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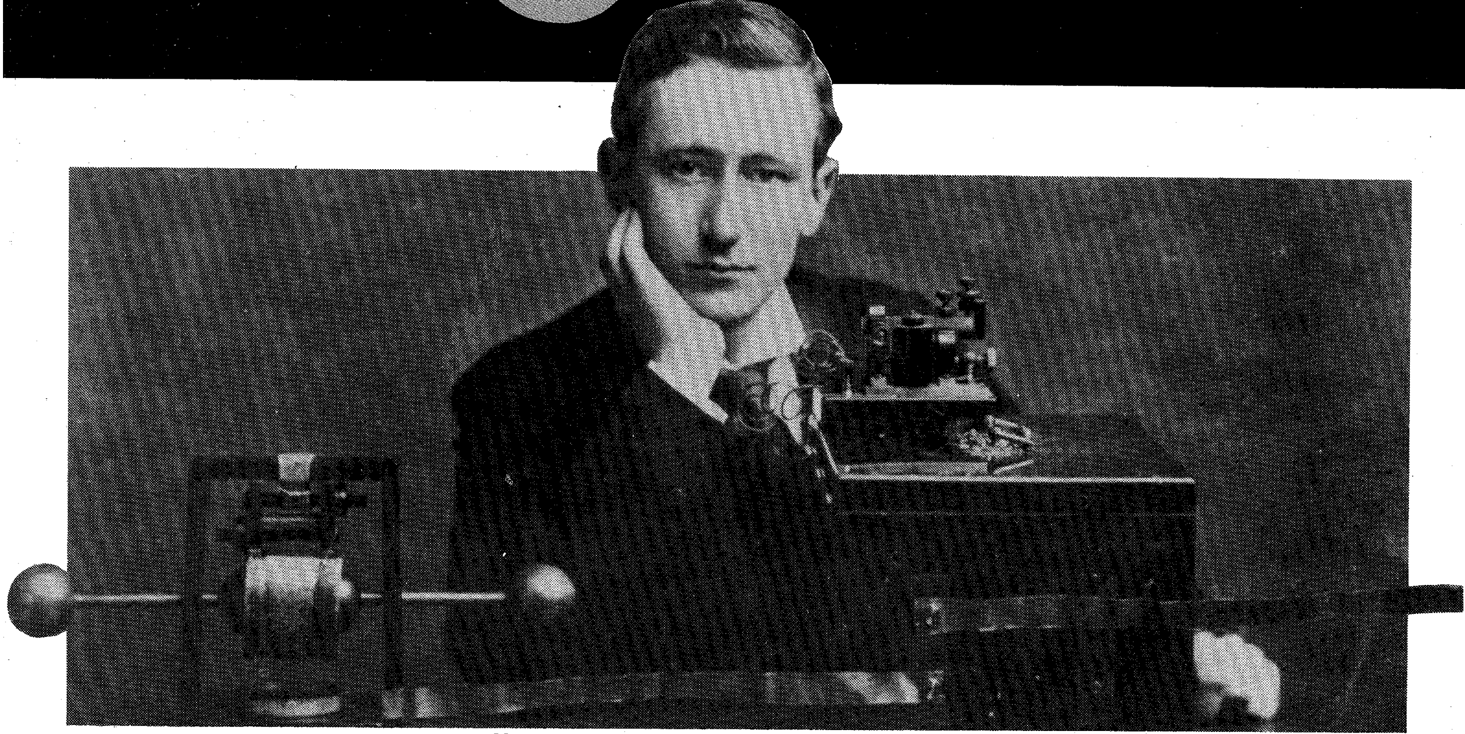
THE STORY OF RADIO

Graham Dixey

XL17T

the story of RADIO



Marconi with his apparatus for 'telegraphy without wires', 1896.

by Graham Dixey
C. Eng., M.I.E.R.E.

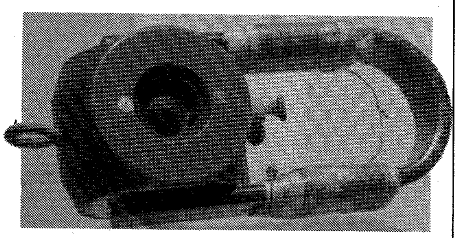
The Early Years

The name of Guglielmo Marconi is synonymous with the birth of wireless or, as we call it today, radio. Communications have always been one of man's obsessions from the times when a runner would be sent with news of a victory in battle or of impending disaster. Allied with the need to communicate under such circumstances was the question of speed. The human runner, the horse, the lit beacons on hillsides, the semaphore of Napoleonic times all represent stages in the quest for fast communications.

Marconi's patents for telegraphy using Hertzian waves was granted on 2nd June 1896

In the 19th century this culminated in the telegraph, communication across country by wires strung between poles. This was an astonishing leap in technology, of course, the speed now being that of the flow of a current in a cable. But it was vulnerable; wires can be cut or brought down by storm or other natural phenomena. And it was expensive to lay across the sea, though in the middle years of the 19th century, Brunel's Great Eastern laid the first successful submarine cable across the Atlantic Ocean.

While due credit must be given to Marconi for his pioneering work in the field of wireless, one must remember that most great innovations are not just the work of one man but are usually brought to a head by that man (or team) as a result of applying his own individual talents to the work of others. In this case, Marconi did not discover the presence of wireless waves; Heinrich Hertz had sent and received them across his laboratory in 1887, James Clerk Maxwell had predicted their existence as far back as 1864. What Marconi did was to confirm the results of both of these gentlemen, to form a basis for his own researches and, using the technology of the day, to push back the frontiers of science. This is akin to the Wright brothers, who did not invent the science of aerodynamics, but confirmed current knowledge of it and applied their engineering skills to producing a practicable lightweight aero engine, thus making flight possible.



Collier-Marr Telephone and Self-Restoring Coherer c. 1900, as used by Marconi to receive the first ever transatlantic signal on 12th December 1901.

Marconi

Guglielmo Marconi was born in 1874 of a Scottish/Irish mother and an Italian father. His education had suffered because he travelled a great deal with his mother. Nonetheless, in spite of an undistinguished academic background, he conducted experiments on Hertzian waves in the attic of his parent's villa near Bologna in 1894. The means of generating these early wireless waves was to develop a high voltage across a spark gap by means of an induction coil, a principle still with us today in the internal combustion engine. However, nowadays we suppress the radiation that Marconi was at such great pains to produce!

In 1897 Marconi transmitted a signal nine miles across the Bristol Channel

In the early summer of 1895 he managed to transmit several yards across his attic laboratory using a pair of metal plates as the radiating elements. Progress was relatively rapid because by August of that year, he had managed to increase the distance to one and threequarter miles. However, there was now another factor to consider in achieving this result.

There is obviously little point in being able to transmit a wireless wave unless there is also some way of receiving it. Hertz had proved the ability of wireless waves to communicate by causing a sympathetic spark to jump across the gap in his resonator (see Figure 1). However, this lacked sensitivity and was rather a dead-end line of enquiry. What Marconi used was a much more practical type of detector, known as a coherer.

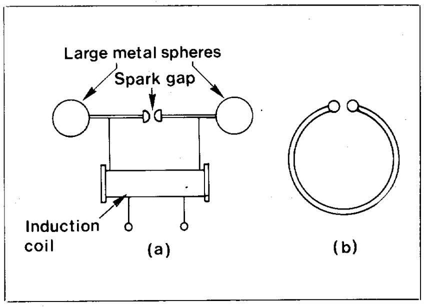


Figure 1. Hertz' original apparatus for sending and receiving wireless waves,
(a) his transmitter, using an induction coil to develop a high voltage across a spark-gap, which then broke down to radiate electromagnetic energy,
(b) his receiver, based on a resonator, which responded to the received energy and produced a weak spark in sympathy across a small spark-gap.

The Coherer

The coherer in the form in which Marconi used it was due to Sir Oliver Lodge, who had improved a similar detector, designed by the Frenchman Edouard Branly in 1890, and used it to transmit morse code over a distance of several hundred yards in 1894. This ushered in 'wireless telegraphy' though so far the range was too short to be taken seriously.

The coherer consisted of a small evacuated glass tube in which were placed two silver plugs attached to platinum wire. The inner ends of the plugs were cut at an angle and set quite close together. In the gap between was a mixture of nickel and silver filings (see Figure 2). Because the filings were loosely packed they possessed a fairly high value of resistance but, when a wireless signal was received, they clung together, bringing a dramatic drop in the resistance value – and a change of resistance on receipt of a signal is a phenomenon that offers obvious possibilities of conversion into some recognisable output.

However, it was necessary to give the coherer a tap to return it to its high resistance state before it would respond to the next signal impulse. In practice, the coherer was placed in series with a battery and a recording inker, so producing a pen trace of the signal; a bell could be included in the circuit so that its hammer could give the coherer the required tap (see Figure 3). Marconi spent much time improving the coherer's sensitivity by experimenting with the ratio of nickel to silver, ending up with a 19:1 ratio as being the optimum.

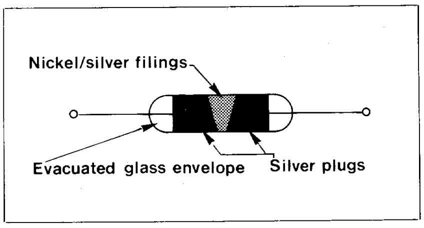


Figure 2. The basic form of Marconi's original coherer. The proportions of silver/nickel were varied to improve the sensitivity. The silver plugs gave a good ohmic contact with the filings.

Marconi , 1896.

Essentially Marconi's transmitter was of the type used by Hertz, and the radiation efficiency of this system was improved by using large metal plates, one suspended in the air and the other set in the ground, giving birth to the idea of the aerial and earth system. A similar arrangement was used at the receiver.

So successful was the transmitter/receiver arrangement that Marconi now approached the Italian Ministry of Posts and Telegraphs who, with lamentable lack of foresight, turned down his offer. It was this rejection that caused Marconi to come to England, which he did in 1896. Here he received help from his cousin, Henry Jameson Davis, and filed a patent application for a system of telegraphy using Hertzian waves. British patent No. 12039 was granted on 2nd June 1896.

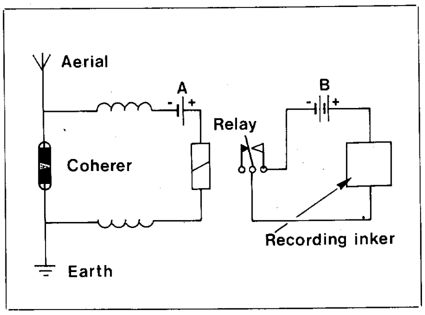
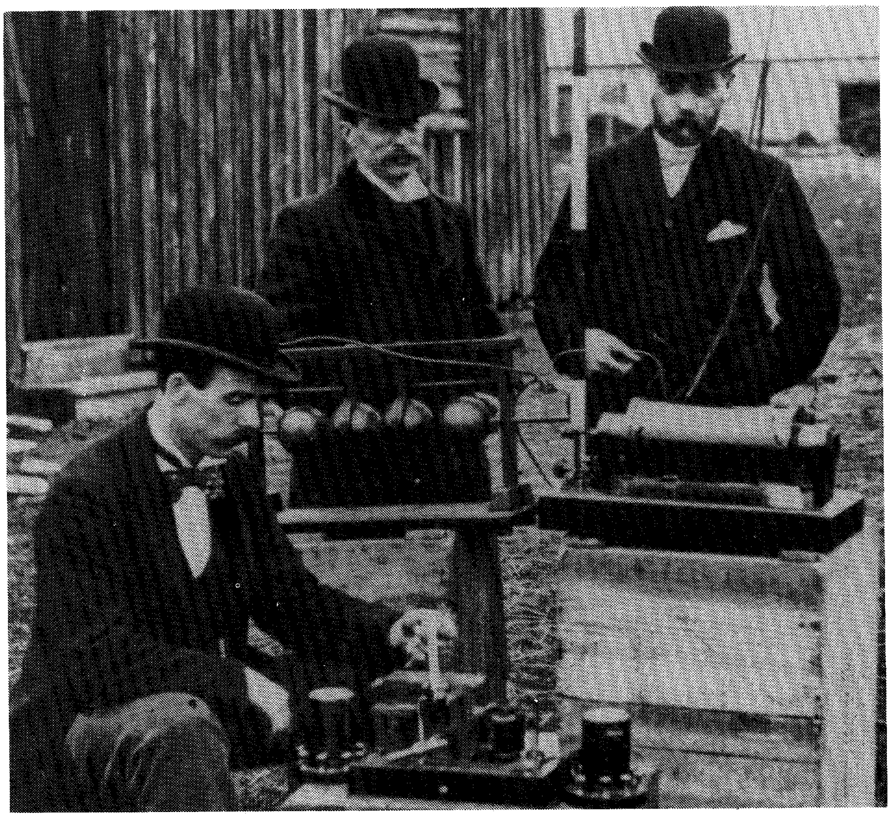


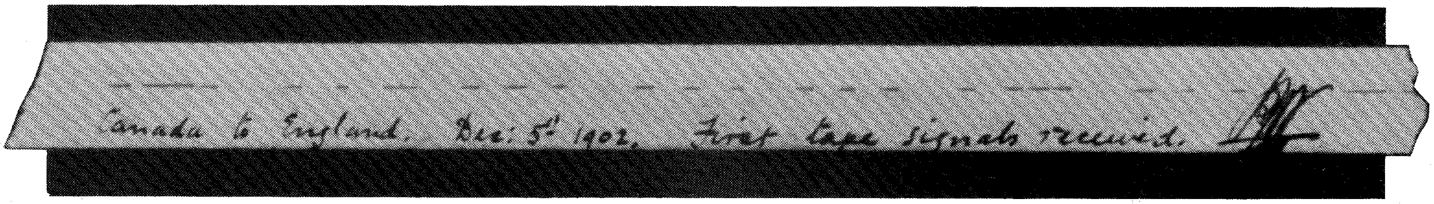
Figure 3. A receiver using a coherer.
The reduction in resistance of the coherer when a signal was received caused the relay coil to be energised by battery A. The change-over contacts then energised the recording inker via battery B, so giving a visible mark on paper tape.

The English Connection

In England Marconi found enough people to take an interest in his work. One person he was introduced to was William Preece, Engineer-in-Chief of the Post Office. Preece was also experimenting with 'wireless communication', but using mutual induction between loops rather than spark



Post Office engineers inspecting Marconi's equipment, 1897.



The evidence – the first Transatlantic signals captured on paper tape.

transmission. After some initial laboratory demonstrations, Marconi was invited to give a demonstration to officials of the Post Office. The transmitter and receiver were set up on the roofs of two buildings a few hundred yards apart, in the city, and a successful demonstration took place. This impressed the officials considerably, especially as the signals had quite obviously cleared the intervening buildings. He was invited to participate in further tests.

These tests took place on Salisbury Plain in September 1896, and Marconi used both his conventional aerial and earth system *and* a parabolic reflector, thus demonstrating both short-wave line of sight transmission in addition to the possibility of obtaining directional beam effects with such transmissions.

Not only was the Post Office represented at these trials but there were representatives from the War Office and the Admiralty as well. The interest shown by the Navy is understandable since a reliable system of wireless communication was likely to be of inestimable value to ships at sea, that were otherwise quite isolated from contact with land once they had sailed. A further demonstration given by Marconi was for the benefit of the public and Press in London, when he walked around with a receiver incorporating a bell. Whenever Preece, who was up on the stage, pressed a button, the bell rang.

Marconi Triumphs!

In the summer of 1897 Marconi participated in further tests of great importance. It had to be proved that transmissions could take place over water, if wireless was to be used to replace, for example, submarine cables. These tests took place in the Bristol Channel and took the form of a direct comparison between Marconi's system and Preece's induction system. Both of them managed to bridge the gap to an island three miles offshore, but Marconi also managed to send a signal right across the nine mile width of the Channel. The question was, what to do next? The answer was quick in coming.

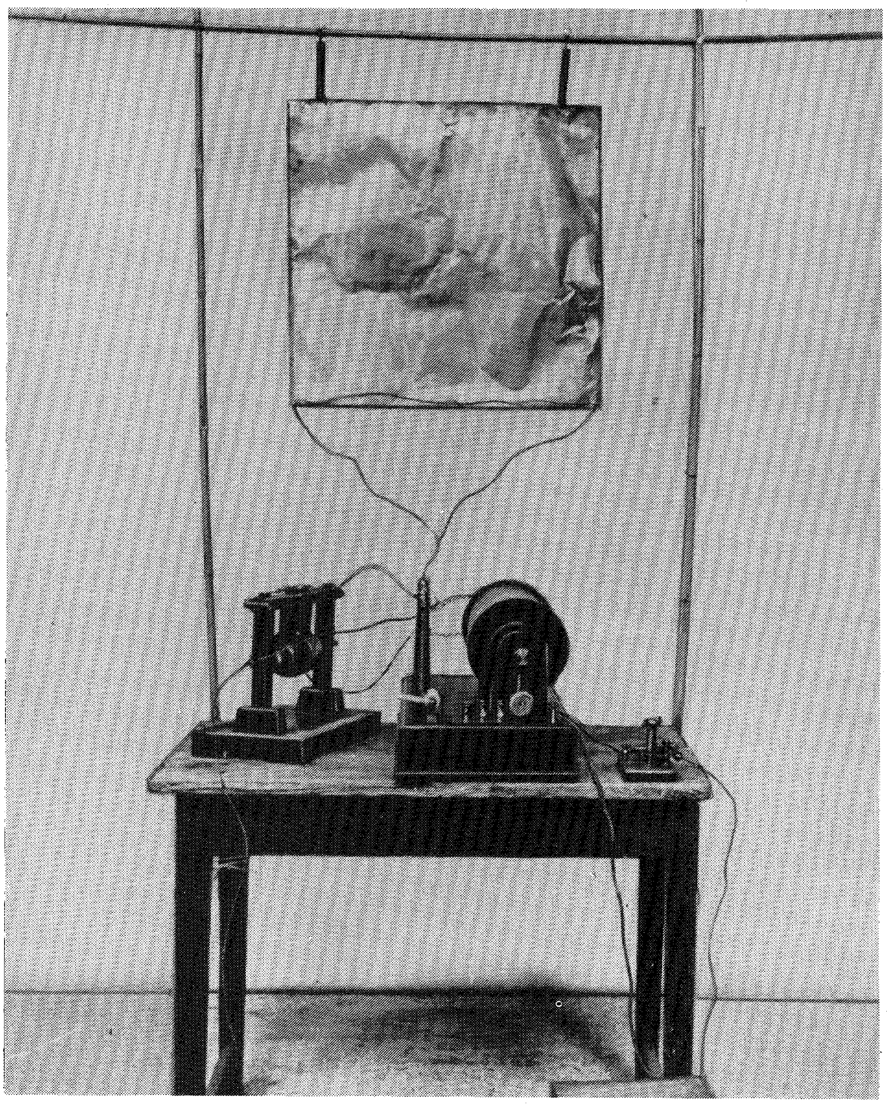
On 20th July 1897, 'The Wireless Telegraph and Signal Company Limited' was formed. Marconi now had to establish sites for the company to use. He chose two coastal sites, the Needles Hotel in Alum Bay on the Isle of Wight and the Haven Hotel in Poole, Dorset. These were about 18 miles apart. By November of that year, he had built a 120 foot high mast outside the Needles Hotel and was ready for some shore-ship tests. A small tug-boat was obtained and, in spite of some heavy weather, successful communication was achieved up to a distance of about 18 miles.

Rescue at Sea

The year 1898 saw some notable events taking place. Marconi, who had been spurned by his own government and had left Italy as an unknown, was now invited back and fêted. Not only this, but the Italian Navy adopted his equipment for use on their ships. Back in England, he set up an experimental station on the Goodwin lightship which communicated with the South Foreland lighthouse. This link proved useful in allowing a number of emergencies to be reported, one of which was the first rescue at sea by wireless, when the S.S. R.F. Matthews collided with the lightship! Other notable events included the setting up of a wireless link between Osborne House on the Isle of Wight and the Royal yacht in the Solent, so that Queen Victoria could communicate with the Prince of Wales.

Royal Patronage as a wireless link is set up in Osborne House so that Queen Victoria could communicate with Prince Albert on the Royal Yacht in the Solent

The following year, 1899, Marconi's newly founded company acquired premises in Hall Street, Chelmsford and so was built the world's first radio factory. The year 1899 was a notable one in the annals of wireless telegraphy. During this year, it took on an international flavour when a station was set up at Wimereux, near Boulogne, to communicate with the South Foreland Station. An interesting side issue grew out of this link. It happened that there was a meeting of the British Association at Dover at the same time that a similar type of meeting was taking place in Boulogne. A



A replica of Marconi's first transmitter used in Italy in 1894.

temporary mast was erected at Dover Town Hall to exchange messages, which worked well, so well in fact that these messages were also picked up at Chelmsford, over 80 miles away! Marconi had discovered the action of the ionised layers of the atmosphere in bending the radio waves back to earth, though it is doubtful if the full significance of this was appreciated at the time.

Also in 1899, W/T, to give it its abbreviated title, went to sea with the Royal Navy on manoeuvres and, due to a high degree of co-operation between Marconi and a naval officer, Captain Henry Jackson, RN, was a marked success. The South African War saw the use of W/T and, in a more peacful context, it crossed the Atlantic to report the progress of the America's Cup races. In November of the same year, The Marconi Wirelss Telegraph Company of America was registered, better known to us today as simply RCA.

