Chapter 4
The First Digital Computers

Key Topics
Harvard mark I
ABC computer
ENIAC
EDVAC
Colossus
Zuse's machines
Manchester mark I

4.1 Introduction

This chapter considers some of the early computers developed in the United States, Britain, and Germany. The Second World War motivated researchers to investigate faster ways to perform calculation to solve practical problems. This led to research into the development of digital computers to determine if they could provide faster methods of computation.

The early computers were mainly large bulky machines consisting of several thousand vacuum tubes. A computer often took up the space of a large room, and it was slow and unreliable.

The early computers considered in this chapter include the Harvard Mark I designed and developed by Howard Aiken and IBM. This was a large electromechanical calculator that could perform mathematical calculations quickly. John Atanasoff and Clifford Berry designed and developed the Atanasoff-Berry (ABC) computer, and this machine was designed to solve a set of linear equations using Gaussian elimination. John Mauchly and Presper Eckert designed the ENIAC and EDVAC computers. ENIAC was a fixed-program computer that needed to be physically rewired to solve different problems, but the EDVAC computer implemented the concept of a stored program. This meant that the program instructions could be stored in memory, and that all that was required to carry out a new task was to load a new program into memory.

The team at Bletchley Park in England designed and developed the COLOSSUS computer as part of their code-breaking work during the Second World War. This allowed them to crack the German Lorenz codes, and to provide important military intelligence for the D-Day landings of 1944.

G. O'Regan, *A Brief History of Computing*,
https://doi.org/10.1007/978-3-030-66599-9_4

Konrad Zuse designed and developed the Z1, Z2, and Z3 machines in Germany. The Z3 was operational in 1941, and it was the world's first programmable computer.

4.2 Harvard Mark I

Howard Aiken (Fig. 4.1) made several important contributions to the early computing field. He showed that a large calculating machine could be built that would provide speedy solutions to mathematical problems.

His idea was to construct an electromechanical machine that could perform mathematical operations quickly and efficiently, and the machine would need to be able to handle positive and negative numbers, scientific functions such as logarithms, and be able to work with minimal human intervention.

He discussed the idea with colleagues and IBM, and he was successful in obtaining IBM funding to build the machine. The machine was built at the IBM laboratories at Endicott with several IBM engineers involved in its construction. The construction took 7 years, and it was completed in 1943.

The machine became known as the Harvard Mark I (also known as the IBM *Automatic Sequence Controlled Calculator* (ASCC)). Aiken was influenced by Babbage's ideas on the design of the Difference Engine and the Analytic Engine.

IBM presented the machine to Harvard University in 1944, and the ASCC was essentially an electromechanical calculator that could perform large computations automatically. It could perform addition, subtraction, multiplication, and division, and it could refer to previous results.

The Harvard Mark I (Fig. 4.2) was designed to assist in the numerical computation of differential equations, and it was 50 feet long, 8 feet high, and weighed 5 tons. It performed additions in less than a second, multiplications in 6 seconds, and division in about 12 seconds. It used electromechanical relays to perform the calculations, and it could execute long computations automatically.

It was constructed out of switches, relays, rotating shafts, and clutches, and it used 500 miles of wiring and over 750,000 components. It was the industry's largest electromechanical calculator, and it had 60 sets of 24 switches for manual data

Fig. 4.1 Howard Aiken

entry. It could store 72 numbers, each 23 decimal digits long. The instructions were read on paper tape, and punched cards were used to input the data and the results were either on punched cards or an electric typewriter.

The US Navy used the Harvard Mark I for ballistic calculations, and the machine remained in use until 1959. It cost approximately half a million dollars, but it was never mass-produced by IBM. It differed from most of the early digital computers in that it used relays instead of vacuum tubes.

The announcement of the Harvard Mark I led to tension between Aiken and IBM, as Aiken announced himself as the sole inventor without acknowledging the important role played by IBM.

4.3 Atanasoff-Berry Computer

John Atanasoff (Fig. 4.3) was born in New York in 1903, and he studied electrical engineering at the University of Florida, and did a Masters in Mathematics at Iowa State College. He earned a PhD in theoretical physics from the University of Wisconsin in 1930, and became an assistant professor at Iowa State College, where he taught mathematics and physics.

He became interested in developing faster methods of computation while doing his PhD research, so as to ease the time-consuming burden of calculation. He did some work on an analog calculator in 1936, but he concluded that these devices

