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## Introduction

*by Peter Corcoran & Tom Coughlin*

Welcome to another in our ongoing series of “Champions” articles for IEEE Consumer Electronics Magazine. One of the benefits of joining the Consumer Electronics Society is that you get access to senior engineers and researchers from our industry. They are often at our conferences and workshops and at local chapter meetings and frequently play an active role in the organization of society activities.

Many of our members are also well known professionally within their own field and have championed some of the many foundation technologies that our industry relies on. There are quite a few of these “champions” lurking in our society and this series of articles is intended to introduce you to them so that should you bump into them at one of our conferences or workshops you’ll know who they are and why they are involved in the Consumer Electronics Society.

In this issue we are very proud to introduce you to one of the best-known early pioneers of the computer industry. His work on the early Apple computers catalyzed today’s home computer industry and he participated directly in the creation of the Silicon Valley phenomenon. Further, he was co-founder of the first of many ‘garage’ start-ups that grew to become one of today’s best-known consumer technology brands. It is a great pleasure to introduce you to the technical genius behind the early Apple Computers Inc. – Steve Wozniak.

# Champions in Our Midst - Steve Wozniak

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Steve Wozniak is an IEEE Consumer Electronics Society senior member. Steve, most often known as "the Woz" was the sole inventor of the Apple I computer. Woz co-founded Apple Computer Inc in 1976 with Steve Jobs to manufacture the Apple I and later the Apple II computers. These were the first broadly available personal computers. Steve continued to work at Apple Computer and was involved in the development of the Macintosh Computer. He also worked on developing the floppy disk for the Apple product line.

Steve went on to found CL 9 which developed the first programmable universal remote control. He also founded Wheels of Zeus (WoZ) in 2002 to develop wireless GPS technology. In 1990 he joined Mitchell Kapor in establishing the Electronic Frontier Foundation. Steve has served various roles with many companies including Chief Scientist for flash memory storage startup Fusion-io

and currently as Chief Scientist at start-up, Primary Data. Each year he gives more than 100 talks all over the world promoting technology and interest in STEM. He is also a strong supporter of STEM organizations such as FIRST Robotics.

Following is a list of other awards and honors that Steve has received: In 1979, Wozniak was awarded the ACM Grace Murray Hopper Award. In 1985, Wozniak received the National Medal of Technology (with Steve Jobs) from US President Ronald Reagan. In December 1989, he received an honorary Doctor of Engineering degree from the University of Colorado at Boulder, where he studied in the late sixties. In 1997, he was named a Fellow of the Computer History Museum "for co-founding Apple Computer and inventing the Apple I personal computer."

Wozniak was a key contributor and benefactor to the Children's Discovery Museum of San Jose; the street in front of the museum has been renamed Woz Way in his honor.

In September 2000, Wozniak was inducted into the National Inventors Hall of Fame, and in 2001 he was awarded the 7th Annual Heinz Award for Technology, the Economy and Employment. In December 2005, Wozniak was awarded an honorary Doctor of Engineering degree from Kettering University. He also received honorary degrees from North Carolina State University and Nova Southeastern University, and the Telluride Tech Festival Award of Technology. In May 2011, Wozniak received an honorary Doctor

of Engineering degree from Michigan State University. The American Humanist Association awarded him the Isaac Asimov Science Award in 2011.

In June 2012, Wozniak was awarded an honorary Doctor of Engineering degree from Santa Clara University. Steve was awarded the Hoover Medal by IEEE President J. Roberto de Marca in 2014. The New York City Chapter of Young Presidents' Organization presented their 2014 Lifetime Achievement Award to Steve Wozniak at the American Museum of Natural History. In November 2014, Industry Week added Steve Wozniak to the Manufacturing Hall of Fame.

On June 19, 2015 Woz received the Legacy for Children Award from the Children's Discovery Museum. The Legacy for Children Award honors an individual whose legacy has significantly benefited the learning and lives of children. On June 20, 2015, The Cal Alumni Association (UC Berkeley's Alumni Association) presented Woz with the 2015 Alumnus of the Year Award.

#### *Patents:*

- 1) US Patent No. 4,136,359 to Wozniak, *Microcomputer For Use with Video Display*.
- 2) US Patent No. 4,210,959: *Controller for magnetic disc, recorder, or the like*
- 3) US Patent No. 4,217,604: *Apparatus for digitally controlling [PAL](#) color display*
- 4) US Patent No. 4,278,972: *Digitally-controlled color signal generation means for use with display*

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- 1) *System Description: The Apple II*, Steve Wozniak, BYTE, Vol. 2, No. 5, May 1977.
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# Inventing the Apple I and Apple II Computers

By Tom Coughlin (Peter Corcoran & Steve Wozniak)

In 2014 the Apple I and Apple II computers were recognized as IEEE Engineering Milestones. These computers, designed by Steve Wozniak, were key elements in creating the personal computer revolution.