We tend to think that the rapid growth of electronic technology is a modern phenomenon, but a moment's thought on what has been written so far will show that a mere five years had elapsed between Marconi's first test transmissions in his attic and the use of wireless as a practical means of communication.

Improvements in range had come about by developing the original circuit, not just by pushing up the input power. The most significant feature of the new transmitters and receivers was the use of radio-frequency transformers, known as 'jiggers'. In the transmitter, the spark gap was used to discharge a high value of capacitor (storing a large quantity of electrical energy) through the primary winding, the aerial being connected in the secondary circuit. In the receiver, the jigger was used as an impedance matching device between the aerial and the high impedance coherer. The use of these transformers allowed the incorporation of a facility that became more vital as W/T communications became more widespread and the 'radio band' more crowded – the need to make both the transmitter and receiver circuits 'resonant' at the same frequency, so as to avoid mutual interference between stations operating simultaneously; this frequency selective method of operation had been impossible initially.

Letter 'S' was the first transmission across the Atlantic

The year was now 1900 and the use of W/T was rapidly being adopted by a variety of services, especially at sea. This was the year in which the marconi International Marine Communication Company Limited was formed; it was also about the time that Marconi began thinking in terms of spanning the Atlantic with wireless waves.

Waves Across The Waves

In 1901, Marconi established comm-unication between the Isle of Wight and the Lizard, a distance of almost 200 miles. At the same time, Marconi's team consisting of Vyvyan, Professor Fleming, Paget and Kemp began the construction of the eastern end of the transatlantic link, at Poldhu in Cornwall. Marconi himself crossed the Atlantic to see about setting up the other end of the chain at Cape Cod.

The weather, the enemy of so many pioneers in many fields, destroyed the aerial systems at both ends of the link. That at Poldhu, which had been on the lines of a vertical cylinder of conductors, was replaced by a fan-shaped design, while the station at Cape Cod was abandoned in favour of a new site at St. John's, Newfoundland. The aerial here was to be launched on a kite, a tricky operation in the high winds. Nonetheless, it was managed eventually and, on 12th December 1901, Marconi and Kemp both agreed that they could just make out the three dots of the morse letter 'S' against the background of static.

There are some significantly interesting technical details concerning the equipment used. Firstly, the system was untuned, unavoidably because the erratic behaviour of the kite aerial made it impossible to hold the receiver on one frequency. Secondly, Marconi was using what was called a 'self-restoring coherer' – which was not a coherer at all but a true r.f. detector, together with an earphone to give an audio output. Thus was the first trans-atlantic wireless contact made, from Poldhu in Cornwall to St. John's in Newfoundland, a distance of 2,099 miles!

There were sceptics, of course. After all, there was no physical evidence to show that the signal had actually been received. Perhaps Marconi and Kemp had both imagined it? To quieten the sceptics, two months later, on the liner S.S. Philadelphia, Marconi recorded signals, using the morse inker, which confirmed on paper tape the reception of the letter 'S' at a distance of 2,099 miles and a full message, which was readable, at distances up to 1,551 miles.

The age of wireless could be truly said to have arrived at that moment. It was now just a question of developing the new science. The following decades were to see some very exciting events as, in peace and war, the infant technology grew to full stature.

The First Decade

Having now proved to a doubting world that the Atlantic could be bridged by wireless waves, Marconi's next act was to establish a permanent station at Glace Bay, Cape Breton Island on the east coast of Canada. This station was augmented on December 21st 1902 and tests began straight away with transmissions between this new station, the one at Cape Cod and Poldhu in Cornwall. It was now vital to show that transatlantic contact was no freak occur-rence but could be depended upon at all times. If this could be done, it would open up a whole new world of possibilities, of which the most obvious, at the time, seemed to be in the realm of marine communications.

Ever since man first set the bows of his vessel toward the open sea, he had had to accept the fact that once out of sight of land, he was totally isolated from humanity, unless he came across another seafarer of course. Now all that could be changed. Right across the breadth of the Atlantic he would be able to send messages to ports at both ends of his route, informing his employers as to his likely time of arrival, giving warning of bad weather or icebergs or some other emergency.

The first widespread use of marine wireless was the setting up of a long range news service for transatlantic liners, using the Glace Bay and Poldhu stations. This was an interim measure because it had been decided to build new, larger aerials at these stations in order to benefit more from the

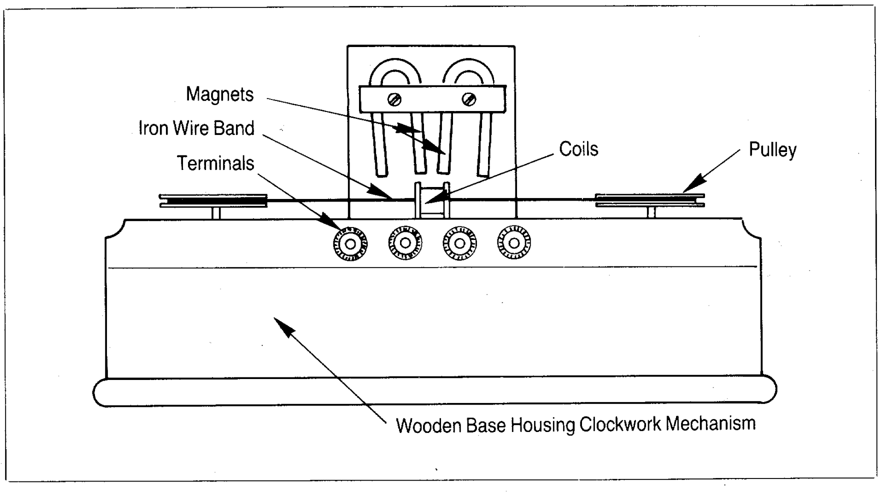


Figure 4. Simplified diagram of Marconi's magnetic detector (the Maggie).

Weekly Dispatch

PURE INDIAN TEA

BRITAIN'S BEST BEVERAGE

No. 5,673.

ESMOLIN NEURITIS

109TH YEAR

SUNDAY, JULY 31, 1910.

SUNDAY SPECIAL EDITION.

ONE PENNY.

CRIPPEN'S LIFE AT SEA DESCRIBED BY 'WIRELESS.'

DETECTIVE INS

DETECTIVE INSP. DEW

MRS CRIPPEN (MISS BELLE ELMORE.)

H.H. Crippen.

THE DOCTOR'S FIRST WIFE MRS CHARLOTTE CRIPPEN

CAPT KENDALL

MISS LE NEVE

CRIPPEN'S LIFE AT SEA DAY BY DAY.

DESCRIBED BY CAPTAIN KENDALL OF THE MONTROSE.

FULL EXCLUSIVE "WIRELESS" TO "THE DAILY MAIL."

THE BOOKS CRIPPEN READS, AND THE SONG HE LIKED.

WHY HE FAILED TO ANSWER THE NAME "ROBINSON."

"ALL WALKED INTO THE SHOP."

NOTICE.

WHOSE REWARD?

Crippen captured by radio.

better service that longer wavelengths seemed to give. Until these new aerials were complete, some sort of practical use would presumably increase public confidence in the new technology. The commercial use of wireless at sea pre-dated this event by a couple of years because in 1900, the Marconi Company had installed untuned equipment in the German liner, Kaiser Wilhelm der Grosse. Such was the growth of this new service that, by the end of 1902, there were some seventy ships operating with wireless and twenty-five land stations available for their use, including several on the eastern seaboard of the North American continent.

Magnetic Detector

A significant technical development was made by the Marconi Company at this time. This was the superseding of the rather insensitive coherer with the new 'magnetic detector'; this also allowed higher signalling speeds and better discrimination against interference. The experimental prototype had been made by Rutherford in 1895 but Marconi developed it into a practical device. Its action was to use a high frequency bias to overcome the 'hysteresis' in magnetic materials, in much the same way that, in modern tape recorders, a high frequency current is superimposed on the signal current in the recording head. However, in the case of Marconi's magnetic detector, the end result was achieved in rather a different way.

An endless band of iron wires was driven past a system of permanent magnets by a clockwork motor, the speed being about 8cm/s. At the point of maximum magnetic field strength due to the permanent magnets, the iron wire band was surrounded by a pair of coils, one carrying the radio frequency energy from the aerial, the other being connected to the headphones. The signal itself consisted of bursts of energy recurring at an audio frequency. In the periods when no radio frequency energy was present, the permanent magnets had little effect, but when their action coincided with the bursts of radio frequency energy, an output, at audio rate, was produced in the headphones by way of the previously mentioned coil. This device remained in use for about twenty years and was known as the 'Maggie', see Figure 4.

Radio for Hire

It is interesting to note that the Marconi Company did not actually sell their wireless equipment to the shipping lines, but hired it out instead – presumably the first example of 'radio rentals'! The installation came complete with a Marconi-trained operator, and the rental included the use of all of the shore stations in the Marconi network. There were naturally competitors at the time, and these were not allowed the use of the Marconi shore stations, since they had not paid the rental charge for their use. Obviously this restriction did not apply to distress calls. Furthermore, the ships equipped with Marconi wireless equipment were not allowed to communicate with ships equipped by their competitors. This may seem a strange state of affairs but should only be judged in the context of the times. The chief competitor of the Marconi company was the German firm of Telefunken, which was a government backed consortium of German radio expertise. It was this latter company who, in 1903, called an International Wireless Telegraphy Conference with the object of allowing all to have free intercommunication regardless of the source of the equipment carried. However, Marconi were not prepared to hand over their dominant position so readily and did not finally agree to this until 1912.

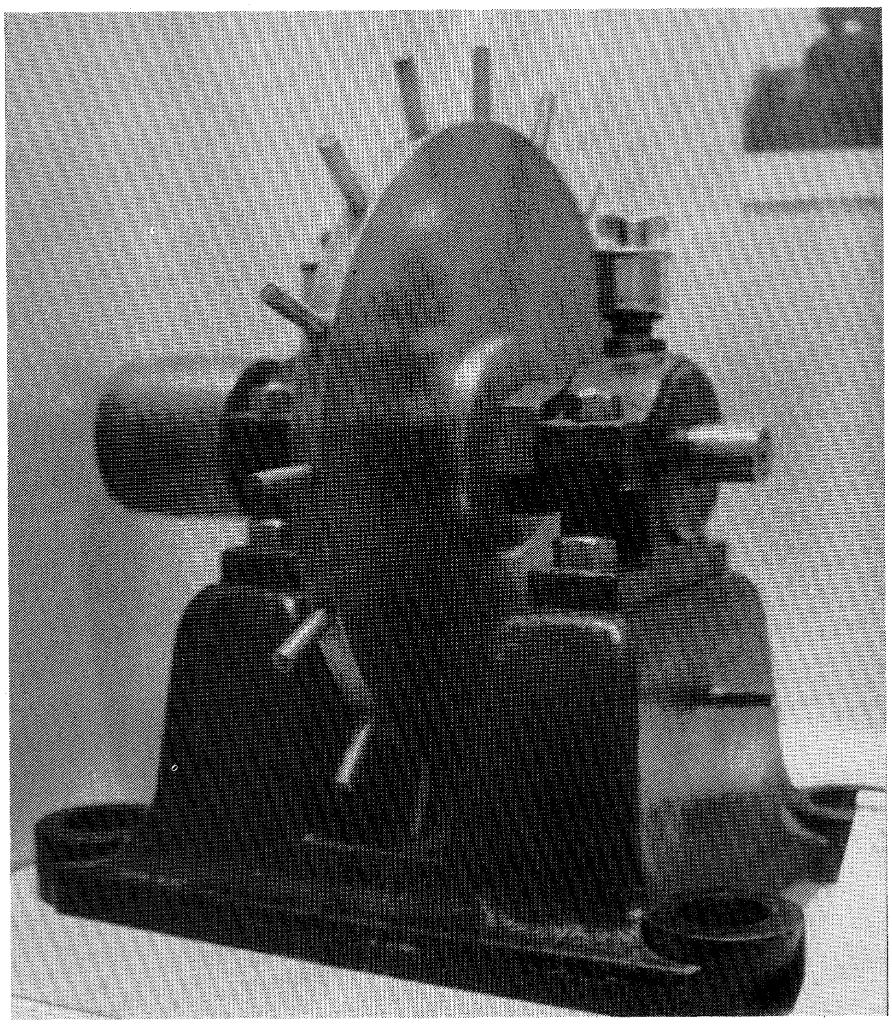
Licencing

An amusing and extremely significant event took place in 1903. The ability to tune the transmissions so that adjacent stations could operate without mutual interference had been developed to a practicable level. However, the case had been rather overstated because it had also been claimed that the medium of wireless allowed 'secret' communication between parties, free from the possibility of interference by a third party. This clearly wasn't true, and one particular person was determined to demonstrate this in as public a manner as possible. The person concerned was Neville Maskelyne, son of the famous illusionist, whose father owned the Egyptian Theatre in Piccadilly, London. Neville Maskelyne had commercial interests in certain of Marconi's competitors, and it was in his interest to disprove unsound claims made by Marconi. This he did by setting up a transmitter on the roof of the Egyptian Theatre at the time that a demonstration was taking place at the nearby Royal Institution. A lecture was being given by professor Ambrose Fleming in the said Institution, which was to have, as its 'piece de resistance', the reception of a ceremonial message from the Marconi Company at Chelmsford. During the lecture Fleming's assistant was supposed to be receiving some test transmissions. To his surprise, indeed no doubt to his horror, rather odd messages began to come through, along the lines of, 'Rats', or 'There was a young fellow of Italy, who diddled the public quite prettily'. This had exactly the effect intended, since Maskelyne ensured that the episode attracted the maximum publicity.

The real significance of this episode was, of course, the fact that some form of control was needed for operators of wireless equipment. This led, in Britain, to the Wireless Telegraphy Act of 1904, which became effective the following year. This was to ensure that wireless was developed under direct government control, for the good of the country and the people, and to enforce international legislation. All stations had to have licences, which included Marconi's shore stations. The latter were supposed to have licences with an eight-year span but, by 1909, the British Post Office obliged Marconi to sell the stations to them. However, it now became possible to extend the Inland Telegrams service to ships at sea, where they became known as Marconigrams.

New Directions

In 1905 Guglielmo Marconi married. He was considered an eligible bachelor, because of his fame and, to be fair, also because of his personality, which exuded self-confidence and a quiet determination. He had had a number of romances, including two engagements to American girls as a result of the many transatlantic crossings that he made. However, his bride was not American, but Irish, a 19-year old by the name of Beatrice O'Brien. Shortly after their marriage, Marconi took his new wife to the inhospitable site chosen in Nova Scotia as a replacement for the original Glace Bay station. Here a new aerial system had been built, which consisted of an inverted cone supported by four 64-metre towers, surmounted by an umbrella roof with a diameter of 615 metres! This gives a fair indication of the dimensions of the aerial required for the long waves in vogue at the time. Having seen to the tuning of the new station, Marconi set off by sea (leaving his wife behind!), to test the range. In daylight a range of 2,900 kilometres was achieved. This offered a significant but still insufficient improvement. However, Marconi then made the interesting discovery that, at the receiver, the signal received was much stronger when the aerial wire, as it lay on the ground, 'pointed away from the transmitter'. This led to the 'inverted-L' configuration, with the horizontal arm being much longer than the vertical one. As a result, the aerial at Glace Bay was modified by having three-quarters of the umbrella removed, the remaining quarter being that which faced away from the Poldhu transmitter. The received signal from England was substantially stronger.



Musical Spark Disc used at Poldhu in 1907.

Photo courtesy of the Science Museum, London

Thus, the innovation that had improved the strength of the received signal showed also that an aerial could have the property of directionality. Put another way, a given aerial in which the directional property was enhanced, achieved a gain in signal strength. This invention was patented in 1905 and became the Company's standard long range aerial. Because the Poldhu site was too small for a directional aerial of any real size to be built, a new site was chosen. This was in the west of Ireland at Clifden, later to be famous as marking the end of Alcock and Brown's first flight across the Atlantic. A propitious choice indeed! The new station put out a power of three hundred kilowatts and generated its own electricity, the boilers often being fuelled with peat cut from the bog nearby; the Company built their own light railway to give access to the station, so remote was it.

A rather incredible feature of the site was the capacitor building, which was over one hundred metres in length, and housed a giant air-spaced capacitor in which the radio-frequency energy was temporarily stored, before being discharged through the aerial transformer!

New Sparks

After the directional aerial came another important development. The spark suffered from the disadvantage of having too broad a bandwidth, which made nonsense of the selectivity that could be achieved with receivers. Also, the erratic nature of the spark meant that it was not always easy to distinguish it from the atmospherics that were a normal accompaniment of long range wireless communication. To overcome this, Marconi made the spark strike and extinguish in a more regular fashion, by means of a studded steel disc in which the length of the spark gap narrowed as each stud approached a stationary electrode producing the spark, and then widened as the stud

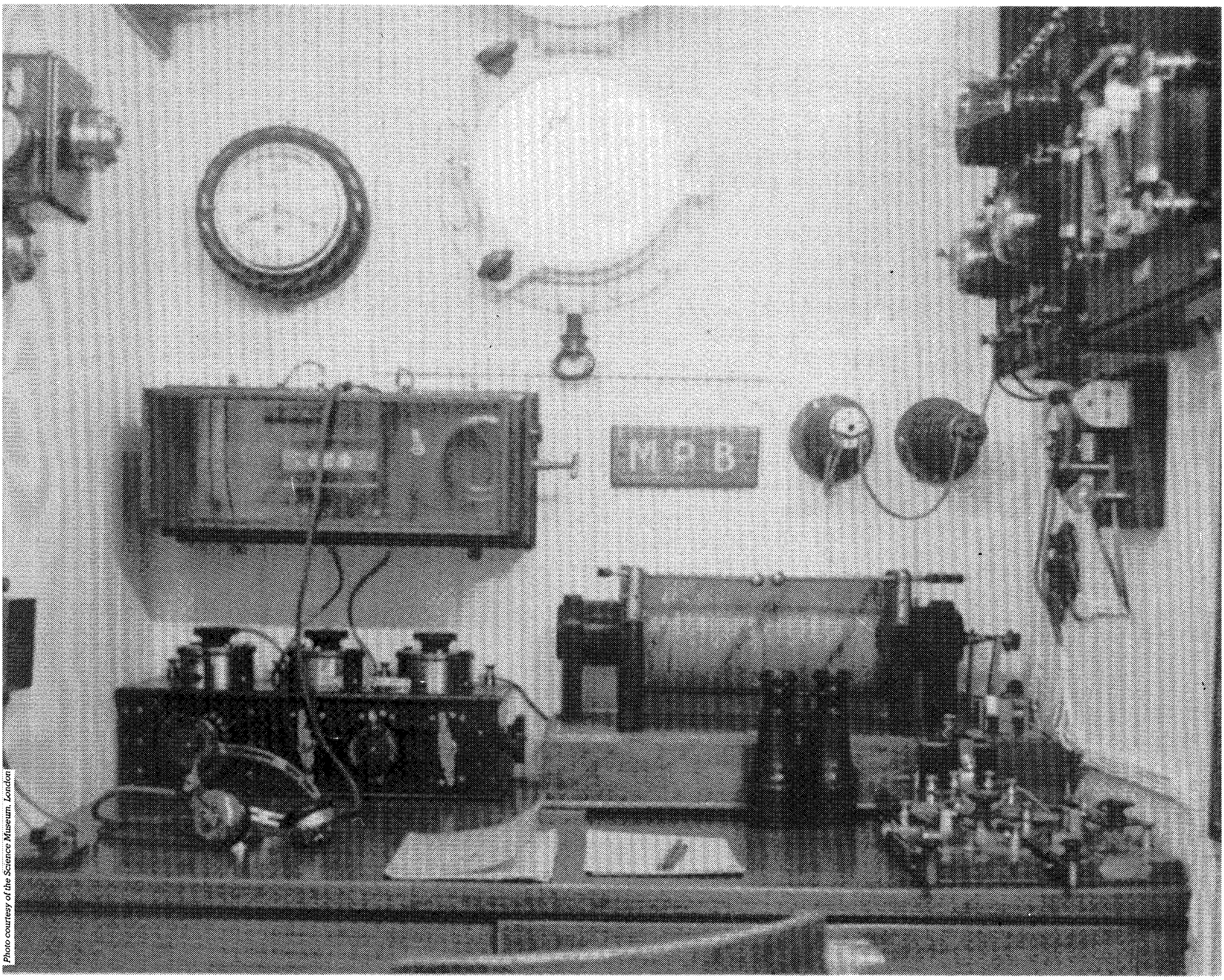


Photo courtesy of the Science Museum, London

Ships wireless cabin, 1910. A 1.5kW installation that was standard for large ships.

passed on, thus extinguishing the spark. This gave the received signal a characteristic musical sound, much more easily distinguished against a background of static. Furthermore, the way in which the spark energy was transferred to the aerial reduced the bandwidth of the transmitted energy, so reducing the interference.

Viable Service

With these two significant developments, Marconi was at last in a position to open a viable transatlantic service, which was done in October 1907. Within three months of opening the service, over 100,000 words had been transmitted. However, there were obviously some technical problems to be overcome, because some messages had to be repeated a number of times before they were understood. Notwithstanding, it was an excellent achievement.

As a culminating achievement, in 1909, Guglielmo Marconi was jointly awarded the Nobel Prize in Physics. The other recipient of this honour was K.F. Braun of Telefunken, later to invent the cathode ray tube.

