The Electronic REVOLUTION

The idea of the computer occurred long before the required technology was available. Here's a brief history of how that technology developed.

IT IS VERY rarely indeed that the birth of a new era can be located exactly on a particular day. The explosion of the first atomic bomb on 16th July, 1945 at Alamogordo, New Mexico is the twentieth century's most obvious candidate for the title of a day which changed the world for ever. But there have been a few others, and the events of 23rd December 1947 at the Bell Laboratories certainly give that date a strong claim to be one of history's great turning points. On that day the world's first transistor was made to work.

Some inventions creep up upon the world rather than burst upon it. Faraday's magnetic induction demonstration in August 1831 took a good half-century to turn into even the beginnings of an electric power industry while radio dawned so gradually that we cannot even say with [illegible] certainty who transmitted the first signal. Some inventions, like television, were eagerly awaited for decades before anyone could produce a workable system, while others like radio-telephony lay around for years before anybody realised what could be done with them.

But the transistor fell into none of these categories. Its birth that day represented the pinnacle of nearly thirty years' concentrated research by some of the most talented physicists in the world, all labouring with the conscious aim of constructing a solid-state analogue of the radio tube. And over the previous three years, Bell Labs alone had invested several million dollars and some of its best researchers in the project. Nor were the implications of the event lost on those present. No one had much idea of the sort of world that the transistor would have produced thirty-five years later, but all those who were there seem to have been conscious that something out of the ordinary had happened and that things would never be the same again. In the event it took a decade for the transistor to be perfected and built into electronic technology, but when this happened it pushed the science of electronics into an age of exponential growth which has done more to change the world in the last generation than steam did in the two centuries before that.

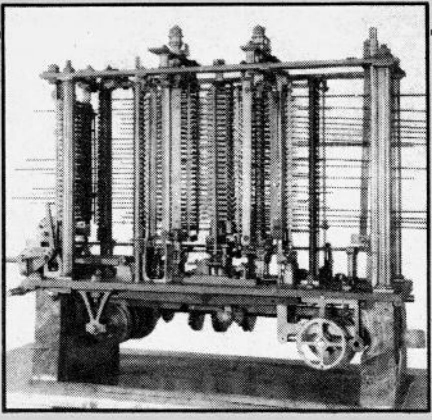
Like its near-contemporary, the atom bomb, the transistor is a classic case of development not by technological push, but by demand-pull. The state wanted the bomb and the corporations wanted the transistor for their own purposes, and both were prepared, whether the project turned out to be feasible or not, to invest any amount of money and time and research talent towards achieving it.

The idea of solid-state transducer was almost as old as radio itself. In fact, radio wave detection began with a primitive semi-conductor, the coherer, and continued for many years afterwards with another form of the semi-conductor in the shape of the crystal detector. Looking back, you might almost see the half century of thermionic tube development following Fleming's diode of 1904 as a blind alley in electronics history. Tubes came in largely to make up for the deficiencies of the crystal detector: its fragility, its need for constant delicate adjustment and above all it puny current output. Tube manufacture began by having access to all the resources and experience of the light-bulb industry out of which it had accidentally sprung, and the tube's versatility as oscillator, detector or amplifier led to it dominating radio from about 1919 onwards.

Down The Tubes

Tube design became remarkably sophisticated between the Wars in the hands of specialists like Philips of Eindhoven, and the Second World War produced great advances in miniaturization. But even in the 1930s it was beginning to be apparent that the law of diminishing returns applied to tube development as to everything else. Research and development could reduce some of the tube's many drawbacks, but could never abolish them: its size, its fragility, the expense of its manufacture, its large power requirement, its need for cooling (40 gallons of water per minute for some of the giant transmitter tubes of the mid-1920s) and its highly unpredictable life-span. For these reasons interest in semi-conductors never died away, despite the apparent death of the crystal receiver some time after 1930. For one thing, pure undirected speculative research went its own sweet way during the 1920s and 1930s. Physicists like Pohl at Gottingen University carried on a long pre-1914 tradition of research into the electrical properties of crystals, though this was sometimes more by accident than by design, as in Pohl's case, where Germany's ruined economy in the years after 1918 prevented him from getting hold of liquid oxygen to study gas conductivity and obliged him to look at solids instead.

