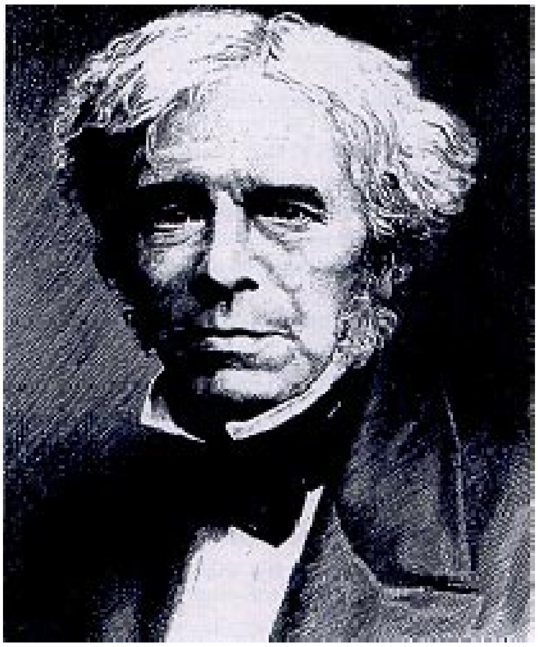
Six great pioneers of wireless

As stressed elsewhere in this issue, no one person was responsible for "inventing" wireless. It is broadly agreed that the works of Faraday, Maxwell and Hertz where vital in laying the foundations for Guglielmo Marconi, who was the first to exploit the practical applications of electromagnetic waves.

To complement the portraits given here of these four great pioneers, the experimental works of Lodge and Popov are also reviewed. Some authorities feel that Lodge's important contribution to the history of wireless has been sadly neglected over the years while, in Russia, Popov is regarded as the inventor of radio communication.

To complete this review, a brief chronology of important events in the history of wireless is given, from the discovery of static electrical charges around 600 B.C. to the European and International adoption of a single standard for tomorrow's wireless system – Digital Audio Broadcasting (DAB).

1. *Michael Faraday (1791 - 1867)*



Michael Faraday's work was fundamental to the development of electromagnetic field theory, and to the exploitation of electromagnetic waves. Without Faraday, the achievements of Maxwell, Hertz, Lodge, Popov, Marconi and others would never have taken place, and the introduction of radio broadcasting would have been delayed by many years.

Faraday was not a trained scientist; he had no university education and no knowledge of mathematics at all. Many of his contemporaries regarded him as an unreliable heretic whose views could not be trusted. With hindsight, however, Faraday is now seen as one of the most brilliant scientists of the nineteenth century. He was a daring theorist who was always prepared to disagree with the conventional ideas of the day.

Faraday was born in Surrey, England, the son of a Yorkshire blacksmith. At the age of fourteen, he was apprenticed to a bookseller and bookbinder in North London, in whose shop he read with keen interest any books on science which came into his hands. Having heard Humphry Davy lecture at the Royal Institution, Faraday applied to him for employment and, in 1812 at the age of 21, he was appointed as an assistant to help Davy with both lecture experiments and research. The young Faraday accompanied Davy on a tour of Europe which greatly expanded his view of science, particularly in the fields of chemistry and electrochemistry: Europe became Faraday's university with Davy, and the many other illustrious men they met, acting as his professors.

In 1820, a Danish scientist Hans Christian Oersted had discovered that the passage of an electric current through a wire could deflect a magnetic needle suspended nearby. He had observed that the "electrical conflict" was not confined to the conductor but was dispersed quite widely in the surrounding space, and the forces of this conflict acted in circles around the wire. The announcement of this discovery caused a sensation throughout the scientific world, particularly as it shattered Newtonian theories that forces only act along straight lines between two points.

Faraday readily grasped that the magnetic force around the wire was circular; had he been mathematically trained, he might have been disturbed by this realization but, uninhibited as he was by traditional beliefs and Newtonian philosophy, he saw nothing very remarkable in a force which appeared to act along a curved path. Thus, in 1821, he went on to make the first of his great electrical discoveries – electromagnetic rotation. The conversion of electricity into mechanical work brought him widespread fame but, alas (from the point of view of radio history), the next ten years of his life were spent on studies of a metallurgical, chemical and optical nature.

In 1821, Faraday was elected to the Royal Society (his election had earlier been opposed by Davy, who had become jealous of Faraday's success in the

The *Ether* versus *Action at a Distance*

From the sixteenth century onwards, arguments had been raging over how the phenomenas of gravitation, light and heat were physically transmitted through empty space. In the early seventeenth century, it is broadly true to say that the theories of *René Descartes* (1596–1650) were widely accepted.

Descartes and his followers (who were known as *Cartesians*) believed that bodies can only act upon each other by direct pressure or impact. They assumed that space was filled with a medium called the *ether* which, although imperceptible to human senses, was nevertheless capable of transmitting forces, such as heat and light, and exerting effects upon material bodies that were immersed in it. The ether was thought to consist of particles which were continuously in motion, which enabled it to perform its mysterious functions.

These theories were gradually overturned by the work of *Isaac Newton* (1642–1727), whose theory of universal gravitation was published in 1687. Newton proposed that all bodies attract one another with a force which is proportional to the product of their masses and inversely proportional to the square of the distance between them. Although he did not seem to realize it, Newton was in fact rejecting the Cartesian concept of an ether in favour of accepting the theory of *action at a distance*.

Initially, Newton's laws of gravitation were not accepted by many, as they seemed to violate the accepted philosophical principle of the time – "that matter cannot act where it is not". Philosophers on the Continent of Europe were particularly slow to adopt this principle and it was not until the end of the eighteenth century that Newton's ideas had come to be accepted. By then, the idea of action at a distance had become so firmly established that the mere idea of gravitational, electrical or magnetic forces requiring a medium such as the ether for their propagation seemed almost as absurd as action at a distance had seemed a century earlier.

However, when *Michael Faraday* arrived on the scene in the early nineteenth century, he was almost alone in rejecting the ideas of action at a distance. Although Faraday may not have understood how forces could be transmitted through a medium and, indeed, what such a medium might consist of, he was firmly convinced that magnetic and electric forces did act in some form of a medium – a view held some years later by *James Clerk Maxwell* who brought about the final rejection of action at a distance.

liquification of chlorine). In 1825, Faraday was elected to the post of director of the laboratory at the Royal Institution and, in 1826, he began to give formal lectures to members of the Institution every Friday, the spirit of which has continued ever since. Faraday also initiated the annual Christmas lectures to young people, and presented nineteen of them himself. As an inspiring lecturer, Faraday was supreme and there are many contemporary accounts of the interest and enthusiasm which his discourses aroused.

