CHAPTER

1

MOS Technology

1974 to 1976

Hi-tech companies need three players in order to succeed: a financier, a technology-God, and a juggernaut with a type-A personality. Commodore would require these three ingredients to take them to a new level. They had Irving Gould, with his financial expertise and deep pockets. They had Jack, so aggressive people sometimes referred to him as the scariest man alive. All Commodore needed was a visionary engineer to take Commodore into a new field of technology.

The Grey Wizard of the East

In the 1970's, the image of a computer genius was not in the mold of the young hacker we are familiar with today. Teenaged tycoons like Bill Gates had not filtered into the public consciousness, and *WarGames* (1983, MGM) was not yet released, with the prototypical computer hacker portrayed by Matthew Broderick. The accepted image of a technological genius was a middle-aged man with graying hair and glasses, preferably wearing a long white lab coat.

Chuck Peddle was the image of a technology wizard, with his wire-frame glasses, white receding hairline, and slightly crooked teeth. At two hundred and fifty pounds, the five foot eleven inch engineer always struggled with his weight. Peddle describes himself at that time as “totally out of shape,” but he was characteristically optimistic and never without a joke or story to tell.

Peddle possessed the ability to see further into the future than most of his contemporaries and he obsessively searched for the next big innovation. His mind was always active, sometimes to the point of causing sleep deprivation. “I don’t sleep much,” says Peddle. “Never did.” In fact, the pattern of sleeplessness went back to his earliest days.

Peddle’s father was one of 21 kids. His family originated in the Canadian Maritimes but the poor region made it difficult to support a family. “The whole area is very depressed,” says Peddle. The family moved to the United States in search of a better economy.

Charles Peddle was born in Bangor Maine in 1937, one of eight children. “My mother said that when I was young I used to lie awake in my crib. I would cry and fuss and didn’t sleep as much as the other kids,” he says.

Peddle was raised in the state capital of Augusta, Maine, with a population of just over 20,000. Unfortunately, the move from the Maritimes to Maine only marginally improved the family prospects. “There is a tremendous amount of leakage across the border [from the Maritimes],” he says. “People are willing to work for nothing because they are starving to death at home. So it keeps wages down [in Maine] and it’s always been a poor state.”

In his senior year of high school, Chuck thought he found his calling. “In high school I worked in a radio station,” he says. “I really wanted to be a radio announcer. For you, now, that really doesn’t mean very much, but back then that was pre-TV and radio announcers were big.”

Nearing the end of high school, Chuck traveled to Boston to try out for a scholarship in broadcasting. For the first time in his life, he saw his competition and realized he did not have enough natural talent. With a sense of relief, he recalls, “I failed as a radio announcer.” Returning to Augusta, Chuck talked things over with the radio station owner, who told him, “I’ll employ you as a radio announcer, but you will always be stuck in Maine because you are not good enough.”

Peddle spent some time in the military as he contemplated his future. “I went into the Marine Corps just before I got out of high-school in 1955 and I went in active reserves in 1960,” he recalls.

During this time, Peddle’s former science teacher recognized a gift in Peddle and encouraged him to enter engineering. Peddle listened to his advice, but was unsure he wanted to enter the sciences.

“I didn’t want a pick and shovel job,” he says. “I wasn’t sure what I was going to do and I was dirt poor. Luckily, in Maine you can be dirt poor and still get by.” Unable to earn enough to pay for tuition fees, he applied for student loans.

At the end of summer, Peddle entered the *University of Maine* and enrolled in engineering and business courses. “When I started, I didn’t have a clue what I wanted to do. I just knew I didn’t want to do pick and shovel jobs anymore," he says. Partway through the first year, the university required students to choose a discipline. "I really loved physics, so I took engineering physics with an electrical minor."

Peddle remembers the dismal state of computing. "There wasn't a computer on campus, nor was there anyone on the campus who was computer literate," he says. In his final year, things began to change. "On the entire campus, there was one analogue computer, which had been bought in the last four months," he recalls. "The analogue computer was so primitive and they didn't know how to use it. There was zero knowledge about computers on that campus."

Peddle received a standard education in engineering, devoid of computers. Over 200 miles away, at the Massachusetts Institute of Technology (MIT), a revolution was occurring which would soon change his situation.

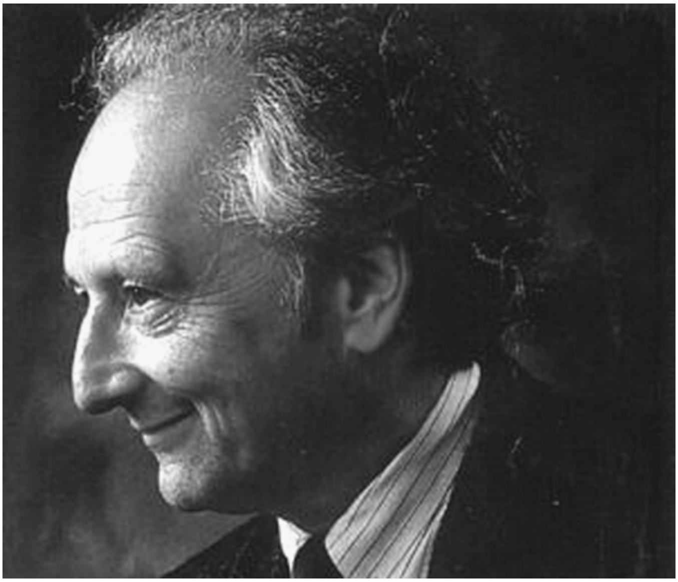
Chuck Peddle's main influence was the legendary inventor and mathematician, Claude Elwood Shannon. Though virtually unknown to the world, Shannon was the founding father of the modern electronic communications age. Shannon was an eccentric, who terrified people by riding his unicycle through the hallways at night while juggling.

Shannon also built a reputation for inventions that were of little practical value to anyone. Over the years, he filled his beachside house with juggling robots, maze-solving robot mice, chess playing programs, mind-reading machines, and an electric chair to transport his children down to the lake.

In 1948, while working at *Bell Labs*, Shannon produced a groundbreaking paper, *A Mathematical Theory of Communication*. In it, Shannon rigorously analyzed the concept of Information Theory and how we transmit pictures, words, sounds, and other media using a stream of 1's and 0's. Chuck Peddle was enchanted with Shannon's theories. "Today, you take this for granted, but you have to remember that someone had to dream all this up," he says. "Shannon was one of those guys that dreamed up from nothing the idea of the way information goes back and forth. Everyone else's work stands on his shoulders and most people don't even know it."

