# = Manchester Small @-@ Scale Experimental Machine =

The Manchester Small @-@ Scale Experimental Machine ( SSEM ) , nicknamed Baby , was the world 's first stored @-@ program computer . It was built at the Victoria University of Manchester , England , by Frederic C. Williams , Tom Kilburn and Geoff Tootill , and ran its first program on 21 June 1948 .

The machine was not intended to be a practical computer but was instead designed as a testbed for the Williams tube , an early form of computer memory . Although considered " small and primitive " by the standards of its time , it was the first working machine to contain all the elements essential to a modern electronic computer . As soon as the SSEM had demonstrated the feasibility of its design , a project was initiated at the university to develop it into a more usable computer , the Manchester Mark 1 . The Mark 1 in turn quickly became the prototype for the Ferranti Mark 1 , the world 's first commercially available general @-@ purpose computer .

The SSEM had a 32 @-@ bit word length and a memory of 32 words . As it was designed to be the simplest possible stored @-@ program computer , the only arithmetic operations implemented in hardware were subtraction and negation ; other arithmetic operations were implemented in software . The first of three programs written for the machine found the highest proper divisor of 218 ( 262 @,@ 144 ) , a calculation that was known would take a long time to run ? and so prove the computer 's reliability ? by testing every integer from 218 ? 1 downwards , as division was implemented by repeated subtraction of the divisor . The program consisted of 17 instructions and ran for 52 minutes before reaching the correct answer of 131 @,@ 072 , after the SSEM had performed 3 @.@ 5 million operations ( for an effective CPU speed of 1 @.@ 1 kIPS ) .

## = = Background = =

The first design for a program @-@ controlled computer was Charles Babbage 's Analytical Engine in the 1830s . A century later , in 1936 , mathematician Alan Turing published his description of what became known as a Turing machine , a theoretical concept intended to explore the limits of mechanical computation . Turing was not imagining a physical machine , but a person he called a " computer " , who acted according to the instructions provided by a tape on which symbols could be read and written sequentially as the tape moved under a tape head . Turing proved that if an algorithm can be written to solve a mathematical problem , then a Turing machine can execute that algorithm .

Konrad Zuse 's Z3 was the world 's first working programmable , fully automatic computer , with binary digital arithmetic logic , but it lacked the conditional branching of a Turing machine . On 12 May 1941 , it was successfully presented to an audience of scientists of the Deutsche Versuchsanstalt für Luftfahrt ( " German Laboratory for Aviation " ) in Berlin . The Z3 stored its program on an external tape , but it was electromechanical rather than electronic . The Colossus of 1943 was the first electronic computing device , but it was not a general @-@ purpose machine .

The ENIAC ( 1946 ) was the first machine that was both electronic and general purpose . It was Turing complete , with conditional branching , and programmable to solve a wide range of problems , but its program was held in the state of switches in patchcords , not in memory , and it could take several days to reprogram . Researchers such as Turing and Zuse investigated the idea of using the computer 's memory to hold the program as well as the data it was working on , but it was mathematician John von Neumann who became widely credited with defining that computer architecture , still used in almost all computers .

The construction of a von Neumann computer depended on the availability of a suitable memory device on which to store the program . During the Second World War researchers working on the problem of removing the clutter from radar signals had developed a form of delay line memory , the first practical application of which was the mercury delay line , developed by J. Presper Eckert . Radar transmitters send out regular brief pulses of radio energy , the reflections from which are displayed on a CRT screen . As operators are usually interested only in moving targets , it was desirable to filter out any distracting reflections from stationary objects . The filtering was achieved

by comparing each received pulse with the previous pulse , and rejecting both if they were identical , leaving a signal containing only the images of any moving objects . To store each received pulse for later comparison it was passed through a transmission line , delaying it by exactly the time between transmitted pulses .

Turing joined the National Physical Laboratory ( NPL ) in October 1945 , by which time scientists within the Ministry of Supply had concluded that Britain needed a National Mathematical Laboratory to coordinate machine @-@ aided computation . A Mathematics Division was set up at the NPL , and on 19 February 1946 Alan Turing presented a paper outlining his design for an electronic stored @-@ program computer to be known as the Automatic Computing Engine ( ACE ) . This was one of several projects set up in the years following the Second World War with the aim of constructing a stored @-@ program computer . At about the same time , EDVAC was under development at the University of Pennsylvania 's Moore School of Electrical Engineering , and the University of Cambridge Mathematical Laboratory was working on EDSAC .

