Studies from a Wireless Laboratory.[1]

By Prof. W. H. ECCLES, F.R.S.

THE studies pursued in a wireless laboratory are mainly of two kinds: first, those directed to the solution of problems that have arisen in the development or use of practical apparatus, and, secondly, those with which we are here concerned, aiming at the application of novel principles or novel physical phenomena to the invention of new methods or apparatus. Little will be said of the methods of wireless communication as they exist to-day; on the contrary, our attention will be devoted to some possibilities of wireless telegraphy—possibilities tested in the laboratory but not yet tried on the large scale. In other words, no attempt will be made to give a record of technical progress accomplished to date but, rather, to discuss wireless communication as it may be.

The new methods to be first described are based upon the phenomena, not yet fully known in detail, which occur when one vibrating body is caused to influence the vibrations of another. Consider the case of a simple pendulum consisting of a weight tied to the lower end of a string the upper end of which is held in the hand, and suppose it is of such a length that it would vibrate freely to and fro in a period of two seconds, when the hand is held still. Then it is easily

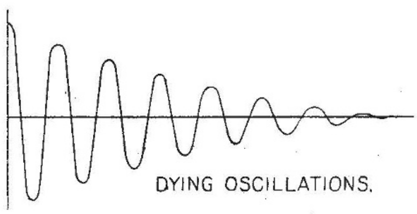

FIG. 1.—Dying oscillations.

seen that on moving the hand horizontally to and fro with a complete period of, say, one second, the pendulum will follow the hand and likewise vibrate with a period of one second. Similarly, when the hand vibrates with a period of, say, three seconds the pendulum will again follow and take the new period. This experiment is very familiar and is known to students of mechanics as an example of the subject of "forced vibration."

A pendulum forced in this manner may be said to vibrate "in time with" the hand, but the experiment shows that it is not "in step with" the hand. It would not be correct to say that it is "in tune with" the hand, since this term is reserved—in electrical physics at any rate—to indicate that the natural period of the free and unpropelled pendulum is the same as the period of vibration of the hand. We may, however, express the state of affairs by saying that the pendulum is forced into accord with the hand and that it is then in the "accordant state." A simple example of this relationship between two alternating movements is seen when a dog, for example, is walking along the road; his hind legs are in time but not in step with his fore legs.

The vibrations of a simple pendulum left free to vibrate with its own period gradually die down as indicated in Fig. 1. The vibration is a dying oscillation, and in such a case the theory of the forced vibrations is easily understood. In a modern wireless laboratory, however, we have to deal with growing and sustained vibrations as in Fig. 2, and in such cases the theory of the accordant state is rather different. This is to be expected—for it is like comparing a living thing to a dying one. Usually the vibrations are sustained by the aid of the triode valves so well known, and the rates of vibration are very high. In order to lead up to an understanding of the accordant state at these high frequencies it is best to study low frequencies first.

For the study of vibrations slow enough to be followed

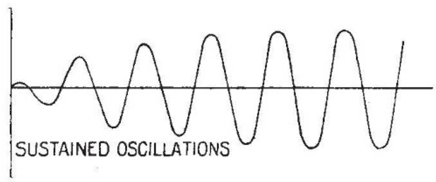

FIG. 2.—Growing and sustained oscillations.

by the eye a new type of oscillator has been designed and constructed and is here exhibited for the first time. Fig. 3 is a diagrammatic plan of the apparatus. The horizontal magnet has a horizontal ebonite rod fixed to it at right angles and the whole is suspended from a vertical torsion wire passing through the centre of gravity. The poles of the magnet confront two horizontal solenoidal coils connected in series with each other and with a battery and diode valve, that is, a thermionic valve of the type invented by Prof. Fleming in 1904 and containing only two electrodes, namely, a filament and a plate. Such a valve possesses the

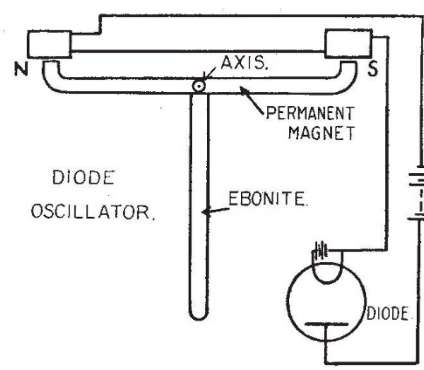

FIG. 3.—Diode-sustained torsion pendulum (in plan).

