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FIFTY YEARS' PROGRESS IN ELECTRICAL COMMUNICATIONS[1]

STEPHEN GRAY AND FRANKLIN

IT is now two hundred years since Stephen Gray discovered that an electrical charge will move with great rapidity along certain substances, called conductors to-day. The motion of electricity began then to attract the attention of the natural philosopher, and it became the subject of many scientific researches, particularly after Franklin had demonstrated that lightning is a motion of electricity. There is no doubt that many a scientist of Franklin's time associated with the destructive power of lightning something resembling the destructive power of a projectile, something endowed with an irresistible momentum. But who would have dared to suggest in those days that moving electricity just like moving matter had a momentum? Nobody suspected in those days that the history of the electrical science of the first half of the nineteenth century would be a record of the gradual evolution of this electrical momentum concept. Oersted's discovery, in 1819, of the magnetic field of force accompanying the motion of electricity marks the first step in the progress of that evolution.

MAXWELL'S CONCEPT OF THE MOMENTUM OF MOVING ELECTRICITY

Faraday was the first to recognize that the magnetic field accompanying moving electricity, and every other magnetic field, gave to the space occupied by it a new physical state; he called it the electrotonic state and saw in the electrical forces of induction which he had discovered a manifestation of the electrical reaction opposing the change of the electrotonic state. Finally the genius of Maxwell succeeded in revealing in Faraday's electrotonic state the momentum of moving electricity. This is one of the two fundamental concepts in Maxwell's electromagnetic theory, and it was destined to play the leading part in the development of the electrical science as well as of the electrical art of telegraphy and telephony. Maxwell showed that the magnetic flux associated with moving electricity is the momentum of that motion, and that the electrical forces discovered by Faraday

[1] Address of the retiring president of the American Association for the Advancement of Science, Philadelphia, December 27, 1926.

were the reactions opposing the change of that momentum in accordance with the law of inertia which has the same mathematical form as that which Newton had formulated for moving matter. From that point of view Maxwell may be called the Newton of the science of moving electricity.

There was, however, an obvious difference between Newton's momentum of moving matter and the momentum of moving electricity; whereas the momentum of moving matter is located in the parts of space where that motion actually takes place the momentum of moving electrical charges extends beyond the places where the electrical charges are moving; it is everywhere where the magnetic flux is. Hence Maxwell's many efforts to detect in the surrounding space hidden motions coupled to the moving charges. Motions of Faraday's tubes of force attached to the charges performed satisfactorily the functions which Maxwell attributed to these hidden motions, and he endowed the motion of these tubes with a momentum. This, broadly stated, completed the foundation of Maxwell's electromagnetic theory.

Faraday's discoveries in the field of electromagnetic induction are the source to which the evolution of Maxwell's concept of the electro-kinetic momentum traces its origin, but the early developments in the science and the art of electromagnetic telegraphy contributed very much to this evolution. The electromagnetic telegraph was invented by Joseph Henry and operated at Princeton in the same year in which Maxwell was born. It requires no stretch of imagination to see in those contributions from telegraphy a stimulating tonic to Maxwell's efforts to interpret dynamically Faraday's discoveries. A brief description of these contributions will be helpful.

Maxwell and Joseph Henry

The field of magnetic force accompanying a given motion of electrical charges is determined by Ampère's law, but the field of magnetic flux is not; it depends upon the magnetic permeability of the medium in which the magnetic field is located; it is proportional to it and to the magnetic force. Since, according to Faraday's law, the variation of the magnetic flux and not that of the magnetic force is the measure of the inertia reaction against the change of that motion, it is obvious the magnetic flux is a load of moving electricity and that magnetic permeability increases that load; it adds more inertia to moving electricity. This, broadly speaking, was Maxwell's reasoning in his gradual evolution of the electrokinetic momentum concept. In this he was undoubtedly aided by Joseph Henry's historical experiments which led to the discovery of self-induction. They are the earliest and the most striking exhibition of the electrical reaction against the change of the magnetic flux interlinked with the magnetizing coils of Henry's great electromagnets; moving electricity was never up to that time more heavily loaded than the electricity moving through these coils.

