Chapter 7
Integrated Circuit and Silicon Valley

Key Topics
Integrated circuit
Silicon
Germanium
Texas Instruments
Fairchild
Silicon Valley
Moore's Law

7.1 Introduction

The invention of the transistor was a revolution in computing, and it led to smaller, faster, and more reliable computers. However, it was still a challenge for engineers to design complex circuits, as they had to wire hundreds (thousands) of separate components together.

It is essential when building a circuit that all of the connections are intact, as otherwise the electric current will be stopped on its way through the circuit, and the circuit will fail. Prior to the invention of the integrated circuit, engineers had to construct circuits by hand, which involved soldering each component in place, and connecting them with wires. However, the manual assembly of the large number of components required in a computer often resulted in faulty connections, and advanced computers required so many connections that they were almost impossible to build. Clearly, there was a need for a better solution.

The invention of the integrated circuit allowed many transistors to be combined on a single chip, and it was a revolution in computing. The integrated circuit placed the previously separated transistors, resistors, capacitors, and wiring circuitry on to a single chip made of silicon or germanium. The integrated circuit shrunk the size and cost of making electronics, and it had a major influence on the design of later computers and electronics. It led to faster and more powerful computers.

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7.2 Invention of Integrated Circuit

The electronics industry was dominated by vacuum tube technology up to the mid-1950s. However, vacuum tubes had inherent limitations as they were bulky, unreliable, produced considerable heat, and consumed a lot of power. Bell Labs invented the transistor in the late 1940s, and transistors were tiny in comparison to vacuum tubes, consumed very little power, and they were faster, more reliable, and lasted longer. The transistor stimulated engineers to design ever more complex electronic circuits and equipment containing hundreds or thousands of discrete components such as transistors, diodes, rectifiers, and capacitors.

The motivation for the invention of the integrated circuit was to find a solution to the problems that engineers faced as the number of components in their design increased so as to enhance its performance. Each component needed to be wired to many other components, and the wiring and soldering was done manually. Clearly, more components would be required to improve performance, and therefore it seemed that future designs would consist almost entirely of wiring.

These components needed to be interconnected to form electronic circuits, and this involved hand soldering of thousands of components to thousands of bits of wire. This was expensive and time-consuming, and it was also unreliable since every soldered joint was a potential source of trouble. The challenge for the industry was to find a cost-effective and reliable way of producing these components and interconnecting them.

Jack Kilby (Fig. 7.1) joined Texas Instruments in 1958, and he began investigating how to solve this problem. He realized that semiconductors were all that were really required, as resistors and capacitors could be made from the same material as the transistors. He realized that since all of the components could be made of a single material that they could also be made in situ interconnected to form a complete circuit.

Kilby succeeded in building an integrated circuit made of germanium that contained several transistors in 1958. Robert Noyce of Fairchild Semiconductors built an integrated circuit on a single wafer of silicon in 1960, and Kirby and Noyce are

Fig. 7.1 Jack Kilby c. 1958. (Courtesy of Texas Instruments)

considered coinventors of the integrated circuit. Kilby was awarded the Nobel Prize in Physics in 2000 for his role in its invention.

Kilby's integrated circuit consisted of a transistor and other components on a slice of germanium (Fig. 7.2). His invention revolutionized the electronics industry, and the integrated circuit is the foundation of almost every electronic device in use today. His invention used germanium, and the size of the integrated circuit was 7/16 by 1/16-inches.

Robert Noyce at Fairchild Semiconductors later invented an integrated circuit based on a single wafer of silicon in 1960, and today silicon is the material of choice for semiconductors. Noyce made an important improvement on Kilby's design in that he added a thin layer of metal to the chip to better connect the various components in the circuit. Noyce's solution made the integrated circuit more suitable for mass production, and Fairchild Semiconductors pioneered the use of the *planar process* for making transistors, and the existing semiconductor companies soon employed this process. Noyce was one of the cofounders of Intel, which is one of the largest manufacturers of integrated circuits in the world.

