

SCIENCE MUSEUM  
SOUTH KENSINGTON

HANDBOOK OF THE COLLECTIONS  
ILLUSTRATING  
ELECTRICAL ENGINEERING

II. RADIO COMMUNICATION

By W. T. O'DEA, B.Sc., A.M.I.E.E.

Part I.—History and Development

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LONDON

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## PREFACE

THE formation of a Museum of Science was first proposed by the Prince Consort after the Great Exhibition in 1851, and in 1857 collections illustrating foods, animal products, examples of structures and building materials, and educational apparatus, were brought together and placed on exhibition in South Kensington. The collections of scientific instruments and apparatus were first formed in 1874, but it was only after 1876 that they became of importance. The Special Loan Collection of Scientific Apparatus which was exhibited in that year in the Museum brought together examples of all kinds from various countries, and a large number of these were acquired for the Museum. Subsequently many additions were made, including in 1884 the collection of machinery formed by the Commissioners of Patents, in 1900 the Maudsley Collection of machine tools and marine engine models, and in 1903 the Bennet Woodcroft Collection of engine models and portraits.

Until 1899 the Art Collections and the Science and Engineering Collections together formed the South Kensington Museum, but in that year the name was changed to the Victoria and Albert Museum, which included both Collections until 1909, when it was restricted to the Art Collections; those relating to Science and Technical Industry have since then formed the Science Museum.

The aim of the Science Museum, with its Collections and Science Library, is to aid in the study of scientific and technical development, and to illustrate the applications of physical science to technical industry.

This is effected by the informative display of objects, diagrams, and photographs—so arranged as to illustrate in each Section the development which has taken place from past to modern practice.

Many of the exhibits are so arranged that they can be operated by visitors or demonstrated to them. Others have been sectioned so that the internal structure can be clearly seen. A detailed descriptive label is placed by each object.

The Collections have been augmented from time to time by loans and gifts from many sources, including many scientific and technical institutions, industrial firms, and also private individuals. In the Museum there are collections illustrating :—

- Textile and Agricultural Machinery.
- Hand and Machine Tools.
- Papermaking, Typewriting, Printing.
- Lighting and Illumination.
- Mining, Ore Dressing, Metallurgy.
- Glass and Pottery.
- Electrical Engineering.

Telegraphy, Telephony, Radio.  
Carts, Carriages, Cycles, and Mechanical Vehicles.  
Railway Construction, Locomotives, and Rolling Stock.  
Roads, Bridges, Lifting Appliances.  
Power Transmission, Pumps, Fire Protection.  
Building Construction, Heating, Water Supply, Sewage  
Disposal.  
Metrology (Weighing and Measuring).  
Steam and Internal Combustion Engines.  
Boilers.  
James Watt's Workshop.  
Marine Engines and Boilers, and Auxiliary Machinery.  
Harbours and Docks.  
Sailing Ships, Merchant Steamers, Steamships of War, Small  
Craft.  
Aircraft, Aero-Engines, and Aircraft Instruments.  
Mathematics, Astronomy.  
Chemistry, Photography, and Kinematography.  
Optical Instruments.  
Geodesy and Surveying.  
Meteorology.  
Terrestrial Magnetism, Seismology, Gravity, Atmospheric  
Electricity, and Tidal Phenomena.  
Applied Geophysics.  
Electrical, Magnetic, Acoustical, and Thermal Instruments.  
Time Measurement.  
Physical Phenomena, Properties of Matter, and a collection of  
Historical Apparatus formerly the property of the late  
Lord Rayleigh.

There is also an extensive Science Library of books and periodicals, dealing with all branches of pure and applied science. The literature is available to the public for consultation in the reading-room, or obtainable on loan through the medium of an approved institution or industrial organization.

NOTE.—In the following chapters, where reference is made to objects which are represented in the Museum Collections by originals or replicas, an asterisk \* has been inserted in the text.

## RADIO COMMUNICATION

### ELECTROMAGNETIC WAVES

THE possibility of electromagnetic wave propagation through the ether was predicted by Clerk Maxwell from his purely mathematical investigations. Heinrich Hertz, by a number of well-devised experiments, demonstrated the truth of Maxwell's reasoning. The phenomena which had puzzled scientists for many years became immediately explicable. Maxwell announced his theory in 1864 while Hertz supplied the practical verification in 1888.

The earliest recorded evidence of the experimental observation of the effects of wave propagation through the ether is probably contained in an "Essay on Electricity" published by Adams in 1780. He noted that, at the moment of discharge of a Leyden jar, minute sparks passed between adjacent but unconnected conductors. The fact that such a discharge was not sudden, but consisted of a number of oscillatory surges, was appreciated by Riess and Henry some sixty years later, while Feddersen, in 1861, devised a rotating mirror experiment which showed definitely that this was the case. Paalzow and Lodge later demonstrated that the amplitude and periodicity of the oscillations depended on the electrical constants of the discharge circuit.

Henry, in 1842, discovered that needles in a basement were magnetized by the discharge of an electrical machine 30 ft. above, despite the intervention of two 14-in. floors. Thomson and Houston, about 1877, were amazed at the ease with which secondary sparks from metallic objects could be drawn while they were working with a large Ruhmkorff coil. Edison, about the same time, noted some induced spark phenomena which he attributed to an "etheric force."

The nearest approach to the true demonstration of "Hertzian waves" before the advent of Hertz was probably made by Hughes in 1879. He was experimenting with his microphones\* and also with the induction balance.\* While using the latter he was unable to get a perfect balance and, after suspecting the insulation of his coils, he finally found a loose contact was the cause of the trouble. The loose contact naturally appealed to Hughes as a microphonic joint, as the microphone was being developed by him at the time. He therefore connected a microphone and telephone in circuit and discovered that, without any direct connection, a sound was heard in the telephone whenever an intermittent current passed through the coils, even at a distance of several feet. The microphone he used (Fig. 2) was a steel needle in loose contact with a piece of coke,\* which provided a self-restoring coherer of the type later rediscovered by Lodge and Branly.

Hughes continued his researches from 1879 to 1886, including a voltaic cell in his receiving circuit, making a clockwork interrupter \* (Fig. 2) for the transmitter so that he could make observations at long distances without requiring an assistant, and trying out many types of discharge. He succeeded in distinguishing signals at distances up to 500 yds., his transmitter in its more usual form consisting of a single coil of his induction balance excited by six Daniell cells. He was convinced that the results obtained were attributable to "aerial electric waves," and he invited many notable scientists to witness his experiments. In February, 1880, the President of the Royal Society, Mr. Spottiswood, with two hon. secretaries, Prof. Huxley and Prof. Stokes, called to see a demonstration. Towards the end of three hours successful experiment Prof. Stokes said that there was enough original matter to form a paper to be read at the Royal Society, but that the results were explicable by known electromagnetic induction effects and he could not accept Hughes' theory of aerial electric waves. In Hughes' own words :—

"I was so discouraged at being unable to convince them of the truth of these aerial electric waves, that I actually refused to write a Paper on the subject until I was better prepared to demonstrate the existence of these waves; and I continued my experiments for some years, in hopes of arriving at a perfect scientific demonstration of the existence of aerial electric waves, produced by a spark from the extra currents in coils, or from frictional electricity or secondary coils. The triumphant demonstration of these waves was reserved to Prof. Hertz, who by his masterly researches on the subject in 1887-89 completely demonstrated not only their existence but their identity with ordinary light, in having the power of being reflected, refracted, etc., with nodal points, by means of which the length of the waves could be measured. Hertz's experiments were far more conclusive than mine, although he used a much less effective receiver than the microphone or coherer."

Hertz constructed oscillators \* (Figs. 3-5) consisting of two metallic plates, from which rods projected inwards carrying spherical electrodes at their inner ends to form a spark gap. These oscillators were charged from an electric machine until they discharged across the gap, the discharge taking the form of three or four rapidly damped electric oscillations. The oscillators acted as powerful radiators of electromagnetic waves. The radiation was detected by inserting "resonators" in the path of the waves. A suitably set sphere spark gap in a circular conductor formed a resonator \* which would display minute induced sparks at the moment of discharge of the oscillator, if roughly in tune with it. FitzGerald, in 1883, had suggested that Leyden jars should emit "Maxwellian radiations," but the practical genius of Hertz led him to transform the Leyden jar for this purpose into a condenser of small capacity with the plates well separated, thereby obtaining a relatively powerful radiator.

Hertz now placed parabolic metal reflectors,\* pitch prisms,\* and grids made of wire\* in their correct positions with regard to the

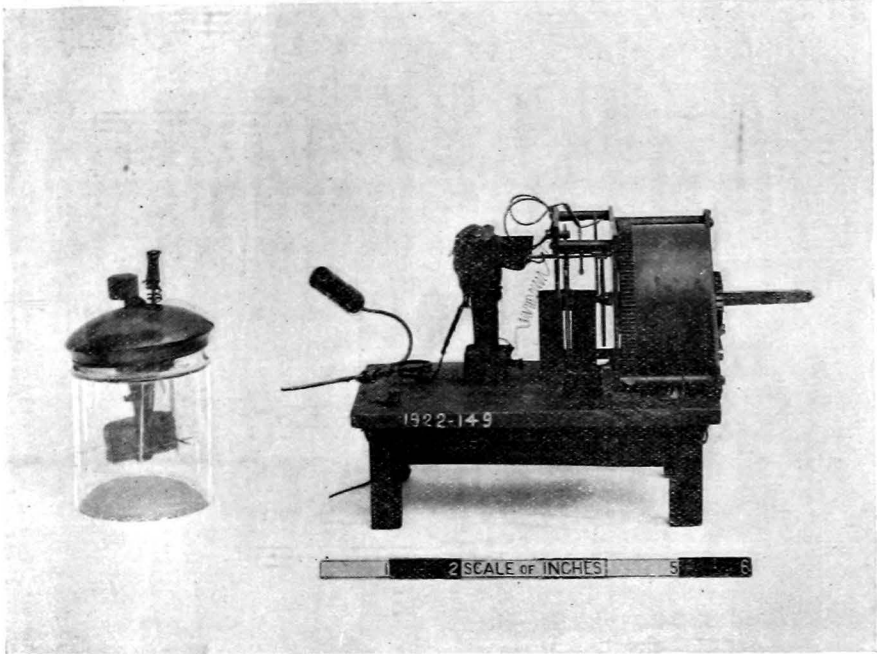


FIG. 2.—Hughes' Clockwork Transmitter and Detector, 1878.

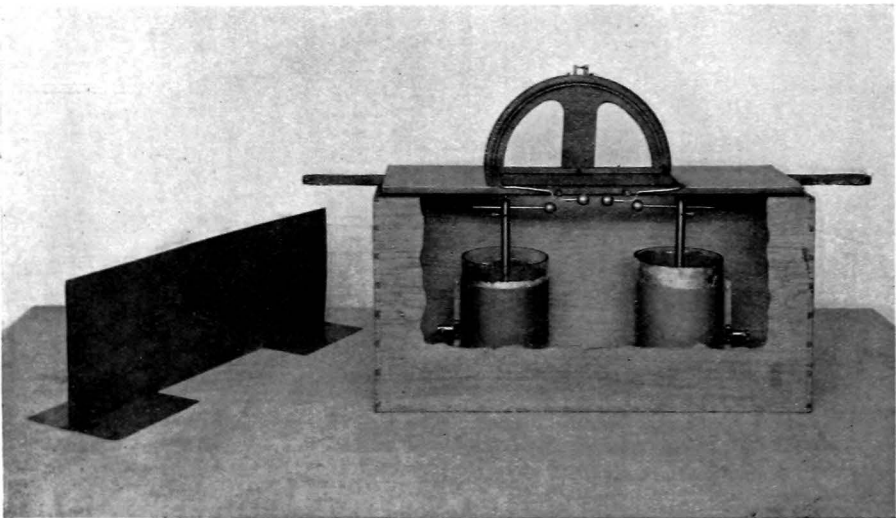


FIG. 3.—Hertz Apparatus to Show Effects of Insulating Materials on E.M. Waves.

When no material is interposed between the oscillator and the rotating circular resonator, no sparks are obtained at the latter when its gap lies in the plane of the oscillator gap, and maximum spark effects at right angles to this position. If a sheet of insulating material is interposed these minimum and maximum positions are displaced by a measurable amount.



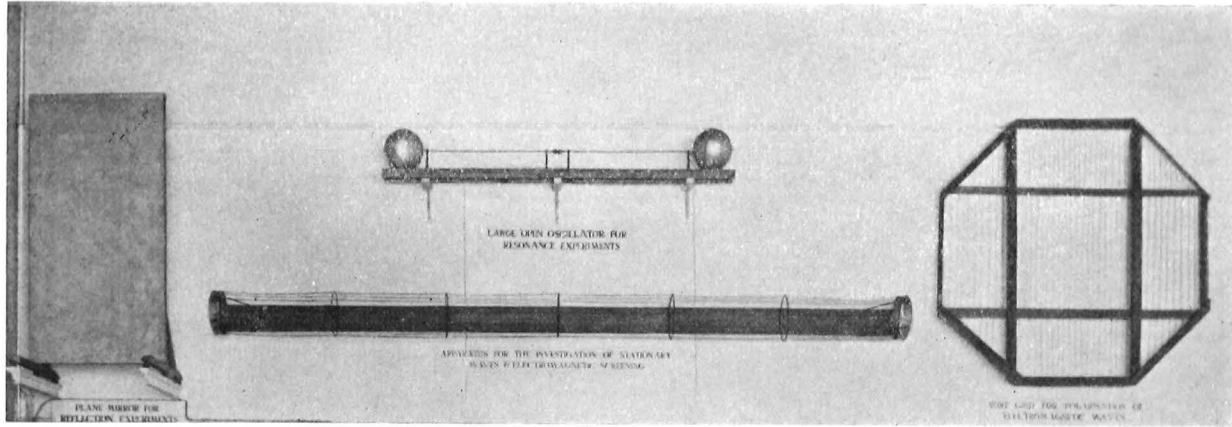


FIG. 4.—Replicas of Original Apparatus of Hertz.

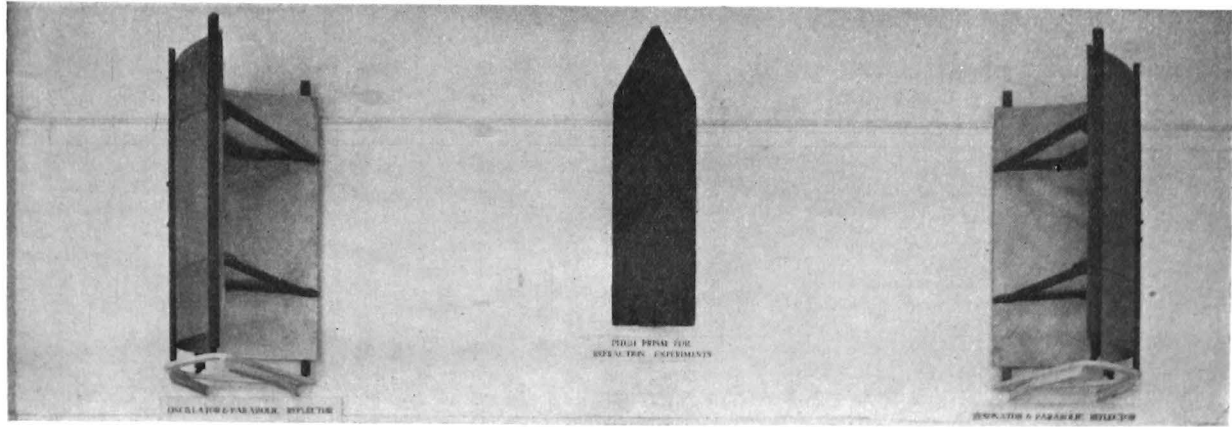


FIG. 5.—Replicas of Original Apparatus of Hertz.

oscillator and resonator to demonstrate the reflection, refraction, and polarization of the electromagnetic waves. The successful results completely verified the mathematical predictions made by Clerk Maxwell in 1864 that electromagnetic waves, differing only in wavelength from light waves, could be propagated through the ether. The length of the waves was obtainable from a consideration of the nodal points obtained when the wave was reflected, and made evident by moving the resonator progressively further from the oscillator.

These researches were conducted purely as physical research and their application to signalling devolved upon others. Hertz, unfortunately, died in 1894 at the early age of thirty-six. He was a pupil of von Helmholtz, an eminent physicist who is remembered, among other things, for his investigations into the oscillatory nature of the discharge from a Leyden jar, in 1847. Von Helmholtz first suggested to Hertz that he should try to obtain experimental proof of Maxwell's theory of displacement currents in dielectrics, and it was while conducting these researches that he made his classic experiments.

An experiment which was of some importance during the interim between the work of Maxwell and that of Hertz was the demonstration by von Bezold, in 1870, that an electric discharge along a wire had a definite velocity of propagation. He showed, by means of Lichtenburg dust figures, that electric impulses are reflected from the insulated end of a wire denoted by the presence of potential nodes and antinodes. This indicated wave propagation at some finite velocity. Many other investigators subsequently amplified von Bezold's work.

Some conception of the nature of electromagnetic waves may be gathered from the description of this early experimental work. There was no obvious practical application to communication at first, the minute effects obtained at any appreciable distance from the oscillator requiring delicate control under laboratory conditions for observation. The development of more sensitive methods of detection, without which many subsequent advances would have been impossible, is dealt with in the next chapter. The improvements made in the oscillator, in order to adapt it to communication, developed concurrently with advances in detector technique. The nature of wave propagation and the influence of factors such as the characteristics of the upper atmosphere were gradually elucidated. The result of research into a phenomenon which seemed to be of purely academic interest has been the growth of a large industry with profound effects on the trend of civilization.

One feature which made the possibilities hard to appreciate in the earlier days was that there were no obvious reasons why the limit of radio communication should not be confined to stations within visual range of each other. Electromagnetic waves possessed many of the characteristics of light rays, but differed in frequency. Their velocity  $—3 \times 10^8$  metres/sec.—was the same, the frequency of the oscillations being that figure divided by the wavelength. They had been shown to be capable of reflection, refraction, and polarization, as with light

rays. It was Marconi, in 1901, who demonstrated practically that they could be received at a station well outside the visual range from the transmitter, and Kennelly and Heaviside, in 1902, suggested that a reflecting ionized layer in the upper atmosphere would account for this deflection round the earth. Subsequent investigations, as referred to on p. 64, have shown that the shorter wavelengths may penetrate this layer and be reflected from a higher ionized layer, thus leading logically to the fact that the relatively short light rays are not reflected but pass through these ionized layers.

## DETECTORS

The secondary spark gap employed by Hertz was so limited in range and so insensitive that many other methods of detecting etheric radiations were devised. The earlier detectors were nearly all suitable for laboratory demonstrations only, and their commercial significance was slight. The results obtainable with them were of great interest scientifically, but did not suggest the possibility of applying Hertzian radiations to signalling.

In 1889-90 Prof. Minchin was experimenting with some delicate photo-sensitive cells which he found to behave abnormally when subjected to mechanical shocks. Experiments were being conducted in the same laboratory with a Hertzian radiator and an electrometer connected to one of Prof. Minchin's cells was found to respond when the radiator discharged. Without appreciating that his cells were acting on the cohesion principle Prof. Minchin employed them as detectors which were responsive at considerable distances from the radiator. Prof. Boltzmann, about the same time, employed a charged gold leaf electroscope in series with a minute air gap, which broke down under the slight excess in charge due to the reception of radiations. The leaves of the electroscope collapsed when such a discharge took place. FitzGerald and Trouton, in 1890, were able to demonstrate reception to an audience by means of a delicate galvanometer.

The Zehnder trigger tube became a popular device for detecting. A vacuum tube was charged to just under glow potential and the terminals of a Hertzian receiver were connected to two closely spaced electrodes in the tube. The reception of a signal supplied sufficient excess potential to make the tube glow. Another popular demonstration was the ignition of a mixture of explosive gases, such as an Abel's fuse, by the secondary spark.

Some interesting measurements were made by Bjercknes using as a detector a one-sided electrometer which had previously been employed by Blyth. The pyrometer, thermal junction, and expansion wire were also experimented with. The first step towards intelligible signalling, however, was the introduction of the coherer.

### Coherers.

Guitard, in 1850, noticed that when air containing particles of dust was electrified the particles tended to cohere into strings or flakes. This cohesion effect was used by S. A. Varley in his lightning protector of 1866 \* which was applied to a considerable extent in telegraph systems. A mixture of powdered carbon and a non-conducting dust normally offered a high resistance to the passage of a current but, when subjected to a high electric pressure, cohered and allowed a large

current to flow. Prof. Calzecchi-Onesti, in 1884, discovered a similar effect in a tube filled with brass filings, while Hughes, as recounted before, employed a microphone contact, or coherer, in his experiments with "aerial electric waves" in 1879.

The deliberate application of the coherer principle to the detection of wireless signals was largely due to Lodge who, in 1889, arranged two metal spheres in such close proximity that they were separated only by the minutest film of air \* (Fig. 7). The passage of a spark made the spheres cohere, but a slight mechanical shock would restore them to their original highly resistive condition. Branly, in 1890, experimented with many powders, pastes, and viscous liquids containing conductive particles and produced a sensitive brass filings coherer \* which could also be restored to its original condition by a mechanical shock. Lodge employed an electric bell in circuit to obtain decoherence automatically by vibrating the coherer. The coherence allowed a current to pass through the bell circuit and the bell then shook the coherer. This device was not so successful with the filings coherer as the sparking at the bell contacts affected the coherer, so that Lodge introduced a clockwork "tapper-back" in 1894. He also evacuated the tube containing the brass filings.

The mercury-iron coherer principle, with which much success was obtained, is attributed to Lieutenant Solari of the Italian Navy. Marconi, in 1895, devised a greatly improved coherer employing fine filings with a little mercury, enclosed in an evacuated tube.\*

In 1897 Appleyard constructed a coherer consisting of two globules of mercury kept apart only by a minute film of oil. The Lodge-Muirhead coherer \* which developed from this was probably the most sensitive coherer made. The resistance at coherence was so low that it was generally unnecessary to interpose a relay between the coherer and the recording apparatus. A small, sharp-edged steel wheel just touched the surface of a pool of mercury covered with a thin film of oil, and was rotated by clockwork. High frequency oscillations were sufficient to break down the oil film while the continuous rotation of the wheel ensured decoherence as soon as the signal finished.

Many other forms of coherer were developed, but nearly all suffered from the fact that an increase in sensitiveness meant a decline in reliability.

## Magnetic Detectors.

Rutherford, in 1895, succeeded in detecting Hertzian oscillations at a distance of three-quarters of a mile, using a magnetized steel needle in the centre of a bobbin of fine wire. He thereby confirmed the investigations of Henry, who had noted the demagnetization of needles due to discharge from nearby Leyden jars as early as 1842. In 1897 Prof. Ernest Wilson constructed a similar detector,\* but with an automatic feature whereby the movement of the needle connected the coil to a local battery circuit which remagnetized it and restored

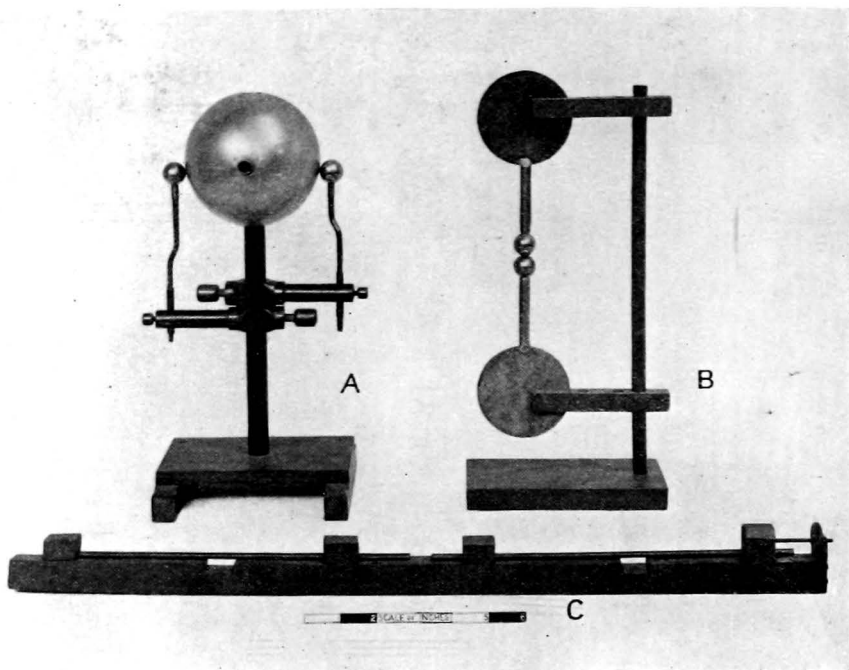


FIG. 6.

- (A) Lodge Spherical Oscillator, 1894.
- (B) Hertz Oscillator, 1894.
- (C) Hertz Resonator, 1894.

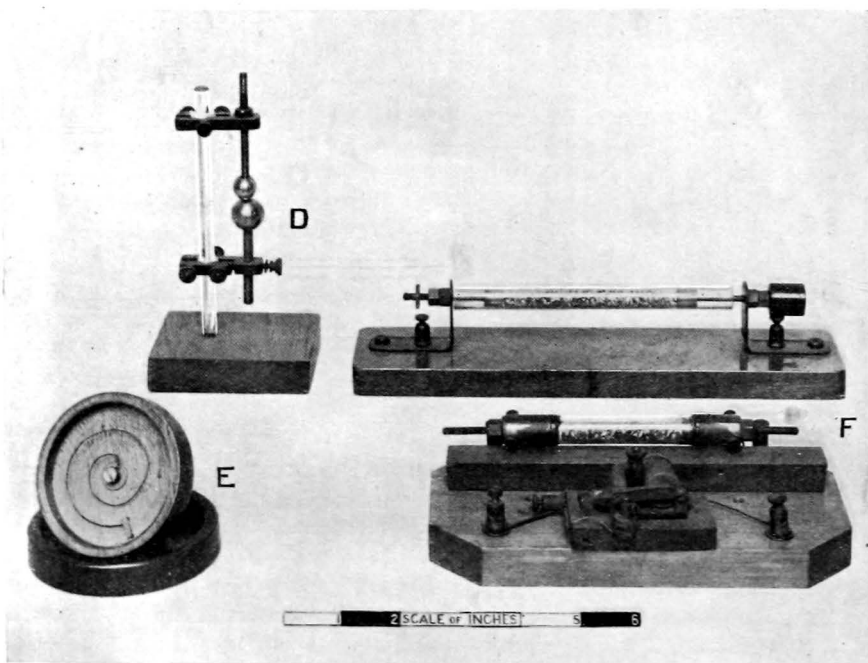
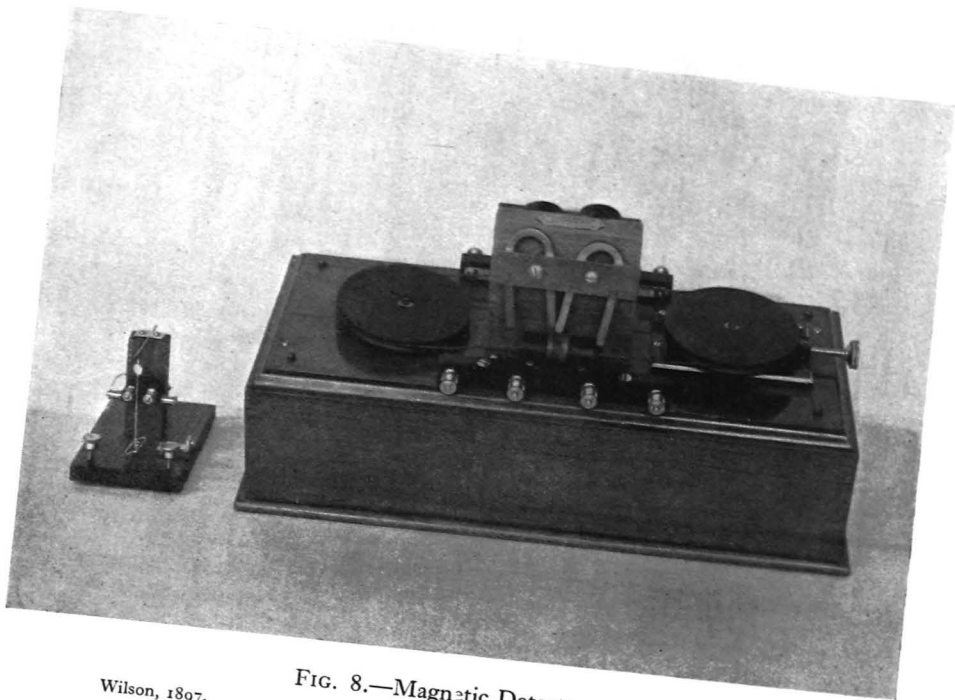


FIG. 7.

- (D) Lodge Spark-Gap Coherer, 1889.
- (E) Lodge Spring Coherer, 1894.
- (F) Branly-Lodge Coherers, 1894.



Wilson, 1897.

FIG. 8.—Magnetic Detectors.

Marconi, 1902.

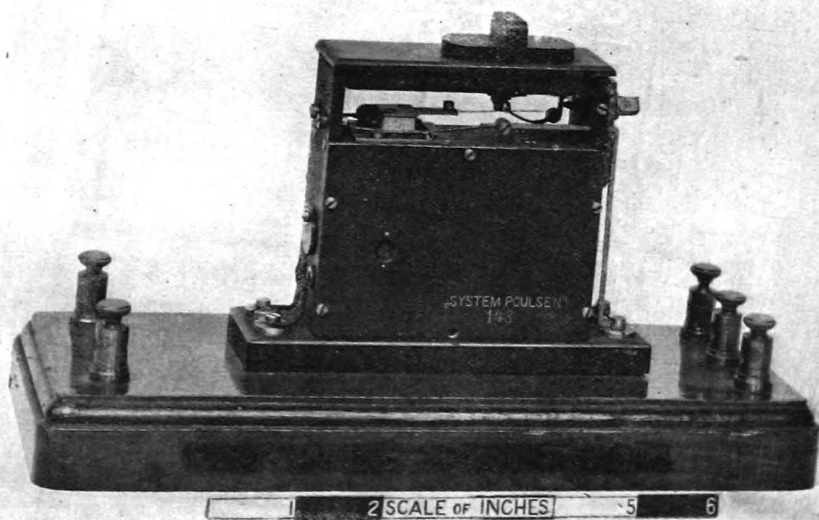


FIG. 9.—Pedersen Tikker, 1901.

it to the condition of detecting further signals (Fig. 8). Marconi, in 1902, further improved on this principle by employing two coils wound on a core of soft iron wires in front of which a permanent magnet was rotated by clockwork. One coil was connected between the aerial and earth and the other to a telephone circuit. The reception of a signal suddenly overcame the hysteresis lag in the periodic magnetization of the core and produced a click in the telephone. In a later form Marconi employed an endless band of insulated soft iron wire driven at about 5 in. per second by two rotating pulley wheels.\* The wire passed first in front of the poles of two permanent magnets and then through a glass tube around which two coils, similar to those described above, were wound. This type of detector was used commercially to a considerable extent (Fig. 8). Its disadvantage lay mainly in the clockwork drive.

### Electrolytic Detectors.

An electrolytic detector was invented by Neugschwender in 1898, and Pupin, in the same year, patented an electrolytic cell for rectifying alternating currents. One of the earliest practical electrolytic detectors was the De Forest Responder \* introduced by De Forest and Smythe and used extensively during the Russo-Japanese war. It consisted of a paste of litharge, glycerine, water, and metallic filings held between electrodes about 0.01 in. apart and through which a constant current from a battery passed. The current caused the growth of crystalline structures known as "lead-trees," which were partially destroyed on the passage of a signal current through the detector, but were instantly restored. A telephone in series with the detector recorded the change in current. This detector, in which the resistance increases with received oscillations, is known also as an "anti-coherer." Following the invention of the electrolytic break for induction coils, by Wehnelt in 1889, three investigators, Ferrié, Fessenden, and Vreeland, independently invented a detector on the same principle in 1900. The following years saw the introduction of improved types, notably the Schlömilch type adopted by the Telefunken Co. in 1903, but all eventually had to give way to the crystal and thermionic valve which were then in the process of development as detectors. Electrolytic detectors in general were non-sensitive to jarring, but were very sensitive to overloading. Sensitivity was in inverse ratio to the area of the positive electrode, the latter in the case of the Schlömilch detector being a platinum wire 0.03 mm. diameter of which only a small portion projected from a glass tube.

### Crystal Detectors.

Ferdinand Braun, in 1874, showed that galena, copper pyrites, and other metallic sulphides offered a much higher resistance to the passage of a current flowing through them in one direction than in the other. In 1901 the Telefunken Co. employed his psilomelan detector, which rectified incoming high frequency oscillations and thereby made the



recording apparatus experience a uni-directional force for the duration of each signal. Its sensitivity was about equal to that of the Schlömilch detector. In 1906 the use of carborundum crystals for a similar purpose was patented by Dunwoody.

The properties of many crystals were soon investigated, notable work being done by Pierce (who discovered the properties of titanium dioxide and molybdenite), Torikata and Yokoyama (who tested a very large range between 1908 and 1910 and classified their results), and Eccles (who obtained the characteristics of many crystal detectors between 1909 and 1911).

The choice of a crystal as a detector depends on its sensitivity and permanence. The Perikon detector patented by Pickard in 1909 was very sensitive but needed frequent adjustment. It consisted of zincite and chalcopyrite in contact. The Bronk cell,\* used extensively in conjunction with the Pedersen Tikker, consisted of tellurium and graphite in sensitive contact. It was difficult to keep in adjustment. An iron pyrites-gold contact or a molybdenite-silver contact was more reliable than the Perikon, but probably the most widely used combination was a silvery-grey straight grained carborundum crystal in contact with a hardened steel point, which was very reliable, relatively free from deterioration due to vibration or strong discharges across it, and fairly sensitive. It worked better with a potentiometer in circuit so that the most curved portion of its characteristic could be employed. Crystal detectors\* were liable to be put out of action by heavy atmospheric conditions and then needed readjustment.

The action of crystal rectifier is very imperfectly understood. The experiments of Pierce and Tissot showed some to be simple rectifiers while others seemed to depend on thermo-electric effects. One explanation is that the different "surface works" required for electron evaporation cause an asymmetrical resistance at the junction.

### **Pedersen Tikker and Tone Wheels.**

These devices were employed particularly for the telephonic reception of continuous wave signals (see p. 33). A large number of regular oscillations at radio frequency make up each dot or dash sent by C.W. systems. Rectification would therefore cause a click to be heard at the beginning and end of each signal period, and nothing—as the oscillations are above audio frequency—in the interim.

The Pedersen Tikker,\* patented in 1906, and extensively used on the Poulsen arc system, consisted of a small reed vibrated electromagnetically at an audio frequency (Fig. 9). The reed interrupted incoming trains of signals, causing them to charge up a condenser which was discharged through the telephones as the reed made contact with the telephone circuit. A note of the same frequency as the vibrations of the reed was thus heard in the telephones during the times that signal currents were being received.

Tesla, in 1901, had proposed the use of an interrupter in a receiving circuit, and Fessenden, in 1902, proposed a method of receiving continuous wave signals by obtaining a "beat frequency." The rotary tikker of Austin and the later tone wheel of Goldschmidt were introduced after the Pedersen Tikker. In the Goldschmidt tone wheel the frequency of the interruptions was controlled so that a pure note, instead of a buzz, was heard in the telephones. Pedersen, using a tikker in conjunction with a photographically recording Einthoven string galvanometer, attained a speed of 300 words a minute between the Lyngby and Esbjerg Poulsen stations.

### Thermionic Valve Detectors.

Hittdorf stated, early in 1884, that if a cathode glows white-hot in a vacuum, electric currents flow across the vacuum which is a perfect insulator at lower temperatures of the cathode. Edison noticed that a platinum spiral heated to incandescence under a glass globe platinized the surface of the glass and, in 1884, he discovered the same effect in his carbon filament glow lamps and intercepted the emission by means of a metal plate. It was also noticed that there appeared to be a transference of carbon from the positive to the negative ends of the carbon filament. Preece examined these effects in the following year and a systematic study of the phenomena was begun by J. A. Fleming in 1889. He interposed metal plates in the path of these particles and made qualitative and quantitative measurements of the effects, finally introducing, in 1904, the first two-electrode thermionic valves, or diodes, applied to the detection of high frequency oscillations\* (Fig. 10). He demonstrated the unilateral conductivity of his device and showed the limits of this conductivity, producing characteristic curves showing the relation between (a) the current through the vacuum and the potential difference of the electrodes, and (b) the percentage rectification and the watts expended in the filament. Sir J. J. Thomson, in 1897, had shown that the emission was due, not to negatively charged carbon particles as had been supposed, but to negative electrons.

The Fleming diode was a stable and efficient detector which was extensively used, but it was not capable of amplifying the received signal. In 1907 Lee De Forest included a third control electrode, or "grid," into the diode, thereby obtaining a device by which amplification became possible and which could also be used for generating undamped oscillations\* (Fig. 11). He did not fully publish his results, however, until 1913, by which time the grid had been used as a control by other investigators, and the importance of his invention was little appreciated before that year. The Lieben-Reisz gas relay\* introduced in 1911 was actually the first to be used (by Meissner in 1913) in the transmission of speech by radio-telephony, prior to which it had been used for the amplification of currents at audio frequency (Fig. 11). In 1915 the Pliotron\* (Fig. 11), which was very highly evacuated compared with earlier valves, was introduced by Langmuir after Richardson had shown (1914) that the presence of gas was not necessary

to emission. The smooth and regular characteristics of the "hard" valve, in which the action is due to pure electronic action and not influenced to any extent by interference from residual gas, has made its adoption universal in modern valves, the development of which is dealt with in a later chapter. The progress made in radio-communication, before the discovery and development of the amplifying and oscillating capabilities of the thermionic valve changed the whole trend of development, will first be considered.

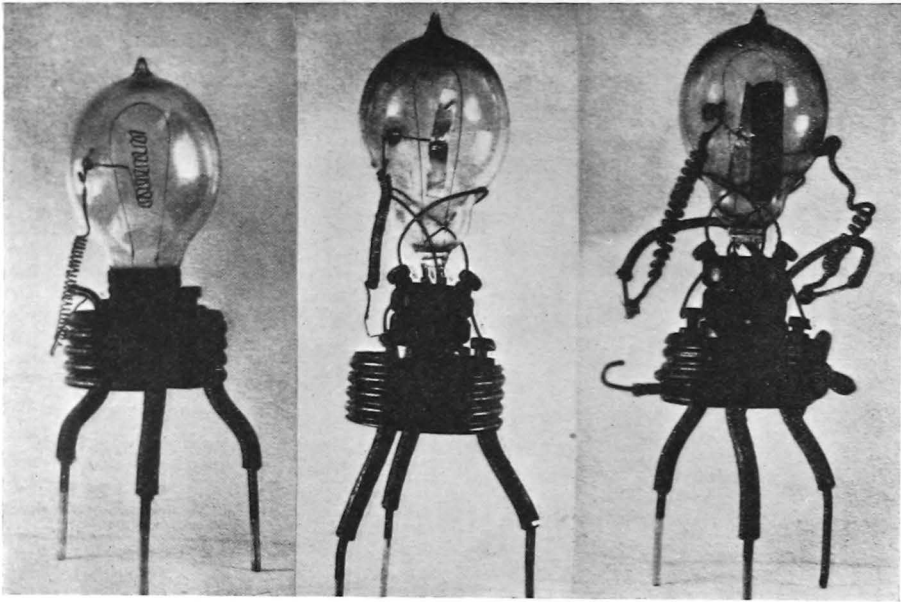


FIG. 10.—Original Fleming Diode Valves, 1904.