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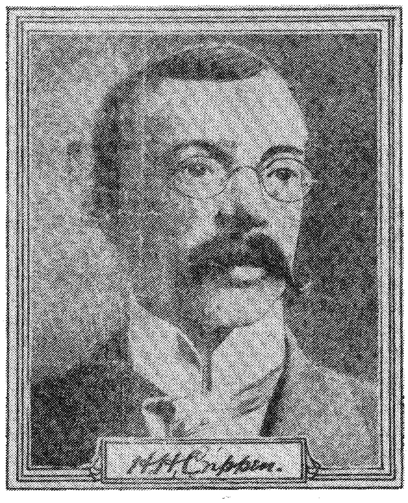

Photo supplied by Marconi Co Ltd.

Dr. Crippen

By the year 1910, there were a good many vessels on the high seas equipped with wireless. Marconi themselves had their own installations in about 250 of them. It was in 1910 also that the very fact of ship-borne wireless put paid to the plans of one particularly notorious character, whose name is still well enough known today. This was the murderer Dr. Crippen, who, with his mistress Ethel le Neve, was fleeing westwards in the liner S.S. Montrose. The ship's captain was able to broadcast this fact back to England where Scotland Yard were alerted and were able, presumably also through the transatlantic wireless link, to arrange for the Canadian police to arrest him when the ship docked.

Also in 1910, Marconi's position in the further developments of wireless took a new turn. So much was happening that it was beyond one man to explore all the possibilities. From then on, he was to lead others to shape the future. In that future, very close at hand, lay the 'wireless valve'.

The Birth of the Valve

One of the difficulties facing anyone who attempts to describe the history of a particular technology is the fact that development does not follow a single, clearly defined path, but proceeds along a number of parallel ones. The significance of what is found on any one of these paths may not always be apparent until much later.

Thus, while Marconi was experimenting with the transmission and reception of wireless waves at the end of the 19th century, other contributions were being made by scientists on both sides of the Atlantic. These initially quite unconnected experiments would culminate in a device that would eventually make the crude spark transmitters and coherer-type receivers obsolete. Instead, there would be a whole new technology, that today we would identify as 'electronics'. This new device was the 'thermionic valve', which would be developed through many forms for many uses, before it too was overtaken by another innovation, born in the Bell Telephone Laboratories in 1948, namely the transistor. And so it is now necessary to return for a while to the Victorian age.

When the cathode ray struck the paddle-wheel, the latter moved along the rails. This proved that the ray was composed of physical particles able to do work.

Cathode Rays

Conduction of electricity through gases had concerned many scientists in the late 19th century, including the eminent Sir William Crookes. Experiments had shown that electricity could cross a gap in the conductor if the voltage was high enough – this being the well known spark. Crookes investigated this phenomenon further by sealing the two conductors into a glass tube, which he could evacuate with a pump, so lowering the air pressure within.

The effect, visually, was remarkable. Apart from the current flowing more easily, which in itself was something of a surprise, the crackling blue snap of the spark was tamed, to become a beautiful stream of light, which particularly surrounded one wire (the cathode) in a violet glow. Crookes had discovered discharge lighting but, for the science of wireless still to come, he had found much more.

As the quantity of air within the tube was decreased further, the light stream changed to a series of alternate dark and light bands. Then there appeared a dark space near the cathode, which increased in size until it filled the whole tube; finally the current stopped completely. This 'dark space' was of interest because it coincided

Dr. J.A. Fleming

Photo supplied by Marconi Co. Ltd.

with a glow that appeared at the opposite end of the tube, as if a ray was leaving the cathode and causing luminescence when it struck the far end. To investigate this further, Crookes placed a metal screen in the path of the 'cathode ray', and found its image projected as a shadow on the luminescent area.

Taking it a stage further, he next installed a small paddle-wheel on rails within the tube and along its axis, so that when the cathode ray struck the paddle-wheel, the latter moved along the rails. This proved that the ray was composed of physical particles able to do work. These particles were, of course, what were later known as 'electrons'.

Fleming had worked with Marconi on the wireless experiments and realised that the Edison effect could be used to detect the radio-frequency currents in a wireless aerial

In fact, the name 'electron' was suggested in 1891 by Dr. Johnstone Storey, who applied it to a particle of electricity that he, correctly as it turned out, predicted existed. In 1897 Sir J. J. Thomson, accepting Dr. Storey's theory, made an announcement to the Royal Society about the 'cathode ray' observed by Sir William Crookes. He said that it was composed of a stream of charged particles, which arose out of the disintegration of gas atoms in the tube.

In the years that followed, the modern theory of atomic construction was developed by people such as Thomson, Rutherford, Moseley, Bohr and others, until the picture emerged that electrons had a positive counterpart, the proton, so that when a cathode ray travelled to the anode within Crooke's partially evacuated tube, a positive ray travelled in the opposite direction. These are some of the principle experiments that were to lead ultimately to the birth of the thermionic valve or, as the Americans have always called it, the 'vacuum tube'. But now it is necessary to go back again in time to 1883, where there is yet another parallel path, a very significant one.

The Edison Effect

In this year Thomas Edison, in the United States, was experimenting with incandescent lamps. At the time he was using carbon as the filament material. Unfortunately, this had the decided disadvantage of blackening the bulb. As an experiment, Edison fitted a metal plate inside the bulb, bringing out a connection through a seal in the glass. To this extra electrode he tried connecting potentials, first positive, then negative. What he observed was later known as the 'Edison effect', which was that when the plate was made positive with respect to the filament, a galvanometer connected in series with it registered a current. However, when the potential of the plate was negative, no current flow was observed.

Fleming's Experimental Diode 1904

Photo supplied by Marconi Co. Ltd.

If a positive plate was now brought near, electrons would be drawn from the space charge and would flow through space to the plate

Totally unaware of its true significance, what he had produced was an elementary 'diode' valve. He demonstrated the effect to others but actually made little use of it himself. But one person who did see it was a British physicist, Ambrose Fleming, who had once studied under the great James Clerk Maxwell in the Cavendish Laboratories in Cambridge. About twenty years later Fleming put Edison's observations to good use when he invented the first practical wireless valve.

It may be remembered that Fleming had worked with Marconi on the transatlantic wireless experiments. As a result of this work, Fleming realised that the Edison effect could be used to detect the radio-frequency currents in a wireless aerial. He, therefore, carried out some experiments with modified Edison lamps. He connected a lamp in series with a galvanometer and the secondary winding of a transformer, whose primary winding was energised from the

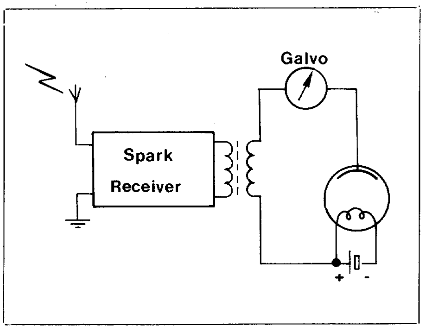

Figure 5. Fleming's arrangement for establishing the principle of the 'oscillation valve'.

output of a spark receiver (Figure 5).

Switching on a spark transmitter, he was gratified to find his predictions confirmed. Each pulse of energy was transformed and then rectified by this elementary diode valve, so producing a deflection on the pointer of the galvanometer. This made it possible for a 'visual' output to be obtained, a matter of some importance to Fleming, whose hearing was now rather poor.

Fleming's Valve

On November 16th 1904, Fleming took out a patent for what he called his 'oscillation valve'. The name arose, not because it generated oscillations (which of course it couldn't), but because it detected them, and he called it a valve because of its 'one way' property of conducting electric current.

The filament was metal and was heated by a battery to white heat. This high temperature caused the electrons in the filament to become so agitated that they actually left the material – an effect known as 'thermionic emission'. Since the filament was now positively charged, the electrons were immediately attracted back by the universal law of attraction between opposites. However, the process was continuous, with electrons being emitted and recaptured all the time. At any instant,

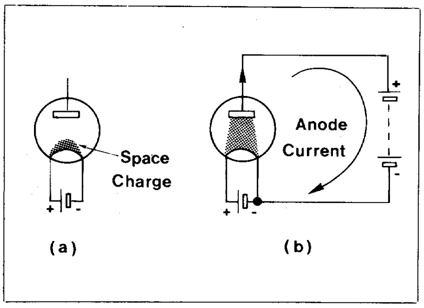

Figure 6.
(a) Formation of space charge by heated filament.
(b) Current flow when anode is positively charged.

however, the filament was surrounded by a cloud of electrons – called the 'space charge' (Figure 6a).

If a positively charged plate was now brought near, electrons would be drawn from the space charge, and would flow through space to the plate (anode). The connection of a battery between anode and filament would create a path for continuous current flow, by allowing the electrons given up by the filament to be replaced from the negative terminal of the battery (Figure 6b).

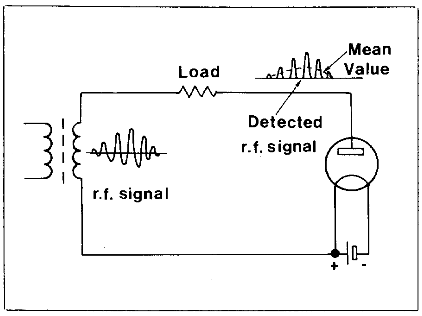

Figure 7. Detection of r.f. wave with diode valve.

Reversing the anode supply meant no current flow, since a negatively charged anode would repel rather than attract electrons. This was the basic principle of Fleming's diode valve.

To apply this principle to a wireless receiver, it is only necessary to imagine that the anode supply is not a battery (DC), but is a high frequency oscillation (AC). The anode is now alternately positive and negative on each successive half-cycle of the r.f., and since anode current only flows on positive half-cycles, the alternating signal is converted to a unidirectional output (Figure 6). Furthermore, since the strength of the anode current depends upon the potential on the anode, strong signals would produce large anode currents and weak signals, small ones.

Thus, the valve produced an output that was both unidirectional and followed the signal amplitude changes

Thus, the valve produced an output that was both unidirectional *and* followed the signal amplitude changes, a process known as detection and which is still in use in modern radio receivers.

The Audion Valve

As often happens once a new device appears, it is soon modfied or improved by someone else. This happened in the case of Fleming's diode valve when, in 1906, an American, Dr. Lee de Forest, produced his 'audion' valve. This was more a development than an improvement, since each still had its own, rather different, application. The audion had an extra electrode, known as the 'grid', inserted between the filament and the

Like many another good idea, the theory was ahead of the current technology. In this case the process that was lacking was the large scale evacuation of glass tubes

anode, with an external connection made to it (Figure 8a). This electrode was an open metal mesh, so it did not form a physical barrier to the electron stream. If it was connected to the filament potential it had no influence on the anode current; the electrons

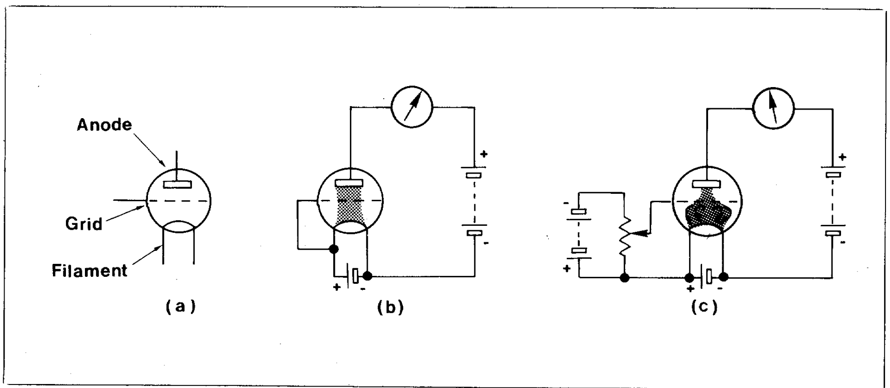

Figure 8. (a) The 'audion' or the first triode valve.
(b) The grid has little effect when taken to filament potential.
(c) Anode current is reduced when the grid is made negative with respect to the fillament.

simply flowed through it (Figure 8b). But, if it was connected to negative potential (with respect to the filament potential, that is), it was then able to repel some of the electrons and return them to the filament (Figure 8c). The more negative it was made, the more electrons it repelled until eventually the anode current was 'cut off' completely. Therefore, the value of the anode current could be controlled either by varying the positive anode voltage, *or* by varying the negative voltage on the grid. But, because the grid was so much nearer to the cathode than it was to the anode, it had a much greater effect on the anode current than the latter.

Without labouring the point further, the practical significance of this was of immense importance. Because the audion valve could take a small input voltage (at the grid) and develop a much larger output voltage (at the anode) if a load was placed in series with the changing anode current, it became possible to amplify oscillatory voltages to any required level merely by following one valve amplifier with another, and so on. The problem was that, like many another good idea, the theory was ahead of the current technology. In this case the process that was lacking was the large scale evacuation of glass tubes to the required degree of vacuum. It was left to the First World War, and the impetus that war always gives to new technology, to make the valve the powerful component that it was to become, and remain for the next few decades.

A Titanic Disaster

Now to return to the world outside of the experimental laboratory. Wireless was now a reality, a commercial proposition that allowed the transmission of messages across the wide Atlantic, that allowed ships to maintain contact with shore stations, of which there were many, and to 'talk' to each other. The potential for saving lives was enormous. A ship in difficulties could, if she had wireless, call for assistance with a good chance of getting some if there was other shipping within a reasonable distance. However, it required a major tragedy at sea to pinpoint the weaknesses in the system and to produce the legislation needed to ensure greater safety at sea in the future.

This tragedy occurred on Sunday, April 14th 1912, when the 'unsinkable' Titanic struck an iceberg and went down with the loss of 1,517 lives. It is interesting to see the part played by wireless in this disaster and what it ultimately led to.

At 7.15 pm on that fateful Sunday, another vessel in the vicinity, the Californian, wirelessed a warning of local icebergs. Several other ships also reported similar conditions. To these messages, the Titanic responded with a routine acknowledgement but maintained high speed. At 10.30 pm that evening, the conditions were so bad that the Californian sent out the message that she was stopped in thick ice. Again the Titanic acknowledged but added curtly, "Shut up, I am busy with Cape Race" (the Newfoundland shore station). At 11.40 pm the Titanic struck an iceberg which ripped open her underwater hull for a length of about 300ft. Bulkhead failures meant that the subsequent flooding could not be contained and, recognising that the end was inevitable, distress signals were sent out.

The Californian was nearby, and equipped with wireless and clearly in a position to help, but her sole wireless operator had just gone off watch, so no calls were received.

However, the Titanic's distress calls were picked up by a number of other vessels, including the German steamer Frankfurt (153 miles away) and the Carpathia (58 miles away). In the latter case, the wireless operator was also off-duty but, by chance, had returned to his equipment to handle some routine calls. At 12.20 am he picked up the distress signals from the Titanic. As a direct result of wireless, some half a dozen vessels raced to the scene of the disaster and 712 people were plucked from the water that night and saved.

What this tragic incident highlighted was not the number of lives that were saved by the intervention of wireless, but the number that had been lost largely because of the inadequacies of the system.

Another rather alarming situation that occurred a few hours after the tragedy, but which would have been absolutely disastrous had it happened during it, was the almost total jamming of the aether by enthusiastic American amateurs, who joined in with the already intense wireless traffic associated with the incident. During this period, intelligible communication became almost impossible.

As a result of the Titanic sinking, an International Conference on Safety of Life at Sea was eventually held in London on January 20th 1914. An agreement was signed by the sixteen participating nations in which a number of clauses relating to Wireless Telegraphy appeared, including:

That all merchant ships, carrying 50 or more persons, must be equipped with wireless. In practice, this covered most sea-going vessels. Certain classes of vessel must maintain continuous watch and there were laid down standards regulating the minimum range of the equipment, and also covering emergency equipment, which should be able to operate from batteries for at least six hours.

The allocation of wavebands for specific purposes was effected in order to avoid the possibility of chaos in the future.

Also established, under the responsibility of the United States, was the wireless reporting service known as the Ice Patrol, a highly effective operation.

Among those called to give evidence at the original Board of Trade enquiry into the loss of the Titanic was Marconi himself. He placed before the Board the idea of the 'auto-alarm' system, in which an alarm was sounded on immediate receipt of a distress signal. But before it could be implemented, another event was to occur that was to give another spur to the new technology. In August 1914, Europe went to war.

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The First World War

In 1899, Marconi gave a demonstration of wireless telegraphy on Salisbury Plain. Present at this event were representatives of the Post Office, the Royal Navy and the Army, the latter including an officer of the Royal Engineers. As a result, some wireless sets were despatched to South Africa to help in the Boer War, which they failed to do and so were transferred to ships. The early military attitude to wireless was lukewarm; at best it might be considered an adjunct to the cavalry. Consequently, at the outbreak of war in 1914, the British Army was not particularly well equipped with the new technology.

The situation in the Royal Navy was much better. Some of their ships had been fitted with wireless as early as 1899 and, in 1900, a contract with the Marconi Company was signed for the supply of two shore stations and twenty-six shipboard installations. By 1903, all ships of the Royal Navy had been fitted with Marconi wireless equipment. The use of wireless had also become universal in the U.S. Navy, and quite widespread in the German Kriegsmarine.

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Wireless with Wings

There was of course, in Britain at least, no separate air force prior to World War One. But experiments had been carried out to take wireless equipment aloft. The Royal Engineers, from which the Royal Flying Corps and, later, the Royal Air Force, emerged carried out some tests with their balloons. In 1907, Lieutenant C.J. Ashton ascended in a captive balloon and became the first person to receive signals from the ground. In the following year, two-way communication was established with a free balloon, the Pegasus, when signals were received from Aldershot, twenty miles away.

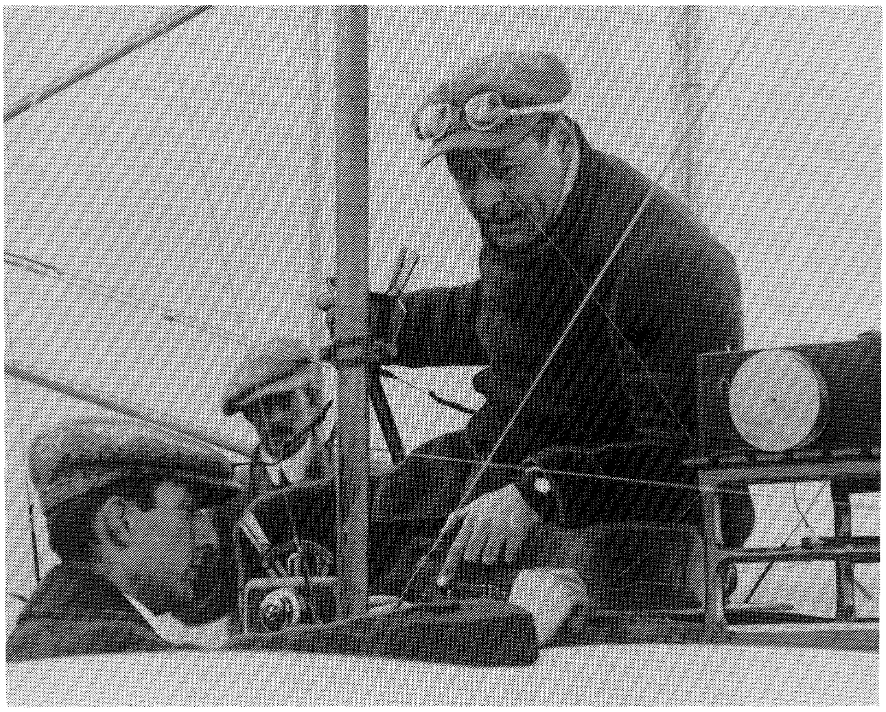

Photo supplied by The Marconi Co. Ltd.

Message transmitted from an aircraft to the ground, September 1910 over Salisbury Plain.

From balloons to airships was a natural step and, in 1911, the airship Beta was used, equipped with a transmitter and receiver. Captain Leroy of the Royal Engineers went up in her and made contact with the ground at distances up to thirty miles. A slight snag was that the airship's engines had to be stopped during reception! However, the value of the 'eye in the sky' was shown during exercises in 1912, when the airship Gamma reported consistently on the movements of the 'enemy' below. It pointed the way for the value of wireless in the conflict to come, though during the Great War the Army used aeroplanes in the spotting role, as airships close to the ground were far too vulnerable.

The feasibility of equipping an aeroplane, as opposed to an airship, with wireless had been shown quite recently, in 1910 in fact. The demonstrations had taken place on both sides of the Atlantic. McCurdy in a Curtiss had effected two-way communication at Sheephead Bay, New York, while the well known British actor, Robert Loraine, had taken up a transmitter in his Bristol during the Salisbury Plain manoeuvres, and made contact with a receiver on the ground.

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Not to be left out of the picture, the Royal Navy were busy putting wireless sets into some of their aircraft and, in 1912, there occurred the first instance of the rescue of an aircrew downed in the drink, as a direct result of wireless. This came about when Lieutenant Fitzmaurice and Commander Samson suffered an engine failure in their Short seaplane and had to put down on the sea. Because of the signals they sent when the trouble developed, they were soon rescued by the ship Hermes.