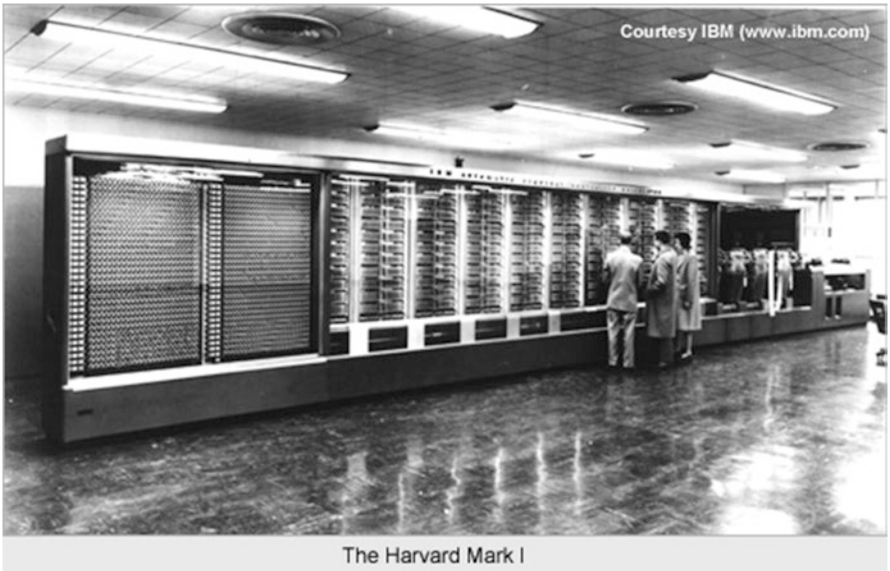

Fig. 4.2 Harvard Mark I (IBM ASCC). (Courtesy of IBM Archives)

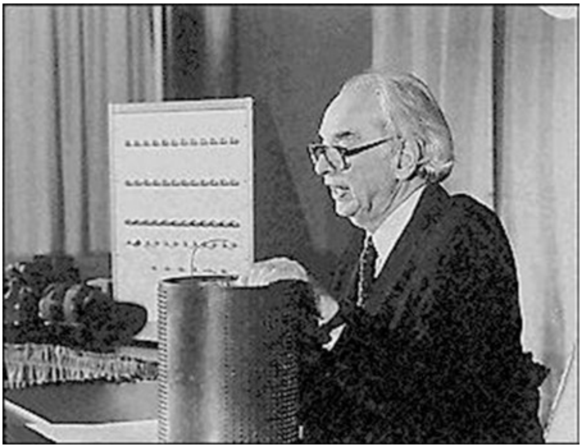

Fig. 4.3 John Atanasoff with components of ABC

were too restrictive and unable to provide the desired accuracy. His goal was to mechanize calculation to enable accurate computation to be carried out faster.

The existing computing devices were mechanical, electromechanical, or analog. Atanasoff developed the concept of digital machine in the late 1930s, and he published his design for a machine to solve linear equations using his own version of Gaussian elimination in the summer of 1939. He then used his research grant of $650 to build the Atanasoff-Berry computer (ABC), with the assistance of his graduate student, Clifford Berry, from 1939 to 1942.

The ABC (Fig. 4.4) was approximately the size of a large desk and had approximately 270 vacuum tubes. Two hundred and ten tubes controlled the arithmetic unit; 30 tubes controlled the card reader and card punch; and the remaining tubes helped maintain charges in the condensers. It employed rotating drum memory, with each of the two drum memory units able to hold thirty 50-bit numbers.

The ABC was a digital machine that was designed for a specific purpose (i.e., solving linear equations) rather than as a general-purpose computer. The working prototype was one of the earliest electronic digital computers.[1] However, the ABC was slow, and it required constant operator monitoring.

It used binary mathematics and Boolean logic to solve simultaneous linear equations. It employed over 270 vacuum tubes for digital computation, but it had no central processing unit (CPU), and it was not programmable.

It weighed over 300 kg and it used 1.6 km of wiring. It used 50-bit numbers, and it could perform 30 additions or subtractions per second. The memory and arithmetic units could operate and store 60 such numbers at a time (60 × 50 = 3000 bits). The arithmetic logic unit was fully electronic, and it was implemented with vacuum tubes.

---

[1] The ABC was ruled to be the first electronic digital computer in the Sperry Rand vs. Honeywell patent case in 1973 (see Sect. 4.4.2). However, Zuse's Z3 computer preceded it (it was completed in 1941).

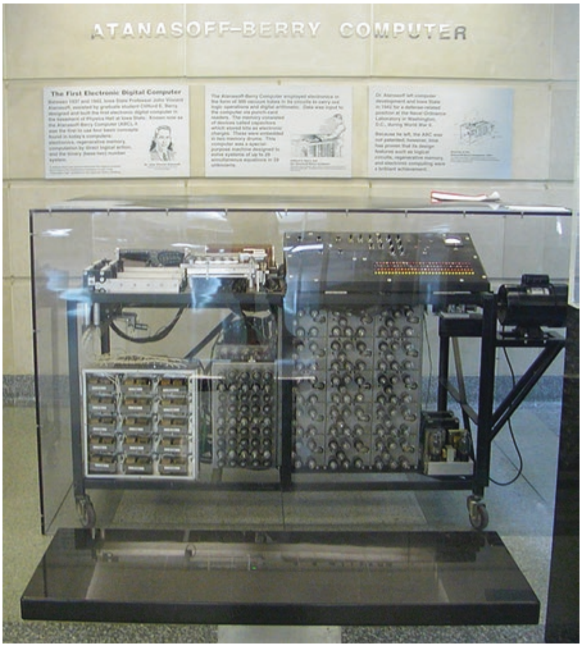

Fig. 4.4 Replica of ABC Computer: Creative Commons.