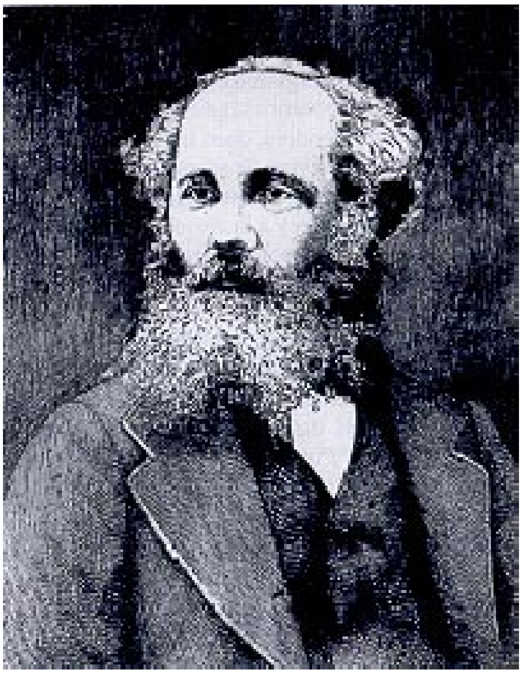
The second great period of Faraday's electromagnetic studies began in 1831. About this time, Faraday and others had argued that magnetism could give rise to electricity, just as electricity had already been shown to have a magnetic effect. However, it was Faraday who showed why the earlier experiments to produce electricity from magnetism had failed; the vital factor of a *change* in the magnetic field had been overlooked. Faraday demonstrated how a change in magnetism could be used to generate electricity and then went on to establish the fundamental laws of electromagnetic induction.

During the course of his experiments, Faraday had observed that an appreciable element of time was required in order to transmit a magnetic force. Similarly, he surmised that charges due to static electricity would also require time to transmit. Pursuing these ideas further, he speculated that electric and magnetic forces were propagated by some form of wave motion, rather like *"the vibrations upon the surface of disturbed water"*.

Faraday's health began to deteriorate around 1839 and he was unable to undertake serious work for a number of years; it was as if he had burnt himself out. However, his health began to return gradually and he resumed duties at the Royal Institution in 1844. He retired from the institution in 1858 and retained a lively interest in science until his death in 1867.

Faraday was possibly the greatest experimental genius the world has known; in addition to his other skills, he had the ability to describe his ideas in clear and simple language. Something incessantly prompted him that certain fundamental relations were waiting to be found and he was not dismayed by numerous fruitless experiments; he persisted until basic discoveries were finally established. In the field of theoretical physics, Faraday's conception of "lines of electric and magnetic force" was to lead James Clerk Maxwell to prove beyond any doubt the existence of electromagnetic waves.

2. James Clerk Maxwell (1831 - 1879)



To the world of the 1860s and 70s, James Clerk Maxwell was almost unknown outside a narrow academic and scientific circle. Today, however, his name is respected everywhere and his work is regarded as the very foundation of electromagnetic theory. In particular, he was responsible for translating Michael Faraday's ideas on electric and magnetic phenomena into mathematical notation, and for linking the phenomena of light with those of electromagnetic waves.

Maxwell was born in Edinburgh, Scotland, and attended Edinburgh Academy, the University of Edinburgh and Trinity College, Cambridge, from where he emerged in 1854 with high honours in physics. His interest in electromagnetic theory was almost certainly inspired initially by another young Cambridge student, William Thomson (later Lord Kelvin) who, in 1846/7, had made a mathematical investigation into the similarities between electromagnetic phenomena and elasticity. However, it was mainly the experiments and ideas of Michael Faraday that excited the young Maxwell.

In 1855, at the age of twenty-four, Maxwell published his first major contribution to the subject of electricity: *On Faraday's Lines of Force*. In this paper, Maxwell translated Faraday's ideas into mathematical notation and was able to show that they led to the same numerical solutions as those of the rival theory of "action at a distance". There was nothing fundamentally new in this first paper from Maxwell but, by expressing and analysing Faraday's theories in a language which was intelligible to mathematicians, it made them accessible to and accepted by a much wider range of learned readers. Prior to the publication of Maxwell's first paper, mathematicians had been contemptuous of Faraday, regarding him as an untutored heretic.

Two years after graduating from Trinity College, Maxwell took the chair of natural philosophy in Marischal College, Aberdeen, Scotland. In 1859, he interrupted his electrical studies to publish a brilliant paper which explained the motion and permanence of Saturn's rings; this essay won the Adams prize of the University of Cambridge and established Maxwell as a leader among mathematical physicists. Shortly after, he moved to London to become professor of physics and astronomy at Kings College.

By about 1860, Maxwell had become impressed with the similarities between light and electromagnetism. However, it was not possible for him to confirm that light itself was of an electromagnetic nature, without first investigating in detail the characteristics and properties of the medium – the *ether* – which was supposed to transmit light.

In 1861-2, Maxwell published a series of papers in the Philosophical Magazine titled *On Physical Lines of Force*, in which he proposed a hypothetical medium that provided a mechanical explanation of the interrelations and effects of magnetism and electricity. Although he did not for one moment suppose that his system of vortices and particles represented the real state of affairs, Maxwell ventured to suggest that it would help rather than hinder anyone who was searching for a true interpretation of the phenomena.

In the last of his series of papers in the Philosophical Magazine, Maxwell showed that it was necessary to suppose that the substance of his vortices possessed the quality of *elasticity*. Developing the theory still further, he showed that the velocity of propagation of transverse vibrations through such an elastic medium would be 193 088 miles per second. Maxwell arrived at an epochal conclusion: the velocity of an electric current through a wire is about the same as the velocity of light in empty space (which had been calculated by the French physicist, Fizeau, to be 195 647 miles per second). Developing his ideas further, Maxwell boldly asserted that *"light consists of the same transverse undulations of the same medium which is the cause of electric and*

Chronology

600 B.C.: The Greek philosopher *Thales of Miletus* observed that amber attracted small particles when rubbed with a piece of cloth.

1600: *William Gilbert*, the physician to Queen Elizabeth I of England, observed that electrostatic forces are different from magnetic forces.

1687: The English mathematician and philosopher *Sir Isaac Newton* published his "Theory of Universal Gravitation".

1745: The Leyden Jar, an early type of capacitor, was invented.

1752: The Swiss mathematician *Leonhard Euler* suggested that all electrical, light and gravitational phenomena were derangements in the ether which were propagated at the same velocity.

1775: The Italian, *Alessandro Volta* invented the "electrophorus", a device which enabled static electricity to be carried.

1785: The French physisist *Charles Augustin de Coulomb* made a series of experimental tests on forces between small charged bodies, which resulted in Coulomb's inverse-square law of electrostatics.

1800: Volta produced the world's first battery.

1820: The Danish scientist *Hans Christian Oersted* discovered that the passage of an electric current through a wire could deflect a magnetic needle, and that the forces of conflict acted in circles around the wire.

1821: The French mathematician *Prof. André Marie Ampère* repeated Oersted's experiments and went on to establish all the elementary laws of "electrodynamics".

1831: The English experimental genius *Michael Faraday* discovered how to produce electricity from magnetism.

1832: Faraday proposed that magnetic action and electric induction are progressive and require time for their transmission; he likened them to vibrations on the surface of disturbed water.

1835: The American scientist *Samuel F.B. Morse* developed his first working electric telegraph.