In the Beginning

During the opening months of World War One, the whole country was caught up in the most incredible spy mania. Most

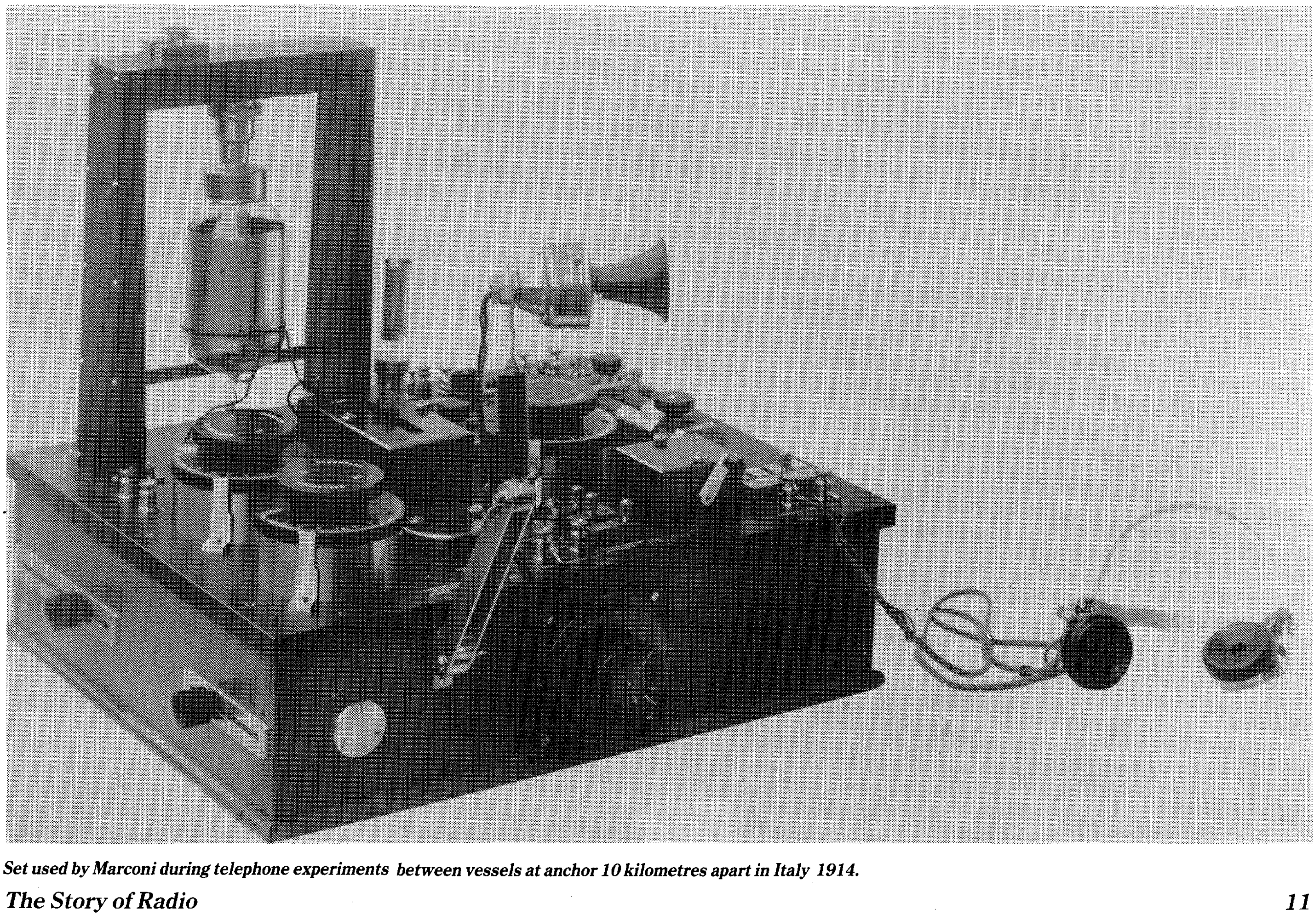

Photo supplied by The Marconi Co. Ltd.

Set used by Marconi during telephone experiments between vessels at anchor 10 kilometres apart in Italy 1914.

people, including those in positions of authority, had little idea of the potentialities of wireless and there was the fear that anyone who owned anything remotely connected with this 'dark art' was likely to be a German agent. As a result, everyone was required by law to register any equipment in their possession, even a simple crystal set! One young man who was an avid

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experimenter was found to have a roomful of apparatus and so languished in gaol for nine months because he hadn't registered it!

By the outbreak of war in August 1914, wireless had not developed sufficiently for Britain to possess transmitters with a world wide range. But, she did have an Empire and a number of cables. The combination of the two made communication with the Royal Navy possible, wherever the ships were to be found. So it was that, on August 3rd 1914, the following messages were received by ships of the Royal Navy.

'Admiralty to all ships – Urgent message. The war telegram will be issued at midnight authorising you to commence hostilities against Germany but in view of our ultimatum they may decide to open fire at any moment. You must be ready for this.'

Followed by a few hours later:

'Commence hostilities against Germany.'

Both the Royal Navy and the German Kriegsmarine had full wireless contact with their ships at sea. Cipher was used in the passing of messages of course but, right at the beginning of the war, the British gained an enormous advantage over their enemy by the most incredible stroke of luck.

The whole country was caught up in the most incredible spy mania; most people had little idea of wireless and there was the fear that anyone who owned anything remotely connected with it was likely to be a German agent.

At the beginning of September 1914, the German light cruiser, Magdeburg, was wrecked in the Baltic. The body of an unter-offizier was hauled out of the sea by the Russians a few hours later and, clasped firmly in his arms, held there by rigor-mortis, were the German Navy's cipher and signal books, together with detailed maps of the North Sea and the Heligoland Bight! The Russians felt that Britain, as the leading naval power, should have the use of these important documents and so they were handed over to us.

As a result, we were able to monitor all communications between Germany and her warships for the early part of the war (until it was realised why we always knew where the German ships were!) and decipher them at ease. Then the Germans changed their codes.

Find the Direction

However, by the time that had happened, wireless was being applied in a new role, that of direction finding. DF stations were set up on the east coast, for example at Aberdeen, Flamborough and Lowestoft, and with them it was possible to pinpoint the activities of enemy vessels. This could only be done if the ships were actually transmitting, of course, but as it happened the Germans had not learnt the value of wireless silence.

In fact, the battle of Jutland came about because the British could follow the passage of the German High Seas Fleet and so were able to put to sea to intercept it.

Submarines were also equipped with wireless in order to maintain contact with their bases and, although the transmissions were brief, they were sufficient to allow the DF stations to plot the course of the German U-boats. By co-operating with the aircraft of the Royal Naval Air Service, it was possible to vector a seaplane or flying boat onto the enemy, with a fair chance of finding and destroying it.

Field Radio

As already mentioned, the British Army entered World War One in a much less happy state than did the Royal Navy, from the point of view of wireless equipment. What the army did have had been designed with the Boer War in mind, and it was almost useless for its task. There were ten sets, supplied for use with the cavalry, that prestigious but largely ineffective arm of the army.

The cart set, to take an example, was mounted on two limbers, weighed two tons and required six horses to draw it. To get the station fully operational was a lengthy process, as it took twenty minutes to set up the aerial system. When it *was* working the selectivity, or lack of it, imposed severe limitations on its use. In fact, so bad was the situation that a special system had to be worked out, known as the 'period system', in which effectively only one station was on the air at a time!

It was not a system that worked very well and so it did little to inspire confidence in the use of wireless. Another problem was that, when the set was used in a 'forward' position, the aerial presented a rather nice target for the German gunners.

However, it was obvious that wireless properly developed and applied would be a useful asset to an army in the field. Telephone lines were used extensively in the trenches, but they were easily cut, and could also be tapped into. What was required was a short-range portable set so, in August 1915, the

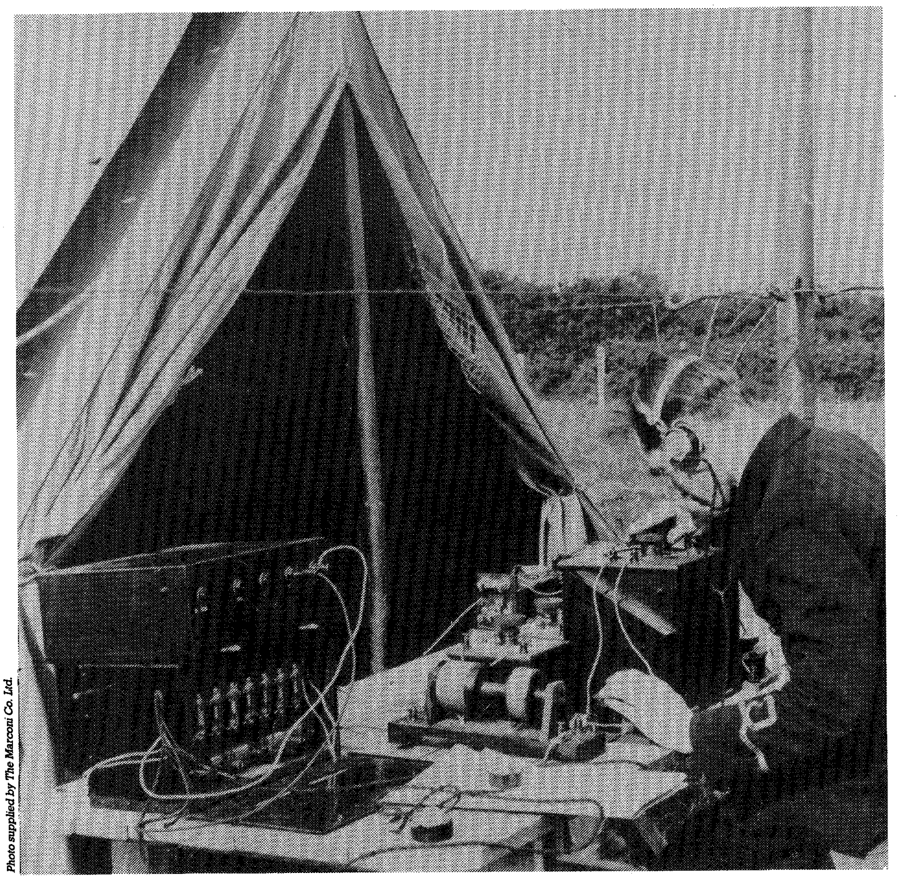


Photo supplied by The Marconi Co. Ltd.

Mobile wireless set 1916.

British field wireless set was ordered.

These were first used at the Battle of Loos and actually worked very well. This set had a range of 4000 yards when it was used with a 180 foot long aerial, supported on 12 foot high masts, but gave a better range on a *longer* aerial! A crystal detector was used. It is interesting to note that, in London where Dr. W.H. Eccles was working on the use of the thermionic valve for wireless, he was able to pick up the transmissions from the Western Front in Flanders.

The early transmitters were of the spark type but when later, in 1917, it became possible to generate continuous oscillations (called CW for Continous Wave), CW transmitters appeared on the Western Front which gave a range of 6000 yards with an aerial system only 30 feet long and 2 to 3 feet high.

The big problem with wireless in the army was not the equipment as such, but the general attitude to its use. It simply wasn't trusted by those in command and, consequently, was never employed to the extent that it could or should have been. Nevertheless, it did have one particular use which was exploited effectively, and that was for artillery observation. In this application aircraft were used as spotters for the artillery, directing the fall of shot.

Wireless Aeroplanes

Two wireless sets were designated for aircraft use, known as the type L and L1 respectively. The former weighed 50lb and had a range of 15 miles for a power rating of 40W; the latter had the very much greater range of 80 miles, achieved using an aerial power of 500W, but weighed 200lb, which made it an unlikely proposition for the typical artillery observation aeroplane whose payload was very limited. However, of a number of methods tried for communicating the desired information to the ground, the use of wireless telegraphy turned out to be the most effective.

There were still some of the old problems though of mutual interference due to lack of selectivity. The answer was to use sets of low power and a minimum spacing of about 2000 yards between adjacent 'wireless aeroplanes'. An example of this type of set was the Sterling, which was manufactured by the Sterling Telephone Co Ltd to the designs of Lt. Leroy, an RNVR officer serving with the RNAS. It weighed only 20lb, which made it possible for an observer to be carried, who could deal with its operation, leaving the flying to the pilot. Hitherto the pilot had had to handle the aeroplane, observe the effects of the artillery bombardment and pound out the relevant information in morse code at the same time!

A special wireless unit was built up, which later became No. 9 Squadron, Royal Flying Corps. Later still every battery of guns had its own spotting plane. By the end of the war about 600 British aircraft were fitted with wireless telegraphy equipment, and there were some thousand or so ground stations.

Wireless 'telegraphy' meant, of course, morse code. However, there were experiments with radio telephony (RT) as early as 1914. A Captain Dowding, later Lord Dowding of Battle of Britain fame, while with No. 9 Sqdn. RFC, took a Maurice Farman biplane aloft, which was fitted with a telephony transmitter. He was assisted by a professional wireless engineer, one C.E. Prince, and was able to lay claim to being the first person in England to receive an airborne radio telephone transmission. The War Office decreed that such impracticable experiments must cease, but evidently relented later because, by 1915 a working RT set had been put into service which had a special microphone capable of working close to the aeroplane's engine.

It took twenty minutes to set up the aerial system . . . When the set was used in a 'forward' position, the aerial presented a rather nice target for the German gunners.

For a long time transmission was a one-way affair, because the high noise level in the air made it difficult to understand messages received from the ground. However, by shouting into his microphone the operator could get a good enough signal/noise ratio to make one-way working practicable. The other problem with airborne reception was the way in which the vibration of the airframe affected the

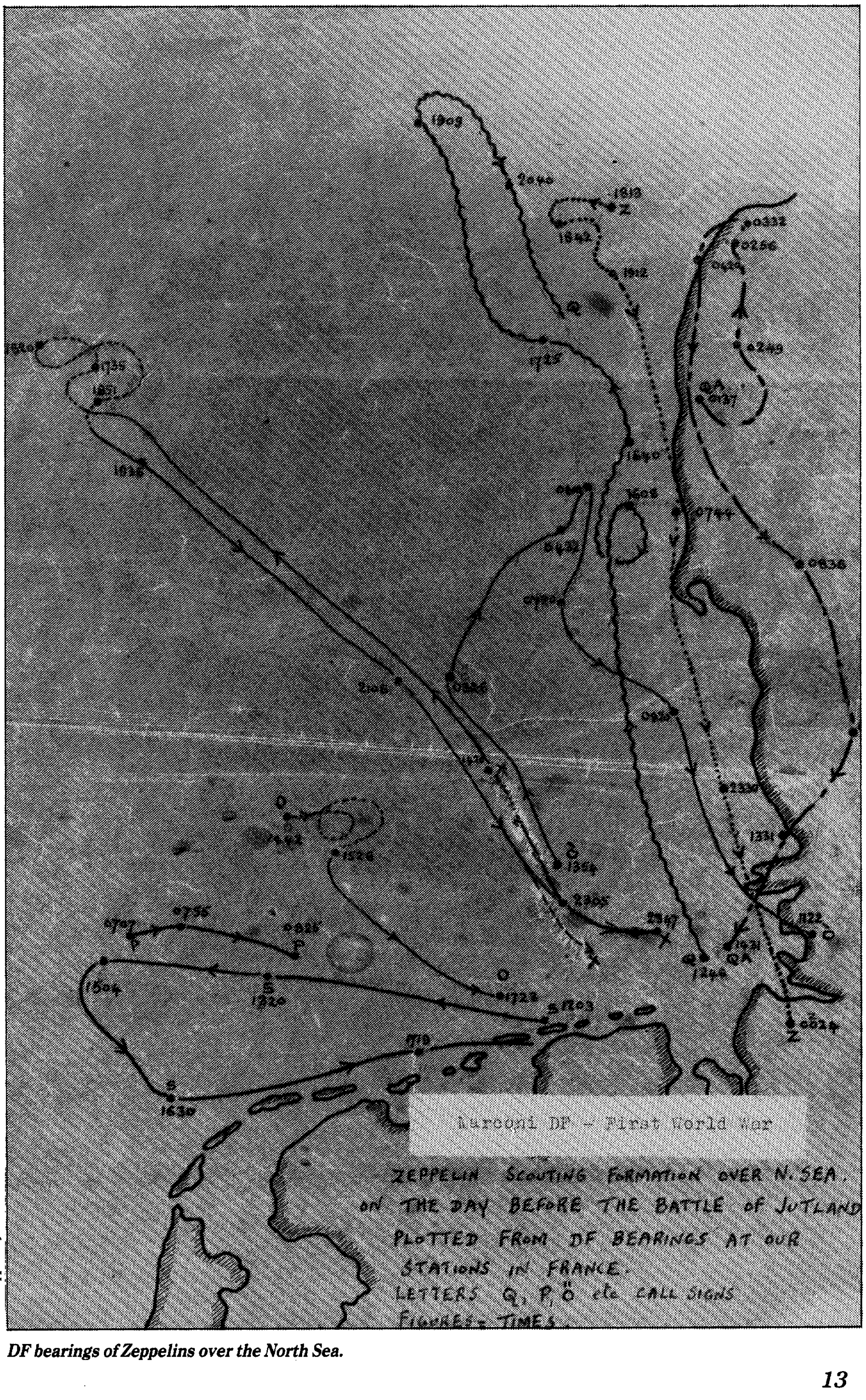


Photo supplied by The Marconi Co. Ltd.

DF bearings of Zeppelins over the North Sea.

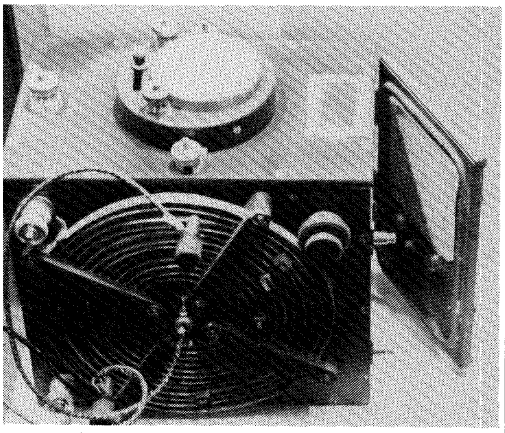


Photo courtesy of The Science Museum, London.

Trench spark transmitter and receiver, 1916. The receiver aerial is laid along the floor of the trench while part of the transmitting section was hoist on a bayonet in the Parapet.

The body of an unterofficier was hauled out of the sea by the Russians a few hours later and, clasped firmly in his arms, were the German Navy's cipher and signal books

stability of the contact between the 'cat's whisker' and the crystal. The introduction of balanced carborundum crystals improved this situation.

Another weapon of war appearing at this time was the tank. To direct the tank force effectively also meant control from the air. RT was tried, but the range was too limited to be effective. WT was much better but here there was also a slight snag. The tank had to stop and set up an aerial whenever it wanted to communicate! There is much we take for granted today.

WT was much better but here there was also a slight snag. The tank had to stop and set up an aerial whenever it wanted to communicate!

Signal Corp

Throughout the various theatres of operations of World War One, wireless was employed with a greater or lesser degree of usefulness, but it seems that the former was more prevalent because, by the middle of 1918, the army 'brasshats' realised that a separate organisation was needed to control the use of wireless, both WT and RT. Though too late to see service in the First World War, the Royal Corps of Signals was formed in 1920.

For the first time the civilians, well away from the battle lines, became involved in a major conflict between combatant powers. This was one of the less desirable by-products of the new age of aerial transportation. The Germans, as well as the British, built some heavy bombers with a moderate war load and respectable range. However, the Germans, just across the Channel had an advantage, which they followed up.

While a substantial number of air raids were carried out on English towns, with the consequent loss of life and extensive damage to property, it is the Zeppelin that has captured the public imagination rather than the Gotha and Friedrichshafen bombers. Perhaps it is their immense size that accounts for this, the huge gas-filled envelopes droning above the cloud cover, dropping their explosive cargoes indiscriminately.

Wireless was used by both sides in this form of warfare. The Zeppelins could only be attacked if the element of surprise could be achieved. This meant knowing sufficiently well in advance the likely course and height of the intruders. Thus, DF was used to plot the enemy's course and the use of wireless communication directed the defending fighters onto him. Although the little single-seater scouts used for air defence were nimble, the giant airships could rise very rapidly out of range, just by jettisoning ballast, carried in the form of water. It was very much a 'cat and mouse' game, but in the end the Zeppelins were too vulnerable. Although 'radar' had to wait for another war to bring it into existence, wireless played a similar and vital role during the Great War.

The Germans used wireless for communication between airships (and aeroplanes), for communication with their bases and also for navigation. For the latter purpose, the Germans set up a network of DF stations, able to take bearings on signals transmitted from an airship, that could provide a fix for an airship commander. It was, of course, this very provision that allowed the British to plot the enemy's incoming track and so scramble the defending fighters in time!

The Germans set up a network of DF stations, able to take bearings on signals transmitted from an airship, that could provide a fix for an airship commander.

As wireless had assisted the purposes of war, in the end it was used to announce to a tired and waiting world the most welcome news of all.

On top of Marconi House in London a constant vigil was kept to listen out for the transmissions of the French station FL on the Eiffel Tower in Paris. At 0500 hours on November 11th, the following message was received and despatched to Downing Street.

'From Marshal Foch to All Allied Commanders – Hostilities will cease at 11.00 o'clock.'

The 1920's

After the Great War (the war to end all wars, so it was thought), little progress was made with wireless in the services for many years. However, there were those who appreciated that, what could be used successfully at sea, could also find application in the air. When Alcock and Brown made the first non-stop Transatlantic flight in 1919, they carried wireless in their Vickers Vimy biplane in order to maintain some contact with the outside world. It is hardly their fault that, shortly after take-off, the propeller of their wind-driven generator broke, leaving them in isolation for the whole of the flight. More successfully, the first regular passenger air service between London and Paris relied upon wireless for communication and navigation, and ground stations were built at Croydon, Lympne and Le Bourget in 1920. The first flight of a civil airliner equipped with wireless happened on the 4th March 1920, when a Handley-Page, registration number G-EALX, equipped with a Marconi transmitter, with 100W DC input and a 5-valve receiver, flew the route from Cricklewood to Paris. Navigational assistance through fog en route was given from Croydon station.