The man who was the first in the field of research dealing with electromagnets and their application to telegraphic signalling was destined to make the discovery of the reaction called self-induction. Every flash of the interrupted magnetizing current announced that reaction. The man who first interpreted these flashes correctly was Joseph Henry and he may be justly considered not only the discoverer of self-induction, but also the inventor of the best means of transforming electrical into magnetic action and of transmitting it to a distance for signalling purposes. The expression "magnetic action" is used here purposely; it is Faraday's favorite expression. Telegraphic receiving instruments in those days operated by magnetic force; that was the force transmitted from one telegraph station to the other; this in all probability suggested to Faraday the expression "magnetic action."

Transmission of Magnetic Action

The laws of propagation of magnetic action were not yet clearly defined in Henry's mind when he sent his first telegraphic messages, neither were they thirty years later in Faraday's mind, although he had thought a great deal about it, and even encouraged his young disciple Maxwell to think about it. The encouragement came like a godsend to this mathematical tripos youth who had just distinguished himself at Cambridge. It came at the very time when William Thomson, the late Lord Kelvin, had succeeded in solving the problem of telegraphic transmission over submarine cables and Kirchhoff, the discoverer of spectrum analysis, had amplified Thomson's solution so as to include transmission over ordinary telegraph wires. Thomson had neglected in his solution the inertia reaction of moving electricity, but Kirchhoff had not, and this resulted in his mathematical proof that the velocity of propagation of signals over telegraph wires was equal to the velocity of light. This remarkable result made, as is well known, a profound impression upon young Maxwell's mind and gave a new meaning to Faraday's intuition that, as he wrote to Maxwell in 1857, ". . . the time of magnetic action . . . must probably be short as the time of light; but the greatness of the result, if affirmative, makes me not despair."

It was nothing less than the greatness of this result which Maxwell aimed at, and guided by Faraday's suggestion and Thomson's and Kirchhoff's mathematical analysis he, in less than eight years, obtained the result, and revealed the general law of propagation of magnetic action covering Thomson's and Kirchhoff's problems as special cases. When in 1865 Maxwell published his great essay "A Dynamical Theory of the Electromagnetic Field" he not only demonstrated that magnetic action moves through space like light, but, moreover, he supplied the telegraphist with new knowledge which would enable him to solve every transmission problem in the art of electromagnetic telegraphy of those days. Henry's invention of the magnetic telegraph and the resulting telegraphic transmission problems, solved thirty years later by Thomson and by Kirchhoff, guided Maxwell in his great endeavors and in return for this precious service he supplied the telegraphic art with a trusty guide in all its future endeavors.