1838: Morse developed his alphabetic code of dots and dashes.

1842: The US physicist *Joseph Henry* discovered the oscillatory nature of a sudden electrical discharge.

1846: The Irishman, William Thomson (later *Lord Kelvin*) made a mathematical investigation into the similarities between electromagnetic phenomena and elasticity.

1850: The coherence of dust particles in air, when electrified, was discovered by *Pierre Guitard* of France.
. . . Lord Kelvin defined the relationship between the resistance, inductance and capacitance of an oscillatory circuit.

magnetic phenomena". What makes his achievement all the more remarkable, however, is the hypothetical medium of rotating vortices and particles which he used to develop his ideas.

In December 1864, Maxwell read a paper to the Royal Society titled *A Dynamical Theory of the Electro-magnetic Field* – widely regarded in later years as his greatest contribution to electrical science. The main purpose of this paper was to investigate the characteristics of the medium which surrounds electric and magnetic bodies and to identify this medium, if possible, with that through which the propagation of light was assumed to take place. In this paper, Maxwell made a very thorough investigation of the fields which surround electrified and magnetic bodies during which he developed his famous "general equations of the electromagnetic field", twenty of them in all, involving no less than twenty variables.

Earlier theories had assumed that energy resides in the form of *potential energy* in electrified bodies, conducting circuits and magnets. In the Royal Society paper, Maxwell showed that energy is stored in the *electromagnetic field* – the space which surrounds electrified or magnetic bodies. He also went on to show that light is an electromagnetic disturbance which is propagated through the field according to electromagnetic laws.

Maxwell's theories were so complex that they were beyond the comprehension of most physicists and engineers of the time. Those who did understand the equations felt that, among other things, Maxwell gave no explanation of reflection and refraction and the doubters found it hard to accept his idea of *displacement currents* in free space.

In 1865, Maxwell retired to the family estate in Scotland. However, his reputation intruded upon the seclusion he desired, and he reluctantly accepted the newly-founded chair in experimental physics at Cambridge University in 1871. Under his direct supervision, the famous Cavendish Laboratory was established and became one of the major scientific workshops of the world.

Maxwell died in 1879 at the early age of forty-eight, ten years too early to witness the brilliant confirmation of his electromagnetic theories at the hands of Heinrich Hertz.

Whereas Michael Faraday was the great experimenter, James Clerk Maxwell was often thought of as the perfect "pencil and paper" theoretician. In reality, Maxwell combined a profound physical intuition – an exquisite feeling for the relationship between objects – with a formidable mathematical capacity to establish orderly connections among diverse phenomena. This blending of the concrete and the abstract was the chief characteristic of all his important studies.

3. Heinrich Hertz (1857-1894)

While it was James Clerk Maxwell who developed the theory of electromagnetic waves, it was Heinrich Hertz who first demonstrated the reality of electromagnetic waves, via his experiments in the production and reception of radio waves.

Hertz was born in Hamburg, Germany, the son of a prominent lawyer. During his school days, he proved to have a phenomenal memory and an insatiable appetite for learning. Not only was his aptitude for mathematics exceptional, he balanced this with a determination to excel at Greek and Latin. He also showed exceptional ability with his hands, being adept at using tools of all kinds. As his school education drew to a close, he was thus in a quandry over whether he should pursue a career in mathematics, the classics or mechanical engineering. Eventually, he resolved to take a degree course in civil engineering – at the College of Technology in Munich – as such a course might provide a shorter road towards financial independence from his parents, than would a career in natural sciences.

However, Hertz was not really interested in civil engineering and, during his second months at the

Munich college, he wrote to his father to seek permission to switch from engineering to natural sciences: *"It is a shameful confession for me to make, but out it must come: I should like to change horses now, at the last moment, and switch to the natural sciences. In this semester I arrive at the crossroads where I must either devote myself to science completely or take leave of science for good and give up all superfluous dallying with the subject if I am not to neglect my proper studies and become merely a mediocre engineer."* His father's letter of reply has not survived but it is evident from Heinrich's next letter home that his father gave him the approval he so earnestly sought. From then on, Hertz "burned with impatience" to reach the frontier of what was already known and go on to explore into unknown territory.

Hertz spent only a year at Munich but that period saw his final conversion from a man of practice to a man of learning. In the autumn of 1878, he transferred to the University of Berlin where he quickly attracted the attention of the celebrated Professor Harmann von Helmholtz.

Shortly after arriving at Berlin, Hertz published a paper titled *Experiments to determine the Upper Limit for the Kinetic Energy of an Electric Current* which won him a prize, and much praise, from the Philosophical Faculty of the university. Helmholtz was so impressed by the work of Hertz that, in September 1880, he offered the young student a post as assistant professor at the Physics Institute of Berlin. Of course, Hertz was thrilled with this opportunity to become a personal assistant to the man whom he so greatly admired.

One of the first jobs given to Hertz was to find a long overdue proof of Maxwell's theory that electromagnetic forces were propagated through space with the same velocity as that of light and that, in fact, light itself was an electromagnetic phenomenon. It was a task ideally suited to Hertz but, after giving the problem long and careful consideration, he was forced to conclude that it would not be practicable to reach a satisfactory conclusion, given the facilities that were then available.

By 1981 – some two years after Maxwell's death – Hertz had become fully conversant with Maxwell's theories However, tugging him in the opposite direction, were peer group pressures to accept the continental approach to electrical phenomena, which was based on the eighteenth century theories of action at a distance.

1852: Faraday wholeheartedly declared his belief in the existence of lines of electric and magnetic force, rather than the existence of an ether.

1855: The Scotsman *James Clerk Maxwell* published his first important paper "On Faraday's Lines of Force".

1862: Maxwell translated Faraday's ideas on lines of force into mathematical terms, and postulated the existence of electromagnetic waves.
. . . *Prof. Harmann von Helmholtz* of Berlin University carried out an important study on the resonance of sound.

1864: Maxwell published his paper "A Dynamical Theory of the Electro-magnetic Field", which is widely regarded as his greatest contribution to electrical science.

1866: The first transatlantic cable was successfully laid by the British ship *Great Eastern*, supervised by Lord Kelvin.

1872: The American *Mahlon Loomis* used elevated aerials to detect thunderstorms.

1876: The US telegraph engineer *Alexander Graham Bell* introduced the telephone, which was the first-ever device to convert sound waves into an electric analogue.

1877: The British physicist, John William Strutt Rayleigh (later *Lord Rayleigh*) published "Treatise on Sound" which is still regarded as a classic work in the field of acoustics.

1879: The Anglo-American *David Edward Hughes* discovered the presence of "extra currents" (i.e. oscillatory HF transients) when the current in an inductive circuit was suddenly interrupted; the signals from his spark transmitter were received over a range of about 400 m.
. . . The American *Thomas Alva Edison* invented the incandescent lamp, and he used a battery for the first time in a telephone transmitter.

1880: Hughes demonstrated the transmission and reception of "extra currents" over several hundred metres to a number of distinguished scientists, but the pundits did not believe the effect was produced by "aerial electric waves" rather than by induction effects.