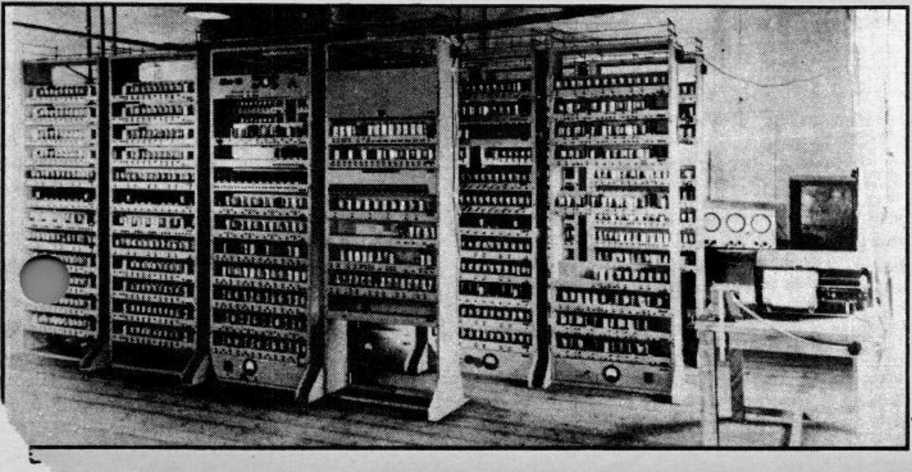
Most of this research was quite innocent of any immediate practical application but, at the back of it, the idea of a solid-state analogue to the tube was never far away. One Lilienfeld patented a crystal amplifier in Germany in 1925, though none was ever built and argument goes on to this day as to whether the thing would ever have worked if it had been. All experimenters had to grapple with serious problems in getting crystals pure enough to experiment with, but gradually some substances began to emerge as front-runners. Copper oxide was in common use as a rectifier during the early 1930s, and in 1935 Oskar Heil attempted to build a field-effect amplifier by passing a current through a slab of the stuff forming one side of a capacitor: an idea which was to be taken up again by Bell after 1945, but which was eventually beaten by electron retention at the slab's surface. Embedding an electrode in a crystal to modulate the current passing through it was the obvious next step, and in 1938 Pohl and Hilsch in Germany announced that they were confident of soon being able to use this technique with a potassium bromide crystal to produce the long-sought successor to the triode tube.



Babbage's "Analytical Engine" was perhaps the earliest computer — a machine designed specifically for performing mathematical calculations.

Enter Germanium . . .

The war which broke out the following year brought most German research to a halt. But in the end it was the war's demands which forced development of the transistor ahead once more, and in particular the development by the Allies, circa 1942, of centimetric radar. Ordinary radio tubes had too high a capacitance to detect the returning signal, so the crystal detector was brought out of retirement — this time in the form of a silicon crystal touched by a tungsten cat's whisker. It worked, but not very well, so germanium was investigated as a substitute. The Massachusetts Institute of Technology and about forty other US research institutions got to work on the problem, and by late 1943 germanium detectors were available which could handle up to 150 volts.



More than a hundred years after Babbage, the ESDAC I computer was built in Cambridge. It was no smaller, but a lot faster!

When the war ended, the research team at Bell Labs, Brattain, Bardeen and Shockley, were tinkering once more with the field-effect transistor, though this time as part of a vast programme aimed at producing reliable solid-state equivalents of the tube. The field-effect approach was eventually defeated by the surface retention which had beaten Heil a decade earlier. But point-contacts with a germanium crystal turned out to be far more promising. It was a semi-conductor of this type, soon to be christened the transistor, which was successfully tested at Bell Labs two days before Christmas, 1947. The more familiar junction transistor followed soon afterwards and the first public demonstration was given at the end of June, 1948.