The Roaring Twenties

Before the middle of the 1920's regulations were issued that required certain classes of aircraft to carry wireless, as had already been done with ships at sea.

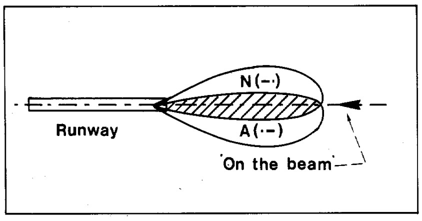


Figure 9. The Beam Homing System for Aircraft.

Radio aids to navigation became essential and direction finding equipment (d.f.) carried in the aeroplane was developed. Also developed was the 'beam homing system', in which the Morse code for 'A' (. -) was transmitted on a beam alongside another carrying the Morse letter 'N' (- .), on a given bearing. An aircraft 'on the beam' heard only the dash (where the beams overlapped) but heard either A or N separately if it deviated to one side or the other (Figure 9). Thus, wireless was used in aircraft for the peaceful purpose of conveying people safely from A to B, a far cry from when it was recently used to call down explosive shells on the heads of the enemy.

Meanwhile at sea, valves gradually came into use more and more, though the spark transmitter remained in service for quite a long time, some examples still being seen as late as the beginning of the Second World War. Another innovation was ship-to-shore radio telephony (i.e. the transmission

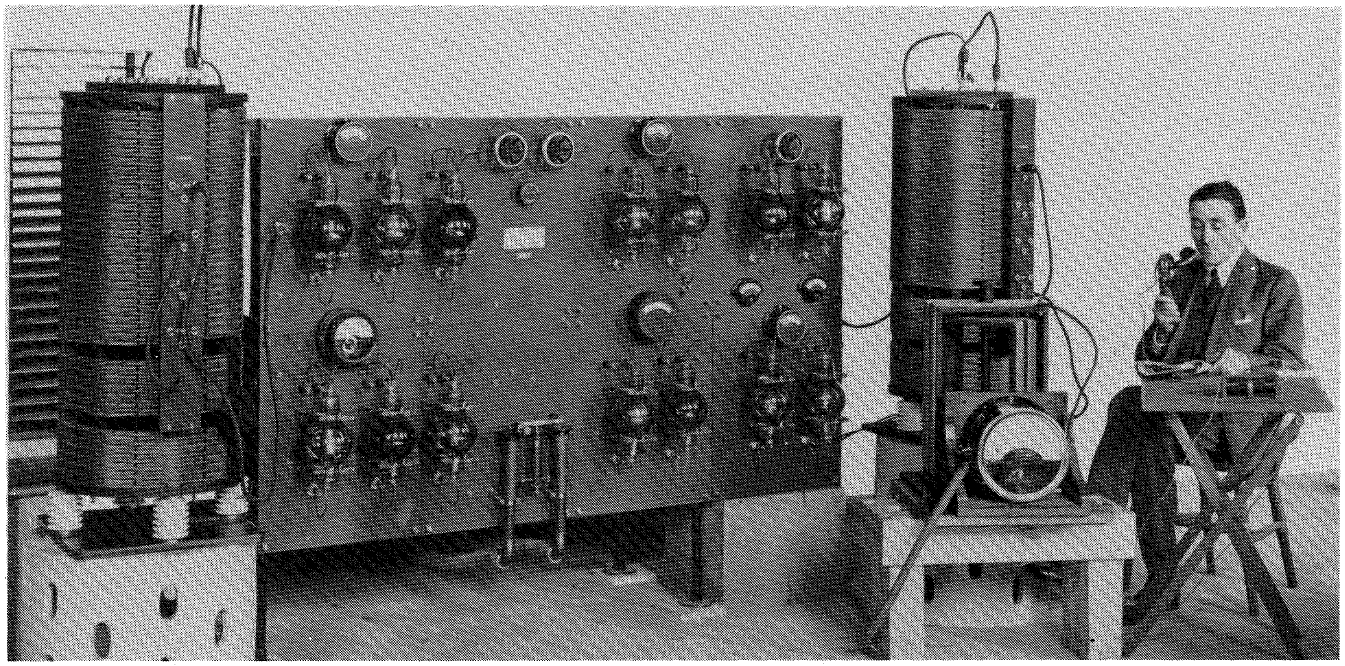


Photo supplied by The Marconi Co. Ltd

6kW experimental broadcast transmitter 1919.

of speech as opposed to code), while the marine sphere saw some lifeboats being equipped with wireless telegraphy equipment. By 1926 the Marconi Company had fitted out 161 lifeboats in this way.

During the 1920's attempts were made to link the British Empire by wireless; in fact cable and wireless links existed side by side. In 1923 station GBR at Rugby was constructed, working on the incredibly low radio frequency of 16kHz. The aerial system required for working at such a long wavelength must be seen to be appreciated, consisting as it does of twelve 820 ft high masts! However, contact with any ship at sea or any part of the world at any time was guaranteed. In addition, a time signal and a news service was provided.

Radio telephony made great impact in that country of vast distances, Australia. Lack of an electric supply at isolated homesteads was overcome by means of pedal power. A generator driven by the adaptation of the motive parts of a bicycle produced the wherewithal that allowed contact between people well separated geographically. As well as the social and psychological implications of this communication link through the aether, a means of summoning assistance was readily available, leading to the Flying Doctor service that could be called up for help or just advice. Education for the children was another serivce that the radio provided, since attendance at a conventional school was often not possible. All this had happened by 1929.

Crimewaves

The first use of wireless for crime detection was the case already described of Dr. Crippen. However, this was a by-product of the public wireless service and not the result of a special police wireless network. Examples of the use of W.T. by the police can be found in Detroit (1921), the Metropolitan Police (1923) and the Lancashire Police, who used it during the General Strike of 1926. In 1928 the Brighton Police Force tested the first 'walkie-talkie' that could be carried by a constable, and it was in general use in the 1930's. But the number of available channels was limited by the bandwidth restriction imposed by broadcasting on the medium waveband.

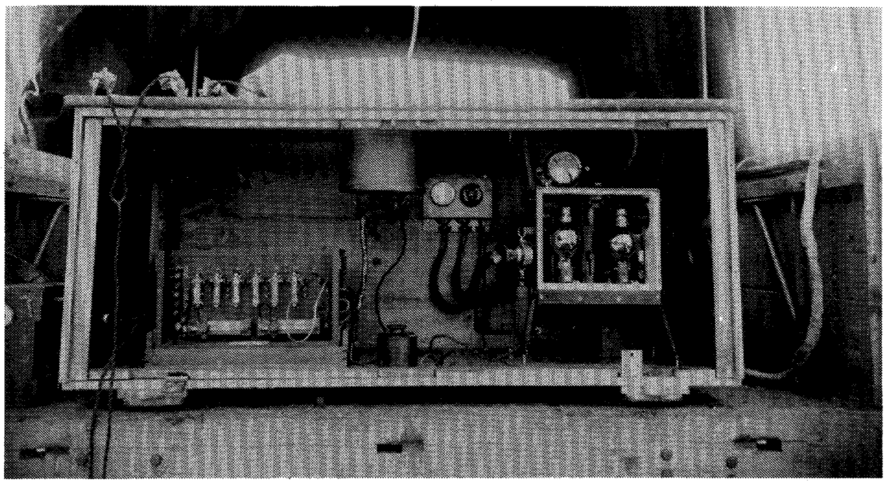


Photo supplied by The Marconi Co. Ltd

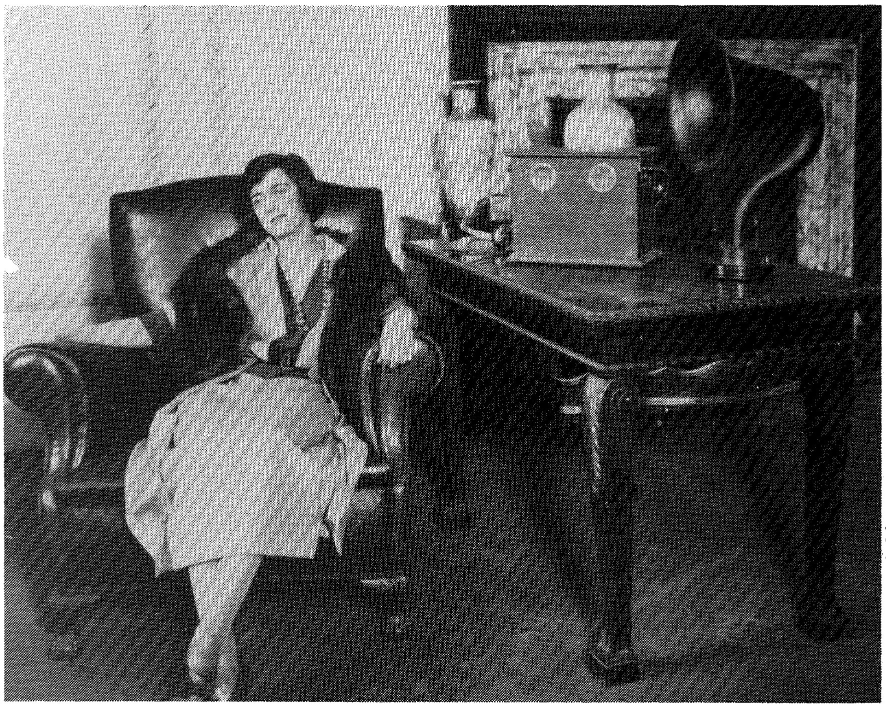
The first Marconi commercial air radio telephone set 1920.

Experiments in 'broadcasting', that is transmitting material for information or pleasure to a wide audience, had taken place before the First World War, but it could only have any real value when large numbers of people could receive the transmissions. The real beginnings of radio for entertainment in the home can probably be traced to the end of the 1914-18 war, when the factories, so long occupied with making instruments for war, were glad of the chance to do something for peace. Also the triode valve was showing its potential, although it was still very expensive. In the USA the Radio Corporation of America (R.C.A.) was formed out of the radio interests of a number of large companies, including Marconi's Wireless Telegraph Company of America. Soon the Americans were 'on the air' with station KDKA from Pittsburgh, transmitting to an estimated 5,000 - 10,000 listeners. By May 1922, there were three-quarters of a million receivers in use in the USA. It may not be easy to re-capture now the excitement of listening to 'the wireless', so used have we become to more and more breathtaking technological advances that no longer seem breathtaking!

British Broadcasting

The birth of broadcasting in Britain was a much more restrained affair than in America, largely due to governmental opposition. However, start it did and, in 1919, Marconi's set up an experimental R.T. station at Ballybunnion in County Kerry, to communicate with Nova Scotia. Well, this

In the boom time of the 1920's even famous names of the motorcycle world diversified into the wireless world.



Listening to the wireless 1922.

Photo supplied by The Marconi Co. Ltd

may not sound much like broadcasting but it did lead to a 6kW transmitter being built at the company's Chelmsford works. The frequency of operation was 120kHz and test transmissions resulted in an increase in power to 15kW. The station, now fully licensed, went on the air on the 23rd February 1920, and introduced the first regular daily broadcast service in the world. It broadcast two half-hour programmes of speech, music and news every day. Although many who broadcast in the early days were just station staff, a notable exception to this was the occasion when Dame Nellie Melba broadcast on the 20th June 1920, at the direct instigation of Lord Northcliffe, then owner of the Daily Mail and one of the most enterprising newspapersmen ever. However, in November 1920, short-sighted bureaucracy triumphed and the British station went off the air, the official view being, that the use of wireless purely for entertainment was trivialising a national asset!

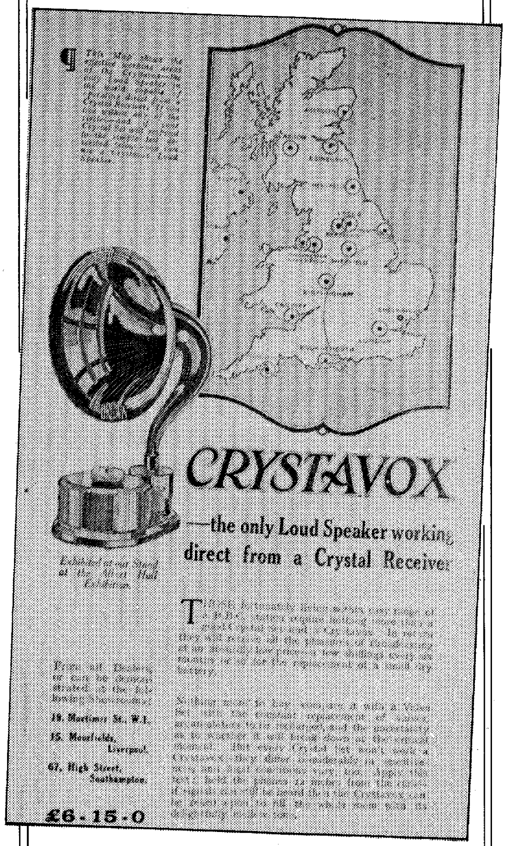
Enthusiastic Amateurs

Other aspects pertinent to the total picture of what was happening in wireless at the time included the beginnings of amateur wireless and of a national industry to serve a public becoming more and more excited by the new diversion.

After World War One, there were many ex-servicemen who had picked up some knowledge of wireless and were reluctant to relinquish it on returning to civilian life. They therefore became enthusiastic amateurs and, to cater for them, courses were run at Marconi House and Crystal Palace. The first wireless clubs were formed and, as a result, much experimenting went on.

Following the first Chelmsford transmissions, an industry began to emerge whose aim was to produce receivers for an anticipated market of eager listeners. As interest grew so did the number of manufacturers. By the end of 1922, when the BBC was in existence, there was a flourishing radio industry in this country. But what of the government ban?

In December 1921, a petition signed by over 3,000 members belonging to 63 societies was presented to the Post Office to demand the resumption of the Marconi Company's R.T. broadcasts. The Postmaster General, early in 1922, told the Marconi Company that a fifteen minute programme of music could be included in their weekly half-hour calibration transmission. A hut at Writtle, near Chelmsford, still in existence but now used as a sports pavillion, housed station 2MT. The first transmission went out on the 14th February 1922. A twenty-five minute broadcast was made every Tuesday evening. Soon after Writtle went on the air, the Marconi Company were issued with a licence for a broadcast station to be set up in Marconi House. This was the famous 2LO, which first broadcast on the 11th May 1922. At first only short speech transmissions were made but, from the middle of 1922, concerts and musical evenings were broadcast. Because of the low power of the first transmitter (only 100W) range was limited to about 40 miles for valve receivers, and 15 miles for crystal sets. But, when the power was increased to 1.5kW, the station could be heard in most parts of the country. Other companies involved in setting up stations were Western Electric and Metropolitan Vickers. The former set up a station, 2WP, in Oswaldstre House, Norfolk Street, London; the latter set up their station, 2ZY, in Manchester, where they also manufactured their 'Cosmos' crystal set, costing £4 10s (£4.50) and a two-valve receiver costing £26 10s (£26.50). However, all broadcasting in the UK came under the corporate cloak of the BBC, when it was formed in October 1922, the participating companies being British Thomson-Houston, General Electric, Marconi, Metropolitan Vickers Electric, Radio Communication and Western Electric.



Advertisement in 1923 for the Crystavox.

The Crystal Set

An obvious advantage of the crystal set was its cheapness and simplicity and its freedom from batteries. It was, however, vital to get the best signal possible and this meant rigging up a long aerial, as high as

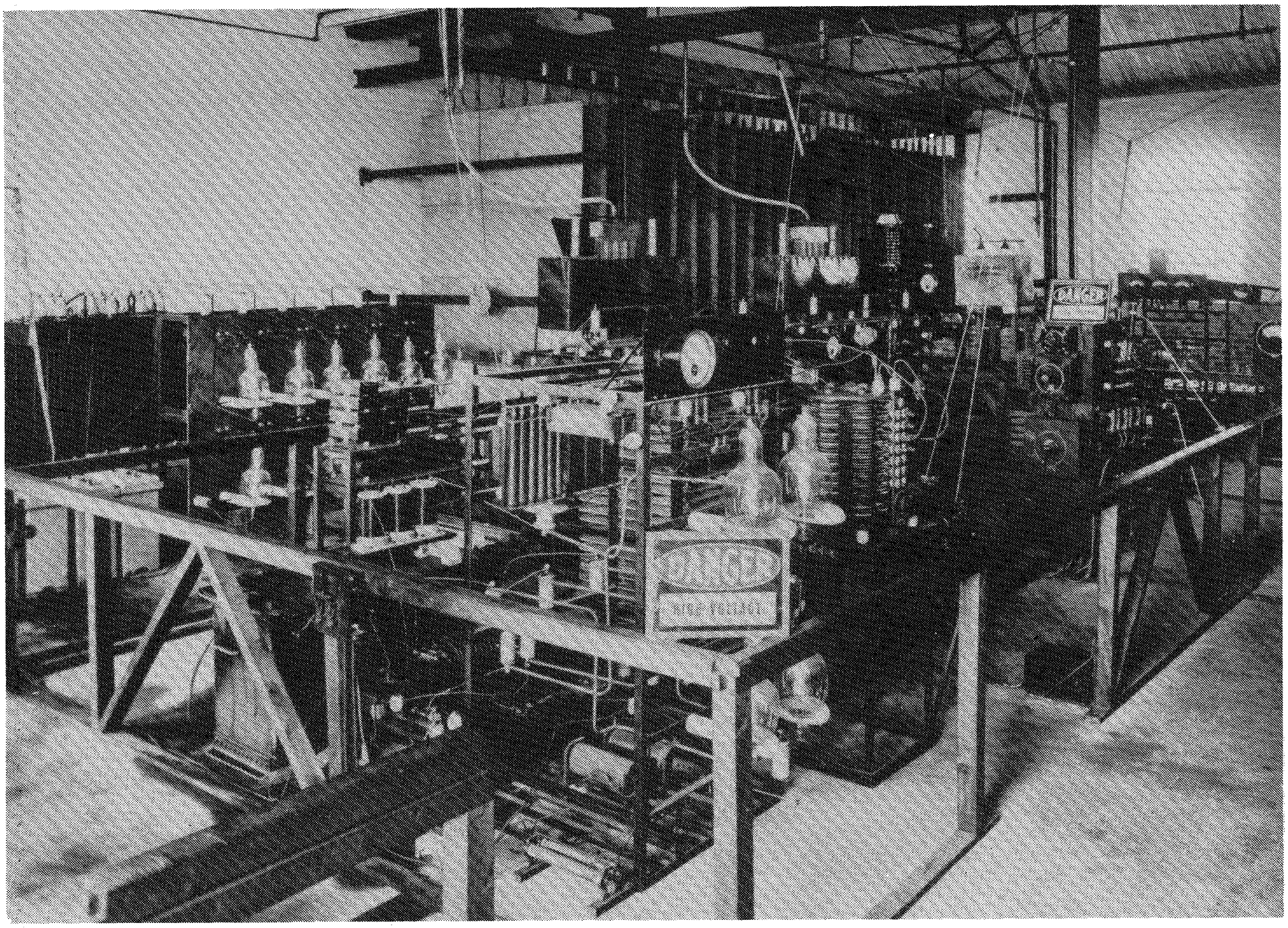


Photo supplied by The Marconi Co. Ltd.

Marconi wireless transmitting station 5XX at Chelmsford 1924.

possible, and also providing a good earth, either by a connection to the domestic plumbing or to a metal plate in the ground, which then had to be kept well watered to maintain a good contact, one of the gardener's extra duties! A number of different circuits were in use, the tapped inductance circuit being shown in Figure 10.

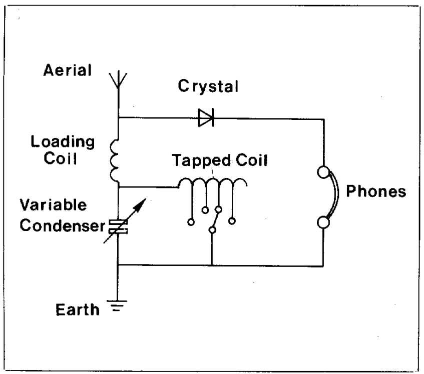


Figure 10. Circuit of a typical 'tapped inductance' type of crystal set of the 1920's.

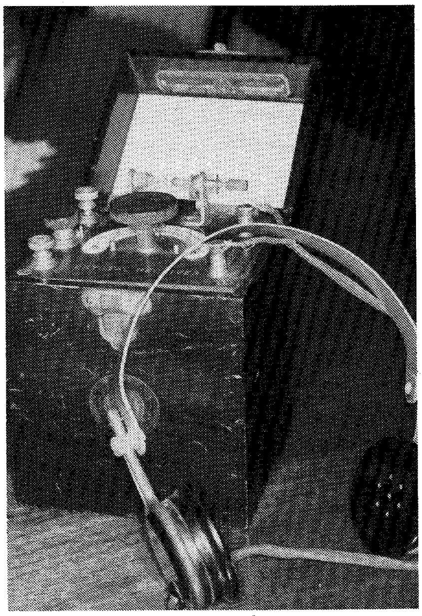
The basis of all circuits was the rectifying action of the point contact formed between a wire 'cat's whisker' and galena crystal (in fact, a semiconductor diode even if it wasn't known as such). A resonant circuit tuned by either variation of capacitance or inductance selected the required station. The audio output from the 'diode' was enough to drive a pair of high impedance phones in a high signal strength area. This meant that 'listening-in' in the family circle tended to be done in turns. To overcome this estrangement from the rest of the domestic scene, one solution was offered by the company of S.G. Brown, with their 'Crystavox'. This was an amplifying loudspeaker with a horn output. It was entirely electromechanical and took its power from a 6V battery, its current consumption being a mere 15 - 20mA. It did allow some degree of communal entertainment, though it literally demanded a close family circle as well as a very good signal from the crystal set feeding it. Apart from complete receivers, manufactured in some cases by some unlikely makers, for example, A.J.S., the well known motorcycle firm, components were available as well as kits of parts for people to make their own crystal sets.