In 1958, Shannon returned to MIT at Lincoln Labs as a lecturer and Artificial Intelligence researcher. While there, he spread his concepts on Information Theory. "He changed the world," says Peddle. "Shannon was not only a pioneer but a prophet. He effectively developed a following, almost like a cult." One of Shannon's cultists would soon spread the word to the University of Maine.

During Peddle's senior year, the University of Maine accepted a lecturer from MIT who studied under Claude Shannon. According to Peddle, "He had a nervous breakdown, so he left MIT. The University of Maine was so happy to get him because he was so superior to the type of instructor they could normally get. They gave him the opportunity to teach only four classes per week between the hours of eleven o'clock and noon. The guy was being totally babied and should have been since he was a great instructor. He decided to put together a class to teach people about Information Theory."



Chuck Peddle, father of the 6502 (Das neue P.M. Computerheft).

At the time, Peddle was enrolling for his final year and the Information Theory class happened to fit into his schedule. As Peddle recalls, "It changed my life."

The class began with the instructor discussing the eyes and ears as the primary sensors for receiving information. "He started teaching us about Boolean algebra and binary logic, and the concept of Information Theory," recalls Peddle. "I just fell in love. This was where I was going to spend my life."

"The whole thing about how information moves back and forth is essential to almost everything I've done," he says. However, the topic that interested Peddle the most was computers. "You have to understand how exciting it was," explains Peddle. "Information Theory was interesting, and I've used it from time to time, but the computer stuff this guy taught me was life changing."

Though this new revelation came late, Peddle immersed himself in computer theory for his final year. “I got an A on my senior paper in physics class by giving a discussion on binary and Boolean arithmetic. I was trying to build an and-gate in my senior class [from early transistors] and the top electrical engineers on campus couldn’t help me figure out the structures and why my and-gate didn’t work,” he recalls. Peddle and a friend even tried growing a transistor crystal but soon gave up.

As graduation approached, Peddle began searching for a place of permanent employment. He had married while in College and already had a family. “I came out of college and I had three kids; two and a half, actually. I had the third one right after [graduation].” The new responsibilities motivated Peddle to find a better life.

Peddle knew he wanted to live in California and he wanted to work in computers. “I only interviewed computer companies,” he recalls. “At all of the companies of any size, like GE and RCA, you went to work on a training program for a year or two. You really were just interviewing to join their training program.”

Of all the companies, GE made the best impression on Peddle. “I kind of fell in love with GE,” he says. “When I got my offer, I thought I would take it, because they had such a good training program.”

Peddle and his young family moved to California to start a new life with General Electric. Before long, Peddle was working at GE’s computing facility in Phoenix, Arizona. Peddle worked with massive mainframe computers, similar to those seen in the 1965 film *Alphaville*. The first computer Peddle used was a GE-225, which he describes as a “very old, very slow machine with small capacity.”

Peddle entered programs into the GE-225 computer by feeding a stack of punch cards into a card reader. Peddle recalls, “I would set up long six or seven hour runs, drive across the city and go to bed with the instructions, ‘If this breaks, call me.’ People would wake me up in the middle of the night, I would find a solution in ten minutes and go back to sleep.”

In 1961, Peddle and two of his coworkers developed the concept for variable sector disk formatting. They even filed a patent for their idea. Years later, Peddle would use this idea to give Commodore disk drives more data storage than the competition.

In 1963, John G. Kemeny developed the *Basic* computer language at Dartmouth College in New Hampshire, along with Tom Kurtz. They developed Basic for the GE-235 mainframe computer, and as a result, Peddle was almost immediately aware of it. “I taught Basic the day after it was invented," claims Peddle. "I got one of the original Basic manuals from a guy in Dartmouth and taught my people in Phoenix."

A year later, Kemeny and Kurtz created the revolutionary *Dartmouth Time-Sharing System* (DTSS) for the GE-235. With the time-sharing system, multiple users could interact with the mainframe computer simultaneously using terminals. General Electric immediately recognized the value of this new system and used it to form the basis of a new multi-million dollar business. "Two years later, GE goes into the time-sharing business," recalls Peddle. "They're selling time-sharing to everybody and GE was selling more computers than they could build. It was a big goddamned deal."

GE-225 Mainframe Computer System (photo courtesy of GE).

With the time-sharing business suddenly ballooning, General Electric sent Peddle to their largest computing center in Evendale, Ohio to set up time-sharing systems for General Electric's jet engine business. The massive computer facility contained ten IBM-7094 mainframe systems, five GE-600's, and 25 GE-225's. Peddle recalls, "We were running time-sharing for about 4000 engineers and programmers." The refrigerated computing facility seemed futuristic in the mid-sixties, with white tiled walls, raised floors, and rows and rows of mainframe computers.

Setting up the time-sharing systems was time consuming, and Peddle often stayed at the computer facility around the clock. During this time, Peddle picked up a habit originated by GE founder Thomas Edison. "I stole the idea of cots from him," he says. "Everyone understood that if I'm tired, I go to my office and take a half hour nap."

After Peddle set up the time-sharing systems, he became administrator for two of the systems. The experience gave Peddle valuable knowledge that he would later use to develop his own computers. “I got a really good understanding of what worked on time-sharing and what didn’t work, and what people wanted,” he says.

While working with GE, Chuck met John Pavinen and Mort Jaffe, computer pioneers who would later become involved with him at Commodore. “John Pavinen was my manager at GE. He’s the guy who put GE in the computer business,” says Peddle. “A lot of the pioneers in the computer industry came out of GE.”

Peddle also remembers some darker moments in the computer scene. “People used to be able to get their hands on computers,” he recalls. “Then, in the late 60’s and early 70’s, there was a big revolt against technology. People were attacking computer centers with axes, claiming computers were taking over our lives. We’re talking about serious hippy-type stuff. So all of the computer rooms locked the doors.”

The need for security drastically reduced the freedom people previously enjoyed. “If you wanted to get a computer run, you walked up with your punch cards and left them on someone’s desk,” says Peddle. “They went from these time-sharing friendly, I-can-do-everything systems to having zero access to the computer.” Peddle detected a strong demand from users to own their own computers.