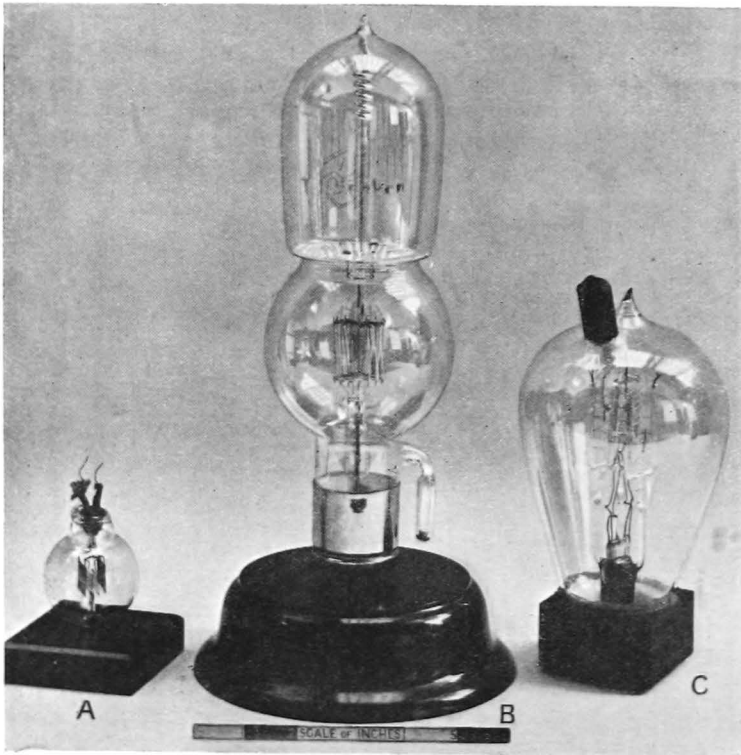


FIG. 11.  
(A) Audion Valve, 1907.  
(B) Lieben-Reisz Relay, 1911.  
(C) Plotron, 1914.

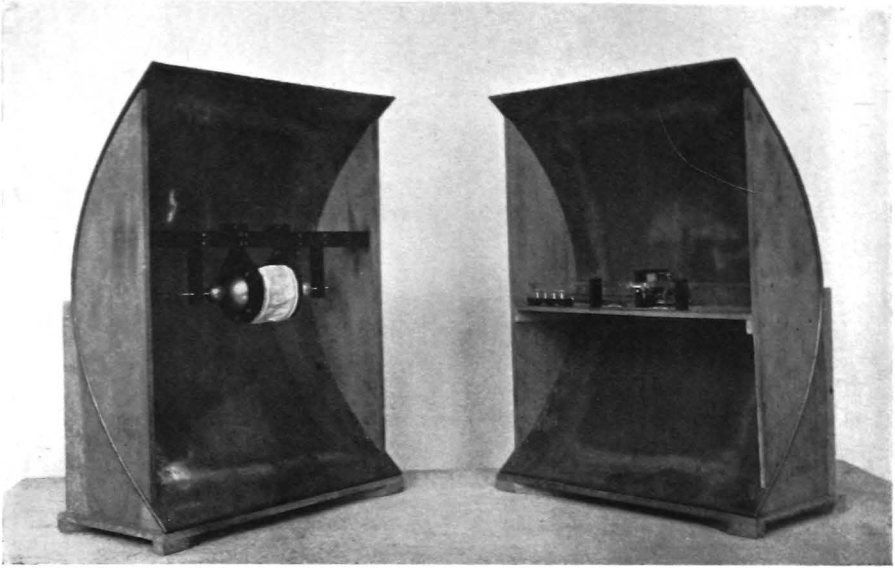


FIG. 12.—Marconi's Beam Transmitter and Receiver, 1896.

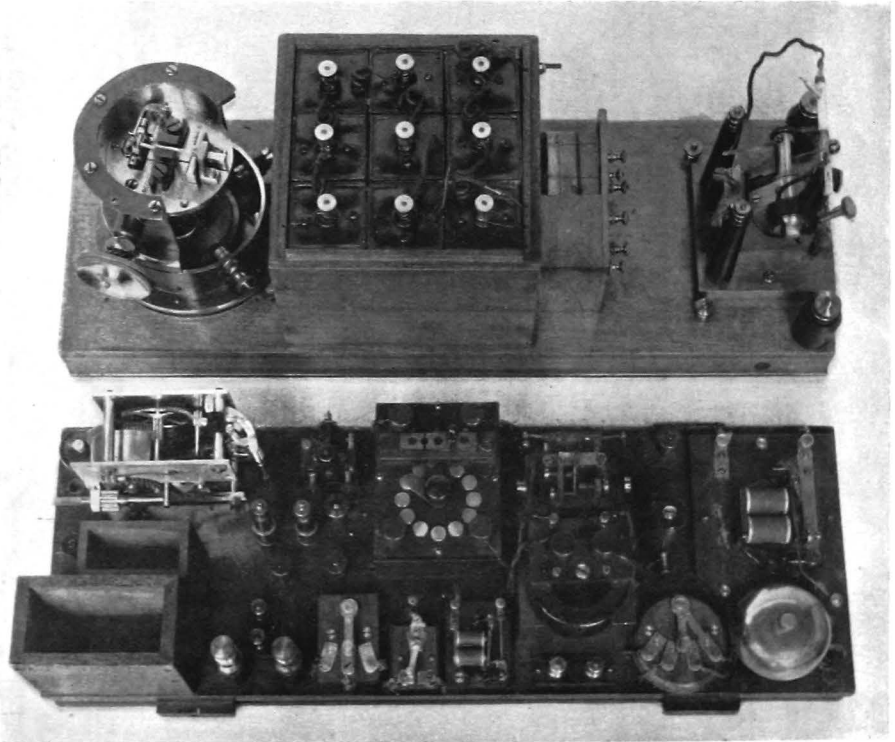


FIG. 13.—(Top) Marconi Coherer, Tapper, and Relay.  
(Below) Experimental Lodge-Muirhead Receiver.

## EARLY WIRELESS TELEGRAPHY EXPERIMENTS

For the first few years after Hertz's experiments, the significance of electromagnetic radiation through the ether was confined to its purely physical import. Many observers confirmed and amplified the results obtained by Hertz: Lodge, Righi, Chunder Bose, Branly, and Rutherford were prominent, as well as those mentioned at the beginning of the chapter on Detectors. The earlier history of the commercial development of radio communication is largely dominated by the work of Marconi, the scientific value of whose results was in no way diminished by their spectacular nature. Other investigators, however, made contributions which may have been less ambitious, but nevertheless influenced considerably the trend of events. A short account of the work of a number of these pioneers will be followed by chapters describing the later developments up to the time of the general adoption of the oscillating and amplifying thermionic valve.

### Sir Oliver Lodge.

The work of Hertz immediately appealed to Sir Oliver Lodge who was already well known as a physicist. He repeated and amplified Hertz's experiments and did some valuable work on coherer methods of detection, of which he was a pioneer. In February, 1890, he published an account of an experiment with "Syntonic Leyden Jars" in which the principle of tuning was described. The value of this contribution towards the use of electromagnetic radiation for signalling was extremely great, but the development of ether-wave signalling in serious competition to the telegraph and telephone seems not at first to have occurred to Sir Oliver.

In 1894 Dr. Alexander Muirhead went home after hearing Lodge lecture at the Royal Institution and was inspired not only to repeat for himself some of the experiments described, but to record signals on a syphon recorder. He later collaborated with Lodge in the Lodge-Muirhead system of wireless telegraphy which attained a considerable measure of success and was one of the better known early commercial systems (Fig. 13). Their sensitive coherer has already been described and the following important patents emanated from the partnership.

No. 11,575 of 1897 describes a method of prolonging the vibrations of a transmitter or receiver by adding inductance so that, although the radiating power may be reduced compared with that of a radiator giving a single pulse, the arrangement is susceptible of tuning. Lodge saw that the increase in selectivity obtained by reducing the decrement of his circuit was valuable as two stations could then be tuned to the same frequency. He was prepared to compromise by sacrificing the

radiating properties of his aerial in order to improve its oscillating properties. He pointed out that Marconi's aerial, while a good radiator, was a poor oscillator, and it was to remedy this defect that Marconi employed the coupled aerial, with one circuit to produce the oscillations and a separate coupled circuit with good radiating properties.

The same patent describes an inductive coupling between the aerial system and a separate coherer circuit, and also describes earth-connected forms of radiators.

No. 29,505 of 1897 describes the benefit to be obtained from exciting a circuit from a supply whose frequency corresponds with the natural frequency of the circuit.

No. 29,069 of 1897 shows a circuit in which one of the balanced halves of the aerial system is replaced by an earth connection, although Lodge later preferred to dispense with an earth in syntonistic circuits as deleterious to tuning on account of the variability of soil resistance.

This patent specification described a metallic box used to screen the coherer from disturbance due to its adjoining transmitter. The send-receive switch could not be put to the "send" position unless the screen was in position. Lodge also described the telephone as being a much more sensitive responder than the inkers which were considered essential for obtaining a record of messages in the earlier days.

In its ultimate form the Lodge-Muirhead system claimed to be unresponsive to wave-lengths  $2\frac{1}{2}$ -5 per cent. removed from that desired, and reliable communication between Burma and the Andaman Islands (300 miles) required less than one horse-power. In 1911 the Lodge-Muirhead patents were acquired by the Marconi Co. and Sir Oliver Lodge became a scientific adviser to that concern.

### **Prof. A. Popoff.**

In 1895 Prof. Popoff used an elevated aerial in a receiving circuit at the Torpedo School, Kronstadt. He connected the receiving circuit, consisting of a coherer, relay, and tapper-back, by means of an insulated wire to an ordinary lightning conductor. He obtained results over a distance of 5 kilometres and also recorded distant lightning discharges with his apparatus.

### **Sir Henry Jackson.**

Captain (afterwards Sir Henry) Jackson commenced experiments in the British Navy in 1895. He employed a conventional coherer method,\* and by 1896 had succeeded in communicating code signals between ships and had noted a fading and subsequent rise in signal strength as the distance between stations increased. His work was quite independent of that of Lodge and Marconi.

### **Dr. Ferdinand Braun.**

A coupled-circuit system of spark telegraphy was developed by Dr. Braun from 1897 onwards. His first patent was dated 1898, and

three years later, in conjunction with the Siemens-Halske concern, he established communication between Cuxhaven and Heligoland. In his patent No. 1862 of 1899, describing a coupled aerial circuit, he did not apparently realize the great advantages to be gained from a loose coupling and tuning the two circuits to the same frequency. In subsequent litigation Marconi's patent of 1900 was upheld in spite of the apparent priority of Braun's patent for a coupled aerial.

### **Prof. Slaby and Count Arco.**

In 1897 Prof. Slaby published a book called "Spark Telegraphy" in Berlin, in which he described successful signalling over distances varying from 3-13 miles. His apparatus was in many ways similar to that of Marconi, of whose experiments he had some knowledge, and also that of Popoff. In conjunction with Count Arco he developed the Slaby-Arco system of telegraphy which later amalgamated with Dr. Braun and Siemens-Halske under the name of "Telefunken."

The joint patents included an electrolytic detector, a damped aerial system and spark gap circuit, and certain coupled circuit arrangements. The latter included Slaby's "Multiplier," whereby two messages could be received at once using only one aerial.

### **Nikola Tesla.**

The contribution of Tesla to the development of radio communication begins with the invention of the Tesla coil, or loose-coupled, air-cored, high frequency transformer. The Tesla coil was devised as a result of work purely on high frequency currents which he commenced in 1882, and was not considered at first in relation to wireless telegraphy.

In 1890 he produced an alternator which would develop 1 kW. at a frequency of 10,000 cycles. In 1896 he patented a synchronous spark discharger, his patent disclosing a clear knowledge of the principle of tuning and a method of adjusting the phase of discharge by altering the position of the stationary electrodes of the gap. Again his device was not invented for radio telegraphy, but in the pursuit of research into high frequency currents. It is interesting to note, however, that his apparatus could have been incorporated without alteration in a spark transmitter and that the Marconi timed disc of 1907, which was widely used, had many points of similarity.

### **R. A. Fessenden.**

Fessenden was one of the earlier workers in the field of wireless communication and radio frequency measurements, and some of his researches are notable for the influence they bore after a lengthy period. Thus he proposed the beat reception of continuous wave signals as early as 1902, before adequate means had been devised to propagate them. He afterwards patented the separate heterodyne method of reception after the introduction of the valve, in 1913. He did valuable work on high frequency measurements and compressed gas condensers, and was one of the pioneers of the high frequency alternator. He



broadcast speech and music, by modulation of the output of a small alternator, in 1906, and also obtained musical spark transmission by means of a rotary discharger independently of Marconi, who also developed such a method.

### Senator G. Marconi.

Prof. Righi of Bologna conducted a number of experiments, subsequent to the work of Hertz, which were described in his treatise "Optice Elettrica." One of his pupils, Guglielmo Marconi, conceived the idea of developing a signalling system which would employ the Hertzian waves. In 1895 he began by constructing an improved type of Branly coherer and placing his radiator and resonator at the focus of parabolic metal reflectors \* (Fig. 12) as used by Hertz. The results he obtained were so encouraging that he was advised to see Sir William Preece, of the British Post Office, while on a visit to Ireland in the following year. At that time Marconi was twenty-two years old. Preece became interested in a demonstration arranged by Marconi in London and encouraged him to continue his experiments with a view to increasing the range of his apparatus.

The first important step was the use of an elevated aerial for transmission as well as for reception (as employed by Popoff). In patent No. 12,039 of 1896 Marconi stated that "the larger the plates of the receiver and transmitter, and *the higher from the earth the plates are suspended*, the greater the distance at which it is possible to communicate at parity with other conditions." He also devised one form of circuit, mentioned in this patent, in which one of the plates was earthed. The advantage of the elevated aerial was conclusively demonstrated in the following year when he was trying to communicate over a distance of 8.7 miles without using reflectors. He was only successful when the height of his aerial was considerably increased. This demonstration was between Lavernock Point and Breamdown, across the Bristol Channel, where Sir W. Preece had conducted previous experiments with his induction system. Marconi used an induction coil giving a 20-in. spark to feed his transmitter, the wavelength employed being about one and a quarter metres. The success of his experiments led him to form the Wireless Telegraph and Signal Company in the same year, with a capital of £100,000.

In 1898 Marconi introduced his "jigger," or oscillation transformer.\* The primary was inserted in the aerial circuit and the secondary was connected to the coherer circuit of the receiver. The newly formed company erected stations for communication between the Isle of Wight and the mainland, the stations being 18 miles apart at first, and later 21 miles. A contract for the supply of shipping information to Lloyd's was obtained and a Dublin newspaper called on Marconi's services to obtain rapid reports of the progress of Kingstown Regatta. The beginnings of commercial radio communication were thereby seen during the year 1898.

The first tuned transmitter to be made by Marconi was constructed in 1899 \* (Fig. 14) after experimental work which began in the preceding

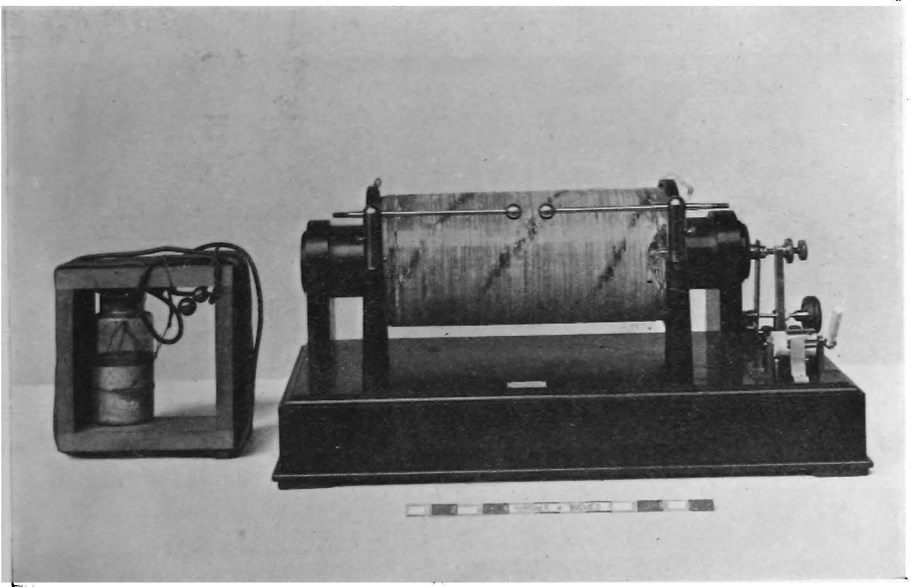
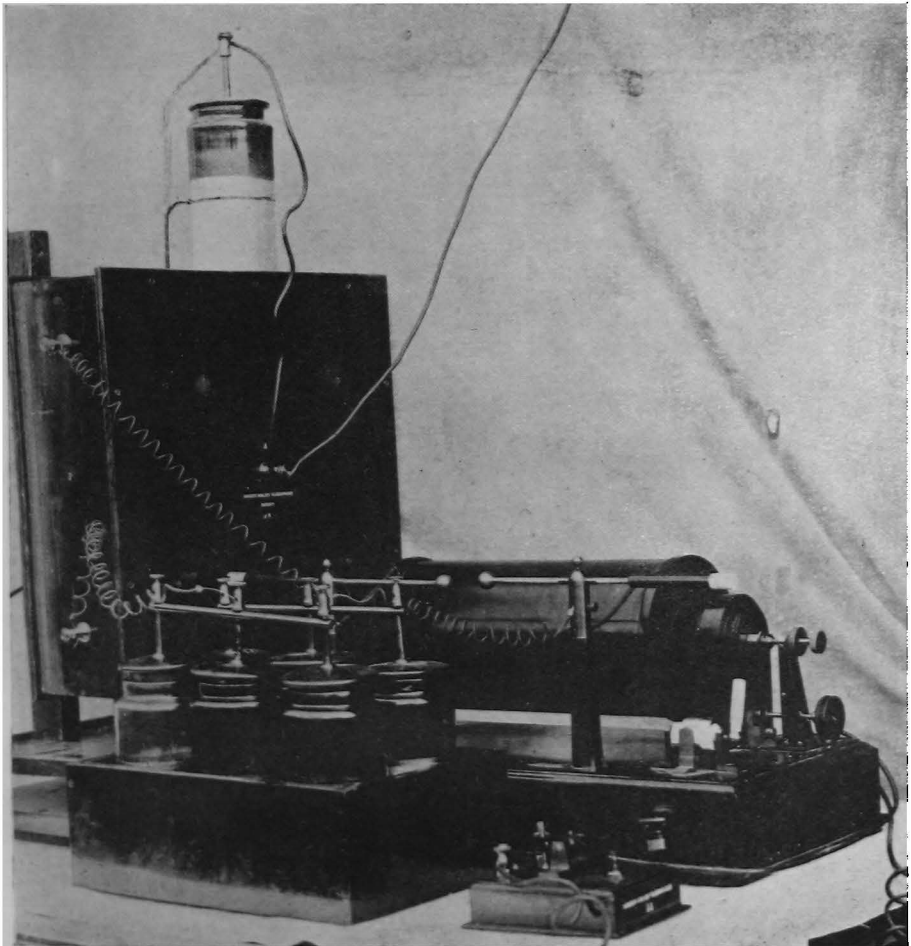
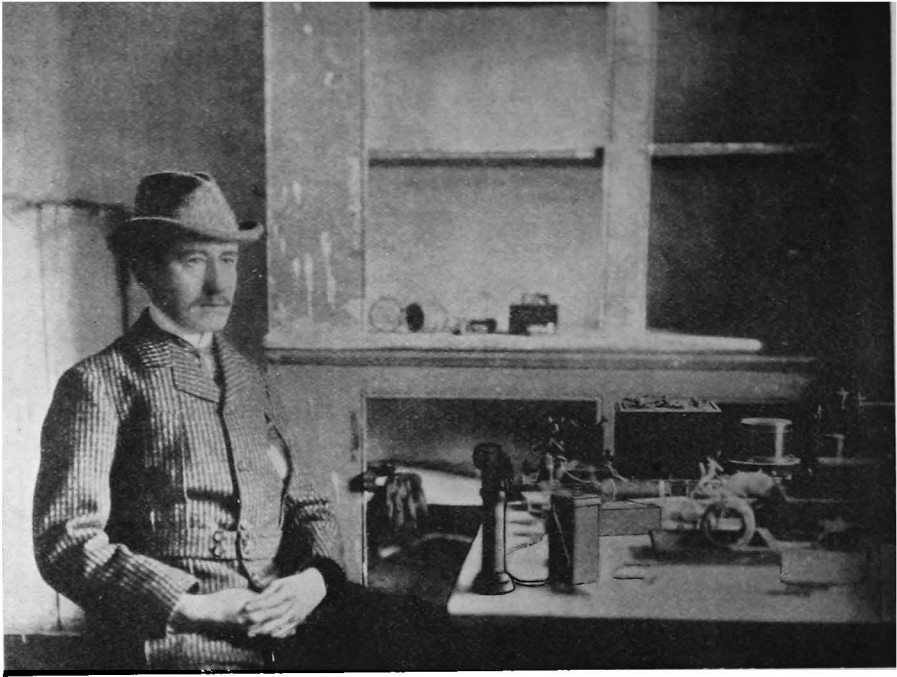


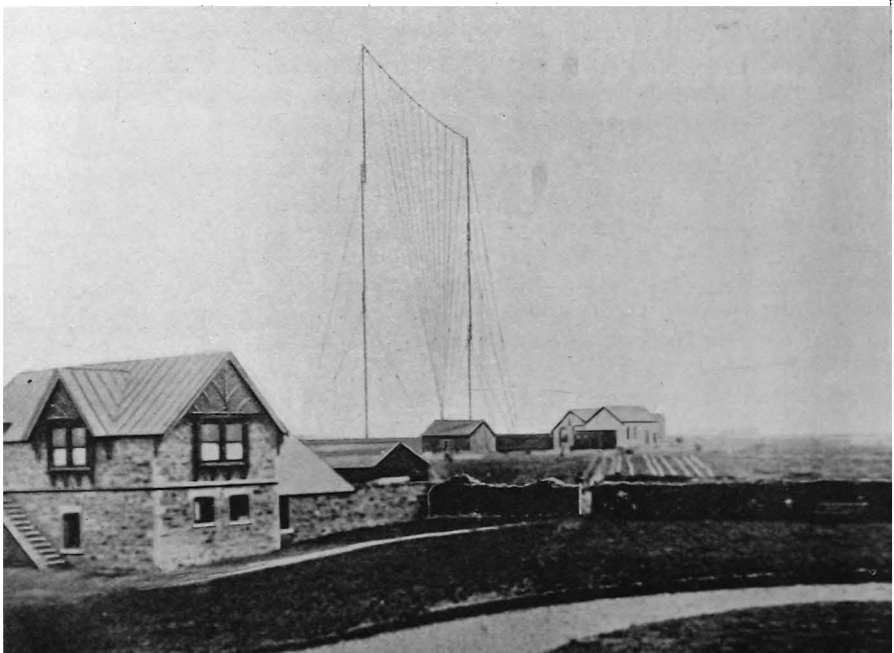
FIG. 14.—Marconi's First Tuned Transmitter, 1899.





[*Marconi's Wireless Telegraph Co., Ltd.*

FIG. 16.—Marconi at Signal Hill, Newfoundland, 1901.



[*Marconi's Wireless Telegraph Co., Ltd.*

FIG. 17.—Poldhu Aerial, 1901.

year. It consisted of an oscillation transformer in the primary of which was a spark gap and condenser while the secondary was connected to an adjustable inductance in the aerial circuit. This transmitter formed the foundation of Marconi's famous patent No. 7777 of 1900, covering the use of improved forms of tuned apparatus without which the spanning of the Atlantic in 1901 would have been impossible. The tuning of four circuits, viz. the spark gap circuit, the transmitter aerial, and the primary and secondary of the receiving transformer, is clearly specified in this patent.

The work of Hertz, in confirming Maxwell's predictions, had established the nature of electromagnetic radiations as being akin to light waves. The popular belief, therefore, was that radio communication was restricted to the optical range. This belief was weakened by the increasing ranges obtained and, in anticipation of an attempt to signal across the Atlantic, Marconi constructed a station at the Lizard, Cornwall, at which he was able to hear signals from St. Catherine's Point in the Isle of Wight, a distance of 198 miles, in 1901. This experiment definitely established that the earth's curvature did not limit signalling to the optical range. Marconi was so encouraged by this result that he commenced, in 1900, to erect a station at Poldhu, Cornwall, and another at Cape Cod, Massachusetts, for trans-Atlantic experiments. His collaborators in the design of these stations were Sir Ambrose Fleming, R. N. Vyvyan, and S. W. Entwistle.

The first aerial at Poldhu was supported by a ring of masts 200 ft. high, but these were blown down by a gale. Two wooden masts 170 ft. high were hastily erected (Fig. 17), and a fanwise aerial consisting of 60 bare copper  $7/22$  wires was strung from a triatic stretched between them. The aerial was not excited by an induction coil, but by a 25-kilowatt 45-cycle alternator charging high voltage condensers through a transformer (Fig. 18).

The results between Poldhu and Cape Cod were not recorded, and were presumably negative, and in November, 1901, the aerial at the Cape Cod station was also blown down. By the middle of November, however, Marconi was able to receive signals from Poldhu at Crookhaven, Southern Ireland, at such great strength that he decided on an immediate trans-Atlantic experiment and chose Newfoundland as the nearest spot for reception. He determined to use kites\* and balloons as a means of suspending a receiving aerial and arranged that the letter "s," three dots, should be transmitted from Poldhu at a certain speed and at certain times during the day.

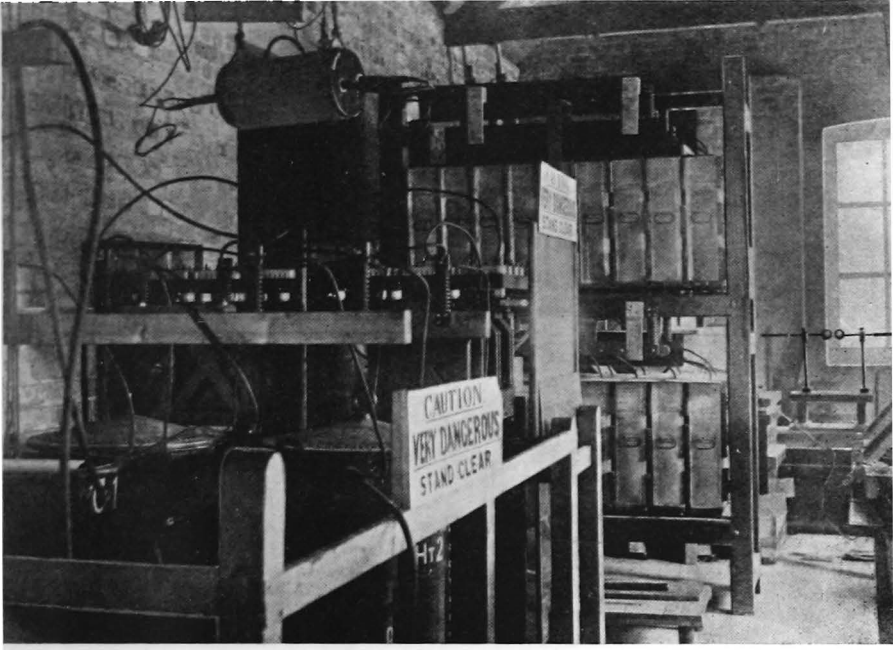
Fleming was left in charge of the arrangements at Poldhu while Marconi sailed with his two assistants, Kemp and Paget, to Newfoundland. There they found balloons unmanageable, but succeeded in flying a kite from which was suspended an aerial consisting of 500 ft. of twin wire. The ear was more sensitive than a recorder, so their receiving circuit consisted of a pair of Collier-Marr telephones\* in a conventional arrangement with a self-restoring coherer.\* On

December 12th, 1901, at 12 p.m., Marconi was able to hear distinctly the three dots being transmitted at intervals from Poldhu (Fig. 16). His assistant also heard them.

His claim was met with considerable scepticism, but three months later complete messages were being recorded on tapes in a ship 1,500 miles from Cornwall and single letters at distances of over 2,000 miles. The commercial development of trans-Atlantic radio communication was still to come. Messages were passed between Poldhu and Cape Cod in 1903, including the first communication to a newspaper on commercial lines, but it was not until the Clifden high-powered station in Ireland and the Glace Bay station near Newfoundland were built that a real commercial service could be started. Clifden, which was commenced in 1905, employed the directional inverted L aerial invented by Marconi in the same year. A limited public trans-Atlantic radio-telegraphic service was commenced in October, 1907.

The aerial systems employed by Marconi in these experiments were such that the wavelength could no longer be in the region of a few metres but had increased to several thousand metres. The Glace Bay station had plant rated at 370 kW., but only about half this power could be used efficiently, and by 1914 the average power used was only 80 kW. Marconi studied the effect of daylight on transmission and gave evidence before the House of Commons Select Committee in 1913 showing that signals were weakest in the morning and evening when darkness only extended partly across the ocean.

The Marconi Co. was responsible for the introduction of many important additions to radio technique, some of which were of Marconi's own invention and others emanating from the highly capable body of assistants which Marconi attracted to work under his direction. The Marconi magnetic detector has already been mentioned, together with the Fleming diode. Fleming was also responsible for the Cymometer,\* an accurate scientific wavemeter introduced in 1904. In 1905 Marconi patented the "inverted L" type aerial, the directional properties of which enabled a radiation about five times that from a plain vertical aerial to be radiated in a certain direction at the expense of the radiation in other directions. The multiple tuner of C. S. Franklin\* (Fig. 29), patented in 1907, enabled greatly increased selectivity to be obtained by using an intermediate tuned circuit between the aerial inductance and a tuned detector circuit. In the same year Marconi patented his high-speed disc discharger\* which enabled what was practically continuous wave telegraphy to be obtained from a succession of spark discharges. Other developments by Marconi and his colleagues are referred to later.



[*Marconi's Wireless Telegraph Co., Ltd*  
FIG. 18.—Transformers, Condensers, and Spark Gap, Poldhu, 1901.

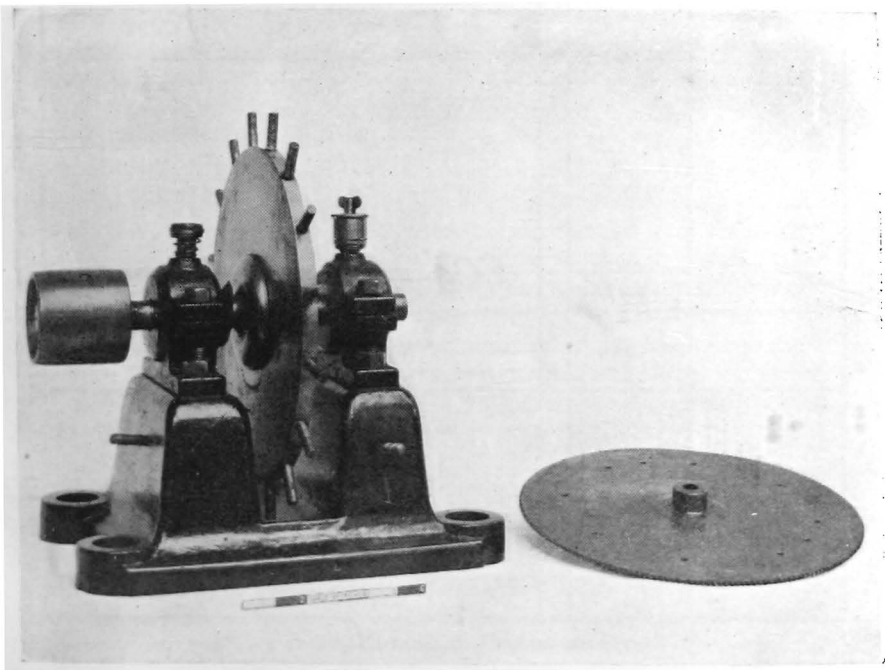


FIG. 19.—Marconi Discs for Musical Spark Transmission, 1906-7.

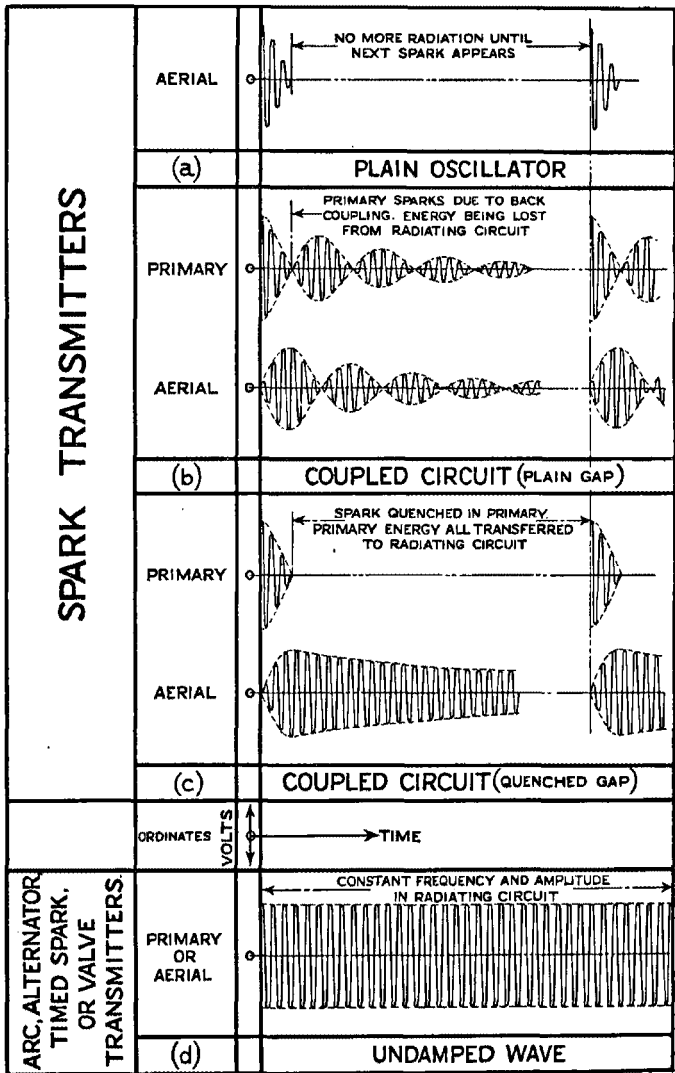


FIG. 20.—Oscillation Diagram.

# THE DEVELOPMENT OF WIRELESS TELEGRAPHY

## WIRELESS TELEGRAPH TRANSMITTING STATIONS

(Pre-Valve)

A short review of the types of transmitter adopted prior to the introduction of the valve is followed by a description of the general trend of development.

Fig. 20 shows, in a general way, the oscillatory conditions set up in transmitters of the various types. The relative areas of the "envelopes" of the curves for the aerial circuits gives a measure of the effective radiation obtainable for a given initial voltage in the primary. It will be seen that the amount of aerial dissipation increases progressively in the various spark circuits up to a maximum for continuous wave transmitters.

### Spark Transmitters. (*Spark, quenched spark, and timed spark.*)

The earliest spark transmitters, such as those of Hertz, employed a simple aerial circuit which included the spark gap. An elevated aerial was found to be the best radiator, but the spark gap in series with it provided a high resistance which led to considerable damping. The wave train at discharge therefore began at a high initial voltage which quickly died away, in a few swings, to zero. After a relatively long interval another spark discharge took place, but in the meantime there was no radiation from the aerial. The radiation power of such a circuit was therefore low.

In the coupled aerial circuit the spark gap was included in a primary circuit and a separately tuned aerial circuit formed the secondary. This latter circuit could be of low resistance so that any oscillations induced in it could persist for a relatively long time before they finally died away. Thus for equivalent radiation compared with the plain aerial the initial voltage might be lower, causing less strain on insulation, while the increased radiation performance demanded less initial power. An additional advantage was that the diffusion covered a narrower wave band.

The energy of the spark was transferred inductively to the aerial circuit, but the advantages described above were considerably lessened if energy was retransferred from aerial to spark circuit after the initial forward energy pulse. There were two main devices for minimizing such undesirable retransference of energy. One was to employ a comparatively loose coupling between primary and secondary. A tight coupling enabled greater efficiency to be obtained provided the spark could not restrike after the first forward energy pulse. On the other hand, with a tight coupling, there was a danger of radiating



two frequencies. A loose coupling increased the time during which the amplitude in the primary remained low. There was therefore an optimum value of coupling where de-ionization of the spark path was given a reasonable time to become effective, without the efficiency being too much impaired. The second device lay in accelerating the de-ionization of the gap after the first pulse in order to build up its resistance to a value which could not be broken down by the reduced potential induced back from the aerial. If the gap did not break down under the induced-back potential no current could flow in the primary circuit and no energy transference could therefore take place. A variety of inventions were introduced to obtain rapid de-ionization of the gap and obtain what was known as a "quenched spark."

In 1892 Elihu Thomson suggested a magnetic blow-out for this purpose, while Tesla, in 1896, patented a rotating disc electrode with which to obtain rapid quenching. Righi had divided the gap at a very early date, and his pupil Marconi elaborated his gap, in 1898, by employing a considerable number of large metal spheres between which were several short gaps in series.\* Later Marconi employed large iron mushroom-shaped electrodes to cool the gap and therefore de-ionize it quickly. Iron or zinc was preferred to copper as the vaporization of the latter tended to leave the gap in a conducting state. Fleming, in 1903, employed a number of water-cooled spheres rotating in a gas-filled chamber.

The "Lepel arc," introduced in 1908, employed a spark gap consisting of two water-cooled copper plates separated by a perforated disc of paper. This was supplied from a D.C. source sufficient normally to break down the very short spark path. The spark frequency, however, was controlled by the constants of the electrical circuits of the apparatus. In 1909 M. Wien of the Telefunken Co. introduced a widely used modification of the Lepel system, employing a quenched gap of special design.\* A series of substantial copper discs, preferably silver-coated and with wide flanges to radiate heat away, were compressed into a pile with intervening mica separators. A perforation at the centre of each mica separator provided a short spark path between each disc, the spark thus being broken up into a number of sections which were quickly cooled and de-ionized after each discharge by reason of the large mass of heat conducting metal surrounding the gaps (Fig. 21).

#### *Musical Spark Transmission.*

Marconi, in 1906-7, conceived the idea of arranging projections around the rim of a rotary disc driven synchronously with the alternator providing the main supply\* (Fig. 19). The spark passed from a stationary electrode across the two gaps in series provided by the intervening disc, to another diametrically opposed stationary electrode. The projections on the disc passed away from the stationary electrodes as they rotated, therefore lengthening the gap and breaking the spark before the next projection came into line. The synchronous drive ensured that fresh projections approached the stationary electrodes

at the correct instant to transmit the next discharge. The result was a succession of "timed" discharges at a definite frequency and was known as "musical spark transmission."

