Part II

1970's -- The Altair/Apple Era.

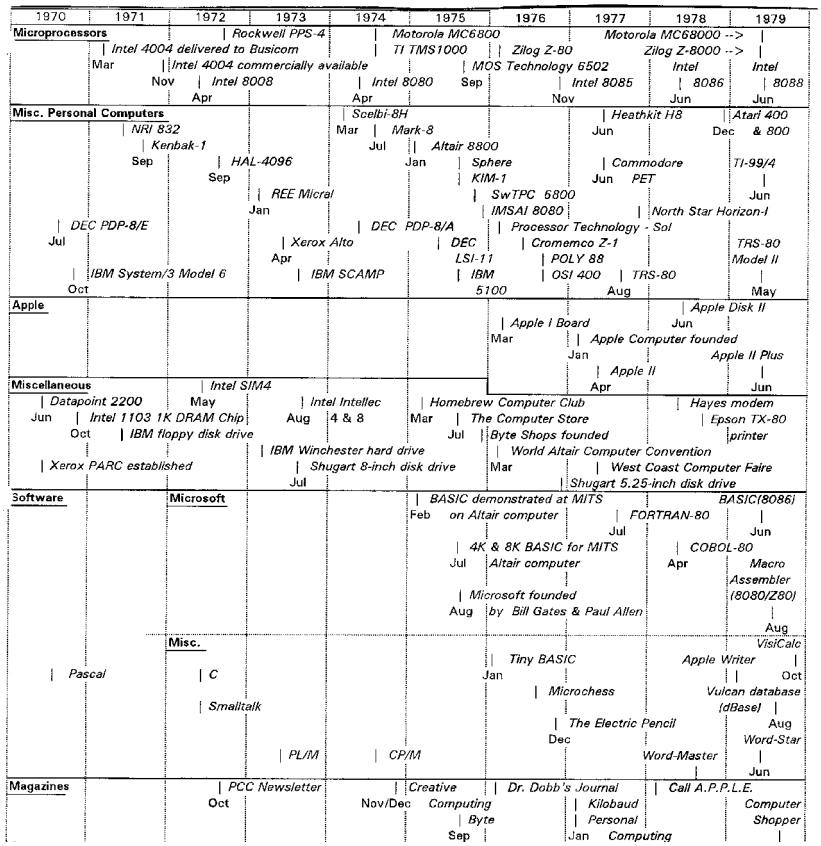

Figure 3.1: A graphical history of personal computers in the 1970's, the MITS Altair and Apple Computer era.

Figure 3.2: Andrew S. Grove, Robert N. Noyce and Gordon E. Moore.

Figure 3.3: Marcian E. "Ted" Hoff.
Photographs are courtesy of Intel Corporation.

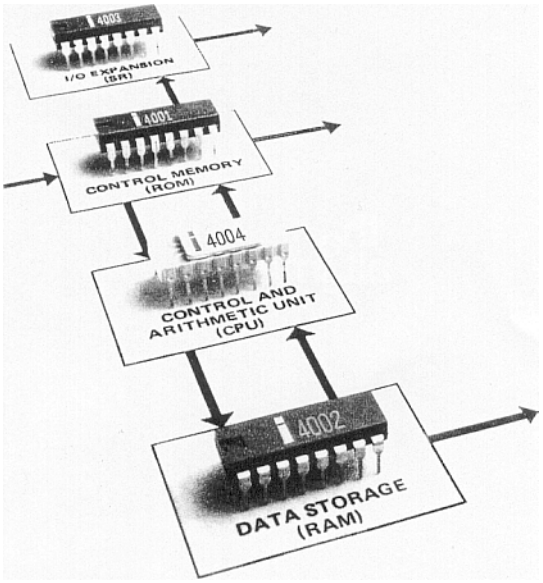

Figure 3.4: The Intel MCS-4 (Micro Computer System 4) basic system.