Contrary to later legend, Bell was anxious from the very first to get the transistor as widely used as possible as soon as possible. To this end it was prepared to grant manufacturing rights at very favourable terms. For the first few years, though, there were few takers. Up until the spring of 1953, in fact, the main optant was the hearing-aid manufacturer Raytheon which was not too concerned about sound quality so long as it could get miniature, low-power amplifiers. Radio, television, the telephone manufacturers and (strangely enough) the military showed very little interest at first. True, apart from its size and its low power requirement, the transistor offered few immediate advantages over tubes. The first generation were noisy, expensive (about eight times the price of an equivalent tube in 1950), limited in the voltages they could tolerate and limited in their frequency response. Manufacturing methods were often astonishingly haphazard by the standards of a generation later, not so much designing a batch of transistors to fit a desired range of characteristics, but rather making the batch and then sifting out those transistors which measured up to the requirements. And there was always the problem of minute traces of impurity left in the crystals, known collectively as 'sudden-deathnium', and the reason for the failure of many early semi-conductors. But above all these difficulties there was the attitude of the industry itself. Though interested in solid-state devices, the engineers of the great American and European electronics firms were men who had grown up with tubes from their earliest youth. For this reason they tended to regard the transistor as a mere tube-substitute until well into the 1950s, by which time it was establishing itself as a technology in its own right and developing the sub-technology of small-scale integrat-

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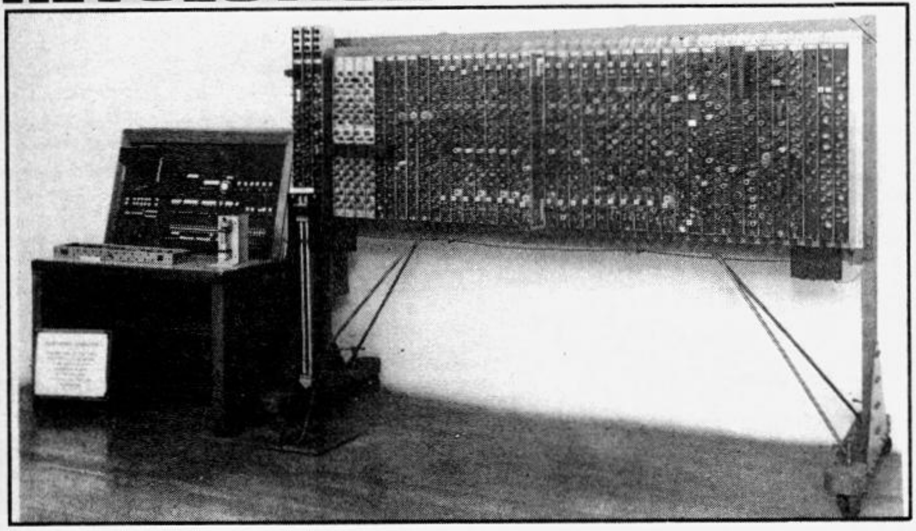


The ACE computer, built in 1950, still used tubes, though less of them than its predecessor ESDAC.

ed circuitry which was to lead to the micro-chip in the early 1970s. This conservatism may have had a great deal to do with the electronics industry's great migration to the Far East from the late 1950s onwards.

The thing that really made the transistor's fortunes, though, was the providential development, at about the same time, of the digital computer. But unlike the transistor, the computer was not propelled into an eagerly waiting world by a massive research program. Instead it crept up on an almost unaware human race.

The idea of calculating by machine was scarcely a new one in the late 1940s when the electronic computer began to dawn upon the public consciousness. The abacus, Napier's bones, the slide rule (remember the slide rule?), Pascal's calculator and the Burroughs comptometer were all attempts — more or less unsatisfactory — to rid calculation of some of that mind-numbing drudgery involved in projects like the one, about 1840, which had an entire company of Prussian army engineers scribbling away for six months to calculate the curvature of a single lens. In 1833, the mathematician Charles Babbage had designed (but not built) his Analytical Engine — the world's first project for an analogue computer with input, ouput and some sort of memory. At the very end of the nineteenth century, the increasing demands of each successive US census had produced a number of increasingly elaborate card-processing machines to deal with the returns. But true computers required an accuracy far beyond the reach of even early twentieth century precision engineering, and in the mid-1930s, the tube began to be built into electronic analogue calculating machines at Harvard University and Bell Labs.