The developed form of this discharger consisted of several wheels coupled together, with the projections on each wheel arranged in mechanical sequence. Each wheel had its own discharge circuit electrically in parallel with the others, the net effect being analogous to a multi-cylinder engine. The interval between a discharge at one wheel and the subsequent discharge at the next wheel was arranged to be exactly equal to one or more oscillation periods of the aerial circuit, so that the successive damped discharges built up into a continuous wave. This system, which was confined by mechanical limitations to very long waves of low frequency, was used in the successful transmission of telegraphy from Carnarvon, Wales, to Sydney, Australia, in 1918. It was possible, but not usual, to employ it for the transmission of speech by modulating the continuous waves produced.

The advantages of the spark system lay in its robustness and durability. Faults could easily be traced and cleared while the signals received were of such a characteristic nature that they could be read even in the presence of considerable parasitic noise. The system in general, however, was wasteful in power, limited in range, and a serious cause of interference owing to the wide waveband covered by each transmitter. The timed spark was more akin to an arc transmitter and did not share these disadvantages to the same extent. The efficiency of an ordinary coupled spark transmitter might be about 10 per cent. The quenched spark might give an efficiency of 50 per cent. or more under the best conditions.

### **Arc Transmitters.**

Spark transmission depends on the production of a succession of oscillatory discharges due to the intermittent breakdown of a spark gap across which a discharge potential is built up. An arc fed from a direct current supply may also be employed to produce electrical oscillations, but the discharge in this case is continuous and the oscillations are not intermittent in character. The arc in itself is not a producer of oscillations, but depends on the employment of its "negative resistance" characteristic in conjunction with an auxiliary shunt circuit containing inductance and capacity.

An arc discharge depends on the state of ionization of the arc path between electrodes. This ionization is influenced by the vaporization of the electrode material, which in turn depends on the heating power of the arc current. A heavy arc current makes a "fatter" discharge which, by its heating power, causes more ionization and reduces the resistance of the arc path. Therefore, when the arc current increases, a smaller voltage across the arc path is sufficient to maintain the discharge. The characteristic of an arc discharge therefore fails to follow Ohm's law and is described as a "negative resistance characteristic" as the volt-ampere curve has a negative slope. It may

be added that an arc fed by a constant applied voltage exhibits great instability unless there is a current limiting resistance in the circuit.

Duddell, in 1900, demonstrated the "musical arc" which was fed from a direct current supply, but produced audible musical sounds of uniform frequency when shunted by an appropriate reactive circuit containing a condenser and inductance. The sounds were due to low frequency electrical oscillations, and it was appreciated that if the frequency of these oscillations could be sufficiently increased they could be adapted to radio communication. Valdemar Poulsen obtained such conditions in 1902. He employed a carbon cathode and a water-cooled copper anode, the electrodes being rotated so that they should wear evenly. They were enclosed in an atmosphere of hydrogen of hydrocarbon and subjected to a strong magnetic field at right angles to the arc path. These modifications increased greatly the slope of the static characteristic of the arc, and the magnetic field ensured that the arc should be extinguished at the correct moment. The magnetic blast tended to blow the arc upwards from the electrode tips and, in addition to stabilising the position of the arc, the series connection of the exciting coils ensured that if the supply current fell the arc was less blown out and therefore shorter. The shorter arc was of lesser resistance and therefore required more current, so that the arrangement was self-regulating.

The action of the Poulsen arc \* may be described with reasonable accuracy without going too deeply into theoretical considerations which may complicate the issue. The arc, as mentioned before, is supplied from a steady direct current potential. Powerful choke coils are inserted in the supply leads so that their considerable electrical inertia prevents rapid alterations in the amount of current drawn from the supply. A tuned electrical circuit consisting of an inductance and condenser in series is placed across the arc when the latter is burning, and a current immediately flows into the condenser. This current cannot come rapidly from the supply because of the retarding action of the choke coils, so it is taken from the arc. The arc current is consequently reduced and the arc voltage rises, as explained before. The increased voltage encourages more current to flow into the condenser which finally becomes charged to such an extent that the current withdrawn from the arc begins to decrease in value. The arc voltage therefore falls, encouraging the further discharge of the condenser through the arc. Finally the condenser becomes so discharged that the discharge current no longer reinforces the arc current to the same extent, and the arc voltage therefore begins to rise again. The constancy of the electrical circuit values ensures that each cycle is a repetition of the one before, the cyclical instability of the circuit giving conditions which enable oscillations of considerable power to be sustained continuously. The frequency of the oscillations depends on the characteristics of the auxiliary circuit across the arc.

The Poulsen arc, in which the arc is extinguished every cycle, may also be regarded as a timed spark with a spark each cycle.

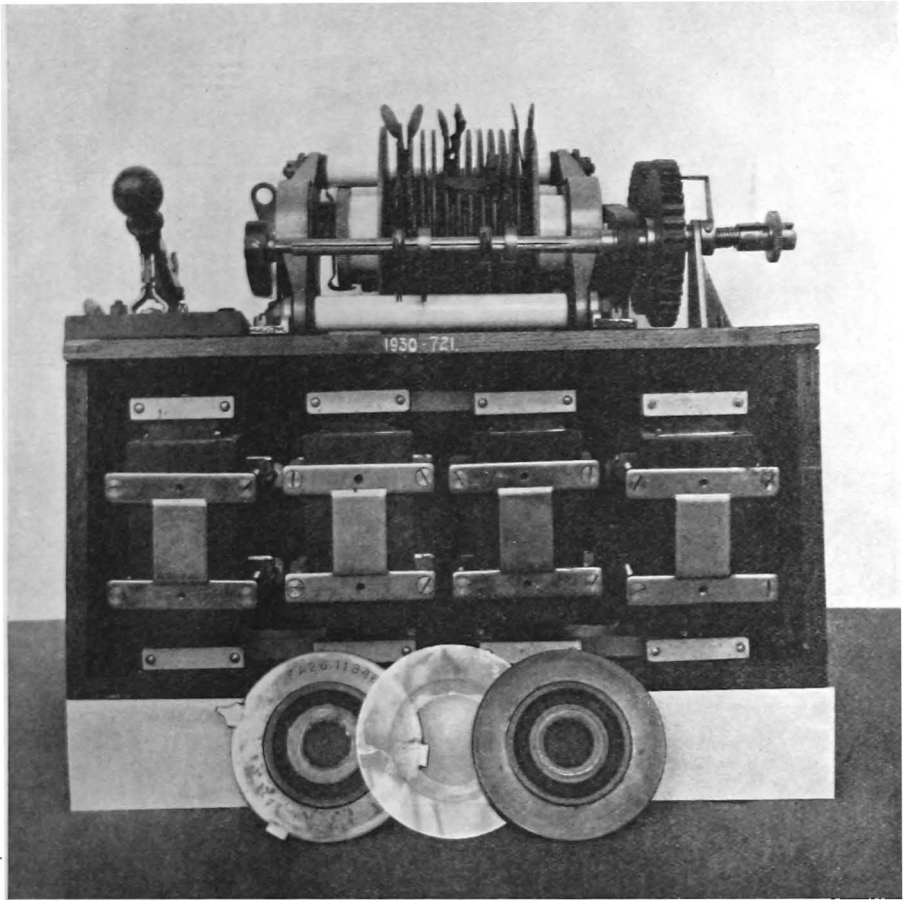


FIG. 21.—Telefunken Spark Gap.

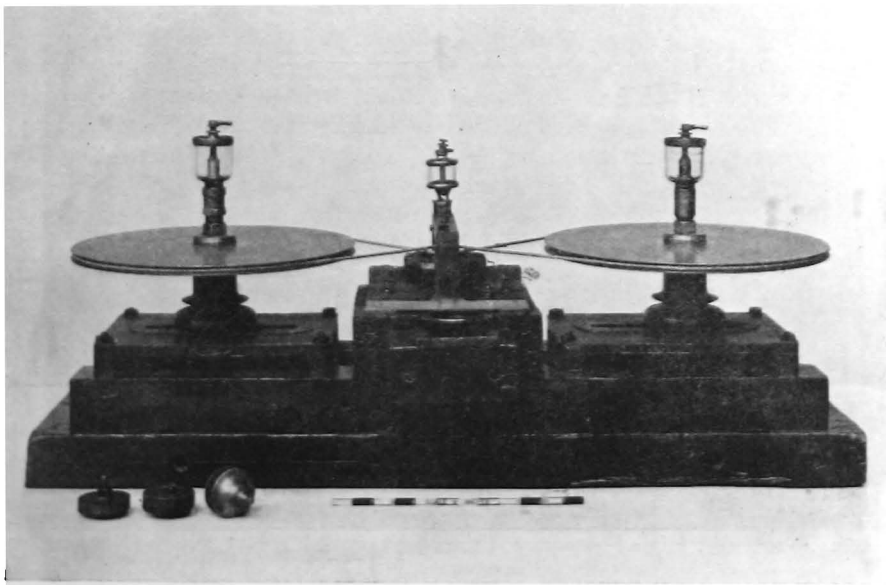
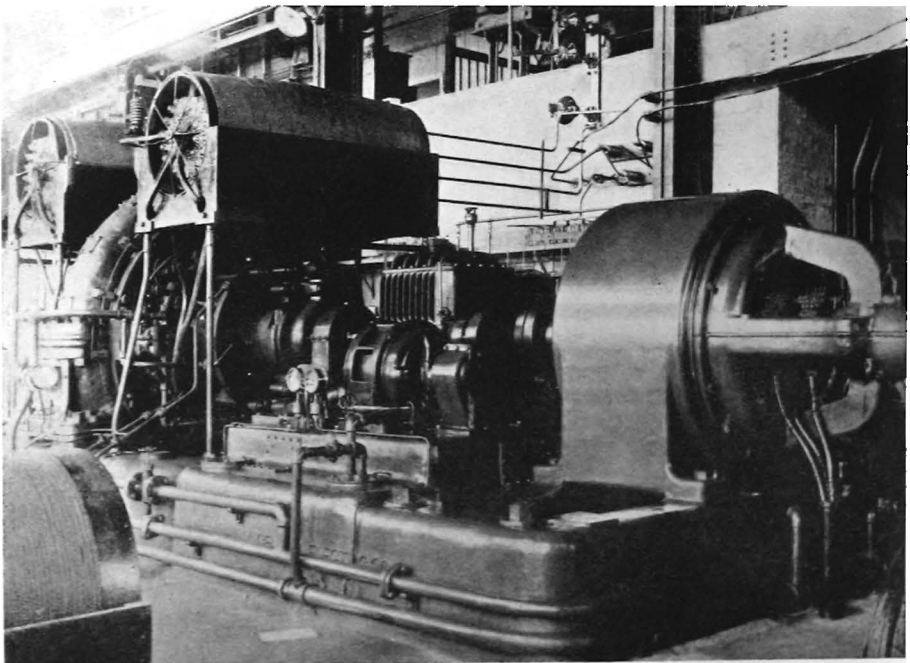


FIG. 22.—Duddell High Frequency Alternator, 1900.



[Federal Telegraph Co., U.S.A.]

FIG. 23.—Poulsen Arc Converter.



[International General Electric Co., Schenectady.]

FIG. 24.—200-kW. High Frequency Alternator installed in Naval Radio Station, New Brunswick, N.J.

The keying of an arc transmitter presents certain difficulties, as any violent disturbance of circuit conditions might lead to instability of a very undesirable kind. There are two principal methods of keying which obviate sudden changes in the arc current.

(a) *Spacing Wave Method.*

The key short circuits an auxiliary aerial coil when depressed. Two distinct wavelengths are therefore emitted, a "marking wave" when the key is depressed and a "spacing wave" when the key is up. The wavelengths may be separated by about 2,000 cycles, a sensitive heterodyne receiver eliminating interference from the spacing wave. The radiation of two wavelengths from one transmitter is obviously an added cause of interference.

(b) *Back-shunt Method.*

Pressing the key changes over from a non-radiating circuit with the same electrical characteristics as the aerial to the aerial circuit. Only one wavelength is transmitted and the arc can be started up without broadcasting, an indication that signals are about to be transmitted.

The continuous oscillations could also be modulated for telephony by means of a microphone, but the range obtainable was severely limited (see "Microphones" and "Speech Transmission").

The arc system shared with the spark system the advantages of robustness, durability, and the easy clearance of faults. In addition large powers could be handled with ease, but high-powered sets were commonly attended by the serious radiation of harmonic frequencies. The arc set was relatively slow to start up after a period of inactivity and considerable care was necessary to avoid obtaining a "bad note" due to variations in the frequency of the oscillations generated. Carbons had commonly to be changed and reground after a period of working as short as half an hour. The arc chamber required frequent attention and the carrying of complete duplicate equipment was desirable. In the largest equipments the field magnets alone might weigh 80 tons (see Fig. 23). Although arc stations rated as high as 3,600 kW. were built and smaller stations became very widely adopted, the Poulsen arc was not ideal as a generator of continuous waves. The efficiency of small arc sets was commonly 15-20 per cent. rising to 50-60 per cent. for the largest types. The use of a dynamo with a rapidly falling characteristic to supply the arc was suggested as a method of reducing the losses involved in working the series resistances necessary to keep the arc stable on a constant voltage source.

### **The High Frequency Alternator.**

The ordinary commercial supply frequency in this country is 50 cycles per second. A two-pole alternator giving an output at this frequency must rotate at 3,000 r.p.m.; a four-pole machine rotates at 1,500 r.p.m.; eight-pole, 750 r.p.m.; etc. A frequency of 100,000 cycles per second corresponds to a wavelength of 3,000 metres, and a machine to generate at this frequency would obviously require a great number of poles if it

was to rotate at a reasonable speed. At a speed of 20,000 r.p.m. it would require 300 poles. The diameter of a rotor at such a speed is limited on account of the tremendous centrifugal forces involved. The crowding of 300 poles round a small diameter is a difficult business, and the output power obtainable depends on the amount of copper which can be accommodated. In addition, the hysteresis and eddy current losses in iron assume alarming proportions as the frequency rises, and are very carefully considered even by the designers of ordinary 50-cycle alternators. Thus the direct generation of high frequency oscillations for radio purposes presented a formidable problem to the machine designer. The problem was complicated by the necessity for extremely accurate workmanship. It was stated that an error 1 part in 1,000 in the alignment of the slots in a Goldschmidt machine might reduce the output by 25 per cent.

Duddell, in 1900, drove an inductor disc carrying 204 teeth at 35,000 r.p.m. and thereby obtained an output of 0.1 amp., 2 volts, at 120,000 cycles per second\* (Fig. 22). Fessenden also had inductor alternators built, and with one alternator, completed in 1906, transmitted clear speech and music by modulating its 80,000-cycle output.

Alexanderson, in 1908, constructed a high frequency alternator giving an output of 2 kW. and his designs were a great improvement on earlier types. As an example of the difficulties encountered, a machine for 100,000 cycles running at 20,000 r.p.m. provided an allowable width of only 3.2 mm. for each pair of coils and their insulation, the rotor diameter being 30 cm. The centrifugal force at the rim was tremendous, being about 2 tons for every ounce of metal at a rim speed of 300 metres per second. The use of the inductor principle, however, enabled the rotor to be an unwound steel disc, both field and armature windings being on the stationary frame. The windings were so designed that the number of armature slots needed was only two-thirds the number of poles, thus allowing more space for insulation and copper.\* The homopolar alternator was also built in France to the designs of Latour and Bethenod.

Another type of high frequency alternator of radically different design was patented by Goldschmidt in 1909. He obtained a double frequency current by induction back from rotor to stator and, by means of two auxiliary tuned rotor and stator windings, doubled this double frequency. Direct current was supplied to the stator of his machine and the rotor and stator circuits, main and auxiliary, were tuned to resonance for the particular multiple frequency to which they must respond. The amplitudes of the various frequencies depended on the tightness of the magnetic coupling between rotor and stator circuits. The air gap was therefore kept exceedingly small, as low as 0.08 cm. on a 100-kW. machine in which the 5-ton rotor was 125 cm. in diameter.

The maintenance of high frequency alternator installations called for expert supervision, and their mechanical delicacy was such that they were confined to land stations where they would not be subjected to excessive vibration. The initial cost was high and they were not

readily adaptable to changed wavelengths when once installed. They provided, however, a very pure wave free from harmonics, were easy to key, and were suitable for telephony. A speed variation of 0.5 per cent. might mean a loss of 40 per cent. in radiated power so that control within 0.01 per cent. was common. The radiation efficiency, however, was greater than that of an arc set employing "spacing coil" keying and they were capable of higher signalling speeds (100 words per minute compared with 60 for arc sets). The difficulties of design made 200,000 cycles the highest frequency reached with Alexanderson machines, and wavelengths of 15,000-20,000 metres were not uncommonly employed. This compares with the 4,000-6,000 metres common to arc stations.

The employment of external static frequency multiplying circuits reduced the necessity for generating very high frequencies. A few particulars may be given of some of the later high frequency alternator installations.

Nauen: 400-kW. Alexanderson 6,000-cycle machine. 1,200 amps., 450 volts, 1,500 r.p.m. operating through three external frequency doubling stages to 48,000 cycles.

New Brunswick: 200-kw. Alexanderson 25,000-cycle machines (Fig. 24).

Eilvese: Goldschmidt alternators, 1918. Aerial power 160 kW., 7,500 metres wavelength. Machines have 384 poles and run at 3,130 r.p.m., 76 per cent. efficiency.

Paris: 500-kW. alternators of French design.

Many of the largest stations, just before the war of 1914-18 and for some time afterwards, were equipped for direct generation by high frequency alternators. Even as late as 1922 the high frequency alternator was still being installed. It was claimed that a 500-kW. alternator had an efficiency of 84 per cent. and a 250-kW. alternator 79 per cent. at 15,000 cycles.

### Frequency Multiplication.

The difficulty of generating directly at very high frequencies drew attention to the possibility of employing external circuits from which multiple frequency components could be drawn. As early as 1898 a frequency doubling circuit was devised by Zenneck who employed rectifying cells in a circuit very similar to that later devised for frequency doubling with thermionic valve rectifiers. Many other investigators, including Joly (1911), Epstein (1902), Leonard and Weber (1906), Plohl, and Taylor, devised methods of raising the generated frequency. One of the more widely applied systems was developed by Count von Arco and Meissner of the Telefunken Co. from the early device invented by Epstein, of the Lahmeyer Co., in 1902, and subsequently improved by Joly and Valouri. Two iron-cored transformers are excited from a common direct current source, but in opposite directions, up to the point where the iron is saturated. On the application of an alternating



current to both transformers one will increase in saturation while the other decreases, and vice versa. The saturated core thus varies only slightly in flux while the other behaves as an unsaturated core during each half cycle. Two secondary windings are connected so that the corresponding voltages induced in each winding are subtracted from one another. The two distorted voltage curves produce a resultant which, if the direct and alternating primary currents are correctly related, is a pure sine wave of double the original frequency. M. Kujerai, in Japan, also developed a commercial system on the same general principle.

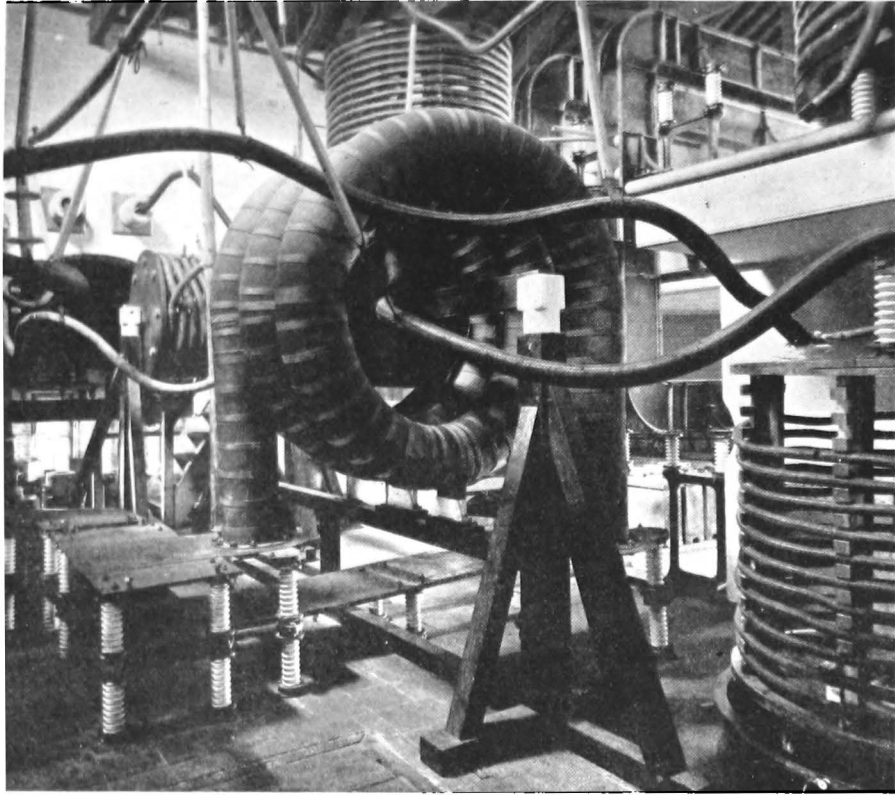
The Telefunken Co. claimed an efficiency of 85 per cent. for one multiplication and 60 per cent. for a double transformation to four times the original frequency. Tuned resonant circuits limit the appropriate frequencies only to that part of the circuit where they are required to be active. This is an important requirement if a reasonable efficiency is to be obtained.

The system devised by A. M. Taylor employed a complicated system of delta connected chokes, in which the separate cores became saturated early in each cycle, and a transformer carrying three primaries in series with each choke, the common core of which never became saturated. The resultant distortion was such that a triple frequency current could be obtained from a three-phase supply. A low frequency efficiency of 86 per cent. was claimed for a 28-kW. installation, but at radio frequencies this probably fell to 30 per cent. or less.

All these systems became rapidly obsolete after the development of the high-powered thermionic valve, but the construction of an alternator to give, say, 6,000-10,000 cycles was so much simpler than the construction of a machine to give four times the frequency that the effect on the initial cost was sufficient to make external frequency multiplication a considerable factor towards the more extensive adoption of the high frequency alternator.

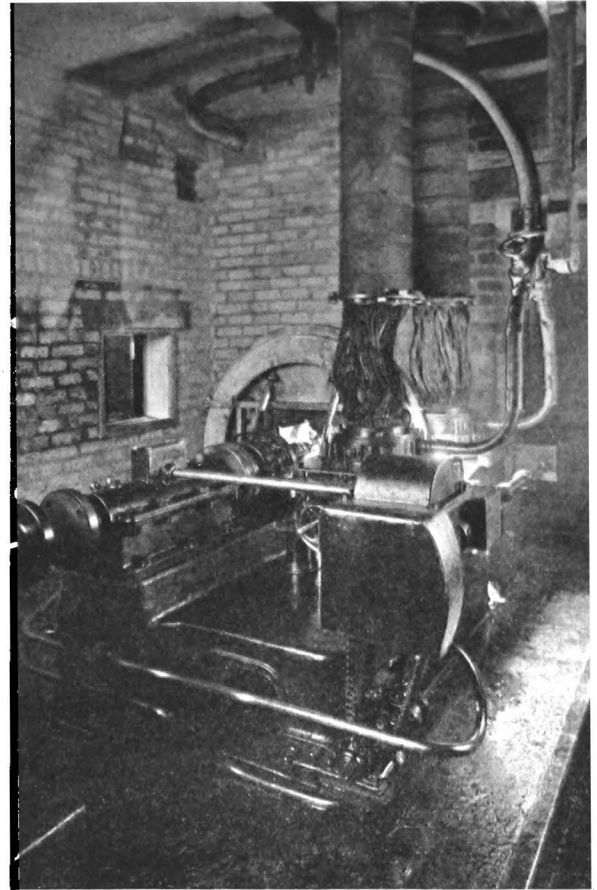
## REVIEW OF PROGRESS UP TO 1919

The relation between the various systems just described in furthering the art of radio communication is difficult to assess. Marconi achieved trans-Atlantic signalling on a commercial basis with relatively crude apparatus, his early stations having been described. The later refinements introduced by Marconi and others did not increase the range of communication by any spectacular amount, but the increase in efficiency and reliability was extremely valuable economically. Efficiency was improved as regards radiation, reception, and speed of signalling, but the factors producing such improvements were extraordinarily diverse.



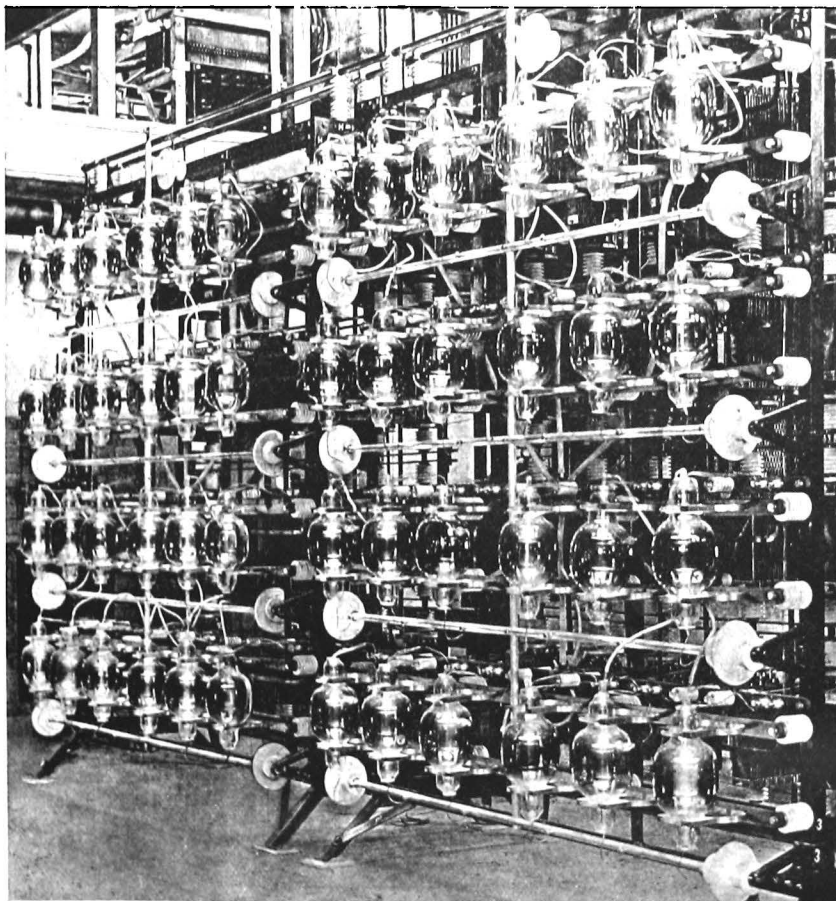
[Marconi's Wireless Telegraph Co., Ltd.]

FIG. 25.—Jigger for Synchronous A.C. Set, Carnarvon, 1919.



[Marconi's Wireless Telegraph Co., Ltd.]

FIG. 26.—C.W. Disc, Carnarvon, 1919.



[Marconi's Wireless Telegraph Co., Ltd.  
FIG. 27.—48-valve Transmitter Panel, Carnarvon, 1921.

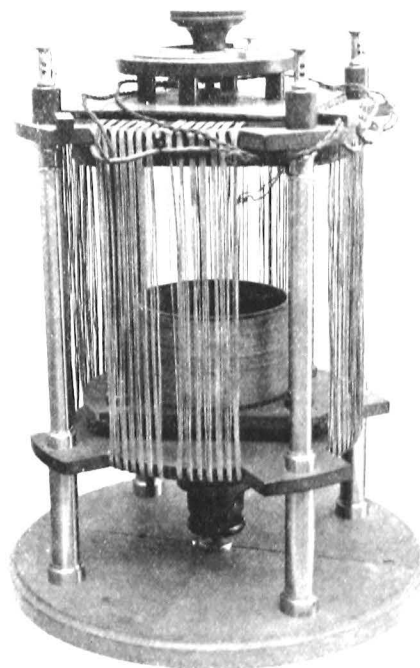


FIG. 28.—Original Bellini-Tosi Radiogoniometer.

The spark and quenched spark became obsolete for all but the smallest stations, and the more general adoption of continuous wave transmission just prior to the war of 1914 provided a noticeable feature in the employment of a musical note in the telephones. It was claimed that this made reception easier, particularly when there were atmospheric conditions about; that the principle of acoustic resonance could be employed; and that (Arco, 1910) duplex reception was possible on one wavelength. The abandonment of the coherer and inker in favour of the telephone was definitely made by the Marconi Co. and the Telefunken Co. about 1903. Prior to this the printed record was considered essential, although both Lodge and Marconi had employed telephones in isolated experiments. The telephone was more discriminative and made accurate tuning easier. The Marconi Co. used the telephone extensively in conjunction with the magnetic detector, and the Telefunken Co. with the Schlömilch electrolytic detector.

The timed spark, the arc, and the high frequency alternator provided means of obtaining continuous wave transmission. The thermionic triode was so limited in power prior to the invention of the copper-glass seal and water-cooled anode, that even in 1920 it was only used as an oscillation generator in the smaller transmitters. Its application to the receiver, and particularly for heterodyning, stimulated the increasing use of the other known methods of producing continuous waves. By 1919 there were twelve stations capable of transmitting telegraph messages on a regular inter-Continental basis. The timed spark was employed at Carnarvon, from which signals were transmitted to Sydney, Australia, in 1918 (Figs. 25, 26). It was also used at the Norwegian trans-Atlantic station at Stavanger. In 1920 a 1,000-kW. arc set was being installed at Bordeaux and a considerable proportion of the trans-Atlantic radio-telegraphic traffic was handled by Poulsen sets of large capacity installed in previous years. The pioneer Nauen stations had a range of 4,000-5,000 miles and used both arc and high frequency alternator sets. New Brunswick employed Alexanderson alternators, and Goldschmidt machines were installed at Eilvese. Paris Radio Central had three 500-kW. machines of Latour-Bethnod homopolar design and could conduct two separate transmissions simultaneously, sending 12,000 words per hour.

The desiderata for long range transmission were held to be an aerial 400 ft. or more in height, of 0.01-0.05 microfarad capacity, supplied with at least 100-300 kW., and a frequency of from 15,000-25,000 cycles per second.

The efficiency of large-timed spark sets might be about 50 per cent.; of arc sets (the rating was the D.C. input) about 30-50 per cent.; of alternator sets 60 per cent. or even much more, falling to very low efficiencies for the smaller sizes. The probable efficiency of static frequency changers had already been indicated although the occasional practice of quoting their efficiencies at low frequencies makes reliable estimation difficult. Many values were given without

full information as to how the efficiency was computed, and some figures of about 85 per cent. for a triple frequency change may well have represented under 30 per cent. at radio frequencies.

Small power sets, such as those used in ship installations, which formed the great majority of the number of telegraphic stations, were mainly quenched spark or arc, with the oscillating valve in the process of adoption in some of the newer installations from 1916 onwards. Arc sets of 20-30 kW. were common in the larger ships. By the end of 1913 there were nearly 4,000 licensed radio telegraph stations, including ship stations, in the world. This number had increased to 5,821 ship stations and 802 land stations in 1919.

### Aerial Design.

One way in which the efficiency of telegraphic transmission was improved was in the design of better aerials. The fan aerial of Marconi's first large stations was a good radiator but expensive to construct. In 1905 Marconi discovered the directional properties of the inverted L type aerial and directional aerials were employed by many stations. The Clifden Marconi trans-Atlantic station had an inverted L aerial supported by 30 masts nearly 200 ft. high between which 200 parallel wires were stretched over an area 6,500 ft. long by 1,100 ft. wide. The natural wavelength of this antenna was about 4,000 metres. The length of the transmitting aerial was later reduced and a separate receiving aerial with only two parallel wires was employed. The Marconi Co. also patented an aerial wire of small high frequency resistance due to the reduction of skin effect by employing bronze wires woven over a flexible non-conducting core. The increased diameter of this wire also reduced "brushing."

The umbrella aerial, used at an early date in the Lodge-Muirhead telegraph system, was a good radiator of a non-directional type. Its radiating power depended on the degree to which the "umbrella" was open and it therefore required a large area for erection, but the cost was not great. The umbrella aerial at Nauen was originally 330 ft. high in 1910, but this height was later increased to 900 ft. That at Funabashi, in Japan, was 650 ft. high with the tips of the umbrella supported by a ring of smaller masts.

The efficiency of radiation was recognized as being dependent on the proper earthing of the aerial system and elaborate earthing methods were employed in the larger stations. Where the earth was particularly non-conducting the "multiple tuned" aerial could be used, consisting of an aerial connected at intervals to ground through separate tuning inductances. The New Brunswick trans-Atlantic station was built on a sandbank, and here the aerial resistance, at 13,600 metres, was reduced from 3.8 ohms to 0.5 ohm by using six independent tuned antennæ. The radiation efficiency rose from 2.6-14 per cent. By regulating the phase displacement between the feeds to each aerial section, directive radiation could be obtained. The multiple tuned aerial was patented by the American General Electric Co. in 1919.

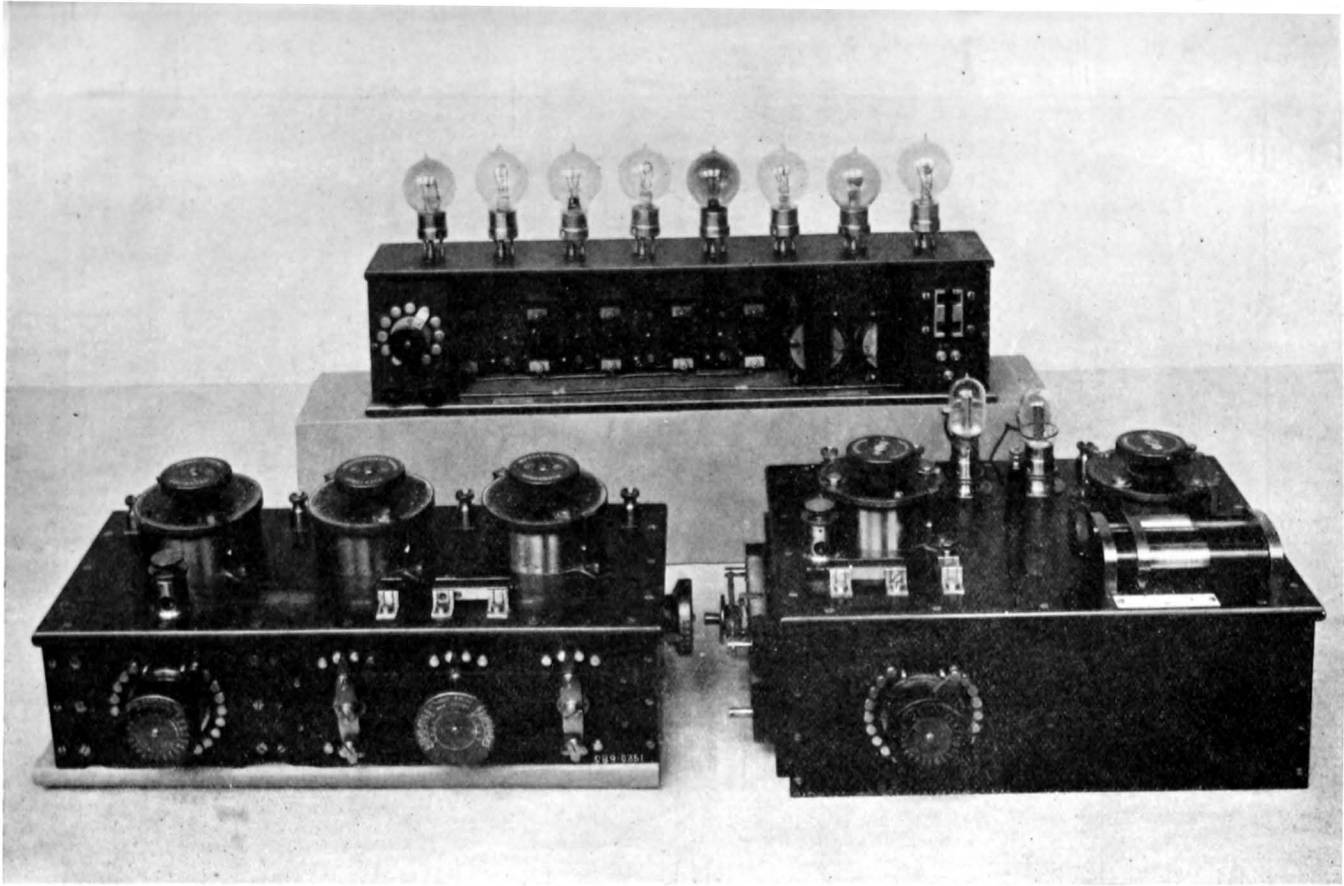
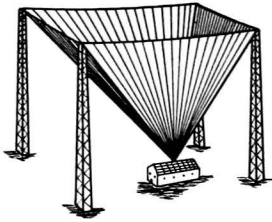
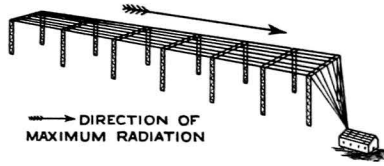


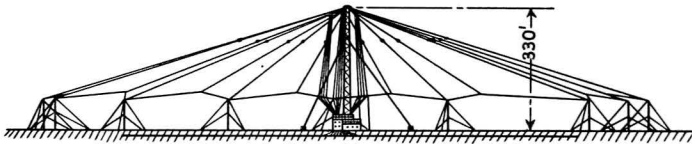
FIG. 29.—French 8-valve Detector-Amplifier (ca. 1917). (5 H.F. resistance-capacity, detector, and 2 L.F. transformer coupled stages.) Marconi Multiple-Tuned Receiver for Use with Magnetic Detector (patented 1907). Marconi Multiple-Tuned Receiver Employing Fleming Diodes.



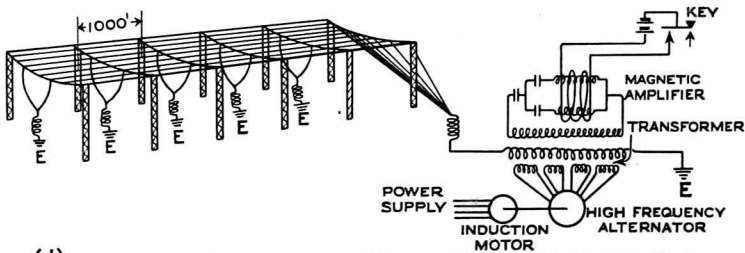
(a). POLDHU AERIAL, 1901



(b) INVERTED "L" AERIAL, 1905



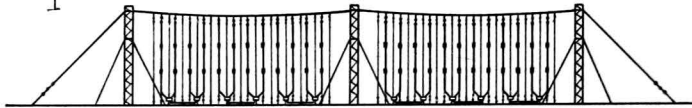
(c). UMBRELLA AERIAL AT NAUEN, 1910



(d) MULTIPLE TUNED ANTENNA AND TRANSMITTER, 1919  
NEW BRUNSWICK TRANSATLANTIC STATION



(e) VERTICAL AERIAL WITH  
PARABOLIC REFLECTOR, POLDHU, 1923



(f). BEAM AERIAL ARRAY AND REFLECTOR, BODMIN, 1926  
(THE THIN WIRES ARE THE REFLECTOR WIRES MOUNTED AT THE REAR)

FIG 30 TRANSMITTER AERIALS

The importance of a low resistance earth is obviated by using a "capacity earth" or counterpoise, first introduced by Lodge in 1897. A network of wires is arranged parallel and close to the ground, but insulated from it, thereby forming one of the plates of a condenser. It must be close to the ground in order not to reduce appreciably the effective height of the aerial, and, provided insulation is good, the results obtained may be superior to the direct earth owing to the better distribution of the earth currents.