1883: Edison observed that electrons are emitted from a heated surface, e.g. the filament of an electric lamp.

1884: The Italian *C. Onesti* noted that when loose brass and copper filings are electrostatically charged, they cohere and there is a resultant decrease in the resistance to the flow of a current.

1886: The German scientist *Heinrich Hertz* discovered that high-frequency oscillations could be generated and detected by means of simple resonance between two unconnected coils. He also developed the "Hertz Dipole" which he would use in subsequent experiments for both transmission and reception purposes.

1887: Hertz was the first to prove conclusively that high-frequency oscillations could be detected over a distance of a few metres. For a while these HF oscillations (i.e. electromagnetic waves) were known as "Hertzian waves".

1888: The English physicist Oliver Lodge (later *Sir Oliver Lodge*) demonstrated the importance of "resonance" where oscillatory currents were concerned.

By 1883, Hertz had been assistant to Professor Helmholtz for three years and it was time to move on – this time to the University of Keil. Although a small university with inadequate laboratories when compared with the University of Berlin, Keil University offered Hertz the opportunity to do some teaching and lecturing, yet leaving him ample time for contemplative study and to develop his theories.

An important product of the "Keil period" was the publication in 1884 of a paper titled *On the Relations between Maxwell's Fundamental Electromagnetic Equations and the Fundamental Equations of the Opposing Electromagnetics*. In this paper, Hertz subjected the Maxwell theory and those of the "opposing electromagnetics" to rigorous mathematical analysis. While he was unable to reach a final decision on the relative merits, he concluded by stating: *"I think we may infer without error that if the choice rests only between the usual system of electromagnetics and Maxwell's, the latter is certainly to be preferred"*.

After less than two years at Keil, Hertz accepted a professorship in 1885 at the Technical High School in Karlsruhe; he was particularly attracted by the laboratories and facilities they could provide for the research programme he wished to pursue.

While experimenting in 1886 with an old pair of "Knockenhauer Spirals" – short fat coils of wire embedded in spiral tracks cut into the surface of wooden discs – Hertz observed a small spark passing between the terminals of one of the coils, whenever a Leydon jar was discharged through the other. It may have been tiny but that spark set alight the train of research which, during the next four years, was to establish Hertz among the leading scientists of the nineteenth century. He had quickly realized that the phenomenon could only be due to the occurrence of oscillatory currents in the spiral coils, but he further realized – and this was the truly significant step – that the period of the oscillations were around a hundred-millionth of a second (estimated, but with the aid of just a little theory!).

By the end of 1886, Hertz had abandoned the use of Knockenhauer Spirals in his transmitter. Instead he used an open-wire linear form of inductance – what we now call a "Hertz dipole". Using these devices, he discovered that they could also be used to "receive" the transmitted vibrations at some distance away (a few metres in those days). Now armed with both a generator and a detector of oscillations, Hertz spent the winter of 1886/7 investigating the properties of electrical oscillations. Further months were spent investigating what we would now describe as the electromagnetic field in the vicinity of a dipole.

Other experiments conducted by Hertz enabled him to show that electromagnetic waves – in the transverse nature of their vibrations and their susceptibility to reflection, refraction and polarization – are in complete correspondence with the waves of light and heat; this established beyond doubt the electromagnetic nature of light.

In 1889, Hertz was appointed professor of physics in the University of Bonn, where he continued his researches on the discharge of electricity in rarefied gases – only just missing the discovery of X-rays which were described by W.C. Röntgen a few years later. However this was to be Hertz's last work, as a long illness took a hold of him. In 1984, he died in Bonn at the tragically early age of thirty-six.

In reviewing his successive achievements, it should be borne in mind that Hertz never once envisaged that the new range of electromagnetic frequencies which he had discovered would have even the smallest application as a means of communication. So if he had no thoughts of radio communication, what exactly were his aims? The answer may lie in the fact that Hertz was a pure physicist, with a passionate desire to work towards the increase of human knowledge – in his own words *"to expand the frontiers of science"*. He was an academic, pure and simple, with little or no interest in any commercial aspects of his dicoveries – these aspects would be left to later pioneers like Popov and Marconi.

4. Sir Oliver Lodge (1851 - 1940)

The great contribution made by Sir Oliver Lodge to the development of wireless telegraphy has been largely forgotten. His work held little of interest to the lay press, compared with that of Marconi in later years, yet it was Lodge who provided a number of the essential elements which made it possible for Marconi to develop a practical system of wireless communication.

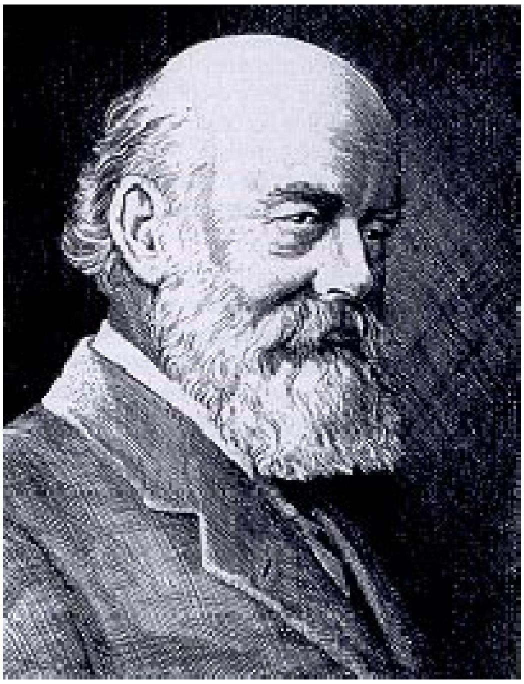
Oliver Lodge was born near Stoke-on-Trent, England, in June 1851, The son of a merchant who supplied local pottery firms with their raw materials, the young Lodge reluctantly joined his father's business on leaving school. However, his real interests lay in science; during an earlier visit to an aunt in London, he had attended several popular lectures on chemistry, geology and heat.

Thus, when a series of educational courses on science – instituted by the old "Science and Art Department" of South Kensington, London – began in a town near his home, the sixteen-year-old Lodge signed up and, shortly after, offered his services to the lecturer as an unpaid but enthusiastic assistant. In the ensuing examinations, Lodge came first in each of the eight science subjects covered on the course. By now, he had developed a broad knowledge of basic physics and he went to London to enrol for further courses at the Science and Art Department in South Kensington.

While studying biology, physics and chemistry at South Kensington, Lodge attended additional evening classes in mathematics and physics. He then enrolled at University College of London for the 1873-4 session and had the good fortune to hear James Clerk Maxwell speak to the British Association in 1873. Lodge's deep interest in Maxwell's theories were very much stimulated by this lecture and, by the time he received his science degree in 1875, Lodge was fully conversant with them. Lodge received a doctorate at University College in 1877 and then joined the staff of the Physics Department as an assistant and demonstrator.