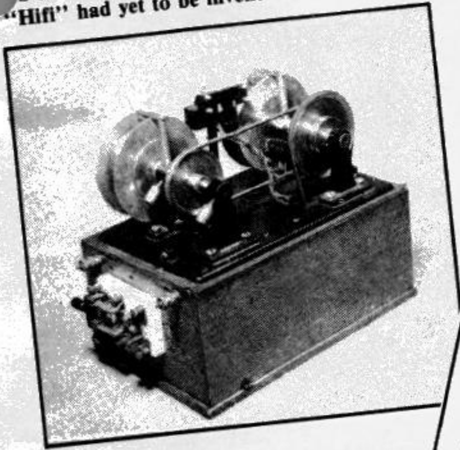
As with the transistor, the demands of the Second World War pushed development forward and began the transition from calculator to true computer. Not only the Manhattan atomic bomb project but also ballistics trials required calcuations of an unheard-of complexity, far beyond the capacity of human beings working unaided. And in this area, the Harvard Mark 1 electronic calculator was able to score a notable triumph in 1942 when it predicted — correctly, as it turned out — that the German army would never get anywhere with the electrically powered long-range gun which it was trying to build. Meanwhile, across the Atlantic, the Enigma code-breaking operation required the building of a succession of increasingly powerful electronic cipher-machines at Bletchley Park. On a more mundane level, the vast complexity of modern armed forces led to the development of electronic personnel selectors in an effort to sort out the right man for the job from among the millions available. Evelyn Waugh's novel *Sword of Honour* mentions one of these latter contraptions installed in a War Department office in London circa 1943. And beyond the strictly technical considerations of electronic systems design, the war led to the first concentrated, systematic study of operational logic, information flow and decision-making — all areas essential to the creation of artificial intelligence after the war was over.

. . . And The Computer

The value of electronic calculation was s evident by the time the war ended that th US Government was keen to sponsor the building of the first true electronic analogue computer ENIAC at the University of Pennsylvania in 1946. The previous year John von Neumann had suggested the use of the binary system for electronic calculation, and after Cambridge University's EDSAC in 1947, all computers went over to digital operation. Meanwhile, Pennsylvania University was building ENIAC's successor EDVAC with the first magnetic core memory, and computers were moving outside the field of strictly scientific calculation with the US Air Force's Whirlwind flight-simulator. Likewise, the universities and government departments lost their monopoly of computer ownership in 1952 when GEC acquired its Univac I, the first computer in the world to be owned by a private firm.

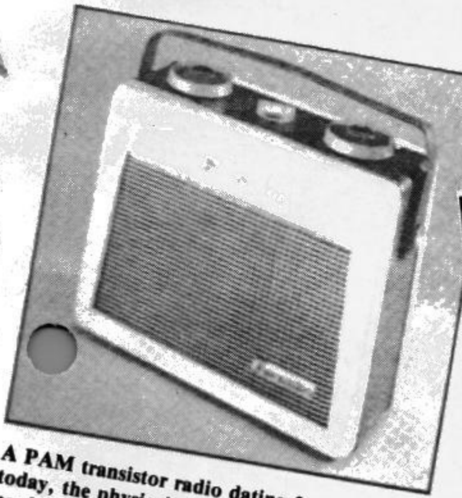
The trouble with these early computers was their sheer size and unreliability. Bell's Model V in 1944 contained over 9,000 tube relays and fifty pieces of teletype equipment. It weighed ten tons and took up over a thousand square feet of floor space. Heat dispersal from these forests of tubes was a major problem and power requirements were vast. ENIAC used 130kW and is said to have dimm lights over half of Philadelphia when was switched on. Above all, down-time was huge, given the number of tubes, their unreliability and the difficulty of getting at them to replace them. When it arrived on the scene at the end of the 1940s, the transistor was the answer to the computer builder's prayers, with its miniscule size, cool operation, low power requirement and — post 1953 or thereabouts — long life. From about 1955 onwards, the tube began to be ousted by the transistor in computer construction, and as the transistor took over, the computer began to move out into the world.