The Crystavox.

Valve Receivers

The valve receiver naturally had real gain and a potentially greater power output than a crystal set, provided it included two or more valves. A 'one-valver' drove 'phones in the manner of the crystal set but had greater range. Even so very good aerials were needed, usually fixed to the wall of the house or the chimney, on a mast system, rather like the wireless aerials in ships. The power for the receiver commonly came from

Some 1920's radio valves from a famous maker, including the renowned R type.



BTH crystal receiver with earphones.

a 90V high tension battery and a 2V lead-acid accumulator, which needed periodic re-charging at the local garage or wireless shop. Such items were expensive, as were the valves, which also had a very limited life. The design of many sets were curious by modern standards, the valves often being mounted on the top in full view. At least this allowed them to be changed easily, and also let the occupants of the room read by the light of their 'bright emitter' filaments! But of course the real advantages of valve receivers were the ability to listen to more distant stations as well as being able to drive a horn loudspeaker so that everyone in the family could listen at once.

Styles in receivers changed in the 1920's, so that the design co-ordinated better with current furniture styles. The valves retreated to their rightful place inside, on a proper chassis, and the horn loudspeaker began to be replaced by paper cone types. These appeared in elaborately fretted cabinets. As enthusiasm for the wireless grew and its place in the home became accepted - as a necessity and not just a luxury - so it matured in design both functionally and aesthetically. Although a lifeline to many people in World War Two, perhaps the 1930's was the 'heyday' of the wireless as a means of entertainment, but more of that anon.

The Golden Age

The 1930's was the 'Golden Age of Wireless'. Even with the Deression (or perhaps because of it), more people turned to the wireless receiver in their leisure time. When the BBC was founded in 1922 there were just over two million licence holders in the UK – by 1939 there were over 9 million. By the middle of the decade, 1935, 98% of the population of this country could listen to one BBC programme and 85% had a choice of two. The listening public crossed all social boundaries. Even the very poorest (and there were plenty of those in pre-war Britain), felt the need for a cheap wireless set to entertain them. The Philco People's set, introduced at the 1936 Radiolympia, sold for 5 or 6 guineas (£5.25 - £6.30). The hire purchase companies did well out of the growing interest, for the cost of a receiver was beyond the cash resources of many, especially if it was of the type that included a gramophone, the popular 'radiogram'. Nearly half of the licence holders of 1939 had incomes of less than £4 per week; some had less than £3.

Wireless on the move!

Radiolympia was the highlight of the 'wireless year', being held in the autumn. At the 1930 show, one of the most noticeable developments was in the number of mains operated receivers. These were classified as 'table models' or 'transportables', that could be moved from room to room. The dials of these receivers were marked with the wavelengths to which they could be tuned. It was only later that the station names were included as well because, at this time, there was still a lot of discussion going on around the conference tables as to what each country should have in the way of wavelength allocations.

It may seem obvious to us that sets which were to be used exclusively in the home should be able to operate from the domestic mains supply, but the fact is that there were many homes still without electricity, and those that were connected might have either AC or DC mains, depending upon the whim of the local board! As recently as the 1950's it was possible to take an AC mains receiver from one part of the country to another and be unable to use it because the supply turned out to be DC. Many a mains transformer primary went up in smoke because of this incompatibility! An obvious advantage of having a receiver capable of operating from the mains was its

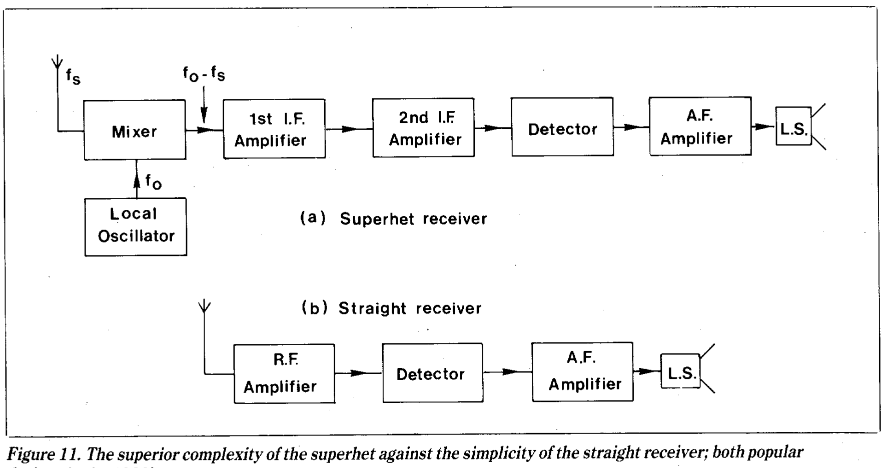


Figure 11. The superior complexity of the superhet against the simplicity of the straight receiver; both popular designs in the 1930's.

Early Emitron TV camera.

Photo supplied by EMI

Alexandra Palace, London, 1937.

negligible operating cost in terms of power consumption. Batteries were then, and still are now, expensive items.

Superhet

The 1930's saw the widespread adoption of the 'superhet' receiver. To give it its full name, it was a 'supersonic-heterodyne' receiver and it has remained the standard type ever since. Its great advantages were, a substantial increase in both 'sensitivity' and 'selectivity', compared with the T.R.F. (Tuned Radio Frequency) or 'straight' receiver. The greater sensitivity resulted from the larger number of stages of amplification (at r.f.) that could be achieved without encountering the instability problems that often resulted with T.R.F. receivers. The improved selectivity (the ability to discriminate against stations on a wavelength close to that of the desired station) followed more or less automatically, because more r.f. amplification implied more resonant circuits, each tending to reject adjacent channels. The problem with the T.R.F. receiver was the extreme difficulty of achieving high gain and variable tuning at the same time without the whole thing bursting into oscillation. High gain meant several r.f. stages, each with its own tuned circuit that had to be 'ganged' to the others – an unwieldy arrangement. The superhet got around the problem by producing an 'intermediate frequency' (the i.f.) that was always the same no matter what the incoming frequency. Most of the amplification was carried out at this lower, fixed radio frequency, and was much easier to do in consequence.

Figure 11 shows block diagrams of both types of receiver. In the case of the superhet, the i.f. is produced by a process known as 'heterodyning', in which the incoming signal is mixed with the output of a local oscillator. The i.f. is one of four frequencies output from the mixer, and is the difference between the r.f. signal and local oscillator frequencies, the other three being the received r.f., the local oscillator frequency and the sum of these two. A tuned circuit immediately follows the mixer output which filters out all but the required i.f. which is passed on to successive stages. This precludes that the local oscillator output frequency must 'track' the received r.f. and so two ganged, tuned circuits are required. Since the local oscillator and r.f. signal tuning are ganged, their difference is always the same. A typical value of i.f. for a modern AM receiver is 470kHz though, in the past, it has been anything from 110kHz to 550kHz, for MW/LW wavebands.

Apart from the benefits of having a receiver that was less prone to 'adjacent channel interference', the owner of a superhet receiver no longer needed the elaborate aerial system that had previously been considered vital. At worst he could probably get by with a piece of flex strung along the picture rail, and so the skyline of a 1930's town became somewhat cleaner than it had been in the previous decade, as the forest of swaying masts was gradually dismantled.

Radio gets Style

Styles in receiver cabinets underwent changes in the 1930's, one significant line of development being the exploitation of plastics, in the form of Bakelite. One company, Ekco, produced a receiver in 1934 called the AD65, which used a Bakelite moulding that broke away (not literally!) totally from traditional furniture styles. This was designed by the architect, Wells Coates, designer of some of the interior of the BBC's Broadcasting House. The use of the term 'furniture' to describe the style of a radio cabinet may seem slightly odd; nonetheless that is how cabinets were viewed up till then, as extensions of existing furniture, subject to the same limitations of wooden construction as sideboards, bookcases, and so on, since a

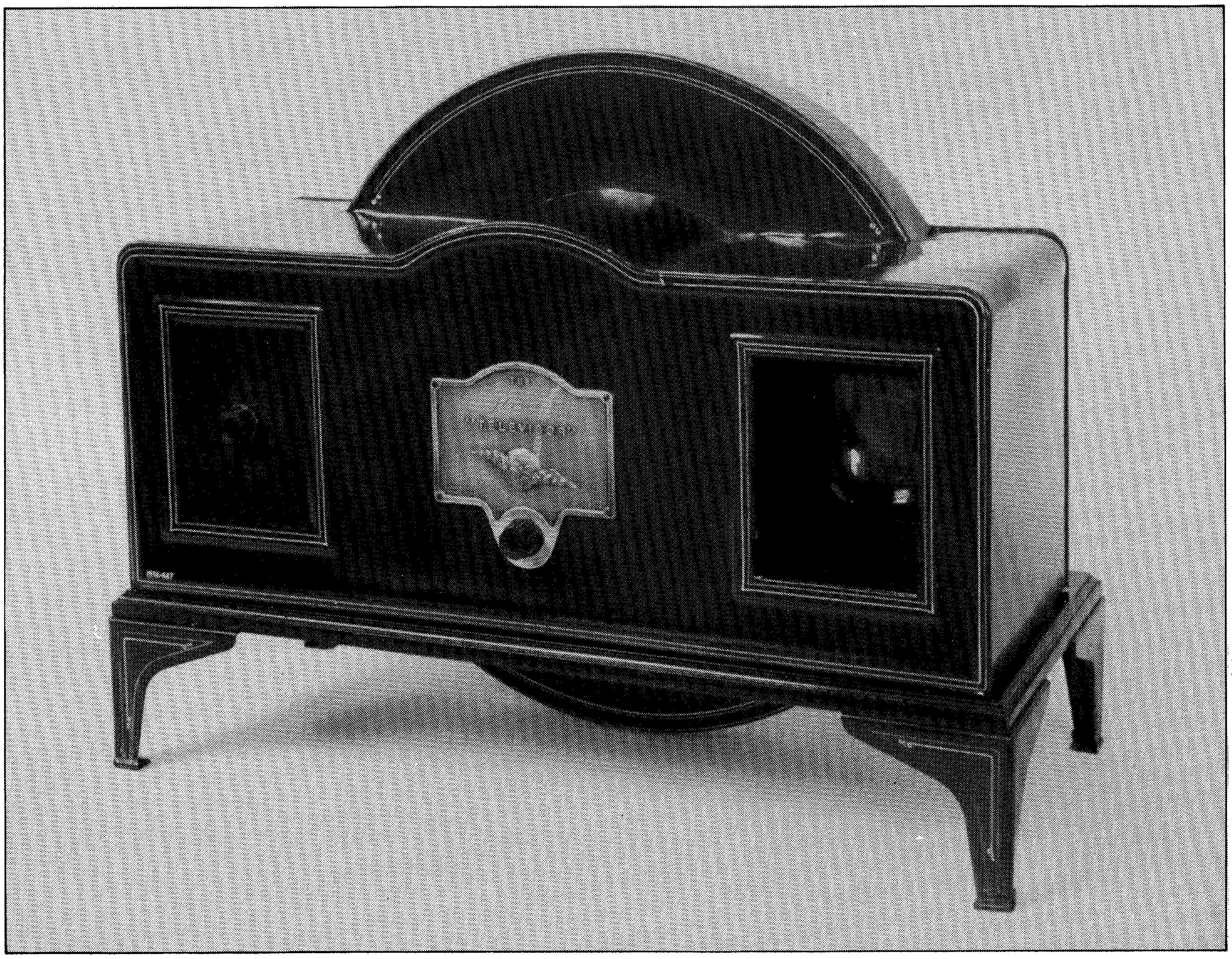
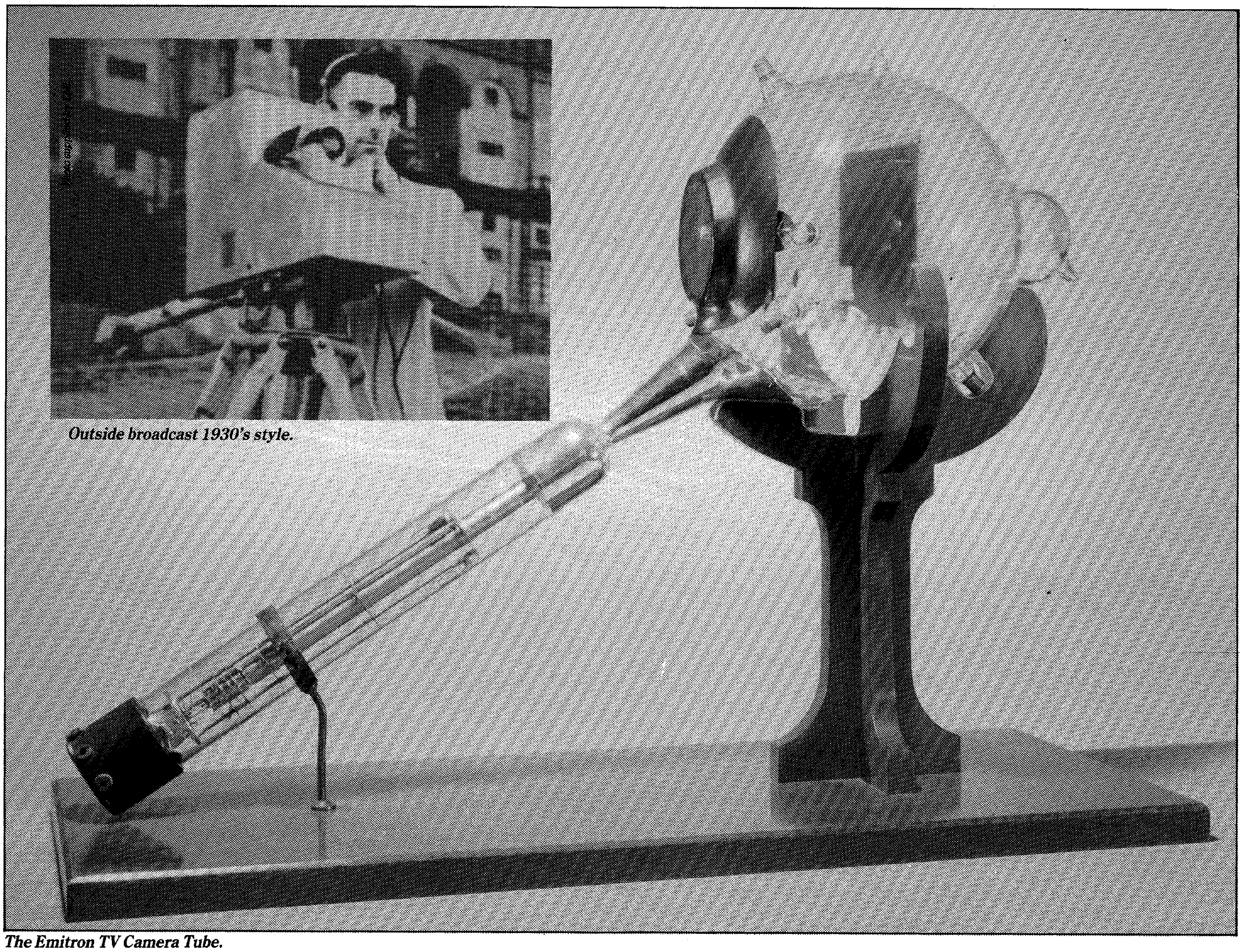


Photo supplied by the Trustees of the Science Museum (London).

Baird Disc Model Televisor 1930.



Outside broadcast 1930's style.

The Emitron TV Camera Tube.

Photo supplied by the Trustees of the Science Museum (London).

typical receiver of this time (let alone a 'radiogram') could be as large as a modern good sized colour TV or bigger! Another handsome and significant design in Bakelite was the Philco 'Peoples' Set, Model 444 of 1935.

The domestic wireless scene was big business in the 1930's. The well-known firms of GEC and HMV were a far cry from the garden shed businesses of a few years earlier. The latter company employed a workforce of 12,000, had their own foundry, timber yard and sawmill, Bakelite moulding facility, generating station and even their own railway siding.

Various innovations were adopted in domestic receivers in the years leading up to World War Two, some successful, some not so. One of the latter category was a 'voice-operated' receiver from the Marconi Company, in which there were no knobs; the tuning was effected by the receiver's response to the human voice. It was combined with a television receiver that was similarly controlled. More successful ideas included visual tuning indicators, an example being the neon indicator, another the cathode ray 'magic eye' indicator valve (which was used much later as the level meter for valve driven tape recorders). Tuning a receiver by ear alone did not always get the best results. In the desire for portability, very small receivers were produced, such as the Empire Portable weighing less than two pounds. Otherwise the main variations were found in the lines of the cabinet, which were sometimes rounded, sometimes angular. However, 1938 saw another trend, in the form of push-button tuning. Here the onus for proper tuning was placed on the set maker rather than the user. A deft stab with one's finger was all that was needed to change stations. An example of this type of receiver was the 1938 Defiant MSH 938, which had a motorised tuner and no less than twenty push-buttons!

Air Travel

Imperial Airways, the British state-owned national airline, was formed in 1923 and continued in existence until the beginning of World War Two. During the two decades preceding this conflict, great pioneering flights opened up the air routes linking the British Empire and the world's capitals. The greater ranges and higher speeds of the current generation of aeroplanes necessitated improved performance in both airborne and ground wireless units, especially those used for the vital role of direction finding. This led to increased use of the h.f. wavebands (as opposed to the lower frequencies) for airborne communication. As a demonstration of the effectiveness of h.f. for long range communication, in December 1928, the transmissions from an airliner flying over England were picked up in Cairo.

March 1930 saw the introduction of another valuable service, air-sea rescue, which originated when the National Lifeboat Institution (later Royal) fitted the new Dover lifeboat with a Marconi XBM1 transmitter-receiver. Other lifeboats were gradually similarly equipped and this led eventually to the RAF Air-Sea Rescue service, which saved so many lives in World War Two.

Television

Any discussion of radio in the 1930's would be incomplete without some mention of television. Was it a companion to wireless or a competitor? In the 1930's the question was a bit academic; very few people owned a TV set. Television is, in a sense, merely 'radio with pictures'. It uses the same principles of modulation, transmission, reception and demodulation of a carrier, though the signal is more complex and two separate components can be identified - video (including sync.) and sound. So it is part of the story of radio, an offshoot, as is radar.

Associated with the 'invention' of television is the name of John Logie Baird, who was certainly an ingenious man but, ultimately, his work ended in a technological blind alley. His first crude 'televisor' consisted of an old tea chest, supporting an electric motor that drove a cardboard scanning disk, cut from an old hat box. The spindle was a darning needle. The projection side of it comprised a lamp in a biscuit tin and lenses borrowed from bicycle lamps. Even so, he was able to transmit an image over a distance of 2 to 3 yards and this led to the Baird 30-line system.

By 1928 Baird had convinced the BBC that his system was sufficiently developed to be put into service, but it wasn't until the following year that any transmissions were made. The first transmitted pictures were appalling, barely recognisable as the human face they purported to be. Even picture and sound were unsynchronised. Afterwards, the system was improved to a point where a recognisable picture with fully synchronised sound was transmitted. Televisors then went on sale at a cost of 25 guineas (£26.25) but there were few takers. The picture quality was about the same as the early movies and look how they had improved! Experiments continued and there were notable broadcasts, including the 1931 Derby and, in November 1932, a transmission was made from Broadcasting House in London to the Arena Theatre in Copenhagen, 600 miles away! But the Baird system was ultimately doomed; it just couldn't offer the picture definition that a viable system demanded.

Company movements are complex operations at best, but in 1934 the Marconi Company joined with EMI to form the Marconi-EMI Television Company Ltd, combining the technology of the two companies, which included experience of high power transmitters and the Emitron TV camera. The important aspects of this were the use of electronic instead of mechanical scanning techniques at the studio end and the cathode-ray tube at the receiver. This put the development of television on a totally different footing although much pioneering work needed to be done to produce a high definition system that would capture a wide audience. The world's first 'regular' television broadcasts were begun by the BBC on November 2nd, 1936. Advance publicity of the event was given by test transmissions between Alexandra Palace and the 1936 Radiolympia exhibition. At this time both the Baird and EMI systems operated side by side, but in February 1937 the Baird system was at last dropped. Not only had there been a disastrous fire at the Crystal Palace, which had destroyed a major part of the Baird Television Company's equipment, but the EMI equipment, which was based on the 405-line standard, was undoubtedly superior. It merely remained now to develop the latter even further and to widen the viewing public.