The input was in decimal format with standard IBM 80 column punch cards, and the output was in decimal format via a front panel display. A paper card reader was used as an intermediate storage device to store the results of operations too large to be handled entirely within electronic memory. The ABC pioneered important elements in modern computing including:

- Binary arithmetic and Boolean logic
- All calculations were performed using electronics rather than mechanical switches
- Computation and memory were separated

The ABC was tested and operational by 1942, and its historical significance is that it demonstrated the feasibility of electronic computing. Several of its concepts were later used in the ENIAC computer developed by Mauchly and Eckert.

4.4 ENIAC and EDVAC

The Electronic Numerical Integrator and Computer (ENIAC) was one of the first large general-purpose digital computers. It was used to integrate ballistic equations, and to calculate the trajectories of naval shells. It was completed in 1946, and it

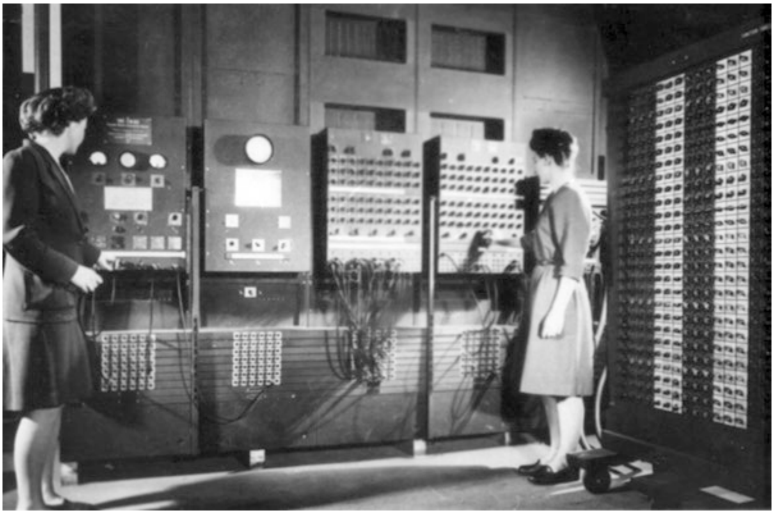

Fig. 4.5 Setting the switches on ENIAC's function tables. Public domain

remained in use until 1955. The original cost of the machine was approximately $500,000.

ENIAC (Fig. 4.5) was a large bulky machine and it was over 100 feet long, 10 feet high, 3 feet deep, and weighed about 30 tons. Its development commenced in 1943 at the University of Pennsylvania, and it was built for the US Army's Ballistics Research Laboratory. The project team included Presper Eckert as chief engineer, John Mauchly as a consultant, and several others. ENIAC had over 18,000 vacuum tubes, and so the machine generated a vast quantity of heat, as each vacuum tube generated heat like a light bulb. The machine used 150 kW of power and air-conditioning was used to cool it.

It employed decimal numerals and it could add five thousand numbers; do over three hundred and fifty 10-digit multiplications; or thirty-five 10-digit divisions in one second. It could be programmed to perform complex sequences of operations, and this included loops, branches, and subroutines. However, the task of taking a problem and mapping it onto the machine was complex, and it usually took weeks to perform. The first step was to determine what the program was to do on paper; the second step was the process of manipulating the switches and cables to enter the program into ENIAC, and this usually took several days. The final step was verification and debugging, and this often involved single-step execution of the machine.

There were problems initially with the reliability of ENIAC, as several vacuum tubes burned out most days (Fig. 4.6). This meant that the machine was often non-functional, as high-reliability vacuum tubes only became available in the late 1940s. However, most of the problems with the tubes occurred during the warm-up and cool-down periods, and it was therefore decided not to turn the machine off. This led

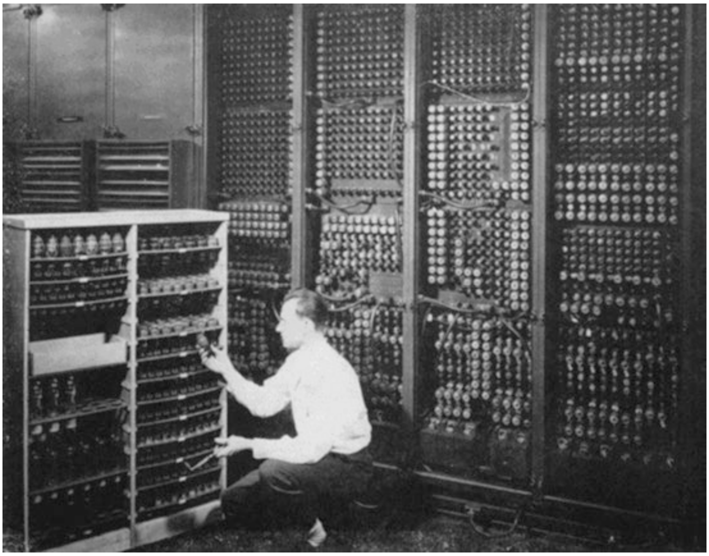

Fig. 4.6 Replacing a valve on ENIAC. Public domain

to improvements in its reliability to the acceptable level of one tube every 2 days. The longest continuous period of operation without a failure was 5 days.