MAXWELL AND THE TELEGRAPHISTS

The very natural question arises, did the telegraphic art take full advantage of the science to the creation of which it had contributed so generously and which was ready to render generous service in return? The answer must be in the negative. The earlier history of the Faraday-Maxwell electromagnetic theory tells an instructive story concerning this. The telegraphist was more concerned about the apparatus at the sending and at the receiving end of the signalling conductors than about the fate of the signal during its journey between these two ends. This is particularly true of submarine cable transmission. When Thomson first attacked the submarine cable problem in the early fifties he had in mind slow speed signalling over transatlantic cables and neglected the inertia reaction of the moving charge; it is small when the momentum of the moving charge varies slowly as in the case of slow cable signalling. Besides, the magnetic field of the moving charge seemed also to be very small, since the conducting copper core in the cable is very close to the conducting seawater. Under these conditions Thomson's theory gave satisfactory results, but the telegraphist jumped at the conclusion that this theory, the so-called Thomson electrostatic theory of transmission, is universally applicable. He was not aware that Kirchhoff's theory of telegraphic transmission told a different story. Even so distinguished a theoretician in the telegraphic art as Heaviside had never heard of Kirchhoff's essay until nearly thirty years after its publication, and then he found fault with it on account of its lack of intelligibility. Nobody else had ever accused Kirchhoff of this shortcoming. Maxwell caught Kirchhoff's meaning readily, and found inspiration in it. The telegraphists also found fault, but not with Kirchhoff; they never had heard of him. On the other hand, they could not help hearing Heaviside's reproachful voice directed against the telegraphists, who were accused by him of worshipping a false divinity, the electrostatic theory of transmission. They answered the charge by finding fault with Heaviside's alleged lack of intelligibility, and so they paid no attention to either Kirchhoff or to Heaviside, who, as I just pointed out, had many years later rediscovered what was known to Kirchhoff and to Maxwell in 1857. This indifference on the part of the telegraphists was unfortunate but excusable, because their minds were polarized by their strong belief in the infallibility of Thomson's electrostatic theory, which had served them so well. Even Heaviside's profound learning, reinforced by cutting sarcasm and satire, could not shake that belief for many years. Those were the years of barren and somewhat bitter controversy, which did not advance the telegraphist's understanding of the good things which Maxwell had in store for him. A splendid opportunity to illustrate one aspect of the Faraday-Maxwell electromagnetic theory by everyday experience in telegraphy was thus lost.

TELEPHONY AND THE HIGH INDUCTANCE DOCTRINE