A number of aeriels are illustrated in Fig. 30.

## Reception.

The efficiency of reception was also the subject of continuous improvement with the introduction of better detectors, more sensitive relays and recorders, and improved telephones. The spark system and the continuous wave system of telegraphy were not distinguishable from each other by any really outstanding advantages at first. The Poulsen arc of 1902 theoretically made sharper tuning possible, but it was not for many years that the arc could be controlled to a degree suitable for working with such highly tuned apparatus.

Spark telegraphy was received in the later years, and prior to 1913, mainly by circuits including crystal detectors or two-electrode valves. Continuous wave signals required the Tikker or Tone Wheel for elucidation. It was claimed, but not with any outstanding force of argument, that musical note reception of continuous wave signals was very superior to other methods for acoustic reasons. The advent of the triode, in the form of the Audion and the Lieben-Reisz relay, gave to continuous wave methods a great impetus. It has been described in the paragraph on the Pedersen Tikker how the reception of continuous wave signals required the production of an audible frequency from the incoming radio frequency oscillations. If oscillations at two different radio frequencies are made to interact they produce a "beat frequency" depending on the difference between them. If the radio frequencies are sufficiently near together the beat frequency will be audible. The production of a local radio frequency to interact with the incoming frequency is known as heterodyne reception and was first proposed by Fessenden in 1902. The triode was not only a manageable producer of such heterodyne oscillations but could also be used as an amplifier. These facts in favour of the triode received general appreciation from 1913 onwards, and the valve was applied to reception for years before its influence was felt to any considerable extent in its application to transmission. The development of high power amplifiers not only enabled reception of weak signals to be undertaken but also, in conjunction with relatively small frame aeriels, enabled more advantage to be taken of the freedom from interference obtainable by directional reception. The directional properties of electromagnetic radiations, demonstrated by Hertz, was also applied to direction finding by ships, aeroplanes, etc.



## Circuits for Reducing Interference.

Directional transmission and reception, as well as being economically advantageous in many cases, involved a reduction in the amount of interference between stations. A number of receiving circuits were also devised to reduce the interference caused by atmospherics.

Marconi, in 1904, used three acceptor circuits in series to reduce the serious jamming from other stations experienced near New York. The inductances of the circuits were tapped to earth at nodal points for the wavelength desired, the result being that signals on wavelengths other than the particular one for which the circuit was designed suffered a considerable reduction in strength. This "triple-node X-stopper," as it was called, was found to be very effective. Fessenden designed a circuit with which similar effects were obtainable. There were two equal parallel paths, one tuned and the other mistuned. Atmospherics or unwanted signals divided between the two paths, but the wanted signal passed to the detector through the acceptor circuit. Other systems relied on a rejector circuit having a low impedance mistuned path for the unwanted signals. The Marconi Co. patented the use of two detectors in opposition, one adjusted for sensitivity and the other insensitive. The insensitive detector had little effect except on strong signals or atmospherics, for which its rectification would be almost as good as the opposed sensitive detector. In such cases the net effect on the telephones would be weak, the device acting as a current limiter. The Germans, during the war of 1914-18, designed double grid thermionic valves with a current-limiting action. A circuit containing two triodes could also be arranged as a current limiter.

In 1916 an underground antenna method of reception was perfected by J. H. Rogers. He buried a highly insulated wire in the ground below permanent water level and claimed that on wavelengths of 6,000 metres the signals obtainable were equal to those on a 100-ft. overhead aerial. On shorter waves, however, the underground antenna was very inefficient. It was found that under suitable conditions the underground system was subject only to about 30-50 per cent. of the static experienced with overhead aerials, that it was highly directional, and that it was cheaply installed relative to towers. A similar system was applicable to submarines.

A number of receiving circuits were devised on the balance system. The Taylor balance employed a loop aerial balanced against an underground wire. The theory was that the strays in the loop substantially balanced out those in the wire and a reduction in static was certainly claimed for the device when properly adjusted. The Weagant system balanced two loops extending a quarter wavelength in each direction away from a three-winding transformer. The strays in each loop are substantially out of phase and tend to balance out, while the wanted signals are additive owing to the dimensions of the system.

In the Fabbri system, used by the U.S. Navy in trans-Atlantic reception, a single six-turn loop was divided into two three-turn aerials, a variable capacity being in series with one half and an inductance in

series with the other half. The net effect was a system in which balance or out-of-phase effects could be obtained by adjustment.

The Alexanderson barrage receiver enabled reception to be efficiently undertaken from one station only, and for signals from another known direction of interference to be considerably suppressed. Two wires, a quarter wavelength long, were laid in or on the ground, or elevated. Both were highly insulated and one pointed to the desired station and the other to the direction in which it was desired to eliminate interference. The greater the deviation of this latter direction from the line of the other wire, the less was the effectiveness of the barrage. The two lines were connected through transformers to earth, the secondaries of the transformers being connected in opposition through two bridge circuits arranged for phase rotation to a desired amount before transferring the balance inputs to the detector.

Balanced systems of varying complexity were devised by many others, and the best tribute to their merits lies in the fact of their very extensive use in practice. The period 1916-19 was one of great activity in this direction.

### Directional Signalling.

Hertz employed parabolic reflectors to direct the very short waves he produced. Marconi also used similar apparatus in his earlier commercial demonstrations. Later, with the earthed vertical aerial, he showed that the longer waves gave an increased range of signalling and for some time range, and not direction, remained of paramount importance. Wavelengths increased until frequencies not far removed from the upper audible limit were reached. Directional systems employing reflectors were handicapped and in many cases prohibited by the physical dimensions necessary to obtain a reflector for long waves. Research into such systems was thus limited to wavelengths of the order of a few metres which could not at the time be produced at high powers and appeared to be subject to rapid attenuation.

There were, however, developments in aerial systems which were practically independent of physical dimensions in their directional properties. The single-loop frame aerial was employed by Fessenden in 1899 to estimate the direction of incoming signals from their varying intensity as the loop was rotated. Such aerials also reduced interference from other stations not on the same line of direction as the one being received, but the single loop, prior to the introduction of amplification methods, was insensitive. In the same year a directive transmitting aerial was patented by S. G. Brown which depended on the principle of interference. Braun, in 1906, developed this idea into a proposition to use three vertical aerials at equal distances from each other, so spaced and fed with correctly phased currents that their effect was additive in one direction and annulative in other directions.

Marconi, in 1905, demonstrated the directional properties of the inverted L aerial which has been described.

One of the most widely used directive systems began with the 1907 patent of Bellini and Tosi \* (Fig. 28). It was applicable to both transmission and reception, the arrangements being as follows :—

In transmission a plain vertical aerial was erected along the common axis of two triangular aerials mechanically at right angles. The plain aerial was connected to a coil pivoted within two other coils at right angles to each other. The latter coils were connected to the triangular aerials and the former to the oscillatory supply. The resultant currents in these circuits interacted to distort the polar curve of radiation into a form which gave a maximum along the plane of the pivoted coil. Rotation of the latter therefore rotated the plane of maximum radiation.

In reception two aerials and inductances were mounted mechanically at right angles in a similar combination. Within the inductances lay a third pivoted coil connected in a detector circuit. The displacement of the axis of this latter coil relative to the incoming signals gave positions of maximum and minimum signal strength which indicated the direction from which they emanated. In 1912 the closed loop aerial was introduced into this system by C. E. Prince, with improved results.

The transmitting system was not used very extensively although stations with aerials 48 metres high with 60-metre sides were installed at the harbours of Dieppe, Havre, Barfleur, etc. In reception, however, the position of a ship could be obtained by taking two bearings, if the distance between the two land stations was known. Deviations, night effects, and the difficulty of estimating precisely the exact position of minimum signal (which was easier to judge than the maximum) gave the bearings an accuracy not usually greater than about  $0.5^\circ$ . Most observations were required within about 100 miles from the land stations although bearings up to distances of 300–400 miles were useful to a practicable degree. The direction and to some extent (depending on the skill and experience of the operator), the order of distance of another vessel could be obtained if direction finding equipment were installed on a ship. The value of such information might be considerable during foggy weather.

The Bellini-Tosi system was developed by the Marconi Co. who obtained control of the original patents. The triangular aerials employed in the early transmitters were also developed by Artom, who found that two slant wires forming the sides of an isosceles triangle, insulated from each other at the apex and fed from a coil joining the lower ends, formed a combination with marked directional properties. The Artom aerial was further developed, in conjunction with Meissner in 1912, as the "Telefunken compass." Marconi, in 1906, had patented an idea for a "radio lighthouse" and the Telefunken compass fulfilled much the same purpose. A number of triangular Artom aerials were arranged symmetrically around a circle and were surmounted by a non-directional umbrella aerial. A starting signal was given from the latter and then each of the directional aerials was excited in sequence. An operator wishing to know the direction in which the lighthouse lay pressed a specially engraved stop-watch on

receiving the starting signal and stopped it when the succeeding signals were of minimum intensity. The stop-watch then gave him the required bearing, the accuracy usually being within  $4-5^{\circ}$  as a result of averaging a number of readings.

The Bellini-Tosi system was also modified by Capt. J. Robinson in a system designed during the war of 1914-18 for use in aeroplanes. Owing to the difficulty of estimating the position of minimum signal in a noisy cockpit, two rotating frames, rigidly fixed at right angles, were used. The D.F. bearing for maximum signal was first obtained on one frame, and succeeding attempts were made until the switching in of the second frame did not affect the signal intensity. The first frame was then judged to be correctly set and its position was read off to give the bearing. During the tests with the first frame a balance coil with exactly the same inductive effect as the second frame, but which could not pick up signals, was included in circuit.

The sense of direction obtained by these methods is liable to a  $180^{\circ}$  error which may be overcome by employing a vertical aerial as well, with a coupling inductance and earth key. The vector addition of the polar curves for the vertical aerial and the frame gives a maximum in the true direction. The effect of switching in the vertical aerial on signal strength denotes which of the two maximum positions of the goniometer coil is the true indicator of direction. Bellini and Tosi, in a patent of 1909, pointed out that it was possible to discover the sense of directionally received signals.

In 1916 Marconi began experiments in Italy on waves of 2-3 metres for use in military signalling. The solid metal reflectors, used in his pioneer experiments with similar wavelengths twenty years before, were replaced by tuned reflector wires arranged on a cylindrical parabola with the aerial at the focus. In association with C. S. Franklin he obtained results over about 6 miles and in the following year resumed his researches at Carnarvon. In 1919, when using valve equipment, a wavelength of 15 metres was selected. The size of reflectors for such wavelengths becomes very considerable. These researches into directional propagation and reception marked the beginnings of a series of developments which culminated in the establishment of an Empire short wave beam signalling system and the design of efficient beam aerial arrays. These developments are referred to in a later chapter.

## THE THERMIONIC VALVE

Although the Fleming diode of 1904\* was a detector with very stable characteristics and good sensitivity it was only one of many employable types of detector. The thermionic principle upon which it worked did not therefore receive recognition as a device which would eventually revolutionize the whole trend of radio communication development. Even the introduction of the third electrode, or control grid, by De Forest in 1907 was not for many years regarded as an epoch making discovery, partly owing to the sparsity of published information, and partly owing to the uncertainty of the poorly evacuated "audions" available.\* De Forest had an instrument capable of amplifying as well as detecting, and of producing oscillations. In his original patent he described a grid condenser circuit for reception. It was not until 1913, however, that the real significance of the audion began to be generally appreciated. In that year Meissner used the Lieben-Reisz relay,\* which had been known as an amplifier of weak audio-frequency currents for about two years, in the first deliberate application of the triode valve as a generator of oscillations. Triodes had been known to oscillate at an earlier date, the phenomenon being regarded as an undesirable contribution to their instability as amplifiers. Meissner made use of this property, maintaining a valve in oscillation by back-coupling between anode and grid.

The power-handling capacity of these early valves was small, and in addition their characteristics were so influenced by the somewhat irregular gas pressure within them that they compared unfavourably with existing transmission methods. Their sphere of usefulness was mostly limited to amplification and heterodyne oscillation in reception. The latter feature was an asset which encouraged the development of existing non-thermionic methods of producing continuous waves. The development of the power valve for transmission was partly concurrent with receiving valve development, but influenced by certain constructional methods which will be mentioned separately at a later point in this chapter. The general development of valve technique, as the theory and possibilities were appreciated, will first be described.

### The "Soft" Valve.

The earlier valves were not highly evacuated and the gases left within them influenced their behaviour. The residual gas pressure was apt to vary, as also was the state of ionization of the gas, thus giving an irregular tendency to soft valve characteristics. The ionization of the residual gases provided an increase of electrons which caused more plate current to be registered for a given swing than would have been experienced with a highly evacuated valve. Excessive ionization, however, due to too much residual gas or too high a positive plate

potential, caused the valve to cease functioning in a controllable manner, and endangered the filament due to a cloud of heavy protons falling upon it. The soft valve was thus worked just below the point where a blue glow appeared and was very sensitive, but delicate in operation. The low degree of evacuation made the soft valve cheap to manufacture, but its life was relatively short.

The development of the Fleming valve (Fig. 10) has already been considered in detail. It was a "soft" valve employing carbon or tungsten filaments, and although its functioning was affected by the presence of gas, Fleming undoubtedly discovered many characteristics which were due entirely to thermionic emission. The unilateral conductivity, the effect of mechanical separation between filament and plate upon plate current, and the non-linear relationship between the difference in potential between the plate and filament, and plate current, were all demonstrated by him. The De Forest Audion was also a "soft" valve and employed at first a tantalum filament (Fig. 11).

The Lieben-Reisz relay contained a small amount of mercury which was vaporized by the hot cathode and provided a plentiful supply of ions for increasing the conductivity between electrodes. On this account the term "gas relay" was applied to this device. The filament was a platinum strip coated with lime, a form which had been shown to be an excellent emitter of electrons by Wehnelt in 1903.

Round, of the Marconi Co., devised a low vacuum triode in 1913 \* which was superior to existing designs. The Wehnelt oxide-coated filament was used, surrounded by a thimble-shaped nickel grid and a cylindrical nickel anode. The cylindrical anode afterwards became very extensively used. The action of the valve depended considerably on the presence of gas, and a tendency towards hardening of the partial vacuum with age was corrected by applying a match flame to a recess containing an asbestos pellet. The heat expelled gas molecules into the body of the valve. In the Marconi No. 16 circuit, which was famous in the early days of valves, Round triodes were employed as high frequency amplifiers in a reaction circuit preceding a crystal detector. Round also devised a modified circuit which fed back a potential derived from the rectified currents to the grid of the same valve, which was thus employed in addition to give low frequency amplification.

The "soft" valve retained a sphere of usefulness for some years after the introduction of more highly evacuated types.

### The "Hard" Valve.

The evacuation of a valve to a degree where residual gases play no appreciable part in its functioning is generally attributed to Langmuir, who developed special pumping devices, and treatments to remove occluded gases from the materials to be employed, in the laboratories of the General Electric Co. of America. His work followed the statement by Richardson, who has conducted research into electron emission for many years, that the presence of gas was not necessary to the

functioning of a thermionic valve. Richardson had first enunciated a law for electron emission, substantiated by published results, in 1902, and it was in 1914 that he followed this up by the opinion referred to above. It is also claimed that H. D. Arnold of the Western Electric Co. appreciated this fact independently as early as 1912, and highly evacuated triodes with oxide-coated filaments, designed by van der Bijl of the same company, were in commercial use as telephone repeaters in America in 1914.

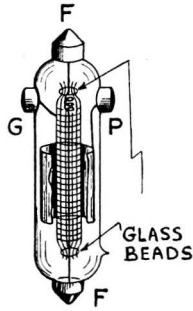
The "Pliotron" valve\* was developed by Langmuir in the same year (Fig. 11), and a published description appeared in 1915. Occluded gases were removed by a succession of heat treatments *in vacuo*, followed by a final electron bombardment of the plate before sealing off the bulb. A glass framework supported a tungsten filament of hairpin shape, the apex of which was connected to a shock-absorbing spiral spring. Two glass arms supported a grid of fine tungsten wire very close to the filament. On either side of the grid were two fine ziz-zags of wire also wound on glass, and forming the plate. In other designs the plate was made of two tungsten sheets. A very high degree of evacuation of the bulb was obtained by the use of specially designed pumps. In 1915 a very important treatise on the application of hard valves to rectification, the generation of oscillations, and amplification when connected in cascade, was published by Armstrong.

The advantage of the hard valve over the types in which gas was present in appreciable amounts lay in the stability of the characteristics obtainable. For military purposes, where the skill of the operator could not always be guaranteed, the hard valve was particularly desirable, and the war of 1914-18 stimulated the French military authorities under the direction of General Ferrié to amplify the work of Langmuir and Armstrong. In 1915 the "French valve" designed by Messrs. Biquet and Péri made its appearance and was adopted by all the Western Allied Armies, and was later copied by the Germans. The British type was known as the "R" valve\* (Fig. 31). The simple design consisted of a highly evacuated spherical bulb from the press of which was supported a horizontal cylindrical nickel anode, a helical grid of nickel or molybdenite wire, and a straight tungsten filament. The 4-volt filament took 0.7 amp. and the anode current at 50 volts was about 1.5 milliamps. The lack of rigidity in the grid led to microphonic troubles which were reduced in the B.T.H. "A" type valve and others by suspending the grid helix from a catenary wire.

M. Latour, who was intimately connected with the development of the French valve, published a treatise on its theoretical operation in 1916. The inter-electrode capacity of valves of this general type became a serious disadvantage in the design of high frequency amplifiers for use on the shorter wavelengths. The resistance-capacity amplifier was then common, and the inter-electrode capacity of the French valve seriously by-passed the resistance with which the valve was in parallel. The French authorities, therefore, introduced a design known as the "horned valve"\* which largely overcame this defect and enabled 4-valve amplifiers to be made for wavelengths as low as 200



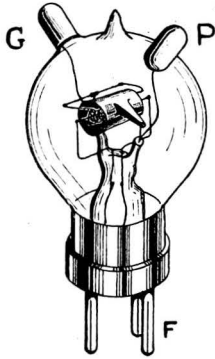
FRENCH  
'R' VALVE  
1915.



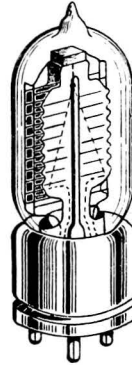
MARCONI  
'Q' VALVE  
1916.



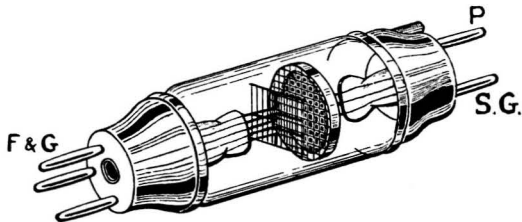
TYPICAL  
GERMAN VALVE  
1916.



FRENCH HORNED  
VALVE  
1916.



WESTERN ELECTRIC  
V.T.I.  
1918.

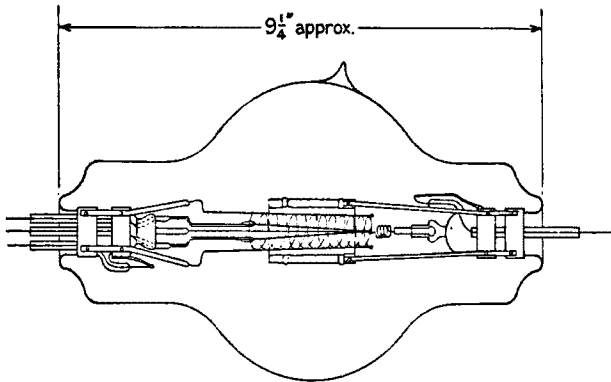


SCREEN GRID VALVE  
(MARCONI) - 1927.

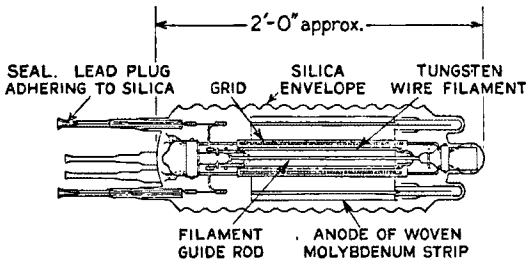
FIG. 31. RECEIVING VALVES.



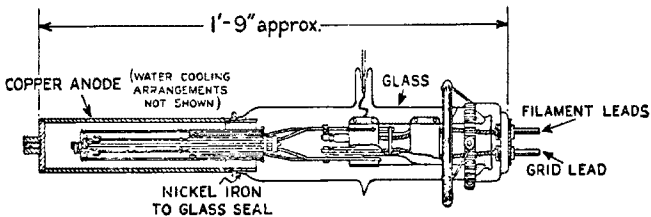
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150 WATT TRANSMITTER VALVE, TYPE T.I.  
WITH GLASS ENVELOPE (1917).



15 K.W. TRANSMITTER VALVE, TYPE N.T.22A.  
WITH SILICA ENVELOPE (1922)



5 K.W. TRANSMITTER VALVE, TYPE C.A.T. I.  
WITH COOLED COPPER ANODE, (1922).

The seal comprises a nickel-iron ring of suitable expansion coefficient, lightly coated with copper and sealed direct to the glass. The ring is brazed to the copper anode before sealing.

FIG. 32. TRANSMITTING VALVES.

metres. The filament connections were carried through the press, as in the "R" valve, but the grid and plate leads were carried to two "horns" in the top of the bulb.

The "Q" valve \* designed by Round of the Marconi Co., in 1916, also had a low inter-electrode capacity (Fig. 31). The chief cause of high capacity between electrodes was from running the connections close together through the press and out through the valve base. The "Q" valve obviated this by enclosing the electrodes in a glass tubular body, closely embracing the plate. The filament was a straight tungsten wire connected through a shock absorbing spiral to terminals at the top and bottom of the tube. The grid was a woven mesh of wire carried on two glass beads, through which the filament passed. The grid and plate connections were taken out through opposite sides of the tube. The "Q" valve was worked at higher plate potentials than the French types (100-200 volts) and took only a small filament current (0.29-0.33 amp.). It gave a good characteristic slope for rectification, amplification, and oscillation, and was relatively free from microphonic troubles. The Marconi V.24 valve \* of 1919 was similar in construction, but with the plate and grid closer to the filament. It was suitable for H.F. and L.F. transformer-coupled amplifiers, but not for rectifying or heterodyning.

The war of 1914-18 prevented the normal interchange of scientific knowledge, a fact which was responsible for the development of valve technique in Germany being at first confined almost entirely to low frequency amplifiers. The German valves of the war period were very rigidly constructed, giving freedom from microphonic troubles, but their characteristics were quite unsuitable for high frequency amplification. Their inability to generate oscillations with ease made them particularly silent as L.F. amplifiers. They were very sensitive to changes in filament voltage, so that baretters consisting of iron wires enclosed in a tube containing hydrogen were commonly used in series with the filaments. If the L.T. supply voltage increased, the increase in resistance of the baretter kept the current constant. Two mechanical designs were used, the first being a circular plate, flat spiral grid, and a horizontal, drooping filament suspended one above the other \* (Fig. 31), and the later form somewhat similar to the "R" valve.\* After examples of the latter had been captured, German copies were produced from 1917 onwards. Double grid valves, which were used as current limiters in earth current signalling circuits, were produced about 1918.\* By November, 1918, there were still no valve transmitters in use in the German lines, although as early as 1915 the French had produced a small valve transmitter for aeroplane work and early in 1917 they had issued several thousand small valve transmitters and receivers.

The valuable work of Schottky in investigating the spontaneous fluctuation of current present in a valve amplifier (the shot effect and flicker effect) was published in the *Annalen der Physik* in 1918. These effects are particularly evident in the amplification of very weak signals.

## Low Temperature Filaments.

The lime-coated Wehnelt filament and the pure tungsten filaments used in the French valve among others, were worked at a very high temperature in order to obtain satisfactory electron emission. The heating power required (i.e. filament volts and filament current, and therefore battery capacity) was large, and the filament distortion at high temperatures necessitated relatively high clearances between electrodes.

In 1911 Dr. W. T. Coolidge of the American General Electric Co. patented the admixture of thorium with refractory oxides and tungsten powder as a means of producing a lamp filament which would be much less brittle than tungsten, after sintering. In 1914 Langmuir found that heat treatments made such filaments into remarkably good electron emitters, but that they were quickly attacked and destroyed by residual gases. He therefore introduced hydrocarbon or alkali-metal vapour into his bulbs to fix the residual gases and, although his results were incorporated in certain British Admiralty valves produced in 1917, the improved emissivity was still obtained at high filament temperatures.

In 1918 the Western Electric Co. brought out the V.T.1 and V.T.2 series of valves in which special oxide-coated platinum alloy filaments worked only at a dull red heat\* (Fig. 31). The filaments took 1 amp. at 2.2 volts, the plate voltages being 20-50 volts, and the plate characteristics were steeper than those of the French valves. The Weco valve introduced into this country by the Mullard Co. in 1923 employed a similar type of filament, taking 0.25 amp. at 1 volt.\*

In 1921 the Marconi-Osram dull emitters were extensively marketed after eighteen months' experimental work. They employed the thoriated tungsten filament. Occluded gases were driven from the anode before sealing by electron bombardment, while the grids were coated with a gas-free varnish. The L.T.1 valve\* of 1920 gave the general characteristics of the "R" valve, but required only 0.61 watt for filament heating compared with 2.8 watts for the "R" valve. In 1921 a modified form was issued, the D.E.R. valve\* requiring a filament current of 0.38 amp., but filaments so fine that they required only 0.06 amp. were later produced and could be run from dry batteries. Electron bombardment by such fine filaments was impracticable and induction heating of the anodes was substituted. Finally, however, a filament taking about 0.2 amp. was adopted.

In 1924 the General Electric Co. of America introduced the magnesium "getter" as a standard manufacturing expedient. The volatile metal was flashed inside the evacuated bulb, to the inside of which it gave a silvered appearance. Any traces of gas appearing inside the bulb, by release from occlusion by any of the parts, was quickly adsorbed by the metallic layer, which thus protected the filament. The use of heated metals of the rare earth group to remove occluded gases was patented by the American G.E.C. in 1917. The effect of residual gas on thoriated tungsten filaments was also reduced by introducing carbon into them.

The thoriated filament had several disadvantages in that it was inclined to be microphonic, that at the lower temperature at which it worked it was affected to a greater degree by the temperature of the grid and anode, and that emission was unevenly distributed along the filament unless the space charge current was limited to within, say, 10 per cent. of the filament heating current (according to Barkhausen). In spite of advances in the technique of the oxide-coated filament, thoriated tungsten remains of great value in valves for high anode voltages (such as high-powered transmitters).

Oxide-coated filaments requiring a heating power of only 0.01 watt per milliampere of emission are now easily produced. (The original pure tungsten filament required 0.5 watt per milliamp.) Manufacture may be carried out by melting a barium compound on to the core wire; by rubbing the heated core wire with a wax containing the barium compound; by evaporating a barium salt solution from the wire; or by directly coating an oxidized core wire with barium vapour *in vacuo*. The oxide-coated filament is widely used in all valves requiring low anode voltages and has largely superseded thoriated tungsten for such applications.

One great advantage of low temperature filaments lies in the ease with which far better characteristics and lower impedances can be obtained by reducing the clearances between the filament and the other electrodes. When indirectly heated valves for mains operated sets were introduced the heating power for a certain emissivity again rose, but with mains supply the extra power was immaterial to the user. The valve designer, however, had to take into account that the extra heating warmed up the grid and anode, a factor which had to be offset against the even distribution of emission obtained along the cathode length.

### Screening Electrodes.

The importance of reducing the inter-electrode capacity of a valve, particularly for high frequency work, has been referred to. The neutralized triode, in which the capacity effect was neutralized in an external circuit, became generally adopted in 1923, and high frequency amplification immediately acquired a new significance in that relatively large stage gains were obtainable under conditions of stable control. Early in 1927 the increasing adoption of the screen-grid valve marked the beginning of obsolescence in the case of the neutralized triode. The first screen-grid valves were regarded as of mainly theoretical interest, but Round appreciated their practical value.

A screen-grid valve described by Hull in the *Physical Review* of February, 1924, employed a fourth electrode in the form of an electrostatic screen between the ordinary control grid and the anode. Schottky also conducted some early research into screening possibilities. The screen-grid was supplied with steady positive potential at a value somewhat below the anode supply voltage. The value had to be chosen so that the anode voltage could not be exceeded by the screen

voltage, in order to obviate the danger of secondary emission. The residual capacitance between anode and screen was a very small fraction of a micro-microfarad while the conductance from grid to anode was little affected and the anode resistance was greatly increased. These characteristics enabled the screen-grid valve\* very rapidly to supersede the triode for high frequency amplification after it had become more widely adopted in 1926-7. Its use enabled improvement of about 10 decibels to be shown over the triode, a figure similar to that obtained by comparison of later triodes with the early "R" valves (Fig. 31).

A later development of the screen-grid valve lay in so designing the grid that the characteristics enabled amplification to be controlled by alteration in the amount of grid bias, without fear of serious distortion or cross modulation. The characteristic consisted of one practically straight portion of low slope employed when dealing with high inputs and another steeply sloping straight portion applicable to low inputs. The "variable-mu" valve,\* as it was called, became prominent in America about 1931 and superseded the ordinary screen-grid type for high frequency amplification. The screen-grid valve then found its main application in the frequency changer stage of superheterodyne sets. The reduction in curvature of the grid volts—anode current characteristic for large bias values was obtained in the variable-mu valve by leaving gaps in the control grid so that much more bias was necessary to prevent electrons from getting through to the screen and anode.

In transmission the screen grid limits the anode potential swing, and a screen potential of about 30-50 per cent. of the anode static potential is usually adopted. Although inter-electrode capacity is reduced in the same way as in a receiving valve, with consequent advantages, the disadvantages are more evident. Efficiencies up to about 60 per cent. are obtainable.

In the Pentode valve,\* which appeared in 1928, a further electrode is introduced between the screen and anode. The screen is supplied with a constant positive potential somewhat less than the anode potential and the extra "grid" is earthed to the cathode inside the bulb of the valve. It is found that the internal impedance of a pentode varies in direct proportion to the anode voltage, within wide limits. The extra grid removes the negative resistance kink from the normal tetrode characteristic and permits a larger anode swing. The maximum undistorted output is relatively large for the anode current consumed and it will work with a smaller minimum signal input than for the triode valve. The pentode found its main application as an output valve where increased efficiency and sensitivity were required at the possible expense of quality. The pentode has a tendency to give an accentuated reproduction of high notes which demands a tone-corrector circuit for the maintenance of quality in broadcast reproduction.

The further development of multi-electrode valves is reviewed later in this chapter.

## Indirectly Heated Cathodes.

The battery as a source of supply for receiving valves was open to objection on the grounds of upkeep, unwieldiness, and initial expense in the cases of both storage cells and primary batteries, while the voltage drop during discharge was an aggravating factor. The ease with which high anode potentials could be obtained from the rectified and smoothed output of an alternating current mains transformer, from which a filament and grid bias supply could also be tapped, opened up possibilities which took some time to reach fruition. The smoothing circuit, consisting of inductance and capacity so combined that it offered a very high impedance to alternating components in a unidirectional supply, was patented by Ferranti in 1888, while the valve rectifier, to give a unidirectional supply from an alternating current source, was available in many forms.

The earlier valves were unsuitable for high anode voltages and, although Round had patented a construction consisting of a carbon filament indirectly heating a platinum tube as early as 1915, the battery-fed filament persisted almost unchallenged up to about 1922 when experiments were made in the construction of sets to work directly off D.C. mains. In 1922 an indirectly heated cathode for alternating currents was included in a valve described by A. W. Hull. The cathode was a large nickel cylinder, barium oxide coated, inside which was a helix of tungsten wire as the heater. The equipotential surface presented by the cathode enabled a characteristic of steep slope to be obtained and enabled the valve to be used as a detector. It was found, however, that in the earlier indirectly heated designs the overheating of the grids, if close enough to the cathode to give good characteristics, involved a tendency towards undesirable electron emission.

It was not until 1927-28 that the indirectly heated cathode became a real commercial proposition and the improved construction of valves enabled high anode voltages to be employed satisfactorily. The indirectly heated cathode has the advantage of presenting an equipotential cathode surface, while the successful employment of anode voltages much higher than those practicable with battery operation, and the existence of an anode supply unaffected by the amount of current drawn from it, enabled the valve\* operated from a mains supply to give a performance far in advance of that economically obtained from a battery operated counterpart. The influence of mains operation on reception is discussed in a later chapter.

## Multiple Valves.

The screen-grid and pentode are the most important of the multi-electrode single purpose valves which have taken many forms since as early as 1912. Other valves with multiple electrodes have been developed in recent years, but in these the construction is equivalent to including two or more valves in the same bulb.

The Loewe multiple valve of 1926 \* combined several triodes (or equivalent tetrodes) with their associated resistances and condensers within a single bulb. The object was to obtain high frequency amplifiers with the minimum of stray capacitance. A valve for obtaining stable neutrodyne balance, designed by E. J. C. Dixon, contained the two valves of a push-pull combination together with balancing condensers within one bulb.

The greatest development of multiple valves, however, is concurrent with the development of automatic volume control. The first serious attempts, in 1925, to apply the rectified carrier wave as bias to the preceding H.F. stages, and so relate the degree of H.F. amplification to the strength of the incoming signal, were handicapped by cross-modulation effects. The variable-mu valve overcame cross-modulation troubles, and the decreasing importance of amplifying in the detector stage, due to the ease with which sufficient amplification could be obtained elsewhere, led to the increased use of diode detectors. The reversion to the diode was a move in the direction of better quality reception, as the diode characteristic was practically linear at large signal inputs. Two diodes can be combined easily in a circuit suitable for providing bias to be fed back to the preceding H.F. stages. Methods of automatic volume control were therefore developed on a satisfactory basis after the reversion to the diode detector in 1931-32.

The manufacturer was quick to appreciate the advantages of combining the necessary electrodes for automatic volume control detection and the first stage of L.F. amplification in a single bulb. The American Wunderlich valve combined a double diode with a triode amplifier, the emission from a single filament being sufficient for this triple purpose valve. Post-detector control may be added to the control described above by employing a double-diode variable-mu pentode which can be arranged so that the L.F. amplification drops as the signal output increases. Volume control by the carrier wave is essential to preserve the original volume variations in the signal, which might otherwise be restricted in volume to a single strength. Automatic volume control is discussed further in the chapter on broadcast receivers.

The inclusion of several electrodes in one bulb was not confined to valves for automatic volume control. Thus, in the Pentagrid converter of 1933 a triode oscillator is combined with a variable-mu detector. It may be used as a frequency changer in superheterodynes to avoid interaction between tuning circuits, and aerial radiation.

Multiple valves, as such, should be distinguished from those which represent a definite advance of radio technique by the use of additional control electrodes. The multiple valve, within limits, may be a convenience attended by economy in outlay and upkeep, but its function may be as readily performed by two or more separate valves.

The disadvantages of multiple valve construction lie in the complexity of the surrounding wiring, the frequent inferiority of the individual component characteristics compared with equivalent

separate valves, and the multiplicity of designs, each requiring special jigs, tools, etc., which would be required if the principle were vastly extended. Certain more obviously interdependent combinations may be advantageously enclosed within a single bulb in spite of such possible disadvantages.

### **“ Class B ” Valves.**

Economy in high tension current consumption is particularly advantageous to the battery set user and, in 1932, a method of achieving this called “ quiescent push-pull ” was included in many American broadcast receivers. Two valves are used in the output stage and are so biased that nearly the whole of their plate current is cut off when no signal is being received. The maximum signal which the valve can handle in such a case is limited by the fact that grid current must not be allowed to flow, so that “ Class B ” amplification supplanted quiescent push-pull shortly afterwards, to take advantage of the low average modulation of broadcast programmes without such limitations. “ Class B ” amplification, using two push-pull valves and a driver valve, was employed for many years in certain apparatus made by Standard Telephones and Cables, Ltd., but in its more recent form the “ Class B ” valve is a double triode arranged in one bulb coupled through a “ driver ” transformer to a small “ driver ” valve, the function of which is to supply the energy loss due to the flow of grid current and therefore to restore the output to an undistorted condition.

### **Receiving Valve Construction.**

There have been few obvious mechanical improvements in valve construction since the early days apart from the mechanization and stabilization of manufacturing methods and the introduction of rigid designs of electrode. The cooling of electrodes has received attention, a notable example of this being the “ micromesh ” valve\* in which the attachment of stout cooling fins to the grid enabled very small clearances to be obtained, giving a very high mutual conductance, without fear of grid emission. The “ Catkin ” valve,\* introduced by Marconi-Osram in 1933, provides one example of revolutionary design (Fig. 33). The metal-glass seal, applied to receiving valves, enables the glass bulb to be dispensed with in this design. It is claimed that apart from added robustness and smaller size the “ Catkin ” allows more precision in mounting electrodes and a reduction in inter-electrode capacity.

## **TRANSMITTING VALVES**

There was little difference between the earlier transmitting and receiving valves, about a hundred small valves in parallel being used in the successful radio telephony experiments between America and Paris in 1915. It was then realized that higher vacua were required to withstand high plate voltages, and that electrodes should be increased in size to handle large powers without overheating.



## Glass Bulb Types.

The earlier valves designed as transmitters had larger electrode systems mounted in evacuated glass bulbs, with the electrodes supported from, and the connections passing out through each end of the bulb. Round designed some early transmitters in 1914-15 which were not highly evacuated but could handle about 40-50 watts.\* Electron bombardment of the plate before sealing was not feasible as it was in contact with the glass walls of the bulb. The French were also experimenting with transmitter valves about this time and, in America, the G.E.C. produced a highly evacuated "Pliotron" which was probably the most advanced design of transmitter from 1915-18. The production of these pliotrons was limited in scale, but the British Admiralty in June, 1916, succeeding in using one for successful signaling between Portsmouth and Gibraltar. The tungsten anode worked at a dull yellow or bright red heat, and with 2,000 anode volts aerial currents of 8-10 amps. were obtainable in a 5-ohm aerial.

Early in 1917 the M.-O. Company commenced the production of transmitting valves for the Admiralty. The B.W.O. type \* was rated at 30 watts with 400-600 volts on the anode and looked very much like an ordinary receiving valve. The T.1 type \* made later in the same year had an anode dissipation of 150 watts and was housed in a double-ended glass bulb (Fig. 32). By 1922 the glass bulb transmitter of 500-watt rating was common, but above this size the price became very high. Attempts to cool glass valves by oil baths and air jets, and so increase their rating, met with limited success. The glass bulb still has its sphere of usefulness in low-powered valves. 1.5-kW. rectifiers \* are still made in this form, and very much higher ratings have been obtained in certain more or less isolated constructions.