The very first program run on ENIAC took just 20 seconds, and the answer was manually verified to be correct after forty hours of work with a mechanical calculator. One of the earliest problems solved was related to the feasibility of the hydrogen bomb, and this program involved the input of 500,000 punch cards, and it ran for 6 weeks, and gave an affirmative reply.

ENIAC was a *fixed-program* computer, and the machine had to be physically rewired in order to perform different tasks. It was clear that there was a need for an architecture that would allow a machine to perform different tasks without physical rewiring each time. This led to the concept of the *stored program*, which was implemented on EDVAC (the successor to ENIAC).

The idea of a stored program is that the program is stored in memory, and whenever there is a need to change the task that is to be computed, then all that is required is to place a new program in the memory of the computer, rather than rewiring the machine. EDVAC implemented the concept of a stored program in 1949, just after its implementation on the Manchester Baby prototype machine in England. The concept of a stored program and von Neumann architecture is detailed in Von Neumann's report on EDVAC [VN:45].

ENIAC was preceded in development by Zuse's Z3 machine in Germany; the Atanasoff Berry Computer (ABC) in the United States; and the Colossus computer developed in the UK. ENIAC was a major milestone in the history of computing.

4.4.1 EDVAC

The EDVAC (Electronic Discrete Variable Automatic Computer) was the successor to the ENIAC computer. It was a stored-program computer and it cost $500,000. Eckert and Mauchly proposed it in 1944, and design work commenced prior to the completion of ENIAC.

It was delivered to the Ballistics Research Laboratory in 1949, and it commenced operations in 1951. It remained in operations until 1961. It employed 6000 vacuum tubes and its power consumption was 56,000 watts. It had 5.5 Kb of memory.

EDVAC (Fig 4.7) was one of the earliest stored-program computers, and the program instructions were stored in memory, rather than rewiring the machine each time.

4.4.2 Controversy Between the ABC and ENIAC

The ABC computer was ruled to be the first electronic digital computer in the 1973 *Honeywell vs. Sperry Rand* patent court case in the United States. The court case arose from a patent dispute between Sperry and Honeywell, where Sperry was

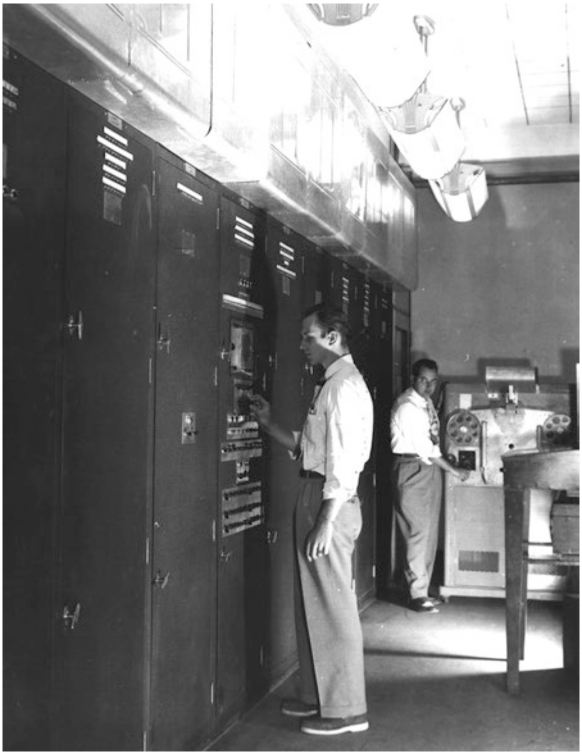

Fig. 4.7 The EDVAC computer. Public domain

charging Honeywell with patent infringement and demanding compensation and royalties. Honeywell countersued and charged Sperry with monopoly and fraud and demanded that the Sperry patent be declared invalid. The ENIAC patent had been lodged in 1947 and was issued in 1964, and the legal proceedings relating to the patent dispute commenced in 1967 and lasted for 6 years.

It is fundamental in patent law that an invention is a novel, and that there is no existing prior art at the time of the patent application. Further, the invention must not be in the public domain at the time of the application, as can happen through a publication or presentation on the invention.

The application for the ENIAC patent was filed in 1947, but there had been a public disclosure of ENIAC in 1946, as well as Von Neumann's draft report on EDVAC in 1945, which legally constituted a publication that disclosed both ENIAC and EDVAC, and in effect placed ENIAC in the public domain. Further, John Atanasoff was called as an expert witness in the case, and the court also ruled that Eckert and Mauchly did not invent the first electronic computer, since the ABC existed as *prior art* at the time of their patent application for ENIAC. This meant that the Mauchly and Eckert patent application for ENIAC was invalid, and John Atanasoff was named as the inventor of the first digital computer.

Mauchly had visited Atanasoff on several occasions prior to the development of ENIAC, and they had discussed the implementation of the ABC computer. Mauchly subsequently designed the ENIAC, EDVAC, and UNIVAC computers. The court ruled that the ABC was the first digital computer, and that the inventors of ENIAC had derived the subject matter of the electronic digital computer from Atanasoff.