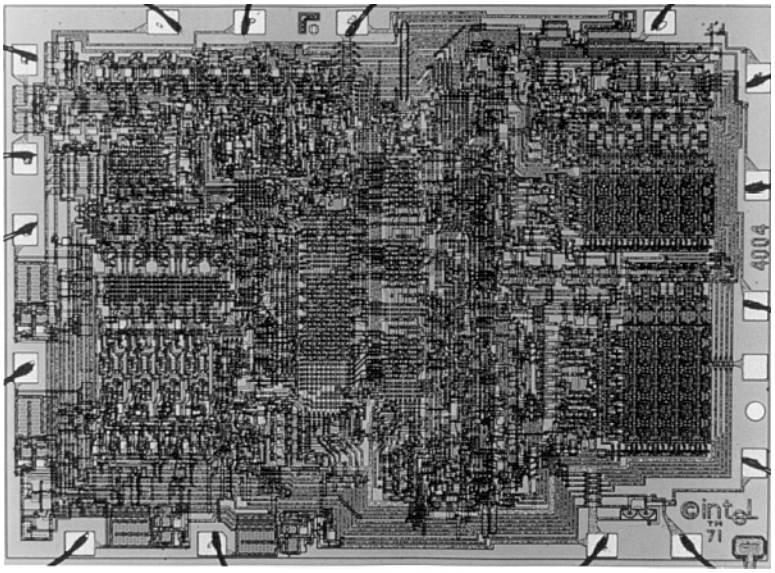

Figure 3.5: A photomicrograph of the Intel 4004 microprocessor.
Photographs are courtesy of Intel Corporation.

Chapter 3 Microprocessors in the 1970's

The creation of the transistor in 1947 and the development of the integrated circuit in 1958/59, is the technology that formed the basis for the microprocessor. Initially the technology only enabled a restricted number of components on a single chip. However this changed significantly in the following years. The technology evolved from Small Scale Integration (SSI) in the early 1960's to Medium Scale Integration (MSI) with a few hundred components in the mid 1960's. By the late 1960's LSI (Large Scale Integration) chips with thousands of components had occurred.

This rapid increase in the number of components in an integrated circuit led to what became known as Moore's Law. The concept of this law was described by Gordon Moore in an article entitled "Cramming More Components Onto Integrated Circuits" in the April 1965 issue of *Electronics* magazine [338]. Moore's Law initially stated that the number of transistors on a semiconductor chip would keep doubling every year. This was later changed to every 18 to 24 months. The "law" has held up remarkably well since 1965 and has had a profound effect on computer technology.

Advanced chip technology enabled Texas Instruments to develop the first electronic calculator in 1967. Then they worked with the Canon company to produce the worlds first pocket calculator, the Pocketronic in April 1971. During this period another company called Intel had entered the semiconductor market.

3.1 ... Intel

The Beginning

Gordon E. Moore and Robert N. Noyce resigned from Fairchild Semiconductor and founded a company called N M Electronics that they incorporated in July 1968. Noyce had been the general manager and was the co-inventor of

the integrated circuit at Fairchild, Moore the director of the research and development laboratory. Arthur Rock and other investors provided venture capital for the company startup. Shortly after, they changed the company name to Intel Corporation, signifying *Int*egrated *el*ectronics. Andrew S. Grove who was assistant director of research and development at Fairchild joined Intel shortly after the founding as director of operations. The company became a public corporation in October 1971.

The initial focus of the company was to develop large scale integrated (LSI) memory chips to replace magnetic core memory. Intel introduced the 1101, a 256 bit MOS static random access memory in September 1969. Then Intel started producing the 1103 chip, the worlds first 1K bit dynamic random access memory (DRAM) in October 1970. This provided significant reductions in the cost of computer memory. However a request for logic chips would change the focus of the company to include microprocessors.

The First Microprocessor (4-Bit)

In April 1969, a Japanese calculator company called Busicom asked Intel to develop a set of at least twelve custom logic chips for a new low cost desk top calculator. Marcian E. "Ted" Hoff evaluated this request and determined that the design configuration proposed by the customer was too complex. Hoff had experience with the DEC PDP-8 architecture and proposed that Intel develop a four-chip set incorporating a general-purpose processor. The processor would accommodate the Busicom calculator BCD (Binary Coded Decimal) requirements and possibly other applications. Intel's executive staff approved the proposal and design proceeded with assistance from associate Stan Mazor. Busicom approved the Intel proposal for a general processor and associated chips in October 1969.

