THE STORY OF MODERN SCIENCE

By

HENRY SMITH WILLIAMS

A NEW and Original Presentation in Every-day English of the Remarkable Progress Made in the Theoretical Sciences, Including Astronomy, Geology, Paleontology, Meteorology, Physics, Anthropology, Chemistry, Horticulture, and Biology.

IN TEN VOLUMES (Illustrated)

— *Volume IX* —

Radio Mastery of the Ether

FUNK & WAGNALLS COMPANY
NEW YORK AND LONDON

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VOLUME IX

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World Radio History

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U. S. Navy Official Photo

THE BATTLESHIP *IOWA* UNDER RADIO CONTROL

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RADIO-MASTERY OF THE ETHER

CHAPTER I

THE NECROMANTIC REALITIES OF RADIO

TELEVISION IN COLOR

THE culminating miracle of radio up to the present is television in color. Not the transmission of a picture, be it understood, but the duplication at a distance of the image of a natural object, such as the human face and figure.

For example, an individual sits or stands before a certain apparatus in New York, and a detailed image in natural color that is instantly recognized appears on the screen of another apparatus in Chicago—as well as on some thousands of similar screens in other parts of the country, or in Europe. That the voice of the individual is heard simultaneously with the appearance of the magic portrait seems a matter of course, merely because the radio transfer of sounds has so long been a matter of every-day observation in millions of homes that it no longer excites the slightest wonder.

Yet if one stops to analyze the phenomena, it might seem that the picture-transfer is rather less remarkable than the sound-transfer, because light waves are so much more intimately related to

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radio waves than are sound waves. Such reasoning, however, has no particular validity, because light waves and sound waves alike are transformed into radio waves at the transmitting station, and retransformed at the receiving station by processes so magical—and in the last analysis so inexplicable—that wonderment concerning either process is so high-keyed as to forbid comparisons. It is better to regard both phenomena as scientific miracles, and let it go at that.

This is not to say, however, that the proximal methods involved, and a proximal explanation of the scientific principles utilized, may not be understood. The fact is rather that, if we use words in their ordinary acceptance, and understand that "explanations" always leave a margin of mystery, we may say that the phenomena of radio, both as to sound-transfer and picture-transfer, may be quite readily understood by any one who chooses to give a little close attention to explanations that are readily forthcoming.

To illustrate, suppose we follow step by step the processes involved in television—the transfer of the visage of a living person, for example.

HOW A FACE IS TELEVISED

The definitive parts of the television apparatus (corresponding in a general way to the microphone and telephone receiver of ordinary radio) are a so-called scanning disc and a photoelectric cell. Other contrivances have been experimentally tested, but these are the ones that first met success, both in America and in Europe.

The scanning disc is one suggestive of a phonograph disc, except that it is perforated with a

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series of holes arranged spirally, each sequential hole barely overlapping the ones before and after.

In operation, a brilliant light behind the scanning disc throws its beams through the successive holes, so that the beams of light become in effect lines of light, crossing the face (or other object) being televised, in the aggregate traversing the entire field of the picture to be transmitted. The disc whirls at a speed of perhaps twelve rotations per second, and since the image of any object on the retina of the human eye persists for the fraction of a second, a casual observer would think the face completely and constantly illuminated.

But the photoelectric cell used in the televisor does not lag in its operations as the human eye does, and therefore is impressed with a constantly changing sequence of variations in intensity of light, accordingly as the beam shot through the holes in the scanning disc reflects more or less brightly from successive parts of the face and background making up the picture. And with each instantaneous impression, corresponding to the minutest modification of light, the photocell modifies the intensity of the current of electricity that passes through it.

The photoelectric cell that first gained recognition in successful television apparatuses was not a selenium cell—as might have been expected—but a vacuum tube lined with a potash preparation. The selenium cell, despite its fame as a modifier of the electric current under influence of light, did not serve, precisely because it lags a little, after the manner of the human retina. Lagging here will not answer, because the result would be a mere blur, instead of the presentation

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of a sequence of sharply defined images. The human eye at the receiving end of the television apparatus will blur the images enough to transform the series of dot-lines into a continuous picture—precisely as the same eye connects the series of independent "snap-shots" of the motion picture, and sees a continuous "movie."

The apparatus that completes the transaction at the receiving end of the television apparatus is merely a duplication of the transmitting photoelectric cell and scanning disc. The fluctuating current of the receiving photoelectric cell causes coincident fluctuations of the beam of light, which passes through a reception scanning disc to impinge on a screen that the human receiver watches.

A moment's reflection will make it clear that the two scanning discs—for transmission and for reception—must be synchronized with something approaching absolute accuracy. Their rates of spin must not vary by the minutest fraction of a second—else the image will become a meaningless blur of light. To effect such synchronization—at a distance of hundreds or even thousands of miles—is a feat presenting mechanical difficulties the overcoming of which constitutes not the least wonderful part of the achievement.

FROM LIGHT WAVES TO RADIO WAVES

In all this we are taking for granted the transmission of the electrical impulses of the photoelectric cell from the transmitting to the receiving station—through indefinite realms of space. And this part of the transaction no longer amazes us, because the phenomena of radio transmission

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have become matters of every-day experience for all of us. Only things that are unfamiliar seem mysterious or amazing.

Yet it must be admitted that the familiar phenomena of radio transmission are intrinsically both mysterious and wonderful, and difficult to visualize clearly in all their bearings. Here as elsewhere when manifestations of energy are in question, we must be content with proximal explanations. For example, we must accept the statement that radio waves are "electromagnetic waves in the ether," without asking for assurance as to just what these alleged waves are like in terms of any sense-perception. We must even permit some of the physicists who accept such a definition to question, in other connections, whether any such entity as "ether" really exists. The point of the matter is that the word "wave" conveys a definite impression to our minds, and that "ether" is a long-current word for the medium which is supposed to fill space. We can not think of waves without assuming that something is oscillating, and it is the scientific convention, despite the objections of one school of physicists, to speak of that hypothetical something as "ether."

Radio waves, then, are electromagnetic waves in the ether. But the same phrase describes light waves. The difference between the two types of waves is merely a difference of length. Light waves are exceedingly short. Radio waves are relatively long. Both travel through space at the same rate of speed—about 186,000 miles per second. The particularity of the light waves is that human beings have sense organs—the retina of

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the eye in association with certain brain cells—capable of recognizing and interpreting them; whereas the long radio waves sweep right through our bodies without producing any sensation whatsoever.

The particularity of the long radio waves is that they are largely reflected from the so-called Kennelly-Heaviside layer of the upper atmosphere, and so are flashed, by repeated reflections, round and round the world, instead of escaping straight off into space. If it were not for that Kennelly-Heaviside layer—consisting, it is believed, of ionized particles liberated by the ultra-violet rays of the sun—radio waves would presumably pass off into space at a relatively short distance from the broadcasting station, and distant transmission would not be feasible. A flashlight beacon is soon hidden by the curvature of the earth. A corresponding radio beacon is reflected from the sky, and may be picked up on the opposite side of the globe. For the matter of that, the radio message may circumnavigate the globe, and be revealed as an echo, about one-eighth of a second belated, at the station from which it was sent out.

The familiar way of testing transmitting apparatus operating on relatively short radio waves is to listen for the echo. A message may even be appreciable after it has made a second circumnavigation of the globe. And there is no reason why even that should be the limit, were the transmitting impulse sufficiently strong and the receiving apparatus sufficiently delicate. The range of any radio impulse is the surface of the entire globe, but of course the power of the impulse decreases rapidly with distance. The

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portion of the wave traveling along the surface of the earth appears to be pretty rapidly absorbed, and the portion reaching the Kennelly-Heaviside layer is of course spread out fan-like and, as it were, diluted, until ultimately it also ceases to have tangible existence.

So much for the reason why the light waves of the television transmitter must be transformed into radio waves for distant transmission. The transformation is effected in a vacuum tube "tuned" to oscillate at any desired frequency. Other tubes magnify the impulse stage after stage, until the electromagnetic waves generated at the aerial have power to carry through space for hundreds or even thousands of miles before they weaken beyond recognition.

FROM SOUND WAVES TO RADIO WAVES

Before we attempt to gain a more concrete understanding of the transformation from light waves to radio waves, let us consider a little more in detail the radio waves themselves, and in particular their relations to the sound waves that are the usual phenomena transmitted (or seemingly transmitted) from broadcasting stations to the receiving apparatuses now installed in a majority of American homes.

At the outset we are confronted with a puzzling anomaly. We are told that the radio waves that bring the messages from broadcasting or other transmitting stations travel 186,000 miles per second, or more than seven times round the world, their medium being the ether. But sound waves, as every one knows, travel not at all in ether (a

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cessive wave will obviously start 200 meters (300,000,000 meters divided by 1,500,000) behind its predecessor. Or consider instead a current alternating only 500,000 times (500 kilocycles) per second. Dividing 300,000,000 by this number, we find that the electromagnetic waves generated are of 600-meter length.

Frequency and wave-length are thus seen to be reciprocals. It has been found convenient to speak usually of the number of kilocycles on which a station operates, rather than of the reciprocal wave-length of the radio waves coming from its antenna; but of course one statement can be translated into the other by a simple process of division, as just illustrated. The terms "long wave" and "short wave" are arbitrary. Commercial transatlantic transmitters may use generating currents of only 20 kilocycles (nine-mile waves); while experimental operators may test currents of higher frequency than 100,000 kilocycles, represented by waves less than one meter in length.

FROM RADIO WAVES TO SOUND WAVES

Even the relatively slow waves of the commercial station, however, would be incapable of producing sound waves directly that the ear could interpret; for the ear is a relatively dull instrument that can not register vibrations that are more rapid than about 10,000 or 15,000 per second. Most audible sounds are of very much slower pulsation than that. The notes of an orchestra for example, range from about 33 vibrations per second (the lowest pitch of the tuba) to 4,752 vibrations per second—the highest note of the

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piccolo. The familiar note "middle C" represents 262 vibrations per second. Ordinary voice sounds have a range of variation of only a few hundred vibrations per second; from about 60 for a low bass to 1,300 for a very high soprano.

How, then, is the gap crossed between the slow vibrations of the voice-sounds and the excessively rapid vibrations of the radio current? The explanation is that in the transmitting radiophone station the oscillations of the radio-frequency are "modulated" or grouped, constituting a so-called "carrier-current," in which each sound wave may be thought of as a sort of envelop about a series of electric waves.

It is these modulated groups of waves, rather than the individual waves themselves, that affect the telephone diaphragms at the receiving stations, and transmute the current back into sound waves again.

THE ALTERNATING CURRENT

But there is yet another complication. When the radio waves rushing through the ether encounter the antenna of a receiving apparatus (either an outside antenna or an indoor loop-aerial) they set up an alternating current at the transmitting station. Indeed, only an apparatus tuned to respond in this way can be used to interpret any particular message. Yet if this alternating current were brought directly to the telephone diaphragm, it would produce no effect whatever, because its oscillations are too rapid to evoke responsive movements in the relatively sluggish diaphragm.

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In effect, the alternating current pulls the diaphragm this way and that so rapidly that it stands still—as a hinged door would stand still if you tap rapidly with equal force on both its sides at the same time.

In order that the diaphragm should respond, and by its movements set up sound waves in the air, it is necessary that the successive pulls of the electrical current should all be applied in one direction—a series of pulsations instead of alternations.

And this object can be attained only if the alternating current is rectified, or transformed into a direct, pulsating current.

RECTIFYING THE CURRENT

To effect such "rectification" of the alternating current is the province of one of the most interesting essential parts of the radio-receiving apparatus—a simple but very extraordinary piece of mechanism called the "detector."

The "detector," as has been aptly remarked, detects nothing. But its action is absolutely prerequisite to the detection of a radio message by the human ear, so the name is not altogether inappropriate.

Names aside, let us make the acquaintance of this fascinating bit of mechanism, which may be called the heart of the radio-receiving apparatus. In so doing, we shall gain information of thoroughly practical character.

The detectors used in radio apparatus to-day are essentially of two types. One is a little piece of mineral called a crystal. The other is a modified electric light bulb called an electron tube,

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otherwise known as a vacuum tube, audion, electric valve, or triode.

These two types ot apparatus have not the slightest resemblance one to the other; yet they accomplish the same elemental function. Each is able to transmit energy in one direction and prevent (more or less effectively) its transmission in the opposite direction. The crystal detector accomplishes this by virtue of some inherent condition of its molecular structure which seems to us wonderful because it is unusual. We do not know just what this peculiarity of molecular structure is, nor why it happens that a few types of mineral exhibit it, whereas all others permit the passage of electrical energy with equal facility in both directions, if at all. But it is a matter of observation, and each individual crystal used as a detector must be tested as to its transmitting action before it can be used effectively.

OPERATING THE CRYSTAL DETECTOR

This is done, in practise, by placing the little crystal in the circuit of the radio-receiver, in such a way that a very fine wire called a "cat whisker" can be adjusted against one of its sides, to convey the message-bearing current; and this fine wire is moved about until a spot is found at which the best results are attained. By results, we mean, of course, sounds heard in the telephone receivers that are adjusted in connection with a wire that leads from the other side of the detector crystal.