The NPL did not have the expertise to build a machine like ACE , so they contacted Tommy Flowers at the General Post Office 's ( GPO ) Dollis Hill Research Laboratory . Flowers , the designer of Colossus , the world 's first programmable electronic computer , was committed elsewhere and was unable to take part in the project , although his team did build some mercury delay lines for ACE . The Telecommunications Research Establishment ( TRE ) was also approached for assistance , as was Maurice Wilkes at the University of Cambridge Mathematical Laboratory .

The government department responsible for the NPL decided that , of all the work being carried out by the TRE on its behalf , ACE was to be given the top priority . NPL 's decision led to a visit by the superintendent of the TRE 's Physics Division on 22 November 1946 , accompanied by Frederic C. Williams and A. M. Uttley , also from the TRE . Williams led a TRE development group working on CRT stores for radar applications , as an alternative to delay lines . He had already accepted a professorship at the University of Manchester , and most of his circuit technicians were in the process of being transferred to the Department of Atomic Energy . The TRE agreed to second a small number of technicians to work under Williams ' direction at the university , and to support another small group working with Uttley at the TRE .

= = Williams ? Kilburn tube = =

Although early computers such as EDSAC made successful use of mercury delay line memory , the technology had several drawbacks ; it was heavy , it was expensive , and it did not allow data to be accessed randomly . In addition , because data was stored as a sequence of acoustic waves propagated through a mercury column , the device 's temperature had to be very carefully controlled , as the velocity of sound through a medium varies with its temperature . Williams had seen an experiment at Bell Labs demonstrating the effectiveness of cathode ray tubes ( CRT ) as an alternative to the delay line for removing ground echoes from radar signals . While working at the TRE , shortly before he joined the University of Manchester in December 1946 , he and Tom Kilburn had developed a form of electronic memory known as the Williams or Williams ? Kilburn tube based on a standard CRT , the first random @-@ access digital storage device . The Manchester Small @-@ Scale Experimental Machine ( SSEM ) was designed to show that the system was a practical storage device , by testing that data held within it could be read and written at the speed necessary for use in a computer .

For use in a binary digital computer , the tube had to be capable of storing either one of two states at each of its memory locations , corresponding to the binary digits ( bits ) 0 and 1 . It exploited the positive or negative electrostatic charge generated by displaying either a dash or a dot at any position on the CRT screen , a phenomenon known as secondary emission . A dash generated a positive charge , and a dot a negative charge , either of which could be picked up by a detector plate in front of the screen ; a negative charge represented 0 , and a positive charge 1 . The charge dissipated in about 0 @.@ 2 seconds , but it could be automatically refreshed from the data picked up by the detector .

The Williams tube was initially based on the CV1131 , a commercially available 12 @-@ inch ( 300 mm ) diameter CRT , but a smaller 6 @-@ inch ( 150 mm ) tube , the CV1097 , was used in the SSEM .

= = Development and design = =

Following his appointment to the Chair of Electrical Engineering at Manchester University , Williams recruited his TRE colleague Tom Kilburn on secondment . By the autumn of 1947 the pair had increased the storage capacity of the Williams tube from one bit to 2 @,@ 048 , arranged in a 64 by 32 @-@ bit array , and demonstrated that it was able to store those bits for four hours . Engineer Geoff Tootill joined the team on loan from TRE in September 1947 , and remained on secondment until April 1949 .

Max Newman had been appointed to the Chair of Pure Mathematics at Manchester University in 1945 . During the Second World War he had worked as a cryptanalyst at Bletchley Park , and had led the team which in 1943 produced the first of the Colossus code @-@ breaking computers . Although Newman played no active role in the development of the SSEM , or any of the subsequent Manchester computers , he was generally supportive and enthusiastic about the project , and arranged for the acquisition of war @-@ surplus supplies for its construction , including GPO metal racks from Bletchley .

By June 1948 the SSEM had been built and was working . It was 17 feet ( 5 @.@ 2 m ) in length , 7 feet 4 inches ( 2 @.@ 24 m ) tall , and weighed almost 1 long ton ( 1 @.@ 0 t ) . The machine contained 550 valves ? 300 diodes and 250 pentodes ? and had a power consumption of 3500 watts . The arithmetic unit was built using EF50 pentode valves , which had been widely used during wartime . The SSEM used one Williams tube to provide 32 by 32 @-@ bit words of random @-@ access memory ( RAM ) , a second to hold a 32 @-@ bit accumulator in which the intermediate results of a calculation could be stored temporarily , and a third to hold the current program instruction along with its address in memory . A fourth CRT , without the storage electronics of the other three , was used as the output device , able to display the bit pattern of any selected storage tube .