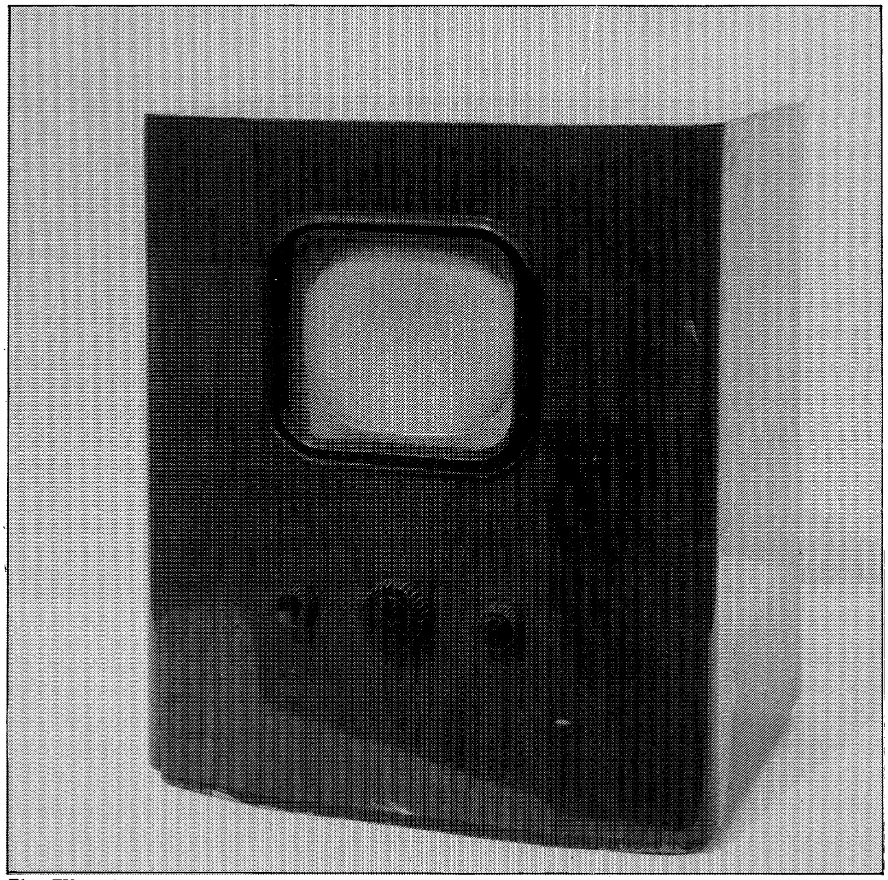

Ekco TV receiver 1938.

Photo supplied by the Trustees of the Science Museum (London).

In May of 1937 the first Outside Broadcast was made, when three cameras showed the Coronation procession as it passed Hyde Park Corner. The Emitron camera tubes produced acceptable pictures in the dull, rainy conditions but, later in the year, they were replaced by Super Emitron tubes having five times the sensitivity. Outside broadcast meant some form of link back to the transmitter and, for this purpose, the Post Office Engineering Department laid a special balanced-pair cable to carry the video signal from Hyde Park to Alexandra Palace. For more distant outside broadcasts the signal was sent to Alexandra Palace by radio, using a 1kW mobile transmitter at 64MHz with an aerial mounted on a fire-escape ladder. The number of receivers sold was low, less than 2,000. This was due to low transmission time, only two hours per day and none on Sundays, and the fact that a receiver may cost some £60, which at the time was equivalent to about half the cost of a small car! This was for a 'large' 12 inch picture. Later, in 1938, sales improved as cheaper sets with smaller tubes, down to 5in. diameter, were produced. By September 1939 there were 20,000 sets in use, but now the Nation was again at war.

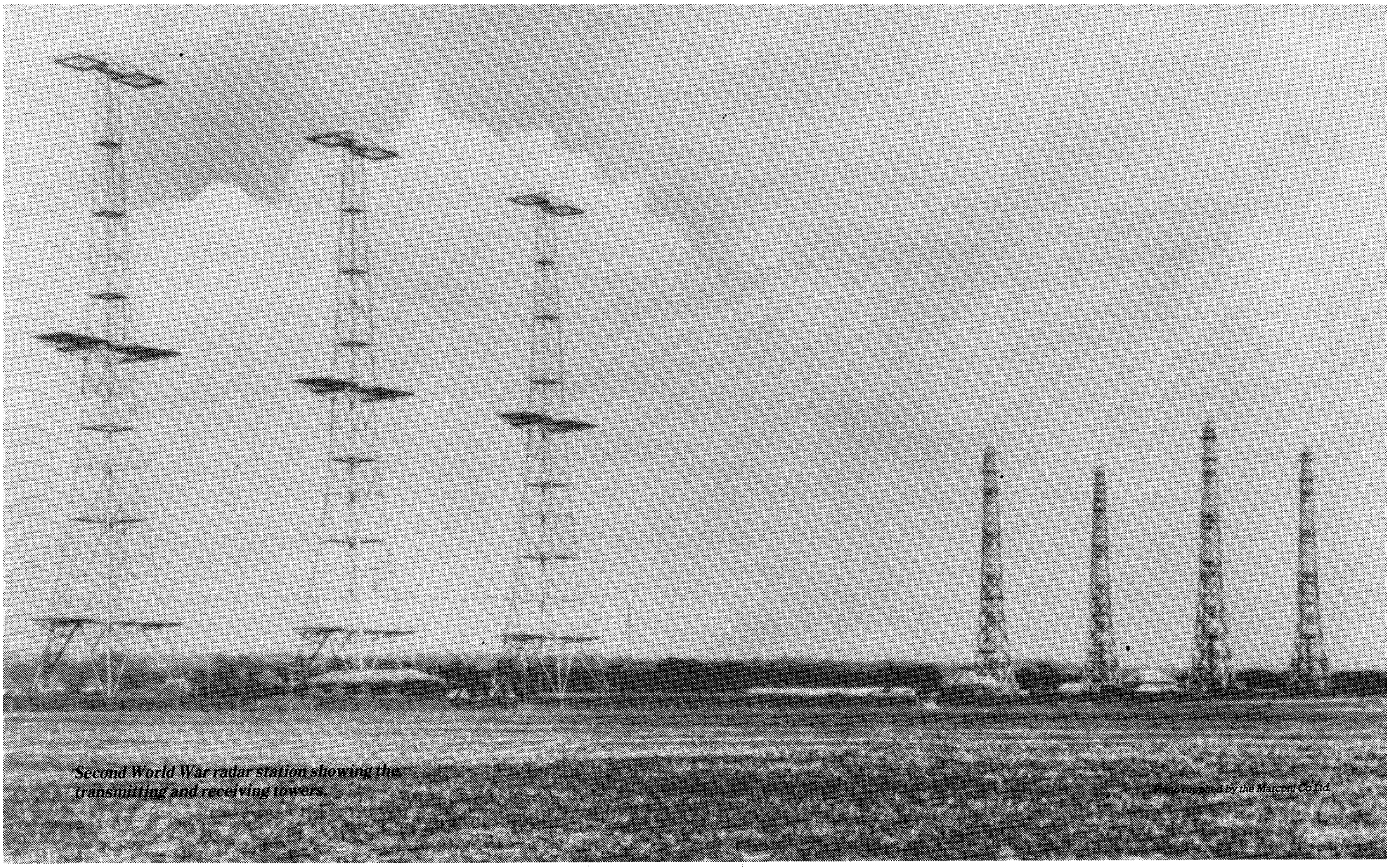
The Second World War

With the coming of the Second World War, the science of radio assumed enormous importance. One aspect of it, that played a vital role in the defence of this country in 1940, was 'radar'. This was an acronym apparently derived from the phrase, RAdio Detection And Ranging, though there are slight variations on this theme.

Early Radar

The need for radar arose from the necessity of being able to put fighters in the able to intercept the streams of enemy bombers. Because of the time taken to reach operational altitude, sufficient advance warning of the enemies approach was vital. Standing patrols were not feasible because of the limited endurance of a fighter (e.g., maximum flying time for a Spitfire would have been only some fifteen minutes) and also because of the need to rest air crews between sorties. Some research into early warning systems had been done as far back as 1934, but based on acoustic techniques, using giant, 200 feet wide concrete 'mirrors' along our coastline, acting as parabolic sound collectors. However, in the few years available, radar (at first called R.D.F. for Radio Direction Finding) developed to the point where, in the Battle of Britain, it was possible to detect enemy aeroplanes at distances of 50 - 100 miles from our shores, and even to see the bombers circling their airfields in Normandy as they formed up for a raid.

Returning to 1934, it was in that year that the Committee for Scientific Survey of Air Defence was formed. Wimperis of this committee wrote to R.A. Watson-Watt, of the Radio Department, National Physical



Second World War radar station showing the transmitting and receiving towers.

supplied by the Marconi Co Ltd.

Laboratory, Teddington, about the so-called 'death ray'. The outcome of getting Watson-Watt interested in the project was most significant.

This 'death ray' was a weapon beloved of fiction writers of the time and there were any number of unauthenticated claims for 'black boxes' that could kill rabbits at short range. The Air Ministry offered the sum of £1000 to any inventor who could demonstrate the killing of a sheep at 100 yards range with one of these devices. Needless to say, the sheep population of the British Isles was not one bit reduced by this offer!

However, what this piece of nonsense did achieve was to focus attention on the idea of energy concentrated in a ray of some form and, although this would not melt the aeroplane or even incapacitate any of its crew, Watson-Watt thought that by such a means it ought to be possible to locate the plan position of an aeroplane by measuring its distance from two reference points. The secret of this technique lies in timing a wave of known velocity. In the Imperial units of the day, this velocity was expressed as 186,000 miles per second, for radio waves. Energy reflected back from the aeroplane (a radio echo) gives a measure of the distance it is from the transmitter. For example, if the time between the transmitted wave and its received echo is measured as one millisecond, then the total distance travelled by the radio wave is given by:

Distance travelled = velocity x time
$= 1.86 \times 10^5 \times 1 \times 10^{-3}$
= 186 miles

Therefore, the object reflecting the radio wave lies at half this distance from the transmitter, namely 93 miles. An obvious way of displaying the result would be on the face of a cathode ray tube which, since it had hitherto been under development for television, was available at that time (see Story of Radio, Part Six). The type of display that would be presented is shown in Figure 12. The large 'pip' at the origin indicates the time of the transmitted pulse and the weaker pip to the right is the echo received from the target. Since there is a direct relationship between time and distance, the X scan can be calibrated directly in miles. Furthermore, the speed of the timebase can be switched to give different ranges. For example, it might initially be set at 200 miles to give an initial warning of enemy aeroplanes and then switched to 20 miles to give more accurate range as they drew closer. This principle was not entirely new as it had been used earlier to locate thunderstorms by detecting the presence of electrically charged clouds.

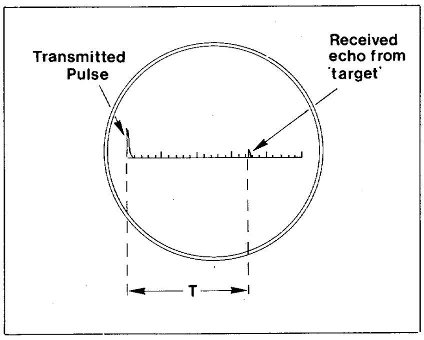


Figure 12. The basic principle of RADAR; the time T, the return journey time of the radio wave, is direct measure of the distance to the target.

Initial tests on aeroplanes were carried out in the beam of the 50m Daventry transmitter, these simply proving that sufficient energy could be reflected from an aeroplane in flight for it to be possible to make measurements of range. From this small seed, sown in the spring of 1935, radar grew. Much of the credit for this pioneering work goes to Robert Watson-Watt, who was later knighted in recognition of the fact.

A team, under the leadership of the above, was set up and a suitable site found at Orfordness, on the Suffolk coast. Here the terrain was flat, ideal for the job. Tests began at the end of May 1935 and progress was rapid. Within six weeks, the equipment was detecting aeroplanes at ranges of 17 miles and, by July, the range had been increased to 40 miles.

Radar Improves

The more specific aims of the radar being developed were to give:

(a) plan position of hostile aeroplanes to an accuracy of within one or two miles, sufficient to be able to guide in a fighter in daylight in good visibility. There were two possible ways of doing this. In the first, two stations were used, the range from each being computed and the hostile being then located at the intersection of their arcs. In the second method, one station provided both range and bearing. These methods are illustrated in Figure 13.

(b) The approximate height of the enemy. This was obviously vital as it was no good sending in fighters to the right spot only to find when they got there that the enemy were 10,000 feet above or below them!

(c) The approximate size of the formations, since this dictated how many fighters to send in.

(d) Whether the aeroplane detected was friend or foe. This would be particularly important at night.

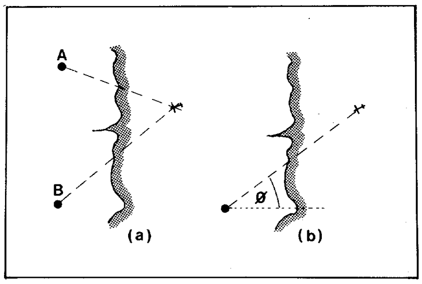
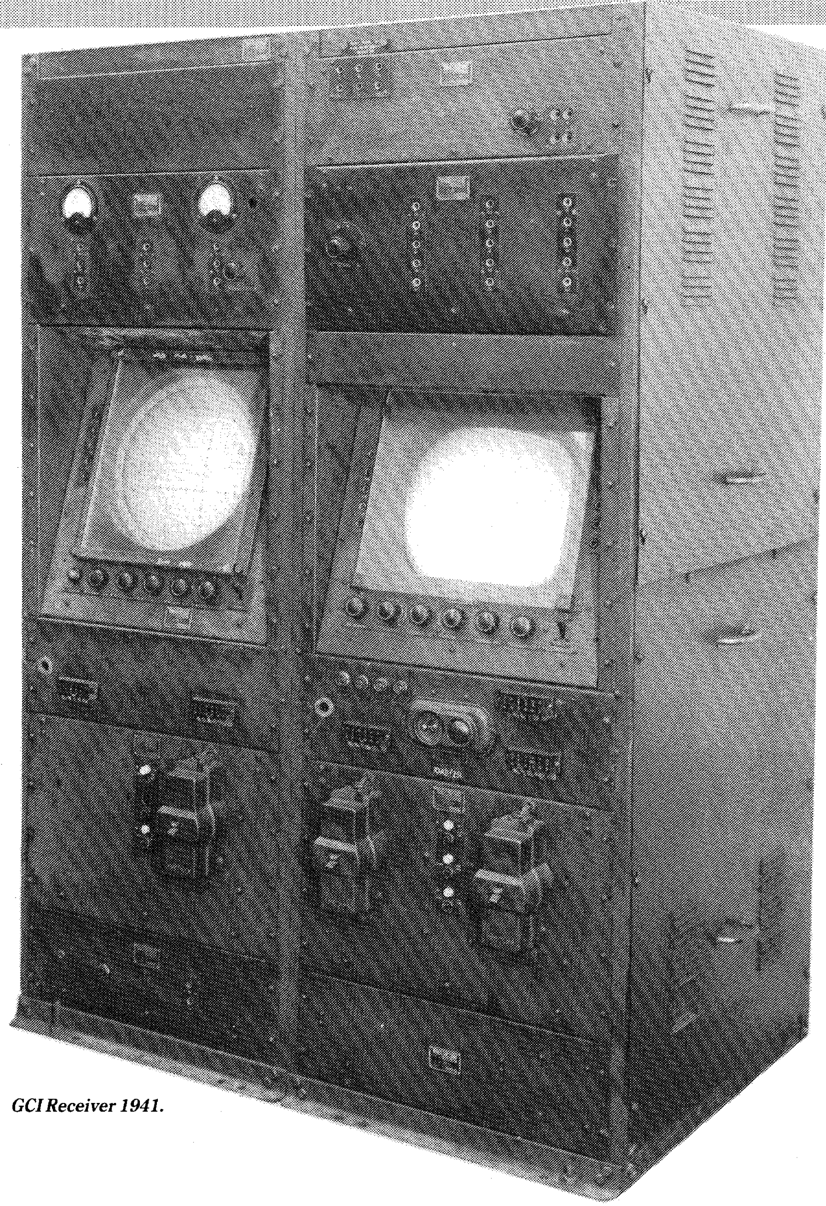


Figure 13. (a) The 'hostile' is located at the intersection of the beams from two stations, A and B. (b) A single station fixes both the range and bearing of the 'hostile'.



GCI Receiver 1941.

Photo courtesy of the Trustees of the Science Museum (London)

The identification of friend or foe was to elude the team for some time but, of the others, by the end of September 1935, a height of 7000 feet ± 1000 feet had been measured, and the problem of range measurement had been overcome.

It was now a question of putting theory into practice. An experimental system was constructed, using a low power transmitter and 70 feet masts. What was needed was very much higher power and taller masts. What was also needed was a whole 'chain' of such stations along the entire coastline facing Europe, together with some organisation to gather and distribute the information obtained to Fighter Command so that they could make the best use of it. A problem that was anticipated even at this stage was the likelihood that the enemy would attempt to 'jam' the radar with transmissions of their own. To avoid total loss of the radar facility under these conditions, there had to be several switched frequencies. The estimated cost ran into millions of pounds, even in the 1930's. However, the money was forthcoming because of the vision of those involved.

This nucleus of the Royal Radar Establishment (as it was later known) needed a new home and one was found at the mouth of the River Deben, Bawdsey Manor, still in Suffolk. This desirable site was bought from the owner by the Air Ministry. The new station opened in May 1936 and it continued in this role until September 1939, by which time a chain of radar stations stretched from Ventnor on the Isle of Wight to the Firth of Tay. The first operational radar station was the one at Bawdsey, and this was handed over to the Royal Air Force in May 1937. In August of that year, radar played its first active part in an R.A.F. defence exercise but this tended to reveal its weaknesses rather than its advantages, not the least being a certain ambiguity in the results obtained from different radar stations.

Credit should also be given to the firms that made the equipment of our first radar defence system. The transmitters were the work of Metropolitan-Vickers, the receivers were made by messrs. A.C. Cossor Ltd, while the Marconi Company made the transmitter antenna 'curtain' arrays.

Preparing for War

In September 1938 came the Munich crisis; from then on, through the inclement weather of the following winter, work went on to meet the war that was inevitable. From Good Friday of 1939, well before the actual start of World War Two (3rd September 1939), Britain's radar stations went on a 24-hour watch.

Radar stations were not only built to defend the British Isles. In those days, Britain exercised much influence abroad and needed radar to watch over strategic points overseas. The island of Malta is a good example where radar was later to play a vital part in the island's defence against the unceasing attacks of the German Luftwaffe and the Italian Regia Aeronautica.

The early radar system that gave warning of impending air raids was known as Chain Home (C.H.). This radiated an enormous amount of power in attempting to 'floodlight' the area to the east of our coastline. It would obviously have been a more efficient use of power if it could have been concentrated into a beam, and the beam swung about to find the enemy aeroplanes. However, this was impossible because of the enormous size of the masts. Those for the transmitter were 350 feet high, and those for the receiver topped 240 feet! It is the difference between trying to find an object in a darkened room by either switching on the room lights, or standing at the door and swinging a torch about to locate it. The power of the torch bulb is a lot less than that of the room lighting.

The answer to this problem lay, of course, in the choice of wavelengths. As stated earlier, the initial tests used 50m, but this was reduced, first to 26m and then to 13m, giving improved results in detection. The C.H. stations used shorter wavelengths still, but they were still of the order of several metres. A further problem that arose with the long wavelengths and the design of the masts was the 'gap' that existed under the radar curtain. It was possible for a wave-skipping aeroplane to reach the coast undetected until the very last minute. Dover, and other coastal towns, received a number of unexpected visits in this way. It was obviously necessary to concentrate development on reducing the wavelength further while maintaining high power for good range. This development led to a power of 1kW coupled with a wavelength of 10cm, and to the birth of the 'magnetron', a special valve that was capable of generation at these high frequencies (a wavelength of 10cm corresponds to a frequency of 3GHz). This was in July of 1940. Later still it would be possible to generate hundreds of kilowatts at the same high frequencies. To use these short wavelengths effectively, the length of the pulse transmitted had to be very short. Whereas Chain Home used pulse lengths of the order of 10-25 microseconds, the pulse lengths on the centimetric waves were more like 0.25 microseconds in length.

Airborne Radar

The accuracies mentioned earlier were fine for daylight but not good enough for night interceptions where the defending aeroplane had to be almost on top of the intruder before there was any chance of a visual sighting. Obviously effort now had to be put into developing airborne radar. With this it would be possible for the defending pilot to be informed of the intruder's presence and probable location by radio and then use his own radar to get close enough to see it. Radars of this type were called A.I. for Airborne Interception.

The new A.I. radar in the air was allied with a new type of ground radar called G.C.I. for Ground Controlled Interception. This latter used a type of display called P.P.I. (Plan Position Indicator). P.P.I. showed a radius of about 50 miles, centred on a circular cathode ray tube. The 'pips' representing both the 'target' (enemy aeroplane) and the interceptor were shown on this display, their relative range and bearing being particularly easy to determine especially as the face of the display was marked out in grid squares. A display of this type is shown in Figure 14. The instructions from the ground controller were aimed at bringing the two pips mentioned into near alignment, at which point the defending pilot should be able to pick up the intruder on his own 'scope'. The fighter also carried a 'black box', known as I.F.F. (Identification Friend or Foe - the problem had at last been solved), which caused the 'friendly' pip to give a characteristic signal every few seconds.

The basis of P.P.I. was a rotating aerial system, giving a rotating beam. This type of scanner can now be seen at any airport, used with the airfield radar. The sweep time of the beam was about 20 seconds. A rotating line, like the spoke of a wheel, represented the radar beam. This was at quite low brilliance. However, when it picked up a reflection, perhaps from an enemy aeroplane, it glowed momentarily in a small arc. The persistence of the phosphors used was very much longer than that used with CRO's or television, in order to hold the image long enough for it to be picked up again on the next sweep. This was virtually the standard type of radar display during the war.