Several types of mineral are used as detectors, one of the most familiar and satisfactory being a natural ore called galena. Bits of crystals of

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HOW THE TRIODE WORKS

The now familiar little instrument looks like, and in reality is, an electric light bulb. It has at its center a filament that becomes incandescent through passage of an electric current from a local battery. But there are two other important elements in the lamp-bulb that fit it for its purpose in the radio apparatus. One of these is a so-called grid, consisting of a little perforated plate or coil of wire adjusted about the filament; and the other is a metal plate, often in the form of a cylinder, adjusted on the outside of the grid.

Both grid and plate, like the filament, have connecting wires that pass through the wall of the vacuum-tube bulb. The one from the grid connects with the wire that brings the radio message from the antenna. The one from the plate connects with the positive pole of an electric battery, called the "B" battery, and with the telephone receiver.

The grid thus receives the alternating current, and its so-called potential (voltage) oscillates incessantly from positive to negative with the oscillations of the incoming current.

To understand what then happens, we must know that the filament of the lamp when it is brought to incandescence is constantly throwing off vast numbers of electrons, the electron being the unit particle of negative electricity. The movement of electrons constitutes the flow of an electric current. Electrons are always flying out from an incandescent surface; but ordinarily they are immediately drawn back again. In the ordinary electric light bulb they have nowhere to go,

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and most of them return promptly to the filament. But in the detector-triode that we are considering, conditions are changed, because the plate is positively electrified, and some of the electrons can escape across the vacuum gap and make their way to the plate, and flow out along the wire to the battery and the telephones.

Such escape of electrons from filament to plate is facilitated by the grid during the instant when it is of positive potential; but is interfered with seriously during the succeeding instant when the grid is of negative potential—because opposites attract and similars repel in the electric world.

It follows that the flow of current in the so-called plate circuit, which conveys the ultimate message to the telephones, is interrupted half the time, with each alternate phase of alternating current; and this is the same thing as saying that the current which flows out of the triode in the plate current is a direct current, pulsating in unison with the alternations of the grid, but flowing in one direction only.

In a word, the triode has accomplished the same thing that the little crystal detector accomplished. It has acted as a valve, permitting the flow of electricity in one direction only. Otherwise stated, it has rectified the current, so that its accumulated pulsations will affect the telephone diaphragm always in one direction, and thus produce the movements that will generate sound waves.

WHY THE TRIODE IS SUPERIOR

But why, it will be asked, should we use an elaborate electric apparatus to do what can be accomplished by a simple bit of crystal?

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altogether ignores all radio waves except those of a particular length. While you are listening to the broadcast program, and hearing nothing else, any number of much shorter waves, from amateur stations, and of much longer ones from commercial stations, may be washing across your antenna, and for that matter through the radio apparatus itself, without being registered.

Unfortunately, tuning is not always perfect, and the simpler types of receiving outfits may not be adapted to anything but "broad" reception. That is to say, they respond to a fairly wide range of wave-lengths, allowing "interference" from stations that a better tuned instrument might shut out altogether.

Even the best tuned instrument may suffer from the invasions of atmospherical electricity known as "static," which becomes a pest particularly in the summer months. It may be added that with a loop-aerial there is usually less disturbance from this source.

BROADCASTING POSSIBILITIES AND COMPLICATIONS

Within ten years of the establishment of the first general radio broadcasting station, there were upward of six hundred such stations in the United States, and practically every second family had a receiving apparatus—a very high proportion of these being vacuum-tube sets of relatively high sensitiveness and selectivity. Radio manufacture had become a major industry. As early as 1927 it had become apparent that a new allocation of broadcasting channels was imperative, and such an allocation was made by the Radio Commission

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The answer is that the triode is far more sensitive than the crystal. It takes cognizance of currents that the crystal would altogether obstruct; and in addition to that, it modifies greatly the force of the current. The energy of the local battery is used to amplify the incoming current. So even a single tube brings a far louder response in the telephones than could be gained from the crystal detector; and by linking several tubes together (making a multi-stage amplifier) sounds may be amplified almost indefinitely. It is nothing unusual to speak of a million-fold amplification.

That is why a radio-receiver apparatus with a triode detector may enable one to "listen in" on stations located scores or hundreds of miles away. Also why a "loud-speaker" may be substituted for the ear 'phones, and the program made audible to the entire family, or even to an audience in a large hall.

The wonder of wonders is that the amplified current retains the modulations of the infinitesimally weak current that came to the detector-tube from the antenna. The reason it does so is because of the action of the grid, as just described. But the thing seems scarcely less miraculous because we know how it is accomplished.

The grid-bearing vacuum tube, or triode, that accomplishes such marvels of detection and amplification of radio currents would be an astonishing mechanism if it did nothing else. But in reality the same apparatus, modified only as to details of construction, is used at the broadcasting station to transmit the radio messages. Used as a detector, as we have seen, it can change an alternating current into a direct current. But, para-

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doxically enough, when used in another way it can change a direct current into an oscillating current. It can produce the high-frequency alternating current that is necessary for the generating of radio waves.

THEORY AND PRACTISE OF TUNING

By modifying the electrical conditions of so-called "inductance" and "capacity," the operator may cause the transmitting tube to oscillate at any desired degree of frequency — with no known upper limit. To produce the 360-meter waves sent from the broadcasting stations, as we have seen, requires a current oscillating more than a million times per second. Oscillations of 200-million frequency have been produced experimentally.

We can form no definite conception of such rapid changes; but the electrical expert can measure them with accuracy. And even the most unscientific user of a radio-receiving apparatus in reality does measure the waves, however unconsciously, when he "tunes" his instrument to receive the message. When his instrument is properly tuned, the conditions of "inductance" and "capacity" in his receiving apparatus harmonize with those of the transmitting station.

This is a matter of utmost importance, because you may not only "tune in" the message that you wish to receive, but at the same time you may "tune out" an unwelcome message. The ether is always vibrant with many messages, and if any particular radio-receiving apparatus were to accept them all, nothing but a chaos of sounds would result. But a properly tuned instrument almost

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altogether ignores all radio waves except those of a particular length. While you are listening to the broadcast program, and hearing nothing else, any number of much shorter waves, from amateur stations, and of much longer ones from commercial stations, may be washing across your antenna, and for that matter through the radio apparatus itself, without being registered.

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in the ensuing year, and put into effect on November 11, 1928.

The difficulty was and is that the number of "channels" for broadcasting is limited. It was found impracticable to limit any given station to a narrower band than 10 kilocycles. That is to say, each station must be permitted to vary the rate of oscillation of the alternating current used in broadcasting its programs to the extent of 10,000 vibrations per second. Beyond that it must not go, because it would then intrude on the field of some other station.

But the entire range of frequencies used in radio transmission extends only from approximately 15 kilocycles (15,000 alternations of current) to 30,000 kilocycles (30,000,000 alternations). And of this total, the part set aside for broadcasting radio programs was limited to the field lying between 550 and 1,500 kilocycles. In this field, as simple arithmetic shows, there are only 96 independent channels each 10 kilocycles wide.

The frequencies higher and lower than this broadcasting band being already preempted for other purposes, and there being several times 96 broadcasting stations in existence, here was an obvious complication. In the nature of the case, two stations can not operate on the same wave channel at the same time in the same territory, without making chaos of both programs. What was to be done?

A partial solution was found by the division of the entire country into five regions or territories. Six channels were reserved for Canadian stations.

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WIRED WIRELESS

It will be seen, then, that radio as a means of communication has inherent difficulties of unique character. Some of these difficulties will temporarily disappear with the advance of broadcasting technique, but even with ideally perfect synchronization there must always remain the possibility of demand for wave channels exceeding the nature-limited supply.

At least a part solution of this dilemma may be found in the broadcasting of messages and programs by what is called "wired wireless," a method devised by Major-General George O. Squier, of the Signal Service, in which high-frequency waves carrying radio messages are conveyed along the electric wires, and may thus be distributed wherever electric lighting is installed. Several messages may be sent along the same wire at the same time, on different frequencies; and there is of course no interference with direct radio messages sent through the ether such as we have been considering hitherto.

Of course the "wired wireless" messages would not be available in homes not supplied with electric light equipment. That is an obvious disadvantage, as compared with the ordinary radio waves, which penetrate everywhere. On the other hand, the "wired-wireless" system might be preferable in large buildings having a steel framework that serves to filter out the energy of the electromagnetic waves; or where there is interference from such metallic structures as elevated railways, systems of electric power houses, as not infrequently happens.

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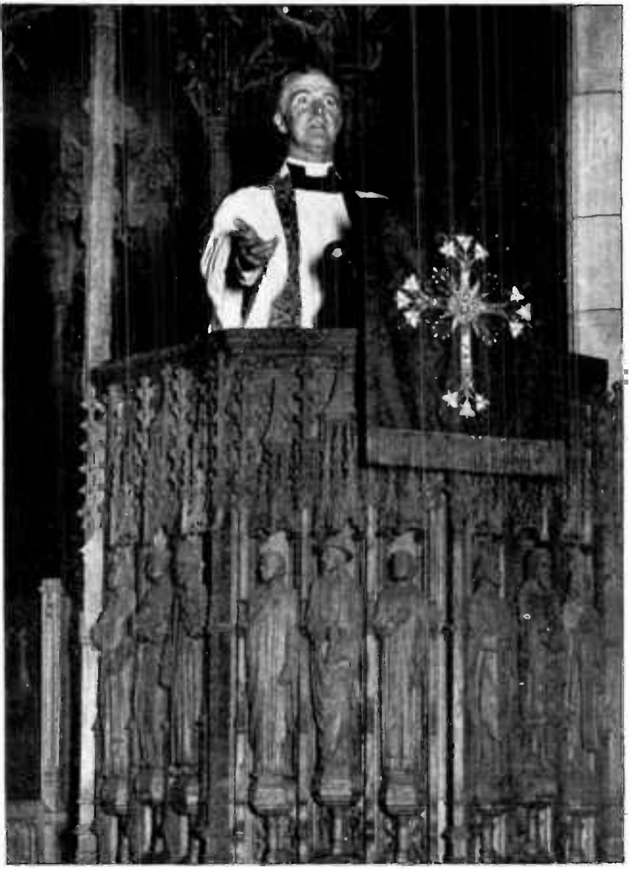

THE RT. REV. ERNEST M. STIRES, BISHOP OF LONG ISLAND, BROADCASTING FROM THE PULPIT

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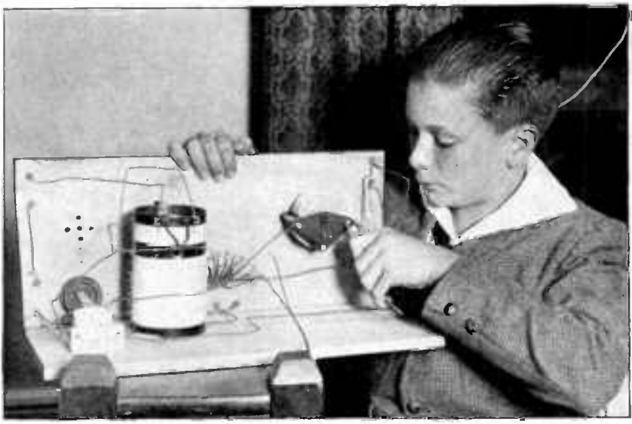

THIRTEEN-YEAR-OLD DAVID ORGAIN BUILDS A PRIZE REGENERATIVE SET FOR THIRTEEN DOLLARS (BELOW) AND EDMUND C. KEAN MAKES A SIMPLE CRYSTAL-DETECTOR SET WITH LOOSE-COUPLER

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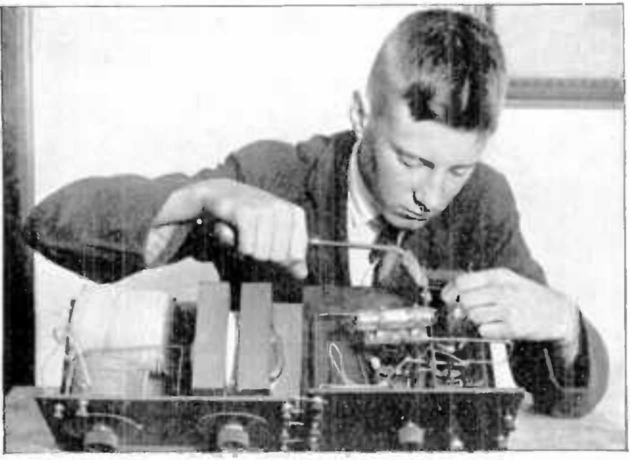

WILLIAM DICKEY WINDS A SPIDER WEB COIL (BELOW) AND CHARLIE MURPHY MAKES A REGENERATIVE SET WITH ONE STAGE OF AMPLIFICATION

