Chapter 6
Early Commercial Computers and the Invention of the Transistor

Key Topics
IBM 701
SAGE
Transistor
IBM 608
IBM 704

6.1 Introduction

This chapter considers a selection of computers developed during the 1950s, and it includes a selection of vacuum-tube-based computers as well as transistor computers. One of the drivers for the design and development of more powerful computers was the perceived threat of the Soviet Union. This led to an arms race between the two superpowers, and it was clear that computing technology would play an important role in developing more sophisticated weapon and defense systems. The development of the SAGE air defense system in the United States and Canada was an early example of the use of computer technology for the military.

The other key driver for the development of more powerful computers was to support business, universities, and government. The machines developed during this period were mainly large proprietary mainframes designed for business, scientific, and government use. They were expensive, and this eventually led vendors such as IBM and DEC to introduce families of computers in the 1960s, where a customer could choose a small cheaper member of the family to meet their needs, and then to upgrade over time to a larger computer in the family as their computing needs increased.

The origins of IBM are in the work done by Hermann Hollerith in developing a tabulating machine to process the 1890 census of the population of the United States. IBM became a very successful international company selling punched cards tabulating machines. Thomas Watson Sr. led the company from 1912 to 1952, and Thomas Watson Jr. became CEO in 1952. He believed that the future of IBM was in computers, and not tabulators, and he transformed IBM to become a world leader in the computer sector.

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6.2 Early IBM Computers

IBM commenced work on computers during the Second World War, with its joint venture with Howard Aiken on the Harvard Mark I (also known as the IBM Automatic Sequence Controlled Calculator (ASCC)). This machine was essentially an electromechanical calculator that could perform large computations automatically (see Chap. 4), and it was delivered to Harvard University in 1941.

IBM introduced the vacuum tube multiplier in 1943, which was an important move from electromechanical to electronic machines (the Harvard Mark I used electromechanical relays to perform the calculations). It was one of the first complete machines to perform arithmetic electronically by substituting vacuum tubes for electric relays. The key advantages of the vacuum tubes were that they were faster, smaller, and easier to replace than the electromechanical switches used on the Harvard Mark I. This allowed engineers to process information thousands of times faster.

IBM introduced its first large computer based on vacuum tubes in 1952. The machine was called the IBM 701 (Fig. 6.1), and it executed 17,000 instructions per second. It was used mainly for government work and for business applications.

IBM introduced the IBM 650 (Magnetic Drum Calculator) in 1954. This was an intermediate-sized electronic computer designed to handle accounting and scientific computations. It was one of the first mass-produced computers, and it was used by universities and businesses. It was a very successful product for IBM, with over 2000 machines built and sold between its product launch in 1954, and its retirement in 1962. The machine included a central processing unit, a power unit, and a card reader.

The IBM 704 data processing system was a large computer introduced in 1954. It included core memory and floating-point arithmetic, and it was used for scientific and commercial applications. It included high-speed memory, which was faster and much more reliable than the cathode-ray-tube memory storage mechanism used in earlier machines. It also had a magnetic drum storage unit, which could store parts of the program and intermediate results (Fig. 6.2).

The interaction with the system was either by magnetic tape or punched cards entered through the card reader. The program instructions or data were initially produced on punched cards. They were then either converted to magnetic tape or read directly into the system, and the data processing was then performed. The output from the data processing was then sent to a line printer, magnetic tape, or punched cards. Multiplication and division was performed in 240 microseconds.

The designers of the IBM 704 included John Backus and Gene Amdahl. Backus was one of the key designers of the FORTRAN programming language, which was introduced by IBM in 1957. This was the first scientific programming language, and it is still popular with engineers and scientists. Gene Amdahl later founded Amdahl Corporation after his resignation from IBM, and Amdahl Corporation later became a major competitor to IBM in the mainframe market. For more detailed information on Backus and Amdahl, see [ORg:13].

Fig. 6.1 IBM 701. (Courtesy of IBM Archives)

Fig. 6.2 IBM 704. (Courtesy of IBM Archives)

6.3 The SAGE System

The Semi-Automatic Ground Environment (SAGE) was an automated system for tracking and intercepting enemy aircraft in North America. It was used by the North American Aerospace Defense Command (NORAD), which is located in an earthquake and nuclear blast proof structure deep inside Cheyenne Mountain in Colorado in the United States. The SAGE system was used from the late 1950s until the 1980s.