## Silica Envelopes.

For high anode dissipations without fear of cracking the silica envelope was introduced about the year 1919. Silica is a very difficult substance to work, but an anode at  $1,500^{\circ}$  A. within 1 cm. of a silica envelope can be used with safety. A silica valve rated at 15 kW. was made in 1922,\* but a more normal size was of the order of 1 kW.\* The envelopes could be opened and used again (Fig. 32).

## The External Anode.

One of the most important developments in the history of radio communication was the introduction of the copper-glass seal.\* The use of a special section of copper at the joint, decreasing to a very fine edge inside the glass, enabled cylindrical copper anodes to be sealed to the glass ends holding the other electrodes. The joint was quite vacuum-tight, and the mechanical weakness of the copper section within the seal seemed to obviate the cracking which had formerly ruined attempts to combine in such intimate contact two substances with dissimilar temperature coefficients. Using a metal-glass construction the anode becomes accessible and can be water jacketed,

thereby making possible a great increase in the permissible rating. The same technique of sealing copper to glass can also be applied to the filament and grid leads which can therefore be very robust (Fig. 32).

Valves with external anodes were made previously to the development of the copper-glass seal. Platinum-glass seals were possible, but expensive, and a special chrome- or nickel-iron alloy with a coefficient of expansion equal to that of glass was used in some earlier 20-kW. valves made by the Philips Co. in 1923. The copper-glass seal emanated from the laboratories of the same firm in 1924. Valves rated at 500 kW. were being made less than ten years later, due to a combination of increasing demands for power and increasing skill in manipulating the seal.

### **Demountable Valves.**

A valve whose electrodes are accessible for inspection and repair is obviously an attractive proposition, but so far all demountable valves have suffered from two main disadvantages. Firstly, they must be continuously evacuated, requiring auxiliary pumps which put up the expense, and secondly, they cannot be put back into commission until a considerable period has elapsed for evacuation after they have been taken down.

Two 10-kW. demountable valves designed by Holweck were installed in 1923 at the Eiffel Tower. The joints were of rubber, which was later replaced by ground surfaces covered in grease. A greatly improved design using a special grease joint was designed by F. P. Burch of Metropolitan-Vickers Electrical Co. in 1931. A 500-kW. valve of this type has been installed experimentally at the Rugby Wireless Station. The advantages of demountability become more apparent in the larger sizes. (Fig. 34.)

## **ELECTRONIC OSCILLATORS**

The more usual type of oscillation, reaction oscillations produced by feed-back from anode to grid in a triode, or dynatron oscillations produced by a negative rate of change of current with voltages, are inapplicable in the case of valves working at the extremely high frequencies necessary for ultra-short wave work, as the motion of the electrons becomes a function of their inertia. At such frequencies oscillations may produce by virtue of this inertia, the work of Barkhausen and Kurz, in 1919, laying the foundations of the technique of the electronic oscillator. The reaction oscillator is usually unsuitable for wavelengths below about 2 metres.

Considering a triode in which the grid is supplied with a positive potential while the plate is at zero or a slightly negative potential compared with the filament, oscillations can be maintained in a circuit

between grid and anode, anode and filament, or grid and filament, if the resonant frequency of the circuit bears some relation to the electron frequency. The electrons which get past the positive grid on their way from the filament are retarded in the grid-anode space, and return towards the grid. Some of these pass the grid again and are retarded in the grid-filament space, therefore setting up an oscillation due to electron inertia.

The anode of the valve is only used to retard the electron stream which passes through the grid. This retardation may also be made to occur by replacing the anode by a magnetic field as in the case of the "magnetron" arrangement developed by Záček, Okabe, and Yagi. The magnetron consists of a cylindrical diode with a field winding outside the bulb to produce a field with its axis parallel to the anode axis. Okabe has produced oscillations on a wavelength less than 5 cm., using the "magnetron" oscillator.

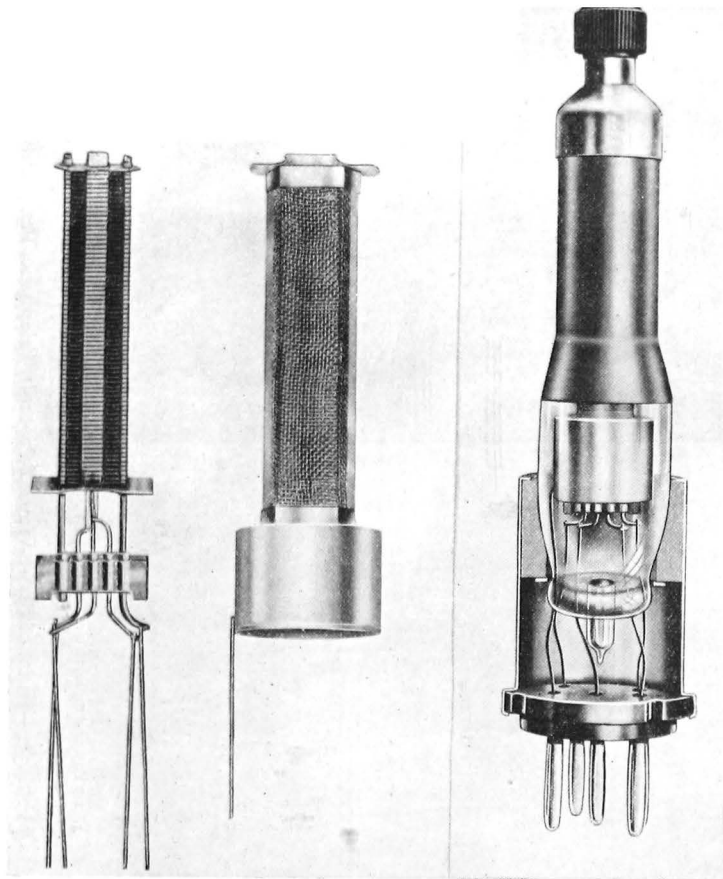
For a treatise on electronic oscillators (with bibliography) refer to a paper by Megaw, *Journal I.E.E.*, No. 436, 1933.

## LIMITS OF VALVES AS AMPLIFIERS

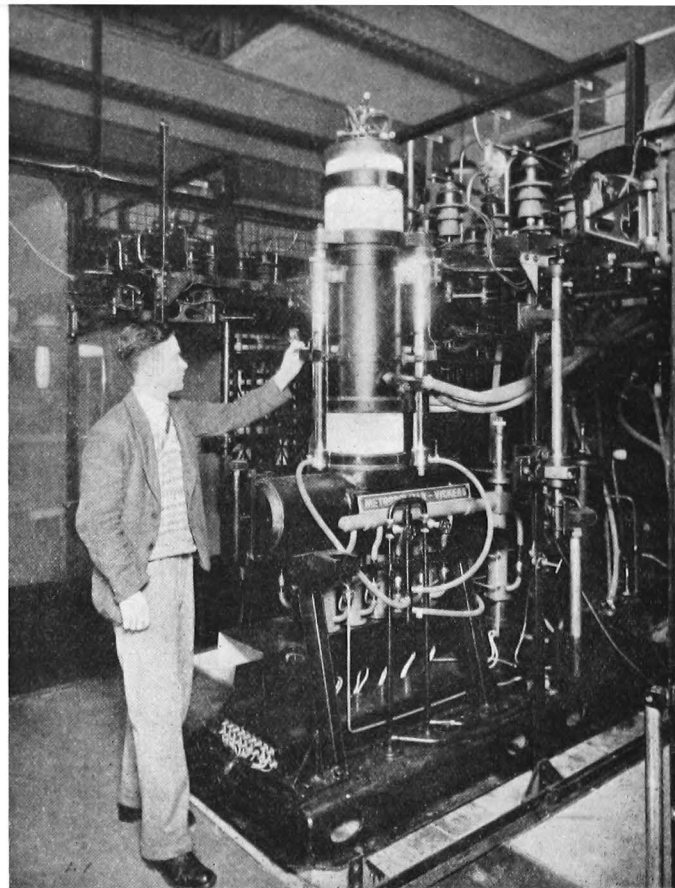
The Schottky effects referred to previously are due to erratic components in electron emission which are unnoticeable compared with ordinary input signal values, but become serious compared with very weak signal currents. To these must be added the "temperature effect" outside the valve due to "random motion of the electrons within a conductor in thermodynamic equilibrium with the molecular agitation" (see Turner, *Journal I.E.E.*, No. 433, p. 26). These effects limit the minimum signal which can be amplified.

A. W. Hull suggests a high frequency voltage of 1 microvolt as the minimum limit which can be amplified. At lower frequencies this figure may be reduced to 0.1 microvolt. Non-variable currents as low as  $10^{-16}$  amps. have been detected in the measurement of photoelectric currents, due to a star of the fourteenth magnitude influencing a photocell connected to an electrometer valve.

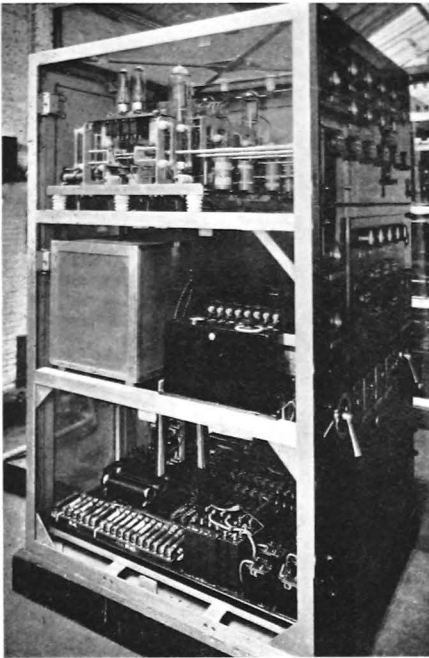
There is, however, a definite low order of signal magnitude below which amplification becomes impracticable.



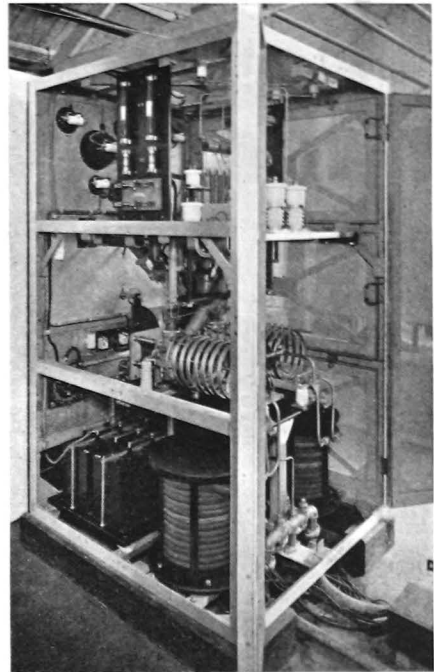
Heater, Cathode, and Grid.      Screen Grid.      General Assembly.  
 FIG. 33.—Marconi Catkin Receiving Valve, 1933.



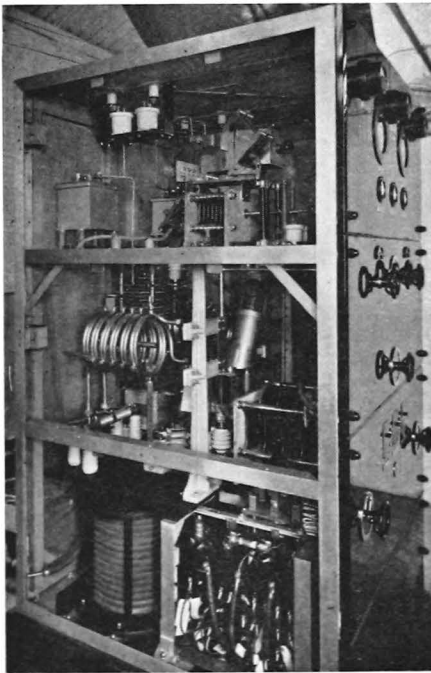
[Metropolitan-Vickers Electric Co., Ltd.]  
 FIG. 34.—500-kW. Continuously Evacuated Valve (as supplied to the Rugby Transmitter).



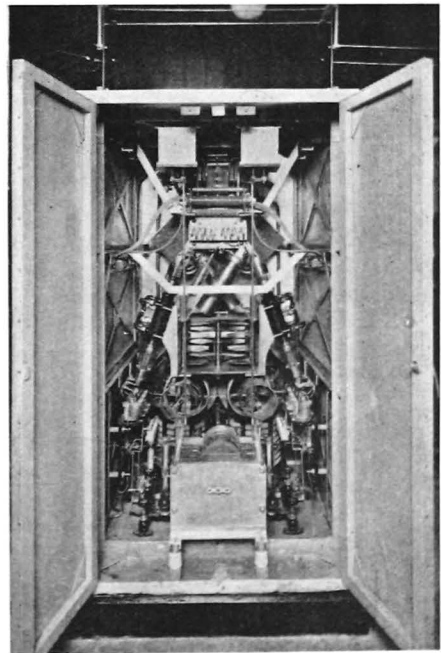
1. Oscillator-Modulator Unit.



2. Intermediate Amplifier Unit.



3. 1st Power Amplifier Unit.



4. 2nd Power Amplifier Unit.

[Standard Telephones and Cables, Ltd.]

FIG. 35.—Units of Short-Wave Telegraph/Telephone Transmitter.

## FURTHER DEVELOPMENTS IN TRANSMISSION

The trend of development up to 1919 has been considered. That year was chosen, not because it had any particular significance from the point of view of revolutionary changes, but rather because it fell in the interim period, when the three-electrode thermionic valve was giving promise of superseding every other device for detection, amplification, and oscillation, but had not been carried as far as to be ubiquitous. The cessation of hostilities in 1918 was also a factor which enabled progress to return to normal and largely eliminated the claims of expediency.

The valve of 1919 was being increasingly applied to reception, as a detector-amplifier, high and low frequency amplifier, and as an oscillation generator for heterodyne reception. It was this latter property which enabled continuous wave transmission finally to be established as superior to spark methods. As a generator of oscillations for transmission, however, the valve was limited in output and the use of many valves in parallel, while possible, was not economically sound compared with other methods. The Poulsen arc and the high frequency alternator (combined in many cases with a static frequency multiplier) were therefore almost unchallenged for the higher powered telegraphy transmitters. The valve certainly showed up to advantage in telephony transmission where it could be employed as an amplifier of the microphone output before modulation, but radio telephony was still no more than adolescent. The code signal was employed for the great majority of communications sent by radio.

Telegraphic code signals are still employed for many commercial services, but telephony has gradually assumed a position of increasing importance, particularly owing to the development of broadcasting and the linking up of telephone systems throughout the world.

### Speech Transmission.

The similarity between the electromagnetic waves and light waves carries the history of speech transmission back to the days before the work of Hertz, when the telephone itself was only in its infancy. The Graham-Bell telephone was introduced in 1876,\* and two years later Bell commenced a series of experiments in conjunction with Sumner Tainter to demonstrate light-beam telephony.

A beam of light, modulated in intensity by means of a voice actuated diaphragm which was deflected across the beam, was caused to fall on a device which responded to the modulations. This device, or receiver, was of selenium which varied in resistance according to the amount of light falling upon it and therefore varied the current in a

telephone circuit accordingly. Other modulating devices employed were vibrating mirrors or a battery and microphone directly modulating a D.C. arc (Bell and Hayes, 1897). Some types of receiver dispensed with selenium and employed the variable heating effect of the modulated beam to produce variable sound pressures by expansion and contraction, but the electrical methods were far more sensitive. The range of the earlier "photophonic" receivers was only a few hundred yards at the most, but Ruhmer, between 1900 and 1902, employed an improved form of modulated arc which enabled him to communicate over 15 kilometres. Recently the introduction of the infra-red sensitive photo-electric cell has enabled photophonic communication to be conducted over considerable distances under conditions of comparative secrecy. The thermionic valve amplifier has also been a prominent factor in recent advances, but the range is obviously restricted by optical considerations.

Speech transmission without intervening wires had also developed from the early telegraphic experiments on the conduction system. Preece, in 1882, established speech communication across the Solent by immersing plates connected to the sending and receiving circuits in the water. In 1886 he also succeeded in transmitting speech over several hundred yards by an induction arrangement, large coils of wire with no earth connections being installed at the transmitter and receiver. The induction method was also applied by Edison and others, about 1885, for speech communication with moving trains. The conduction method is still applied in mines and, though not for speech transmission, for military purposes in the form of the buzzer.

Collins, in 1900, obtained a certain measure of success with an electrostatic method proposed by Dolbear in 1882. The fundamental idea was to vary the potential of a large elevated capacity area by variations in the resistance of a microphone connected through a battery to an induction coil. A second capacity area, within the electrostatic field of the first, was connected to earth through a telephone and battery and was influenced by the changes in potential of the first plate which was connected to earth through the secondary of the induction coil. Collins, employing this method, gradually increased the speech range from 200 ft. in 1900 to a distance of 3 miles in 1902.

True radio telephony, however, may be said to involve the employment of electromagnetic waves modulated by the speech currents. An essential condition for success is the use of undamped waves as the carrier, and the carrier frequency must be high compared with the highest speech frequency. One of the pioneers of radio telephony was Fessenden who claimed to have heard speech over a distance of about a mile as early as 1900. He approximated to the undamped wave by employing a high-speed commutator which enabled him to obtain a very high discharge rate in a spark transmitter. The speech he received was of very poor articulation. The high frequency alternator was a far better producer of undamped waves and it was Fessenden's early association with such machines which enabled him

to obtain a range of 25 miles with speech and music by modulating the output of an inductor alternator in 1906. About the same time the modulation of the output of a Poulsen arc set was tried by the Telefunken Co. In 1906 they succeeded in communicating over the 20 miles between Nauen and Berlin. The improvement of the high frequency alternator enabled Fessenden to obtain results over a distance of 100 miles in 1907. The range with arc sets was also improved. In 1908 the Colin-Jeance arc was successful over 30 miles from the Eiffel Tower, and F. Majorana, using his liquid microphone and an arc generator, began by obtaining speech transmission over 35 miles, and later from Rome to Sardinia (156 miles) and eventually to Sicily (300 miles). In 1909 Poulsen obtained successful telephony between Esbjerg and Lyngby, a distance of 170 miles, employing a Poulsen arc transmitter. Telephony from San Francisco to Los Angeles, nearly 500 miles, was conducted in 1910, using H. P. Dwyer's arc apparatus.

The Moretti spark gap, which handled an extremely rapid succession of discharges by de-ionization on the principle of the Wehnelt electrolytic break, and therefore gave an approximation to continuous wave transmission, was used by Vanni, in conjunction with the Vanni microphone, in an impressive performance in 1912. Speech was heard over the 625 miles between Rome and Tripoli. In 1913 the Nauen high frequency alternator and static frequency multiplier achieved a range of 550 miles.

All spark systems of telephony had the disadvantage of being even more subject to background noises than arc systems. Arcs tended towards instability under microphone control unless adequate precautions were taken. The high frequency alternator was better, but was an expensive oscillation generator to apply to speech transmission over the small ranges normally obtainable at the time. In 1918 the American G.E.C. employed one of the 200-kW. Alexanderson alternators at New Brunswick, modulated by a valve circuit, for telephony which was successfully received in Europe.

The great handicap of earlier methods lay in the necessity for direct modulation by microphone in the aerial circuit, on account of the absence of a satisfactory microphone amplifier. A number of special microphones and relays were introduced, but either their power-handling capacity was limited or other factors militated against their wide adoption. The reliable economic range for telephony was therefore about 100 miles.

The possibilities of the valve in speech transmission were demonstrated in a spectacular way by an achievement of the American Telephone and Telegraph Corporation, in conjunction with International Western Electric, in 1916. They combined about a hundred small valves in parallel and followed a 5,000-mile radio telephony transmission between Arlington and Hawaii in September by a similar demonstration between Arlington and Paris in October. The wavelength was 6,000 metres, the antenna current 50 amps., but

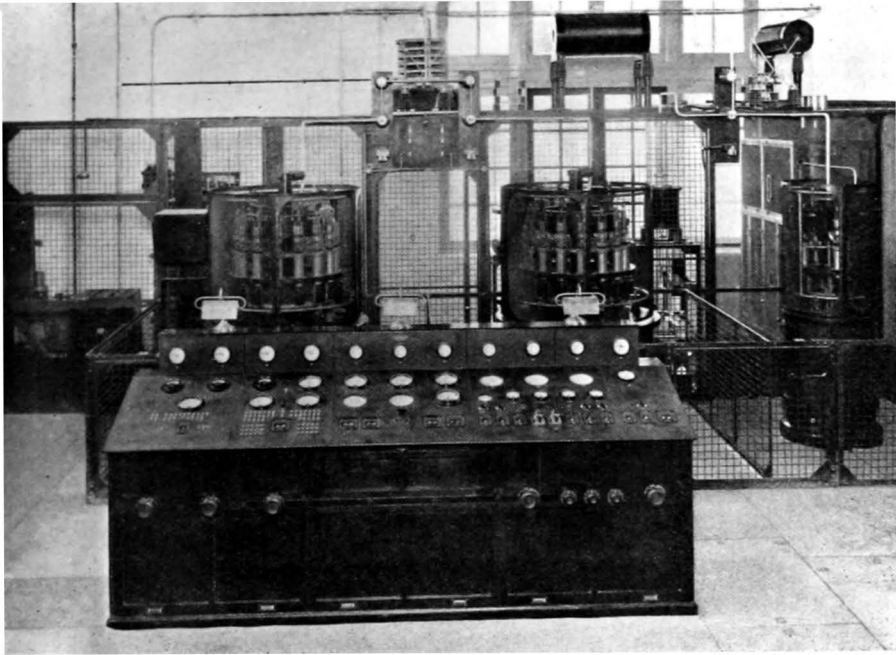


the speech received was faint although the articulation was quite understandable in parts. The need for high-powered valves, with high vacua to withstand high plate voltages and large electrodes to handle the power, was evident. Their development has been considered in the previous chapter. Rectifying valves such as Langmuir's Kenotron were also developed to provide anode supplies.

The properties and functioning of the thermionic valve were gradually more clearly understood, and for some years the progress of radio communication was seemingly slow, but was punctuated by apparently minor happenings which nevertheless pointed to the future. Although experimental valves rated at 100 kW. had been made in 1922 and six 20-kW. valves were worked in parallel in 1923, in the latter year it was proposed to fit a projected Bavarian telegraphy station with a 2,000-kW. Poulsen arc and high frequency alternator equipment. In 1922 a 500-kW. machine was made in France, among others. The valve, however, was beginning to merit serious consideration even for high-power stations. Broadcasting, too, had been developed in England, the United States, France, Holland, Germany, Denmark, Brazil, Argentine, and Italy by 1923, and many more countries were considering broadcast proposals. The valve was quite capable of handling the small powers common to the early broadcast stations.

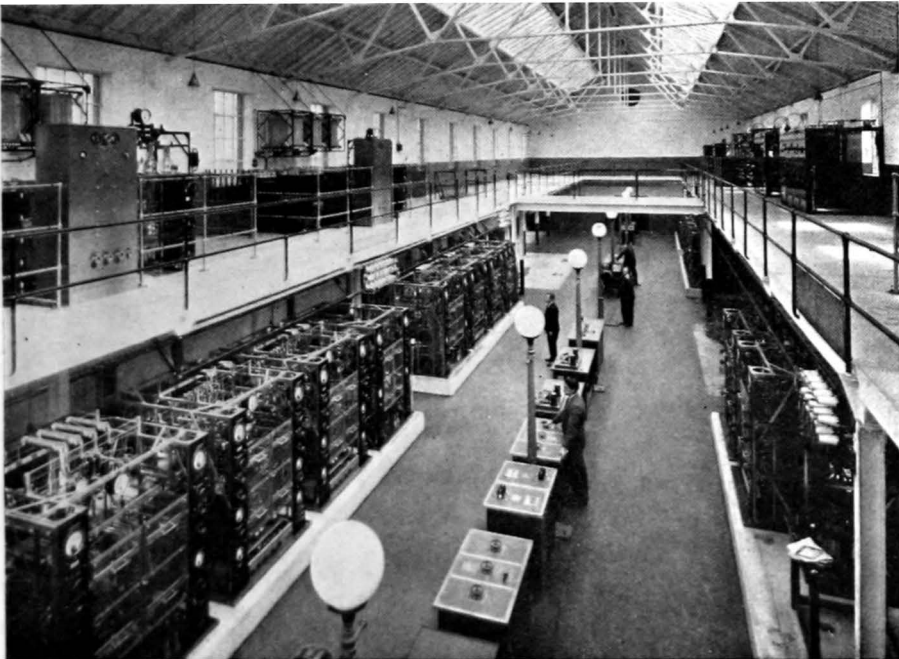
### Single Sideband Transmission.

In 1922 the same companies responsible for the Arlington-Hawaii and Arlington-Paris demonstrations of 1915 were concerned in another spectacular success which established the value of an important principle. A mathematical analysis of the radiation of a modulated carrier wave shows the transmission of two frequency bands above and below the carrier frequency, as well as the carrier. The carrier is essential to the reproduction of the audio frequencies superimposed upon it, but there is no mathematical objection to the carrier being supplied at the receiving end and being suppressed, together with one of the two sidebands, at quite an early stage in the transmitter. The carrier and one sideband can be suppressed by filter circuits immediately after modulation, and subsequent amplification applies only to the remaining sideband which is transmitted. This system was used in 1922 for speech transmission over 70 miles of landline between New York and Long Island and thence by radio to London. The final amplifier in this experiment contained twenty 7.5-kW. valves in parallel. The resupply of the carrier wave at the receiver presents some difficulties, but these are not insurmountable. Energy is radiated only when speech is on the circuit, giving a power saving of about 70 per cent. on a highly loaded station. Fading seems to be less with single sideband transmission, less wavelength space is required between stations, and highly selective receivers may be employed. The special receiver required makes the signals less accessible to unwanted listeners.



[Standard Telephones and Cables, Ltd.]

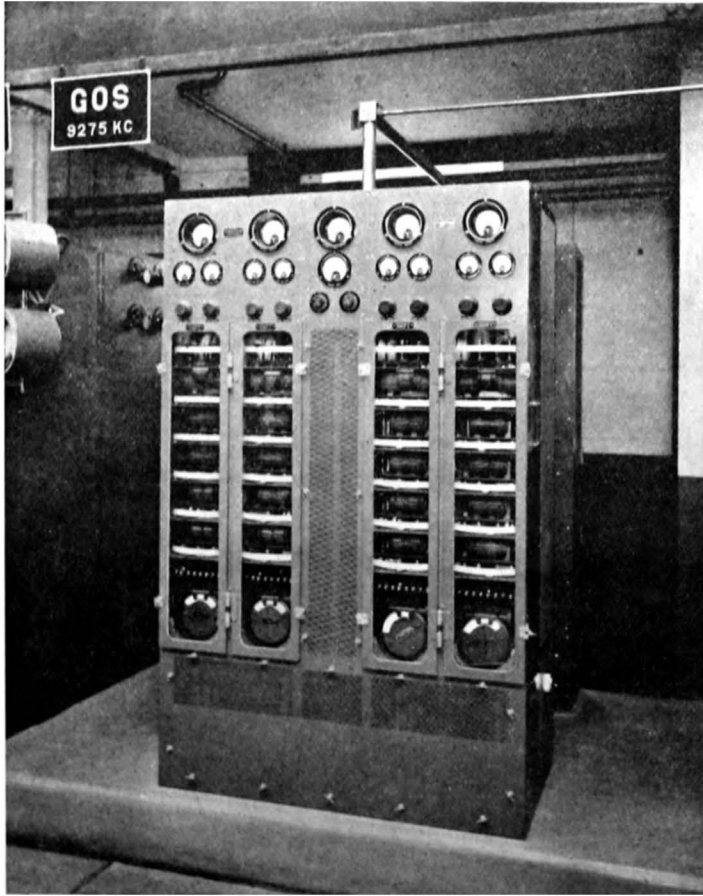
FIG. 36.—Rugby Single Sideband Long-Wave Transmitter, 1927.



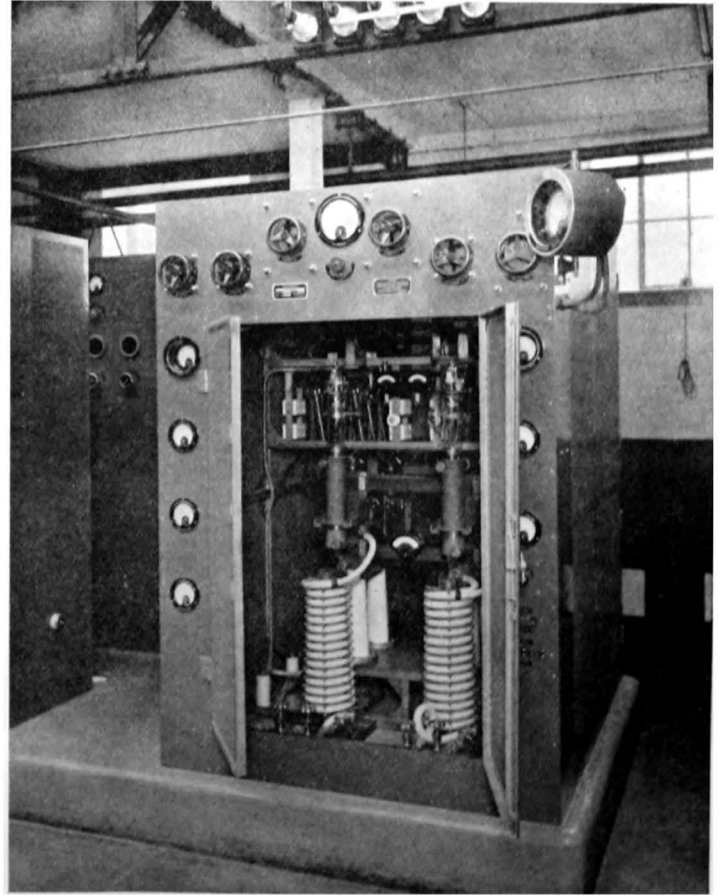
[Marconi's Wireless Telegraph Co., Ltd.]

FIG. 37.—Ongar Short-Wave Transmitter Hall, 1934.

2 New York beam transmitters on the left. 4 wavelengths 20·81–39·525 metres.  
1 transmitter on the right. Wavelength 27·45 metres.  
Salisbury and Nairobi transmitters on far right. 4 wavelengths, 14·51–33·58 metres.  
Control tables in the centre.

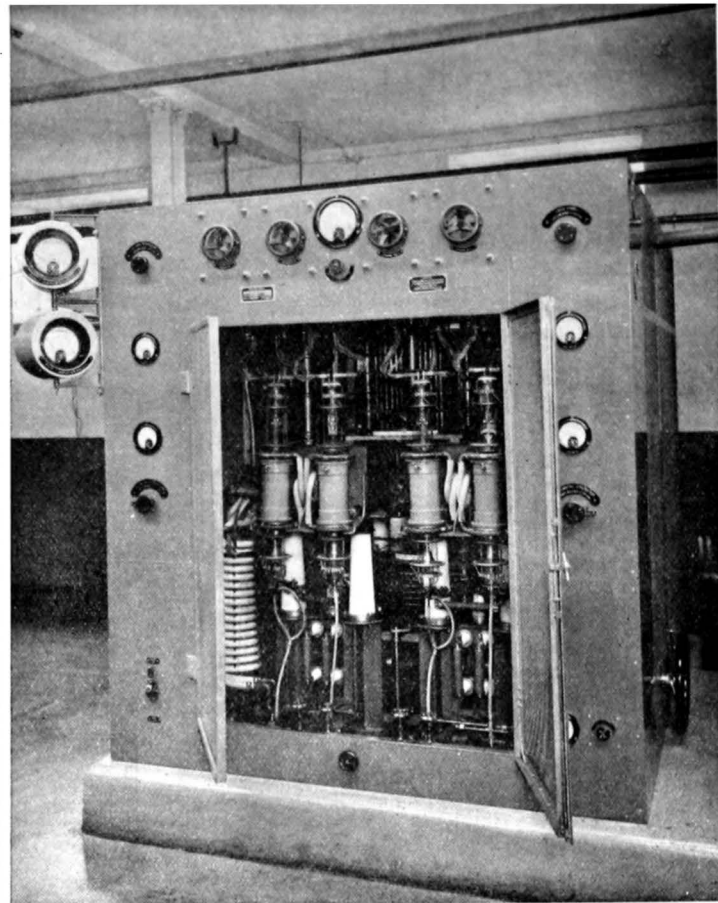
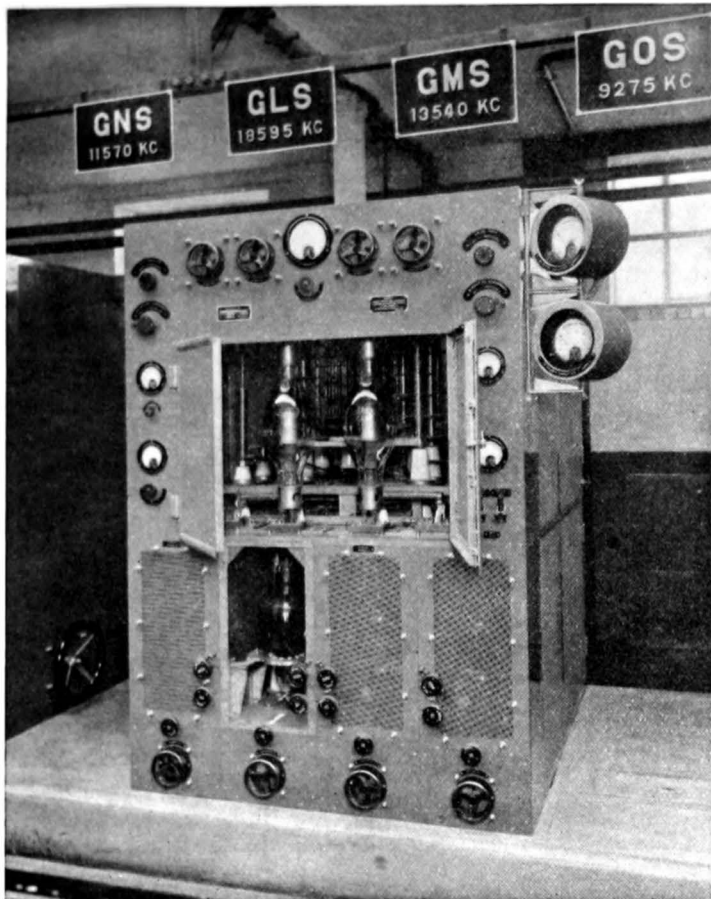


Master Oscillator.



Absorber Panel.

FIG. 38.—Ongar S.W. Transmitter of Imperial and International Communications, Ltd. (See also below.)



1st and 2nd Intermediate Amplifiers.

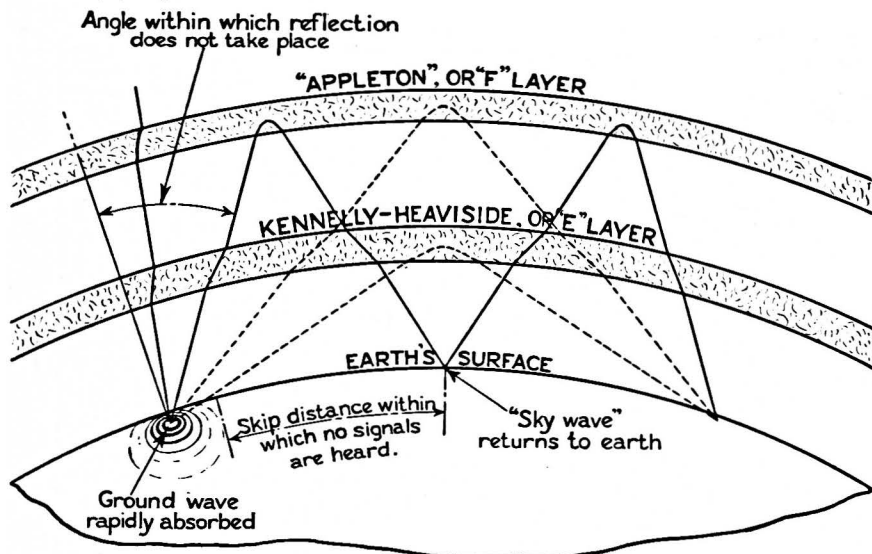
Main Amplifiers.

FIG. 39.—Marconi 40-kW. Short-Wave Transmitter at Ongar. The four main units.

The transmitter is arranged to work on any of four predetermined wavelengths.

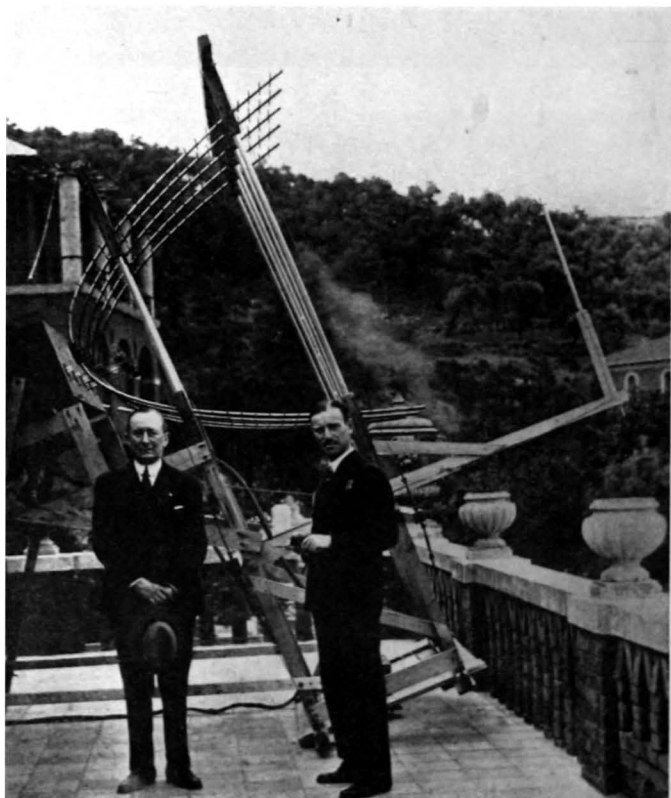
[Marconi's Wireless Telegraph Co., Ltd.]

To face page 55.]



### EFFECT OF IONISED LAYERS ON WAVE PROPAGATION

FIG. 40.



[Marconi's Wireless Telegraph Co., Ltd.

FIG. 41.—Marconi Ultra-Short-Wave Transmitter.

The British Post Office opened a public trans-Atlantic telephone service on this system in 1927 at their Rugby station with a transmitter installed by Standard Telephones and Cables, Ltd., which radiated on 5,130 metres. The power of the transmitter was over 100 kW., the final stage at first consisting of thirty 10-kW. water-cooled valves (Fig. 35). In 1931 a 500-kW. demountable valve was installed experimentally at this station by Metropolitan-Vickers Electrical Co. The Post Office system also employs circuits to distort the audio frequencies at the transmitter and restore them to their proper values at the receiver, thereby making conversations unintelligible to unauthorized listeners. This system is known as "speech scrambling."

### Short-Wave Transmission.

The shorter wavelengths were at one time considered almost valueless for commercial transmission and were assigned to amateur experimenters. These enthusiasts obtained some truly remarkable results and the commercial interests began to realize their possibilities.