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A CRYSTAL RADIO-RECEIVER IN THE FORM OF A NECKTIE-PIN INVENTED BY MR. C. SAUNDERS (RIGHT), AND A GROUP OF VACUUM TUBES FROM FLEMING VALVE TO PEANUT AUDION OR TRIODE

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ONE-PIECE RADIO-RECEIVER CONSTRUCTED BY B. S. LEWELLEN: COIL, CRYSTAL AND TELEPHONE RECEIVER IN HEADPIECE (RIGHT), AND BROADCASTING MICROPHONE USED BY ANNOUNCER AT W. E. A. F., NEW YORK

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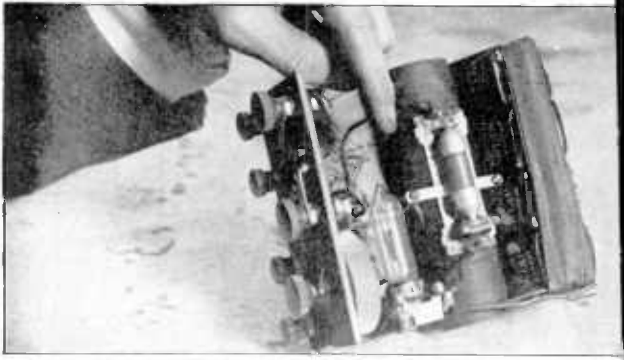

MINIATURE TRANSMITTING AND RECEIVING SET FITTED INTO A CAMERA CASE, MADE BY STERLING G. SEARS (ABOVE), AND WILLIAM A. BRUNO WITH EFFICIENT RECEIVER USING ONE DRY CELL INSTEAD OF STORAGE BATTERY

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TWO HOME-MADE LOUD SPEAKERS THAT ARE SAID TO GIVE SURPRISINGLY GOOD RESULTS

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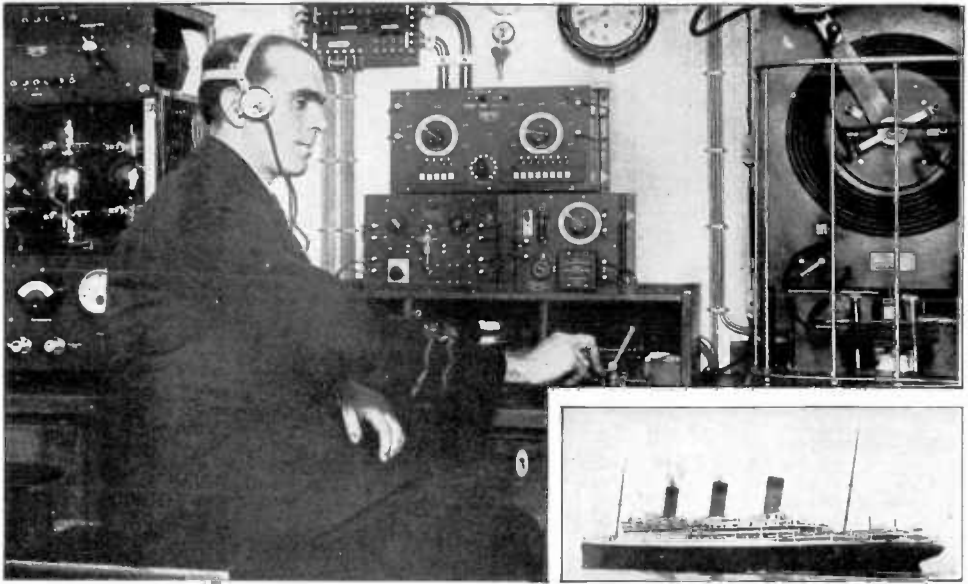

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OPERATOR TAMPLIN OF THE *MAJESTIC* SENDING A CODE MESSAGE

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THE LOOP-AERIAL

There are yet other possibilities of discriminating between messages from different radio transmitting stations in the same region based on the fact that the type of antenna known as the loop-aerial has very marked directional power. It will receive a message adequately only when its edge is directed toward the transmitting station. If you rotate the loop on its axis, the message fades away until, at 90 degrees, it disappears altogether. The operator may thus select the station to which he wishes to listen, by merely rotating the little loop until it points in the right direction.

Unfortunately the loop-aerial can be used only with a very sensitive radio-receiving apparatus, involving several amplifying triodes in addition to the detector.

But radio will one day have its Henry Ford, who will produce a "flivver" receiving set of genuine efficiency at a price within reach of short purses. Major Edwin H. Armstrong's super-regenerative circuit, which makes two or three tubes perform the service hitherto allotted to eight or nine, perhaps points the way.

DIRECTIONAL TRANSMISSION

Meantime Senator Marconi's studies of directional sending of radio waves give intimation of future possibilities of inter-communication between individuals that may bring radio into further rivalry with the ordinary telephone. But that possibility, altho its importance is obvious, concerns an aspect of the subject different from that we are at the moment considering. The

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problems of broadcasting rather than those of individual communication at present call for solution. The message sent from concert hall or information bureau or lecture platform or pulpit by radio must of a preference spread in all directions impartially. Selections between messages, as we have pointed out, should be the problem of the individual receiving station.

To be able to pick out this message or that when the ether is cobwebbed with waves seems an amazing feat of wizardry, but it is a feat that any one provided with a properly equipped receiver can readily perform.

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CHAPTER II

THE MAKERS OF RADIO

I THINK it was Goethe who made the sagacious observation that the history of a science is the science itself. There is a world of truth in the comment. And a moment's reflection makes it obvious that the historical approach has many advantages for the student who would seek a relatively easy road to acquisition of knowledge, because as a matter of course the less intricate discoveries came first, and later discoverers built upon the foundations laid by the pioneers.

Perhaps we can not do better, then, in attempting to gain a somewhat comprehensive and intimate view of radio phenomena, than to go back a little in time and approach the subject under guidance of the pioneer workers, following on through the leadership of more recent investigators to the accomplishments of the immediate present.

As a matter of course, the first name that comes to mind when one thinks of the history of radio is that of the celebrated Italian, Guglielmo Marconi. Everyone knows that it was Marconi whose efforts were chiefly responsible for proving that the sending of telegraph messages without wires had commercial possibilities. Everyone is familiar with the word "marconigram" as a synonym for "wireless telegram." Incidentally we may note that the word "radio" has virtually supplanted "wireless" in recent usage.

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Of course Marconi built upon foundations laid by earlier experimenters, as every inventor must do. And if one intends to go back to the very beginning, one scarcely knows what to count as the first foundation stone. All the work of several generations of students of electricity might appropriately be considered as of necessity preliminary. In particular the workers who had to do with electromagnetic phenomena and those who sent electrical signals through the water or along the surface of the earth were independently preparing the way for radio.

Even more directly in line was the work of the famous English physicist, Clerk Maxwell, in demonstrating that light is an electromagnetic phenomenon. An extraordinarily imaginative man, Maxwell conceived the possibility of signaling with the aid of the larger electromagnetic waves that he likened to light-waves; but he made no practical progress toward the realization of the idea.

The theoretical work of Clerk Maxwell stimulated a young German scientist, Heinrich Rudolph Hertz, to take up the investigation of waves in the ether, and, unlike his predecessor, this young experimenter attempted to demonstrate the possibility of signaling with the long, invisible electromagnetic waves,—the ones we now speak of as radio waves.

It is in honor of this experimenter that these waves are very commonly referred to as Hertzian waves. Fully to realize the justice of thus honoring Hertz, we must gain a clear impression of the status of wireless telegraphy at the time when

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his experiments were inaugurated, about the year 1886.

WIRELESS THAT WAS NOT RADIO

It may surprise the reader to have reference thus made to wireless telegraphy as something that was in existence as long ago as the year 1886; especially when it is recalled that the experiments of Marconi, out of which modern wireless grew, were not begun until about ten years after that date. Nevertheless it is true that experiments of very striking character, many of them highly successful, had been carried out prior to 1886, and were being conducted at that time and during several years following, in which communication was made over considerable distances (three or four miles in some instances) both by telegraph and by telephone, without the use of conducting wires.

Let it be at once explained, however, that altho reference is here made to what may be quite properly called wireless telegraphy and telephony, the tests in question were not made with the electromagnetic waves with which Hertz experimented, and with which, as the reader is aware, modern "wireless" is conducted.

It is partly because the word "wireless" is subject to this ambiguity that it is desirable to substitute it, as has been done so largely in recent literature, with the word "radio" when reference is made to the modern method.

Otherwise there is unavoidable ambiguity; for there are at least four other methods of establishing communication with the aid of electricity, operating telegraph or telephone apparatus across

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spaces of land or water without the use of wires to connect the sending and the receiving stations.

The names of such men as Professor J. Trowbridge and Graham Bell and Thomas A. Edison and Professor A. E. Dolbear in America and of Sir W. H. Preece and A. W. Heaviside and Willoughby S. Smith and W. B. Granville and C. A. Stephenson and Sir Oliver Lodge in England; and of Professor E. Rathenau in Germany, among others, are associated with successful efforts at wireless communication prior to the time when the Hertzian waves were made available.

Mr. Edison, for example, worked out a system of communication between railway stations and moving trains in 1885. The principle involved was that of electrostatic induction between charged insulated metallic sheets and ordinary telegraph wires. Older readers may recall newspaper accounts of the practical operation of this system on the Lehigh Valley Railroad in 1887. It is recorded that the system worked well, but that there did not appear to be a commercial demand that justified its continued operation.

The electrostatic field, through which the telegraph wires were energized across a gap of several yards between plate and wires at sending station and between a moving train and the wires all along the line, was of the same type as that which exists between the aerial wires and the ground in the modern radio operation. But it will be recalled that in the modern apparatus, this electrostatic field is utilized only to aid in generating the electromagnetic waves; whereas in the Edison method the electromagnetic waves—that is

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to say, in the Hertzian sense—were not considered at all.

Here, then, was one type of wireless communication antedating radio and differing radically from modern radio in its principle of operation.

EXPERIMENTS WITH INDUCTION

The chief interest of this successful experiment (questions of practical utility aside) lies in the demonstration that the lines of electrical energy constituting a field about a charged body extend effectively far beyond what would ordinarily be supposed to be their limits of influence.

In reality, we are perhaps justified in supposing that there is no limit whatever to the extent of such an electrical field, altho of course the force ultimately becomes so weakened or attenuated as to be undemonstrable by any available instruments.

There are theoretical grounds for believing that the magnetic field about the electron extends throughout space. That the aggregate magnetic fields of groups of electrons in motion, constituting an electric current, has an effective range of astonishing extent was demonstrated long before the electron itself was discovered.

Practical study of the effects of this magnetic field may be made with the simplest induction coil. But such studies would not, perhaps, lead one to suppose that the magnetic influence would reach out effectively to a distance measured not merely in feet or yards, but in miles.

Yet such had been proved to be the case as long ago as 1882, when Sir W. H. Preece, in connection with experiments to test the conductivity of earth and water (experiments not dissimilar to

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those that Professor Trowbridge had performed in America a little earlier), was led to observe that where parallel lines forming portions of telephonic and telegraphic circuits were arranged on opposite sides of a considerable channel of water, inductive currents precisely similar in character to those generated in an induction coil could be detected.

For example, in an experiment conducted in 1885 by Preece in association with A. W. Heaviside, it was shown that when two completely insulated circuits arranged in a square, with each side about 440 yards, were placed a quarter of a mile apart, telephonic speech was conveyed from one to the other by inductance. That this was by no means the limit of the inductive influence was proved by separating the coils to a distance of 1,000 yards or three-fifths of a mile, when telegraphic signals could be heard distinctly.

Demonstrations of an even more spectacular character were made by Preece in succeeding years, in some of which communication by telephone was established between an island and the mainland over a stretch of four miles, even in one instance of six and a half miles, the current being generated in a long stretch of wire grounded at either end; and the induced current being developed in a corresponding wire placed approximately parallel to the other.

WIRELESS THROUGH EARTH AND WATER

Here was "wireless" communication, in the sense that a stretch of miles intervened between sending and receiving wires;—the only sense, let

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it be recalled, in which modern radio is wireless.

But the experimenters, and the engineers who observed their work, were never quite certain as to just what part of the effect was due to electromagnetic induction and what part to actual conduction of the electric current through the earth or along the surface of the earth or through the water.

That earth and water could be used as conductors in the place of wires was shown by many experimenters; notably by Professor E. Rathenau of Berlin, who in 1894 demonstrated a conductive system of wireless telegraphy by signaling through three miles of water.

There was no question, however, that in many of the experiments of Preece and various others, electromagnetic induction played an important part; and Sir Oliver Lodge was among those to demonstrate the feasibility of utilizing the energy of the electromagnetic field. His experimental demonstration of a system in which the primary and secondary circuits were tuned with the use of condensers was not made, however, until 1898 when, as we shall see, Marconi's demonstration of the possibility of using Hertzian waves was by way of rendering the earlier type of endeavor utterly futile.

That the electromagnetic field about the electrified wire could be detected even at the distance of several miles was an interesting fact that ceased to have significance for the would-be wireless operator so soon as it was demonstrated that this electromagnetic field, in connection with the electrostatic one, could be utilized to set up

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electromagnetic waves in the ether the range of which is practically limitless.