property that the electron current across the vacuum is sensitive to outside electrical influences if the electrodes have suitable relative positions—an ebonite rod charged by rubbing causes a diminution of the electron current when it approaches the diode and allows the current to increase again when it recedes. The action of this diode-sustained pendulum is now easily explained by supposing it swinging, and noticing that the ebonite rod as it moves to and from the diode causes an alternation of magnitude of the currents in and magnetic fields of the coils, which is automatically in correct time relation

[1] Substance of a discourse delivered at the Royal Institution, Friday, April 13.

to assist the motion of the magnet. By means of a small mirror fixed to the magnet, and a lamp and scale, the building up of the motion from a small initial amplitude is easily seen.

With two such pendulums the accordant state can be studied by eye observation. Dr. Winifred Leyshon is engaged upon this task. As arranged for the investigation one of the pendulums is made the master by sending some of its current through an auxiliary winding influencing the magnet of the other pendulum. The frequency of either the master or of the servant pendulum can be varied by the aid of a movable permanent bar magnet placed near the oscillating magnet. Then it is seen that as one natural period becomes nearly the

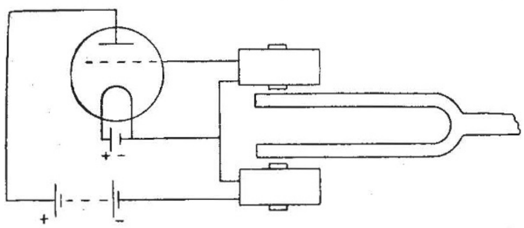

FIG. 4.—Triode-sustained tuning-fork.

same as the other the master catches hold of the servant, compels it to abandon its own natural period and to move in time with the master's—though not necessarily in step. The amount by which the servant is out of step depends upon the difference of the natural periods and therefore can be regulated.

These slow vibrations are seen and not heard; but it is also possible to use vibrators of acoustic frequency and so make the according process evident to the ear. A tuning-fork sustained by a triode is very effective as the master oscillator. The circuit is shown in Fig. 4, from which it will be seen that when the fork is vibrating the induced electromotive force acting upon the grid controls the anode current so as to sustain the motion.

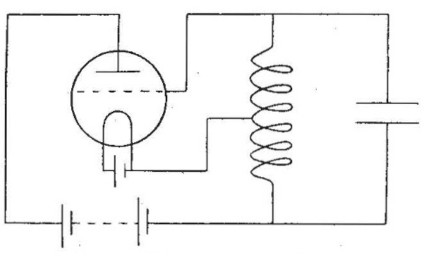

FIG. 5.—Triode electrical oscillator.

(See Eccles and Jordan, "Sustaining the Vibration of a Tuning-fork by a Triode Valve," The *Electrician*, June 20, 1919.)

On the other hand, an electrical oscillation, which is independent of moving matter, makes a good servant oscillator. Its circuit is shown in Fig. 5. The linkage between the two oscillators is effected by passing some of the current from the fork coils through an auxiliary winding on the electrical oscillator. The fork is audible when oscillating because it agitates the air; the electrical oscillations can be made audible by inducing currents in another circuit containing a loud-speaking telephone, and their frequency can easily be altered through a semitone or more by varying slightly the capacity of the condenser shown in Fig. 5. Now, as the natural frequency of the electrical oscillator is made to approach that of the fork, loud throbbings (called "beats") are heard, which become gradually slower until at a certain point the master suddenly drags the servant into time and the throbbings cease. If the movement of the condenser is continued the natural period of the electric oscillator is carried through resonance and then beyond, and finally the servant breaks away from the master and the throbbings indicating their difference of frequency begin anew.

This experiment is reminiscent of that of the two air-blown organ pipes discussed by the late Lord Rayleigh many years ago (*Phil. Mag.*, 1879, Collected Papers, vol. i. p. 409). Rayleigh showed that two organ-pipes nearly in unison dragged each other into a common frequency if brought into propinquity.