The time-sharing business Peddle helped develop at GE was phenomenally successful, but in the late sixties, it started failing due to increased competition. By this time, Peddle had risen to a high-level management position. GE sent him to Phoenix to start another time-sharing company. Suddenly, “Time-sharing crashed; out of business; goodbye,” says Peddle. “Companies started figuring out how much money they were spending on these time-sharing services and it was millions. GE was just cleaning up, but it just wasn’t cost effective the way it was being done, so companies kept cutting it off and they moved the computers internally.”

GE gave Peddle an assignment to work on cash registers, which made Peddle start to think about the concept of distributed intelligence. At the time, shared computing kept the brains of the computer at one central location and people could only interact with the computer system using dumb-terminals (a keyboard and monitor).

Peddle envisioned distributed intelligence, where he would transform the dumb-terminal into an intelligent-terminal that could have a printer connected to it, or other peripherals and data entry devices. “I sat down and derived the principles of distributed intelligence during a four-month period,” says Peddle. “There was a focus on five or six stations around a minicomputer in a centralized architecture. My concept was you moved the intelligence to the place where you used it." It was a step towards networked computers.

"Then I started trying to teach GE about it," says Peddle. Unfortunately, in 1970 GE decided they were no longer interested in computers. "I was getting nowhere with GE because they were getting ready to sell the computer business. Two months later, they sold the company to Honeywell."

Peddle had the option to receive a severance package or move elsewhere in GE. For Peddle, the decision was easy. "Myself and two other guys took the termination agreement. We said, 'This is found money, so we're going to start our own business.' We had already started on the cash register business, and I had a deal with *Exxon*."

The three partners immersed themselves in their intelligent-terminals. "We got it all done and actually built the electronics that demonstrated the concepts," says Peddle.

During this time, Peddle devised many concepts that would have made him wealthy if he chose to patent them. "We invented the credit-card driven gasoline pump, the first credit verification terminal [i.e. credit card scanners] and the first point of sale terminal [i.e. computerized cash registers]." Peddle now laments, "It's too bad we didn't patent the shit out of it because we could have been very wealthy as a result of that."

Peddle realized the intelligent terminal needed a fundamentally new component to make their ideas work. "We needed our own microprocessor," he says. This realization would lead Peddle on an extraordinary journey that would change millions of lives.

At first, Peddle tried to develop the technology within his fledgling company but it was hopeless without funding. "We had everything going for us, but we didn't know how to raise money," he says. It was time for Peddle and his team to move on.

Chuck Peddle and his wife now had four children, but the stresses of Peddle leaving his secure job at GE caused the marriage to disintegrate. They divorced in 1971. "I put a bag of clothes in my [Austin-Healey] Sprite and drove away," he says. Within weeks, in what Peddle terms a 'planned transition', Peddle remarried a voluptuous blonde with two children from a previous marriage.

"I took some time out, because there was a change in life; going through the divorce and all that," says Peddle. In 1972, Peddle tried to start a Word Processing company using *Digital Equipment Corporation* (DEC) time-sharing systems. "We actually did the first on-line text processing system, setting type for newspapers," he says. Peddle was too early. "That company couldn't make it either."

The experience gave Peddle valuable knowledge he would need to develop the next generation of microprocessors. “I had done all the microelectronics and knew why a microprocessor needed to happen, and how to make a microprocessor, and how to make things that used microprocessors,” he says. “But I didn’t have a microprocessor because they weren’t around yet.”

In 1973, Peddle spotted an employment ad from *Motorola* for their new microprocessor program in Mesa, Arizona. He recalls, “I went down and talked to the guy who was running the program, who was a calculator guy.” Peddle’s experience at GE won him the job. “He basically hired me to finish the program.”

Chuck started work at Motorola in 1973, around the time when Large Scale Integration (LSI) of semiconductor technology allowed the circuitry of a calculator or computer to fit onto a single chip. As the Intel 4004 and 8008 processors were gaining popularity, Motorola decided to enter the microprocessor market with their own chips.

A Motorola designer named Tom Bennett created the original architecture for the 6800, but Peddle felt it needed some changes. “They kind of muddled their way through the architecture for the 6800, which had some flaws in it. I was able to fix some of those flaws but it was too late for others,” says Peddle. The final 8-bit microprocessor had 40 pins, 4000 transistors and an instruction set of 107 operations.

Peddle also made a major contribution to the project by designing the support chips for the 6800. Computers had to interact with peripheral devices like disk drives and printers, so Peddle designed a specialized support chips for this purpose. One chip to emerge was the 6820 Peripheral Interface Adapter, which most people just called the PIA chip. The 6820 became a major reason for the eventual popularity of the 6800.

Although Motorola engineers grasped the importance of what they had created, the management and salespeople knew very little of microprocessors. According to Peddle, some managers at Motorola even tried to kill the project. “So I built a demo of the chip using some of the hardware for my cash register to show everybody that microprocessors really did work,” he says.

The salespeople at Motorola required an education on microprocessors but there were no courses. “They didn't know how to sell it, so I put together a training class for their applications engineers,” says Peddle.

Peddle was instrumental in making some of the first deals for Motorola, including *Tektronics*, *NCR* (National Cash Register company), *Ford Motor Company*, *Unisys*, and *Burroughs* (makers of calculators). “I wound up going into the field presenting the architecture because I was the only one in the company who could intelligently talk to customers and have architectural discussions," he says.

The presentations usually ended the same way. "The guys would sit down, we would explain the 6800, and they would just fucking fall in love," says Peddle. However, the $300 price tag for a single 6800 processor prevented engineers from adopting the 6800 microprocessor in low cost products.

According to Peddle, someone would invariably say, "You're charging too much for it. What I want to use it for is not to replace a minicomputer. I want to use it to replace a controller, but at $300 per device it's not cost effective."

Armed with this knowledge, Chuck Peddle had an epiphany. He recognized the vast market for cost-reduced microprocessors. Both Intel and Motorola were overlooking an important market. Peddle slavered at the possibilities.

In August 1974, Motorola publicly introduced the 6800 chip for $300. The 6800 would eventually become successful for Motorola, in no small part to the efforts of Chuck Peddle. It almost became too successful and Motorola saw no reason to attack other markets.

Peddle pushed Motorola for a cost-reduced microprocessor. According to Peddle, "One week I returned to Motorola after one of these trips, and I had a letter there, formally instructing me Motorola was not going to follow a cost reduced product. I was ordered to stop working on it," recalls Peddle. Undeterred, Peddle wrote a letter (which he still owns today) saying, "This is product abandonment, therefore I am going to pursue this idea on my own. You don't have any rights to it because this letter says you don't want it." From that moment on, Peddle stopped working on microprocessors for Motorola. He continued teaching classes and finished the 6520 PIA chip he was developing, but his true focus was finding a way to make his low-cost microprocessor.