In 1881, Lodge was appointed Professor of Experimental Physics at the newly-formed University College of Liverpool. While waiting to take up this appointment, he made a tour of Europe, mainly to establish contact with other leading scientists of the period. While in Berlin, Lodge called – without an appointment – on the great Professor Helmholtz. The Professor was just leaving to go out and handed Lodge over to his young assistant – Dr. Heinrich Hertz. From that day on, Lodge and Hertz maintained a close friendship until Hertz's untimely death in 1894.

Back in Liverpool, it was some time before Lodge was able to devote much time to Maxwell's theories. However, in preparation for two important lectures to the Society of Arts in 1887, he carried out some important experiments on the discharge of Leyden jars which showed beyond doubt that lightning discharges are oscillatory in nature. During the course of these experiments, Lodge showed the need for *resonance* between oscillatory circuits if an adequate transfer of energy was to take place between them; one of his experiments illustrated the "recoil kick" that occurs when an oscillatory discharge takes place in a resonant circuit.



However, although Lodge could by now demonstrate the physical existence of electric waves along wires and could measure their wavelength, he still had no means of detecting their presence in space. The honour of being first to do this goes to Hertz who, at the end of 1886, had discovered that his "dipole" spark transmitter could also be used to detect the transmitted vibrations across the room.

The news of Hertz's discoveries were warmly welcomed by Lodge but, just like Hertz, he saw no practical application for these transmitted vibrations (known by now as "Hertzian" waves but later given the name *electromagnetic waves*). Nevertheless, in 1889, Lodge made some important observations on the cohesion between metallic surfaces when subjected to a nearby electric discharge; these observations led to his development a year or two later of the *coherer* which, in his own words, *"is the most astonishingly sensitive detector of Hertzian waves"*.

In 1893, Lodge's attention was directed to the work of Edouard Branly in Paris who had found that the resistance of metallic dust or filings to the passage of an electric current was greatly lowered if a small electric discharge occured in the vicinity. (It is doubtful if Branley recognized at the time that the effect was due to electromagnetic radiation but his observations were thorough and conclusive.) Lodge at once proceeded to experiment with a tube of metallic filings and found it to be immeasurably superior as a detector when compared with the cohering knobs and delicately-balanced spring contacts which he had been using.

Lodge was invited to deliver a memorial lecture on “The Work of Hertz” at the Royal Institution, a few months after Hertz’s death on 1 January 1894. This lecture disseminated an understanding of the properties of Hertzian waves well beyond the small circle of mathematical physicists to whom the subject had previously appealed; the lecture was reprinted in serial form in the weekly journal *The Electrician*. The title of the lecture was actually a misnomer as Lodge dealt more with his own work (in particular, how he had developed the coherer) and that of others who had followed Hertz, than with the work of Hertz himself. The lecture provided great stimulation for Dr. Alexander Muirhead, an eminent telegraph engineer, and led to close collaboration between Lodge and Muirhead which was to last for almost twenty years.

A few months later, in August 1894, Lodge was asked to repeat his lecture at a meeting in Oxford of the British Association for the Advancement of Science. By now, Muirhead had supplied him with a range of telegraphic equipment including a Kelvin marine galvanometer and a Morse inker. At the lecture, Lodge arguably became the first person in the world to demonstrate wireless telegraphy when he transmitted Morse-coded letters over a distance of about 60 m, and through several brick walls, to a simple Morse receiver based on his improved coherer. This achievement was widely reported but, *at the time*, nobody foresaw any commercial applications for a system of “telegraphy without wires”. This had to await the subsequent arrival of Marconi in England, during February 1896. (Marconi and Lodge virtually ignored the existence of one another and it is interesting to speculate on how the development of wireless communication might have proceeded, had they agreed to collaborate.)

By his failure initially to follow up the practical possibilities of his own researches, Lodge lost the opportunity to acquire popular acclaim as the “inventor” of wireless telegraphy but his influence on its early development was profound. With his deep understanding of the phenomenon of electrical resonance, he was the first to emphasize the importance of tuning. In May 1897 – some two months before the publication of Marconi’s original patent – Lodge applied for a patent which gave him priority in the exploitation of selective tuning by means of added inductance. This patent was to become one of the most famous and fundamental in the whole history of radio communications.

As the century drew to a close, Lodge was still pre-occupied with his academic studies at Liverpool and, from 1900 onwards, at the new University of Birmingham where he was appointed the Principal. Nevertheless, in association with Muirhead, he found time to develop a well-engineered and practical system of wireless telegraphy in 1903 which, for a time, rivalled that of the Marconi Company. However, a widespread adoption of the system was thwarted, partly by the virtual monopoply which had been created between the Marconi Company and Lloyds (the company which ran the signalling system around the British coastline in those days) and partly because the Postmaster General had refused to issue licences to competing stations.

In 1911, Lodge received a time extension to the master patent of 1897, which had given him continuing priority in exploiting the principles of resonance and selective tuning. This was a serious embarrassment to the Marconi Company who opened negotiations with Lodge for the purchase of the patent. An agreement was reached in October 1911 whereby the Lodge-Muirhead Syndicate disposed of all their patents and royalties to the Marconi Company, in exchange for a very large sum of money. The agreement also provided for the winding up of the Syndicate and for the appointment of Lodge as Scientific Advisor to the Marconi Company for an initial term of seven years.

Sir Oliver Lodge (he had been knighted in 1902) retired from the University of Birmingham in 1919 and died in 1940 at the ripe old age of 89.

5. Aleksandr Stepanovich Popov (1859 - 1906)

Aleksandr Stepanovich Popov was born in 1859 in Tourinskii Roudnik in the Urals, Russia, where his father was a priest. In 1877, he went to study physics and mathematics at St. Petersburg University, where he was awarded a higher degree upon completion of his dissertation. In 1883, he started to teach at the Kronstadt Torpedo School, one of the most prestigious naval teaching establishments in Russia. It was here that he first grasped the Russian navy’s acute need for wireless communication. The excellent equipment of

the physics laboratory enabled Popov to conduct many valuable experiments.

At the beginning of 1895, Popov re-ran the experiments of Heinrich Hertz and Oliver Lodge and refined the Branly-Lodge coherer. He introduced the solenoid tapper, to ensure reliable functioning of the coherer by enhancing its sensitivity and potential. A Morse recording device was then added and Popov increased the sensitivity of the system by connecting it to a lightning conductor, which acted as the antenna. The result was the wireless telegraphy receiver, a very reliable and stable piece of equipment. Popov used it to demonstrate that it was possible to transmit short, continuous signals (using a Hertz oscillator as the transmitter) over a distance of up to 60 metres.

Popov publicly presented the results of his work in the spring of 1895 at a meeting of the physics section of the Russian Physical and Chemical Society (RPCS) and an account of this meeting was subsequently published in the August 1895 issue of the RPCS Journal. In January the following year, this same journal carried a detailed article by Popov together with a diagram of the wireless apparatus. During the first six months of 1896, Popov's experiments and apparatus were described in a total of 11 publications.