Busicom paid Intel $60,000 to produce the chip family configuration for use in their calculators in early 1970. Federico Faggin who joined Intel in April 1970, did the detailed circuit design and layout of the chips. The final configuration consisted of four 16 pin chips. Those chips were; a 4-bit central processing unit

(CPU), a 256 by 8-bit read only memory (ROM), a 320-bit random access memory (RAM) and a shift register for input/output (I/O). The CPU chip measured one-eighth of an inch wide by one-sixth of an inch long and had about 2,300 transistors. The CPU included a 4-bit parallel adder, sixteen 4-bit registers, an accumulator and a push-down stack on one chip. This CPU chip became known as the 4004 4-bit microprocessor. It had a set of forty five instructions, operated at 108 kilohertz and could execute 60,000 operations a second. Faggin produced working samples in nine months and Intel delivered sets of chips to Busicom in March 1971.

In early 1971, Busicom got into financial difficulties and Intel obtained the design rights for applications other than calculators in return for a lower price on the chips. In mid-November 1971, the first advertisement for a commercially available microprocessor, the Intel 4004 appeared in *Electronic News*. Intel advertised it as the MCS-4 (Micro Computer System 4-bit) family of four integrated chips. The advertisement stated it was "Announcing a new era of integrated electronics... A micro-programmable computer on a chip!" The 4004 CPU chip sold for $200. It was indeed the beginning of a new era, but the 8-bit microprocessor is what started the microcomputer industry.

8-Bit Microprocessors

In late 1969, concurrent with the Busicom development, Computer Terminal Corporation (CTC), which later became Datapoint, contracted with Intel and Texas Instruments to evaluate a set of chips for a new intelligent terminal. Ted Hoff and Stan Mazor analyzed the request and determined that a single 8-bit integrated chip could contain all the logic. Intel initially assigned the chip design to Hal Feeney. Then at the end of 1970 Federico Faggin directed the development of the chip that became the Intel 1201. During the summer of 1971 Datapoint agreed to let Intel use this architecture in exchange for a release from the development charges. Experience with the Intel 4004 microprocessor facilitated adaptation and development of

the 8-bit chip. Intel then changed the number of the 1201 chip to 8008.

Intel introduced the first 8-bit 8008 microprocessor in April 1972 as a family of products, the MCS-8 (Micro Computer System 8-Bit). The 16 pin 8008 had 3,500 transistors and operated at about 0.2 MHz. The microprocessor had a set of 66 instructions, with 45 instructions oriented toward character string handling, six 8-bit general registers and could address 16K bytes of memory. The chip implemented interrupts, however the interrupts worked poorly. This chip with its 8-bit architecture suited the handling of data character processing as compared to the 4004 4-bit microprocessor. It was the first true general purpose microprocessor.

This is the microprocessor that started the microcomputer industry. The earliest microcomputers such as the French Micral in 1973 and the Scelbi-8H and Mark-8 in 1974 used the Intel 8008 microprocessor.

The 4004 and the 8008 chips had started the technology, but a new chip, the 8080 had a more significant impact on the microcomputer market. Federico Faggin proposed the new faster chip and its use of high-performance NMOS (N-channel Metal Oxide Semiconductor) technology as compared to PMOS (P-channel Metal Oxide Semiconductor) used on the 4004 and 8008 microprocessors. Masatoshi Shima who had moved from Busicom headed the design team. Intel approved development in the summer of 1972 and introduced the 8-bit 8080 chip in April 1974.

This new 40 pin chip with 5,000 transistors, operated at 2-3 MHz, could execute 290,000 operations a second, had 111 instructions and could address 64K bytes of memory. The chip offered a tenfold increase in throughput compared to the 8008. It also required only 6 support chips for operation as compared to 20 for the 8008. Intel had an initial price of $360 for the chip in quantities up to 24, with significant discounts on volume purchases.