While still employed at Motorola, Peddle tried raising money to fund his microprocessor. He visited *Mostek* (not to be confused with MOS Technology) and talked to prominent venture capitalist L.J. Sevin of Sevin-Rosen[1], but he was not interested in Peddle's idea. Peddle continued talking to people in the semiconductor business.

One day, Peddle ran into an old friend from GE who now worked at Ford Motor Company. His friend mentioned John Pavinen, another ex-GE employee who was now running a semiconductor company near

[1] L. J. Sevin is responsible for funding startups like Compaq, Lotus, Cyprus, and Mostek.

Valley Forge, Pennsylvania. “When I started looking around for partners, I knew Pavinen was a killer computer guy,” he recalls. “I called him up. He said, ‘Come on down. Let’s talk about it.’”

Peddle flew to Pennsylvania to examine MOS Technology. The facility was located at 950 Rittenhouse Road, a 14-acre site in an industrial park, called the *Valley Forge Corporate Center*. Peddle was impressed with the small firm. It had good credentials and many customers, among them a calculator company named Commodore.

Satisfied, Peddle sat down to discuss his new project with John Pavinen. “Pavinen immediately loved the idea of doing the product,” says Peddle. The two discussed the specifications for the microprocessor, but MOS Technology was only capable of manufacturing chips using the P-channel process. Peddle wanted the more advanced N-channel process.

Pavinen felt he could deliver the N-channel process. “He had taught himself process development when he was working at General Instrument, and was really good at it,” says Peddle. “He considered himself to be a competitor to [Andrew] Grove [of Intel]. He was convinced he could do a five-volt N-channel process in the same amount of time it would take me to develop the microprocessor.”

The partnership between Chuck Peddle and John Pavinen seemed to hold promise. For his part, Pavinen badly needed a new product to replace the shrinking calculator market. MOS Technology engineer Al Charpentier describes the situation that caused MOS Technology to accept Chuck Peddle’s proposal. “Here’s a company that is somewhat dying, and the calculator margins are shrinking,” he says. “They wanted market share.”

Pavinen told Peddle, “Move your people and we’ll set up a second group within the company. You run your own show.”

As Motorola publicly unveiled the 6800, Chuck Peddle and seven coworkers from the engineering and marketing department left Motorola to pursue their own vision. The team included Will Mathis, Bill Mensch, Rod Orgill, Ray Hirt, Harry Bawcum, Mike James, Terry Holt[2], and Chuck Peddle. The departure of several of Motorola’s top engineers seriously drained the company of much needed expertise on the eve of the 6800 debut.

Pavinen gave Peddle and his team a stake in the company. “The deal was, if the microprocessor took off, we would have a piece of the company,” he recalls.

---

[2] Terry Holt later became president of S3, a semiconductor company that supplied a popular all-in-one chipset for IBM PC compatible computers.

On August 19, 1974, the team started work on their new processor at MOS Technology. With Chuck Peddle and his band of engineers, MOS Technology would radically change the market for computers.

MOS Technology

In 1969, a large industrial manufacturing company called *Allen-Bradley* wanted to enter the new semiconductor business. They financed the creation of MOS Technology. The three men who founded and operated the new startup had previously worked with Peddle at GE. They were Mort Jaffe, Don McLaughlin, and John Pavinen.

For the first five years, MOS Technology supplied calculator chips and other semiconductor parts to the electronics industry. Then Chuck Peddle and his team of ex-Motorola employees began working on a revolution within the microprocessor industry.

This revolution would occur at Valley Forge, Pennsylvania on the East Coast, approximately 100 miles inland from the Atlantic Ocean and 20 miles from Philadelphia. It was an appropriate place for a revolution. Almost 200 years earlier, Valley Forge was the turning point in the American Revolution when General George Washington's tired and bloodied troops retreated to Valley Forge for the winter, only to emerge with an unwavering offensive. Chuck and his band of engineers would also retreat for the winter, and in the following summer, they would unleash a powerful new weapon.

In the seventies, Valley Forge was a small, dispersed town with a population of about 400 people. MOS Technology headquarters resided in the peaceful setting, along a lone country road surrounded by wildlife. Street names like Adams Avenue, Monroe Boulevard, Madison Avenue, and Jefferson Avenue celebrated the revolutionary past. Directly across the road from MOS was a beautiful golf course, *General Washington Country Club*, tempting the MOS executives to squeeze in a round of play. Less than a mile away was the *Audubon Wildlife Sanctuary*, a park filled with serene trails where Canadian geese gathered in the fall while migrating south. Horse trails snaked in and out of the surrounding countryside. Riders would often emerge from the bushes and stare at this out of place high-tech firm. They could scarcely understand what was going on inside.

The headquarters hearkened back to the 1950's. It was a box-shaped two-story building with glass windows along the front and sides. Stray golf balls frequently bounced off the front windows, occasionally leaving small bullet sized holes that no one ever repaired. To the side and rear of the building were two huge parking lots, largely deserted since most people preferred to use the circular driveway out front.

The engineering lab on the second floor was the fountainhead of ideas for the company. This was where engineers invented the semiconductor chips. The engineers subdivided the lab into a maze of smaller rooms, each with a specific task. It was in this environment that Chuck Peddle would plan the centerpiece of his revolution.

Although Peddle envisioned a true microprocessor, it is a delicious irony that he did not design it for computers. "It was never intended to be a computer device. Never in a million years," he reveals. Instead, he envisioned the microprocessor for home electronics, home appliances, automobiles, industrial machines – just about everywhere except personal computers. "If we were going to do a computer, we would have done something else."

Price was the key to achieving widespread use of his microprocessor. Peddle envisioned a series of processors of varying size and complexity. The full featured microprocessor would sell for between $20 and $25. This meant the actual production cost could not exceed $12; otherwise, it would be unprofitable.[3]

With microprocessor economics, MOS desperately needed to sell high volumes of chips to overcome their design costs. According to Al Charpentier, the burgeoning microprocessor industry was having problems establishing itself. "You've got a new technology that everybody is interested in but it's not taking off," he explains. "The numbers back then were tiny. They were scientific curiosities because they were so expensive. So [MOS] wanted to drive the interest level way up, and that's how the $20 price tag got hammered in."

The price seemed unreasonably low compared to Motorola. "We wanted to own the market," says Peddle. "If you want to own a market, you take a price point that you make good money at, and you make sure nobody else can play with you. You build big, fast companies that way."