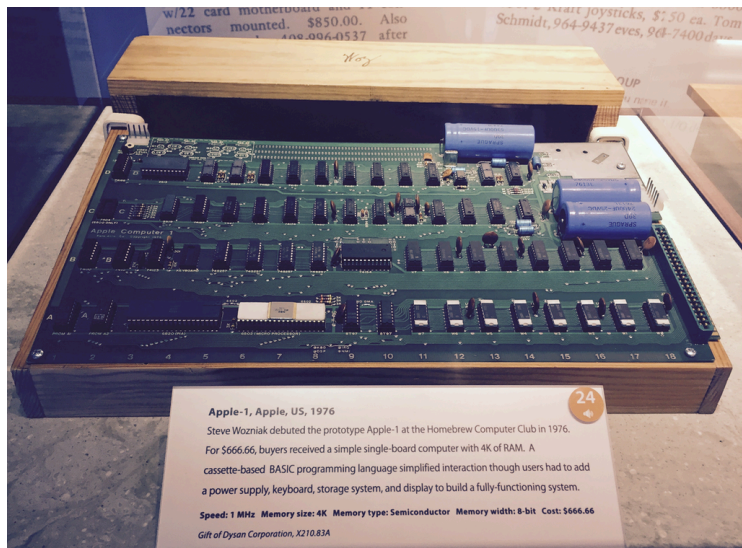
## ***The Apple I Computer***

The features essential for a personal computer were first encompassed by the Apple I: a fully-assembled circuit board with dynamic RAM, video interface, keyboard, mass storage and a high-level programming language. This affordable computer platform triggered a software industry that grew as the sophistication of these essential features grew, and the Apple I thus helped launch the personal computer revolution. Figure 1 shows the Apple I Computer.

It (*the Apple-I*) wasn't a completely finished product like the Apple 2 – it was just a board with a microprocessor, 8k of memory and a video terminal.

*Steve Wozniak from 1979 article & interview with Robin Bradbeer in The Non-Kit Computer, Practical Computing 1979*

**Figure 1. Apple I Computer (Photo by Tom Coughlin, from the Computer History Museum)**



All computers before the Apple I, including hobby computers, had a front panel for entry of binary data into memory, for observing binary data in memory, and for running software. All computers after the Apple I followed its formula of startup code in ROM, keyboard input, a video display, and elimination of the front panel. The Apple I design was given away publicly at

Homebrew Computer Club meetings in the San Francisco Bay Area. In a real sense, the Apple I computer was one of the first open computer architectures.

The Apple I was designed, built and sold in limited numbers in 1976 for \$666.66. In 2013, a working Apple I computer was sold at auction for \$671,400. The early success of the Apple I led to the development of the Apple II computer, which was one of the first successful personal computers. It is believed that there are about 50 Apple I computers left in the world<sup>1</sup>.

I got good at typing-in hex; I had no development aids, no cassette recorder, no floppy disc, no assemblers, so it was all done on paper and hand-coded.

I was pass 1, I was pass 2, I was the linking loader, I was the text editor, I was everything: I became very good at working out the op-codes in my head and putting it all down on paper.

*Steve Wozniak from 1979 article & interview with Robin Bradbeer in  
The Non-Kit Computer, Practical Computing 1979*

Prior to the Apple I, hobbyist computers were sold as kits that included components from different companies, and were affordable only in configurations that could not easily solve real-world computer problems. Early hobby computers such as the MITS Altair 8800 were programmed with front-mounted toggle switches, and indicator lights on the front panel provided output<sup>2</sup>. Separate hardware was required to allow connection to a computer terminal or teletypewriter. Due to high cost, these machines typically only had 256 to 1024 bytes of RAM. In addition, the front panel components were a considerable cost factor. A remote teletype terminal with specialized hardware cost at least \$700<sup>3</sup>, making this an unattractive option for cost-conscious hobbyists.

Early attempts to create personal computers were based on expensive static RAM, and 4KB of this expensive memory was needed to support a higher-level language such as the BASIC interpreter written by Bill Gates. With their input and output limitations, these early computers were primarily used by computer hobbyists who were willing to dedicate a lot of effort to make them work. It was very difficult for a small business or home user to enter useful programs into, or even to play computer games on, these early computers.