The Marconi Co. had meanwhile conducted tests with a view to proposing that a short-wave Empire beam system should be inaugurated. In 1921 duplex telephony had been obtained between Southwold and Oslo with 1 kW. in the aerial at 100 metres. In 1923 an experimental beam station was erected at Poldhu, but the state of development at the time was such that the long waves of 20,000-30,000 metres were chosen for the Post Office Rugby Station for communication with Australia, South Africa, and India. By employing a 1,000-kW. transmitter and 800-ft. aerial supports a regular 24-hour service was obtained, but at an installation cost of about £500,000 per station.

The Poldhu station was equipped with a parabolic beam reflector strung from triatics between 325-ft. masts, and a half-wave aerial working on 92 metres. The maximum input power was 12 kW., and the short-wave code signals at St. Vincent, 2,300 nautical miles away, were found to be stronger and more free from interference than the long-wave signals from the Leafield station of the Post Office which had been equipped with a 250-kW. arc set in 1921. One difficulty in short-wave transmission was discovered in the form of end-seal trouble in the valves, due to induction heating of particles occluded in the glass. Eight specially designed air-cooled  $1\frac{1}{2}$ -kW. valves were used at Poldhu. In 1924 telephony from Poldhu was heard at Sydney, Australia.

The effect of employing different wavelengths was next investigated and it was found that the daylight range increased rapidly as the wavelength was reduced in stages to 32 metres, in 1924. A transmitter circuit was also devised in which the valve capacities were balanced out. In the following year even shorter waves from 15 metres down to 2 metres were investigated and in 1926 the first portion of the beam system, between Bodmin and Canada, was opened for regular service on 16.6 and 32.4 metres. As early as July, 1924, the Marconi Co. had been optimistic enough to sign a contract with the Post Office for the provision of continuous seven days' working, duplex, at a minimum of

100 words per minute, for 18 hours per day on a Canada circuit, 11 hours to South Africa, 12 hours to India, and 7 hours to Australia. The system begun in 1926 more than fulfilled these requirements at an initial cost per station of about a fifth of that applying to long-wave working.

The beam array at Bodmin, designed by C. S. Franklin, marked a great advance in directional aerial construction. It consisted of a vertical sheet of separate aeriels, each with its own feed. The parallel wire feeders formerly employed were replaced by concentric copper air-spaced tubes fitted with expansion joints. The outer tube was earthed and the inner one connected to a suitable tapping on a screened transformer. The open transmission line, however, may be employed with suitable precautions, and is cheaper. The lengths of all feeders were compensated electrically to obtain uniformity. The vertical wires were divided into half wavelengths by spiral phasing coils so arranged that the currents in the vertical wires were all in phase, and a highly directive radiation was obtained at right angles to the plane of the mesh. A reflector system, with double the number of wires of the aerial system, was mounted one-quarter or three-quarters of a wavelength behind the aerial, thereby reflecting the back radiation so that it reinforced that in the desired direction. The divergence of the beam was found to be about  $11^\circ$  (Fig. 30).

The development of beam arrays has frequently enabled the field strength at a desired position to be increased by the order of sixty times what it would have been if a single non-directional radiator were used. The advantages of an increase in the signal/noise ratio are evident. Directional receiving antennæ help to increase this ratio and are widely employed. Quick fading effects are reduced by combining two or three aeriels at the receiving station in what is known as the "diversity" system of reception.

Short-wave telegraphic and telephonic radio communication has increased rapidly in extent, the Marconi beam transmitters at Dorchester, for example, communicating high-speed telegraphic signals to North and South America, Japan, and Egypt on wavelengths between 15 and 37 metres, while numerous radio telephone links have been established, such as those constructed by Associate Companies of Standard Telephones and Cables, Ltd., since 1929, for communication between Britain and U.S.A., Spain, and South America. It was possible, by 1933, for the British telephone subscriber to communicate with about 95 per cent. of the world's telephones.

Radio links are employed to interconnect telephone networks where economic or physical reasons preclude the use of ordinary telephone cable. They are used in trans-oceanic and ship-to-shore services and to cross intervening stretches of land where establishment and maintenance of lines would be costly and difficult due to extreme climatic and physical conditions, or the presence of hostile inhabitants. The distance spanned by such links varies from 50 to 12,000 miles, and it is common for several long-distance lines and radio links to be used in

communicating between two points. A passenger in an Atlantic liner, for instance, might communicate with a subscriber in Uruguay by means of a ship-to-shore radio link to Great Britain, thence by land line to Madrid, from Madrid to Buenos Aires by radio link, and thence by land line to Uruguay.

A radio link system usually consists of two one-way radio channels working in opposite directions, the two channels being interconnected at either end by means of land lines to form a two-wire connection which can be extended to any standard telephone system. The link comprises a Radio Transmitting Station, a Radio Receiving Station, and a Central Terminal Office at each end. The radio stations are usually located in open country well away from towns so that electrical noise currents may not be picked up by the receiver and that efficient and undistorted radiation may be emitted from the transmitter. The Central Terminal Office is usually located in a large city where it is in close touch with the ordinary telephone system.

If the Central Terminal Office equipment at either end of a radio loop is not sufficiently accurate and the losses in the radio paths (which are variable) are small there may be "singing" or "echo" round the complete loop formed by the two unidirectional radio paths, the interconnection wire circuits, and the Central Terminal Office equipment. "Singing" and "echo" may also occur round the local loop due to the receiver picking up energy from the transmitter when the transmitting and receiving wavelengths are close to one another. The losses in the complete loop and the local loop may be increased to a considerable value without impairing efficiency by apparatus which ensures that one or other of the paths is always inoperative.

The operation of apparatus of this kind, which may be described as voice-operated differential anti-singing equipment (V.O.D.A.S.), is briefly as follows :—

When there is no speech on the circuit, both transmitting paths are inoperative and both receiving paths are operative. Speech entering one end of the circuit operates, by means of amplifying detectors, certain switches which render the transmitting path operative and the local receiving path inoperative. The speech is transmitted over the radio link and is received by the distant receiving station whence it passed by land line to the distant Central Terminal Office. Here the speech currents actuate switches which render inoperative the switches controlled by speech on the distant transmitting circuit so that the distant subscriber cannot interrupt the conversation of the home subscriber.

In order to prevent false operation of switching by noise currents the amplifying detectors are made somewhat insensitive and do not actuate the switches until the speech currents have built up to a value well above that of the noise currents. The resulting lag in operation would tend to clip the speech at the beginning of a sentence and therefore "delay networks" are introduced into the circuit, between the



inputs of the amplifying detectors and the outputs of the local transmitters and receivers, to hold back the speech currents until the switches have operated. The various switches are set so that they "Hold up" during pauses between words but release quickly enough to prevent clipping of the reply.

Amplifying and volume controls are included between the various stages of the V.O.D.A.S. equipment, and a skilled technical operator listens continuously on the circuit to make whatever momentary adjustments may be desirable. He can communicate with attendants and operators at all important points of the system by means of auxiliary circuits and can also speak to the home and distant subscribers.

The two-wire line leading from the V.O.D.A.S. equipment is connected to an operating position in a Trunk Exchange and traffic is handled in a manner similar to that adopted on ordinary trunk circuits.

*A number of photographic transparencies are exhibited in the museum to illustrate the above developments.*

### Frequency Control.

The close adherence of a transmitter to its allotted wavelength is now considered to be a matter of much greater importance than in the earlier days when a self-oscillator working directly into the aerial was good enough.

Dr. W. H. Eccles, in 1918, patented a method of tuning-fork control of a valve oscillator \* (Fig. 58). A tuning fork was caused to vibrate by the plate current of the valve, the oscillations of plate current being also controlled by the movements of the tuning fork in front of an electromagnet in the grid circuit. The constant frequency of the tuning fork thus appeared in the oscillations of the valve which was maintaining the fork in a state of vibration. Frequency control by this means was later applied to many large radio transmitters (Northolt, Rugby, etc.), a suitable harmonic being selected and amplified and applied to the control of the station frequency.\*

The piezo-electric effect discovered in 1880 by J. and P. Curie is confined to a few substances of which quartz is used commercially owing to its combination of marked piezo-electric properties with sufficient mechanical stability. When a slab of quartz is cut parallel to the optical axis and parallel or perpendicular to an electrical axis, the application of an electric stress between the faces of the slab is accompanied by mechanical deformation of the slab. Conversely mechanical stresses are accompanied by the appearance of electric charges on the faces of the slab. If alternating stresses are applied, maximum effects are obtained at the natural frequency of mechanical resonance of the slab as determined by its thickness, density, and elasticity.

In practice a slab is carefully ground to the correct dimensions for the frequency required and is mounted between two metal plates \*

(Fig. 58) which are then connected to the grid-filament circuit of a valve oscillator, the anode circuit of which contains a normal electrical-tuned oscillatory circuit. Such a combination constitutes a crystal oscillator capable of generating oscillations of frequency stable to a degree almost wholly dependent on the constancy of temperature at which the crystal is maintained. A stability of one part in 100,000 is commercially attainable, with ease, the crystal being mounted in a suitable oven with automatic temperature control. Much greater constancy can be obtained under suitable conditions of control.

Cady, in America, published descriptions of some valuable work he had done on crystal control of radio stations, in 1924-5, after some preliminary investigations published in 1922. Since that date the application of crystal control has developed in practice to an enormous extent.

### General Developments.

The problem of fading and low signal strengths has been largely overcome in receiver design by employing distortionless automatic gain control to cover variations up to 60 decibels in received signal strengths, and by making the permissible overall gain of the receiver so large (about 130 decibels) that field strengths falling as low as 0.5 microvolt per metre are commercially acceptable. The problem of resupplying the carrier wave at the receiver at exactly the right frequency in the case of single sideband transmission is relatively simple with long waves, but on a wavelength of 15 metres an accuracy of at least one part in 1,000,000 is required. The combination of quartz crystal control and synchronization by means of a special pilot signal has led to considerable success being achieved in this direction.

Greatly increased use is now made of radio apparatus on ships, valve transmitters being common on all sets with a power greater than 300 watts. A range greatly in excess of the statutory 100 miles is normally obtainable on the 548-830 metre band while short-wave ship-to-shore communication and longer wave (2,000-2,400 metres) communication is becoming common on the larger passenger carrying vessels. All passenger vessels above 5,000 tons have to carry direction finding equipment. One type of direction finder used is direct-reading, consisting of the moving coil of a galvanometer in the air gap of an electromagnet rotating at about 600 r.p.m., an aerial loop being on the magnet shaft. The moving coil tends to set itself in the strongest part of the field, that is where the signal received in the loop is at its maximum. For shore work, on the ground, more accurate direction finders are used such as the Adcock type in which "night-effect" errors are very slight (patented in 1919). The aerial system is such that only the vertical members are influenced by the electromagnetic waves, therefore eliminating the effect of any vertical component in the polarization of the received waves. One direction-finding application to ships and aircraft is the equi-signal beacon in which two equal signals at slightly different modulation frequencies are transmitted

directively and actuate tuned reed indicators at the receiver. Any deviation from a straight course between the two beacons is seen visually by the unequal response of the reeds.

## BROADCAST TRANSMISSION

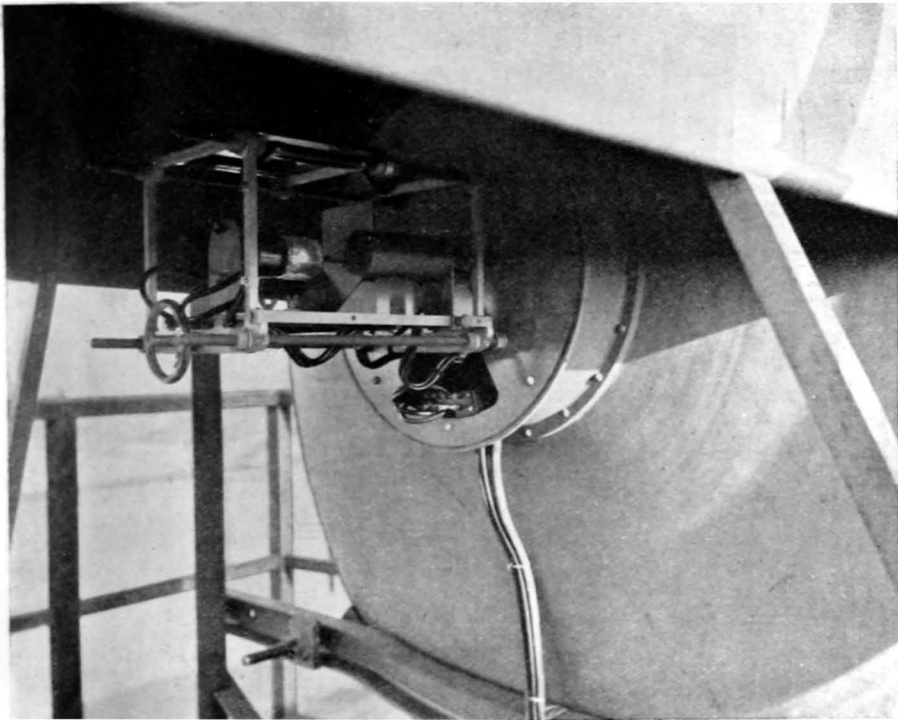
Broadcasting dates back at least to 1906 when Fessenden transmitted musical items as well as speech from a high frequency alternator station at Brant Rock, U.S.A. The idea of regularly broadcasting entertainments, however, had to await the development of the thermionic valve before it reached fruition.

Modulation was the chief difficulty in the way of earlier broadcasting, as the absence of microphone amplifiers required the microphone to be capable of carrying the full aerial current, except in certain connections to which other disabilities applied. One of the most successful of these earlier schemes of modulation was Alexanderson's magnetic modulator, developed from an early proposal by Osmos, in which the microphone currents passing through a coil altered the permeability of an iron core and therefore changed the effective inductance of two separate coils wound on the same core and connected in parallel with one of his high frequency alternators. The output of a Goldschmidt alternator could also be modulated by including a microphone in the excitation circuit. The direct modulation by microphone and valve amplifier, however, was a further development which preceded the general introduction of broadcasting.

Many factors complicated the purely scientific problems confronting those to whom the idea of broadcasting proved attractive. A few of these, some of which are still in evidence, may be enumerated.

1. Authority to set up stations was required.
2. Financial return might be reaped through :—
  - (a) licence fees if a monopoly were granted ;
  - (b) profits on the sale of receiving apparatus, provided non-participants in the expense of running the broadcast station did not have equal sales rights ;
  - (c) the interspersion of commercial advertising matter between broadcast entertainment items.

The schemes which have been the subject of extensive development fall under headings (a) and (c). In this country the monopolistic system has been adopted and shows advantages with regard to programme developments of æsthetic merit, responsibility in the handling of controversial matters, and the elimination of doubtful commercial methods. It relies for impartiality on a liberal directorship. In some countries the propaganda value of radio broadcasting is considered a prerequisite of the controlling body. Even those countries which have adopted the sponsored programme system (c) have found it necessary



[Standard Telephones and Cables, Ltd.

FIG. 42.—Microray Transmitting Valve and Reflector.

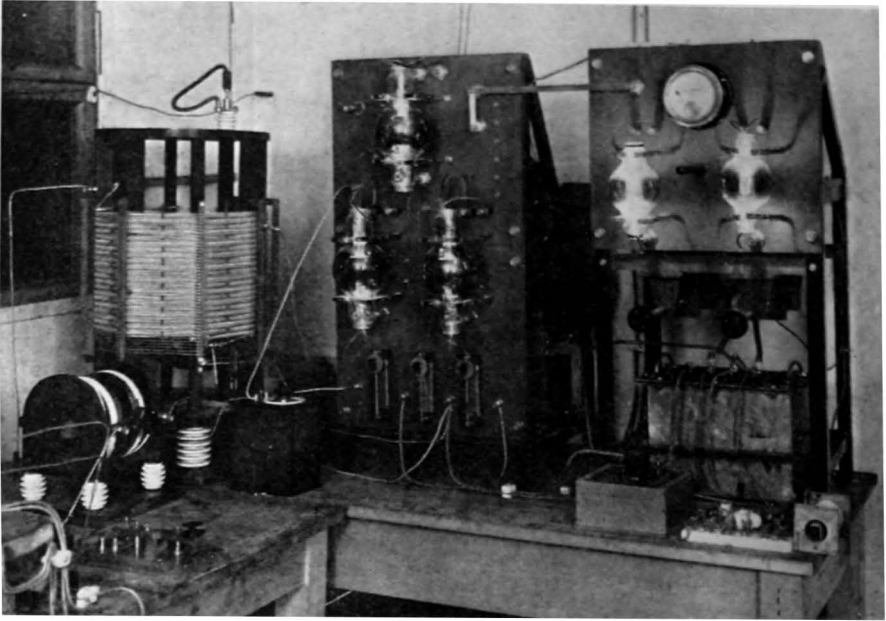
To the right of the valve can be seen a small cylinder, which contains a thermocouple energized from an auxiliary dipole aerial on the other side of the reflector and forming part of the radiation indicating circuit.



[Standard Telephones and Cables, Ltd.

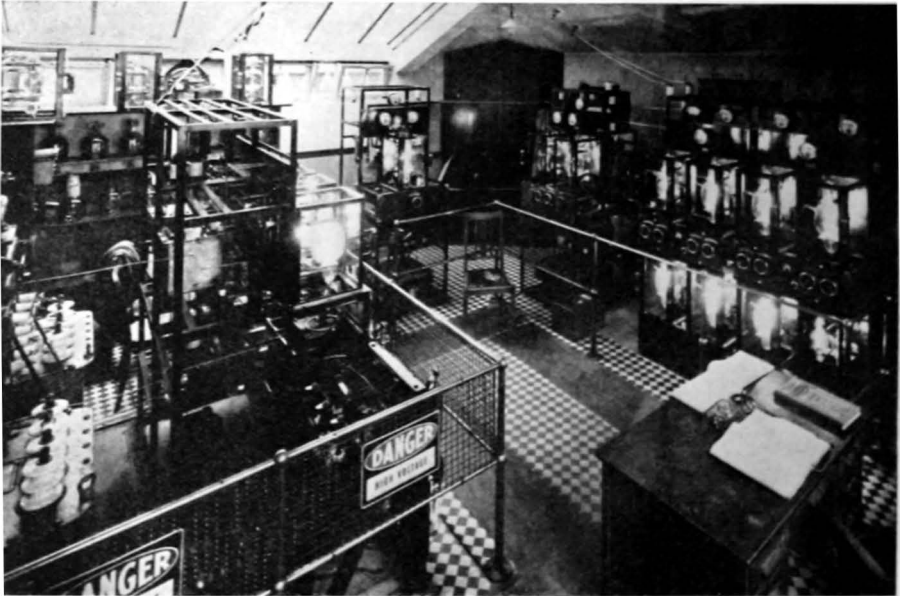
FIG. 43.—Microray Receiving Reflector.

Showing large parabolic reflector, with tubular transmission line connecting to aerial which is concealed by the small hemispherical reflector. The two reflectors, parabolic and hemispherical, have a common plane or aperture, which also contains the focal point of the parabola and the centre of the radius of curvature of the hemisphere; the dipole aerial is at the focal point of the parabola.



[*Marconi's Wireless Telegraph Co., Ltd.*]

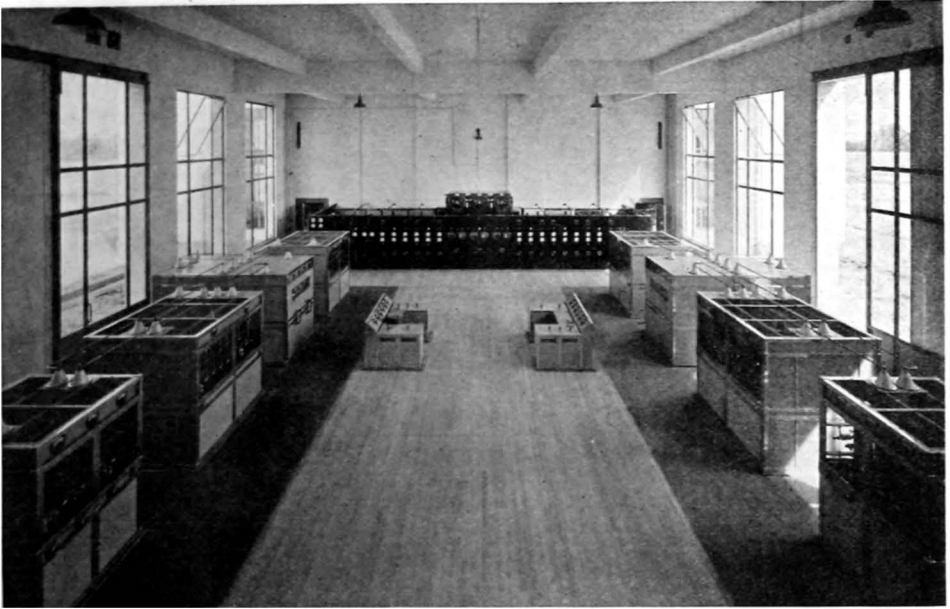
FIG. 44.—Broadcast Transmitter at Writtle, 1921, 0.25 kW.



[*British Broadcasting Corporation.*]

FIG. 45.—2LO, London Transmitter, 1923. 1.5 kW.

On the right the 1st stages of sub-control and modulator panel followed by two oscillators. The master oscillator is in the centre background and the rectifiers and transformers on the left.



[*British Broadcasting Corporation.*

FIG. 46.—Brookman's Park Twin Regional Transmitter, 1928.



[*Standard Telephones and Cables, Ltd.*

FIG. 47.—Empire Short-Wave Broadcasting Station, Daventry, 1932.

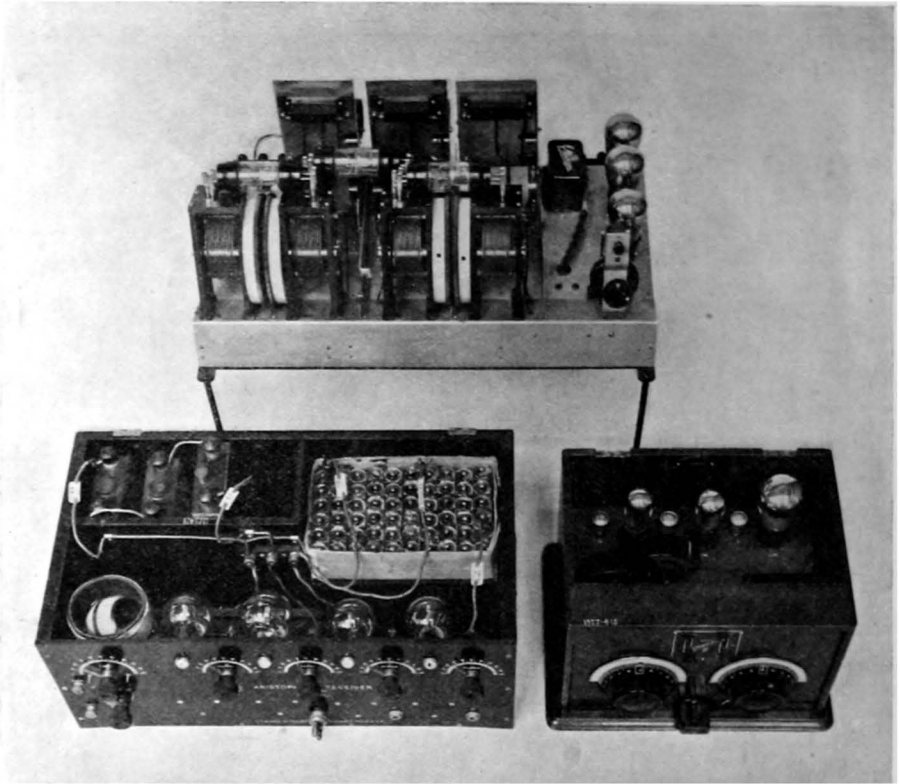


FIG. 48.—Early Broadcast Receivers.

Marconi Type 61, 1927, employing screen-grid valves.

Elwell Aristophone, 1922.

Burndeft Ethophone III, 1926.

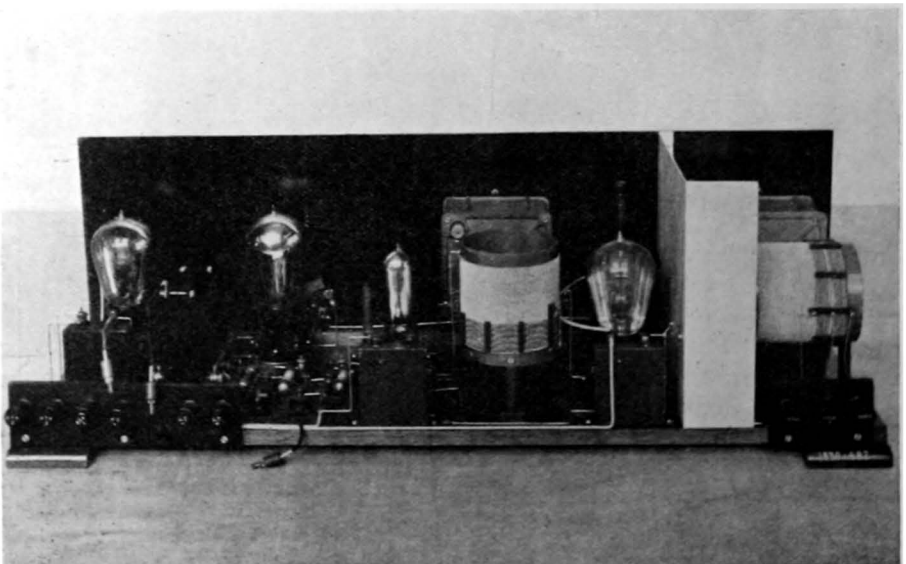


FIG. 49.—" Everyman Four " Receiver, 1926.

to adopt certain regulations inherent in the monopolistic system. The limitation of the number of stations in any particular area is very necessary on account of the limited wave-band available to broadcasting undertakings.

The Marconi Co., after experimental transmissions from Chelmsford in 1920, set up a broadcasting station with a power of 0.25 kW. at Writtle, in 1921 (Fig. 44). A station at Pittsburg, America, commenced regular operations in the same year. The British Broadcasting Co. was incorporated in December, 1922, a chain of eight stations of about 1.5 kW. being erected within a year. Each station gave its own programme and eleven relay stations of 0.12 kW. power were then erected to diffuse programmes sent by landline from the main stations. Nearly six hundred broadcasting stations had been licensed in the United States by the middle of 1923, while central receiving stations relating to subscribers had also been formed there.

The B.B.C., in 1924, became interested in an experimental high-power (15 kW.) long-wave station installed at the Marconi works at Chelmsford. The success of this transmitter led them to order a 25-kW. 1,600-metre transmitter, which was installed at Daventry in 1924. The object was to supplement local transmitters by one giving a reasonable field strength over most of the British Isles. The idea of providing twin high-powered regional stations was also developed in the same year, the stations to be erected at sites convenient to a number of populous areas. Daventry medium wave (38 kW.) was ready in 1927, London Regional (50 kW.) in 1928 (Fig. 46), North Regional (70 kW.) in 1931, Scottish Regional in 1932, and South-West Regional in 1934.

Prior to this the insufficiency of wavelength channels available for broadcast requirements led the B.B.C. to investigate whether a number of low-powered stations could not be worked on the same wavelength. During 1926 four relay stations were tied together with an accuracy of 100-200 parts in a million, a figure which had been reduced to 10-15 parts in a million by 1928. The low power and relatively large distances between stations made the problem of common-wave interference, experienced in more recent years in attempts to tie in high-powered stations, of little significance.

The first conference on the International Control of Radio Telegraphy, held during 1903 in Berlin, ended in failure. A certain measure of success accompanied further efforts, but the introduction of broadcasting raised further international issues. In 1925 a conference was called in London by the B.B.C. to discuss the wavelength problem. Plans for wavelength allocation were prepared at Geneva, 1926, Washington, 1927, Brussels, 1928, Prague, 1929, Madrid, 1932, and Lucerne, 1933. At Geneva a separation of 10 kilocycles between stations was agreed, and is still common in America. At Prague this figure was reduced to 9 kilocycles. Any further reduction would be disastrous to high quality reception. The conflicting National demands, however, require such delicate adjustment that complete agreement on



wave-band allocations seems almost impossible. Disaffected interests have been free to increase the power of their limited number of transmitters without contravening any regulations. By this means a large area can be covered at high field strengths. Other interests, who considered themselves more fortunately placed, then find that they also require to use increased powers in order to avoid being swamped by other transmissions. The receiving set must therefore be designed on more and more selective lines in order to discriminate between transmitters which have increased not only in number but in power. Fortunately the control of transmitter frequency has progressed to such an extent that the wavelength of a station is usually adhered to with considerable rigidity. Nevertheless the 500-kW. station may be a doubtful blessing, from a disinterested point of view, and the signatories at the Lucerne Conference came to some agreement on this matter.

Developments in broadcast technique have been so interlinked as between transmission, reception, valve design, etc., that it should be sufficient to indicate a few of the major points which receive particular attention at the transmitter.

The apparatus employed consists of:—

- (i) The microphone housed in a studio, hall, or outside broadcast position. The output of the microphone must be amplified before being transmitted, possibly by landline, to the modulation stage of the transmitter.
- (ii) The radio frequency oscillators which provide the carrier wave of constant high frequency.
- (iii) The modulation stage in which the amplified microphone currents are imposed on the carrier wave.
- (iv) The final amplifier stages in which the modulated carrier is amplified before being transferred to the aerial circuit.
- (v) The aerial circuit which should radiate, in general, more or less uniformly in all directions. In special cases a highly directional radiation is required.
- (vi) The control equipment wherein the control of volume, etc., is centralized and where the output of the various studios may be directed into the proper channels.
- (vii) The power equipment complete with filter circuits capable of handling the heavy loads, which may be comparable with that of a small town in the case of a high-powered station.
- (viii) The studio building which must be specially designed for the housing of many different types of sound production units, ranging from a single speaker to a full orchestra. The acoustic problems involved greatly complicate the building methods employed, as many items may be taking place at the same time. A steel frame and resonant walls might cause interference between, say, a dance band rehearsal and a religious broadcast. The transmission of sounds along ventilating ducts might be an even more serious source of interference. A description of the precautions taken in the design of Broadcasting House,

London, is given in the B.B.C. Year Books, 1932-3, and also in a separate B.B.C. publication.

- (ix) A landline circuit for simultaneous broadcasting from several stations of a network including transmission from local studios to their respective transmitters. The lines must be designed to avoid cross talk, etc. A wider frequency range than in the case of ordinary telephonic communication must also be carried by these lines. Some limitations are discussed in the B.B.C. Year Book, 1934.

Some of the major electrical problems demanding attention are :—

1. Wavelength stability. In the earlier stations, when the ether was not so crowded and receivers were not so selective, a wavering of frequency was not very serious and reliance could ordinarily be placed on the inherent stability of the electrical circuits. It is now usual to employ a master control dependent on piezo-electric (crystal), tuning fork, or magnetostriction oscillators.

2. Amplitude and frequency distortion. For good modulation, in which the modulation amplitude is exactly proportional to that of the low frequency currents, the high frequency output must be obtained by pure valve action, unaffected by capacity coupling from the grid. In the modulating valve the high frequency carrier oscillations are applied to the grid and the high tension supply, together with the low frequency currents, are applied to the anode. The grid should be highly negative in potential and the high frequency oscillations applied to it should be capable of controlling the valve fully at the highest anode voltage.

The modulating circuits should be incapable of affecting the master oscillator as, although if such were not the case the average frequency might remain constant, the frequency might change during modulation and introduce what is known as frequency distortion. A carefully neutralized separator valve may therefore be employed to obtain minimum coupling between the master oscillator and the modulated amplifier, which may itself be neutralized as a further precaution. Grid current must be eliminated from the separator.

3. The tuned circuits must be of high decrement as a circuit of low decrement, while good from telegraphic considerations, would introduce considerable distortion into telephony.

4. The designs of individual components and amplifiers. Any distortion or unwanted noises introduced in the earlier stages by bad circuit or component design, or by variations in the average or momentary magnitude of applied potentials, becomes much more evident after final amplification. Great care is therefore taken in the detail design of transmitter equipment, but the subject is too large to be considered more fully in this handbook.

It is now almost standard practice to erect a broadcasting station at a considerable distance from the most populous portion of the area it is desired to serve. A high-powered station set in the centre of a

populous area would make it very difficult for transmissions on adjoining wavelengths to be received by a large number of people, while the steel frames of large buildings in the neighbourhood of a station absorb a considerable amount of the radiation and thereby restrict the effective service area. Thus, in the case of London, the B.B.C. have erected their Regional Station at Brookman's Park, about twenty miles away.

The B.B.C., in 1932, commenced a long-distance broadcasting service to the British Empire in all five continents. Disparities in time made the use of disc or steel wire recording of items an advantage (Fig. 47). The items were recorded as required and re-broadcast at a convenient hour for the distant listener. The final amplifiers employed four 15-kW. valves in push-pull and various wavelengths between 14 and 48 metres were selected.

Experiments on shorter wavelengths may help to solve the problem of the crowded ether and also assist in the progress of television. An enormous frequency band would be made available if these experiments were attended by success. There are 14,700 kilocycles between 6 and 8.5 metres, for instance. The range of stations working on very short wavelengths is very limited as far as the ground wave is concerned. More knowledge of the sky wave is still required and investigations into its behaviour, together with the "skip distance" in which no signals are heard (because the ground wave has been absorbed and the sky wave has not yet been reflected to earth), are required (see Fig. 40).

*A number of photographic transparencies are exhibited in the museum to illustrate the development of broadcast and commercial transmitters.*

### **Investigations of the Upper Atmosphere.**

The properties of the upper atmosphere have been investigated first by geophysicists who made observations on terrestrial magnetism and such luminous manifestations as the auroral discharges; then by Kennelly and Heaviside who, in 1902, showed that a reflecting ionized layer would account for the bending of the electromagnetic waves round the earth's surface; and later by physicists in many countries who have made observations by wireless wave exploration. Eccles, in 1912, suggested that changes in ionization due to solar radiation might account for diurnal variations in signal intensity. Appleton, in 1925, showed that there was a further ionized layer at a greater height than the Heaviside layer by observing the echo effects from short-wave signals projected vertically upwards. The echo signal denoted reflection from a higher layer, the time interval being due to the second signal having traversed a longer path than the first. It has since been found that there are intermediate states of ionization, that the waves may be polarized, that the state of ionization may be affected by distant thunderstorms as well as by the sun, and that there may be a direct connection between the undisturbed value of noonday ionization and the eleven-year sunspot cycle. All these results, while at present of mainly physical import, may serve to give that greater understanding which will enable more control to be exercised over communication by

radio, particularly on the shorter wavelengths. Long waves appear to be reflected from the lower ionized layer. Shorter waves may pass through this layer, depending on their angle of incidence, and be reflected by upper layers. Other short waves may not be reflected at all, particularly if they are projected in a nearly vertical direction towards the ionized upper atmosphere. The phenomenon of refraction has also been observed.

One peculiarity in the propagation of short-wave signals appears to lie in the silent zones observable at certain distances from a transmitter. These may be attributed to the complex nature of the propagation which may be analysed as consisting of the direct wave, or ground wave, and other waves reflected from ionized layers of the atmosphere. These latter waves must necessarily follow a longer path than the ground wave, so that the observed signal, due to them, comes somewhat later than that of the ground wave. The ground wave may be absorbed in a relatively short distance from the transmitter, before the reflected wave has again come to earth (Fig. 40). These conditions would imply the existence of a silent zone, such as is actually observed in practice. A resumé of the development of scientific research into the upper atmosphere is given in the *Journal of the I.E.E.*, December, 1933, in a paper by Sir Frank E. Smith (with bibliography).

Ultra short-wave communication has been the subject of much experiment since Barkhausen and Kurz enunciated the theory of the electronic oscillator in 1919. They used their oscillators, without amplification, for telephony and telegraphy over distances of several hundred yards. By 1930, Uda, with highly directional aerials and a wavelength of 50 cm., had telegraphed over 30 km. and telephoned over 10 km. with a 2-valve transmitter giving an output of 0.1 watt. Beauvais, on a wavelength of 17 cm., telegraphed over 38 km. with about the same power.

The International Telegraph and Telephone Corporation, in March, 1931, gave a successful demonstration of two-way telephony across the English Channel on a wavelength of 18 cm. The distance was 40 km., the output about 0.5 watt, and the beam was concentrated into a very small solid angle by parabolic circular shields at both transmitter and receiver which gave a gain of the order of 50 decibels. The first commercial application of this system was a link between the aerodromes of Lympne and St. Inglevert opened in 1933 (Figs. 42-43). The transmission and reception of messages by teleprinter enabled a permanent record to be kept. A wavelength of 15 cm. was specified, the transmitting aerial being less than an inch in length, situated at the focus of a circular reflector 10 ft. in diameter.

Marconi, in 1933, communicated over a distance of 168 miles on a wavelength of 57 cm., thereby demonstrating conclusively that signalling on ultra-short wavelengths is not limited to the optical range (Fig. 41). Many other workers are conducting researches into communication at these wavelengths.

## WIRELESS TELEPHONY RECEIVERS

Some reference has been made in the previous chapter to developments in commercial receivers, and the present chapter will be confined mainly to broadcast receivers which should cover a wider audio-frequency band than ordinary telephone receivers and have developed concurrently with and interdependent upon the latter.

A brief summary of the earlier factors appreciated in the design of valve receivers may be made here.

"Reaction" or regenerative circuits were produced independently in 1912-13 by Armstrong, Langmuir, De Forest, and Meissner. In 1915 the use of reversed reaction to control oscillation was patented by G. M. Wright.

Fessenden had proposed beat reception of C.W. signals in 1902, and in 1913 patented the use of a separate heterodyne circuit which obviated the slight mistuning necessary with the self-heterodyne, or "autodyne," which had been patented by Round in the same year. Round's circuit involved the generation of audio-frequency beat notes by a valve arrangement. In 1919 the supersonic or "superheterodyne" circuit was described by Armstrong. The frequency of the incoming carrier was heterodyned to produce a lower frequency, still above the audible limit but low enough for easy detector-amplification. The amplified current was then rectified to obtain the original audio frequencies which could be further amplified in the usual low frequency amplifier circuits.

In 1916 Marius Latour designed iron-cored inter-valve transformers\* suitable for high frequency amplification stages. The use of low frequency transformers, the design of which did not present the same difficulties, had been known in telephony since the 1885 patent of Addenbrooke and Ferranti.

Detection by means of a grid condenser and triode was mentioned in De Forest's original patent of 1907. The grid-leak method was due to Langmuir.

Langmuir was also responsible for the resistance-coupled cascade amplifier, patented in 1913, and which was mainly applicable to the higher wavelengths. Resistance-capacity amplifiers were suitable for wavelengths above 1,000 metres.

## BROADCAST RECEIVING SETS

The advent of commercial broadcasting in 1921 confronted the receiving set designer with problems which necessitated many modifications to existing circuit designs. Speech and code signals could be

reproduced intelligibly by a very limited band of audible frequencies, but when quality of reproduction assumed great importance, and at the same time the requisite frequency range extended, existing receivers were quite inadequate. The aim of the British Broadcasting Corporation was, and still is, the distortion-free transmission of all frequencies from 30 to 10,000 cycles per second. Their earlier transmissions were far removed from this standard, but improvements in transmitter design have gradually led to the attainment of a reasonably effective compromise. The frequency range is open to criticism, but does give a recognizable copy of an original performance. The hypercritical want the 16,000 or 20,000 cycles range which may be desirable, but this is not practical in the present state of ether congestion and is difficult to reproduce at the receiver. The regional transmitters and control apparatus can reproduce from 50 to 9,000 cycles per second with a loss of less than 3 decibels. Very few receiving sets are capable of reproducing even the 9,000 cycles, many having a cut-off at half this figure or less.