When asked why he did not chose a slightly higher price, say fifty dollars, Peddle says, "Because then I don't get the design in. At twelve bucks and fifteen bucks and twenty bucks I get design-ins everywhere." Peddle was after widespread success. "We wanted people to put microprocessors everywhere. We were trying to change the world."

The ex-Motorola employees split into three groups, each with their own areas of expertise. "We came in and effectively took over two or three rooms, and operated totally independent of the rest of the company for a long time," says Peddle.

---

[3] Generally, the manufacturer doubles the manufacturing cost when selling to a dealer, who then doubles the price again to sell to the consumer. Since MOS Technology would sell the microprocessor directly without an intermediary, they only doubled the manufacturing cost once.

Making Chips

Chuck Peddle, Will Mathis, and Rod Orgill would collaborate to design the initial architecture for the new microprocessor. “It was just the perfect product, the perfect time, the perfect team,” says Peddle.

The architects’ task was similar to designing a small city, except the streets in this city would be paved with metal. Electrons would inhabit their city, traveling the streets until they reached a transistor. Timing within this little city would be critical, otherwise traffic would halt, causing the chip to lock up.

Peddle and his group intentionally numbered their chips starting with 6500, so it would sound similar to the Motorola 6800. “It was a cheaper version of the 6800 and there was intended to be a whole string of them,” he explains. “In hindsight, with many years and lawsuits behind us now, it was designed to sound like the 6800.”

The first chip in the series was the 6501, which could drop into a 6800 slot. “It was definitely not a clone,” says Peddle. “Architecturally it’s a 6502. The only difference is it plugs into Motorola socket.”

Peddle explains the 6501 strategy. “We were competing in a market where we were selling to people who might have bought the 6800,” he says. “Having a plug-in compatible version was just a marketing game.” Unfortunately, socket compatibility would later provoke Motorola.

The centerpiece of their project was the 6502 microprocessor. “The 6502 was what we were driving for,” he says.

To create the architecture of the chip, the three engineers created a simple diagram to represent the structure of the chip. “We would start with a basic block diagram,” says Peddle.

Some of the most important design work took place away from MOS Technology. “We put some of the more significant stuff in while drinking booze at Orgill's house one night,” says Peddle. “The way to do really creative work is to work on it and then sometimes you’ve got to let it alone. If somebody gets a bright idea at a party, you take time out and you go argue about it. We actually came up with a really nice way of dealing with the buses that came out of a discussion at Orgill’s.”

Al Charpentier was one of the calculator chip designers at MOS Technology. He witnessed Peddle driving his team to build the new processor. “Chuck was an interesting character,” he recalls. “He could be a bit pompous, but he had a vision and he was pushing that vision. Chuck was the visionary.”

Peddle created a concept called *pipelining*, which handled data in a conveyor belt fashion. Instead of stopping while the microprocessor performed the arithmetic, the chip was ready to accept the next piece of data right away, while internally it continued processing data. This feature would make the chip faster than anything produced by Intel or Motorola at the time. A one-megahertz 6502 was equivalent to a four-megahertz Intel 8080.

The semiconductor team not only developed a microprocessor, they also developed the supporting chips. The first was the 6520 PIA chip, which was a clone of the Motorola 6820 PIA. One chip, called the 6530, contained 1 kilobyte of ROM, 256 bytes of RAM, a timer, and two IO ports. This allowed engineers to assemble a complete computer using only two chips. The team also developed 128-byte 6532 RAM chips.

One by one, the architects passed their designs to the layout people.

The layout team consisted of two main engineers: Bill Mensch and Rod Orgill. A third engineer, Harry Bawcum, aided the layout artists. It was their task to turn an abstract block diagram into a large-scale representation of the surface of the microprocessor. Orgill was responsible for the 6501 chip, Mensch the 6502.

Chuck Peddle originally hired Mensch at Motorola after Mensch graduated from the *University of Arizona*. “Mensch was literally right out of school,” says Peddle. One of eight children, Mensch grew up in a small farming community in Pennsylvania. According to Mensch, “I lived on a dairy farm, got up at 4:30, milked the cows, and went off to school.”[4]

At Motorola, Peddle was impressed with Mensch’s natural talent. “He was just spectacular doing N-channel design and layout. He was the worlds best layout guy,” raves Peddle.

Mensch was dependable, which made him a favorite with MOS engineers. “Bill was a good guy,” says Charpentier. “He was very knowledgeable and knew what he was doing.”

Rod Orgill, the youngest member of the team, worked at Motorola on the fabrication process of the 6800. Out of everyone on the team, Orgill had the most diverse set of abilities. Peddle relates, “Rod was a combination of chip designer and architect.” For the first time in his life, Orgill would acquire layout abilities as an understudy to Mensch.

Peddle claims the 6501 was a marketing game, but Rod Orgill believed the 6501 would be more successful than the 6502. According to Mensch, “We made a bet and said who's going to have the highest volume and Rod says, ‘There's no question: following Motorola's marketing, the

[4] The quote is from an interview with William Mensch by Rob Walker, *Silicon Genesis: An Oral History of Semiconductor Technology* (Atherton, California, October 9, 1995)

6501 will surpass your [6502] design and yours won't even have a chance.'"

The small group of young engineers worked in a small room on the second floor containing several large art tables. Here, Mensch and Orgill brooded over thick sheets of vellum paper. The layout consisted of thousands of polygons, each a specific size and shape. Thin lines called *traces* connected the polygons, creating a complex circuit. Incredibly, the engineers created the layout in pencil, one component at a time. The task was formidable, with a completed diagram containing approximately 4,300 transistors.[5]

Near the end of the design process, disaster struck. The engineers realized their architecture would not fit within the allotted area of the microchip. "When we sat down to optimize the system, we discovered we were 10 mills too wide," says Peddle. "The design was almost done. Mathis and I put a big piece of paper down on a table and sat there and optimized every line until we got rid of 10 mills."

The engineers were on a tight deadline to have the product ready for the upcoming *Wescon* show in September. They obsessively searched for ways to recycle lines in the schematic, thus reducing the area. Peddle grimly recalls, "Mathis and I had to keep redoing the architecture to make sure they stayed within that area."

To print the microchips, the engineers used a process called Metal Oxide Semiconductor, or simply MOS. This process used six layers of different materials, printed one on top of the other, to build the tiny components on the surface of a silicon wafer. This meant the layout artists had to create six different diagrams, one on top of the other.