There was thus no inexpensive computer that could be used by a casual user, and the very concept of a computer in the home was a novelty. In addition to the need to make a computer useful to regular users, there needed to be marketing about home or “personal” computers<sup>4</sup>. The Apple I computer was the first product that was sold as a single assembled piece of computer hardware that could be easily used in the home, and which was marketed as a personal computer.

I sold my HP calculator and Steve sold his van and we used the money to hire a printed circuit artist to layout the boards. While we were thinking about making the first boards, Steve received a telephone call to place a \$25,000 order for 50 complete computers, fully built.

We were able to turn the whole thing around very fast, in less than a month. That put us in business – in a garage.

We decided to call the company Apple. Steve was working at a place called Apple Orchard, or something like that, in Oregon. It's a really great name – it's one of those names which sticks.

*Steve Wozniak from 1979 article & interview with Robin Bradbeer in  
The Non-Kit Computer, Practical Computing 1979*

Unlike earlier hobbyist computers, the Apple I was not sold as a kit to be assembled by the user. Instead, it was a fully-assembled circuit board containing over 60 chips. To make a working computer, the user had to add a power supply transformer, ASCII keyboard and a composite video display such as a conventional TV of that time. Some users also added a case and/or a power switch. An optional board providing a tape cassette interface for program and data storage was introduced after the initial product introduction<sup>2</sup> and this option allowed the BASIC<sup>5</sup> interpreter to be loaded into RAM.

The Apple I skipped all the expense of a front panel, which included switches, wiring and chips to support input using switches and output using lights. The Apple I used an electronic keyboard as its input device. The 4096 bytes of Dynamic RAM (DRAM) used in the Apple I was less costly than magnetic core memory used in many prior computers, and it had just been introduced at the time of the Apple I design. This DRAM was also many times less expensive than the Static RAM (SRAM) used by other low cost kits, although its need to be refreshed made its use more complex than that of SRAM.

DRAM used as working memory meant that logical addresses needed to be supplied in an organized fashion. The Apple I used the video circuit timing chips, from a prior terminal design of Steve Wozniak's. These timing chips were used for a double purpose, since they also supplied the refresh addresses<sup>6</sup>. This sharing of functions saved parts, and thus reduced the overall product cost. The video output and keyboard input were accomplished through a parallel interface chip.

The video memory was optimized (for cost) around dynamic shift register technology, and it could be updated with new characters at a rate of 60 Hz. All the timing was based on the NTSC color standard frequency, divided down for DRAM timing, display timing, processor clocking and more. Thus, a single timing circuit replaced many independent timing circuits that were common in prior computer designs. Together, these factors made the Apple I computer small and low cost.

March 1976 was when we formed the partnership and started selling the computers. In June, I started on the Apple II which was designed to do all the things Apple I could do, but better.

I think we were the first people to use the 4K dynamic RAMs which were coming in at the time, so the Apple I used a lot less power and cost much less. With Apple I beginning to make an impression, we needed a cassette interface. That was our second product; it was a really fast development. We couldn't do it so fast now – it took about a month.

*Steve Wozniak from 1979 article & interview with Robin Bradbeer in  
The Non-Kit Computer, Practical Computing 1979*

As Steve Wozniak considered a high-level language essential for the usefulness of the Apple I, he wrote the BASIC<sup>5</sup> interpreter. Without this BASIC interpreter, the Apple I would have been useful only for hard-core computer types. With a standard high-level programming language, software could be written and then distributed and used on multiple computers. This enabled a software eco-system that would increase the usefulness of the computer to casual users.

