

THE DEVELOPMENT OF RADIO COMMUNICATION.

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In introducing my subject before the science teachers of New Jersey, it is particularly appropriate to refer to the fact that the first person to knowingly produce an electric oscillation and to detect its effects at a distance was a science teacher of New Jersey—Professor Joseph Henry, then (1842) at Princeton.

The oscillatory discharge of a condenser through an inductive circuit and the production thereby of electric waves, then achieved by Henry, were later to constitute the foundation of Hertz's scientific researches on electric waves and Marconi's development of radio telegraphy, and today are employed by the greater number of ship and amateur radio transmitting stations.

Henry was also an independent discoverer of the fundamental phenomenon of electromagnetic induction (following Faraday by only a few months, 1831-32), was the first to discover self-induction, deserves the major credit for the wire telegraph, and laid the foundation on which the alternating-current transformer was built. All of these are of prime importance in radio communication.

The keynote of radio is the electric wave. What is its true genealogy? Marconi made it useful, but he built on the experiments of Hertz, who employed the formulations of Maxwell, who in turn based his theories on the conceptions of Faraday.

Faraday's greatest contribution was a *point of view*. Where his contemporaries saw only material conductors and magnets, Faraday saw magnetic and dielectric fluxes (his "lines of force") extending throughout space. He not only saw them, but he told how to measure them and he determined their laws—such a foundation did he lay that it has never needed alteration or addition! All electrical engineering is built on it.

Maxwell "popularized" Faraday's ideas in a strange way. He clothed them in mathematical dress to suit the taste of the mathematical physicists of his day. But clothing another person's child was not his major achievement. He showed that the ideas of Faraday lead inevitably to the conclusion that

electromagnetic effects could be propagated as waves through space; and he advanced the idea that light was in fact such an electromagnetic wave phenomenon (1865). He calculated the theoretical velocity of an electromagnetic wave and showed that it agreed with the measured velocity of light—the best proof we have of their identity.

Hertz gave reality to Maxwell's wave theory by producing electric waves in an electrical way (1888). He reflected, refracted and absorbed them, like light waves, and measured experimentally their velocity.

Marconi adapted electric waves to communication purposes, primarily by arranging his oscillator vertically, so that the waves could travel along the surface of the earth (1895). And he made his oscillator large enough and powerful enough to transmit detectable power to great distances.

To sum up, the dynasty consisted of Faraday, who supplied the raw material, Maxwell, who provided the tools, Hertz, who made the machine, and Marconi, who adapted the machine to the service of man.

A few years ago it was the universal fashion to describe electric waves and light by reference to an *ether*. Today there is a growing school who feel like a colleague of mine in considering that "ether" is an example in the English language of a word without any corresponding idea. It seems that the notion of an ether came from a false extension of the analogy of light to sound; both consist in the transfer of a vibration progressively from point to point in space; but the analogy stops there. Sound is a vibration of material particles and so requires a medium; while light is a purely electrical vibration and requires magnetic and dielectric fluxes for its propagation, but no necessary medium. Let us quote Faraday's ideas on this point:

"The view which I am so bold as to put forth considers, therefore, radiation as a high species of vibration in the lines of force which are known to connect particles and also masses of matter together. It endeavors to dismiss the ether, but not the vibration."

These words, written in 1846, anticipate (but without demonstration) Maxwell's electromagnetic theory of light and even the most recent views.

Let us now consider electric oscillations and waves by reference to familiar analogies in mechanics. Oscillations occur in bodies by virtue of their *inertia* and their *elasticity*. Inductance is electrical inertia and capacity is electrical elasticity: hence

electrical oscillations can occur in circuits having these properties. When the inertia and the elasticity of a material body or medium (as air) are distributed throughout space, the mechanical oscillation takes the form of a wave, such as a sound wave. Correspondingly, when inductance and capacity are distributed (as they are in any insulating space, including a vacuum) the electrical oscillation takes the form of an electrical wave.

The electric oscillations of Hertz and of Marconi's early experiments were produced by the electrical breakdown of a spark gap, which allowed a previously charged condenser to discharge through an inductive circuit, and were so rapidly damped as to be almost impulsive. The analogy is a tank into which air is pumped until it bursts and radiates a sound wave as a "bang." Marconi detected his impulsive electric wave by the breakdown of the insulation in a coherer, thus closing a local circuit through a relay; and to restore the coherer preparatory to receiving the next impulse, he regularly tapped it. Similarly we might detect an explosive sound by the bursting of a soap bubble (as window panes are sometimes burst at a distance from a severe explosion), and we might regularly blow new bubbles to detect subsequent sounds.