Fifty years ago when this lively controversy was started in England a new method of electrical communication was born; Alexander Graham Bell invented the telephone, the practical application of which demanded a new type of electrical transmission engineering. The telegraphists trained in the school of Thomson's theory could not qualify, said Heaviside, alleging that in their analysis of the transmission of magnetic action they ignored the inertia reactions of moving electricity. Heaviside was right, but he had no sufficient reason to feel highly provoked about it; Kirchhoff was as gentle as a dove when he pointed out that Thomson had neglected the inertia reaction of moving electricity. Heaviside's charge against the telegraphists was supported by the highest authority, Maxwell's electromagnetic theory, in which the inertia reaction of moving electricity is one of the foundation pillars. But the weight of this authority did not add weight to Heaviside's attacks, because there were in those days very few scientists in England or anywhere else who understood clearly Maxwell's meaning. Heaviside was certainly one of these chosen few, but his extraordinary mathematical exuberance obscured to the non-mathematical mind of the telephone engineer his interpretation of Maxwell.

The momentum of moving electricity and its beneficial effects in the propagation of magnetic action, as Faraday called it, were already clearly visible in Kirchhoff's essay of 1857, and nothing was plainer than this beneficial action in Maxwell's description of electromagnetic transmission through absorptive media. Every herdsman's boy in my native village, instructed by practical experience, knew that sound is transmitted more efficiently through dense and hard ground and through water than through air. When the full meaning of Maxwell's electromagnetic theory first dawned upon me I thought of that knowledge which I had gained on the pasture lands of my native village. The meaning of Maxwell's propagation constants, which I called figuratively magnetic density and electrical stiffness, reminded me immediately of the dense and hard ground through which the chums of my boyhood days and I transmitted sound signals. The physical reasoning concerning this simple matter appeared to me as being of the most elementary kind and not at all involved in complicated mathematical formulae. When energy is transmitted along a prescribed path, say a stretched string, or along an unguided path through a continuous medium, it is passed along from one element of the path to the next by the interaction between these neighboring elements. One element acts and the other reacts, and nothing is plainer than the simple dynamical relation that the greater the conservative reactions of the elements, that is, their inertia and elastic reactions, in comparison with their dissipative reactions the smaller will be the energy loss during the transmission. A clear grasp of these elementary physical principles makes it obvious that Maxwell's theory insists upon increasing as much as practicable the inductance of telegraphic and telephonic transmission lines, because that increases the conservative inertia reaction of each element of the wire and, the other reactions remaining the same, that increase results in a greater conservation of the energy moving from the transmitting to the receiving station. When Heaviside failed to convert the unbelievers among the telegraph and telephone engineers of former years to this simple doctrine he proved conclusively that as an apostle of his great master, Maxwell, his missionary work among the unbelievers had failed to reach their understanding. Many of them even thought that the high inductance doctrine was invented by Heaviside himself, and that it had no direct connection with either Maxwell or his great predecessors. The high inductance propaganda lost thereby the propelling power of these great names. Even to-day a distinguished telephone engineer says this in the new volumes of the Encyclopedia Britannica:

> Toward the end of the nineteenth century Oliver Heaviside had proved mathematically that uniformly distributed inductance in a telephone line would diminish both attenuation and distortion, and that if the inductance were great enough . . . the circuit would be distortionless.

The mathematical proof, mentioned here, was not needed by him who understood Maxwell, but, alas! Maxwell's great essay, even after Hertz had thrown the searchlight of his genius upon it, remained a sealed letter to many telephone engineers; hence their erroneous estimate even to-day of Heaviside's relation to Maxwell's theory of transmission of magnetic action. The very language employed in the above quotation shows a lack of clear understanding. The writer says "if the inductance were great enough"; if he had added the words "in comparison with the resistance" he would have made an intelligible statement. He would have also made a valuable contribution to the history of telephony if he had stated that Heaviside's mathematical proof never enabled anybody to find a way of making "the inductance high enough."

During the first score of years following Maxwell's publication of his epoch-making essay, the field of telegraphy and telephony offered the best opportunity for interpreting one important aspect of this theory. The opportunity was wasted through lack of understanding in spite of Heaviside's and Vaschy's noble missionary efforts among the telegraph and telephone engineers, and the advancement of the telegraph and telephone art was retarded. What is the real obstacle which prevented the creation of a harmonious cooperation between theory and practice?

A Missionary Effort which succeeded

I trust that I will be pardoned for speaking now about my own missionary efforts among the unbelievers in the telegraph and telephone industries. I began to make these efforts a few years after Hertz, by his classical experiments, had clarified my ideas and everybody else's ideas concerning Maxwell's meaning. At that time I had never even heard of Heaviside or of Vaschy and of their advocacy of high inductance, but I had heard from my friends in the telephone industry of the inefficiency of telephonic transmission and of the failures to improve it by increased inductance. It was obvious that the increase which they described was too small and full of absorptive losses. Highly efficient coils of large inductance inserted at periodically recurring intervals into the line was the remedy which I proposed. But I was told that the remedy had been tried and that a dismal failure had resulted. I was also reminded that universal experience recommended the removal of inductance coils from telegraph and telephone lines; their interference with transmission, they said, had earned for them the opprobrious name "choke coils." It was clear that I had to furnish a proof which would convince even the most prejudiced among the telephone and telegraph engineers that inductance coils in a transmission line do not always act as "choke coils." Such a proof would have been worthless if it had consisted of mathematical formulae only. I needed the formulae myself for my own guidance, but watching the developments in wireless telegraphy which was born at that time I learned that full-sized apparatus and successful operation was the only proof which would appeal to the so-called practical engineer. He is like the man from Missouri who "wants to be shown," by actual experimental performance and by nothing less. My mathematical solution of the problem of transmission over a lumpy telephone line containing inductance coils at periodically recurring points filled me with confidence; it had never been even attempted by the advocates of high inductance. They evidently had missed an important concept in the physical character of the transmission problem. The length of the wave to be transmitted was not considered and hardly ever mentioned by them, and hence their failure to recognize in it one of the fundamental elements in the study of transmission of magnetic action over a line. Instructed by the Hertzian experiments in which the wave length occupies a place of honor, and guided by Maxwell's general theory, there was no difficulty in recognizing the simple physical truth, plainly exhibited by my mathematical formulae, that the periodically recurring intervals between the inductance coils had to be considerably less than half a wave length of the transmitted wave, if they are to produce a beneficial effect. Under these conditions the transmission line acts like a uniform line of high inductance. All experience suggested that this simple rule, when pointed out, is obviously true; even the telephone engineers twenty-five years ago could understand it, and they liked it. At my suggestion they made the coils in their own way, using no iron core, inserted them into their own transmission line without my meddling and found by experiments, conducted by themselves, that my simple rule was correct, although they had made a clumsy error in the construction of their coils. They were converted by their own experience in the practice of the new doctrine, and I began to consider myself a successful apostle of Maxwell's gospel. But the telephone engineers wanted more. They wanted an inductance coil which does not disturb the transmission in neighboring lines; I consulted Faraday and Maxwell and gave them a symmetrically wound toroidal coil and they welcomed it, because they found to their great surprise that no outsider listening in the immediate vicinity of the coil can tell anything about the motion of electricity through the windings of such a coil. There was no appreciable cross-talk between adjacent coils belonging to different transmission circuits. Then the engineers amplified their requirements and demanded a coil of small dimensions, so as to be able to put a large number of them in a single pot. I consulted Maxwell again and gave them a suitably laminated toroidal steel core; they welcomed it. Finally they wanted a core of fairly constant permeability; I consulted Ewing's and Lord Rayleigh's magnetic researches and gave them core laminate of cold rolled steel; they welcomed that, too, after I had supplied them with an experimental method of testing my figures relating to the efficiency of these coils. Then they surprised me with a strange request; they asked me to go to court and prove that I had not been anticipated by anybody. In other words, I was called upon to carry on a missionary propaganda among lawyers and convert them to Maxwell's doctrine, in order to prepare them for a demonstration of the validity of my claim that I had done something which the other missionaries, who preceded me, had not done. I succeeded speedily, thanks to the psychological fact that the unprejudiced mind of a lawyer is much more easily converted than the mind which is hemmed in by the narrow experience of some technical practitioners. This imprisoned mind can not be liberated except by the irresistible force of experimental demonstration. Heaviside and Vaschy trusted too much to mathematical symbols; they offered nothing which is tangible and of immediate value to the practical engineer. Hence the failure of their missionary work mentioned above.