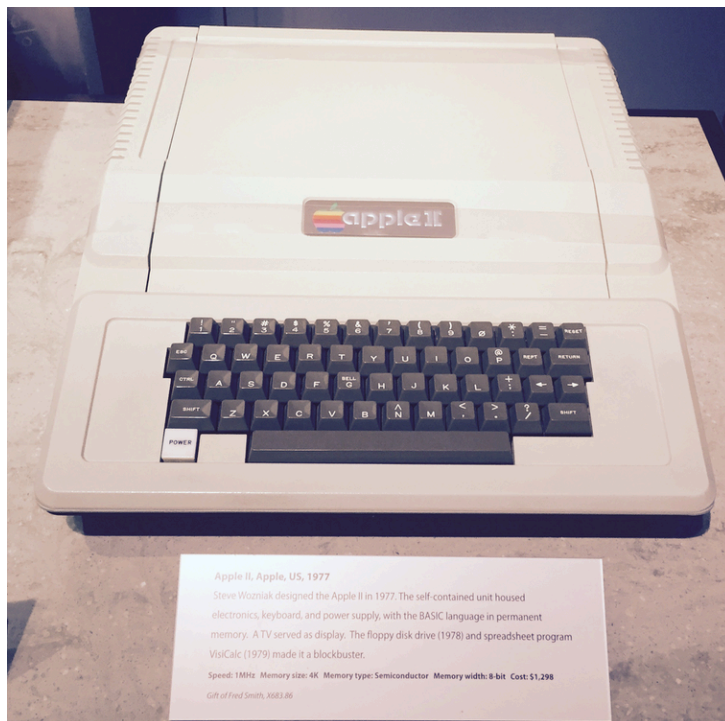
The Apple I defined the elements of a personal computer, thus making it affordable and useful for “normal” people. The cost reductions that made this possible were (1) an integrated and fully assembled working computer circuit board based on the powerful 1MHz 6502 microprocessor, (2) state-of-the-art but low-cost DRAM, (3) clever sharing of components, (4) the use of a typewriter-style keyboard to replace the front panel, and (5) NTSC output to an owners' existing TV<sup>6</sup>. The Apple I was thus able to realize the goal of a low-cost, easy-to-use personal computer<sup>7</sup>.



## ***The Apple II Computer***

The Apple II was the first low-cost computer to offer quick start-up, pre-addressed standard expansion slots, processor RAM-based bit-mapped NTSC color graphics and random access storage in a handsome compact package. Combined with a BASIC interpreter and assembler in ROM, gaming and graphics features, and an economy of design, this device spurred software and hardware suppliers to help create the worldwide personal computing industry. Figure 2 shows the Apple II Computer.

**Figure 2. Apple II Computer (Photo by Tom Coughlin, from the Computer History Museum)**



In June, I started on the Apple II which was designed to do all the things Apple I could do, but better. I was also very interested in color video.

It had proved almost impossible to design a simple color circuit for the Apple I, so I decided to start completely with a new system and in fact everything turned out cleaner.

Steve Wozniak from 1979 article & interview with Robin Bradbeer in  
The Non-Kit Computer, Practical Computing 1979

The Apple II computer was the first widely successful personal computer. Introduced in 1977, it included bit-mapped graphics, viewable on a standard NTSC color television<sup>6</sup>, eight slots for expansion cards, and a BASIC programming language interpreter and mini assembler that executed out of ROM. The NTSC television data resided in the computer's main memory, so blocks and pixels could be altered in microseconds without the need for a slower serial bus. Game paddles and sound were supported in the hardware, and the BASIC interpreter had game



and graphics extensions tailored to the hardware. An important design feature was use of a switching power supply to reliably power up to eight expansion cards. These hardware and software features were packaged in a handsome case with a built-in keyboard, and a magnetic cassette interface to allow for cassette storage of programs and data<sup>7</sup>.

The computer was a true “garage operation.” Co-founders Steve Jobs and Steve Wozniak borrowed money from friends to fund component and assembly costs in order to manufacture the product, initially out of the garage at the Los Altos, CA home of Steve Jobs and his parents. The resulting company established the first retail personal computer sales channels, and the resulting popularity of the product resulted in the growth and development of the personal computer industry.

I realised that Basic was the language which was becoming more and more popular, so I tried to write a Basic compiler with a few things of my own. A friend wrote an Algol program which ran on a HP2000 mini and simulated the 6502 chip, so I was able to write the guts of the Basic compiler. It eventually became our Integer Basic.

The next step was to design a system. There was this video terminal on my desk, so I put the microprocessor on it with enough circuitry to make it work as a system. I interfaced it to some RAMs, put a ROM monitor on it and powered up the thing. It started to interact with the keyboard and I could get it to go to various memory locations; it was a very basic first-level system.

Steve Wozniak from 1979 article & interview with Robin Bradbeer in  
The Non-Kit Computer, Practical Computing 1979

In 1978, Apple introduced the Disk II, a 5 ¼” floppy disk drive with an expansion slot controller card that effectively supplanted its original cassette tape drive. It was a design marvel of Apple co-founder Steve Wozniak’s in that it used just six low-cost chips as compared with the dozens of chips used by other floppy disk controllers that were then on the market. The six chips required special software that was included in the Apple DOS operating system in order to perform all of the operations necessary to fully support a fully functional floppy disk drive. The software was streamlined to run in a small footprint of the machine’s limited memory space.

The Apple II with its unique floppy disk subsystem quickly became a popular platform for hobbyists and game creators, as well as for educational, research and business applications. The computer’s combination of software and hardware defined the general design and operation of all subsequent machines within the new personal computer industry.