The introduction of electrical tuning (largely through the work of Pupin) permitted selection between electric waves of different frequency. The oscillations at the transmitting circuit were then made slowly damped, and the receiving circuit had its inductance and capacity adjusted to give it the same natural frequency, with the result that it was strongly affected by the desired signal and but weakly affected by interfering signals of other frequencies. The analogy is a tuning fork which when struck will produce a slowly damped oscillation and will affect a second tuning fork in its neighborhood, provided this has the same natural frequency or pitch.

Later *continuous* (or "undamped") electrical oscillations were introduced for radio communications (as initiated by Fessenden). These are produced in three ways: (a) by direct generation (Alexanderson, alternator); (b) through the electrically unstable arc (Poulsen); and (c) by the three-electrode vacuum tube with the feed-back circuit (Armstrong).

The direct generation of high-frequency current may be likened to the mechanical production of sound by the interrupted air jet of the siren or by the telephone receiver supplied with alternating current.

The conversion of direct current into alternating current by virtue of the unstable action of the electric arc is analogous to the conversion of a steady air stream into a sound vibration through some form of instability at the mouthpiece of a wind musical instrument.

The story of the three-electrode vacuum tube and its application in the production, detection and amplification of radio signals is too long to be more than touched on, for it would include nearly all of modern radio and much of the recent advance in electrical science. Edison discovered the phenomenon of one-way electric conduction through the space between the hot filament of an incandescent lamp and a second electrode inside the lamp. Fleming introduced such a two-electrode vacuum tube into the radio art, and thus provided an electric valve to convert the interrupted high-frequency received current into an interrupted direct current that could actuate an ordinary telephone receiver. When DeForest added the third electrode, the grid, as a control member, he opened a new field; for the received signal energy was thereby no longer required to actuate the telephone receiver directly, but merely to *control* a local source of practically unlimited energy (the plate-circuit battery). It was like the substitution of an electric motor for manual labor; it still takes some work to close and to open the switch that controls the motor, but far less than that which may be done by the motor. The three-electrode tube thus has an amplifying action, giving out electric energy of a desired form under the control of a minute input energy; this action may be, and is, employed in other fields besides that of radio communication.

Armstrong took advantage of the amplifying property of the three-electrode vacuum tube to feed back some of the output energy into the input, or control, circuit. This would reinforce any oscillation that might be present in the input circuit, and if powerful enough would maintain a continuous oscillation without any impressed signal or other help. Thus was achieved the vacuum tube oscillator, now universally used for radio telephone transmitting and likely to supplant the other methods for all radio transmission.

The vacuum tube oscillator is essentially a self-controlled electric valve which converts the direct current of a battery or a generator into an alternating current, thus being the converse of the rectifier. A mechanical analogy is the steam engine,

which receives a continuous flow of steam and converts it into a reciprocating motion through the appropriate operation of its valves. Just as the valves of the steam engine are actuated through mechanical coupling by the motion of the piston which they effect, so the grid of the vacuum tube is actuated through electrical coupling by the alternating current which it causes.

A closer analogy to the oscillation of a vacuum tube is the "howl" produced when the telephone receiver of a house set is placed in front of the transmitter. Here any sound impulse which actuates the transmitter will be carried electrically to the receiver, which in turn will send a sound wave into the transmitter, the action being cumulative and being maintained by the battery in the circuit.

ORAL VERSUS WRITTEN INSTRUCTION AND DEMONSTRATION VERSUS INDIVIDUAL WORK IN HIGH SCHOOL SCIENCE.

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Much time recently has been devoted to the problems relating to the teaching of school subjects more efficiently. Many methods have been discussed, and, to a very small degree the effectiveness of the instruction has been objectively measured. It seems that more "talking" has been done than "objectively measuring," the latter of which seems to be the real key to a determination of efficiency. It is with these ideas that this study is presented.

In this study an attempt was made to determine the relative values of oral and written instruction and the relative values of demonstration and individual work in laboratory work in high school science. The data for this study was secured by giving twenty-four laboratory exercises to forty-two students in a class of biology of sophomore grade in high school. The first problem was to grade the pupils according to their mental ability. This was done by giving the "Chicago Group Intelligence Test" devised by F. N. Freeman and H. O. Rugg. As a result of this test, the students were placed in three sections of fourteen students in each section. The average ability for each of the three sections was 48.21 as shown by the intelligence tests. The average school grade for the three sections was 82.88 per cent; 82.97 per cent; and 82.42 per cent respectively. These school grades vary but little and add weight to the fact that the students were divided into sections of nearly equal ability.