MITS used this chip on the Altair 8800 in 1975. The microprocessor had a significant impact on the early development of microcomputers. However Motorola and Zilog had now entered the microprocessor marketplace.

The Motorola MC6800 had a single +5-volt power supply requirement and the Zilog Z-80 was faster with more features.

The competitive pressure from Motorola and Zilog resulted in the release of a faster 8-bit microprocessor, the 8085 in November 1976. It had more functions integrated, a 113 instruction set and only required a single 5-volt power supply.

The 8085 was faster but National Semiconductor Corporation had announced the 16-bit Pace microprocessor in 1974. Intel had started a 16-bit microprocessor project but was having problems that resulted in a conservative development schedule.

16-Bit Microprocessors

Management had approved development of a unique 16-bit architecture in late 1974. Then in mid 1975, William W. Lattin who had been the manager of memory and microprocessor products at Motorola, moved to Intel and was put in charge of the design team. The new microprocessor would incorporate a complex multiprocessing architecture that became the 32-bit iAPX 432 (Intel Advanced Processor Architecture) product. However due to product development delays and competitive pressures, Intel released the 8-bit 8085 in 1976 and began a second 16-bit project that became the 8086.

Development of the 8086 microprocessor with a 16-bit architecture started in 1976. Jean Claude Cornet was assigned to manage the project and William B. Pohlman who had managed the 8085 design was also the leader for the 8086 design team. Stephen P. Morse defined the microprocessor architecture and created it as an extension of the 8080 architecture to provide software compatibility. Intel introduced the 8086 with ten times the performance of the 8080 in June 1978.

The chip has 29,000 transistors with a minimum feature size of 3 microns and at a clock speed of 5 MHz it has a rating of 0.33 MIPS (million instructions per second). The instruction set is an expanded version of the 8080 with 133 instructions. Memory addressability is 1 megabyte and the microprocessor is available at clock

frequencies of 5, 8 and 10 MHz. The price at launch was $360.

Intel introduced the 8088 microprocessor in June 1979. It has a 16-bit internal architecture with an 8-bit external data bus. This 8-bit external data bus allowed for a simpler interfacing to the rest of the system. The number of transistors and operating characteristics is similar to the 8086. The memory addressability is 1 megabyte and the microprocessor is available at clock frequencies of 5 and 8 MHz.

IBM selected this microprocessor for the PC computer announced in August 1981. This computer became a dominant product in the personal computer marketplace of the early 1980's, and was crucial in helping to position Intel as a major supplier of microprocessors.

An *IEEE Micro* article entitled "A History of Microprocessor Development at Intel" [342] and an Intel publication entitled "A Revolution in Progress: A History of Intel to Date" [48] provide additional details on Intel microprocessors and a history of the company. Intel had pioneered the introduction of microprocessors. However other companies had entered the marketplace with competing products. One of the other dominant companies was Motorola.

3.2 ... Motorola

Paul V. Galvin founded the Galvin Manufacturing Corporation in Chicago, in 1928. Then the company name changed to Motorola, Inc., in 1947. Following the name change and the invention of the transistor in 1947, the company opened a research laboratory in 1950, in Phoenix, Arizona to explore solid-state electronics. Motorola is now a major supplier of discreet semiconductors, integrated circuits and microprocessors.

Motorola introduced the 8-bit MC6800 MPU (Micro Processor Unit) in mid-1974. Principals in the design of the microprocessor and peripheral chips were Charles Melear and Chuck Peddle. The MC6800 used six-micron NMOS technology, contained 4,000 transistors and was the

first microprocessor to require a single 5-volts power supply. This simplification of the power supply requirements and the related Motorola family of chips lowered product costs. Some early microcomputers using this chip were the MITS Altair 680B, Sphere and SwTPC 6800.