The preceding experiments have carried us from vibrations at 2 per second to vibrations at 200 per second; we now pass to the problem of accordance when the vibrations are of frequency 200,000 per second, such as are commonly used in wireless telegraphy and telephony. Such high frequencies are neither seen nor heard, but can be detected by special methods. The electrical oscillator nsed comprises a triode and an inductance and capacity connected as in Fig. 5 and chosen of suitable magnitudes. The detecting apparatus is an inductance coil and variable condenser connected to a crystal detector just as in many a household crystal apparatus used for listening to the broadcasting stations. A galvanometer is connected to the crystal and a spot of light moves on the screen when the condenser is varied while the triode apparatus is in action. A maximum deflexion is soon found and then the receiver is in tune with the triode oscillator. Another triode oscillator is now substituted for the first and varied in frequency until in tune with the crystal receiver. Clearly both triode oscillators are now of approximately the same frequency. Let them both be put into action simultaneously so as to act upon the crystal circuit, and let a pair of auxiliary coils, connected in series, be placed confronting the respective triode oscillators in order to establish a linkage. The crystal circuit is receiving energy from both of the triode oscillators and actuates the galvanometer. The accordant state is then easily found by varying one of the oscillators very slowly and watching the spot of light. At the moment when the two oscillators come within a certain frequency difference, they suddenly pull into time and the spot of light gives a sudden kick. This phenomena was discovered by Dr. J. H. Vincent and described in the Physical Society Proceedings (p. 84, Feb. 1920). One of his curves is reproduced in Fig. 6.

This curve illustrates that as the condenser of one triode oscillator is increased the galvanometer in the crystal circuit shows first an increase and then a very sudden decrease of deflexion. The nearly vertical parts of the curve are due to the establishment of accordance. In a rough way one may explain the phenomenon by saying that at the lowest point of the curve, where there is a sharp cusp, the two oscillators though vibrating in time with each other are oscillating oppositely. In fact one oscillator is moving like the front legs and the other like the hind legs of the dog cited already. The curve or the experiment shows that a very minute variation of the condenser of either oscillator makes the deflexion increase enormously.

There are several ways of applying this novel phenomenon to wireless telegraphy. Two of these may be illustrated here. Suppose one of the two oscillators to be a distant transmitter from which electric waves are proceeding, and that these waves are picked up by the antenna at a receiving station. Let the antenna be coupled to a local oscillator in the relationship of master, and let a tuned detector circuit be acted upon by both the antenna and the local oscillator. Then suppose the local oscillator adjusted until it is in the accordant state with the antenna oscillations, and, in fact, adjusted until the detector current is at the minimum value corresponding to the cusp of Vincent's curve (Fig. 6). It then follows that a very minute variation of the frequency of the oscillations emitted by the distant station will give rise to a deflexion of the galvanometer. It is suggested that signals could be transmitted by up and down changes in frequency—such changes would be far smaller than the changes of frequency employed by the accepted methods of the present day, and thus the interference between stations

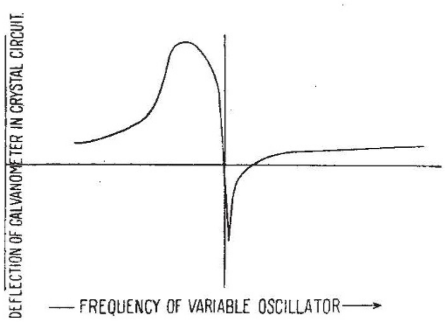

FIG. 6.—Vincent's curve.

would be minimised. There are many easy ways of producing small changes of frequency at the transmitting station.

Another and very different method of signalling may be illustrated by this same apparatus, after again adjusting the receiving apparatus to the minimum deflexion obtained in the accordant state. On trial it is found possible to bring the spot of light to any desired point of the scale—that is, to any desired point on the vertical portion of the Vincent curve—by appropriate adjustments of the frequency of the transmitting unit. These latter adjustments are for this purpose conveniently effected by the motion of a short circuited coil of wire near the inductance coil of the transmitting oscillator. Therefore, to every position of the auxiliary movable coil at the transmitter there corresponds a position of the spot of light actuated by the receiving apparatus. It might even be possible to mark the scales at each place with an alphabet and so communicate intelligence without the aid of the Morse code.