The interception of enemy aircraft was extremely difficult prior to the invention of radar during the Second World War. Its introduction allowed fighter aircraft to be scrambled just in time to meet the enemy threat. The radar stations were ground based, and they therefore needed to communicate with and send interception instructions to fighter aircraft to deal with hostile aircraft.

However, after the war the speed of aircraft increased considerably, thereby reducing the time available to scramble fighter aircraft. This necessitated a more efficient and automatic way to transmit interception instructions, and new approaches to provide security of airspace for the United States. The SAGE system was designed to solve this problem, and it analyzed the real-time information that it received from the various radar stations around the country, *and it then automated the transmission of interception messages to fighter aircraft* (Fig. 6.3).

IBM and MIT played an important role in the design and development of SAGE. Some initial work on real-time computer systems had been done at Massachusetts Institute of Technology on a project for the United States Navy. This project was concerned with building an aircraft flight simulator computer for training bombing crews, and it led to the development of the Whirlwind digital computer. This computer was originally intended to be an analog machine, but instead it became the Whirlwind digital computer, and it was used for experimental development of military combat information systems.

Whirlwind was the first real-time computer and Jay Forrester and his team at MIT created it. The US military saw Whirlwind as a potentially useful starting point for an air defense system, and so George Valley and Jay Forrester wrote a proposal to employ Whirlwind for air defense. This led to the Cape Cod system, which demonstrated the feasibility of an air defense system covering New England. The design and development of SAGE commenced in 1953, and a detailed account of the development of SAGE from the initial work done on Whirlwind is in [ReS:00].

IBM was responsible for the design and manufacture of the AN/FSQ-7 vacuum tube computer used in SAGE. Its design was based on the Whirlwind II computer, which was intended to be the successor to Whirlwind. However, the Whirlwind II was never built, and the AN/FSQ-7 computer weighed 275 tons and included 500,000 lines of assembly code. It used magnetic core memory, which was much faster than the Williams tube discussed in Section 4.7.

Fig. 6.3 SAGE IBM AN/FSQ-7 Console. (Creative Commons)

The AN/FSQ holds the current world record for the largest computer ever built. It employed 55,000 vacuum tubes, covered an area over 18,000 square feet, and it used about three megawatts of power.

There were twenty-four SAGE Direction Centers and three SAGE Combat Centers located in the United Sates. Each SAGE site included two computers for redundancy, and long-distance telephone lines linked each center. Burroughs provided the communications equipment to enable the centers to communicate with one another, and *this was one of the earliest computer networks*.

Each site was connected to multiple radar stations with tracking data transmitted by modem over a standard telephone wire. The SAGE computers then collected the tracking data for display on a cathode ray tube (CRT). The console operators at the center could select any of the targets on the display to obtain information on the tracking data. This enabled aircraft to be tracked and identified, and the electronic information was presented to operators on a display device.

The engineering effort in the SAGE project was immense, and the total cost is believed to have been several billion US dollars. It was a massive construction project, which involved erecting buildings and building power lines, and communication links between the various centers and radar stations.

SAGE influenced the design and development of the Federal Aviation Authority (FAA) automated air traffic control system.

6.4 Invention of the Transistor

The early computers were large bulky machines taking up the size of a large room. They contained thousands of vacuum tubes,[1] and these tubes consumed large amounts of power and generated a vast quantity of heat. This led to problems with the reliability of the early computers, as several tubes burned out each day. This meant that machines were often nonfunctional for parts of the day, until the defective tube was identified and replaced (see Fig. 4.6).

There was therefore a need to find a better solution to vacuum tubes, and Shockley (Fig. 1.2) set up the solid physics research group at Bell Labs after the Second World War. His goal was to find a solid-state alternative to the existing glass-based vacuum tubes.

Shockley was born in England in 1910 to American parents, and he grew up at Palo Alto in California. He earned his PhD from Massachusetts Institute of Technology in 1936, and he joined Bell Labs shortly afterward. His solid physics research team included John Bardeen and Walter Brattain, who would later share the 1956 Nobel Prize in Physics with him for their invention of the transistor (Fig. 1.3).