The process required incredible precision because the layers had to line up exactly. The surface of the chip was necessarily dense in order to fit everything into a small area, so the artists squeezed transistors and pathways close to each other. If a single layer deviated by more than a few microns, it could touch another pathway and create a short circuit.

After the layout was completed, the engineers faced the soul-draining task of rechecking their design. The most sophisticated tool in this process was a small metal ruler, or more accurately, a scale. Herd recalls, "They would take their scales out of their pocket - don't call them a ruler – and they would measure for months! They would measure each transistor and make sure it was two millimeters by point seven."

Mensch, Orgill and Bawcum sat bleary-eyed over their drawings, sometimes for 12 hours a day, painstakingly measuring every point on the layout. They measured the size of components, the distance between

[5] In contrast, the Intel Pentium 4 released in 2000 has 42 million transistors.

components, the distance between traces, and the distance between traces and components. With a touch of sympathy in his voice, Herd explains, “You could be a really talented designer but if you couldn’t check your design with the mind-numbing repetitiveness, your stuff didn’t work and you would get a bad reputation.”

Mensch and Orgill kept small cots in the room so they could work for long uninterrupted periods followed by a few hours rest. “With the semiconductor guys, that tends to be something you do when you are doing that at a certain level of design,” recalls Peddle. “You tend to just keep going.”

Even today, Peddle is still in awe of Mensch’s ability as a layout engineer. “Bill has this unique ability to look at the requirements for a circuit, and he can see how it is going to layout in his head,” he says. “He’s just totally unique. Nobody matches Mensch.”

In June 1975, the chip design was ready. It was up to the process engineers to imprint the design onto tiny silicon wafers. Months earlier, Pavinen promised Peddle he would have the N-channel process ready. Pavinen was true to his word. “He gave me everything I wanted,” says Peddle.

The procedure to shrink a large, dense design onto something smaller than a thumbtack is both mysterious and under-appreciated. In many ways, it is also the most important step and, if intelligently planned, it can reduce the cost of a microchip dramatically. Engineers simply call this step the *process*.

When Pavinen and his two partners founded MOS Technology, it was their explicit goal to be the best process company in the business. “MOS Technology’s business premise when they started was that they knew how to process better than other people,” says Peddle. Engineers at the time documented very little of what they did, and most process engineers stored the process in their heads.

In order to print the transistors and other components to a silicon chip, the engineers had to create a *mask*. The mask blocks out everything except for the parts of the chip they want, much like a stencil blocks spray paint to produce letters. The mask relied on the principles of photography and light.

To transform the circuit diagram into a mask, the engineers used a material borrowed from the graphics industry called *Rubylith*. Rubylith is a sheet of acetate film with a red base covering the surface. Since the semiconductor industry was in an early stage of development, the tools to transfer the diagram were outrageously primitive. According to Bil Herd, “They were doing chips by cutting Rubylith with razor blades. They would kick their shoes off, push some tables together, and jump up on them." It was up to engineers Mike James and Harry Bawcum to perform the tedious task of cutting out pieces from the Rubylith to form the mask.

According to Bob Yannes, who arrived at MOS just after the Rubylith years, "I can't imagine using that stuff. You're looking at this huge red plastic thing in front of you and you're supposed to peel off the parts that are supposed to stay and leave the parts that are supposed to go away. Unless you were very careful, you got the two confused and you ended up peeling off the stuff that is supposed to go away. Then you start taping it back down again."

With engineers crawling all over the huge sheets of acetate film, it was vital sharp toenails were not exposed; otherwise they would drag over the surface and slice into the acetate. Engineers were not known for their attention to appearance and it became vital to keep pairs of fresh socks available. "Everyone would wear fresh socks with no holes in the toes for getting on the table," explains Herd with some amusement.

Orgill and Bawcum created six Rubylith masks for the 6502 chip, one for each layer. Once completed, the engineers photographically reduced each of the large sheets of Rubylith to create a smaller negative. Engineers chemically etched a tiny metal mask using this negative. The technicians would eventually use this mask, almost like a rubber stamp, to create thousands of microprocessors.

Precise robotic machines used the tiny metal mask to duplicate the pattern over the entire surface of the silicon wafer. In the early seventies, the metal mask made contact with the surface of the silicon so the electrons could flow through the mask, imprinting the design to the surface. "People used to have what they call contact masks, which were pretty destructive on the mask," recalls Peddle. "They actually put the mask on the chip and it got worn out very quickly." Every time a mask wore out, the designers had to go through the laborious process of making a new mask.

At MOS Technology, John Pavinen pioneered a new way to fabricate microprocessors. "They were one of the first companies to use non-contact mask liners," says Peddle. "At that time everybody was using contact masks."

With non-contact masks, the metal die did not touch the wafer. Once the engineers worked out all the flaws in the mask, it would last indefinitely.

Pavinen and Holt handed off the completed mask to the MOS technicians, who began fabricating the first run of chips. Bil Herd summarizes the situation. "No chip worked the first time," he states emphatically. "No chip. It took seven or nine revs [revisions], or if someone was real good they would get it in five or six."

Normally, a large number of flaws originate from the layout design. After all, there are six layers (and six masks) that have to align with each other perfectly. Imagine designing a town with every conceivable layer of infrastructure placed one on top of another. Plumbing is the lowest layer, followed by the subway system, underground walkways, buildings, overhead walkways, and finally telephone wires. These different layers have to connect to each other perfectly; otherwise, the town will not function. The massive complexity of such a system makes it likely that human errors will creep into the design.

After fabricating a run of chips and probing them, the layout engineers usually have to make changes to their original design and the process repeats from the Rubylith down. "Each run is a couple of hundred thousand [dollars]," says Herd.

Implausibly, the engineers detected no errors in Mensch's layout. "He built seven different chips without ever having an error," says Peddle with disbelief in his voice. "Almost all done by hand. When I tell people that, they don't believe me, but it's true. This guy is a unique person. He is the best layout guy in world."

With the mask complete, mass fabrication of the microchips could begin. Fabrication occurred in an alien-like environment on the second floor of the MOS Technology building called the clean rooms. These hermetically sealed rooms produced a nearly dust free environment. The precautions were extreme, since a single grain of dust during the etching process could cause a miniature short circuit.

To enter the clean rooms, lab technicians were required to don hairnets, beard nets, moustache guards, gloves, paper booties, and white jumpsuits. "It makes you look like a bunny," says Peddle. "We used a lot of them." As a final measure, the technicians walked over a sticky-mat to remove the last traces of dust before stepping into the airlock.