The above-described methods of signalling are based on the discovery of accordance between triode oscillators. Another distinct series of methods can be suggested and illustrated. These methods depend on the fact that the combination of two high-frequency electrical vibrations of slightly differing frequencies yields a throbbing amplitude which may be made of audible frequency and, of any desired pitch by adjusting the frequency of either of the original vibrations. The formation of relatively slow throbbings from two quicker oscillations is shown diagrammatically in Fig. 7. The existing modern method of receiving continuous waves known as the heterodyne method utilises this principle in the following way: The transmitting station emits long and short trains of waves

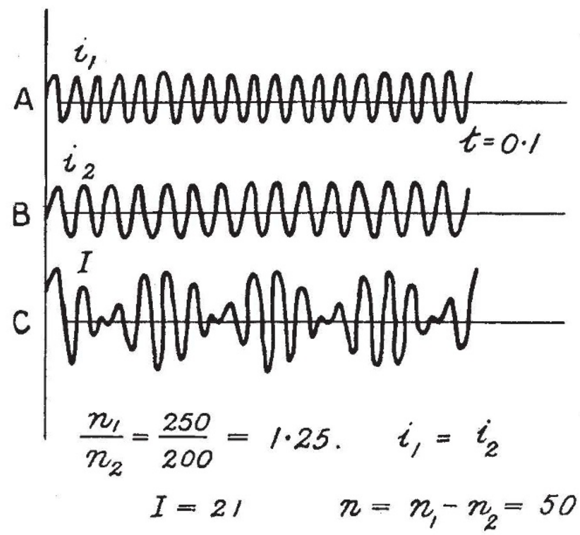

FIG. 7.—Illustrating the heterodyne method of reception.

corresponding to Morse dashes and dots and of frequency, say 200,000 per second. These waves produce in the receiving antenna feeble oscillations which are combined with locally generated oscillations of about the same strength and of frequency, say, 200,500 per second. The result is a compound high-frequency current with 500 throbbings in it per second. These when rectified can be heard in a suitably connected telephone. The long and short trains of waves from

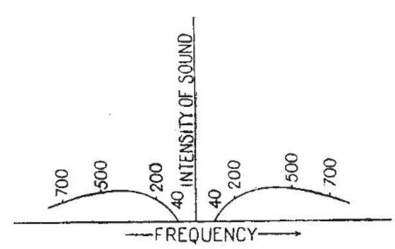

FIG. 8.—Diagrammatic representation of sounds heard in heterodyne reception.

the transmitting station thus give rise to sounds of long and short duration and of constant pitch. The pitch is adjustable by altering the local frequency from 200,500 to other values.

By altering this frequency from, say, 199,300 per second to 200,000 and then to 200,700 the sounds in the telephone run through a continuous scale of notes as represented in Fig. 8. This starts on the left with a note of 700 which falls in pitch to about 40 and becomes inaudible, passes through resonance, becomes audible again, and ascends a scale in opposite order to the first scale. Thus a note of any desired pitch can easily be obtained, but the intensity varies on account of the varying sensibility of the ear and the apparatus. This possibility of variation of pitch makes a number of new methods of wireless signalling feasible. One of the easiest resembles a very early kind of moving needle telegraph apparatus called Bright's bells in which the needle moved to one side and struck a bell in order to indicate a dot and moved to the other side and struck a bell of different tone to indicate a dash. This method was faster than the dot and dash sounder and apparently easier to learn. In its proposed wireless form the transmitting station would emit equal wave trains to represent dots and dashes, say of 200,200 frequency to represent the dots and 200,500 frequency to represent the dashes. Each Morse sign is then heard as a little melody at a receiving station using a local oscillator of 200,000 frequency. Besides the advantage mentioned above there is a likelihood that these signals would be less distorted by atmospheric discharges than are longs and shorts of constant pitch.

