the C$4,139,000 loss incurred by the company in 1972.[26] That fall, MIL shelved the CPS/1 microprocessor hardware and software, high-frequency linear devices, and hybrid telecommunications products development projects—all classified as having no immediate bearing on the company's marketing and manufacturing objectives. MIL's restructuring was followed by massive layoffs and a major senior management shuffle with A. Olaf Wolff resigning as MIL's president and director. According to Monico, MIL's Systems Engineering Department was decimated from about 200 to just a few employees.

MIL's fall 1973 restructuring also marked the end of the company's interest in the MF7114 CPU. Since 1972, when MIL acquired the second-source rights to Intel's 8-bit 8008 microprocessor, the company's interests had started to shift from 4-bit to 8-bit LSI CPUs. MIL's first 8-bit microprocessor—the MF8008—required hardware and software tools that the company could offer its customers for the development of the MF8008-based applications. After all, Intel had developed similar tools for its 8008 chip around the SIM8-01 microcomputer. ''We didn't have the rights to any [Intel] development systems,'' said Monico, ''anything on the systems level was not a part of the agreement [between MIL and Intel].'' Therefore, to stay competitive in the market place, MIL had to construct its own microprocessor development system. To that end, MIL's Systems Applications Group led by Freeman, who survived the fall 1973 layoffs, embarked on the MOD8 project—an MF8008-based modular microcomputer.

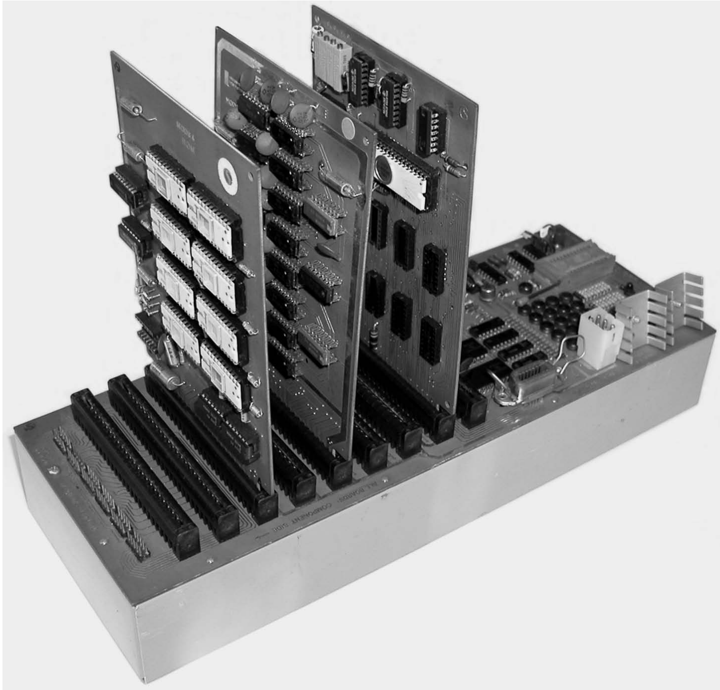

Figure 4. The MOD8-80 backplane with the CPU, ROM, and RAM modules mounted. (Courtesy of York University Computer Museum.)

The MOD8 inherited its modular architecture and the user-oriented system design philosophy from the CPS/1 computer. The ''modularly expandable bus organized structure [of MOD8] allows the memory capacity and type and the number of I/O ports to be tailored to any particular system requirement.''[27] Similar to its 4-bit CPS/1 predecessor, the MOD8 computer was easy to interface with external devices, expand, and modify; to build an MF8008-based system of a desired configuration, a user simply plugged the required memory and interface cards into the bus connectors that, in the MOD8 case, were mounted on top of the computer's aluminum chassis. When the MF8008 CPU plug-in card was replaced with the MF8080 CPU board, users ended up with the more powerful 8080-based microcomputer, the MOD80 (see Figure 4).

According to Freeman, the MOD8 design was implemented by Tom Dale, an electrical engineering student from the University of Waterloo, Ontario. Initially hired by MIL for the summer, Dale enjoyed the projects so much that he decided to take a one-year

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leave from the university to complete the MOD8 hardware and write the MONITOR8 software for the computer.

MIL itself did not survive the closure of its CPS/1 microcomputer project by much longer, however. In June 1975, the company closed its doors for good, never making a profit since its incorporation and losing approximately C$37 million in federal government money, including nearly C$30 million in grants plus another C$6.7 million in loans. MIL's demise was the subject of an intense political debate in the Canadian parliament and press. Accusations of gross mismanagement of the company, rumors of missing equipment installed in MIL's manufacturing plants in Ottawa and Malaysia, as well as accusations of unethical, if not fraudulent, practices on the part of MIL's parent company Northern Electric gave rise to persistent demands for public enquiry into MIL's collapse.[28]

In the end, Northern Electric, which claimed that MIL had to be closed because it was unable to pay its debts and it had no source of further funding, absorbed part of MIL's operations by repaying outstanding government loans to MIL. Whatever was left of MIL was auctioned.

Despite its short life, however, MIL seeded the Canadian high-tech sector with scores of semiconductor, computer, and telecommunications spin-offs and start-ups founded by former MIL employees. By the end of the last century, the industry that MIL helped to create was bringing in more than C$4 billion in annual revenues. Some of the companies seeded by MIL grew into successful, internationally renowned firms. For example, Mitel was cofounded by Michael Copland and Terrence Matthews and quickly become a market leader for small microprocessor-based telephone switch equipment (PBX and central office), and the semiconductor memory company Mosaid was cofounded by Richard Foss (a member of the CPS/1 group) and Robert Harland.