Within a crimson-tinted darkroom, technicians replicated print after print of the 6502 circuit. They coated the round silicon wafers with thin layers of metallic substances. After each layer, technicians placed the wafer into a special machine that copied the circuit from the metal mask to the surface of the silicon wafer. Electrons flowed through the mask, causing a thin layer to harden in the shape of the circuit. Each wafer had the chip pattern imprinted approximately fifty times.

In another room, bathed in yellow light, technicians developed the microchips. This process was almost exactly like developing a photograph. A studious technician carefully washed each wafer with chemical solutions that removed all but the hardened circuitry. The industrial strength solvents went by names like trichloroethene, trichloroethane, dichloroethene, dichloroethane, and vinyl chloride.

The technicians repeated the process six times for the six layers, each time using a different set of chemicals and metallic substances. According to Peddle, “You put this mask on the device and do whatever step you are going to do, and then you take it off, put another mask on, and do another step.”

The top layer was aluminum, which was the best conductor. Beneath the aluminum were various semiconductors such as Germanium. Each layer went by a different name, such as diffusion layer, buried contact, depletion layer, polysilicon, poly-metal contact, and metal. With all six layers applied, the wafers entered an oven to bond the circuitry.

Technicians then added a passivation layer[6] to protect the fragile metallic circuitry from oxidation. After applying the passivation layer, a machine sliced the wafers into individual chips, each smaller than a fingernail.

The chemical etching process used dangerous industrial solvents. Inevitably, the solvents evaporated into the air, which worried some of the staff. Robert Russell, an early Commodore employee, chuckles about the general indifference regarding this threat. “MOS had a little cafeteria at the back alongside the production line,” he explains. “They had a chemical release in the production line that turned all your blueprints that were hanging on the walls different colors. You would come in and they would all be yellow or green. You kind of hoped that wasn’t happening when you were breathing it.”

“The production of semiconductors produces all kinds of nasty byproducts,” says engineer Bob Yannes. Inevitably, accidents occurred. “I remember things happening like occasionally we’d have a gas leak in the front end and you’d have people walking through the building saying, ‘Hurry! Get out of the building!’”

Most people were ignorant of the dangers posed by the semiconductor industry. “This is a time in history when everybody looked at the clean rooms and the guys all wearing their bunny suits, and how sterile it was, and everybody wanted a semiconductor company in their hometown,” says Peddle. “It was high tech, big money, and clean as opposed to a foundry or something like that. What they didn’t realize was these guys

---

[6] This final layer, called the passivation layer, was difficult for Pavinen to perfect. For mysterious reasons, small pinholes appeared in the passivation layer. After a year or so, the areas on the chip around these tiny holes would begin to oxidize and the chip ceased functioning.

were dealing with the most poisonous, noxious shit in the world, and they had to put it somewhere."

The semiconductor industry was still new in 1970 when John Pavinen and his partners created MOS Technology. "Nobody in the semiconductor industry had a clue about how to deal with the stuff they were making for years," says Peddle. "John did the best he could and he actually did pretty well."

The industrial solvents drained from the chip fabrication line into a 250-gallon concrete holding tank. "They built these double tanks and they stored it underground. But you know, we just didn't have the technology," says Peddle. "Let me just make a point; John Pavinen was a very meticulous guy, and he absolutely designed his tanks the best he could given the environment at the time."

In early 1974, a serious disaster occurred. Technicians monitoring the tank realized the tank was emptier than it should have been. During the cold Pennsylvania winters, the concrete tank developed a small crack. "Some of their storage tanks leaked and it leached into the ground," recalls Yannes.

Pavinen kept the spill quiet, even from Peddle. "We didn't join him until the summer of 1974, and they wouldn't have told us about it anyhow," says Peddle. "With all due respect, they keep that stuff a lot quieter in Silicon Valley. There's been a whole bunch of stories about breast cancer being much higher in Silicon Valley, and there's a bunch of other anomalies."

As the Environmental Protection Agency later determined, the leak was the source of groundwater contamination in the area.[7] The Valley Forge Corporate Center bordered a residential development that relied on well water, so there was cause for concern. Fortunately, water tests at the time indicated the solvent had not yet entered the water table. Pavinen replaced the faulty tank with an unlined steel tank.

After the chemical solvents etched the chips, the technicians inserted the flecks of silicon and metal into an easy to handle package.

[7] According to EPA reports, in December 1986, the EPA performed a site inspection in which they collected soil samples, surface water, and water from nearby residential wells. Tests revealed low levels of trichloroethene and other volatile organic compounds in the soil and shallow bedrock underneath 950 Rittenhouse. Furthermore, the EPA found traces of volatile organic compounds in the well water supply, but they did not approach dangerous levels. MOS Technology began a soil-cleaning program to extract the dangerous solvents, and in 1996, the residents received public water lines from an outside water source.

Today, semiconductor companies typically place their chips in black plastic shells with silver pins. Back in 1975, MOS Technology placed their microprocessors in distinctive white ceramic shells with forty gold plated pins.

As if a price drop from $300 to $25 was not radical enough, Peddle and his team planned to release an ultra-low cost microprocessor called the 6507. “Our goal was to do a $5 processor,” Peddle states flatly. “The 6507, which was a subset of [the 6502], could be made at a cheaper price. It was designed to be a really small package.”

The packaging determined how cheaply Peddle could sell his chips. “Packaging costs money and pin outs cost money,” explains Peddle. “Back in those days, those big 40-pin packages were very expensive.” The 6507 contained only 28 pins.

In a perfect world, every single chip would work. If they fabricated 10,000 chips, they would ideally have 10,000 working chips. However, imperfections snuck in from every imaginable source. Inconsistencies in the etching process caused flaws. Small particles of dust getting in the way of the mask caused flaws. Even impurities in the silicon wafer produced flaws. The number of flaws the engineers could defeat determined the *chip yield*.

Technicians methodically tested every single chip to determine if it worked. In 1975, most chipmakers considered a 30% yield to be quite successful. The industry simply discarded the remaining 70%. The process was inherently inefficient and resulted in monumental chip prices. If Pavinen wanted to achieve low cost microprocessors, he would have to use every trick available to raise the yield.