Set designers, confronted by a 9,000-cycle range, began by eliminating progressively those features liable to introduce distortion. The cause was not hard to find, but the elimination was more often a matter of compromise. The human ear in itself is capable of wide adjustment to compensate for amplitude variations and is therefore not ultra-sensitive to compromise. The increase in the power and number of stations has complicated the matter by making selectivity of greater importance, thereby leading to the introduction of further distortion-producing components. Compromise is often influenced by commercial considerations as the limits of improvement may not be attainable economically. It is generally admitted, however, that the noise tolerated from earlier receivers, on account of the compensatory sense of novelty in reception, has now been replaced by a pleasing and reasonably accurate reproduction of the items broadcast, even though the frequency cut-off is commonly well below 9,000 cycles. The developments which have led up to this state of events will be reviewed briefly.

### **Crystal Sets.**

The most commonly used receiver for some years after the birth of broadcast entertainment consisted of a variometer or a pair of concentric solenoids, one coil being in the aerial circuit and the other in a tunable circuit containing a crystal detector and headphones.\* The range of such a set was confined to within a few miles of the transmitter as no amplification was employed. The absence of distortion-producing amplifier components earned for the headphones a reputation for purity of reproduction which was fundamentally fictitious. The amplifier of the time usually fed a loudspeaker having an even worse frequency response characteristic than the headphones.

### **Amplifiers.**

In 1922-24 the loudspeaker began to replace the headphones. Crystal or valve detection was followed by low frequency amplifier

stages in which valves which were commonly overloaded were coupled together by badly designed low frequency transformers. High frequency amplifiers, at first, were liable to serious instability on broadcast wavelengths owing to the effect of anode-grid internal capacity coupling. The tuned anode circuit was therefore limited to very low stage gains and the superheterodyne became popular. The inter-electrode capacity was less serious at the intermediate frequencies after heterodyning, so that amplification was more stable and effective in the superheterodyne. Eight-valve sets, however, required heavy battery currents; intermediate frequency transformers caused side-band cutting; the fear of re-radiation restricted the aerial to a small frame; many low frequency transformers meant many distortion-producers; and the valves were still overloaded. The quality obtainable from these early superheterodynes fell far below present-day standards.

The super-het was not without competitors in the form of cascade amplifiers for broadcast frequencies, in which stability was obtained in various ingenious ways. The mathematical investigations of M. J. Miller and H. W. Nichols, in 1919, had established the relation between stability and circuit conditions. Devices were therefore introduced (i) to ensure that the anode circuit remained capacitative, and (ii) to limit the stage gain. Screened coils and toroidal coils limited the magnetic coupling, and reversed inductive action was employed. Damping was obtained by close coupling to the aerial or allowing grid current to flow in the valve. Damped circuits and untuned couplings were tried, and many attempts were made to improve poor sensitivity by compensating anode and coupling circuits. Quality remained bad.

Round, in 1913, and Wright, in 1915, had both employed external methods of balancing out the inter-electrode capacity of valves. In 1923 and the succeeding years the principle of neutralization achieved a very wide popularity in broadcast receivers and the neutralized triode superseded the superheterodyne in favour. C. W. Rice and L. A. Hazeltine are credited with the introduction of the most widely used methods of neutralizing in high frequency amplifiers.

Hazeltine, who had previously devised a method of neutralizing stray capacitance between aerial and grid coupling coils of a receiver, introduced his circuit in America in the early part of 1923. Both his circuit and that of Rice depended on impressing on the grid circuit an e.m.f. equal and opposite to that impressed by the natural capacitance coupling due to the inter-electrode capacity of the valve. This was achieved by employing a tapped coil in one half of which was included a balancing condenser. The coil was connected, in its simplest form, to the anode, filament, and grid, the filament being connected to the centre tap. The neutralized triode was capable of being employed for very much higher stage gains without fear of instability.

Reaction, which was discovered more or less independently by De Forest, Meissner, Round, and Armstrong, in 1913, was commonly

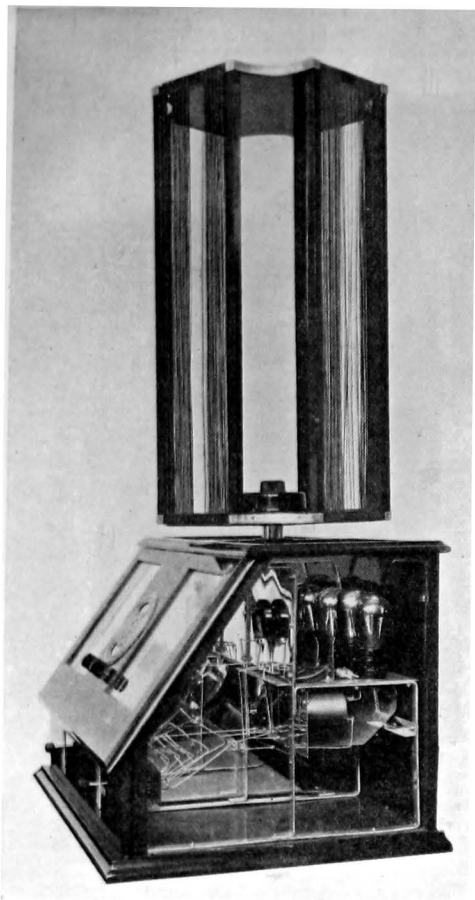


FIG. 50.—Marconiphone Superheterodyne,  
1927.

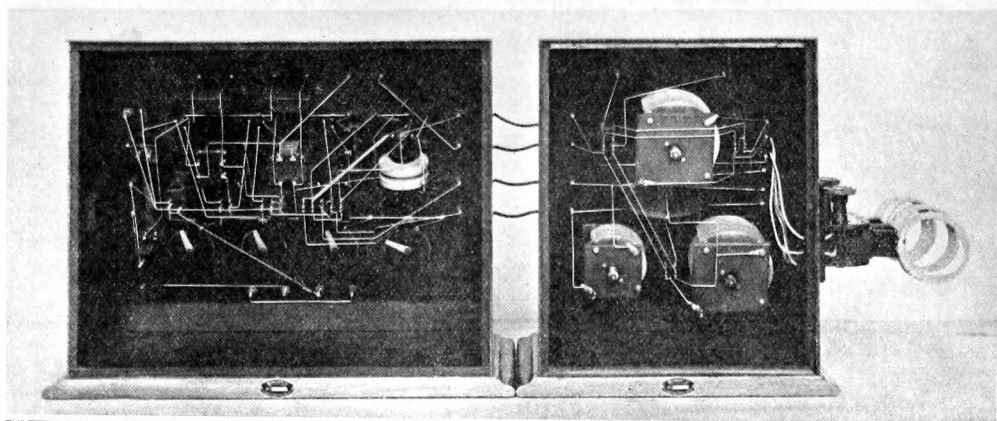
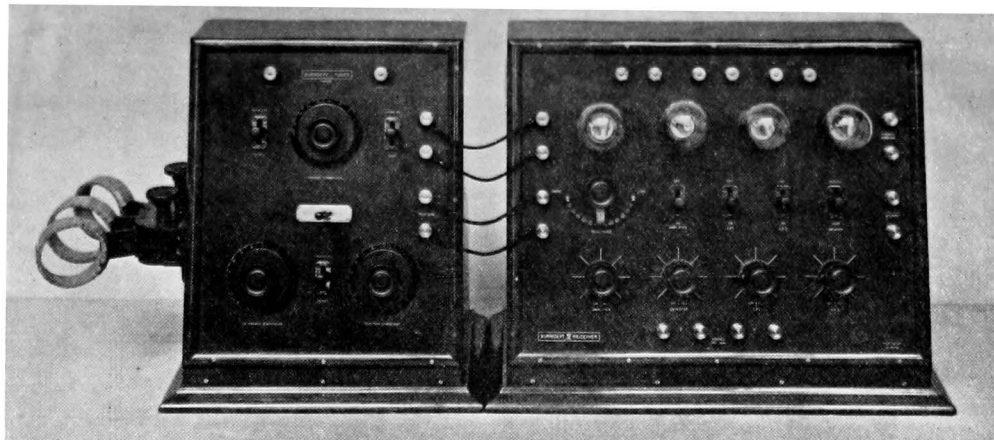


FIG. 51.—Burndept 4-valve Receiver, 1923.  
Tuner and Detector-amplifier Units.



To face page 69.]

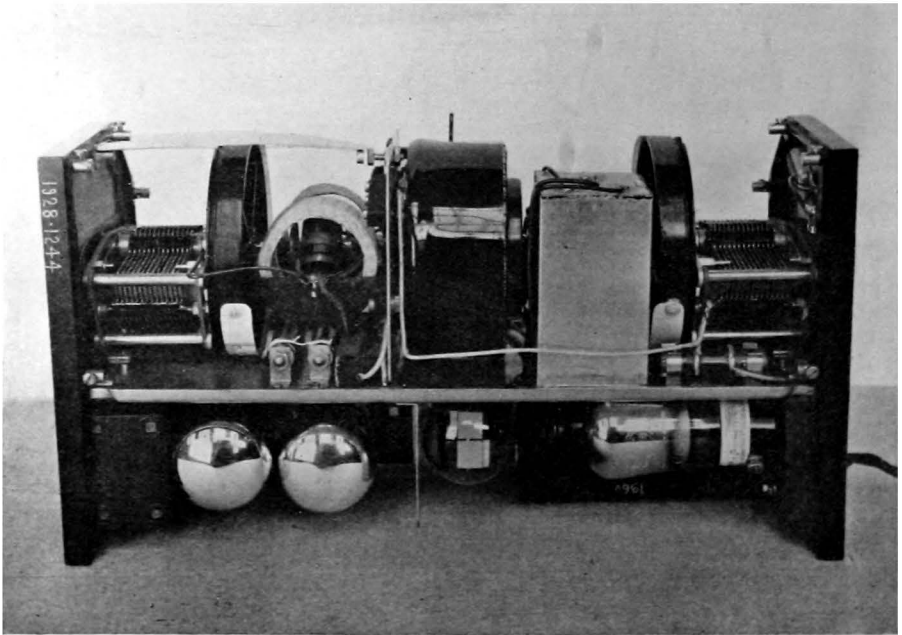
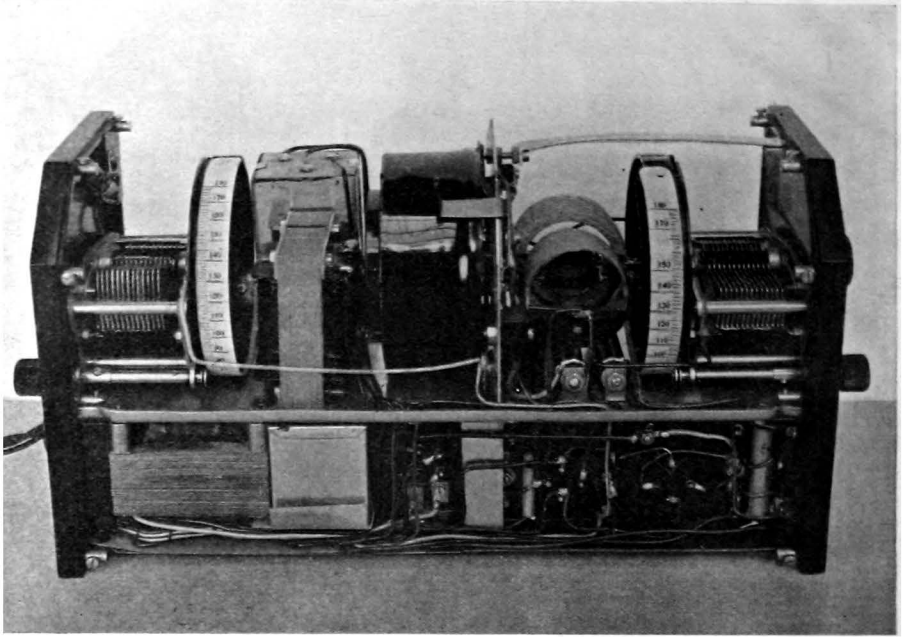


FIG. 52.—Philips All-Mains Receiver, 1928.  
(Cover removed.)

employed in order to increase the range of a set, at the expense of quality. The plate current of the first valve may be made to flow through a reaction coil coupled to the aerial circuit, the induced oscillations in the latter being fed again to the grid of the valve. The degree of high frequency amplification is thus increased, but care must be taken to control the oscillatory conditions set up.

The tuned H.F. circuits employing variometers of the Lorentz concentric type practically disappeared with the adoption of the flat type honeycomb coils. The coupling between these coils was varied by altering the angle between them. The flat coil was not a new device, having been used long before the war of 1914-18. The Telefunken variometer designed by Rendahl (and independently by Péri) was a particularly effective design which had been described as early as 1911. The untidy appearance of such variometers, which were usually mounted on the outer panels of broadcast receivers, was a feature which disappeared on the introduction by Butterworth of the low loss high frequency transformer wound on cylindrical formers of large diameter. The secondaries of these transformers were commonly of "litzendraht," a composite wire made of many fine insulated strands twisted together. The high frequency resistance of such wire (as appreciated by Ferranti in a patent of 1888) was low owing to the reduction of "skin effect." High frequency currents tend to confine themselves to the metal near the surface of a solid wire, thereby increasing the effective resistance. A solid wire of large diameter is more liable to show such an effect than a number of small insulated wires of equivalent area as the surface/area ratio is greater in the latter case.

Another improvement was the adoption of variable condensers of the logarithmic type instead of the semicircular vane types. The logarithmic shape of vane enabled more even frequency increments to be obtained per degree of rotation of the vanes, and therefore obviated insensitive tuning at the end of the scale. It was suggested by Bethenod in 1909.

The general construction of receivers was still somewhat untidy up to the introduction of the screen-grid valve, but as an example of the advantages obtained from incorporating the improvements described above, it may be mentioned that the "Everyman Four" receiver\* introduced by the *Wireless World* in August, 1926, achieved what was considered a phenomenal stage gain of 45 times the input strength (Fig. 49).

The screen-grid valve made external neutralization unnecessary as the screen reduced the anode-grid capacity to negligible proportions. It was, however, essential that this eliminated inter-electrode capacity should not be restored, at least in part, by the interaction between anode and grid external connecting wires. Very high stage gains were possible with the screen-grid and even a small stray capacity could cause instability. Systematic external screening therefore became necessary and a revolution in existing construction methods was inevitable. The

appearance of the screened set, in which the elimination of stray capacity outweighed other considerations in positioning the components, was quite distinctive. The improvement in performance may be gauged by comparing a Marconiphone set of October, 1927 \* (Fig. 48), with the "Everyman Four." Three screen-grid stages gave an overall high frequency amplification of 27,000. A notable feature of this 1927 receiver was the inclusion of a choke in series with the grid-filament circuit of one of the low frequency stages in order to increase the high note responses by resonance with the inter-electrode capacity of the circuit. As usual with battery sets the variation in filament brilliancy served as a volume control. Reaction was employed freely in this receiver.

### Detector Stages.

The increase in the efficiency of high frequency amplification from the time of the introduction of the neutrodyne circuit led to much stronger signals reaching the detector stage, particularly as the power of transmitters was being increased, but detector-amplification was still considered desirable. The diode detector, known since 1904, was incapable of amplification as well, but with the triode it was possible to secure amplification in the detector stage by feeding the signal voltages to the grid of the detector valve. Two methods of detector-amplification were tried at first, the "anode-bend" method and the "grid-leak" method. The former could handle a larger signal and was therefore preferred to the latter, in which distortion due to overloading was a possible danger. The latter, however, was far more sensitive for weak signals.

The anode-bend detector was made to work on the bend of the anode current/grid volts characteristic by applying suitable negative bias to the grid. The bend is such that an increase in positive applied grid voltage increases the anode current to a large extent, compared with the decrease for a similar decreased grid voltage, and rectification is thus obtained.

The grid-leak method employed the grid-filament portion of the valve as a diode detector. Its characteristic was almost linear for low inputs in the earlier designs, but the values for grid leak and grid condenser were inaptly chosen for higher inputs. The whole valve was employed as an amplifier of the rectified currents. The disability of the grid-leak detector was later removed by improved electrical design and it began rapidly to supersede the anode-bend method under the title of "power grid detection."

The screen-grid valve can also be used as a detector in which higher amplification may be obtained and in which the "Miller effect" of feed back from the anode circuit through the inter-electrode capacity of the valve may be eliminated. The "Miller effect" may cause very appreciable damping of the tuned circuit preceding an ordinary triode detector, due to grid current loss.

Another way of eliminating the effect is to combine two valves in push-pull for detection. This method also cancels automatically any residual high frequency currents and makes elaborate filter circuits unnecessary. Both halves of the signal are rectified and become effective, and the higher audio frequencies may be preserved while using a much larger leak resistance. At the cost of employing an extra valve a detector is obtained having a straighter characteristic and the overall efficiency of the stage is very greatly increased.

### Mains Operation.

The battery provides a supply free from oscillatory components, but requires constant attention and is liable to a drop in voltage under steady load conditions. There is also an economic limit to the voltages and currents available for quite reasonable requirements. In 1922, therefore, attempts were made to produce broadcast receivers which would work satisfactorily off direct current mains, but little practical success was obtained. For alternating current supplies the advantages of easy voltage transformation could be gained by the use of subsequent rectification. The valve rectifier was not highly developed and the low anode voltages normally employed could be obtained without transformation from D.C. mains, or were quite conveniently within battery limits. It was the introduction of improved valves requiring high anode voltages, about 1925, which stimulated the widespread demand for H.T. battery eliminators. Concurrent with this development was the increasing demand for L.T. battery chargers.

In 1926 a Gambrell set was introduced which relied entirely on an alternating current supply. A valve rectifier with a capacity of 60 milliamps was employed, and the output was passed through a smoothing circuit. The valve filaments were connected in series, high tension and grid bias supplies being available also. The indirectly heated filament valve of 1926 was liable to overheating, leading to electron emission from the grid. As an alternative to the valve rectifier the metal rectifier depending on the asymmetrical resistance of a copper-copper-oxide contact was described by Grondahl in 1926.

The design of indirectly heated cathodes, in which the greater heat required could be dissipated without undue heating of the grids, had reached such a stage by 1928, that the firm of Philips introduced an all-mains set into this country employing such valves\* (Fig. 52). The mains rectifier was of the full-wave valve type and the 3-valve set comprised a screen-grid high frequency stage, detector, and pentode output.

The progress made since 1928 has been swift. The flow of anode current through a bias resistor in the cathode lead may be used to self bias the valves. In earlier types the poor insulation between cathode and heater precluded this. A reasonably constant screen voltage is obtained by potentiometer connections, and anode supplies of varying magnitudes are readily obtainable by the use of suitable series resistances. The superior efficiency of mains-operated valves, which give large outputs with the least trouble, has firmly established the

set driven from alternating current mains as a reliable, flexible, and economic product which would be even more advantageous if much of the interference coming through the mains themselves were eliminated at the source.

The adoption of direct current mains supply has been much slower. Transformation, to obtain anode voltages higher than the mains voltage, involves the use of a machine which might as well be designed to provide alternating currents to obtain the advantages of the A.C. set at little extra cost. Accepting the limitations of anode voltage also means potentiometer methods of reduction to obtain grid supplies, etc., and the series connection of valve filaments is expedient, but not wholly desirable. Further developments in D.C. valves, on which much work was being done in 1933-34, may go far towards solving the problem.

### **Increasing Selectivity.**

The number of tuned circuits in a receiver rarely exceeded two prior to 1930, when the rising power and number of transmitters created a demand for further selectivity. The expert could tune a set with three or four dials controlling separate high frequency tuned circuits, but the general public demanded simplicity. The obvious reply to this demand was to have accurately matched condensers all mounted on a single spindle, but even after matching by means of small "trimming condensers," the accuracy of ganged tuning was not of the highest. Single-dial tuning was therefore marked by an increase in the number of tuned circuits, but a reduction in the efficiency of each circuit. Screened coils of relatively low efficiency were introduced, and the elaborate screening of complete stages was discontinued for ordinary purposes. The screened component assembly on a metal chassis became usual.

In 1928-29 considerable attention was given to the development of circuits for band-pass tuning, which had been the subject of investigation since at least as early as 1922. An important paper by Veerland in the "Proceedings" of the Institution of Radio Engineers, in 1928, is worthy of mention. The underlying principle is to modify the simple finely-tuned circuit, which gives a tuning curve declining steeply on both sides of a sharp maximum response at one particular frequency, so that the response at the sideband limits is not unduly reduced. The band-pass two-element circuit gives a tuning curve which is in effect a combination of two curves with their maxima displaced by a certain frequency width. The result is a "double-humped" curve which gives a reasonably uniform response to a band of frequencies, instead of a single frequency, but retains the sharp cut-off on either side of this band. The band width is designed to be twice the audible frequency range which it is desired to reproduce, selectivity thereby being obtained without sacrificing quality. The method of accomplishment is to combine two tuned circuits in a single stage by coupling them with a common capacity, a common inductance, mutual induction, or a combination of capacity and inductance. The use of any other number of band-pass elements would produce a corresponding number

of maxima in the tuning curve. Another method of improving quality while retaining selectivity is to design tone compensation circuits which tend to restore the distorted response of a sharply-tuned simple circuit to an even level by responding more fully to the attenuated notes. These circuits may be included in the L.F. stages only, with consequent disadvantages.

The congestion of the ether, which demanded increasing selectivity, became more serious as time went on, and interest in the highly selective superheterodyne was renewed. The additional tuned circuits of the intermediate frequency stages were an advantage in this respect. The introduction of dull emitter valves removed the prohibitive factor of filament consumption, and the years 1924-25 saw a great advance in superheterodyne popularity. It was not, however, until about 1930 that the use of band-pass tuning and more modern technique in general design enabled reasonably good quality to be obtained from the formerly poor superheterodyne. Another advantage was the design of non-radiating frequency changer circuits which made possible the use of an efficient outside aerial without fear of causing local interference. Second channel interference, which became more evident with the larger number of stations available, was minimized by employing two pre-selector circuits.

In 1931 the Robinson "Stenode" was the subject of much interest. It was a highly selective superheterodyne in which the loss of quality due to the use of sharply-tuned high efficiency circuits without band-pass was corrected in subsequent tone-corrector stages designed to respond more readily to the depleted frequencies. In the following year this principle was combined with band-pass, while difficulties in ganging were so effectively solved that single-dial tuning became possible.

The accuracy with which ganged condensers could now be made commercially enabled the high-efficiency coil to reappear. A further development in design became common in 1932-33 with the introduction of iron-cored coils which were suitable for use on broadcast frequencies. The telephone engineer had used iron-cored transformers since 1885, when Ferranti and Addenbrooke patented their use. At audio frequencies they had been applied to radio communication early in the history of the valve amplifier, but the iron-cored high frequency transformers designed by Latour in 1916 were only successful on the longer wavelengths. The core losses at higher frequencies tend to become excessive, increasing the effective resistance of the coil. The eddy currents set up are not only large but reduce the apparent permeability of the iron by impeding the full penetration of the magnetic flux. Even the highly permeable alloys, such as the nickel-iron "permalloy" with a permeability of 100,000 at power frequencies, were not good enough at radio frequencies, the penetration appearing to vary inversely with the permeability. The telephone engineer produced successful loading coils by using a moulded core consisting of finely divided particles insulated from each other electrically by shellac. These coils were improved by the use of finely pulverized electrolytic

iron coated with zinc and subjected to pressure with a binding of electrically insulating cement. The pressure was such that the elastic limit of the iron was exceeded and the particles "flowed" into a substantially homogeneous mass. At 100 kilocycles the permeability of such a core was about 50, but it was not until 1932 that the process had been developed sufficiently to obtain cores applicable to broadcast frequencies. In one process the iron particles are aligned magnetically and the core is interleaved with thin tissue paper.

The resistance caused by iron losses in iron-powder cores is great compared with copper loss so that a very large number of turns of fine wire may profitably be wound on a small core, thus giving a high inductance in a small space. A variable core may be included in the coil, variations in the core causing the permeability, and therefore the inductance of the coil, to alter. These variations form the basis of the method known as "permeability" tuning.

The employment of highly efficient iron-powder cored coils in broadcast receivers, which became popular in 1932-33, enabled sets to be designed employing fewer valves but comparable in selectivity with small superheterodynes. The iron-cored core, however, could also be applicable to superheterodynes with advantage.

The application of the screen-grid valve and the variable- $\mu$  screen-grid valve to high frequency circuits has been described in a previous chapter. Pre-detector volume control by alteration of the bias in a variable- $\mu$  screen-grid stage became common, freedom from cross modulation being a feature of the variable- $\mu$  type. The influence of such valve designs as the H.F. pentode and the frequency-changing pentagrid or heptode was also very noticeable in set design.

### **Audio-Frequency Amplifiers and Output Stages.**

The frequency response characteristics of the earlier inter-valve transformers was so poor that resistance-capacity coupled stages gave much better quality. The design of transformers with large primary inductance, to maintain the lower frequencies, and low mutual capacity between windings and low secondary self-capacity, overcame many of the former disadvantages. The demand for high outputs led to the use of stages with two valves in parallel, the push-pull connection being favoured round about 1927-28. Push-pull valve connections were published in many patent specifications, beginning with the Western Electric Co.'s No. 275 of 1915. The cancellation of second harmonics in push-pull circuits enables more of the characteristic of each valve to be used, while "motorboating" is obviated by the automatic elimination of alternating components of anode current. The Pentode valve made its appearance in 1928, and although it could readily handle large outputs, required means of correcting the high note loss caused by its high input impedance.

Some of the causes of distortion in audio-frequency output may be traced to the pre-detector portion of a set, but one of the essentials

of the final stage is the matching of the loudspeaker load to the valve characteristics. The loudspeaker itself is a source of distortion, but tone-corrector circuits may be developed to correct its more obvious deficiencies in many cases.

### **Battery Operation Developments.**

The adoption of mains supply was confined to cases where supplies were readily available and the problem of the battery still remained. Its importance for portable designs, including motor-car radio sets, is evident, apart from other cases. Economy in high-tension battery consumption may be obtained by the use of "class B amplification" described in the chapter on the thermionic valve.

### **Automatic Volume Control.**

Amplification in the detector stage became of so little importance, due to the excellence of pre-detector amplification, that it was frequently an economic proposition, about 1932, to take advantage of the nearly linear characteristic obtainable with diode detection at large inputs. The reversion to the diode detector was responsible for the development of metal rectifiers with suitable characteristics, such as the "Westector," and advantage was also taken of the applicability of diode detection to automatic volume control. The adjustment of subsequent amplification to compensate for variations in the strength of the incoming carrier wave was not a new device, as explained later, but it became of rapidly increasing significance in broadcast receivers about this time, and was subject to extensive development.

The rectified carrier wave, if fed back and applied as bias to pre-detector stages, controls the degree of high frequency amplification and therefore relates the detector input to the strength of the incoming signal. The variation in amplification involves a variation in background noise, which is not so apparent and undesirable as variations in output volume. Fading is thus substantially corrected except in so far as frequency distortion effects are concerned. The maximum volume obtainable at even strength without distortion due to overloading is dependent on the minimum signal received, unless delayed control is introduced. The use of a duo-diode triode, so arranged that one diode is employed for rectification while the other "delays" the automatic volume control until the signals reach a pre-determined minimum level, is one way of removing the main force of this disadvantage. Some degree of fading is a liability with this method, but only when circumstances are such that the lesser of two evils must be chosen. The triode portion of the multiple valve is employed in the first low frequency amplifier stage.

The tendency of automatic volume control to amplify interference and background noises to full signal level, during tuning intervals when no carrier is being received, may be corrected in two ways. The sensitivity of the set may be reduced by means of a hand-operated switch during tuning, giving partial relief. Programmes which cannot



be received under these de-sensitized conditions are usually incapable of being reproduced with quality sufficient to give good entertainment value. The reduction in sensitivity may be obtained automatically by employing an additional valve to pass current through a high resistance to the grid of the first low frequency valve when no carrier is being received. The overbiasing of this valve automatically reduces sensitivity and nothing is heard until the set is accurately tuned to a station. The control valve is operated by the incoming carriers through a sharply tuned circuit, which in some cases is specially provided along with a separate rectifier. The range of delayed automatic volume control may be increased by employing a duo-diode pentode of the variable-mu type, the biasing of the low frequency pentode portion enabling post-detector control to be added in such cases.

Automatic volume control was applied to line telephony in 1918, and many isolated but somewhat limited solutions have been devised for broadcast reception since 1925. The use of the carrier wave for biasing enables the correct relationship between the pianissimo and fortissimo passages of the audio-frequency components to be preserved. Any control by the audible signal components would obviously result in an output of constant sound intensity. Before the advent of the variable-mu valve the problem of avoiding cross-modulation seriously handicapped attempts at automatic control of volume.

## TELEVISION (and Picture Telegraphy)

Broadcast programmes, without television, are marked by a technique as restricted as that of the silent film in comparison with the later talking film. Their range of subject matter is limited, the aural effect exaggerated, and their entertainment value, while satisfactory enough to be appreciated, is open to improvement. Television, when it has reached the necessary stage in development, should provide the means towards such improvement.

### 1. *Picture Telegraphy.*

The reproduction of a still picture at a distance by wire or radio involves a process known as "scanning" The picture may be considered, not as a complete subject, but as a number of successive light and shade values which, when arranged in their correct sequence, build up into the required scene. A close examination of a newspaper illustration or one of those in this book will show how a large number of dots of varying intensity can be made into a "half-tone" illustration. A picture of average detail, about 3 in.  $\times$  2 in., may contain 60,000 of these dots. Therefore, for picture telegraphy, if the scene is divided into 10,000 elements per square inch of area and the light and shade value of each element is resolved into an electric current by focussing it on to a photo-electric cell, 10,000 electric signals must be transmitted to correspond to each square inch of picture. If these signals are received at a distant station and can be converted back into light and shade values at that station, a reproduction of the original picture will be formed if the light and shade values are arranged in their correct sequence.

In practice the received signals are used to modulate a light source which is focussed on a photographic screen. The receiving apparatus moves in synchronism with the "scanning" device at the transmitter. Several minutes may be required for the reproduction of one average-sized picture.

Picture telegraphy, of relatively poor definition, dates back at least to 1881, when Shelford Bidwell gave a practical demonstration before the Physical Society. A light shone through a transparency of the picture on to a selenium cell in a battery circuit. The picture was moved in synchronism with a platinum pointer at the receiver. The pointer moved over a paper moistened with potassium iodide, the amount of free iodine liberated, and consequently the discoloration of the paper, being proportional to the received current. Simple pictures could thus be reproduced.

The sensitivity of selenium to light was discovered by May in 1873. As early as 1875 a selenium-controlled lamp screen was proposed by Carey for picture transmission, but the number of lamps

required made the proposition impracticable. Three years before Bidwell, in 1878, De Paiva explored a plate of selenium upon which a design was shone, and in the following year Senlecq combined the ideas of Carey and De Paiva in a scheme using synchronized contactors for exploration and lamps for reproduction.

In 1880 a method of scanning the picture by a mirror was proposed by Maurice Leblanc. The mirror was actuated by currents of two distinct frequencies, one to correspond to the persistence of vision (10-20 cycles per second), and the other to the fineness of detail required (about 1,000 cycles). Nipkow, in 1884, showed that a picture could be scanned (i.e. divided into a number of adjacent elements) by means of revolving spirally-pierced discs, a method later used by Baird, while the mirror drum, with a number of mirrors arranged successively round its periphery was attributed to Weiler in 1889. The mirror drum and its developed form, the mirror screw, have been applied to mechanical systems of television for which some measure of success has been claimed.

Von Leiben, in 1906, suggested a method of exploring a picture by means of a stylo and reproducing it by means of the cathode ray oscillograph. The following year A. A. Campbell-Swinton predicted that both scanning and reception by cathode ray oscillograph held out the only real hope of effective television owing to the complete freedom from inertia of the rays which enabled them to be used at immense speeds. His proposals were published in *Nature* of June 18th, 1908.

Earlier in the present century a method of resolving a picture into a code telegram was demonstrated by Korn. It meant laborious handwork both at the transmitting and receiving end.

Two factors emerged to make picture telegraphy over long distances a practical proposition. The first was the development of the thermionic valve amplifier enabling the feeble light responses to be augmented, and the second was the introduction of the more sensitive and rapidly responding photo-electric cell in place of selenium.

Further consideration of the development of still picture telegraphy is not within the scope of this handbook. It is sufficient to state that the rapid transmission of news photographs of reasonable quality is now common over great distances, using both line wire and radio circuits.

## 2. *Television.*

The transmission of a still picture may take several minutes. The cinema, however, by projecting a succession of twenty-four different still pictures every second, sustains an illusion of continuous motion due to the persistence of human vision. A picture 3 in.  $\times$  2 in. containing 60,000 picture elements (or changes of light and shade value) was considered above. Transmitting a picture of this size twenty-four times a second entails producing, transmitting, receiving, and arranging in exact synchronism, 1,440,000 signals per second. An amplifier,

to handle these signals, should be capable of dealing with a band width of 720 kilocycles. These figures are arbitrary and give a somewhat pessimistic idea of the requirements for good television, but they are sufficient to indicate the magnitude of the problem confronting the television worker. The same apparent quality is obtainable with less actual detail when a rapid succession of pictures is being viewed, as in television.

The application of television to radio communication and even the transmission of still pictures by telegraph could not advance to any appreciable degree until the valve amplifier with the necessary response characteristics had been developed. In addition the time lag in the response of selenium to light changes was a severe handicap. In 1923 Baird in England and Jenkins in America succeeded in sending "shadowgraphs" by television. In such transmissions the available light took the form of intense direct rays and no graduations between light and black were required, whereas in television only the small amount of light reflected from the scene is available.

In 1925 Baird succeeded in the wireless transmission of outlines which led to the achievement of a crude form of true television in a demonstration given by him in January, 1926 (Fig. 53). He flooded the scene to be transmitted with very powerful lights, using the reflected light to vary the current in a photo-electric cell circuit through a Nipkow scanning disc. After transmission over a carrier wave modulated by these variations, he reconstituted the picture at the receiver by interposing a synchronously driven scanning disc between the eye and a neon lamp, which varied in intensity according to the variations in the original photo-electric cell currents. The discs at both transmitter and receiver were driven by synchronous motors, and by pulling them into the correct mechanical phase the picture elements of the transmitter were seen in the correct position and sequence at the receiver. The image at the receiver was 2 in. square, dull, flickering, and liable to distortion. It was, however, recognizable, and the forerunner of what promises to be an epoch-making period of scientific development.

In the following year Baird employed "noctovision" or the illumination of his scene by the invisible infra-red rays obtained by putting ebonite sheets in front of his floodlights. (The sensitivity of light cells to infra-red rays had been shown by Pontois in 1890.) He also patented the light-spot method of scanning in which a brilliant light spot traverses the scene and the reflections from the scene elements fall on to a photo-electric cell. The need for a brilliant illumination of the whole scene is obviated by this method which also enables greater signal strengths to be attained more easily.

These early attempts, which also stimulated many other investigators to experiment with and improve upon similar apparatus, employed mechanical means of scanning and reconstitution of the scene. The number of signals handled was limited by mechanical considerations, leading to poor definition and a reduction in the number of scenes per

second to 12.5, a threshold figure involving a pronounced tendency to flicker.

The mechanical features have since been greatly improved, but they leave much to be desired, the difficulty of obtaining perfect synchronization being one troublesome factor. The mirror drum and mirror screw were found to be improvements on the Nipkow disc. On the electrical side the instantaneous response and increasing responsiveness of the photo-electric cell to light is of great assistance. The poor illumination of the neon lamp is no longer such a handicap in reception since the directly-modulated arc or the more favoured Kerr cell equipment replaced it. The Kerr cell contains a liquid, such as carbon disulphide, through which a beam of light polarized by a pair of crossed Nicol prisms may pass. The plane of this polarized beam rotates under the influence of an electromagnetic field across the cell. If the field is created by the received television currents the plane rotates in harmony with the modulation. The beam impinges on a second set of crossed Nicols which pass an amount of light dependent on the degree of rotation. The arrangement is very inefficient, but the initial brilliance of the light source more than makes up for this compared with the neon lamp.

The speed of scanning for a given degree of definition may be reduced by dividing the scene into several portions, each of which is scanned and reconstituted independently. This development, in mechanical methods, was demonstrated to some extent in 1931.

#### *Cathode-Ray Systems.*

The cathode-ray oscillograph method of transmission and reception was proposed by Campbell Swinton as early as 1908, before effective means of utilizing its properties had been invented. He foresaw that the freedom from inertia of the cathode rays within the wide limits required for television might be used to obviate one of the greatest disadvantages of mechanical systems.

In 1921 some investigations were undertaken by Schoultz, with little practical success. Belin and Holweck used a cathode-ray receiver to reconstruct shadowgraphs in 1927, but it was not until 1930 that the researches of von Ardenne and Thun produced more encouraging results. They received mechanically-transmitted images on cathode-ray equipment with definition as good as in contemporary mechanical receivers, in 1931, and then proceeded to devise a complete cathode-ray device on different lines.