Popov went on to perfect his device for wireless communications, enhancing the sensitivity of the apparatus and increasing the distance over which the signals could be carried. In 1899, he

1890: The French physicist *Edouard Branly* published his discovery that the resistance between loose iron filings in a glass tube decreases when exposed to radiated electric waves, which is the principle upon which the “coherer” works.

1891: The Croatian/US electrician *Nikola Tesla* publicised his discoveries and applications in the field of high-frequency alternating currents, including his HF resonant transformer which became known as the “Tesla coil”.

1894: Lodge transmitted Hertzian waves over a distance of about 60 m; his receiver consisted of a tuned circuit and a Branley coherer. Subsequent improvements to the coherer extended the range to about 800 m.

1895: The Italian entrepreneur *Guglielmo Marconi* transmitted Hertzian waves over a range of around 2-3 km using an elevated aerial and an earth connection.
. . . The Russian physicist *Aleksandr Stepanovich Popov* demonstrated the reception of short continuous signals over about 60 m, using a refined version of the Branley-Lodge coherer and a lightning conductor which acted as an aerial.

1896: Marconi moved from Italy to England, he took out the world's first patent in wireless telegraphy and he demonstrated his radio-signalling system to the British War Office, The Admiralty and the General Post Office on Salisbury Plain, Southern England.
. . . Popov sent Hertzian waves into a receiver over a range of about 300 m.

1897: Marconi officially demonstrated his signalling system to the British Post Office over a 14 km stretch of water at Lavernock Point, near Cardiff (Wales), and he established The Wireless Telegraph and Signal Company Limited which later became the *Marconi Company.*
. . . The German scientist *Prof. Adolf Slaby* succeeded in sending telegrams over a distance of about 20 km in the Berlin area.
. . . Lodge patented his tuned circuit, following earlier experiments with “syntonic jars”.

1898: Marconi devised tuned circuits at the transmitter and receiver, based on a practical application of Sir Oliver Lodge's tuned-circuit principle.

1899: Marconi sent the world's first international wireless message across the English Channel to France, over a distance of about 50 km.
. . . Popov applied for a patent in Russia for his radio receiver.

1901: Marconi bridged the Atlantic Ocean between Poldhu in Cornwall, England, and St John's in Newfoundland, Canada, using Morse transmissions on a wavelength of perhaps 1000 m.

1902: The Danish electrical engineer *Valdemar Poulsen* developed the Poulsen arc generator, which enabled high-power narrow-band transmitters to be constructed before the discovery and subsequent exploitation of the thermionic valve.
. . . *Arthur Edwin Kennelly* (USA) and *Oliver Heaviside* (Great Britain) independently suggested the existence of the “ionosphere”.

developed a wireless receiver based on the detector effect discovered by his assistants, P.H. Ribkin and D.S. Troytsk, which he later patented in Russia, England and France. Shortly thereafter, the production of wireless telegraphy apparatus in France started up under the name Popov-Ducretet. This wireless apparatus was awarded a gold medal and diploma at the World Exhibition in Paris in 1900.

In 1901, Popov was appointed Professor of Physics at the St. Petersburg Electrotechnical Institute, where he set up a wireless telegraphy research laboratory and gave a course on the subject. In 1905, he became the first elected director of this institute but died on 1 January 1906, at the relatively young age of 45.

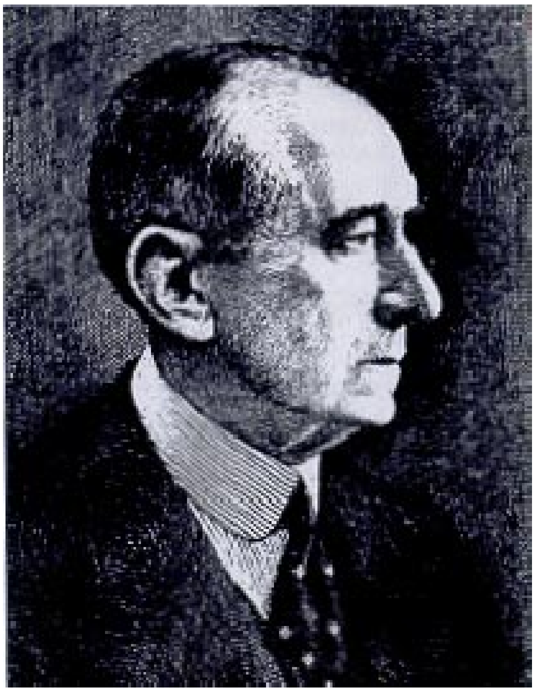
Popov achieved much during the ten short years when he was involved in the development of radio technology in Russia. He devised and continually refined the apparatus used for radio communications, he organized the training of experts in this field, and initiated the setting up of the first wireless telegraphy transmitters in Russia.

In 1903 and 1904, Popov headed the first higher institute to specialize in electrical communications, together with his post-graduate assistant, S.Y. Lifchits. He conducted experiments in transmitting the human voice via radio, represented his country at international exhibitions and conferences, and was personally involved in launching the production of Popov system equipment at three sites: the E. Ducretet factory in Paris, the radio workshop in Kronstadt and the Siemens and Halske factory which opened during 1904 in St. Petersburg.

Over the past 100 years, Russia has revered Popov as the inventor of radio communications and monuments have been erected to him in several Russian towns. A gold medal and prize have been instituted in his honour and are awarded by the Russian Academy of Science to Russians and foreigners for their outstanding work in the field of radio electronics.

The Russian government has decreed 1995 as marking the centenary of the invention of radio.

6. Guglielmo Marconi (1874 - 1937)



Guglielmo Marconi was born in April 1874, the son of an Italian country gentleman who had married an Irish woman. Educated in Bologna and later in Florence, Marconi went on to the technical school in Leghorn where he studied physics under Vincenzo Rosa and had every opportunity to investigate Hertzian (i.e. electromagnetic) waves.

In 1894, Marconi began to experiment with radio transmission at his father's estate near Bologna and by the summer of 1895, he had succeeded in transmitting signals over a distance of a few metres. For these early experiments, his transmitter consisted of a battery in series with a Morse key, connected to the primary of an inductance coil. The secondary of this coil was connected to two metal plates, separated by a spark gap. At the receiving end was a simple coherer. Marconi went on then to improve the primitive coherer and began to experiment with a raised aerial and a ground connection, at both the sending and receiving ends, to increase the range of his signalling system. He also experimented with reflectors around the aerial to concentrate the radiated electrical energy into a beam instead of spreading it in all directions. By August 1895, Marconi had achieved transmission-reception over a distance of 2-3 km.

As Marconi received very little encouragement to continue with his experiments in Italy, he moved with his Irish mother to England in February 1894 and lost no time in applying for his first patent to protect his invention. It was filed as No. 5028 at the British Patent Office on 5 March 1896 and had the title *Improvements in Telegraphy and in apparatus therefor*. However, Marconi subsequently chose to abandon this application and, with the help of an eminent patent agent of the time, made a second application which was filed as No. 12 039 at the Patent Office on 2 June 1986; it was the first patent relating to wireless telegraphy ever granted.