In the seventies, most semiconductor houses tested their chips with a *Fairchild Century* system. The huge machine occupied almost an entire room and cost almost a million dollars. As Bill Mensch explains, “We couldn't afford them at MOS Technology.” Instead, Mensch constructed a small handheld chip tester that resembled a computer motherboard covered in IC chips. Every single chip from MOS Technology was hand tested by the homebrew device for the first year and a half of 6502 production.

Through careful planning and innovation, MOS Technology achieved a chip yield of 70% or better. Peddle attributes this success to Pavinen and his non-contact mask process. “Because they could afford to spend a lot more money making a perfect mask, they got much better yields,” he says. The low production costs meant Peddle’s vision would come true.

Selling the Revolution

The team now had hundreds of working microprocessor chips, but their battle was just beginning. “We brought it out on schedule, on cost, and on target,” says Peddle. With almost no budget for advertising, it would be up to Peddle and his team to create as much fanfare as possible.

“We wanted to launch the product in a spectacular way because we were a crummy ass little company in Pennsylvania,” explains Peddle. At first, he attempted to garner free publicity from newspapers. “Some people liked the story and put us on the cover of their newspaper, which hyped us up,” he recalls.

Prior to launching the 6502, MOS Technology hired Petr Sehnal, a friend of Chuck’s from his days at GE. “Petr was a Czechoslovakian intellectual who came over to this country,” recalls Peddle. “He was kind of acting as a program manager and getting everything ready for the show, and he was the West Coast sales manager.”

To reach their target audience, Sehnal wanted to take the 6502 to the masses. The annual *Western Electronic Show and Convention* (Wescon) was showing in San Francisco in September. Sehnal knew the show would be the best place to launch Peddle’s revolutionary new product.

The microprocessor would be useless to engineers without documentation. Peddle recalls, “We were coming down to launching, and my buddy [Petr Sehnal] kept telling me, ‘Chuck, you’ve got to go write these manuals.’ I kept saying, ‘Yeah, I’ll get around to it.’” Peddle did not get around to it.

With Wescon rapidly approaching, and no manual in sight, Sehnal approached John Pavinen and told him, “He’s not doing it.”

“John Pavinen walked into my office with a security guard, and he walked me out of the building,” recalls Peddle.

According to Peddle, Pavinen gave him explicit instructions. “The only person you’re allowed to talk to in our company is your secretary, who you can dictate stuff to,” Pavinen told him. “You can’t come back to work until you finish the two manuals.”

Peddle accepted the situation with humility. “I wrote them under duress,” he says. Weeks later, Peddle emerged from his exile with his task completed. The 6502 would have manuals for Wescon.

The team planned to sell samples of the 6501 and 6502 microprocessors at Wescon, along with the supporting chipset. “We then took out a full-page ad that said, ‘Come by our booth at Wescon and we’ll sell you a microprocessor for twenty-five dollars.’ We ran that ad in a bunch of places,” recalls Peddle. The most prominent advertisement appeared in the September 8, 1975 issue of *Electronic Engineering Times*.

Things were going well until his team arrived for the show. Peddle recalls, “We went to the show and they told us, ‘No fucking way you’re going to sell anything on the floor. It’s not part of our program. If we had seen these ads we would have killed you.’”

Having come so far and worked so hard, Peddle and his team were not ready to give up. “They told us this just enough in advance that we took a big suite, the *McArthur Suite,* at the St. Francis Hotel,” says Peddle. MOS Technology would sell their contraband microchips from booth 1010 by redirecting buyers to a pickup location, much like drug dealers.

“People would come by the booth and we’d say, ‘No you can’t do it here. Go to the McArthur Suite and we can sell you the processors,” recalls Peddle. “We became so popular people would get on the bus at the convention center and ask, ‘Is this the bus to the McArthur suite?’”

The promise of low-cost microprocessors caused a sensation. Many people thought the $25 chip was a fraud or assumed it performed poorly. Peddle was confident these questions would resolve themselves once people started using his chips.

Eager hobbyists and engineers lined up in the hall outside the McArthur Suite. Chuck's wife Shirley greeted the engineers, collected their money, and handed out chips. “My very pretty wife was sitting there, and we had this big jar full of microprocessors,” recalls Peddle. “You walked up, we would take your microprocessor off the top, and she would put it in a little box for you.”

The large jars full of microchips seemed to indicate MOS Technology was capable of fabricating large volumes of the 6502 chip. This was subterfuge. “Only half of the jar worked,” reveals Peddle. “The chips at the top of the jar were tested and we knew the ones on the bottom didn’t work, but that didn’t matter. We had to help make the jar look full.”

Shirley Peddle also sold manuals and support chips. Peddle explains, “You could buy this little RAM/ROM I/O device for another $30 and we would sell you the two books we wrote, which turned out to be very popular.”

The manuals gently introduced readers to the concepts of microprocessor systems, explaining how to design a microprocessor system using the 6500 family of chips. It was a bible for microcomputer design. “Everyone told us how good they were to use,” he recalls. “We were very proud of that.”

After completing their purchases, customers entered the suite. Here, Peddle demonstrated the 6501 and 6502 chips, along with tiny development systems such as the TIM and KIM-1 microcomputers.

"They would go around the suite and they would see the development systems, and they would find out how to log onto the timesharing systems so they could develop code," he says. "Then they would wander away."

The purpose of selling the chips at Wescon was not to raise money. It was to cultivate developer interest in the chip. If all went well, the engineers and hobbyists would go out into the world and design products with the 6502. Waiting in line outside Chuck's hotel room was Steve Wozniak, who thought he might be able to use the chip for a homebrew computer project. Peddle's documentation undoubtedly influenced Wozniak.

In the months that followed, engineers and hobbyists began reporting success with the MOS microprocessors. Thanks to a review in the November issue of Byte magazine, the chips soon gained a larger following. Dan Fylstra, founder of the company that would someday sell the legendary VisiCalc spreadsheet, wrote an article titled, 'Son of Motorola'. People soon became convinced that the 6502 chip was a legitimate microprocessor.

The 6502 did not immediately improve MOS Technology's finances, but it had a major impact on the computer industry. "It spawned a whole class of users, called hackers back then," says Charpentier.

"It changed the world," says Peddle. In September 1995, as part of their 20th anniversary edition, Byte magazine named the 6502[8] one of the top twenty most important computer chips ever, just behind the Intel 4004 and 8080.

[8] Even pop-culture recognizes the 6502 chip. The animated television show *Futurama* revealed that one of its characters, a robot named Bender, has a 6502 microprocessor for a brain. *Futurama*, "Fry & the Slurm Factory" (Season 2, Episode 4).