Other start-ups were less successful, such as the short-lived Great Northern Computers started by the CPS/1 coordinator Juan Monico. His new company sold the MOD8 and MOD80 hardware to industrial customers and computer hobbyists. According to Monico, eight of the MOD80 computers were sold by his company to Tandy Corporation, which introduced its own first microcomputer, the TRS-80 Model I, in 1977.

A number of former MIL engineers who didn't become independent entrepreneurs were absorbed by Bell-Northern Research (BNR), a renowned R&D lab jointly owned by Bell Canada and Northern Electric. John Freeman arrived at BNR with considerable microprocessor experience and a number of MOD8 and MOD80 microcomputers. In his capacity as BNR's manager of the Microcomputer Applications Group, he taught in-house workshops on microcomputer applications and acted as an in-house consultant to systems design groups incorporating microprocessors into their new product developments. He assembled and successfully demonstrated numerous MOD80s that, according to Freeman, played a pivotal role in introducing BNR to microprocessor technology.

The MIL MOD8 and MOD80 computers caught the attention of North American computer hobbyists, whose movement played a crucial role in forming the early microcomputer industry and social acceptance of personal computers. MIL's two sales offices in California (in Palo Alto and Santa Ana) gave away the "MF8008 Central Processor Bulletin" to almost anybody who knocked on their doors. This bulletin introduced many computer enthusiasts to microprocessor technology for the first time. MIL's MF8008 bulletins even circulated among the participants during the first meeting of the now-legendary Silicon Valley Homebrew Computer Club (HCC) on 5 March 1975.[29] Steven Wozniak, who in less than two years after that meeting would cofound Apple Computer, was one of the attendees who received a copy of the bulletin during that meeting. In his 2006 autobiography *iWoz*, Wozniak described this event and his initiation to microcomputing this way:

> I was scared and not feeling like I belonged, but one very lucky thing happened. A guy [Marty Spergel] started passing out these data sheets—technical specifications—for a microprocessor called the 8008 from a company in Canada.... I took it home, figuring, Well, at least I'll learn something.
>
> That night, I checked out the microprocessor data sheet ... I realized that all I needed was this Canadian processor or another processor like it and some memory chips. Then I'd have the computer I'd always wanted! ... I could build my own computer, a computer I could own and design to do any neat things I wanted to do with it for the rest of my life.[30]

Of course, that "Canadian processor" described in the MIL's "MF8008 Central Processor Bulletin" was just a clone of the Intel 8008-1 CPU. However, apart from the 8008 microprocessor's technical specifications, the bulletin contained a detailed description of the MOD8 computer, from its schematic diagram and printed circuit-board layouts to the listing of the MONITOR8 software, as well as the address of Space Circuits, a company based in Waterloo, Ontario, that was manufacturing and distributing good-quality and inexpensive MOD8/80 boards. Some early hobby computer clubs bulk-purchased sets of unpopulated MOD8 or MOD80 printed circuit boards directly or indirectly from Space Circuits to build and experiment with their first computers. One such club was organized by a group of enthusiasts working for Chevron Research in San Francisco that eventually merged with HCC. Another computer club was the Toronto Regional Association of Computer Enthusiasts (or TRACE) organized in Mississauga, Ontario, by electronics enthusiasts employed by Control Data Canada.[31] MIL's MONITOR8 and the cassette interface software allowed the hobbyists to develop and store their programs on ordinary audio cassettes instead of Eproms, which were more expensive and less convenient to use.[32]

Despite MIL's demise, a moderate demand for the MOD8/80 hardware among the hobbyists continued until 1977. MiniMicroMart, a popular computer store in Syracuse, New York, not only continued to sell these computers to the hobbyists but also developed a series of modular MOD80-like computers around other popular CPUs such as Zilog Z80 and Motorola 6800. In its September 1976 product bulletin, MiniMicroMart wrote to its clients that "While MIL is long gone, their system concept will live on."

Conclusions

In the end, the 4005 didn't take the 4004's historical place in starting "a new era in integrated electronics." Instead, the 4005's role was to be a vehicle for the transfer of the microprocessor technology on the onset of LSI and microcomputing.

At Intel, the 4005 CPU architecture grew out of concerns for Intel's MOS silicon-gate process abilities to handle random logic of the 4004's complexity cost effectively. Asked about Intel's possible course of action in the event of the 4004's development failure, Mazor offered a conjecture that "[Intel] would either give up on the Busicom project ... and hence this [4005] hedge was just to give us a 4-bit general-purpose microcomputer ... or we'd consider how to reengineer the Busicom calculator if and when we needed to pursue the backup plan." It is also evident that Intel's Applications Research Group intended to penetrate the electronic calculator market with its own 4005-based calculator chipset. "[W]e were looking for something less aggressive than the 4004," said Mazor. "We were looking for something we could sell outside of the Busicom deal—this I know for fact since I personally visited the Chicago calculator company Victor [Comptometer] and left a [4005] spec with them."

At MIL, the 4005 concept evolved into the MF7114 microprocessor and that process allowed MIL engineers to come up with the modular and user-oriented architectures for general-purpose microcomputers, as exemplified by the CPS/1 and the MOD8 designs. Then, after MIL's closure, the microprocessor and microcomputer expertise developed at MIL was disseminated throughout the Canadian high-tech industry and the North American computer hobbyists' movement.

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References and notes

1. The research reported in this article is based primarily on documents released by Microsystems International between 1972 and 1974. It also significantly relies on oral histories because there is a lack of relevant primary and secondary sources on these topics, such as the genesis of the Intel 4005 chip. Quotations by J. Freeman, J. Heckman, M.E. Hoff, J. Monico, and S. Mazor, were obtained through interviews and email correspondence with the author between 2003 and 2008.
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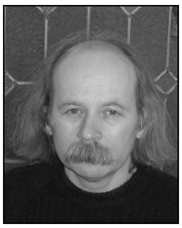

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