WIRELESS TELEGRAPHY AND MAXWELL'S DOCTRINE

The early history of wireless telegraphy illustrates the wisdom of the procedure which I have just described. I witnessed the birth of wireless telegraphy and watched its growth from the very beginning; that taught me how Maxwell's gospel must be preached among the unbelievers. A few brief statements relating to this interesting bit of history will explain my meaning. A youth of barely twenty was repeating in the laboratories of the University of Bologna the Hertzian wave experiments; they were still fresh in everybody's mind and many an ambitious young physicist was doing the same thing in other university laboratories which young Marconi was doing at Bologna. But he was the only one who thought of trying a Hertzian oscillator consisting of a long and grounded upright wire and a similar Hertzian detector. The Hertzian pulse, excited in the oscillator in the usual way, was felt in the detector at quite a long distance, much longer than Hertz or anybody else had ever reached. Maxwell's theory, reinforced by higher mathematics, could easily explain this remarkable increase of the distance. But young Marconi knew very little about these things and had no time to consult Maxwell's theory or even Heaviside's or Vaschy's interpretation of it. He packed his crude apparatus, took it to London, and called on the very unbelievers whom Heaviside could not budge. He put his apparatus into their hands, they operated it and found that it could do what no other telegraphic apparatus could do; it could send signals to ships at sea and receive an answer from them. Communication with the ships at sea! Just imagine what that meant to the British mind! Nobody understood that better than young Marconi. This understanding marked him as one of the greatest practical psychologists that the world had ever seen. One who is a follower of the belief that there is nothing new under the sun might say, and some have done so, that Marconi's invention was no invention at all, because it was an obvious inference from the Hertzian wave experiments. The courts have thrashed that out to Marconi's and everybody else's satisfaction; they found that he is the real inventor, and that he is the best type of inventor; experimental achievement first, and theoretical elaboration afterward. It was Marconi's experimental achievement which converted the British high priest of unbelievers who enjoyed all the official privileges of his mighty throne in the British Post Office, and whom Heaviside could not convert. Just think of it! A Heaviside equipped with the biggest guns of higher mathematics and guided by the greatest general, Maxwell, failing in his attacks where an Italian youth with nothing but crude wave apparatus and blazing southern imagination and enthusiasm succeeded! The high priest of the British Post Office surrendered and the mighty British Navy followed suit; the unbelievers had finally caught the first glimpse of Maxwell's meaning and they bowed their heads in deep reverence. This was the most picturesque victory recorded in the history of science. Marconi's maneuvering which ended in this victory taught me how to preach the doctrine of high inductance to the telegraph and telephone engineers. Not mere words, pictures, and formulae but experimental demonstration. It should be observed, however, that telephone engineers showed a much greater inclination to listen to Maxwell's gospel after our city fathers, some thirty years ago, had passed a law which ordered that within city limits telephone wires must be put under ground. This was a great service to the apostles of the high inductance doctrine. The city fathers who rendered this service were perfectly unconscious of their great aid to science as well as to the art of electrical communications. Underground wires, so-called telephone cables, could not transmit articulate speech over much more than a score of miles without a great increase of their inductance, and that demanded a great increase in scientific knowledge in telephone engineering. How well the telephone engineers have responded to this demand may be gathered from resolutions adopted recently in Paris at an international conference of telephone engineers. They resolved that in international telephonic communications over great distances it is equipped with inductance coils in accordance with principles first demonstrated in my laboratory as practicable twenty-five years ago. "Cables pupinizé" is the international name for such cables. This is a graceful compliment on the part of the European telephone engineers; our telephone engineers lack the artistic temperament which seeks expression in graceful compliments.

When my missionary work among the telegraph and telephone engineers started in the nineties they had already caught a glimpse of Maxwell's teaching, thanks to the irresistible appeals of the Hertzian experiments reinforced by Marconi's wireless transmission. Self-induction was "in the air" according to a statement made by Sir William Thomson, when he first heard of the Hertzian experiments, and immediately Heaviside made the following comment upon this epigrammatic remark:

> Then there are the electromagnetic waves. Not so long ago they were nowhere; now they are everywhere, even in the Post Office . . . Now these waves are also in the air, and it is the ''great bug'' self induction that keeps them going.

I wonder what Heaviside said about their "going" when twenty-five years ago they leaped across the Atlantic carrying a message from England to Newfoundland! Heaviside said thirty-eight years ago that the British engineers' self-induction was standing still and would not move. It would be fairly good guessing to-day to credit him with the opinion, suggested by Marconi's England-Newfoundland leap, that the self-induction of an Italian youth in his early twenties was "going" so fast that its momentum was greater than that of the self-induction of all British telegraph and telephone engineers put together. Long distance telephony and telegraphy over wires of high inductance and the bridging of the Atlantic by Marconi's waves were, twenty-five years ago, the most striking experimental interpretation of Maxwell's meaning in terms of a language which was intelligible to the engineer. This language and the story it told was inspired by the appearance of the Hertzian waves.

The art of electrical transmission of messages over wires or without wires became thus a part of the great science which Maxwell had formulated. This will be recorded as the greatest asset with which this art entered into the twentieth century epoch of its history.