Shortly after his arrival in England, Marconi met A.A. Campbell Swinton, a well-known electrical engineer, who introduced him to William Preece, Chief of the Engineering Department of the General Post Office. Preece swiftly arranged for Marconi to demonstrate his wireless telegraphy system in central London and, after this initial success, a series of tests took place on Salisbury Plain in southern England (over a distance of about 3 km). The following year (1897), Preece assisted Marconi with another important demonstration of his system to Post Office officials at Lavernock Point near Cardiff, Wales, over a distance of nearly 15 km. Signor Marconi was just 23 years of age!

In July 1897, with the help of his English cousin, Marconi set up the *Wireless Telegraph and Signal Company Limited* (which was renamed the *Marconi Company* in 1900).

By now, the Italian government was beginning to show interest in the young Marconi and he was invited to return to Italy to demonstrate his equipment to the Italian navy. He returned to his native land in triumph, was presented to the King and Queen of Italy, and for once his father glowed with pride at his son's achievements. The first message Marconi transmitted to demonstrate his system was *Viva l'Italia!* and he went on to show how wireless transmissions could be used to communicate with ships at sea – even well beyond the horizon. Marconi's achievements were publicised widely in the Italian press and even the English newspapers followed his progress with considerable interest.

When Marconi returned to England after these Italian demonstrations, he had become even more famous. However, he did not let this fame go to his head and one of his first goals was to be able to communicate internationally by means of wireless telegraphy. Thus, in the spring of 1899, Marconi arranged the first international radio transmission, which took place over a distance of about 50 km between the southern coast of Britain and the northern coast of France. In July that year, three British warships were equipped with Marconi wireless apparatus for the summer manoeuvres and

1903: The Canadian physicist *Prof. R.H. Fessenden* successfully transmitted speech over a distance of about 20 km, using a modulated arc.
. . . The *Telefunken* company was created in Germany from an amalgamation of interests and became the greatest rival to the Marconi Company in the Europe of that time.
. . . The International Radiotelegraph Union (the forerunner of the ITU) held its first preliminary Radio Conference in Berlin.

1904: The Englishman *Sir John Ambrose Fleming* invented the thermionic diode, which was to have a very profound influence on later developments in wireless communication.

1905: The first frequency modulation (FM) patent was issued.

1906: The American *Lee de Forest* added a third electrode to Fleming's diode to produce the "audion" (i.e. the triode); this device took soon over from the alternator, in the generation of high-frequency oscillations.
. . . The first *Radio Regulations* were drawn up at the ITU's Berlin Conference, at which the German *Ernst Ruhmer* demonstrated radiotelephony over a distance of 30 m.
. . . Prof. Fessenden broadcast gramophone records to ships 80 km away, arguably the first wireless *broadcast.*

1908: Sound transmissions began from the Palais de Justice in Brussels, Belgium, using a modulated arc on a wavelength of 1750 metres.
. . . Prof. Slaby and *Count Arco* transmitted a Caruso record by radio from Berlin.

1909: The first regular broadcasts of time signals began from the Eiffel Tower in Paris, France.

1910: Lee de Forest transmitted a live Caruso performance to fifty amateurs in New York, USA.

1912: Lee de Forest exploited his triode valve as an amplifier, a most important breakthrough in the history of wireless communication.
. . . Wireless communication saved many lives when the ocean liner *Titanic* struck an iceberg and sank.

1913: *Prof. Meissner* was the first to describe an efficient triode-valve generator, when he experimented with radiotelephony between Berlin and Nauen in Germany.
. . . Capt. Round introduced positive feedback ("reaction") in receivers to increase the amplification.

1914: Amateurs began Saturday afternoon transmissions of music from the Royal Castle at Laeken, Belgium, which have a strong claim to being the first *regular* wireless broadcasts.
. . . Marconi experimented with valve transmitters for the British navy.

1915: The first international transatlantic broadcast took place, from Arlington in Virginia, USA, to Paris, France, using a 3 kW transmitter with over three hundred valves operating in parallel.

1918: Armstrong developed the *superheterodyne* principle for radio receivers.

1919: Regular sound broadcasting began in Holland from station PCGG; these broadcasts were widely known as the "Hague Concerts".

regularly communicated with one another over distances of nearly 100 km.

By now, Marconi dreamt of spanning the Atlantic Ocean. Due to the curvature of the earth, there would be a mountain of water 320 km high between the proposed sending and receiving sites but, nevertheless, Marconi managed to persuade his fellow directors to agree to the building of the necessary transmission and reception sites. Thus, on 11 December 1901, Marconi succeeded in transmitting the pre-arranged Morse letter “S” (dot-dot-dot) from a site at Poldhu in Cornwall, England, to the receiving site at St. John’s in Newfoundland, Canada. This experiment led Marconi in 1907 to introduce a commercial transatlantic message service in competition with the telegraph (which relied on transatlantic submarine cables).

During a voyage on a liner in 1902, Marconi was able to receive messages over a maximum distance of around 1100 km by day, but 3200 km by night – he had witnessed the phenomenon that some radio waves can travel greater distances via reflection from the upper regions of the atmosphere. In 1910, assisted by Capt. H.J. Round, he was able to receive messages from Clifden, Ireland, some 9600 km away in Buenos Aires, Argentina, using a wavelength of 8000 m.

When the liner *Titanic* struck an iceberg and sank in 1912, wireless communication saved many lives. This must have gratified Marconi whose primary aim in communication without wires had been to break the isolation of those at sea.

When Italy joined the First World War (1914 – 1918) on the Allied side, Marconi joined the Italian forces as an advisor on radio communications and also served as a diplomat. One communications project that he worked on was a short-range ship-to-ship communication system which used shortwaves. This wartime project eventually led to the establishment in the mid-1920s of a worldwide communication system called the *Beam System* which transmitted messages using Morse code.

1920: Long-wave broadcasting began from the Eiffel Tower in Paris, France, and from Königswusterhausen in Germany.
. . . An entertainment broadcast station (KDKA) was inaugurated in Pittsburgh, USA.
. . . Dame Nellie Melba gave an historic 30 min broadcast from Chelmsford, near London.

1921: Sound broadcasting began on a regular basis in France.

1922: Sound broadcasting began on a regular basis in Great Britain and Russia.

1923: Sound broadcasting began on a regular basis in Belgium, Germany and the former Czechoslovak Socialist Republic.

In 1919, the Marconi Company opened a 6 $^{1}/_{2}$ kW experimental transmitter in Chelmsford, near London, with which telephony range tests were carried out (it was replaced in 1920 by a 15 kW installation). Although entertainment was not the primary consideration, music was occasionally transmitted – as a variant to reading such items as railway timetables – and was greeted enthusiastically by wireless amateurs. The famous recital of songs by Dame Nellie Melba from the Chelmsford transmitter on 15 June 1920 was the first advertised programme to be broadcast in the UK.