Making a useful, low cost computer in the 1976-1977 timeframe was a challenge, but convincing people that a computer had a place in the home was a greater challenge. Creating a product that could meet people’s needs and that was ready to use, easily understandable and attractive took some time. In particular, creating standard expansion slots to enable easy modification and enhancement of the computer was much harder than the more common approach of a dedicated I/O channel designed independently of the computer.

Meanwhile, the garage was filling with racks and test equipment and there was no way that we were going to be able to do the Apple II in there. There just weren’t enough of us involved.

We knew we had an exciting product and just knew we could sell it so we started to look for other people.

Steve Wozniak from 1979 article & interview with Robin Bradbeer in  
The Non-Kit Computer, Practical Computing 1979

A key to rapid expansion of Apple II sales was the availability of software and expansion cards to make the device useful. The VisiCalc spreadsheet program ran on the Apple II, and created a demand beyond the needs of the computer hobbyist. Apple and other companies developed expansion cards, which greatly expanded the original machine's capabilities. The original Apple II stored programs and data on magnetic tape cassettes, but Steve Wozniak's dramatic design improvements for the Disk II 5 1/4" floppy disk drive made software creation and distribution easier and cost-effective. As a consequence, the Apple II computer became more useful for business and professional use.

The first advertisements showed the Apple II in somebody's kitchen and people started buying it; that really put us on the road. It really wasn't until we came out with our disc that our sales really took off. We were the only people really delivering a complete disc system.

We felt that a disc was what it really needed, so I pulled out the old design and finally incorporated it.

The floppy disc is really the way to use the system. The minifloppy is a real credit to Shugart and its ingenuity. It was the first low-cost peripheral of that power that really gives your a good system, and it's so important for a personal computer that it makes sense to build it in.

Steve Wozniak from 1979 article & interview with Robin Bradbeer in  
The Non-Kit Computer, Practical Computing 1979

There was no software industry to bootstrap the personal computer market until the Apple II. Because its BASIC interpreter, mini assembler and cassette interface were built into the machine from the outset, software was easy to develop. Demand for the Apple II swelled as software became available in the marketplace, and Apple Computer created an international distribution channel in response to this. In many regards, the initial growth of the personal computer industry that the Apple II initiated was based upon continuous development and distribution of products and services that had never before existed.

What set the Apple II apart from all of its predecessors was the fact that it was a complete system: it consisted of built-in input (keyboard, cassette interface, and game paddles), built-in output (bit-mapped color graphics, sound and cassette interface), and built-in software that executed out of ROM (monitor, BASIC interpreter and mini assembler). All of these components were included in a small, portable and attractive form-factor case that was usable with a standard color television set, and yet it was easily and inexpensively expandable.

News of the product had started getting out. For example, I was going to Los Angeles to demonstrate the Apple I to a group there and I forgot the transformers or some- thing like that. All I had with me was an Apple II which I could demonstrate. So I showed that. It was still in breadboard form but there were about a dozen people at that meeting and eight of them ordered Apple IIs.

Steve Wozniak from 1979 article & interview with Robin Bradbeer in  
The Non-Kit Computer, Practical Computing 1979

The NTSC color generation circuitry was subdivided for DRAM timing and processor timing using very few chips. Graphics displayed on the television screen were updated at processor speeds, due to every screen element being in memory. RAM refreshes were the result of constant video display accesses on the RAM<sup>9</sup>. Color animated arcade games were easy to create for the Apple II, and as a consequence the computer game industry began.

The motherboard was expandable from 4KB to 48KB, and its eight expansion slots for Z80-based cards allowed for upgrades from Apple and third parties. The phenomenal growth of the expansion card industry was due in large part to the fact that the cards was very easy to create – they only required a few chips to interface with the slot since most of the decoding circuitry was

on the motherboard itself. In addition, thanks to a unique design from Allen Baum, each card had firmware space pre-decoded so that its driver could reside on the expansion card itself. The most popular expansion cards included memory expansion beyond 48 KB, software emulators, video cards, process accelerator cards, and peripheral interface cards.

The Apple II computer was the first broadly successful personal computer, and it helped to create the personal computer industry, and future generations of microcomputer- based consumer electronic products<sup>10</sup>.

Apple was beginning to be accepted; it was a more natural sort of product and it wasn't considered a brand new product any more – remember that at that time there were many companies coming out with really neat-looking products which might well be advertised in perhaps five issues of a magazine and then disappear.

So we finally made it to that point where our momentum was going to carry us. We knew we were going to survive unless some- thing very drastic happened.

Steve Wozniak from 1979 article & interview with Robin Bradbeer in  
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