THE TWENTIETH CENTURY PROGRESS

No development in the technical arts illustrates so well the intimate connection between abstract science and its applications as the rapid development of wireless transmission during the last twenty-five years. Marconi's sharp electrical pulses, resembling cracks of a whip, were soon replaced by fairly sustained oscillations obtained by the obvious instrumentality of coupling to Marconi's oscillators suitable inductance and capacity. This prepared a place for patiently waiting electrical tuning and selectivity in Marconi's scheme. It was badly needed, but many other things were badly needed before this electrical selectivity could prove its full value. These additional things, like, for instance, the high frequency dynamo electric generator, were gradually supplied. Wireless transmission stations began to look like offsprings of good engineering design. But the conviction grew strong that without a fundamentally novel element in the wireless transmission scheme further progress would be slow. That additional element was found in a modest corner of the science of physics. There sat, unnoticed by the practical engineer, the tiny electron and waited patiently to be harnessed in useful service to the art of electrical communications.

The Röntgen rays were discovered at about the same time when Marconi exhibited his wireless scheme to the British Post Office. Nobody expected that Röntgen's vacuum tube phenomena had anything in common with wireless transmission. The study of these phenomena revealed the existence of the electron, the infinitely small electrical unit whose independent existence had been prophesied by Maxwell long ago. It was this infinitely small servant which rendered incomparable service to electrical transmission, both with and without the wires. Wireless telegraphy was so revolutionized by this service that a new name was invented for it. It was called "Radio" to-day. Similar revolutionary changes were introduced by this service into the other parts of electrical communications. The service of this infinitely small servant is remarkable not only on account of its magnitude but also on account of the ideal simplicity of the operation which performs it. A word or two regarding it will be helpful.

The study of the Röntgen's phenomena led to the discovery that a hot filament throws off electrons. Such a filament in a vacuum tube will keep it filled with electrons. They are there as a swarm of many billions of tiny electrical units moving within the tubes' vacuum in a perfectly non-coordinated fashion. They are an electrical mob, each member of this mob moving in its own sweet way. Introduce now into the tube a cold electrode and connect it to the hot filament by an electrical battery, the hot filament being connected to the negative and the cold electrode to the positive pole of the battery. The electromotive force of the battery immediately transforms the electrical chaos in the tube into a beautiful cosmos of coordinated motion. The vast and chaotic army of tiny electrons like drilled soldiers march in orderly columns from the negative to the positive electrode. One end of the columns disappears as it enters the positive electrode and the other end of the columns receives new electronic recruits from the hot filament. This beautifully coordinated motion of the myriads of tiny electronic units is the steady electrical current sustained by the battery. This was all done as far back as 1884 by a modest German physicist Hittorf, long before anybody heard anything about electrons. But his remarkable experiment attracted no attention and was soon forgotten.

This, the so-called thermionic current, was, therefore, a perfectly familiar phenomenon in the beginning of this century; but there was something which was also known at that time. When a third electrode is introduced into the path of the marching columns and an extraneous electrical force is communicated to this electrode from any source, then this force, like a commander on the side line, modifies the progress of the marching columns, that is to say, it diminishes or increases the current. It was then discovered that within certain wide limits the change in the current follows the mode of change of the extraneous force. The change of the local battery current produces electrical reactions in the battery circuit which are very considerably greater than the extraneous electrical force and they can be made to resemble it in every detail. The extraneous force is thus amplified without change of form. The reproduced and amplified extraneous force can then be applied to the third electrode of another vacuum tube and increased again. By repeating this simple procedure the amplification can be carried to any desirable and practicable extent. This is the vacuum tube amplifier which has revolutionized electrical communications over wires and without wires. The magnetic action transmitted in electrical communications is no longer employed to act directly upon the signalling apparatus at the receiving station, in order to move its heavy parts which is quite a task for this feeble action. Its incomparably easier job is to stimulate the third electrode in the amplifying tube. The local battery which keeps up the orderly march of the army of billions of busy electronic workers does the rest by the responsive reactions of its circuit. The discovery of these tiny electronic workers in the vacuum tube; the method of coordinating their movements, by a local battery, and the method of modifying these coordinated movements by the command of an external force applied at the stimulating third electrode are an essential part of the scientific foundation of the art of electrical communications of to-day. The other part is the asset with which this art entered its twentieth century period.