Motorola introduced the MC6801 in 1978, as "the world's first 35,000-transistor single-chip microcomputer." This microcomputer system had ROM/EPROM, RAM, I/O, timer, clock and CPU. The MC6809 was a microprocessor with an 8-bit external bus that processed data internally in 16-bit words. Motorola announced the microprocessor in 1978. Apple Computer selected this chip for the initial Macintosh computer design in 1979.

The MC68000 was the first of the MC68000 family of 16/32-bit microprocessors. Principals in the design were Tom Gunter and Gene Schriber. The MC68000 has 61 instructions and a capability of two million instructions per second (MIPS). The chip had 68,000 transistors. It can address 16 megabytes directly and 64 megabytes through functional segmentation. It has a 16-bit data bus that processed data internally in 32-bit words. Motorola introduced the MC68000 in 1979. Motorola also released an 8-bit external data bus version, the 68008.

This microprocessor had a significant impact in the marketplace. Apple Computer selected the MC68000 for the Lisa computer, with the processor operating at 5 MHz, and for the final design of the Macintosh personal computer, with the processor operating at 7.83 MHz.

Motorola and Intel became two dominant designers and suppliers of microprocessors for microcomputers in the 1970's. However the other company that played a significant role in the introduction of the microprocessor was Texas Instruments.

3.3 ... Texas Instruments

J. Clarence Karcher and Eugene McDermott founded Geophysical Service as a partnership in May 1930. The company name changed to Coronado Corporation, with Geophysical Service, Inc., (GSI) as a subsidiary in January 1939. Cecil H. Green, J. Erik Jonsson, Eugene McDermott, H. B. Peacock and others purchased the GSI subsidiary in 1941. The Coronado Corporation dissolved in 1945 and GSI's name changed to Texas Instruments, Inc., in 1951.

Texas Instruments (TI) obtained a license for the manufacture of transistors in May 1952 and aggressively expanded its semiconductor business during the 1950's. Jack St. Claire Kilby of TI co-developed the integrated circuit in 1958. During the 1960's TI was a significant supplier of chips for consumer products such as calculators, watches and toys.

Computer Terminal Corporation (CTC), which later became Datapoint, contracted with Texas Instruments (and Intel) to evaluate a set of chips for a new intelligent terminal in late 1969. This requirement resulted in TI developing and submitting a single-chip microprocessor to CTC.

TI has stated in company literature that it invented the single-chip microprocessor in 1970. The company applied for a patent in 1971 with the invention being credited to Gary W. Boone an Michael Cochran (the patent was approved in February 1978). The company described their invention as a "microcomputer --the first integrated circuit with all the elements of a complete computer on a single chip of silicon" [178]. TI advertised the integrated circuit developed for the Datapoint terminal in the *Electronics* magazine with the caption "CPU on a chip" in June 1971. This was the first announcement of a single-chip microprocessor. TI had functional problems with the chip and never marketed it. However, it did lead to the subsequent development of the TMS1000 microprocessor.

TI released the TMS1000 4-bit microprocessor in 1974. The chip had a set of 43 instructions and included

a 256-bit RAM for data storage and an 8,192-bit ROM for program storage. The chip was used mainly in low-cost embedded applications. TI announced the TMS9000 series of 16-bit microprocessors in the spring of 1976, then the TI 9980 in the late 1970's. The TI 9980 had an 8-bit external bus but processed data internally in 16-bit words. Texas Instruments used the TMS9900 microprocessor in the TI-99/4 microcomputer released in 1979. However the computer was not successful and TI discontinued it in 1983.

Texas Instruments failed to penetrate the microcomputer market and concentrated in other applications. Texas Instruments is a leading supplier of 4-bit microprocessors for games, toys and low-end controller applications. However a number of other companies had entered the microprocessor market.

3.4 ... Other Companies

A number of other companies produced microprocessors in the 1970's. However two companies produced products that had a significant impact on the microcomputer market. Those two companies were MOS Technology and Zilog.

MOS Technology

In July 1975, MOS Technology, Inc., started advertising the 8-bit 6501 microprocessor that would be compatible with the Motorola MC6800 and would cost only $20. Chuck Peddle who had left Motorola and joined MOS Technology was a principal in the design of the microprocessor. Motorola subsequently forced the company to withdraw the 6501 because of technology infringements.