4.5 Bletchley Park and Colossus

Tommy Flowers (Fig. 4.8) was a British engineer who made important contributions to breaking the Lorenz codes during the Second World War. He led the team that designed and built Colossus, which was one of the earliest electronic

Fig. 4.8 Tommy Flowers

computers. The machine was designed to decode the top-level encrypted German military communication sent by German High Command to its commanders in the field. This provided British and American Intelligence with important information on German military plans around the D-Day invasion and later battles, and it helped to ensure the success of the Normandy landings and the ultimate defeat of Nazi Germany.

Flowers was born in East London in 1905, and he obtained a position with the telecommunications branch of the General Post Office in 1926. He moved to the research station at Dollis Hill in 1930, and he investigated the use of electronics for telephone exchanges. He was convinced at an early stage that an all-electronic system was possible.

He became involved with the code-breaking work taking place at Bletchley Park (located near Milton Keynes north-west of London) during the Second World War. Alan Turing and others had cracked the German Enigma codes by building a machine known as the Bombe. This machine employed a crib to deduce the settings of the Enigma machine for that day. Turing introduced Flowers to Max Newman who was leading British efforts to break a German cipher generated by the Lorenz SZ42 machine.

Their existing approach to deciphering the Lorenz codes was with the Heath Robinson[2] machine (a slow and unreliable prototype machine containing a small number of vacuum tubes) that was designed by Max Newman and build by the Post Office Research Station at Dollis Hills. Flowers proposed an alternate electronic machine in 1943, and this machine was called Colossus and it employed 1800 thermionic valves. The management at Bletchley Park was skeptical, but they encouraged him to continue with his work.

Flowers and others at the Post Office Research Centre built the machine in 11 months, and its successor, the Mark 2 Colossus, contained 2400 valves and it commenced operations on June 1, 1944. It was a large bulky machine and took up the space of a small room and weighed a ton.

It provided vital information for the Normandy landings, and it confirmed that Hitler had been successfully misled by Allied disinformation into believing that the Normandy landings were to be a diversionary tactic. Further, it confirmed that no additional German troops were to be moved there. The Colossus Mark 2 machine played a key role in helping the British to monitor the German reaction to their deception tactics.

4.5.1 Colossus

Flowers and others designed and built the original Colossus machine at the Post Office Research Station at Dollis Hill in London. The machine was used to find possible key combinations for the Lorenz machines rather than decrypting an

---

[2] William Heath Robinson was an English cartoonist who was well known for drawing elaborate machines to solve simple problems.

intercepted message in its entirety. The Lorenz machine was based on the *Vernam cipher*.

Colossus compared two data streams to identify possible key settings for the Lorenz machine. The first data stream was the encrypted message, and it was read at high speed from a paper tape. The second stream was generated internally, and was an electronic simulation of the Lorenz machine at various trial settings. If the match count for a setting was above a certain threshold, it would be sent as output to an electric typewriter.

The Lorenz codes were a more complex cipher than the Enigma codes, and they were used in the transmission of important messages between the German High Command in Berlin and the military commanders in the field. The Lorenz SZ 40/42 machine performed the encryption. The Bletchley Park code breakers called the typewriter-coding machine "*Tunny*" and the coded messages "*Fish.*" The code-breaking work involved carrying out complex statistical analyses on the intercepted messages.

The Colossus Mark 1 machine was specifically designed for code breaking rather than as a general-purpose computer. It was semi-programmable and helped in deciphering messages encrypted using the Lorenz machine. A prototype was available in 1943 and a working version was available in early 1944 at Bletchley Park. The Colossus Mark 2 (Fig. 4.9) was introduced just prior to the Normandy landings in June 1944.

The Colossus Mark 1 used 15 kW of power and it could process 5000 characters of paper tape per second. It enabled a large amount of mathematical work to be done in hours rather than in weeks. There were ten Colossi machines working at Bletchley Park by the end of the war. A replica of the Colossus was re-built by a team of volunteers led by Tony Sale from 1993 to 1996, and it is at Bletchley Park museum.

The contribution of Bletchley Park to the cracking of the German Enigma and Lorenz codes, and to the development of computing remained clouded in secrecy

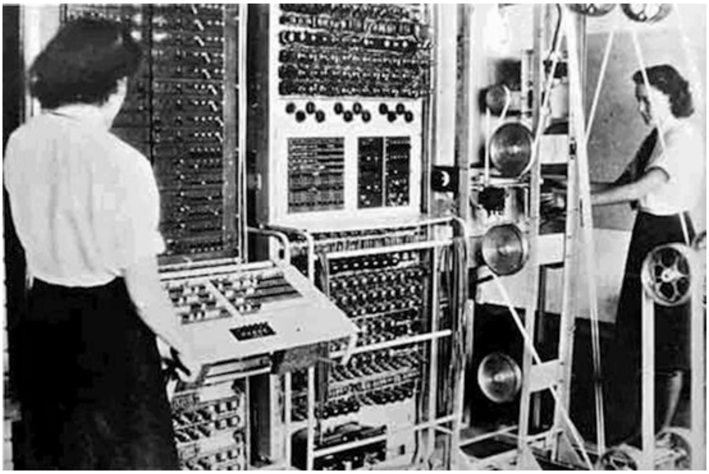

Fig. 4.9 Colossus Mark 2. Public domain

until recent times.[3] The museum at Bletchley Park provides insight to the important contribution made by this organization to code breaking and to early computing during the Second World War.