There was no directly sequential relation between the experiments with induced currents and the development of the Hertzian system; yet the earlier experiments have sufficient analogy to be of interest to every student of radio.

FORERUNNERS OF MARCONI

The man who found the practical way to utilize the Hertzian waves, and thus became the father of radio, was the young Italian, soon to be world-famous, Signor Guglielmo Marconi. As to that, there is no dispute whatsoever. There are comparatively few instances in the entire range of the history of discovery in which the record is so incontestable, and therefore in which there is so little opportunity for difference of opinion.

As a rule there are many claimants to a discovery. We shall see that fact illustrated presently in connection with some of the later developments of radio. But Marconi stands alone, without rival, as the man who put into practical effect a conception that had been only a dream in the minds of other men, and to most men a dream that seemed impossible of realization.

Yet it is curious, looking back, to see how many men were on the track of the idea; in particular, how many had made experiments that, had they been correctly interpreted, might have led to practical results. But here as always the experimenter was hampered by the influence of preconceived ideas. The wonderful and seemingly magical condition of induction, in which the energy of electrcity passes from one circuit to another through

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space—the condition that meets us on every hand whenever currents of electricity are in question, as we shall see—could account for so much that experimenters not unnaturally turned to it for the explanation of all obscure phenomena associated with the transfer of electrical energy through space.

EXPERIMENTS OF JOSEPH HENRY

Thus it was, for example, that a very remarkable experiment recorded by the famous American, Professor Joseph Henry, failed to receive the attention it deserved.

Henry observed that an electrical spark about an inch long, developed in a circuit of wire in an upper room, could magnetize steel needles included in a parallel circuit of wire placed in a cellar thirty feet below with two floors intervening.

Here, as the present-day expert would interpret it, was the observation of a veritable radio phenomenon. It was not mere induction that was in question, but the generation of radio waves by the spark-producing current.

The simple experiment had really opened up a new world of almost infinite possibilities; or rather it opened a door into that world through which entrance might have been made. But even the imaginative Henry, glimpsing through the door, did not recognize the new world as unknown territory. He thought merely that he had observed an interesting new by-path in the old territory of electrical induction. And so nothing tangible came of his curious observation of the magnetization of the distant needle.

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WORK OF THOMAS EDISON AND OF D. E. HUGHES

As regards results, at least, the same thing may be said of the experiments of various other investigators, including Mr. Edison, in which "distance-phenomena" were observed and studied, and even made the subject of speculation that at the time seemed more or less fantastic.

Edison had the genius to realize that some of his observations had to do with forces that were not readily classified under any preexisting formulas. He referred to a new "etheric force" which, viewed from the present-day standpoint, is comprehensible, but which did not seem to link itself effectively with the knowledge of that time.

Again, the Englishman, D. E. Hughes, made some really remarkable observations, to the effect that a tube of metallic filings, loosely packed, was sensitive to electric sparks made in its vicinity, through the reduction of its electrical resistance. He detected effects on such a tube connected to a battery and telephone at a distance of almost half a mile.

It appears that he was clearly disposed to believe that he had to do here with some force other than mere electrical induction. But unfortunately some influential friends with whom he discussed his experiments did not take this view. In their eyes the experiment appeared merely as another illustration of the familiar phenomenon of induction; and their counsel prevailed, so that Hughes did not publish an account of his experiments until something like twenty years later—after the demonstrations of Marconi had revealed the practical significance of signals utilizing a tube of metallic filings.

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PROFESSOR BRANLY AND SIR OLIVER LODGE

Subsequently to Mr. Hughes' observation of the action of the metallic filings, Professor Branly, of Paris, quite independently made rediscovery of the curious phenomenon. Unlike the other investigators, he published his results. In 1890, he made known to the scientific world the fact that an electric spark at a distance has the power to change loose aggregations of metallic powders, under certain conditions, making them good electric conductors instead of extremely poor ones.

Sir Oliver Lodge in England took up the investigation of similar phenomena, studying the action of the electric waves in reducing the resistance of the contact between two metallic surfaces. The device that he developed, which utilized either a metallic plate and a point or two bulbs, was given the name of "coherer."

Following up a suggestion probably received from Professor Branly's experiment, Lodge tested the effect of placing filings of iron or brass in a tube plugged at either end and connected in an electric circuit. He found that if the filings are not too tightly packed, the resistance of such a tube to the passage of a current of electricity is almost infinite. But when an electric spark was generated in a neighborhood circuit not far away, the resistance in the tube is instantly overcome, and the current of electricity passes through it.

To restore the tube to resistance nothing more was necessary than to tap it lightly.

In 1894 Sir Oliver Lodge exhibited a tube of metal filings in connection with which he had developed an apparatus for automatic tappings to restore resistance, so that a discontinuous cur-

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rent passed through the tube. In attempting to explain the phenomenon, Lodge suggested that the influence of the spark led to a fusing or welding of the surfaces of particles, thus causing them to cohere. Hence the name "coherer" that he suggested for the apparatus,—a name that was presently to become famous because of the use Marconi made of the metal filings as a detector in his practical wireless apparatus.

At the moment, however, the coherer had significance rather as a laboratory toy than as an apparatus of practical utility. It came to be spoken of as a Lodge tube; but Professor Branly has protested very vigorously against such a characterization, pointing out that he was the pioneer in the making of such tubes. His claims are apparently justified; and the name of this French savant must always be remembered and given an important place by the historians of radio invention.

Recalling that Hughes had not published his experiments and apparently was not convinced of their significance; and recalling also that the experiments of Sir Oliver Lodge, which aroused great scientific interest, were undertaken in part at least as supplementary to Professor Branly's investigations, it would appear that Branly must be considered as being, after Hertz, perhaps the most important of Marconi's forerunners.

THE COMING OF MARCONI

The justification for this estimate is found in the fact that it was by the use of an improved coherer of the Branly-Lodge type that Marconi gained his first great practical success.

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A native of the City of Bologna, Marconi was a very young man when, about the year 1895, he began the experiments that were to lead to such momentous practical results.

The famous experiments of Hertz had been made about ten years before. Hertz had proved that an electromagnetic wave could set up a current that would cause a spark between the open ends of the loop of wire that he called a "resonator." It required but little effort, however, to show that the Branly-Lodge tube of metallic filings was a much more sensitive detector of electromagnetic waves.

Marconi's efforts were presently directed to the perfection of this tube, and the development of methods of generating powerful electromagnetic waves. The definite object that he had in mind was the discovery of a practical method of signaling through space. At the outset, however, he either failed utterly to pregage the possibilities of the method, or else through modesty declined to let his imagination take wings; for we find him, in an interview published in *McClure's Magazine* in 1897, when a considerable measure of success had been attained, declaring that it would be possible by the perfection of his method to send signals to a distance of at least twenty miles.

If one is disposed to smile now on recalling the incident, this only shows how easy it is to forget that at the time when the conservative estimate was made there were probably very few electrical experts in the world who, if they heard of it, did not regard the young Italian's prophecy as over-enthusiastic—the expression of the dream of a

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visionary that would probably never be realized in human experience.

In any event, it was not prophecy as to future possibilities, but practical tests of present possibilities, that concerned the young Italian at the outset of his investigations.

MARCONI'S PROBLEM

In concrete terms, he must perfect an apparatus for sending signals through the ether and for receiving them. The thing could be done. The experiments of Hertz and the more recent ones of Sir Oliver Lodge and various other workers had made that certain enough. But these experiments had to do with short distances. It is interesting to know that you can transmit an electromagnetic wave that is invisible and inaudible across a laboratory and make it produce a signal at the other side. But the human voice will carry across a laboratory. And it is easy enough to make visible signals that may be observed at the distance of a mile or more.

Could the electromagnetic signals be made effective at greater distances? That was the problem.

It is a matter of now familiar history that Marconi answered the question by sending a wireless message across the English Channel in the year 1899; and by signaling across the Atlantic in 1901. Let us briefly inquire what apparatus he had developed in order to make such achievement possible.

It may fairly be said that Marconi's early achievement consisted in a new application of old methods rather than the discovery of new principles. But something like that may be said of

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most great practical inventions. Almost always the laboratory worker precedes the practical engineer.

Nevertheless it must be recalled that Marconi's own work involved a vast deal of laboratory study; and that the perfection of methods gave opportunity for the exercise of inventive ingenuity of the highest order. If in principle what was accomplished was due to the use of a familiar device in an electric circuit to generate electromagnetic waves at the transmitting station; and the combination of a Hertz resonator with a Branly-Lodge coherer at the receiving station, it is equally true that the practical mechanisms through which these principles were utilized were altogether novel and constituted the mechanism as a whole as a new and highly important invention.

It may fairly be said that the mechanism for wireless telegraphy, as Marconi developed it, and first demonstrated its use in 1897, was a wider departure from any antecedent mechanism due to other investigators than was, for example, the steam-engine of Watt, the steamboat of Fulton, the locomotive of Stephenson, or the telegraph of Morse.

More than that need not be said to establish the position of Guglielmo Marconi among the great inventors of all time.

THE MARCONI TRANSMITTING APPARATUS

The most spectacular feature of the apparatus consisted of the elevated wire structures that came to be spoken of as antennæ,—the prototypes of the now familiar antenna or aerial.

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At an early stage of development, Marconi used a vertical wire with a ground plate below and a second plate, insulated at the end, extended high in air, the two connected by a wire that was put in circuit with an electrical transformer using a spark-gap in its primary circuit. A telegraph key, also in the primary circuit, permitted the antenna to be alternately charged to a high potential and discharged with the production of high-frequency oscillations.

In effect, we thus have a conductor with one plate in the air and the other on the ground, connected with lines of electrostatic force, which are released when the condenser is discharged by touching the telegraph key.

It was subsequently discovered that the vertical wire, without the addition of a metal plate, served the purpose of the aerial and ultimately the advantages of a horizontal wire or series of wires were noted, and the modern aerial came into being. The earlier type of Marconi aerial, however, operated with relative effectiveness, generating electromagnetic waves precisely as does the modern aerial.

At the receiving end of the first practical Marconi apparatus, there was an antenna duplicating the general appearance of the transmitting outfit. Here, however, in place of the transformer there was a single voltaic cell and a sensitive telegraphic relay in series with the Branly-Lodge tube of metallic filings, together with little resistance coils called choke-coils. The relay, actuated by a local battery, operated an ordinary Morse telegraphic instrument. One end of the sensitive tube, or coherer, was connected to the

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earth and the other to the antenna with its metal plates high in the air.

The coherer itself, which of course was the most essential part of the receiving apparatus, consisted of a glass tube having an internal diameter of about four millimeters, with silver plugs sealed into it at either end connected with platinum wires. The plugs had smooth ends that approached each other within the tube leaving only a space of about a millimeter, which was filled loosely with filings of nickel and silver, about ninety-five per cent. of the former and five per cent. of the latter.

The air in the tube was exhausted. An apparatus was thus provided which offered great resistance to the electric current, but which became a ready conductor when acted on by the electromagnetic waves. It was, in other words, a "detector" in the modern sense, performing the function which in the more recent radio apparatus is performed either by a crystal or by a vacuum tube (audion, or triode).

The waves sent out by the transmitting station were of course damped waves—that is to say, waves that fluctuate in amplitude and intermit periodically. At the receiving station the message was printed on a strip of telegraphic paper, with dashes and dots corresponding to the relative duration of the electric wave currents sent out from the transmitter.

FROM SPARK-GAP TO CONTINUOUS WAVE

The improvements introduced by Marconi himself and by numerous imitators during the halt decade or so following the demonstration of the practical utility of wireless had to do for the most

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part with details of method rather than with new principles. Various commercial systems, such as the Slaby-Arco and that of Professor Ferdinand Braun, represented the efforts of inventors to make better commercial systems. The German systems just named reached their culmination in an amalgamation of interests into a system known as Telefunken which represented the relative perfection of the so-called "damped-wave" method.

It was early recognized that there are certain inherent defects in the type of waves produced with an apparatus in which the electrostatic discharge is regulated by a spark-gap. The spark is not a continuous but an alternative phenomenon, of rapidly decreasing energy. This is always the case when a condenser, as for example a Leyden jar, is discharged. The first spark to force its way across the gap comes at high potential; subsequent ones represent the residuum of the charge and are of successively decreased power, suggesting the shorter and shorter swing of a pendulum that is coming to a stop.

The electromagnetic waves developed from the aerial show corresponding decrease of amplitude; the pulsation representing each successive discharge of the spark constituting a wave train in which the waves after quickly reaching a maximum amplitude decrease to the vanishing point, disappearing altogether for an appreciable period before the next train of waves starts. These are the so-called damped waves.

The number of such trains of waves produced per second is known as the group, or wave train, frequency, and in practise this may be from one hundred to one thousand per second,—each wave

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train consisting, as just explained, of a series of individual waves of widely varying amplitude.