At the end of the 1940s the experts had confidently predicted that a country like Britain would never need more than two or three computers to serve all its needs, while the USA itself would only require a hundred at most. But as is the way with these things, the increase in supply created its own demand. As the computer became smaller and cheaper, it was found that more and more previously manual administration jobs could be handed over to the machine — not just censuses and scientific calculation, but banking and payrolls and stock control and police records. From then on it began to aff the lives of every one of us. Computer a transistor were the twin foundations of the post-1945 electronic age, and neither could really have existed without the other.



Poulsen's "Telegraphone" was patented in the S in 1898 and used mainly as a dictaphone. "Hifi" had yet to be invented!

The "Walkman" and similar cassette players probably represent the ultimate in personal hifi.



A PAM transistor radio dating from 1956. As today, the physical size was determined by the need for a relatively large loudspeaker.

The modern tape recorder was developed in Germany during World War II, when it was used to replay and broadcast speeches by the Nazi leaders.

The miniaturization of electronics made possible by the semi-conductors, and the durability and low power consumption which they brought with them, caused another great leap forward (or upward) in the second half of the 1950s. After all, where would space exploration be if it relied upon tubes? The nasty blow dealt to American prestige by the launching of the Sputnik in October, 1957 led directly to the race to the moon. But so far as this century is concerned, its most important consequence may turn out to have been the birth of space communications. As early as 1928 the German rocket pioneer Hans Oberth had suggested space relay stations in geosynchronous orbit 22.300 miles above the Earth, though in case he proposed beaming messages up and down by heliograph because of the limited power available from the transmitters of the day. And this idea was taken up again by Arthur C. Clarke in 1945. But it was not until the late 1950s that the idea came anywhere near realization when the United States launched its first Echo communications relay satellites.

These were passive reflectors — mere balloons of metallized PVC which were supposed to act as mirrors for microwave signals. They were not particularly successful, and it was not until July, 1962 that the first active relay satellite, Telstar I, was put into orbit, powered by solar cells and capable of redirecting TV signals for the part of the day when it was above the horizon. Geosynchronous orbit followed with the Syncom series of satellites launched from February 1963 onwards. By 1980, upwards of fifty communications satellites were in orbit with a further fifty planned. The tariffs demanded by the international Intelsat corporation were too high at first for more than a minimal amount of direct TV broadcasting via satellite, but from the mid-1970s onwards, US television networks and Third World governments alike began to see the advantages of a satellite-based TV system. And not only the advantages of satellite TV but also the benefits of secure telephone communications and computer data links of a hitherto unimaginable speed and purity. Again, once the transistor made it possible, people began to think of needs they had never considered before.

Getting Taped

This kind of self-sustaining growth, with new developments creating demand and demand calling forth new developments, has been particularly noticeable in the world of home entertainment over the past eight-odd years. Radio and television we all know about, of course. But what about recorded music? After all, one of radio's first and greatest conquests in the late 1920s was its absorption, for a time at any rate, of the gramophone — previously a scratchy, faint-sounding, clockwork instrument, but transformed by the tube, the loudspeaker and electric drive into a robust, reliable means of entertainment. The great success story of the age, however, was the tape recorder. The idea of recording sound on magnetic steel wire had been suggested as far back as 1888. But it was ten years before the Danish inventor Valdemar Poulsen took out a US patent on his Telegraphone. This operated by means of clockwork-driven spools passing wire through a magnetizing/demagnetizing coil at a rate of 7 feet per second. It was hailed as a major new discovery when it appeared on the market and Poulsen set up the American Telegraphone Company to sell it, but in the end the idea came to nothing. The machine's frequency response was too poor for use as anything except an office dictaphone and the wire suffered from an incurable tendency to twist and stretch — as well as occasionally snapping and

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slashing around at high speed until the spools could be stopped. (Wire recording was eventually used for aircraft flight recorders, because of its robustness, but it was decidedly not bound for the entertainment industry.) All the same, interest never died away completely, and post1918 AEG, Bell, 3-M and the US Naval Research Laboratories were all looking into the idea.