4.6 Zuse's Machines

Konrad Zuse is considered "*the father of the computer*" in Germany, as he built the world's first programmable machine (the Z3) in 1941 (Fig. 4.10).

He was born in Berlin in 1910, and he studied civil engineering at the Technical University of Berlin. He commenced working for Henschel (an airline manufacturer) after his graduation in 1935. He resigned after 1 year with the intention of forming his own company to build automatic calculating machines.

His parents provided financial support, and he commenced work on what would become the Z1 machine in 1936. Zuse employed the binary system for the calculator and metallic shafts that could shift from position 0 to 1 and vice versa. The Z1 was operational by 1938.

Fig. 4.10 Konrad Zuse. Courtesy of Horst Zuse, Berlin

---

[3] Gordan Welchman was the head of Hut 6 at Bletchey Park and he published his book "The Hut Six Story" in 1982 (in the United States and United Kingdom). However, the security services disapproved of its publication and his security clearance was revoked. He was forbidden to speak of his book and wartime work.

He served in the German Army on the Eastern Front for 6 months in 1939 at the start of the Second World War. Henschel helped Zuse to obtain a deferment from the army, and they made the case that he was needed as an engineer and not as a soldier. Zuse re-commenced working at Henschel in 1940, and he remained affiliated with Henschel for the duration of the war. He built the Z2 and Z3 machines during this period, and the Z3 was operational in 1941, and it was the world's first programmable computer.

He started his own company in 1941, and this was the first company founded with the sole purpose of developing computers. The Z4 was almost complete as the Red Army advanced on Berlin in 1945, and Zuse left Berlin for Bavaria with the Z4 prior to the Russian advance. His other machines were destroyed in the Allied bombing of Germany.

He designed the world's first high-level programming language between 1943 and 1945, and this language was called Plankalkül. He later re-started his company (Zuse KG), and he completed the Z4 in 1950. This was the first commercial computer, as it was completed ahead of the Ferranti Mark 1, Univac, and LEO computers (discussed in Chap. 5). Its first customer was the Technical University of Zurich (ETH).

Zuse's results are all the more impressive given that he was working alone in Germany, and he was unaware of the developments taking place in other countries. There is more detailed information on Zuse in [ORg:13].

4.6.1 Z1, Z2, and Z3 Machines

Zuse was unaware of computer-related developments in Germany or in other countries, and he independently implemented the principles of modern digital computers in isolation.

He commenced work on his first machine called the Z1 in 1936, and the machine was operational by 1938. It was demonstrated to a small number of people who saw it rattle and compute the determinant of a three by three matrix. It was essentially a binary electrically driven mechanical calculator with limited programmability. It was capable of executing instructions read from the program punch cards, but the program itself was never loaded into the memory.

It employed the binary system and metallic shafts that could slide from position 0 to position 1 and vice versa. The machine was essentially a 22-bit floating-point value adder and subtracter. A decimal keyboard was used for input, and the output was decimal digits. The machine included some control logic, which allowed it to perform more complex operations such as multiplications and division. These operations were performed by repeated additions for multiplication, and repeated subtractions for division. The multiplication took approximately 5 seconds. The computer memory contained 64 22-bit words. Each word of memory could be read from and written to by the program punch cards and the control unit. It had a clock speed of 1 Hz, and two floating-point registers of 22 bits each. The machine was unreliable, and a reconstruction of it is in the Deutsches Technikmuseum in Berlin.

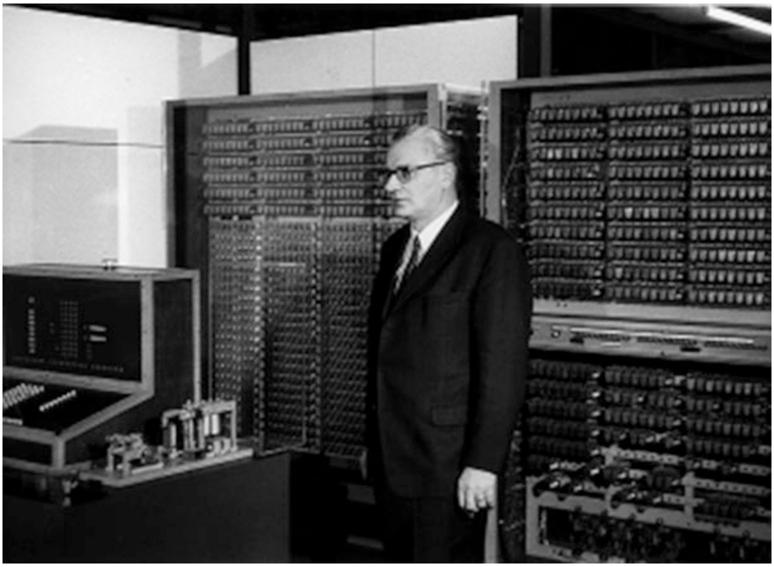

Fig. 4.11 Zuse and the Reconstructed Z3. (Courtesy of Horst Zuse, Berlin)

His Z2 machine aimed to improve on the Z1, and this mechanical and relay computer was created in 1939. It used a similar mechanical memory, but it replaced the arithmetic and control logic with 600 electrical relay circuits. It used 16-bit fixed-point arithmetic instead of the 22-bit used in the Z1. It had a 16-bit word size and the size of its memory was 64 words. It had a clock speed of 3 Hz.