The disadvantage incident to such a system of damped waves were early recognized, and energetic efforts were made to find substitute methods,—methods, that is to say, of sending out waves of uniform amplitude, known as undamped or continuous waves.

The theoretical way of accomplishing this would be to have the alternating discharge that releases the electromagnetic waves a phenomenon of uniform intensity instead of the varying discharge of the spark-gap. Several methods of accomplishing this were developed in the course of the decade following Marconi's discovery; and it was demonstrated that the continuous waves have the advantage of greater selectivity, increased range of transmission, conservation of power, and more accurate adjustment of signal notes, permitting a modulation making it possible to substitute a telephone transmitter and receiver, actuated by the human voice, for the telegraph key.

These advantages are inherent in the fact that the continuous wave is produced by the uniform expenditure of energy throughout the period of wave-generation; whereas with the damped wave the energy is applied intermittently and in decreasing scale during the period of operation.

At the receiving end, the tuning for the damped wave can not be as sharp as could be desired because of the varying amplitude of the waves making up each wave-train. With continuous waves, on the other hand, all the oscillations are of uniform amplitude, and it is theoretically possible to tune the receiving apparatus so that any signals

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that differ by one per cent. from the desired signal are inaudible.

Stated in practical terms, this means that if our receiving telephone is tuned to receive a message coming on 200-meter wave-lengths, other messages that chance to be coming through the ether on waves 198-meter or 202-meter lengths would be inaudible. Nothing like this degree of nicety of selection could be theoretically attained with the damped waves sent out by the spark apparatus.

PRACTICAL METHODS OF CONTINUOUS-WAVE RADIO

There is no difficulty about producing an alternating current. The way in which this is done by the power-house dynamo is more or less familiar to everyone. There is difficulty, however, in producing alternations of sufficient rapidity to generate the high-frequency waves of radio. Half a dozen important ways of overcoming the difficulty have been devised, nevertheless, some of them utilizing modified forms of alternators, others introducing new principles.

One method, introduced by Marconi himself, is called the multi-gap generator, because it utilizes a rotating apparatus with a series of revolving contact-makers synchronising the gaps between related spark circuits so that each circuit may act inductively on a common secondary circuit to produce continuous waves. This method had practical utility, but has been virtually superseded by more recent methods.

Another method, now obsolescent, utilized a rectifying element in the primary circuit; the flux in the iron core of the transformer being set up always in the same direction regardless of reversal

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of the spark gap. The method need not here be described in detail, because it is of no practical interest to the amateur.

For the same reason we need make but brief reference to three other methods, in themselves commercially important, that solve the problem of reducing undamped waves; namely, the Poulsen arc, the Alexanderson alternator, and the Goldschmidt alternator.

The Poulsen arc (named after its inventor, Valdemar Poulsen, a Danish engineer) is extensively used in commercial transmitting radio plants. It has great theoretical interest for the engineer, owing to its novelty of construction. Professor Morecroft, following the analysis of P. O. Pedersen, describes the Poulsen arc as differing from the ordinary arc light in that it is necessary to bring the two electrodes in contact to start the flow of current, so that the initial discharge does not take place through an ionized gas. But the intense heat developed by the current passing through the point of contact vaporizes some of the electrode material, and as the electrodes are separated a vapor stream or arc of ionized gas is produced which forms a conducting arc for the current.

As ionization increases, resistance to the passage of the current decreases. Modifications of resistance result in an oscillating current. The precise theory of action is in dispute among technical students of the subject, but the practical utility of the method is matter of every-day demonstration. The arc is caused to take place in hydrogen or gas rich in hydrogen; the positive electrode is kept as cool as possible by circulating water; the

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negative electrode, of carbon, is rotated slowly on its axis to improve the regularity of the oscillation; and the arc is acted upon by a transverse magnetic field, which assists in the rapid deionization or scavenging of the gases of the arc.

The high-frequency alternators, of which the most popular are those developed respectively by Dr. E. Alexanderson in the United States and Dr. Goldschmidt in Germany, utilize the general principle of the production of alternating currents by rotating electromagnets, but call for a high grade of engineering skill in the construction of the practical apparatuses to produce the extremely high frequencies required.

In one type of generator, the armature is the rotating element, the direct current being stationary; in another the field rotates with respect to the armature which is fixed in position; the latter arrangement having advantages that have led to its adoption in all modern alternators.

For the purpose of very high-frequency generation, however, an apparatus in which both the field and the armature windings are stationary in space, the flux linking the armature winding being periodically varied by means of a revolving inductor, has several inherent advantages. Proper insulation is much simplified by the fact that both windings are fixed in position. For example, insulation is simplified, the difficulty of placing insulated winding on a rotor revolving at high speed with associated high centrifugal stress being avoided.

Alternating generators have present popularity in the great radio transmitting commercial plants; but it is probable that they will ultimately be re-

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placed altogether by a totally different type of apparatus the essential mechanism of which is a modified form of the marvelous little device familiar to every radio novice as the three-electrode vacuum tube, or triode. Of the many extraordinary potentialities of this little tube, none is more mystifying than that associated with the production of oscillating currents that can effectively develop the radio waves.

That a little electric light bulb that may be held in the hand should take the place of a mammoth generator like the dynamo of a power house in appearance, is one of the most bewildering revelations of a subject replete with necromantic features. Yet the 100-kilowatt triode and the 1,000-kilowatt Fleming valve are present-day realities. Before we attempt an explanation of this strange phenomenon, however, we must give attention to the development of the receiving apparatus, through which substitutes have been found for Marconi's original detector, the "coherer." We shall find that once more the path leads us to the vacuum tube: but we must briefly review the stages of transition.

THE DEVELOPMENT OF RECEIVING APPARATUS

One of the earliest modifications of the Marconi coherter was an arrangement to do away with the necessity for constant readjustment through tapping.

It was found by Cartelli, an officer in the Italian army, that if a small drop of mercury was contained in a glass tube between a plug of iron and carbon, under certain conditions the arrangement was nonconductive to the current from a

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single cell, but became conductive when electric oscillations passed through it.

Other experimenters, utilizing this idea, worked out an arrangement in which such a tube was connected with a telephone and with the receiving antenna. Sounds were then heard in the telephone corresponding to the wave currents from a transmitting station, due to the fact that the mercury-seal junction in the little detector was made conductive during the passage of the electromagnetic waves.

Numberless detectors were invented utilizing the principle of modified resistance. A different principle was utilized, however, in a class of wave-oscillation-detectors depending upon the power of electric oscillations to affect the magnetic state of iron.

A third type depends upon the power of electric oscillations to annul the electrolytic pulsations of electrodes of small surface immersed in an electrolyte.

Yet another plan makes use of the fact that electric oscillations create heat in a fine wire through which they pass. A fifth type depends upon the peculiar property of rarefied gases or vapors, which under some circumstances possess a unilateral conductivity. Such, at any rate, was the explanation at first given (tho subsequently modified) of the use of a detector invented in 1904 by Professor J. A. Fleming, which came to be known as the Fleming valve.

This instrument consists essentially of an electric light bulb in which, in addition to the ordinary filament, there is a plate of platinum that is connected with the positive pole of a battery. It was

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by introducing a third electrode, in the form of a grid, in the Fleming vacuum tube that Dr. Lee De Forest developed the audion, or triode, with which modern radio is so vitally concerned.

We shall have more to say about the Fleming valve presently, when we come to consider the work of the vacuum tube more in detail. At the moment, however, we are concerned with the various substitute detectors of radio waves that were used in place of the original Marconi coherer before the incomparable value of the vacuum tube came to be fully recognized. The importance of those already mentioned, in the eyes of the amateur, is negligible. There remains one form of detector, however, which is still extensively used, and to which we shall have occasion to refer again and again; namely, the rectifying crystal.

Discovery of the very important fact that certain crystals have the curious property of conducting electricity better along one axis than another, and will permit only half of the impulses of an alternating current to pass, serving as a barrier to the retrograde current, is ascribed to General H. H. C. Dunwoody. Even the radio novice is aware that various types of such crystals, in particular the natural galena and several commercially developed minerals including carborundum, are used extensively, and, indeed, are the exclusive detectors employed in the more simple forms of radiophone receivers.

It is also familiarly known, however, that the crystal is strictly limited in capacity, owing to a relative lack of sensitiveness and to the fact that it has no power to amplify the pulsing waves that come to it. So it is only for the beginner, or for

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the operator who is content to work at short range, that the crystal has present significance. The amateur who passes beyond the novice stage is certain to wish to abandon this simple detector (or to retain it as an accessory only) substituting the three-electrode vacuum-tube, or triode, which has made the modern radio receiver the marvelously sensitive apparatus that it is.

It will be of interest, therefore, to examine this extraordinary little implement more carefully; observing its amazing versality of action not merely as detector and rectifier of radio waves, but as the amplifier that has made long-distance radio telephony and loud speaking possible; and also as the most important medium for the development of oscillating currents to generate the radio waves at the transmitting station.

The remaining studies of radio will for the most part be concerned, then, with the triode—the Aladdin's lamp of science. We shall examine somewhat comprehensively the theory of action of the necromantic tube and observe the practicabilities of its application in the radio mechanism.

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CHAPTER III

THE ALADDIN'S LAMP OF SCIENCE

DR. LEE DE FOREST

IT has never been in question that the originator of the three-electrode vacuum tube, which has come to occupy a position of such supreme importance in the radio world, was Dr. Lee De Forest. It may seem a little singular, then, that the name "audion" which the originator gave to the implement should not have been universally employed. Probably the fact that the strange little device presently became a bone of contention between rival commercial companies may in part explain the seeming anomaly.

But whatever the explanation, the fact remains that the amazing little instrument which Dr. Lee De Forest christened "audion" is rather seldom referred to by that name in current literature; going under such aliases as "vacuum tube," "three-electrode vacuum tube," "ionic valve," "thermionic valve," and "electron tube." The name approved at the Washington Conference was "triode." In popular parlance it has come to be spoken of rather generally as the "Aladdin's lamp of science." How well the title is merited will appear as we proceed.

But whatever the name, and however modified in form and size and detail of construction to meet various needs, every three-electrode electric light bulb used in modern radio (and there are such

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tubes in connection with every up-to-date outfit, whether for transmitting or receiving) is in effect a De Forest audion. It is but justice to the inventor of one of the most marvelous mechanisms ever devised that this essential fact should be known to every amateur. When the history of radio is finally written, the outstanding name following that of Guglielmo Marconi will be the name of Lee De Forest.

Of course no one needs to be told that the audion did not originate *de novo,* as a thing utterly different from any antecedent mechanism. Great steps in the progress of invention, even the greatest steps, are not made that way. Each inventor builds on the substructure laid by earlier inventors.

THE "EDISON EFFECT."

In the present instance the apparatus which served as the basis for the introduction for Dr. De Forest's revolutionary improvement has already been mentioned as the Fleming valve. It remains to note that when we trace the origin of the Fleming valve itself, the path leads us, as so many paths lead, to Mr. Thomas A. Edison. It was through consideration of what had long been familiar to engineers as the "Edison effect," that Dr. J. A. Fleming was led to develop the apparatus which bears his name, and which he spoke of as a thermionic valve.

What, then, is the "Edison effect," and how did the "Wizard of Menlo Park" come to observe it?

The answer is that the "Edison effect" is a phenomenon associated with the flow of an electric current through an electric light bulb that is provided, in addition to the ordinary filament, with

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a platinum plate sealed into the bulb at a little distance from the filament; and that Mr. Edison observed this effect in the course of numberless experiments that he performed while developing the incandescent light bulb which was presently to outrival all other means of artificial illumination.

Specifically, what Mr. Edison observed was that when he made an electric circuit outside the bulb, connecting the platinum plate with the negative pole of the lamp filament, a galvinometer in this circuit revealed the passage of an electric current; but that when the plate was similarly connected with the positive electrode of the filament, no current passed.

THE FLEMING VALVE

Mr. Edison reported this curious phenomenon, but apparently neither he nor any one else at the time (away back in the pre-radio days) was able to give a plausible explanation of the thing observed.

But by the time Dr. Fleming had occasion, in his capacity of electrical expert for the Marconi Company, to consider all manner of electrical phenomena that might conceivably have to do with the practical solution of radio problems, newer knowledge of the nature of electricity had developed out of the studies of Sir J. J. Thomson with the electron.

In the light of the electron theory, the "Edison effect" could be explained.

The explanation, or at least an explanation that seems plausible, and one that is scarcely challenged by present-day electricians, is that the

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actual direction of flow of an electric current is not from positive to negative, as the older electricians always assumed, but from negative to positive.

A negatively electrified body has a relative excess of electrons, and some of them can escape; whereas a positively electrified body has a shortage of negative electrons, and therefore will attempt to gain more electrons rather than to give up any part of its present supply. So when Mr. Edison made a circuit connecting the platinum plate, the electrons that were thrown out from the heated filament were drawn across the vacuum-space of the bulb to the platinum plate, which acted as a positive electrode in receiving them. But the relatively cold platinum plate could not discharge electrons to the hot filament when the conditions of the circuit were reversed. So a current could be developed in one direction only.