Electronic Warfare

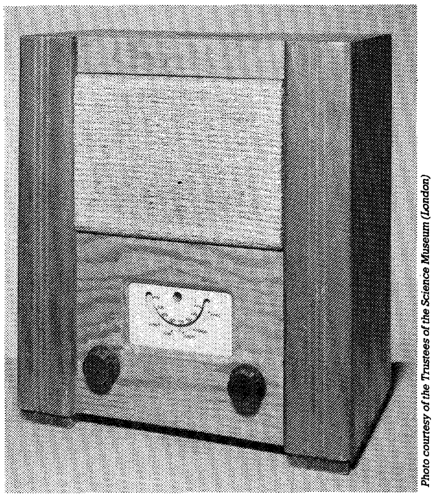
As is now ancient history, radar played a vital part in the Battle of Britain. However, many other fascinating aspects of the story of radar could be told. One of these is the 'electronic warfare' that followed. The following gives a brief idea of what this involved.

Germany, in her attempt to find targets in Britain, was using a modified form of her Lorenz beam system, known as 'Knickebein' (crooked leg). To counter this, we used jamming, which was at first generated using modified diathermy apparatus produced by Marconi and other companies, this being originally a sophisticated form of heat treatment equipment used in medicine. Later, powerful jamming transmitters were used. To combat these quite successful countermeasures, the Germans developed a new type of radar called 'X-Gerat'. This led in turn to more intensive jamming by the British. At the third level of development, the Germans produced 'Wotan', which was so effective that it had us scratching our heads for a time. But along came a solution in the form of 'beam-bending', by which the guidance beam apparently changed direction, causing the bomber to wander off on a wrong course. As a result, the poor old Luftwaffe expended their valuable armaments on the open countryside or even tried to make holes in the sea! And so it went on, each side gaining a temporary advantage.

Wartime Radio

As for 'radio' itself, perhaps one of the most famous pieces of equipment to be produced during the war was the development of a Marconi project begun in 1937. This was an airborne MF/HF transmitter-receiver known originally as the AD67/77. This subsequently became the T1154/R1155, of which more than 80,000 were made during World War Two. They were fitted in all aeroplanes of Bomber and Coastal Commands and were still in service in the 1950's.

At the outbreak of war all experimental licences were withdrawn. The role of the receiver was seen as a means of informing the public on the news and Civil Defence matters and providing entertainment to help boost morale. Programmes were often relayed in factories where many of the nation's women worked. A popular programme that began at this time and continued long after the war was 'Music While You Work'. On 1st September 1939, the Home Service, operating on a single nationwide frequency, replaced all National and Regional Programmes, this avoiding the possibility that the Regional transmitters might act as 'beacons' for enemy aeroplanes.



The Wartime civilian receiver.

By November 1939 the BBC was transmitting two services for overseas listeners, the European Service and the World Service. At home, there was a great demand for receivers, especially portables. Shortage of spares, especially valves, brought the crystal set back into use, as a stand-by set at least. Home constructions became popular, particularly when the new 'battery valves', with their 1.4V heaters appeared. On 7th January 1940, the Forces Programme was introduced in order to cheer up the British Expeditionary Force in France.

On the 'home front' the demands of war meant that little effort could be spared for producing radio receivers to amuse the poor old civilians. Nonetheless, the British radio industry jointly produced a 'War-time Civilian Receiver' or 'Utility Set'. This was not, however, until July 1944 when the spares situation for existing sets, as well as the lack of trained personnel to service them, had made some form of replacement necessary. It was a fairly basic looking set and had only two stations marked on its dials, Home and Forces. It was to be a long time before effort was once again available for the pleasures of peace.

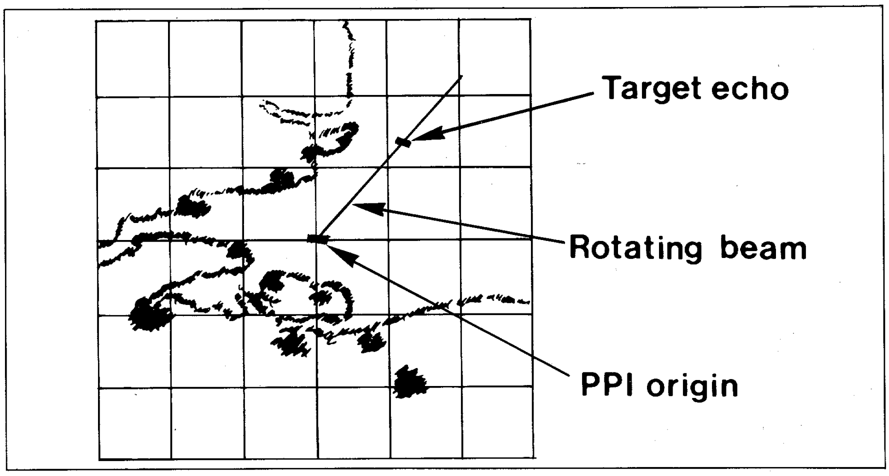


Figure 14. Typical return from PPI display. The rotating beam illuminates both the target and the main topographical features, e.g. coastline and towns. In this case the PPI equipment is on a ship in the Thames estuary.

The Post War Years

On 7th May 1945, at 1405 hours, Count Schwrin von Krosigk, Germany's foreign minister, newly appointed by Grossadmiral Donitz, Hitler's successor, broadcast a statement from Flensburg to the effect that, "Germany has surrendered unconditionally". The war in Europe was finally over. The radio industry, hitherto operating in top gear for the war effort, could now begin to think again in more peaceful terms.

On July 29th 1945, the BBC introduced the Light Programme to provide light entertainment for an audience that badly needed re'axation after six years of war. All war contracts to manufacturers were cancelled and new licences issued to some seventy manufacturers for the production of a million or so receivers over the twelve-month period commencing December 1945. There was, of course, no shortage of components or materials now. Of the first post-war sets made, it is interesting to note that 400,000 were intended for export, no doubt in an attempt to re-vitalise the economy.

On September 24th 1946, King George VI opened an exhibition at the Victoria & Albert Museum, called 'Britain Can Make It'. It was meant, naturally, as a morale booster, an incentive to British industry to get cracking on new ideas for the post-war world. The Radio Industry was represented by 25 receivers, but they were largely 1939 designs resurrected.

The coming of peace marked a dividing line between old and new technologies. The valve, which had contributed so much to the history of radio and electronics would now begin to dwindle in importance in the face of the growth of the new 'semiconductors'. In a similar way television, put into cold storage by the recent conflict, would soon push radio into second place as the prime form of home entertainment. In fact television transmissions began again on June 7th 1946, the broadcast licence fee having been raised the previous week from 10s (50p) to £1.

Photo courtesy of the Trustees of The Science Museum, London.

The first transistor receiver in production in the UK, the PAM 710 of 1956.

Transistors

However, valves and semiconductors had existed side by side for the better part of half a century. The first silicon crystal detector was patented in Britain in 1904, coincidentally the very year of Fleming's valve. The first carborundum detector was patented in the U.S.A. in 1906. Various other crystals followed in quick succession. In general the crystal detectors did little to excite the imagination. They could neither amplify nor oscillate, and the job that they could do, detection or rectification, was often done by valves anyway. This was especially true in the field of communications.

In 1941 the semiconductor junction diode appeared, formed from the fusion of two crystals. On 23rd December 1947 the junction triode was born in the Bell Telephone Laboratories in the U.S.A. It could amplify and it could oscillate. It was called a 'transistor' (from transfer-resistor). Its discovery was an accident, made by a

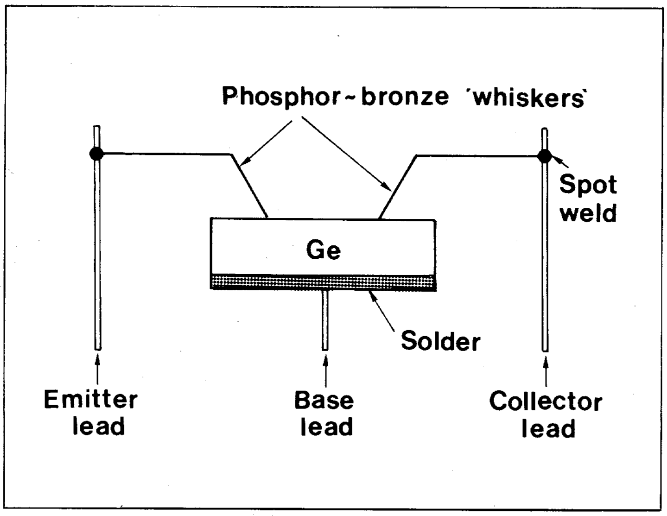


Figure 15. Construction of early point-contact transistor.

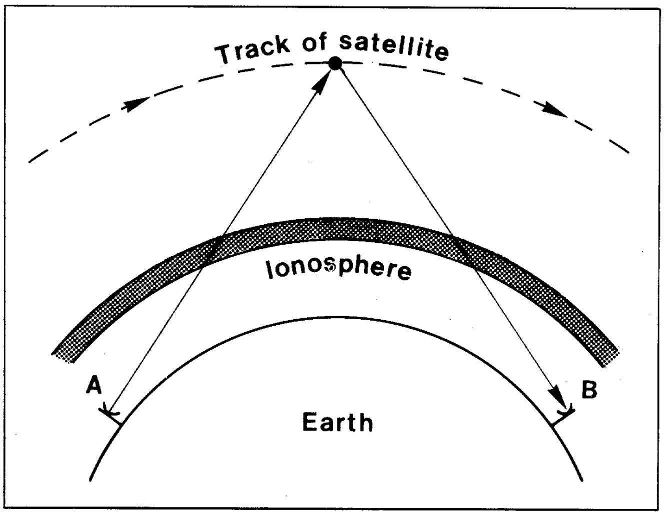


Figure 16. Effective 'line of sight' communication between two points, A and B, on the Earth's surface via orbiting satellite.

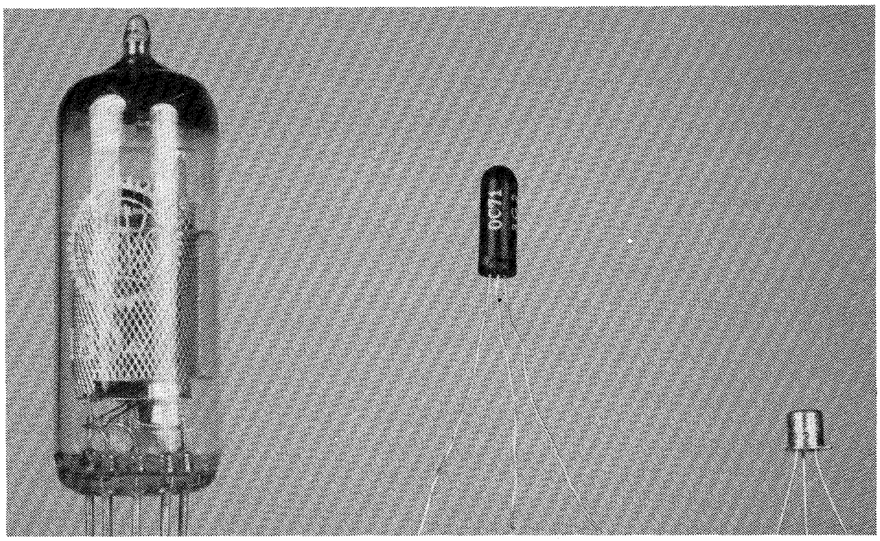
team of three men, whose names were, Bardeen, Brattain and Shockley. They were actually investigating an amplifying mechanism called the 'field effect' at the time. As with many new inventions, its likely role in the future was not fully appreciated. Why should it have been? It's always easy to be wise after the event. It was evidently a solid-state amplifier, but not one to compete with the thermionic valve, surely? But it did and more, because it was actually to sound the virtual death knell of the device on which the whole of radio and electronics had hitherto depended.

This first transistor was made of germanium (Ge) and was of a type now obsolete, the 'point-contact transistor'. The junction transistor followed and it was this new type that sparked off the 'semiconductor revolution'. Modern junction transistors are quite different in construction from the early types, which were either 'alloy' or 'grown' junction types. The construction of a point-contact transistor is shown in Figure 15.

During World War Two much development work had been carried out to improve the crystal diode. This may seem strange if it is thought of only in the context of the elementary crystal receiver. However, because of its small physical size, it was proving very useful as a detector and mixer at the high frequencies used in radar equipment. The crystal diode was itself, a point-contact device (cat's whisker and crystal), so it is hardly surprising that the first transistor was also a point-contact type.

As crude as the first transistors were, they obviously had a number of advantages. They were less bulky and consumed far less power than their thermionic counterparts. For a start, there was no heater; it was the heater-cathode assembly that consumed so much power, generated so much heat and invariably failed after a few thousand hours of operation. The transistor, by comparison, promised an unlimited life. Its small size ushered in the age of miniaturisation. One of the earliest commercial developments that it made possible was the personal, portable receiver, which quickly became universally known as the 'transistor radio', and with it the 'special' 9 volt 'transistor' batteries used to power it. The big mains-powered receivers in their polished wooden cabinets gradually began to disappear.

The early junction transistor made more of an impact in some fields than others. One field in which it failed to impress at first, was the computer field, where it was considered to be much too slow, bearing in mind that the device had to operate in common base mode even to be able to handle modestly high medium-wave RF frequencies. Nonetheless, wisely the computer industry kept an eye on its development because the failure rate of thermionic valves was so high that early computers suffered from poor reliability and spent more time 'down' than actually working! But, in 1958, the planar transistor, which combined high speed with high reliability, appeared on the scene. The computer people pounced on it and from then on it really took off. Within a year, Texas Instruments began talking about developmental 'integrated molecular devices'.



Thirty years of development:- a miniature valve of the 1950s compared with the once popular Mullard OC71 (a germanium PNP device) and the Ferranti ZN414, a complete AM radio in a TO18 can.

Now, almost thirty years on, the impact that integrated circuits have made in everyone's lives should be evident. The fundamental approach to the design of a wide range of electronic devices has changed from a 'circuit-orientated' one to a 'systems' one. In the field of radio and television, with which we are specifically concerned here, the impact has also been significant. Many former discrete functions have now been integrated into specific function chips. The systems approach mentioned has affected not only those who design the equipment but those who service it as well. One cannot help wondering what Guglielmo Marconi would have thought of it had he been alive today.

Television Thrives

As already stated, the coming of peace meant the re-emergence of television broadcasting. This brought with it a new phenomenon, the 'television party'. This would be given by the fortunate owner of a television set (there weren't that many about at the time), for his neighbours and friends, and it comprised an evening with light refreshments with everyone sitting in a semi-circle peering at what was likely to have been about a 12 inch screen! But the new entertainment ousted other forms of home-made entertainment and was seen by some as a mixed blessing.

The growth of television as an entertainment medium was most impressive. In 1946 there were about one million receivers in use 'world wide'; by 1960 this figure had grown to 225 million. The televising of an important event could trigger off a demand for sets, as happened in 1953, when the coronation of Elizabeth II was televised.

The miniaturisation of components made possible the use of higher and higher frequencies. Television at this time used Band I (BBC) and Band III (ITV), both coming under the classification of VHF (Very High Frequencies, i.e. in the range 30-300MHz). However, the modern 625 line TV system operates in the UHF wavebands, at frequencies in excess of 470MHz.

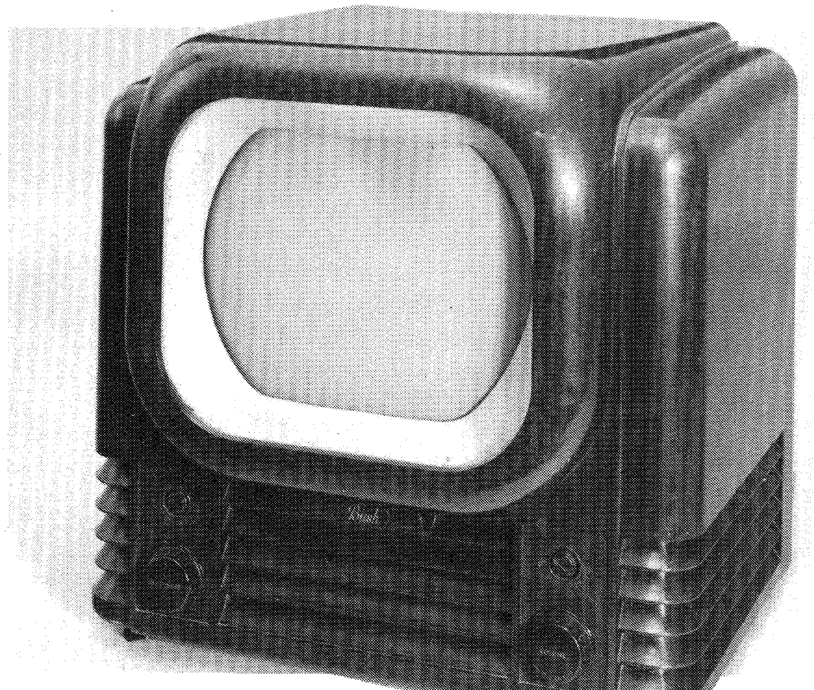
FM Radio

One field where miniaturised radio equipment could obviously be applied was in the police force. Although some attempts (seen in a previous article) had been made in the 1930s to so equip them, the adoption had not been widespread and they continued to lack these vital communications. Development of relatively heavy VHF equipment began at the end of the war and continued for some years. There appears to have been little real progress for a long time after this, since there was still indecision over the specification when, in 1965, Pye pre-empted the whole situation by introducing their UHF Pocketphone. The experiments with VHF were then dropped.

However, there was a use of VHF that gave a boost to radio as an entertainment medium. This was FM, Frequency Modulation, especially since it allowed the transmission of stereo signals, although the initial advantage was that of a much superior sound quality compared with AM. Stereo reproduction of radio, disc and tape sources is taken very much for granted nowadays. However, only thirty years ago, many hi-fi systems were mono only, and having a stereo system (which one had probably built oneself) was definitely being one up on the 'Jones's'! But the advantage of FM radio, whether mono or stereo, as far as domestic use was concerned, was the possibility of a quality which could not be realised with medium or long wave broadcasting.

To back-track a bit, FM was put forward as a system of communication in the early days of radio, certainly before the 1920s. In 1925 a certain Major E.H. Armstrong, credited as being the pioneer of FM, began to take an interest in the idea. At first it was thought that small values of deviation would provide narrow-band FM, allowing stations to be spaced at 9kHz, as were the AM medium wave stations. However, it was soon appreciated that FM gave rise to many pairs of sidebands, especially at the low modulation frequencies. This made it impossible to use an FM system at the low carrier frequencies then in use. It was necessary to await the development of VHF operation before a practicable FM system could be realised. Experiments continued in the U.S.A. both before and during the Second World War, to the extent that it was actually used during the war for purposes of communication.

After the war the Americans adopted VHF FM domestically but things moved rather slower in Europe, where it was considered that an AM system could be developed to give the same quality. In Britain the problem was approached pragmatically and test transmissions were made from Wrotham in Kent. These tests compared directly the merits and demerits of the two systems, AM versus FM. As we know, FM won and was adopted as a means of high quality broadcasting; it is also used for UHF TV sound.



The Bush TV22; a BBC (Band 1) only television receiver, with a 9 inch screen, of 1950.

Photo courtesy of the Trustees of The Science Museum, London.

Radio from Space

It is a characteristic of radio waves that, when the wavelength is very short, the waves are not reflected back to Earth by the ionosphere but pass through it and travel on into space. This has the disadvantage that communication, of any sort, at frequencies from 'high VHF' upwards, has to be by line of sight, with repeaters if necessary, to allow the radio waves to bridge high ground, such as ranges of hills, or travel beyond the horizon. On the credit side, it means that radio waves can be directed out into space to control satellites, space probes, etc. A satellite orbiting the Earth (Figure 16) can be used to re-transmit signals from one location on the Earth's surface across vast distances to another location, a feat made possible by the two 'line of sight' links, transmitter to satellite, satellite to receiver. Signals that are handled in this way include high-quality speech and television pictures, thus making it possible for live broadcasts of significant events to be made available to a world-wide audience.

The first communications satellite was named Telstar 1 and was launched from an American base on the 10th July, 1962. Spherical in shape and 34.5 inches in diameter, Telstar weighed 170lb, contained 16,000 parts and was powered by a battery, which was kept charged by 3,600 solar cells. It orbited the earth at a height of about 100 miles.

Immediately after its launch an attempt was made to communicate using the satellite. This was not successful but, by evening of that day, events turned out better when the American President, John F. Kennedy, and other officials were able to transmit a message from Washington D.C. across to Goonhilly Down in Cornwall. There was also a transmission to France. During the evening of the same day a successful transmission was made in the opposite direction.

The low orbiting height of 100 miles of Telstar 1 raised certain problems. The rate of orbit was out of step with the rate of rotation of the Earth. Consequently, communication via the satellite could only take place at certain times, when the satellite occupied the correct position relative to both transmitter and receiver. The problem was solved by placing the next satellite into a much higher orbit, at a height of 2,300 miles, at which altitude it followed the Earth's rate of rotation perfectly.

Radio has played an important role in the, so far, short history of space exploration, in controlling the functions of in-space vehicles from the ground, in maintaining communications between manned space vehicles and base and in telemetering information back to Earth from distant space probes. For now it is worth remembering those often quoted words that came back to us out of space when man first landed on the moon on 20th July 1969. The first words that listeners on Earth heard the American astronaut, Neil Armstrong, say on that historic occasion were, "Contact light on, engine off, the Eagle has landed."

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Graham Dixey

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