The Z3 machine (Fig. 4.11) was the first functional tape-stored-program-controlled computer, and it was created in 1941. It used 2600 telephone relays; the binary number system; and it could perform floating-point arithmetic. It had a clock speed of 5Hz, and multiplication and division took 3 seconds. The input to the machine was with a decimal keyboard, and the output was on lamps that could display decimal numbers. The word length was 22 bits, and the size of the memory was 64 words.

It used a punched film for storing the sequence of program instructions. It could convert decimal to binary and back again. It was the first digital computer since it pre-dates the Atanasoff-Berry Computer by 1 year. It was proven to be Turing complete in 1998. There is a reconstruction of the Z3 computer in the Deutsches Museum in Munich.

4.7 University of Manchester

The Manchester Small Scale Experimental Computer (better known by its nickname "Baby") was developed at the University of Manchester. It was the *first stored-program computer*, and it was designed and built at Manchester University in England by Frederic Williams, Tom Kilburn, Geoff Tootill, and others.

The machine demonstrated the reliability of the Williams Tube, which was a form of electronic memory based on the cathode ray tube (CRT). The data in the tube could be read and written to, where each memory location contained either a positive charge to represent the binary value 1, with a negative charge representing the binary value 0.

It was the first stored-program computer: Another words the task to be computed is defined by the computer instructions that are placed in memory, and in order to change the task to be computed, all that is required is to load a different program into the computer memory. Kilburn wrote and executed the first stored program, and it was a short 17-instruction program written to determine the highest proper divisor of 2^{18}. The program was successfully executed in 1948 and it ran for 52 minutes.

The prototype "Baby" (Fig. 4.12) demonstrated the feasibility and potential of a stored-program computer. Its memory consisted of 32 × 32-bit words (1024 bits), and it took 1.2 milliseconds to execute one instruction, that is, 0.00083 MIPS (million instructions per second). Today's computers are rated at speeds of thousands of MIPS or billons of instruction per second (GIPS). The team in Manchester developed the machine further, and in 1949, the Manchester Mark 1 was available.

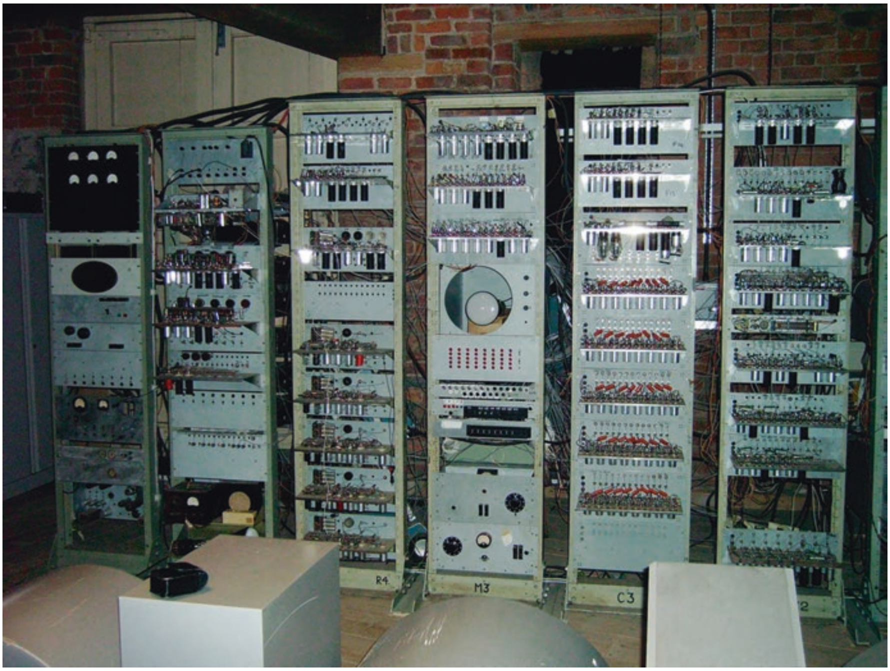

Fig. 4.12 Replica of the Manchester Baby. (Courtesy of Tommy Thomas)

4.7.1 Manchester Mark I

The Manchester Automatic Digital Computer (MADC), also known as the Manchester Mark 1, was developed at the University of Manchester. It was one of the earliest stored-program computers, and it was the successor to the Manchester "Baby" computer. It was designed and built by Williams, Kilburn, and others.