An apparatus that would permit the current to flow in one direction only was precisely the sort of thing that Dr. Fleming was looking for. And when he had repeated Mr. Edison's experiment, and developed an improved type of electric light bulb with filament and platinum plate properly adjusted in an electric circuit, he had precisely the sort of thing he wanted. He called it a thermionic valve because it operated to permit the flow of electrical energy in one direction only, just as an ordinary valve permits the flow of water in one direction only.

Other people came to call the apparatus the Fleming valve, in honor of its developer; and under that name it became familiar to radio investigators. It found practical application as a

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substitute for Marconi's coherer and the other types of detectors or rectifiers of alternating currents.

DR. DE FOREST'S EXPERIMENTS

Among the workers who experimented with the flow of electricity in vacuum tubes and elsewhere was young Lee De Forest. In the course of his tests, this young investigator had chanced to observe that the mantle of a Walsbach burner was influenced by vibrations of sound.

That observation was the initial one that led him on finally to the introduction of the mantle-like plate or cylinder, which he called a grid, between the filament and the plate in a tube which without the addition would constitute a "Fleming valve."

The addition was vastly important; but it will readily be understood that there might be differences of opinion as to the amount of creative ingenuity involved in making the improvement. There always are such questions in connection with patents covering any improved device of commercial value. For, as already pointed out, a new device is never a thing *sui generis,* but always a modification of some earlier device.

To give a classical illustration, the steam-engine of James Watt, which gained for its developer immortal fame, was merely a modification of a practical steam-engine, made by an earlier inventor named Newcomen, which had been brought to Watt to be repaired.

The modification that Watt introduced into the engine of Newcomen was far less radical than the modification that De Forest introduced in the

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two-electrode bulbs which Mr. Edison had originally devised and which Dr. Fleming had perfected.

ENTER THE AUDION

An inventor is, as a matter of course, a man of imagination. In the opinion of his neighbors, he is usually a visionary. But had the inventor of the audion tube been the most visionary dreamer that ever lived, he could not by the wildest flight of imagination have forecast the destiny of the little implement he had devised.

Doubtless he had clearly in mind certain things that he hoped it might do; but surely he could never have preconceived that when he placed a little mantle about the filament in an electric light bulb he was directly preparing the way for the pushing back of veils of mystery in the realms of science; the development of new industries; the transformation of important aspects of social and industrial life.

James Watt realized that he had made an improved steam engine; but the first use to which he put his new creation was the pumping of water from below a dam in order that the water might turn a mill wheel by flowing over the dam. He had no clear conception of the possibilities of directly turning the wheels of commerce with the thrust of a piston; and so far as the application of the steam engine to locomotion was concerned, he remained to the day of his death an ardent opponent of every attempt at such application.

Just what Dr. De Forest expected of his audion at the outset, has not been recorded, so far as I am aware. Probably he himself could not to-day

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distinguish clearly between his early expectations and those developed with the growing revelation of the possibilities of the necromantic tubes. But it is safe to say that he never dreamed of the audion as an oscillator to develop radio waves and a possible distributor of power to take the place of alternating dynamos, however fully he may have foregaged the potentialities of the instrument as a receiver of radio waves.

REALITY OUTSPEEDS PROPHECY

Yet all the potentialities hitherto revealed were inherent in the original audion, with its three essential component parts, the grid, the filament, and the plate.

The new applications to which the tube has been put in recent years have come about primarily through the adjustment of the apparatus in different relations to its surroundings, rather than through any fundamental change in the apparatus itself. The tube that acts as detector, the one that acts as amplifier, and the one that functions as transmitting oscillator, differ in details of construction (chiefly as to size and the degree of exhaustion of the air within the bulb), but are identical as to fundamental principles of action.

First and last, what the audion accomplishes is the transfer of a greater or less number of electrons from the incandescent filament to the grid, and from both filament and grid to the plate; electrons that pass then along the connecting wire to the outside circuit, where they constitute a part of a modified or enhanced electric current.

That is what the audion tube accomplishes, as

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stated in technical language. It does not seem a very strange or spectacular feat. But the practical result is that the audion tube is an incomparable detector and transmuter of radio impulses; that it makes audible sounds incomparably more attenuated than the footfall of a fly on the ceiling; that it enables men to hear one another's voices and to hold conversations over the oceans and across continents; and that it furnishes a transmitting implement that can send out radio waves oscillating five times or five million times per second at the will of the operator.

The best radio-receiving telephone that is not equipped with an audion tube has a normal range of perhaps twenty-five miles; the range of the best audion-equipped radio receiving telephone has no limit within the semicircumference of the world.

THE AUDION AS RECTIFIER

The simplest type of radio receiving telephone apparatus that has advanced beyond the status of the crystal-detector outfit is equipped with a single vacuum-tube to act as detector in place of the crystal.

It will be recalled that a brief account was given in an earlier chapter of the way in which the grid serves to modify the flow of the alternating current, permitting the passage of pulsations in one direction only, so that the current that flows out of the tube along the plate circuit is a continuous current. The interpretation was made, it will be recalled, in terms of the movement of electrons—that being the way in which we nowadays think of an electric current.

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HOW THE TRIODE DETECTOR OPERATES

Briefly stated, by way of recapitulation, action is based on the constant throwing off of electrons from the incandescent filament, part of which are added to the current that flows from the tube through the plate. When the grid potential is positive to just the right degree, the flow of electrons is facilitated. In effect the grid adds its influence to that of the positive plate to attract the negatively charged particles. But when, at each alternation of the current, the grid potential is negative it tends to repel the electrons that fly out from the filament, and thus to send them back to the filament, preventing their escape to the plate.

No considerable number of electrons will flow from the plate or grid to the incandescent filament in any event, owing to the repulsing influence of the vast numbers of electrons that are being liberated in the filament by heat; so the effect of the action of the grid is to accentuate the flow of the current half the time and to retard or obliterate it the remaining half; the alternations taking place with the inconceivable rapidity of electromagnetic waves at radio frequency.

There are conditions of modified grid-filament voltage under which the action is quite different, but at the moment these do not concern us. They will claim attention in the course of our future examination of the triode in its multiform capacities of amplifier and "regenerator" and oscillating transmitter of radio waves. Before we come to this, however, it will be worth while to make further acquaintance of the radio waves themselves. This we shall do in the succeeding chapter.

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CHAPTER IV

THE RADIO MESSENGERS THEMSELVES

DEALING WITH DAMPED WAVES

CERTAIN characteristics of the current that flows from the triode in the plate circuit are predetermined by the type of the electromagnetic waves that enter the tube from the receiving antenna by way of the grid circuit.

We have seen that the radio waves are of two fundamental types, called respectively damped waves and undamped (continuous) waves. The damped waves, it will be recalled, are generated at a station using a spark gap, and their peculiarity is that they are broken into pulsation or trains, each group being represented by waves of widely different magnitude—waves that quickly reach full amplitude and then rapidly become attenuated to the vanishing point.

In considering these waves, we must constantly bear in mind that the term amplitude and its converse, attenuation, as here employed, have no bearing whatever upon the question of wave length. All the waves that come from a transmitting antenna when the apparatus has been tuned for sending a given message are of the same length. That is to say, the oscillations that produce them are of uniform rapidity.

We know, too, that at their very slowest these oscillations are enormously rapid in comparison with any vibration that affect our ears. They are

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said to be of "radio" frequency, and we are aware that the most delicate receiving diaphragm can not respond to them, and that if it could the ear would still be unable to receive the message, owing to the relative sluggishness of the ear drum.

If for the moment we consider the generation of these damped waves at the transmitting station, we shall realize at once that during the brief interval of time when the telegraph key is pressed down to make the very shortest signal, there will rush out from the antenna field great numbers of electromagnetic or radio waves, represented by a series of the wave-trains just described.

FROM SPARK TO WAVE

Let us make the illustration specific. Suppose that the particular message we are considering is being sent out with a current having 100,000 oscillations per second (generating 3,000 meter waves). Let us suppose, further, that the operator, in making his signal, presses down the key, thus completing his circuit, for the period of one-tenth of a second in making the dot of the Morse code. During that tenth of a second, then, there will have occurred in the antenna circuit 10,000 oscillations, and each oscillation will have resulted in a pulsation in the ether constituting a radio wave.

Such, at any rate, would have been the effect had undamped or continuous waves been in question. But in the case we are considering, the spark-gap introduces a complication, for its action is to interrupt the flow of the current, permitting the accumulation of static electricity and its intermittent discharge at intervals that are exceedingly

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short, yet much longer than the intervals between the oscillations that directly produce the electromagnetic waves. This, as we have seen, is what causes the wave trains.

For convenience of illustration, let us assume that the discharge at the spark gap is of such duration as to permit twenty oscillations of the wave-generating current during its discharge. Each wave train will then consist of twenty of the electromagnetic waves in length, and in time will occupy twenty one-hundred-thousandths of a second.

If the interval between successive wave trains due to the interval between spark discharges is equal to the wave train itself, we shall have twenty plus twenty or forty one-hundred-thousandths of a second as the interval between wave trains.

COUNTING THE WAVE TRAINS

Otherwise stated, there will be five thousand of these wave trains per second; or five hundred of them during the tenth of a second that elapses while the telegraph key is depressed.

We visualize, then, the effort of the operator who has pressed down the telegraph key for one-tenth of a second to make the Morse dot as resulting in the sending from the antenna of ten thousand electromagnetic or radio waves, divided into five hundred equal groups (each group made up of waves that reach a certain amplitude and then dwindle; maintaining, however, uniform length of 3,000 meters).

Of course the act of the operator in pressing the key is succeeded by a moment of inaction

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during which the key is not pressed; and during that interval no electromagnetic waves are sent out from the antenna. The group of waves representing the dot constitutes a pulsation ten thousand wave lengths in extent (broken into five hundred minor groups), separated by an interval of time and space from the group that will come next.

As the waves making up this group all travel at the same speed, and as that speed enables them to compass 18,500 miles in the tenth of a second, it will be obvious that the waves in the van have reached their mundane destination (even if the receiving station were at the Antipodes) long before the final waves of the series representing the single Morse dot leaves the transmitting antenna.

If an interval of another tenth of a second elapses before the telegraph operator again presses the key, the rear-guard waves of the Morse dot will be 18,000 miles away before he starts in their wake the waves that will represent another dot or dash.

So far as that particular transmitting station is concerned, all the ether within 18,600 miles will be free of radio vibrations during the interval between signals.

WAVES AT THE RECEIVING STATION

Meantime at the receiving station, which (in order to simplify the calculation) we may assume to be 186 miles away, the strength of waves of the group representing the Morse dot will arrive one-thousandth of a second after the sending telegraph key established contact, and the last wave

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will arrive one-thousandth of a second after the contact is broken. But of course the passage of the entire group of waves representing the dot will occupy at the receiving antenna precisely the same length of time, namely, one-tenth of a second, that was occupied in generating the waves at the transmitting station.

It is not the same tenth of a second; but the interval between the two is only one-thousandth of a second.

Let us imagine ourselves now at the receiving station, and let us focus attention again upon the three-electrode vacuum tube, or audion, the grid of which is in circuit with the receiving antenna. Ignoring for the moment any and all inductances or condensers that magnify the strength of the current, we see the antenna grid circuit transmitting a current that corresponds, oscillation for oscillation, with the current that was generated at the transmitting station when the telegraph operator pressed the key.

We can visualize with a certain degree of definiteness the 500 wave trains, each made up of a group of waves of decreasing amplitude (but all of the same length) surging in upon the grid during the tenth of a second under consideration.

VISUALIZING THE ETHER WAVES

Each wave, it will be recalled, consists of a vibration in two directions—a crest and a hollow if you seek a comparison with the familiar waves of water.

In electrical terms, each wave consists of a positive and a negative element. Or you may think of it as a forward and backward thrust.

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The latter illustration is probably the best for the present purpose; for in that view we can understand why the diaphragm of the telephone receiver could not respond to the impact of an alternating current.

The thrust that tended to push it in one direction would be instantly neutralized by the thrust in the opposite direction, and the diaphragm would stand perfectly still, just as an open door would be held still if people pushing with equal strength were on opposite sides of it.

But the province of the audion tube (when acting as rectifier, or detector), as we have seen, is to reject each alternative vibration, so that the current that flows out of it is no longer oscillating. These are still five hundred wave trains as before; and the wave lengths are unmodified; but the five hundred pulsations are now all in one direction, the many thousands of little waves all pushing one way, each adding its impulse to the push of the ones that went before.

So during the tenth of a second of their drive against the diaphragm, the diaphragm is pushed forward, making a contact that is audible as a signal interpreted as a dot of the Morse code.

CRESTS AND HOLLOWS

In the analysis just made, in which we have attempted to visualize what takes place when a signal is sent from a transmitting station using the spark method and which therefore sends out damped waves, we have had occasion to deal with the amplitude of waves in contradistinction to their length.

The distinction should be kept constantly in

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mind. Wave-length has to do, as the name suggests, with the linear distance between the crests of succeeding waves; whereas amplitude has to do with what may be likened to the height of the wave,—the distance between crest and hollow.