Their early research was unsuccessful, but by late 1947 Bardeen and Brattan succeeded in creating a point-contact transistor independently of Shockley, who was working on a junction-based transistor. Shockley believed that the point-contact transistor would not be commercially viable, and his junction point transistor was announced in mid-1951, with a patent granted later that year. The junction point transistor soon eclipsed the point-contact transistor, and it became dominant in the market place.

Shockley published a book on semiconductors in 1950 [Sho:50], and he resigned from Bell Labs in 1955. He formed Shockley Laboratory for Semiconductors (part of Beckman Instruments) at Mountain View in California. This company played an important role in the development of transistors and semiconductors, and several of its staff later formed semiconductor companies in the Silicon Valley area.

Shockley was the director of the company, but his management style alienated several of his employees. This led to the resignation of eight key researchers in 1957 following his decision not to continue research into silicon-based semiconductors. This gang of eight went on to form Fairchild Semiconductors and other companies in the Silicon Valley area in the following years.

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[1] ENIAC contained over 18,000 vacuum tubes and the AN/FSQ-7 computer used in SAGE contained 55,000 vacuum tubes.

For more detailed information on Shockley and Bell Labs, see [ORg:13, ORg:15].

6.5 Early Transistor Computers

The University of Manchester Experimental Transistor Computer was one of the first transistor computers.[2] The prototype machine used 92 point-contact transistors and had a 48-bit word size, whereas the full-scale version used 200 point-contact transistors. There were problems with the reliability of the point-contact transistors, which meant that there were reliability problems with the machine. Metropolitan-Vickers (a Manchester company) adapted the design and changed the circuits to use the more reliable junction-based transistors and created a full-scale version called the Metrovick 950 in 1956.

Other early transistor computers include the TRADIC designed and developed by Bell Labs in early 1954. This machine also used some vacuum tubes. The Harwell CADET was an early fully transistorized machine when it appeared in early 1955. The IBM 608 was the first IBM product to use transistor circuits instead of vacuum tubes. The prototype of this product appeared in 1955, and the fully transistorized calculator was introduced in late 1957. It contained 3000 germanium transistors. The Burroughs SM-65-Atlas ICBM was an early-transistorized computer, which appeared in 1957.

The IBM 7090 was one of the earliest commercial computers with transistor logic, and it was introduced in 1958. It was designed for large-scale scientific applications, and it was over thirteen times faster than the older vacuum tube IBM 701. It used 36-bit words, had an address-space of 32,768 words, and could perform 229,000 calculations per second. It was used by the U.S. Air Force to provide an early warning system for missiles, and also by NASA to control space flights. It cost approximately $3 million but it could be rented for over $60K per month.

[2] It was not a fully transistorized computer, in that it employed a small number of vacuum tubes in its clock generator.

6.6 Review Questions

1. Explain the significance of the transistor in the computing field.
2. Explain the significance of the SAGE system to the computing field.
3. Describe the contributions made by the University of Manchester to the computing field.
4. Describe the early transistor computers.
5. Describe the contributions of John Backus and Gene Amdahl to the computing field.
6. Describe the contributions of Bell Labs to the computing field.
7. Describe the contributions of IBM to the computing field.

6.7 Summary

This chapter considered a selection of computers developed during the 1950s, including a selection of vacuum tube-based computers, as well as early transistor computers.

Among the early vacuum tube computers considered were the IBM 701 and IBM 704. The IBM 701 was introduced in 1952; it was used mainly for government work and for business applications. The IBM 704 data processing system was a large computer that was introduced in 1954. It was used for scientific and commercial applications, with Gene Amdahl and John Backus involved in its design.

The SAGE air defense system was developed for the United States and Canada, and it was an early example of the use of computer technology for the military. It was an automated system for tracking and intercepting enemy aircraft in North America, and it automated the transmission of interception messages to fighter aircraft.

The invention of the transistor by Shockley and others at Bell Labs was a revolution in computing, and it led to smaller, faster, and more reliable computers. The University of Manchester experimental transistor computer was one of the earliest transistor computers.