However MOS was also developing another chip, the 8-bit 6502 with additional features that would only cost $25. The chip had approximately 9,000 transistors. This pricing had a significant effect on the lowering of prices for microprocessors at both Intel and Motorola. This reduction in the cost of microprocessors resulted in additional impetus to the development of the

microcomputer. MOS sold the new 6502 microprocessor at the WESCON show in September 1975.

The MOS 6502 microprocessor had a significant impact on the early microcomputer market. The Apple II, Atari 400 and 800 and Commodore PET microcomputers used the chip. Commodore International purchased MOS Technology in October 1976.

Zilog Inc.

In the summer of 1974, Federico Faggin and Ralph Ungermann decided to leave Intel and founded Zilog Inc., in November. Zilog is an acronym for the "last word (Z) in integrated (i) logic (log)." Shortly after the founding, the powerful oil corporation Exxon, invested $1.5 million in Zilog for a 51 percent controlling interest in the company. Faggin and Ungermann developed ideas for a new microprocessor and family of components that would be compatible and more powerful than the Intel 8080. Assisting in the design effort was Masatoshi Shima who had also left Intel and joined Zilog. It would be faster, have more features, registers and instructions than the 8080.

Zilog announced the Z-80 microprocessor in 1975 and it became available in February 1976. It operated at 2.5 MHz, could address 64K bytes of memory and incorporated the 8080's instruction set within 158 instructions. The chip had 8,500 transistors and was manufactured by the Mostek company. The Z-80 with a low price of $200, became a successful alternative to the Intel 8080. Zilog announced a faster 4 MHz version of the chip, the Z-80A in February 1977. A number of early microcomputers such as the Radio Shack TRS-80 used the Z-80.

The Z-8000 was a 16-bit microprocessor with 17,500 transistors and 110 instructions. The memory address capability was 48 megabytes in six segments of eight megabytes and the operating speed was 2.5 to 3.9 MHz. Zilog priced the microprocessor at $195 for small quantities and announced it in early 1979. The instruction set was not compatible with the Z-80 and other design problems prevented it from becoming successful.

Other Sources

A number of other companies became second sources for the major suppliers. The following are some of the more significant suppliers.

Walter Jeremiah (Jerry) Sanders was a principal in the founding of Advanced Micro Devices (AMD), Inc., with seven other Fairchild personnel in mid 1969. Sanders had worked for Motorola then Fairchild Semiconductor where he became sales and marketing director. AMD had an initial orientation as a second source for other manufacturers chips by creating an equivalent design or by obtaining a license agreement from the other company. Early license agreements were with Intel for the 8085 microprocessor and with Zilog for the Z-8000. AMD became a public company in September 1972 and the Siemans AG company made an investment of $30 million for nearly 20 percent of AMD in late 1977.

Hewlett-Packard developed a proprietary microprocessor in the late 1970's. This microprocessor was used in the company's HP-85 personal computer released in 1980.

Mostek was founded by L. J. Sevin and subsequently became a subsidiary of United Technologies. It was a major supplier of semiconductor memory chips and a second source for other company's microprocessors such as the Zilog Z-80.

National Semiconductor Corporation was founded in 1959. Charles E. Sporck who had been at Fairchild Semiconductor joined the company in 1968, became the president and a significant contributor to the success of the company. The company offered microprocessor systems on a 8.5 by 11-inch PC card. The IMP-8 was an 8-bit microprocessor system and the IMP-16 was a 16-bit microprocessor system available in 1973. Then National Semiconductor announced the first 16-bit single chip microprocessor, called the Pace in 1974. A faster microprocessor called the Super-Pace followed. The SC/MP was an early 8-bit microprocessor developed by National.

RCA introduced the 1802, the first complementary metal oxide semiconductor (CMOS) 8-bit microprocessor in 1974, that was followed by the 1804 microprocessor.