There is another service of the electronic workers which deserves a special mention here. It is that of the vacuum tube oscillator. When by a simple provision a part of the responsive reactions of the local battery circuit is added to the external electrical force which the transmitted magnetic action produces in the third electrode of the vacuum tube then there is a progressive increase of the stimulating action of the third electrode and, therefore, a progressive increase of the signal strength. When the local battery circuit contains inductance and capacity it is capable of oscillatory electrical motions; that is to say, oscillatory motions of electricity are started in it by any external disturbance and, therefore, continuous oscillations will result if the provisions exist to carry a part of the electrical reactions of the battery circuit to the stimulating third electrode. The period of the oscillations is accurately adjusted by adjusting the inductance and capacity of the circuit. This is the vacuum tube oscillator, a most effective instrument in radio broadcasting.

Summing up the fifty years' progress of electrical communications one can describe it concisely as follows: It is, in the first place, the progress in the application of Maxwell's electro-magnetic theory to the method of transmission of what Faraday called magnetic action. In the second place, it consists in the harnessing of the electrons emitted by a hot filament in a vacuum tube. This gave us the amplifier and the vacuum tube oscillator, the instrumentalities which have during the last sixteen years advanced the art of telegraphy, telephony and radio more than any other contribution from abstract science during the last twenty-five years. I can not miss this opportunity of pointing out the remarkable fact that since Faraday every great advancement in the art of electrical communications originated not in the operating rooms of this art or in the research laboratories of its industries but in the research laboratories of the universities.

When we speak of electrical communications we usually mean exchange of messages between man and man. But a careful study of the static, of the fading of radio communications, and of the so-called earth currents in cables will undoubtedly reveal that they are not, as usually believed, disturbances only which annoy the clumsy methods of human operators. They are messages which are far more important to mankind than mere communications between mortals. For instance, I can not help feeling that the so-called earth currents in cables are messages telling us many secrets which are going on in the sun, the central power station which supplies the moving power to all our organic and human activities.

M. I. PUPIN

COLUMBIA UNIVERSITY

THE INTERNATIONAL UNION OF SCIENTIFIC RADIO TELEGRAPHY

ONE of the most active of the international scientific unions is the U. R. S. I. (International Union of Scientific Radio Telegraphy). The several international unions are organized under the International Research Council and their American sections are under the National Research Council. Since its organization in July, 1919, the U. R. S. I. has made notable progress in the direction of its aims, which may be stated as follows: (1) to promote the scientific study of radio communication; (2) to aid and organize researches requiring cooperation on an international scale and to encourage the discussion and publication of the results; (3) to facilitate agreement upon common methods of measurement and the standardization of measuring instruments. The International Union itself is an organization framework for carrying on the international phases of the administrative work. The actual technical work is done by the various national sections. The officers are:

President—General G. Ferrié, France.
Vice-Presidents—
Dr. L. W. Austin, United States.
Dr. W. H. Eccles, England.
Dr. Vanni, Italy.
Dr. V. Bjerknes, Norway.
General Secretary—Dr. R. B. Goldschmidt, Belgium.

The International Union holds a general meeting every three years. The next such international meeting is to be held in Washington in 1927 during the time of meeting of the International Radio Conference. For the purpose of correlating the work done by the several national sections, the International Union has four international "commissions." These are: (1) Methods of measurement and standards; (2) radio wave transmission phenomena; (3) atmospheric disturbances; (4) liaisons. The American section of the U. R. S. I. was organized in 1920. It is made up of an executive committee and five technical committees. The executive committee is made up as follows:

	Representing
Dr. L. W. Austin, Chairman	(Vice-Chairman, International Union)
Dr. J. H. Dellinger, Technical Secretary	(Department of Commerce)
Dr. W. E. Tisdale, Corresponding Secretary	(Div. of Phys. Sciences) ex-officio
Prof. J. S. Ames	(Div. of Phys. Sciences) ex-officio
Major-General C. M. Saltzman	(Army)
Dr. A. H. Taylor	(Navy)