If we think of waves radiating in an ever-widening circle across the otherwise smooth surface of a pond, from the point at which a pebble was dropped into the water, we have probably as clear a mental picture of the electromagnetic waves as we are likely to get.

The thing to recall, in the present connection, is that the distance from crest to crest, in linear direction, of succeeding radio waves that go out from any given antenna system at a given time (assuming, of course, that the tuning remains unchanged), is always uniform. The rate of oscillation not varying, and the waves moving at uniform speed, wave lengths are necessarily unvarying also. In the case we are considering, where the oscillations number 100,000 per second, the wave length would be three thousand meters, but that particular point is immaterial at the moment.

What is material, is to understand that whereas the length of wave and speed of transit will be uniform for all the waves sent from an antenna system having certain specified conditions of inductance and capacity, the height or amplitude of these waves may be varied indefinitely with variations in the force of the oscillating current that generates the waves.

To state the matter in familiar terms, there may be strong waves or weak waves. Moreover, they

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may be intermingled with one another in any combination.

CONTINUOUS-WAVE RADIO

To be sure, this is only re-stating a fact that was made evident to us in considering the damped waves making up a wave train or signal. It is, indeed, precisely the condition of varying amplitude that constitutes a "damped" wave. If we were to modify our transmitting apparatus in such a way that the radio waves produced would be all of one amplitude, we should produce "undamped" waves. And in actual experience, that is the essential characteristic of the waves that are used in what is called "continuous-wave" ("C.W.") radio, which now claims our attention.

We have learned that these undamped waves may be produced by various types of transmitting mechanisms, including the Poulsen arc, sundry alternating generators, and the oscillating vacuum tube. We have no further present concern with the method of production of the waves, but we are to attempt to visualize the conditions that obtain when the experiment of sending a telegraphic signal, representing a dot of the Morse code, which we have just seen performed, is duplicated with an apparatus sending undamped waves.

Let us assume the same conditions as to wave lengths and length of signal that we used in the other experiment, namely, 100,000 waves per second, and a signal lasting one-tenth of a second.

If now we further assume that the strength of the generating current is the same as before, we shall have the waves not only of the same length as before, but also of amplitude corre-

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sponding to the maximum amplitude of the waves of successive damped wave trains.

Note the distinction. The undamped or continuous waves that we are now using are all of an amplitude that is matched by only a few waves in each of the successive wave trains of the damped series. Recalling that there were five hundred such wave trains in our tenth-of-a-second signal, with only two or three waves of full amplitude in each, it appears that the entire series of damped waves representing the signal comprised only 1,500 or 2,000 waves of full amplitude, as against the 100,000 waves of full amplitude representing the undamped signal of the same length.

If we recall further that there was a gap between each successive pair of the 500 wave trains of the damped system during which no waves were sent out at all; whereas there is no gap in the sequence of undamped waves, we shall at once realize that the damped waves of the first series numbered only about half as many as the undamped waves of the second series.

Couple this fact with the observation just noted that the major part of the damped waves of each train are relatively weak, and we are led to the natural inference that the signals sent with undamped or continuous waves in the experiment we are making must be far more powerful—represent vastly more energy—than the signals sent with damped waves in our earlier experiment.

The validity of this inference has been amply demonstrated by numberless observations. It is universally admitted that undamped or continuous waves have far greater strength than those sent

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with corresponding power from a spark-wave system.

ADVANTAGES OF THE C.W. METHOD

But that is by no means the only advantage of the undamped waves. It is not even the most important advantage. The salient merit of these waves is that they can be used, as the damped wave can not be to advantage, for the purposes of radio telephony. If we continue our analysis by following up the continuous waves of our present experiment to the receiving apparatus, we shall understand where there is this important distinction.

Let us, then, focus attention on the group of undamped waves, sent out from the continuous wave transmitting station in response to the pressure of the telegraphic key.

By the terms of the experiment, the key is being pressed for one-tenth of a second. We therefore have to do with a group of waves of uniform amplitude, following one another, to the number of ten thousand. Between each pair of crests (3,000 meters apart) there is of course a corresponding hollow; crest and hollow representing, in electrical terms, magnetic and electrostatic receiving antenna system, will be transformed forces which, when the waves beat against the into positive and negative oscillations of the alternating current.

As in the earlier experiment, we follow the alternating current to the grid of the vacuum tube, and witness its modification into the continuous current represented by 10,000 pulsations moving all in one direction along the wire that

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leads from the plate to the diaphragm of the receiving telephone.

The ten thousand waves, as we know, are all of the same amplitude, and hence they wash against the telephone diaphragm with 10,000 successive pushes of the same strength, making an aggregate push that is far stronger than the push that was made by the 500-wave train of our earlier experiment. It is the difference between 10,000 full-size waves dashing against a wall, and perhaps 5,000 waves mostly of much smaller size dashing against the same wall.

The sound that will result from the thrust of the diaphragm against the air will naturally be much louder when the thrust comes from the larger number of uniformly full-sized undamped waves; but the two sounds will be of the same length.

Moreover, the two sounds will be of the same maximum pitch; but the sound from the undamped waves will be much purer in tone, because all the waves have the same strength; whereas, contrariwise, the sound of the damped waves will tend to depart from a uniform pitch, because the successive waves have varied constantly in force, rising and falling between maximum and minimum and disappearing altogether and reappearing, 500 times in the same sequence in the tenth of a second during which the signal lasted.

CONTINUOUS WAVES FOR RADIO TELEPHONY

And that comparison tells us, if we stop to think about the matter somewhat attentively, why it is that the damped waves are not suitable for the uses of radio telephony.

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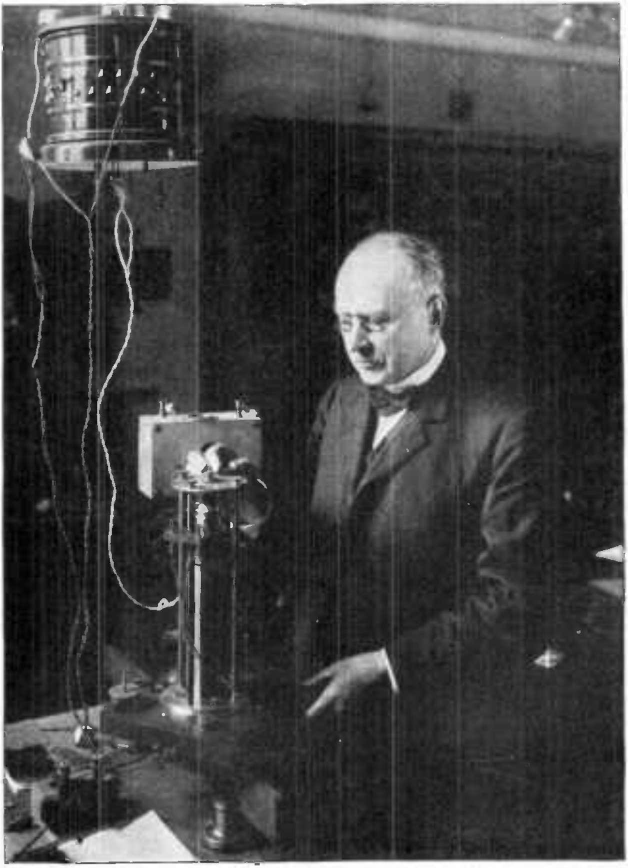

PROFESSOR BRANLY OF PARIS, FORERUNNER OF MARCONI

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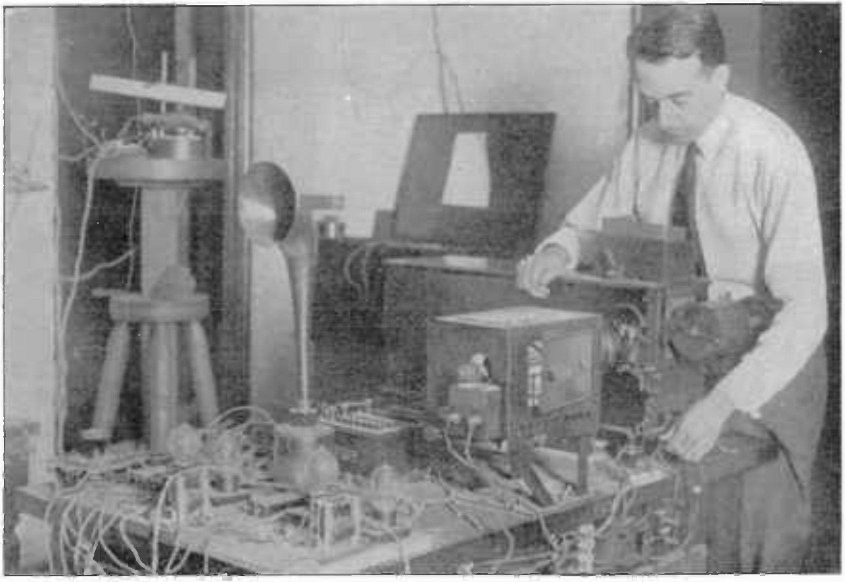

THE OSCILLOGRAPH FOR PHOTOGRAPHING RADIO WAVES

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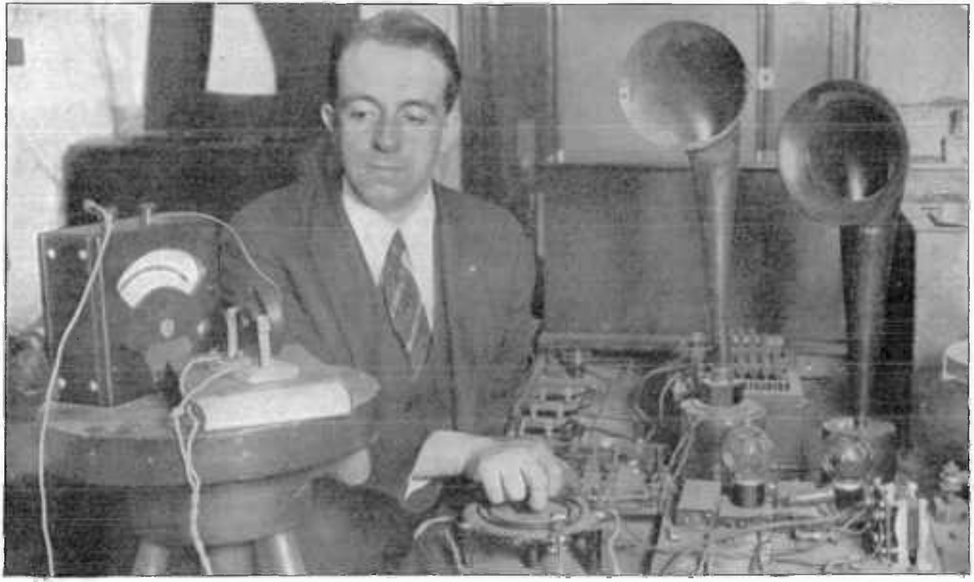

J. C. ACEVES AT COLUMBIA UNIVERSITY RESEARCH LABORATORIES TESTING THE QUALITY OF LOUD SPEAKERS

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E. T. DICKEY AT THE CITY COLLEGE, NEW YORK, CONTRASTING POULSEN ARC WITH PLIOTRON VACUUM TUBE

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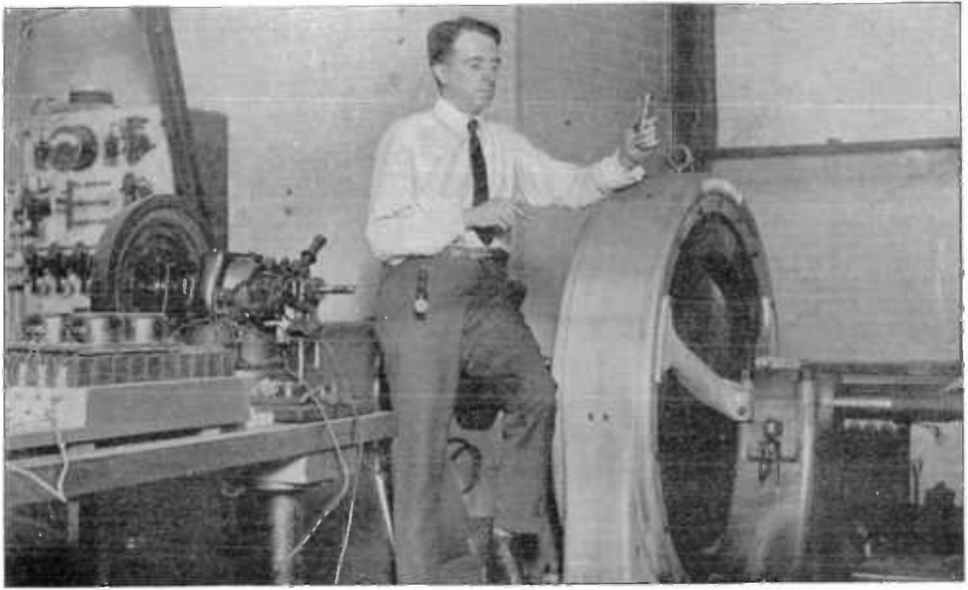