An integrated circuit (IC) consists of a set of electronic circuits on a small chip of semiconductor material, and it is much smaller than a circuit made out of independent components. The IC is made on a small plate of semiconductor material that is usually made of silicon. An integrated circuit is extremely compact, and it may contain billions of transistors and other electronic components in a tiny area. The width of each conducting line has got smaller and smaller due to advances in technology over the years, and it is now measured is in tens of nanometers.[1] The

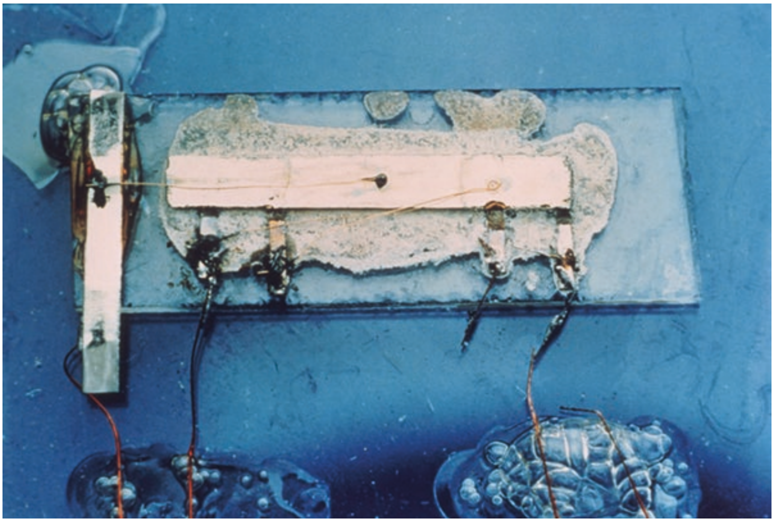

Fig. 7.2 First integrated circuit. (Courtesy of Texas Instruments)

[1] 1 nanometer (nm) is equal to 10^{-9} m.

invention of the integrated circuit led to major reductions in the size and cost of making electronics, and it impacted the design future computers and electronics.

The size of the components in a modern fabrication plant is extremely small, with thousands of transistors fitting inside the cross section of a strand of hair. The production of a chip requires precision at the atomic level, with tiny particles such as those in tobacco smoke large enough to ruin a chip. For this reason, chip production takes place in a clean room, which is a special room designed with furniture made of special materials that do not give off particles, and very effective air filters and air circulation systems.

There has been a massive reduction in the production costs of integrated circuits, with the initial production cost of integrated circuits at $1000 in 1960. However, as demand increased and production techniques improved, the cost of production was reduced down to $25 by 1963.

There are several generations of integrated circuits from the small-scale integration (SSI) of the early 1960s, which typically had less than 30 transistors on the chip, to medium-scale integration (MSI) of the late 1960s with less than 300 transistors on the chip; to large-scale integration (LSI) of the mid-70s with less than 3000 transistors on the chip; to very large scale (VLSI) of the 1980s, which have over a million transistors on the chip to and ultra-large-scale integration (ULSI), which have over a million transistors on the chip.

There are several large companies that design and make semiconductors. These include companies such as Texas Instruments (TI), which is an American electronics company that is one of the largest manufacturers of semiconductors in the world. Intel and AMD (Advanced Micro Devices) are among the largest makers of semiconductors in the world. For more detailed information on Jack Kilby and Texas Instruments, see [ORg:13-b, ORg:15-d].

7.2.1 Moore's Law

Gordon Moore observed that over a period of time (from 1958 up to 1965) that the number of transistors on an integrated circuit doubled approximately every year. This led him to formulate what became known as *Moore's Law* in 1965 [Mor:65], which predicted that this trend would continue for at least another 10 years. He refined the law in 1975 and predicted that a doubling in transistor density would occur every 2 years for the following 10 years.

His prediction of *exponential growth* in transistor density has proved to be accurate over the last 50 years, and the capabilities of many digital electronic devices are linked to Moore's Law.

The exponential growth in the capability of processor speed, memory capacity, and so on is all related to this law. It is likely that the growth in transistor density will slow in the coming years.

The phenomenal growth in productivity is due to continuous innovation and improvement in manufacturing processes. It has led to more and more powerful computers running more and more sophisticated applications.

7.3 Early Integrated Circuit Computers

It took some time for integrated circuits to take off, as they were an unproven technology, and they remained expensive until mass production. Kilby and others at Texas Instruments successfully commercialized the integrated circuit by designing a hand-held calculator that was as powerful as the existing large, electromechanical desktop models. The resulting electronic hand-held calculator was small enough to fit in a coat pocket. This battery-powered device could perform the four basic arithmetic operations on six digit numbers, and it was completed in 1967.

The earliest computers that used integrated circuits appeared in the 1960s, and their early use was mainly in embedded systems. The use of integrated circuits played an important role in early aerospace projects such as the Apollo Guidance Computer and Minuteman missile. The Apollo flight computer was one of the earliest computers to use integrated circuits, and it was developed by MIT/Raytheon and introduced in 1966. It provided capabilities for the guidance, navigation, and control of the Apollo spacecraft. The Minuteman II program used a computer built from integrated circuits, and the guidance system of the Minuteman II intercontinental ballistic missile was much smaller due to the use of the integrated circuits.