Still another simple method consists in utilising three very close high-frequency oscillations at the transmitting station, say 200,200, 200,100 and 200,050, and making a new code for the alphabet out of permutations of these. The local oscillator would have a frequency of 200,000, and therefore the sounds heard in the telephone would be short tunes. The method would be faster than Morse, but might demand that the operators should have musical ears. Still another method can be imagined in which chords of three notes instead of arpeggios are used for the letters of the alphabet, but this might require an even more musical ear.

But there is one kind of chord which every one can recognise without special training, which even the horse can discriminate in the sounds of "whoa" and "gee." The vowel sounds are in fact chords. Lately Sir Richard Paget has given (Vowel Resonances, International Phonetic Association) a list of the chief tones occurring in the English vowels. For example, the vowel sound in the word "calm" contains the tones of frequency 1360 and 810 per second. Suppose, therefore, a transmitting station is arranged to emit simultaneously electric waves of frequencies 201,360 and 200,810, and suppose these waves when received at a great distance are combined with local oscillations of frequency 200,000 per second. Then the tones 1360 and 810 are perceived simultaneously as a chord in the operators' telephones. But this chord by itself is scarcely if at all recognisable as a vowel. Recognition is ensured by superposing a larynx note by aid of a buzzing contact included in the receiving circuit. Then whenever a train of two waves leaves the sending station the vowel is pronounced by the receiving apparatus. This is easily illustrated to an audience by the aid of a loud-speaking telephone. Lecture apparatus for producing and detecting the two vowel sounds represented by *o, a,* is shown in Fig. 9. The change of

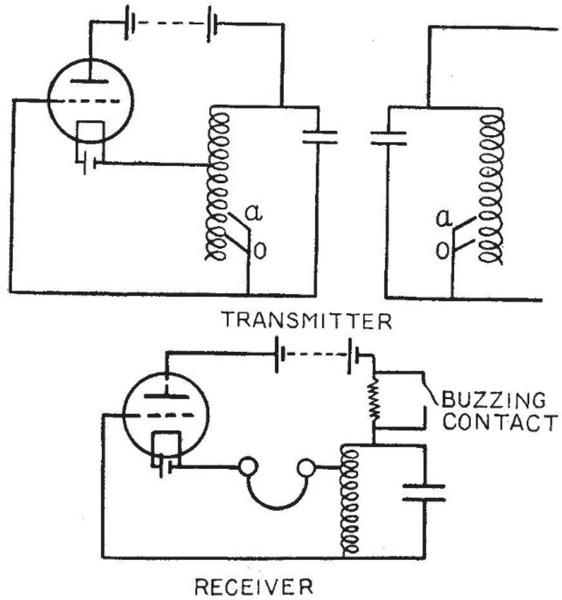

FIG. 9.—Heterodyne vowel apparatus.

radio frequency necessary for passing from one vowel to another is provided by the tappings on the inductance coils. In this apparatus the transmission occurs across a short distance; in practical telegraphy the transmitter would be more powerful and would be provided with an aerial and the receiving apparatus would also have an aerial.

The apparatus, which was built and made to work by Messrs. C. F. A. Wagstaffe and E. S. Smith, two former Finsbury Technical College students, was constructed to produce six vowels, namely, those heard in the words eat, all, hate, shoe, calm, and earth. These six vowels taken in pairs yield thirty-six symbols which, together with the five vowels *a, e, i, o, u* representing themselves, amount altogether to forty-one symbols. An alphabet formed in this manner is much briefer than the Morse code; that is to say, there are fewer efforts of the sending key in making the same message. For example, in the word London there are seventeen efforts when Morse is used but only eight when the vowel code is employed. Besides the gain in speed there is a possibility of reception through atmospheric disturbances being more easily accomplished with the vowel code than with the customary dots and dashes of constant pitch, but this can only be tested by actual trials.

Ur of the Chaldees.

BY C. LEONARD WOOLLEY.

IN 1919 Dr. H. R. Hall, on behalf of the British Museum, spent three months excavating at Ur. Last summer the British Museum and the University Museum of Philadelphia decided to send out a joint expedition which should continue for a term of years the work begun by Dr. Hall, and clear as much of the site as seemed likely to repay the necessarily heavy cost of a scientific mission. The first season's work of the joint expedition is now over, and the results amply justify the confidence of those who promoted it, and give every promise of even greater success in the future.