Each word could hold one 40-bit number or two 20-bit instructions. The main memory consisted of two pages (i.e., two Williams tubes with each holding 32 × 40-bit words or 1280 bits). The secondary backup storage was a magnetic drum consisting of 32 pages (this was updated to 128 pages in the final specification). Each track consisted of two pages (2560 bits). One revolution of the drum took 30 milliseconds, and this allowed the 2560 bits to be transferred to the main memory.

The Manchester Mark I (Fig. 4.13) contained 4050 vacuum tubes, and it had a power consumption of 25,000 watts. The standard instruction cycle was 1.8 milliseconds but multiplication was much slower. The machine had 26 defined instructions, and the programs were entered into the machine in binary format, as assembly languages and assemblers were not yet available.

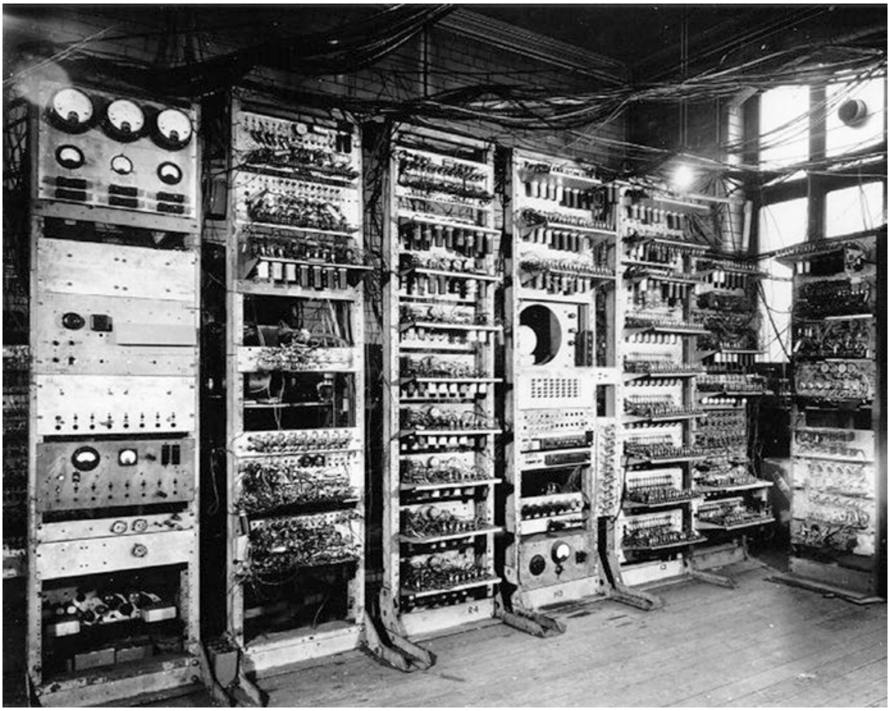

Fig. 4.13 The Manchester Mark 1 computer

It had no operating system and its only systems software were some basic routines for input and output. Its peripheral devices included a teleprinter and a 5-hole paper tape reader and punch.

A display terminal used with the Manchester Mark 1 computer mirrored what was happening within the Williams Tube. A metal detector plate placed close to the surface of the tube detected changes in electrical charges. The metal plate obscured a clear view of the tube, but the technicians could monitor the tubes used with a video screen. Each dot on the screen represented a dot on the tube's surface, and the dots on the tube's surface worked as capacitors that were either charged and bright or uncharged and dark. The information translated into binary code (0 for dark, 1 for bright) became a way to program the computer.

The Manchester Mark I influenced later computer development such as Ferranti's Mark I general-purpose computer which was released in 1951, as well as early IBM computers such as the IBM 701.

4.8 Review Questions

1. Explain the significance of the ABC computer.
2. Explain what is meant by a "stored program" computer, and its advantages over a fixed-program machine such as ENIAC.
3. Explain why Konrad Zuse is considered the father of the computer in Germany.
4. Explain the significance of the Manchester Baby computer.
5. Explain the significance of the work done at Bletchley Park during the Second World War.
6. Explain the significance of the Harvard Mark I?

4.9 Summary

This chapter discussed some of the early computers developed in the United States, Britain, and Germany. These were mainly large bulky machines consisting of several thousand vacuum tubes. A computer often took up the space of a large room, and it was slow and unreliable.

We discussed the Harvard Mark I which was a large electromechanical calculator that was designed by Howard Aiken. Atanasoff and Berry designed and developed the ABC computer, and this machine was designed to solve a set of linear equations. Mauchly and Eckert designed the ENIAC and EDVAC computers, and the EDVAC computer implemented the concept of a stored program.

The team at Bletchley Park in England designed and developed the COLOSSUS computer as part of their code-breaking work. This allowed them to crack the

German Lorenz codes, and to provide important military information during the D-Day landings of 1944.

Konrad Zuse designed and developed the Z1, Z2, and Z3 machines in Germany. The Z3 was operational in 1941 and it was the world's first programmable computer. Williams, Kilburn, and others implemented the first stored-program computer. This machine was popularly known as the Manchester Baby.