DEC's first minicomputer to use integrated circuits was the popular PDP-8 (Fig. 7.3), which was designed by Edson de Castro, and introduced in 1965. Hewlett-Packard introduced the 2116A minicomputer in 1966, and this minicomputer used Fairchild Semiconductors integrated circuits.

The Honeywell ALERT airborne computer was designed to handle complex airborne data in a real-time environment, and it was introduced in 1966. The Central Air Data Computer, was designed in the late 1960s, and it was used for flight control in the US Navy's F-14A Tomcat Fighter. These were among the early computers to use integrated circuits.

7.4 Birth of Silicon Valley

Silicon Valley is the nickname for the southern portion of the San Francisco Bay area. It is home to many of the world's largest high-tech companies, as well as thousands of startup companies.

The term "Silicon Valley" first appeared in the printed media in 1971, in a series by Don Hoefler titled "Silicon Valley in the USA," which was published in the weekly newspaper *Electronics News*. The term was used widely from the early 1980s following the introduction of the IBM personal computer and given the high

Fig. 7.3 The DEC PDP-8/e

concentration of semiconductor technology companies in the area. The word “silicon” originally referred to the large number of silicon chip manufacturers in the area, as most semiconductors are made from silicon. The word “valley” refers to the Santa Clara Valley.

Bill Hewlett and Dave Packard started their two-person company (Hewlett-Packard) in a Palo Alto garage (Fig. 7.4) on 367 Addison Street in 1938. Fruit orchards covered the surrounding area, as Silicon Valley as it is known today did not exist. This 12 by 18 feet garage is now a historical landmark, and it has been officially declared the “birthplace of Silicon Valley.” HP purchased the property in 2000 to preserve it for future generations.

William Shockley (one of the inventors of the transistor) moved from New Jersey to Mountain View in California to start Shockley Semiconductors in 1956. Shockley’s work served as the foundation for many electronics developments. However, Shockley was a difficult person to work with and his management style soon alienated several of his employees. This led to the resignation of eight key

Fig. 7.4 HP Palo Alto Garage. Birthplace of Silicon Valley. (Courtesy of HP)

researchers in 1957, following his decision not to continue research into silicon-based semiconductors. Shockley described them as the "traitorous eight."

This gang of eight went on to form Fairchild Semiconductors and other companies in the Silicon Valley area in the following years. They included Gordon Moore and Robert Noyce, who founded Intel in 1968. Other employees from Fairchild Semiconductors formed companies such as National Semiconductors and Advanced Micro Devices in the Silicon Valley area in later years. Shockley Semiconductors and these new companies formed the nucleus of what became Silicon Valley.

Stanford University played an important role in the development of Silicon Valley, and Frederick Terman, the Dean of Engineering and provost of Stanford University in the 1950s, encouraged graduates to form companies in the Silicon Valley area. Stanford University set up an industrial park (Stanford Research Park) for high-technology companies. Terman has been described as the father of Silicon Valley.

7.5 Review Questions

1. What is an integrated circuit?
2. Explain the significance of Moore's Law and its relevance to the computing power of electronic devices.
3. Explain the importance of the integrated circuit?
4. Describe the early computers that were based on the integrated circuit.
5. Describe how Silicon Valley was formed.
6. Describe the role played by Stanford University in the success of Silicon Valley.

7.6 Summary

An integrated circuit consists of a set of electronic circuits on a small chip of semiconductor material, and it is much smaller than a circuit made out of independent components. The integrated circuit was a revolution in computing, and it shrunk the size and cost of making electronics. Its invention placed the previously separated transistors, resistors, capacitors, and wiring circuitry onto a single chip made of silicon or germanium.

There are several generations of integrated circuits that have evolved from the small-scale integration of the early 1960s with less than 30 transistors on a chip to the ultra-large-scale integration with over a billion transistors on the chip. Gordon Moore formulated *Moore's Law* in 1965, in which he predicted exponential growth in transistor density. His prediction has proved to be accurate over the last 50 years, and the capabilities of modern digital electronic devices are linked to Moore's Law.

The earliest computers to use integrated circuits appeared in the 1960s, and their use was mainly in embedded systems. They played an important role in early aerospace projects such as the Apollo Guidance Computer and Minuteman missile. DEC's popular PDP-8 was one of the early computers to use integrated circuits, and it was introduced in 1965.

The garage where HP was formed is considered the birthplace of Silicon Valley, and it is home to the world's largest high-tech companies and thousands of start-ups.