In 1928, the German researcher Pflumer abandoned wire in favour of paper tape coated with iron oxide. Meanwhile the Magnetophon company, also in Germany, worked on plastic-based tape. The Blattner system — used by the BBS for studio recording from 1934 onwards — favoured steel tape which had the disadvantage of having to be cut with shears and spot-welded in splices which went through the heads with a deafening clatter. But during the early 1930s magnetic tape recording was upstaged by the photo-optical system developed for the talking films.

Interest picked up once more during World War II, and the German Magnetophon system began to pull ahead of its nearest American rival Brush. It was strongly sponsored by the German Propaganda Ministry, who found its acoustic accuracy and the portability of the tapes very useful for broadcasting speeches by the Nazi leadership at times and places which would puzzle Allied intelligence. The result was that by 1945 Magnetophon tape recorders were way ahead of anything that the Allies could produce, with a frequency response of up to 10kHz. American scientists were highly impressed by German recorders captured at the end of the war, and after several years' work to perfect tape-coatings tape recorders began to appear on the US domestic entertainment market. Meanwhile, small battery-powered tape recorders came to replace wax-disc machines in radio outside broadcasting, doing away with the need for a technician to sit beside the machine with a camel hair brush to get rid of the debris thrown up by the needle. The only technological developments which stood between the tape recorder and a mass prerecorded music market were the compact cassette to do away with the need for threading the tape (introduced by Philips in 1963), and CrO_2 tape (launched by Dupont five years later). Once these were achieved, hifi came to be a feature of most households with any pretensions to civilization.

Once sound recording on magnetic tape had become an established technology, it was only natural that people should begin to think of some better means of recording TV programs than merely pointing a cine-camera at the screen. It is odd to remember, though, that video recording is an idea as old as television itself. In 1930 the Baird Television Company had tried to market shellac video discs with its 'Televisor' receivers — no great problem in theory, since all the disc had to do was to vary the output of a neon lamp shining through a Nipkow disc onto the back of a ground glass screen. The Baird discs turned out to be even less of a success than the Televisor itself and sank without trace after a few months. It was not until 1951 that the Crosby Laboratories developed a video recorder which could register a TV signal magnetically — in this case along the length of a tape running past at over eight feet per second. This method gave tolerable picture quality but was so greedy of tape — something like three miles for a half-ho program — that the idea never made it outside the laboratory. The first commercially usable video system came in 1956 when the American Ampex Corporation brought out a recorder which entered each picture frame transversely on a two-inch-wide tape. A similar system was taken up by the BBC under the acronym VERA in the same year, and between them these two video systems dominated broadcast TV for the next twenty years, even though they were both about the dimensions of two wardrobes stuck together, and used tape spools the size of bicycle wheels. They gave a very good picture, but they and the later, smaller, versions of the studio VTR were clearly out of the question for the home user.

Helical scanning was developed by Sony in the mid-1960s as a compromise between tape width, speed and picture quality. It opened the way to a consumer video market, but for some reason — perhaps because people were still absorbing hifi sound recording — it failed to catch on until the late 1970s when TV addicts in the USA began to appreciate the domestic VTR's time-shifting capabilities. Suddenly the market exploded as it became profitable for the Japanese el tronics industry to tool up for mass p duction of domestic video recorders. The American film industry began its belated shift towards producing for TV and video first and the traditional movie theatre second. Meanwhile cable TV, satellite TV and the prospect of fibre-optic cable TV were starting to follow the way cut by the VTR in fragmenting TV audiences to the point where people now speak of 'narrowcasting' as the dominant home entertainment form of the 1980s.

It is only just over a century and a half since Faraday made his historic demonstration of electro-magnetic induction and only just over a century since Britain got its first public electricity supply. During that time, electricity has advanced from being a barely understood and not particularly useful scientific freak to a point where it is the lifeblood of our civilization. A great many of its innovations have merely helped us to cope with difficulties which we would never have had in the first place without those same innovations — the pocket calculator and the photocopier are the two examples which come readiest to mind — but good thing or not, the technology was there, and so it happened. The only safe prediction now, in AD 1983, is that we are seeing the beginning.