Other broadcasts were also made by Marconi from Chelmsford but had to be closed down eventually, due to many complaints of interference to aircraft and other communications. However, under pressure from amateur wireless enthusiasts, the Postmaster General granted the Marconi Company a licence to make regular though very restricted broadcasts from a new transmitter near Chelmsford, whose call-sign was *2MT*. A licence was also granted soon after for a second station *2LO* which opened in London in May 1922. Enthusiasm for “listening-in” to the wireless was growing rapidly. To avoid a free-for-all broadcasting chaos, the Postmaster General that year asked the Marconi Company and five other large British companies to put up the capital to form the British Broadcasting Company – which was superseded by the British Broadcasting Corporation (BBC) in 1926.

So overwhelming was the interest aroused by broadcasting that wider and wider coverage was needed. Therefore, in 1924, the *5XX* high-power longwave station was inaugurated at Daventry on behalf of the BBC.

Marconi’s interest in shortwave transmissions continued throughout the 1920s and beyond. At first, he had thought that shortwave signals could only travel over short distances but he soon began to receive reports of SW reception over much greater distances. In 1923, using a transmitter of only 1 kW power at the Poldhu shortwave station, Marconi was able to receive clear signals on his steam yacht *Elettra* over a distance of 2200 km. The signals were much louder and clearer than those sent out from Caernarvon, Wales, on a wavelength several hundred times as great, and with 100 times the transmitter power. Thus began the development of shortwave wireless communication which, in conjunction with the beam aerial system mentioned above, enabled Marconi to obtain a contract from the British Post office to establish such a system between Britain and the countries of its Commonwealth.

Running parallel to Marconi's shortwave communication activities were shortwave *broadcasting* activities. The appetite for the new medium was insatiable and, in 1927, the BBC commissioned Marconi to build an experimental shortwave transmitter at Chelmsford, where it operated under the call-sign *G5SW*. This led to the inauguration in 1932 of the BBC's *Empire Service* on shortwaves.

Around this time, Marconi's research interests were turning towards even shorter wavelengths of around half a metre, which enabled him to deploy a parabolic reflector of moderate size to provide greater radiated power in the desired direction. In 1932, he installed the first-ever microwave telephone link, which connected Vatican City with the Pope's summer residence.

Spending more and more time now in Italy, Marconi developed a navigation system for ships, based on the use of microwave signals. In 1934, he staged a dramatic demonstration which was to be his last major public event. He arranged for his yacht *Elettra* (with all its windows blacked out) to steam into the Italian harbour of Sestri Lavante at normal speed, guided only by the microwave beacon he had installed on the cliffs overlooking the harbour. During some of these tests, Marconi observed that if an object such as a car or another ship passed through the beam, a hissing noise was heard through the receiver. This observation led to the subsequent development of radar.

In the late 1920s, Marconi had developed angina and, although this slowed him down considerably, he still insisted on enjoying his fame. In 1933-4, he undertook a triumphant world tour which involved him in attending "Marconi Day" at the Chicago Exposition in the United States. He was entertained by President Roosevelt at the White House and stayed with the Hollywood film star, Mary Pickford. He was also received by the Emperor in Japan, before returning to Italy via China and India – hardly a restful journey! He suffered two severe heart attacks in late 1934 from which he recovered.

1924: Sound broadcasting began on a regular basis in Austria, Finland and Italy.
. . . Professor E.V. Appleton (later *Sir Edward Appleton*) demonstrated the existence of the "ionoshere".
. . . Marconi and Franklin were the first to exploit "skywave propagation" via the ionosphere, when sending shortwave signals over a distance of 4000 km.

1925: Sound broadcasting began on a regular basis in Denmark, Hungary, Norway, Portugal and Sweden.
. . . The *International Broadcasting Union* (IBU) was created by European broadcasters in Geneva.

1926: Sound broadcasting began on a regular basis in Poland, Switzerland and in the former Federal Republic of Yugoslavia.
. . . Regular overseas shortwave broadcasts began in Europe from Eindhoven, Holland.

1933: The commercial station *Radio Luxembourg* began to broadcast transnationally to Europe.

1935: Armstrong gave his first public demonstration of the frequency modulation (FM) system.

1946: The Organisation Internationale de Radiodiffusion (OIR) was formed in Brussels, which left the future of the IBU (in Geneva) looking decidedly shaky.

1947: The ITU Conference at Atlantic City, USA, assigned VHF Band II to sound radio broadcasting, and created the International Frequency Registration Board (IFRB).

1948: The Americans *W. Shockley*, *J. Bardeen* and *W.H. Brattain* invented the transistor.

1949: Eleven radio organizations announced their resignation from the OIR, which relocated to Prague.

1950: The *European Broadcasting Union* (EBU) was formed from members of the old IBU and radio organizations who had resigned from the OIR.

1954: The first-ever transistor radio was launched in the USA.

1957: The first artificial earth satellite *Sputnik 1* was launched by the USSR and sent back wireless signals from outer space.

1958: The first integrated circuit (IC) was completed by the American *J.S. Kilby*.

1966: The CCIR recommended the Zenith-GE pilot-tone system for stereophonic broadcasting on the VHF/FM band.

1982: Field trials of the Radio Data System (RDS) were conducted in Berne, Switzerland, proving that the system would be viable.

1984: The EBU published its RDS specification.

1987: The Eureka 147 Digital Audio Broadcasting (DAB) project was established.

1990: CENELEC adopted RDS as a European Standard.

1994: The ETSI European DAB Standard was established, based on the Eureka 147 system.
. . . Agreement was reached by the ITU on a single worldwide standard for Digital Sound Broadcasting, based on the Eureka 147 system.

Marconi had already become a Senator and had joined Mussolini's Fascist party as long ago as 1923. Mussolini had heaped honours on Marconi, including the title of *Marchese* (Marquis). Thus, when Italy invaded Abyssinia in 1935, Mussolini asked Marconi to defend this action by visiting those countries that disapproved. Privately, Marconi had come to have doubts about the Fascist régime and he felt that the Italian dictator would listen only to what he wanted to hear. But, as a true Italian patriot, Marconi insisted on carrying out the exhausting travel that Mussolini was now asking of him.

In the following eighteen months, Marconi grew steadily more feeble and died on 20 July 1937. In a fitting tribute to his achievements, wireless stations throughout the world observed a two-minute silence. The airwaves, just for a brief moment, were as silent as they had been before Marconi had conquered them. He was accorded a state funeral by the Italian government and, at his own wish, was buried at his native town of Bologna.

Acknowledgements

The material for this article has been derived from a number of published sources, in particular: *The Early History of Radio* by G.R.M. Garratt, which is reviewed on page 95; *Encyclopædia Britannica* (1970 edition) and *BBC Engineering 1922-1972* by E. Pawley. Alexander Nagapetian of Radio-televidenie Ostankino, Russia, provided the text on Aleksandr Popov.

The portrait "drawings" which accompany the article are the copyright of the International Telecommunication Union, Geneva. Starting in 1935, the ITU commissioned a series of portrait etchings to honour distinguished "pioneers" in the world of telecommunications. By 1955, there were 26 etchings in this important series.

The newsroom of *I.N.R.*, Brussels, in 1935.