Rockwell introduced the PPS-4 that was a 4-bit parallel processor in late 1972. It had a 50 instruction set. Rockwell subsequently released the PPS-8.

Signetics Corporation was founded by four Fairchild Semiconductor executives in 1961. The company name is an acronym for "Signal Network Electronics." The company shipped an 8-bit Programmable Integrated Processor (PIP) in 1974 that had more than 64 instructions. The Signetics 2650, is another processor available from the company around 1978. Signetics was also a second source for microprocessors to companies such as Motorola.

3.5 ... Miscellaneous

Patent Controversy

During the 1960's and early 1970's, integrated circuit technology continued to improve the capability of integrating a larger number of circuit elements. This evolved to consideration by some in the industry of possibly creating a central processor unit (CPU) on a single chip. However the assignment of credit for the invention of the microprocessor and the awarding of patents for it have been controversial. Companies such as Intel and Texas Instruments and entrepreneur Gilbert Hyatt are principals in the controversy.

According to Gilbert Hyatt he built his first breadboard concept of a small computer in 1968, trademarked the term "microcomputer" and started a company called Micro Computer Inc (MCI). Hyatt made application for a broad patent with a title "Data Processing System" in 1969. The application was rejected by the U.S. Patent Office. This was appealed by Hyatt and in December 1970 the Patent Office accepted a new application with a title "Factored Data Processing System for Dedicated applications." Hyatt continued working on printed circuit prototypes but did not demonstrate or prove that his concept was practical. In question was Hyatt's ability to implement the patent on a single chip at the time of the patent application. At that time the technological capabilities were just

evolving and Hyatt had not created his concepts on a single integrated chip. In September 1971, Hyatt's Micro Computer company went out of business. Hyatt continued to have problems with his patent application that resulted in further appeals and changes to the application. Then in July 1990, the U.S. Patent Office awarded Hyatt a patent that now had a title of "Single Chip Integrated Circuit Computer Architecture." This immediately created significant controversy in the industry. However in June 1996, the patent was overturned.

Between 1969 and March 1971, Intel conceived and developed the 4004 microprocessor as described in Section 3.1. Intel did not consider that they had developed a unique patentable device, but had merely extended existing technology. This rather casual approach resulted in Intel not filing a patent application for the microprocessor. Ted Hoff has stated that he published an article in March 1970 describing the feasibility of building a central processor on a chip. This in essence placed the concept of a microprocessor in the public domain, thereby precluding a viable patent application.

Texas Instruments has stated that it invented the single-chip microprocessor in 1970 as described in Section 3.3. However TI withdrew their microprocessor due to functional problems and the following products were not accepted by any major microcomputer manufacturer. As stated previously TI has been a major supplier of microprocessors for consumer products.

The Texas Instrument patent that was approved by the U.S. Patent Office in 1978 has not been successfully contested. However Hyatt's patent that was approved by the U.S. Patent Office in July 1990 was overturned in 1996. Neither of these patents has affected Intel which became the dominant supplier of microprocessors for personal computers.

An article in *Byte* magazine "Micro, Micro: Who Made the Micro?" details the patent controversy with interviews of Hyatt, Hoff and Faggin [328]. Some additional comments by Federico Faggin are in another *Byte* magazine article, "The Birth of the Microprocessor"

[331] and in a *Popular Science* article "Gilbert Who?" [324].

References

A further article in *Byte* magazine entitled "Evolution of the Microprocessor" provides an informal history [333]. The *IEEE Micro* article entitled "A History of Microprocessor Development at Intel" provides some details of developments at other companies [342]. The *Encyclopedia of Microcomputers*, "Architecture of Microprocessors," Vol. 1, pages 269-282 [236] contains an extensive bibliography.

Conclusion

A number of companies became second sources for different manufacturers. For instance Synertek and Rockwell International produced the 6500 series of microprocessors designed by MOS Technology. Solid state technology had made significant advances during the 1970's. The integrated circuit enabled the development of low-cost memory chips and the microprocessor. These are the developments that resulted in the personal computing transition to microcomputers.