In 1911 a method of "variable speed cathode-ray television" was proposed by B. Rosing. It was revived by Thun in 1929 and brought to practical realization by von Ardenne in 1931. The basic principle is so to actuate the cathode stream that it travels quickly over dark parts of the scene being reproduced, and correspondingly slowly over the light parts. The degree of illumination of the fluorescent screen in the cathode-ray tube depends on the speed at which the rays traverse

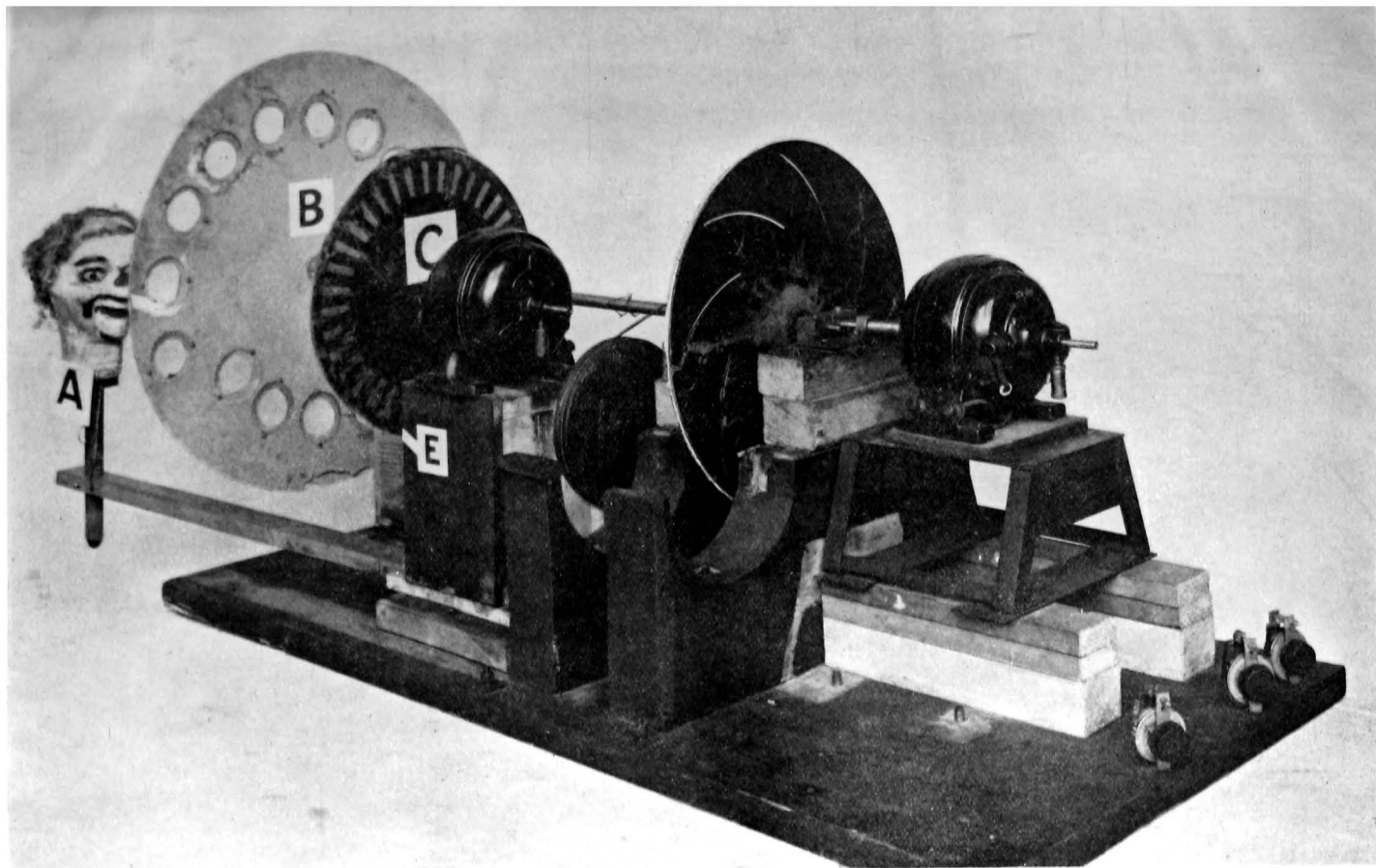
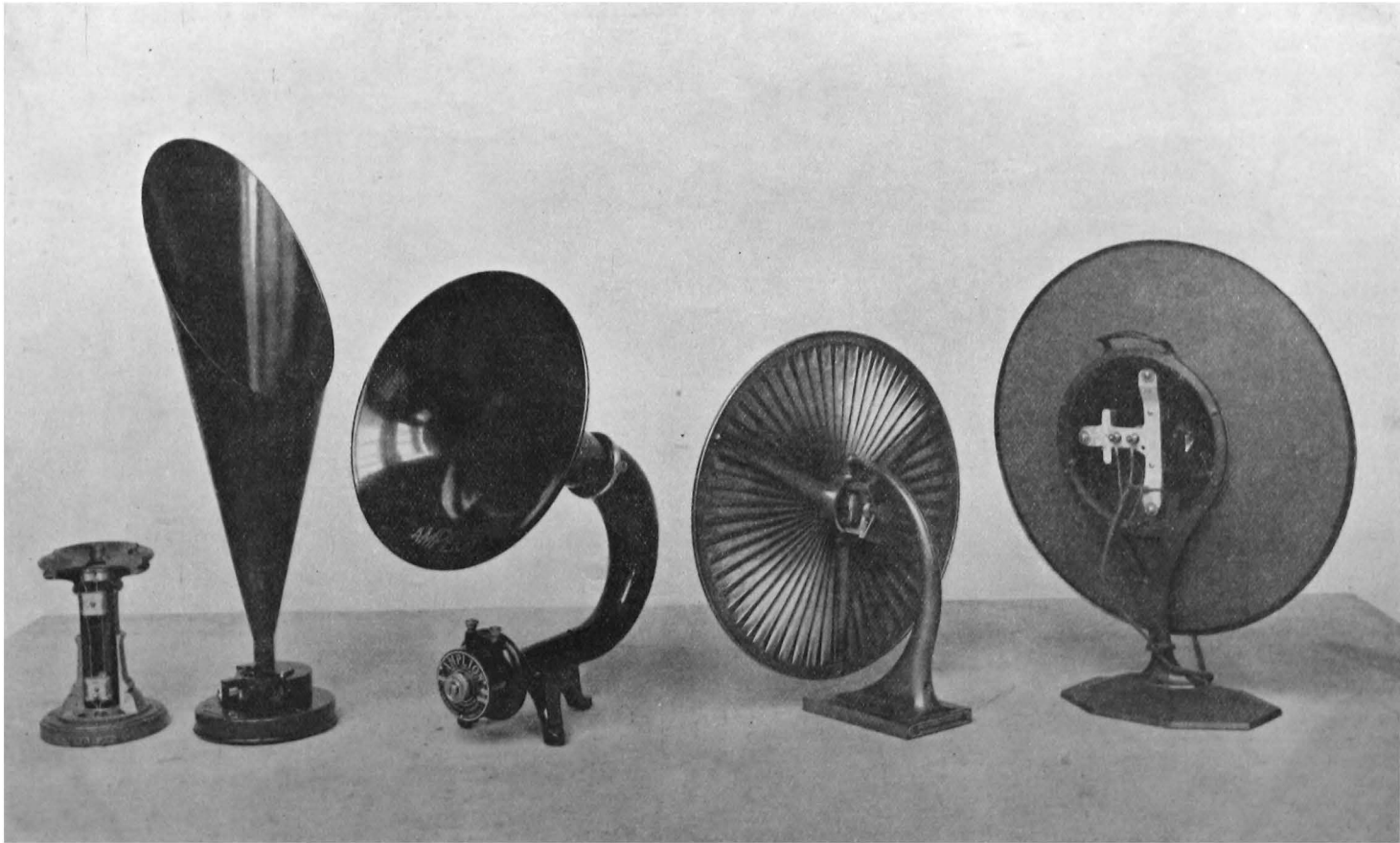


FIG. 53.—Original Baird Television Transmitter, 1926.



Loudspeaking Telephone, Conical Horn,

FIG. 54.—Early Loudspeakers.  
Amplion Horn, Sterling Primax Lumière

Western Electric Cone,

it. The advantage of this method is that the cathode-ray beam may remain constant in intensity, and this is generally desirable as the older and alternative system, depending on modulating the intensity of the beam, led to difficulties in keeping the spot accurately focussed on the screen.

The process of cathode-ray television on this system may be described briefly as follows :—

1. Owing to requirements of scanning-light economy with present cathode-ray transmitters, it is desirable to have a film of the scene to be transmitted.

2. The light from the fluorescent screen of the transmitting tube is projected through the film on to a photo-electric cell.

3. The output of the photo-cell amplifier operates a time base circuit (through a screen-grid valve and a thyratron) which supplies a potential difference to one pair of the deflecting plates in the tube. The ray is thus swept across the picture in a straight line with a velocity depending on the transparency of the picture.

4. A second time base circuit is connected to the second pair of deflecting plates in the transmitting tube in order to traverse the scanning line across the picture in successive steps, so as to cover the whole area of the picture.

5. The two voltages applied to the deflecting plates of the transmitting tube are sent to the receiving tubes, which necessarily move their beams through similar evolutions, thus reproducing the picture on their fluorescent screens.

For a picture scanned in 120 lines with a picture frequency of 25 per second, a frequency band of about 240 kilocycles is required for transmission. An advantage of the system is that detail is concentrated in the lighter parts of the picture. Many investigators are now engaged in research on such systems, and also in the development of "hard" tubes to give a longer life.

Dr. Zworykin was prominently associated with the early development of the photo-electric cell and of television in America. In 1925 he devised a system of colour television employing tri-coloured mosaic filters in front of the screen of a cathode-ray receiver. In 1933 he introduced an ingenious device known as the "iconoscope." It consists of a photo-electric mosaic containing millions of small silver globules sensitized by caesium. The globules are deposited on the reverse side of a sheet of mica coated with metal and the scene to be televised is thrown on the photo-sensitive surface by a lens system. The whole is contained in a tube containing a cathode-ray "gun," a stream of electrons being swept over the screen by the usual electromagnetic scanning action. The electrons tend to discharge the small condensers as they impinge upon them, the discharge currents being collected and transmitted to a receiving cathode-ray equipment in which the rays synchronously scan a fluorescent screen. The original



scene is thus reproduced by the modulated receiving beam. A somewhat similar device was made in the same year by Dr. Henroteau, in Canada.

The wide frequency band-widths required for elaborate transmission form a great deterrent to development of 120-240 line scanning (demonstrated in Germany) compared with the 30-line pictures employed in the mechanical system first developed in this country at a picture speed of 12.5 per second. Anything from 150 to 1,000 kilocycles per second is desirable, but the Geneva Convention came to an agreed station separation of 10 kilocycles. The shorter wavelengths have therefore received attention as there is a separation of 1,000 kilocycles between, say, 7.5 and 7.7 metres. The problem of designing an amplifier for such a band-pass, without introducing appreciable distortion, is far from simple. The Schottky effects evident in valves handling very low inputs were shown by Johnson in the *Physical Review* of 1925 and 1928 to be attended by a third type of fluctuation which he termed the "temperature effect." This effect applies to a considerable degree to amplifiers handling wide band-widths and weak signals. An increase in the number of strips into which a picture is divided during scanning leads to weaker current responses from the photo-electric cells, for a given source of illumination, and therefore demands greater amplification. At the same time the band-width to be handled is increased.

The televised scenes considered hitherto have been very small. In order that they may be viewed by a large audience the Fernseh A.-G. in Germany receives them on cinema film which may be developed and projected within a few seconds.

The future of television seems now to be hopeful to a degree which, only a short time ago, would have been decidedly optimistic.

## MISCELLANEOUS DEVELOPMENTS

### Microphones.

The early experiments in the transmission of speech frequencies by radio relied on existing designs of telephone transmitters for modulation of the continuous wave carrier. The frequency response of these instruments was very uneven and confined within narrow limits, while the absence of suitable amplifiers and systems of modulation made it necessary to pass the whole of the aerial current through the microphone. This caused overheating with any but the smallest powers, and many devices were introduced to obviate this disadvantage.

The telephone instrument began, as far as practical success was concerned, with the electromagnetic receiver introduced by Graham Bell in 1876.\* These receivers were also used for transmission, but were inefficient, the carbon button transmitter of Edison being a great improvement. In 1878, the year after Edison's invention, Hughes developed his first carbon microphones\* which depended for their great sensitivity on loose contact phenomena. The carbon granule microphone, which in effect multiplied the number of active loose contacts, followed from the work of Edison and Hughes and provided the material on which the first radio-telephony investigations were made.

The first problem to be attacked was that of cooling, and in the light of modern valve amplification, these attempts have purely historical interest. Their success did make telephony an accomplished fact over considerable distances with arc sets, but as late as 1913 it was considered that the practical sphere of radio communication lay almost entirely within the bounds of code signalling. It was appreciated that the introduction of indirect modulation, such as the inclusion of a microphone to control the exciting current of a Goldschmidt Alternator, might stimulate progress, and the amplifying valve was on the horizon. A brief survey of the development in methods of direct modulation is given below.

Air-, oil-, and water-cooled microphones were tried by many investigators including Fessenden (1906), Dubilier (1911), and Egner and Holstrom (1912). Fessenden, who used his water-cooled microphone in a relay circuit for transmission of speech over a landline to a radio-telephone transmitter, claimed that 15 amps. could be handled. This may be compared with the 0.1 amp. which was about the limit of the ordinary uncooled single solid-back microphone. Dubilier used a number of microphones in parallel connected to a single mouth-piece, and Goldschmidt, in 1912, patented a method of connecting parallel microphones whereby circulating currents between them

could be avoided. In the Marzi microphone of 1910\* a stream of carbon granules poured continually on to a carbon plate, the stream varying in resistance according to the movement of the plate holder which was actuated by an electromagnet in an auxiliary weak current microphone circuit. This was, in effect, a somewhat cumbersome amplifier.

The liquid microphone, in which oscillations of a diaphragm alter the angle of a plate which in turn deflects a column of liquid, altering its resistance, was first introduced by Jervis-Smith in 1879. Chichester Bell, in 1886, discovered that sound waves impinging on a jet of liquid caused it to form corresponding variations in volume. F. Majorana employed this phenomenon in his microphone, in which the resistance between a metallic disc and a concentric ring insulated from it varied in accordance with the volume impinging from the jet on to the disc and flowing away across the ring. Majorana's first patents were dated 1905. His microphone had reached a practical degree of success by 1909-10 and was the subject of a further patent in 1913. Speech over 300 miles was successfully received in conjunction with a 500-volt Poulsen generator and two stations of moderate power. Another hydraulic microphone to achieve some success was invented by Chambers in 1910. The diaphragm directly alters the resistance to a closely placed nozzle from which a jet of acidulated water is forced. Such microphones could handle 250-500 watts.

The Vanni liquid microphone was used in the telephony demonstration between Rome and Tripoli in 1912, and was used for the direct control of aerial currents up to 15 amps. A jet of acidulated water passed between a nozzle and a fixed slanting plate. The jet could be deflected by another plate connected by a lever mechanism to a diaphragm actuated electromagnetically from a step-up transformer and an ordinary carbon microphone. The resistance of the jet could be made to vary with speech currents to a large degree, but the control of the hydrostatic pressure was very critical to obtain the best results.

Alexanderson's magnetic modulator, referred to on p. 60, was a type of microphone amplifier which aroused much interest. His patents were taken out in 1911, 1913, 1915, and 1916. The microphone currents, which later were amplified by thermionic valves, were at first used without amplification to vary the permeability of an iron core which was common both to coils in the microphone circuit and to two coils connected across the terminals of a high frequency alternator. The variation in the permeability of the core due to microphone currents in the first set of coils varied the impedance of the alternator circuit coils, with consequent modulation effects on the alternator output. The output of a 75-kW. 40,000-cycle alternator was successfully modulated with this arrangement.

Dolbear, in 1879, invented an electrostatic telephone in which the space between a diaphragm and a fixed plate varied with the impingement of sound waves on the diaphragm. Such variations altered the capacity between the plates. This principle is used in condenser

microphones, early experiments with which were conducted by Fessenden, and Burstyn (1909). The condenser microphone was not readily applicable before the advent of the valve amplifier as its direct power-handling capacity is very small.

During the war of 1914-18 considerable use was made of a microphone depending on the sensitiveness to sound of a hot wire included in one arm of a Wheatstone bridge circuit. The wire was surrounded by a resonator which could be tuned to reject the sounds of rifle fire and detect the otherwise inaudible notes of big gun fire. The arrangement is credited to Major Tucker and is a development of Koepsel's relay of 1907.

The Einthoven string galvanometer, employed by Marconi for high-speed reception, was adapted by F. Majorana as a microphone in 1903. The microphone contact was between a fixed contact and the fibre of the galvanometer. In the earlier days of broadcasting such microphones, with modifications, were employed by the British Broadcasting Co.

The advent of broadcasting created an immediate demand for microphones which would respond evenly over a wide frequency range. The development of valve amplifiers made it almost immaterial what output could be obtained directly. Earlier valve amplifiers were themselves far from distortion-free, so that, although good microphone characteristics were desirable, existing deficiencies were less noticeable. With the improvement of amplifiers the response of the microphone has become of increasing importance.

In 1921 the Western Electric Co. employed a microphone of the "push-pull" type in some very successful demonstrations of a public address system\* (Fig. 56). The diaphragm was an air-damped steel disc with a natural frequency of 8,000 cycles. Two carbon buttons, connected in series, were placed on each side of the diaphragm, which gave good results.

The British Broadcasting Corporation used microphones of a modified Bell telephone construction at the London studio in 1923\* (Fig. 56). These microphones replaced the carbon type formerly employed by them, but in the same year they standardized on an improved form of the Sykes microphone developed by Capt. Round of the Marconi Co.\* (Fig. 56). The Sykes microphone is actuated electromagnetically, employing a very heavy field magnet and an extremely light flat spiral coil as the moving element. This coil is suspended in an annular gap in the magnet, and its movements in response to acoustic vibrations set up currents in the coil by electromagnetic action.

In 1926 a greatly improved carbon granule microphone was introduced. In the Marconi-Reisz microphone\* the diaphragm was virtually discarded, a very thin sheet of mica keeping the carbon granules in place. The granules, which filled a large shallow area, were capable of a certain amount of free movement although they were made of

varying sizes so that the interstices between large granules might be filled by small ones. These microphones were consistent in performance and easy to maintain, but they suffered from background noise and a lack of linearity in their characteristics with amplitude, which involved a tendency towards "blasting."

The condenser microphone became a practicable proposition with the development of the valve amplifier, a design being evolved in which a stretched diaphragm of thin metal was fixed about 0.001 in. away from a solid metal plate. Sound waves impinging on this thin diaphragm caused it to vibrate and vary the capacity of the condenser formed by the two metallic areas. Stretching the diaphragm increased its natural frequency which might be increased to a resonant point somewhere near the upper response limit. The higher frequencies were thus brought within the range of the microphone, but in practice a natural frequency of 4,500 cycles and a negligible response above 6,000 cycles denoted the usual limits. In addition to this construction, favoured by the Western Electric Co., slack diaphragm condenser microphones have been made. One design, by Voigt\* (Fig. 56), used since 1931, was very simple and effective, having the additional advantage of being practically non-directional. The response was appreciable over a reasonably wide range. The output from condenser microphones is so small that a valve amplifier must be mounted at the microphone itself. This is apt to be undesirable, particularly under certain conditions such as outside broadcasts of certain types and in talking film work.

The B.B.C. investigated two types of moving-coil microphone during 1933, with encouraging results. In the first type (see B.B.C. Year Book, 1934) the mass of the diaphragm and the elasticity of its suspension were arranged to form the first elements of a low-pass mechanical filter circuit. Certain resonant features, deliberately introduced, formed the remainder of the filter. The cut-off frequency was 10,000 cycles, a figure considerably higher than the limits of the condenser type. The filter system of construction tended to eliminate pronounced resonances. The second type allowed a pronounced resonance to appear at about 500 cycles, the design aiming at making this resonance as simple as possible, between the mass of a rigid diaphragm and the elasticity of its suspension. A simple electrical circuit could then be introduced which would almost exactly correct the effect of this resonance. In this system a very small diaphragm may be employed, thus eliminating most of the directional effect which otherwise becomes apparent with the higher frequencies. Unless the diaphragm size is small a progressive diminution, with frequency of the response to sounds coming from directions other than axial to the diaphragm, is experienced.

### Loudspeakers.

The general adoption of the telephone in wireless reception began about 1903, when its sensitivity was preferred to the advantage of preserving a printed record of the message received. The telephone,

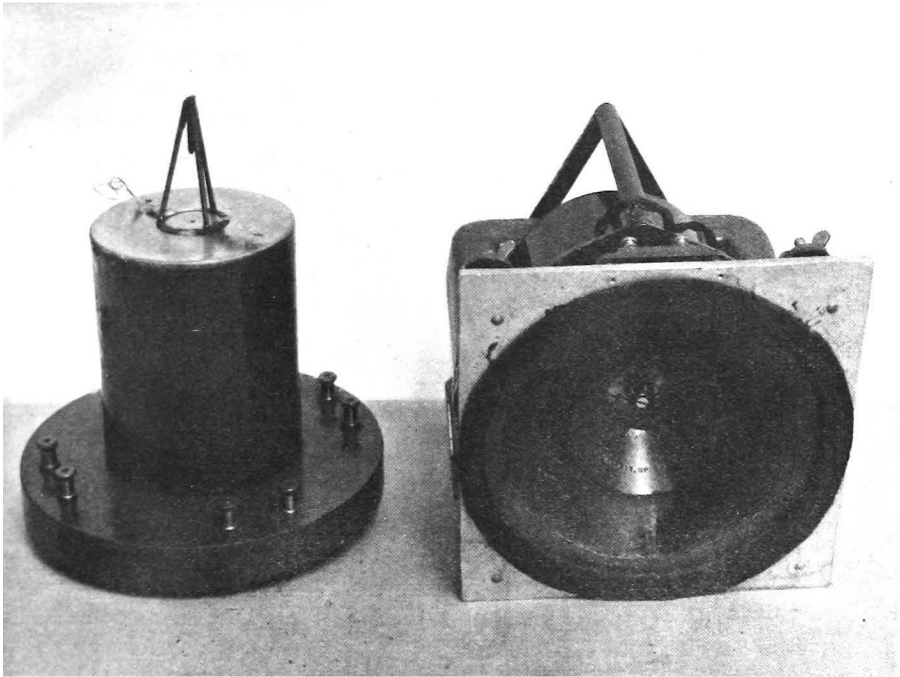


FIG. 55.—Moving-Coil Loudspeakers.

Lodge, 1898.

Voigt, 1934, with auxiliary free edge cone for reproduction of upper frequencies.

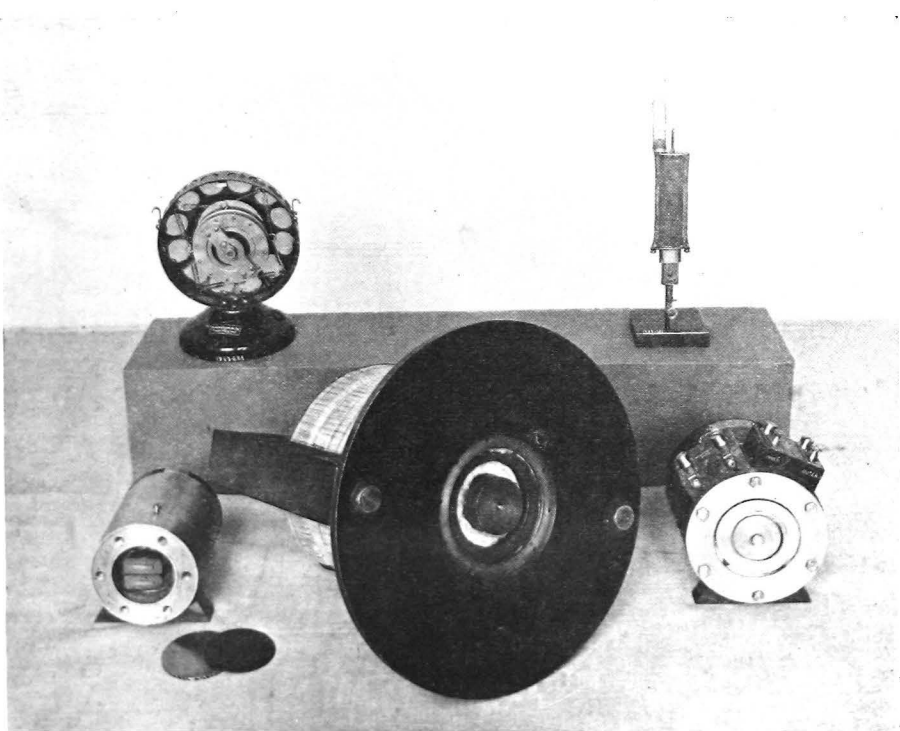


FIG. 56.—Microphones.

Western Electric Push-pull, 1921.  
B.B.C. Bell Type, 1923.

Sykes (ca. 1922).

Voigt Condenser Type, 1932.  
Marconi-Sykes, 1923.

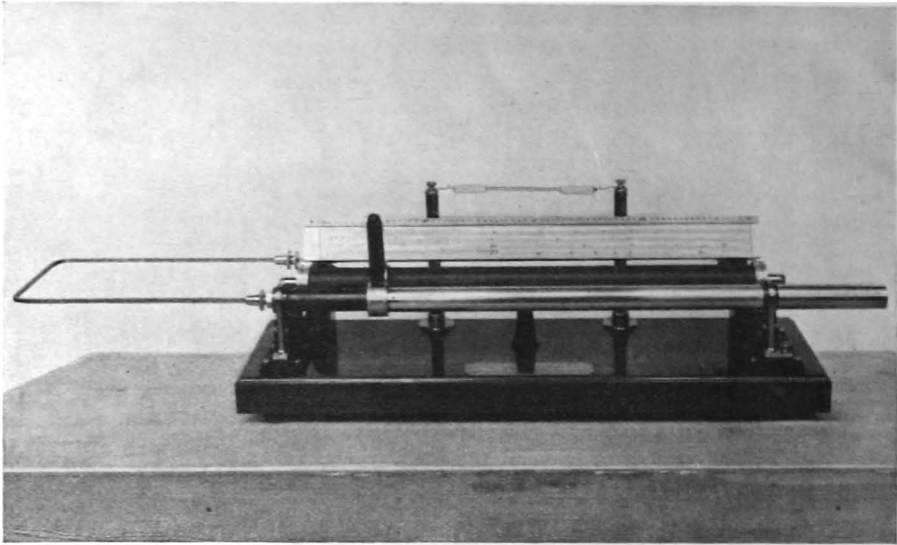


FIG. 57.—Fleming Cymometer.

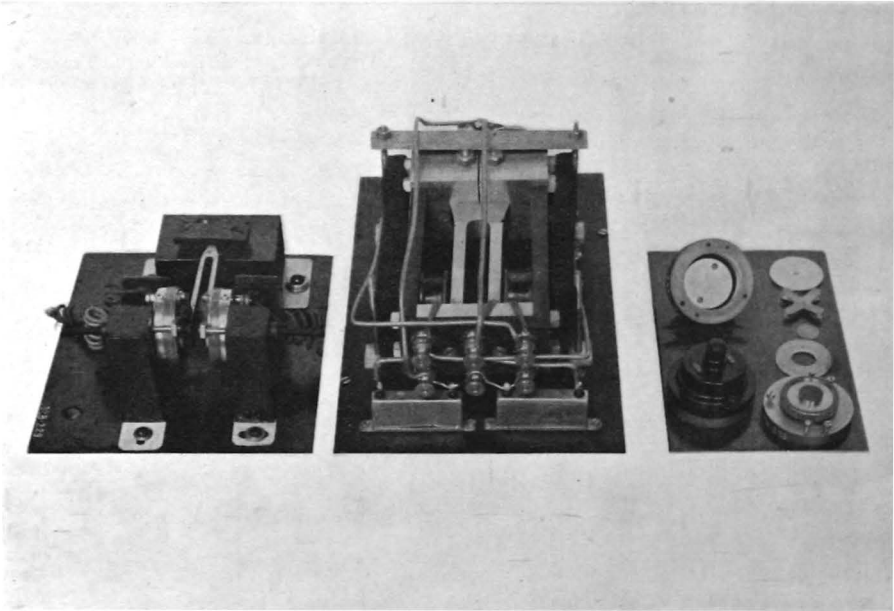


FIG. 58.—Frequency Control Devices.

Original Tuning Fork Control Apparatus of Eccles, 1918.

Tuning Fork Control used by the B.B.C. in 1926.

Piezo-Electric Crystals and Mountings.

with certain improvements, persisted almost unchallenged up to 1921, when the demands of broadcasting led to consideration of loudspeakers capable of handling large outputs. The loudspeaker, in radio reception, depended for success on the amplifier and, prior to the introduction of the amplifying valve, was of little use. In line telephony, however, the loudspeaker had been known and used for many years in certain applications where conditions were favourable. In addition the investigations of the earlier telephone engineers had almost wholly anticipated the more recent developments applied to loudspeaker technique.

Probably the earliest loudspeaker design was the chalk telephone of Edison known as the "electromotograph" \* which was introduced for line telephony in 1877. The friction between a platinum contact attached to a large mica diaphragm and a rotating chalk cylinder moistened with potassium iodide varied with the speech currents passing, thereby actuating the diaphragm. These receivers, which were used in the early days of telephony, were abandoned by 1880 on account of the difficulty of upkeep, but when in good condition gave exceptionally loud speech from ordinary telephone currents. The same principle, but using the more permanent lithographic stone in place of chalk, was employed in the Johnson-Rahbek loudspeaker \* which excited considerable interest in 1921. (It was patented in 1917.)

The Brown Telephone Relay of 1910 \* and the Telefunken Tone Intensifier of 1911 are worthy of mention. In the former a relay tongue connected to a microphonic cell vibrated and thereby strengthened or weakened an auxiliary battery current in the telephone circuit. The latter responded only to one particular frequency, having a resonant armature. They were both, however, more of the nature of amplifying devices than loudspeakers designed to reproduce at strong intensities.

The Brown loudspeaker of 1920 \* (Fig. 54) could handle a high output over a reasonable frequency range and was well known in the early days of broadcasting. An electromagnetically-operated reed was connected to a light conical metal diaphragm which could move as a plunger, as its edges were flexibly supported. A straight conical horn was fixed to an aperture above the diaphragm. The quality of reproduction was quite good within a limited frequency range, although certain resonances were evident.

The Bell telephone served as a basis for the design of a number of the earlier trumpet type loudspeakers. The flat circular polarized iron disc supported above an electromagnet was varied in detail by many manufacturers. Thus the Western Electric loudspeaker employed corrugated diaphragms to reduce peak frequency responses, and the diaphragms were actuated by mechanically-coupled armatures.

The moving-coil type of loudspeaker was also employed to some extent during these earlier years. Its history actually goes back to 1877 when C. W. Siemens described an arrangement consisting of a light coil, attached to a trumpet-shaped parchment membrane, and working



in an annular field obtained from a specially constructed horse-shoe magnet. Sir Oliver Lodge, in 1898, patented a form of moving-coil telephone in which a light coil, attached by means of a tripod to a sounding board, was suspended in the annular recess of a pot magnet \* (Fig. 55). In 1920 the Magnavox loudspeaker employed substantially the same arrangement.

The development of hornless loudspeakers was a noticeable feature of the years 1924-26. Conical diaphragms with different edge surrounds were discussed in a paper by Preece and Stroh read before the Royal Society in 1879. In 1908 some work was done by Lumière on a diaphragm consisting of a series of radially disposed ridges and furrows which gradually widen out and become more shallow as they reach a circumference with an edge clamped in one plane. Every part of the surface is under tension and the diaphragm vibrates as a whole in a manner fairly free from resonances. In 1914 the large cone diaphragm was patented by Hopkins. The Lumière pleated diaphragm was employed to a noticeable extent in mechanical gramophone reproducers of 1923 (His Master's Voice). In 1924 it was applied in the Sterling "Primax" hornless loudspeaker \* (Fig. 54). In the following year the smooth conical shape replaced the pleated diaphragm in such loudspeakers as the popular Western Electric "Kone" \* (Fig. 54). Much valuable pioneer work on the conical diaphragm was also done by Dr. N. W. McLachlan, who combined the cone and the moving-coil in many successful designs.\*

In 1925 the Rice-Kellogg moving-coil loudspeaker, sold as the B.T.H. "R.K." type in this country in 1926, made its appearance in America. The movement actuated a cone, and gave a fairly distortionless bass response which had been lacking in former types. Further developments of moving-coil designs \* in the succeeding years were mainly directed towards replacing the heavy energized magnets by permanent magnets,\* the wide use of which dates from about 1928, and increasing their sensitivity so that they became available for use on sets of lower power. Increase in sensitivity has required, in addition to powerful field intensities, a reduction in clearances and lightening of the coils. Swift, Levick, and Darwins, in 1929, introduced the four-claw cast-steel permanent magnet with mild-steel pole pieces to supersede the earlier heavy built-up types. In 1932 forged bars replaced the cast steel types while in 1933 the composite cobalt and tungsten steel magnet was introduced. The price and weight of magnets has been greatly reduced since 1928 while efficiency has at the same time increased. The energized magnet, however, is still widely used for quality reproduction. The characteristics of many materials for the cone have also been studied with profitable results.

The advent of talking pictures made high quality sound reproduction at high intensities essential and the coil-driven diaphragm with exponential horn was developed to meet this demand. In the Western Electric type, 555 W.\* of 1929, the diaphragm acts nearly as a rigid piston, the centre portion inside the coil being dished for rigidity while

the outer rim is made flexible. The efficiency of these units is about 40 per cent. compared with the 2-5 per cent. of domestic speakers. The efficiency of other types of moving-coil speaker has been increased to a comparable degree by the narrowing of clearances and intensifying of the field. The economic factor militates against the adoption of these methods for ordinary domestic use.

The "inductor-dynamic" type of moving-iron loudspeaker became popular in 1930-31 as an attempt to produce results comparable with those of a moving-coil unit. In a limited way a certain amount of bass response was obtainable. The patent of C. F. Varley, No. 270 of 1877, should be referred to as an example of the "inductor-dynamic" principle which involves the suspension of the armature in a manner which produces a substantially lateral motion. The "balanced armature," working in the neutral position between the poles of a permanent magnet, was patented by Siemens in 1877. The "balanced reed," in which the reed, connected to an external diaphragm, is similarly placed was patented by Husbards in 1882. Both these arrangements have been applied subsequently in the development of the moving-iron loudspeaker. The origin of the double diaphragm may be traced back at least to Cox-Walker's patent, No. 844 of 1878, and the stretched diaphragm dates at least from Bettini's patent of 1889.

The development of the loudspeaker has thus proceeded on lines which were foreshadowed in the work of some of the earliest experimenters with the telephone. The condenser type of loudspeaker is of even earlier origin, dating back to the "speaking condenser" to which attention was drawn by Elihu Thomson in 1863. Improvements have certainly been effected and problems such as matching impedance to the output valve have received attention, while tone-correction, to make up for irregularities in response, has been developed. The compensating action of the human ear is still relied on to a large extent, but methods of combining loudspeakers of different characteristics, to give a joint performance more nearly approaching the ideal, have reduced the onus laid upon aural adaptability.

The matching of two moving-coil loudspeakers of opposed characteristics became a popular expedient about 1932. In the same year the condenser loudspeaker, which had previously appeared in many ingenious designs, was developed in a popular form giving a good high frequency response but an early bass cut-off. The design of special circuits allocating the audible frequencies between the condenser loudspeakers for the top notes and moving-coil loudspeakers for the lower notes was effected. Another type of loudspeaker, developed in 1933 for use in combination with a moving-coil unit, was the Brush piezo-electric reproducer. The deformation of a large rochelle salt crystal cut along appropriate axes (or a combination of several crystals) was communicated to a diaphragm. The piezo-electric response was found to be appreciable over a desirably wide frequency range.

The use of two or more loudspeakers together is not free from disadvantages. Apart from the economic aspect, the matching of two characteristics is usually far from perfect. This may involve accentuated distortion at some parts of the scale, and phase distortion may also be experienced. The desirability of an increased range of frequencies in reproduction also depends on the capabilities of the receiving circuit, which in turn depend on the degree of selectivity required and further economic factors. Most commercial receivers sold to-day (1934) probably cut-off at 6,000 cycles or less. The human ear responds from 16 cycles to 17,000 cycles, and may even be responsive up to 30,000 cycles. The best loudspeaker is therefore a decided compromise when used for radio reception.

The criteria for judging the performance of loudspeakers or groups of loudspeakers have not yet been standardized and response curves, as published, must be accepted with caution. The usual curve is taken by means of a microphone on the loudspeaker axis, a heterodyne note varying over the audible range at a regulated speed being reproduced by the loudspeaker, and its apparent intensity being recorded by an instrument in the microphone circuit. The result obtained depends on the microphone characteristic and the speed at which the note is varied, too high a speed tending to flatten out resonances as the friction and inertia in the recorder may require a greater time to register the full effect than that taken to pass the resonant point. In addition the non-axial characteristics of loudspeakers may show great discrepancies in the relationship between high and low note reproduction in directions off the main axis.

### Measurement of Wavelength.

The adjustment of transmitters and receivers to the same resonant frequency is as old as the early "syntonic Leyden jar" experiments of Lodge. The receiving circuit was tuned by means of a contact sliding along two parallel wires, a device also used by Lecher in 1891. Resonance was indicated by sparking across at the jar in the receiving circuit. It is clearly an advantage, with tuned circuits, to be able to determine the resonant frequency to which they are tuned. There are two ways of doing this. The resonant frequency of a transmitting circuit can be obtained by observing the maximum effect in a calibrated variable circuit inductively coupled to it. The variable scales of a receiver can also be calibrated by means of a specially calibrated oscillator of which the wavelength for certain settings are known.

In 1892 the parallel wire circuit was investigated by Zenneck as a device for the absolute measurement of wavelength. Braun devised a circuit consisting of an adjustable air condenser in series with an inductance which was placed in the neighbourhood of a single turn of wire in a transmitter circuit. The calibrated condenser was turned until resonance was indicated by a spark, or in some cases by the use of a coherer. Later the hot-wire ammeter was used to indicate resonance. The Telefunken Co. and Marconi Co. later produced commercial wavemeters of this type. Wavemeters in which the condenser was of

fixed capacity and the coil of variable inductance were produced by Seibt, Ives, De Forest, and Lorentz. In the Fleming "Cymometer" of 1904 \* (Fig. 57), both the capacity and inductance were variable, the moving parts of the condenser and coil being linked together.

One of the earliest commercial wavemeters designed by Zenneck in 1902 was of the variable inductance type and employed a Geissler tube as a resonance indicator. A bolometer was included for decrement determinations (for description, see "Wireless Telegraphy," Zenneck, 1915). A neon tube indicated resonance in the "Cymometer." Slaby, in his tunable coil circuit, relied on the indication given by the maximum fluorescence of a plate with pieces of gold leaf attached. The Arco and Rendahl tuned coil circuit employed the spark-gap method. The later Lorentz \* and Marconi Co.'s wavemeters worked with the aid of telephones, and the Franke-Dönitz (Telefunken) meter employed the hot-wire ammeter (and included a set of inductance coils for alteration of the range). In the Townsend wavemeter of the war period a dully lighted electric lamp was caused to increase in brilliance at the resonance point.

The development of the separate heterodyne circuit led to the introduction of a new class of wavemeter. The heterodyne wavemeter was employed to a considerable extent during the war of 1914-18.\* Tuning was carried out by means of telephones, the beat note due to a difference in the received frequency and the wavemeter frequency becoming too low to be audible at one point on the scale and just audible again at another point. The wavelength was indicated by the mid-point between these readings.

At a later period the modulated C.W. wavemeter patented by McLachlan (No. 310,915) \* was practically independent of fluctuations in filament brightness and anode voltage, and employed screen-grid valves. It generated a modulated wave, the audio-frequency component of which was received by the set to be calibrated, and indicated resonance.

Crystal or tuning-fork control has also been applied to wavemeters in certain cases. An example is the Abraham-Bloch multivibrator (first described in 1917) in which two triodes were arranged to produce particularly prominent harmonics of a fundamental frequency which was later stabilized by such control. The wavemeter has benefited by general advances in radio technique and may be calibrated in reference to standards. The modern practice of wavelength checking forms a somewhat specialized subject of study, and as shown above, the earlier methods of indicating resonance were typical of the crudity of station testing at a period when the relative freedom of the ether did not demand such rigid adherence to an allotted frequency channel.

A more comprehensive description of radio frequency measuring devices is given in the "Dictionary of Applied Physics," Vol. II (MacMillan, 1922), and there are many excellent books devoted to such measurements. The scope of this handbook does not allow of further discussion of a highly interesting branch of radio technique.

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*The assistance of Dr. E. Mallett and Mr. A. S. Radford in reading through the script and offering suggestions is gratefully acknowledged.*

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