Each 32 @-@ bit word of RAM could contain either a program instruction or data . In a program instruction , bits 0 ? 12 represented the memory address of the operand to be used , and bits 13 ? 15 specified the operation to be executed , such as storing a number in memory ; the remaining 16 bits were unused . The SSEM 's single operand architecture meant that the second operand of any operation was implicit : the accumulator or the program counter ( instruction address ) ; program instructions specified only the address of the data in memory .

A word in the computer 's memory could be read , written , or refreshed , in 360 microseconds . An instruction took four times as long to execute as accessing a word from memory , giving an instruction execution rate of about 700 per second . The main store was refreshed continuously , a process which took 20 milliseconds to complete , as each of the SSEM 's 32 words had to be read and then refreshed in sequence .

The SSEM represented negative numbers using two 's complement , as most computers still do . In that representation , the value of the most significant bit denotes the sign of a number ; positive numbers have a zero in that position and negative numbers a one . Thus the range of numbers that could be held in each 32 @-@ bit word was ? 231 to + 231 ? 1 ( decimal : ? 2 @,@ 147 @,@ 483 @,@ 648 to + 2 @,@ 147 @,@ 483 @,@ 647 ) .

= = Programming = =

The SSEM 's three bit instruction set allowed a maximum of eight ( 23 ) different instructions . In contrast to the modern convention , the machine 's storage was arranged with the least significant digits to the left ; thus a one was represented in three bits as " 100 " , rather than the more conventional " 001 " .

The awkward negative operations were a consequence of the SSEM 's lack of hardware to perform

any arithmetic operations except subtraction and negation . It was considered unnecessary to build an adder before testing could begin as addition can easily be implemented by subtraction , i.e. x + y can be computed as ? ( ? x ? y ) . Therefore , adding two numbers together , X and Y , required four instructions :

 LDN X / / load negative X into the accumulator
 SUB Y / / subtract Y from the value in the accumulator
 STO S / / store the result at S
 LDN S / / load negative value at S into the accumulator

 Programs were entered in binary form by stepping through each word of memory in turn , and using a set of 32 switches known as the input device to set the value of each bit of each word to either 0 or 1 . The SSEM had no paper @-@ tape reader or punch .

= = = First programs = = =

 Three programs were written for the computer . The first , consisting of 17 instructions , was written by Kilburn , and so far as can be ascertained first ran on 21 June 1948 . It was designed to find the highest proper factor of 218 ( 262 @,@ 144 ) by trying every integer from 218 ? 1 downwards . The divisions were implemented by repeated subtractions of the divisor . The SSEM took 3 @.@ 5 million operations and 52 minutes to produce the answer ( 131 @,@ 072 ) . The program used eight words of working storage in addition to its 17 words of instructions , giving a program size of 25 words .

 Geoff Tootill wrote an amended version of the program the following month , and in mid @-@ July Alan Turing ? who had been appointed as a reader in the mathematics department at Manchester University in September 1948 ? submitted the third program , to carry out long division . Turing had by then been appointed to the nominal post of Deputy Director of the Computing Machine Laboratory at the university , although the laboratory did not become a physical reality until 1951 .

= = Later developments = =

 Williams and Kilburn reported on the SSEM in a letter to the Journal Nature , published in September 1948 . The machine 's successful demonstration quickly led to the construction of a more practical computer , the Manchester Mark 1 , work on which began in August 1948 . The first version was operational by April 1949 , and it in turn led directly to the development of the Ferranti Mark 1 , the world 's first commercially available general @-@ purpose computer .

 In 1998 , a working replica of the SSEM , now on display at the Museum of Science and Industry in Manchester , was built to celebrate the 50th anniversary of the running of its first program . Demonstrations of the machine in operation are held regularly at the museum . In 2008 , an original panoramic photograph of the entire machine was discovered at the University of Manchester . The photograph , taken on 15 December 1948 by a research student , Alec Robinson , had been reproduced in The Illustrated London News in June 1949 .