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J. C. ACEVES AT COLUMBIA UNIVERSITY CONTRASTING VACUUM TUBE AND ALTERNATING GENERATOR

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E. J. HEFELE BROADCASTING FOOTBALL SCORES AT FORDHAM UNIVERSITY

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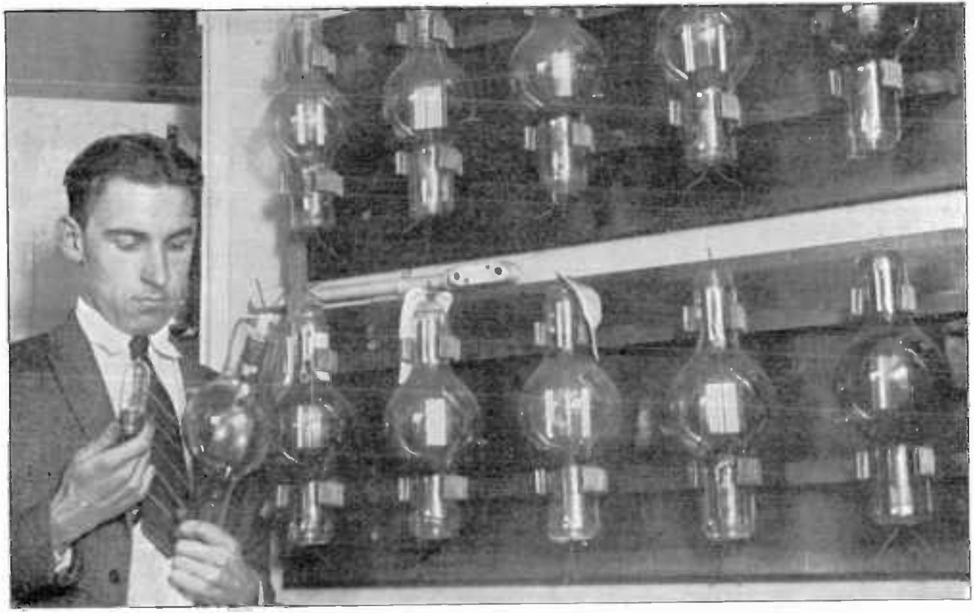

RAYMOND F. GUY AT W J Z CONTRASTING RADIOTRON TUBE WITH 250-WATT AUDION MODULATORS AND OSCILLATORS

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ADJUSTING WAVE LENGTHS WITH A WAVE METER AT W J Z, THE WESTINGHOUSE STATION AT NEWARK, NEW JERSEY

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The point is that the impulses that correspond to the signal made with the telegraph keys in our experiment are determined, in radio telephony (as in ordinary telephony) by modulations of the voice.

Being interpreted, this means that the air-waves made by the speaking voice constantly vary in both length and amplitude; and that the electrical current which generates the radio waves at a transmitting station is subject to corresponding modification. By the same token, the electric current that comes to the receiving telephone diaphragm reduplicates the modifications.

The 100,000 waves sent out in any second under these new conditions are no longer uniform in amplitude, even tho they are continuous (undamped). On the contrary, they are of all possible amplitudes, between maximum and minimum, now swelling, now receding, in correspondence with the ever-varying pulsations of the voice,—or the still more intricate pulsations of a chorus of voices or an orchestra.

It must be obvious that the continuous waves (the unbroken series of oscillations) offer opportunity for such modulation that can not possibly be duplicated by the series of waves of the damped system, which half the time consists of no waves at all and throughout the other half is being perpetually modulated from weak waves to very strong ones and then to waves successively weakening; such modulations having no relation whatever to the modulations of sound that are being transmitted, but quite obviously making it difficult or impossible to reproduce the sound-modulations accurately.

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And so in practise we find that radio telephony did not become feasible, except in the most experimental way, until methods had been found of generating undamped radio waves.

We have now to learn that still another innovation was necessary before radio telephony could assume anything like the importance that it has attained in recent years.

The innovation in question was the development of an apparatus for amplifying the electrical current at the transmitting station, and also that at the other end of the journey, which ultimately passes through the receiving telephone. Messages that travel far necessarily come to the receiving antenna on exceedingly feeble waves (since the electromagnetic waves necessarily weaken as they spread in all directions); and hence the range of radio telephony must be very restricted indeed unless means could be found to fortify and amplify the current at the receiving station.

This problem of amplification of the message-bearing current will be considered in a later chapter.

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CHAPTER V

THE MAGIC TUBE AS REGENERATOR AND OSCILLATOR

THE RELAY EFFECT

FROM the outset it was evident that Dr. De Forest's three-electrode tube, in addition to being the most sensitive of detectors, had the anomalous effect of magnifying the message that came to it from the receiving antenna.

This amplifying capacity is, indeed, inherent in the very nature of certain of the tubes. It is essentially a relay, inasmuch as its functioning depends upon the existence of currents from local batteries (so-called "A" and "B" batteries) that are enormously powerful as contrasted with the exceedingly feeble current that comes to the grid from the antenna.

Before we consider in detail this relay action of the tube and its magnification by placing tubes in series with intervening transformers, it is desirable to tell of another discovery through which new potentialities of the magic tube were revealed; a discovery made by a very young man who since boyhood had been sedulously experimenting with radio, and who glimpsed hidden possibilities, presently to make them body forth as tangible realities.

"FEED-BACK" ARMSTRONG

The young man in question was Edwin H. Armstrong, of Yonkers, New York. The prac-

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tical thing that he did was to introduce what he called a "feed-back" circuit in connection with the plate circuit of the audion, thereby causing the little tube to accomplish still greater feats of amplification of the message-bearing current.

Some details of the romantic story of the achievements of "Feed-back Armstrong" have been given to the public. We learn of the difficulties that the young man encountered, not merely in making his invention but in securing a patent and contesting a long-drawn-out suit which ultimately eventuated in his favor. No less an authority than Professor Michael I. Pupin, of Columbia University, is quoted as characterizing this invention as one of the most important, if not the most important, in the history of radio art. We have now to enquire what, precisely, the invention involves, and what it accomplishes. We shall then realize the validity of Professor Pupin's enthusiastic estimate.

It will be understood from what has already been said that Armstrong's invention was not concerned primarily with the audion itself, as regards its interior mechanism; but with the adjustment of exterior electric circuits connected with the audion.

The mechanism involved in young Armstrong's original invention, as depicted in the diagram of January, 1913, which played so important a part in the subsequent patent litigation, is extremely simple. It shows a "hook-up" in which batteries for filament and plate, instead of being labeled respectively A and B batteries as they are in more recent nomenclature, are labeled B-1 and B-2. Battery 2 is connected by one pole, through the

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medium of a variable inductance, with the audion plate; and to the other pole through the medium of a variable condenser with the antenna-grid circuit. The introduction of the inductance coil is the essential novelty—a fundamental improvement according to the decision of the final courts. The fact that a certain amount of the current from the plate circuit is sent back inductively to the grid circuit, constitutes the essential feature of the invention, and explains the popular name by which the method is now commonly referred to.

THE FEED-BACK PRINCIPLE

The popular name, however, has no official or scientific status. It has the merit merely of conveying, vaguely at any rate, an idea to the effect that part of a locally generated current is "fed back" into the current that comes from the receiving antenna. The idea usually conceived is that the feeble incoming current is thereby accentuated—its pulsations given greater amplitude—without losing their essential character.

There is a measure of truth in this interpretation, but such a description conveys an altogether inadequate idea of the Armstrong circuit. In fact, to speak merely of an accentuation of the current is to miss the really essential feature of the discovery about which we are speaking. So much more than the mere accentuation of current is involved, that the technician speaks of the Armstrong circuit as "regenerative circuit." And with good reason, for the current that has been subject to the "feed-back" influence is not merely accentuated—it is indeed regenerated, or made to take on essentially new attributes.

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It retains the fundamentally important modulations that it had as it came along the antenna, of course; it must necessarily retain these to the end of its journey in the telephone receiver, else it could not serve the purpose of transmitting speech. But its rate or alteration of oscillation may be fundamentally changed and changed at will of the operator of the "feed-back" circuit.

Consider, for example, the current of 100,000 cycles per second (3,000-meter ether waves) which we used in the hypothetical experiment that we followed out in our study of damped and undamped waves. As the current oscillating at this rate comes through the primary coil of the inductance apparatus in circuit of antenna and ground, sets up, under ordinary conditions, a circuit matching it beat for beat in the secondary coil and is thus passed on to the grid. Under ordinary conditions of the original operation of the audion, it is desirable to tune this secondary or grid circuit in harmony or resonance with the primary antenna circuit, which in turn is tuned, as we know, in resonance with the transmitting antenna circuit.

Such tuning, as we know, consists essentially of adjusting inductance and capacity of the different circuits in harmony.

THE MATTER OF RESONANCE

But young Armstrong made the discovery in the course of his practical experiments with the receiving apparatus, that he sometimes got better results, could hear more clearly, reach farther stations—when his secondary circuit was not accurately tuned to the primary. He followed up

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this lead, putting an extra condenser in the circuit; and then modifying the inductance and the capacity of plate circuit in which the telephones are located by putting in it a coil inductively linked with the secondary coil just referred to as part of the grid circuit.

This new coil in the plate circuit has since become familiar as the "tickler coil."

The purpose of the new device was not merely to "feed back" more current into the secondary or grid circuit; nor yet to establish a closer resonance (better tuning) between the different circuits. Its purpose was to make defective tuning —paradoxical as that may seem. It was not desired that the inductance and capacity of the tickler coil circuit should be precisely in harmony with that of the secondary coil or grid circuit. And, as we know, the rate of oscillation of an alternating current in any circuit depends upon the inductance and capacity of the circuit. Hence the oscillations in the tickler-coil circuit could be made to vary from those that were originally generated in the antenna circuit and inductively conveyed to the grid circuit.

In effect, as the engineer conceives it, the audion tube, under these circumstances, is being permitted to generate an oscillating current, originating in the local battery, that is independent. The capacity of the audion to develop such oscillations will claim our attention presently. For the moment we are concerned, just as young Armstrong was when he was making his experiments, with the fact that the incoming current, bearing its modulated message caught from the electromagnetic waves of the ether, could be met by

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and blended with (via the tickler coil induction route) a current the oscillations of which are more rapid or less rapid than its own.

Taken by itself, that statement conveys scarcely more than the fact that the two circuits in question could be out of tune—which is scarcely more novel than if one were to say that a piano may be out of tune. But the essential point of the Armstrong experiment was that the two circuits could be so adjusted that they were out of tune by a precisely determined amount.

THE HETERODYNE, OR "BEAT" PRINCIPLE

If, for example, the incoming current was oscillating at 100,000 cycles per second, the current in the regenerative circuit could be held at 99,000 oscillations per second. And then it appeared that—to put the matter crudely but tangibly—the 99,000 neutralized or obliterated a corresponding number of oscillations of the other current, leaving only the remaining 1,000 oscillations per second in the blended currents as it passed through the audion tube and on to the telephone receivers.

But a current oscillating 1,000 times per second is of audio frequency—adapted, therefore, to move the telephone receiver effectively and transfer pulsations to the air that the ear will interpret as sounds. So what the "feed back" or regenerative circuit has accomplished is to transform the radio-frequency waves to waves of audio frequency. And perhaps the most astonishing feature of the entire transaction is that the new current with its relatively sluggish oscillations is modulated precisely as was the original current,

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so that it conveys to the receiving telephone diaphragm the ever-varying fluctuations of influence that will result in an accurate reproduction of the voices and other sounds from the transmitting station.

In attempting to explain this phenomenon, it is customary to draw an analogy from a familiar experiment in which two tuning forks or other vibrating mechanisms are made to vibrate at slightly different periods, with the result that a pulsing sound or "beat" is produced at intervals determined by the difference in number of vibrations of the two implements. If, for example, one tuning fork would vibrate 100 times per second, and the other 97 times per second, the "beat note" will be heard three times per second.

The analogy between this phenomenon and the phenomena of the regenerative radio circuit just recorded is at least sufficiently close to serve an explanatory purpose. A radio receiving apparatus utilizing the feed-back or regenerative principle is therefore now commonly spoken of as operating on the "beat" principle. In more technical uses, such an apparatus is said to have an "autodyne" or self-heterodyne receiver.

In later developments of the method, it is sometimes found expedient to generate the oscillations of the tickler-coil circuit in an audion not otherwise connected with the one that receives the radio current and that acts as detector. The principle of the blended currents is not modified; but the practical difference of operation leads to the characterization of this method as the outside "heterodyne" method, in contradistinction to the self-heterodyne, or "autodyne."

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The word heterodyne is constantly encountered in present-day radio, and the meaning should be clearly borne in mind by every reader. We shall presently come upon the word "super-heterodyne" as applied to a perfected apparatus used by the advanced amateur who is reaching out for distant messages and requires a supersensitive mechanism.

For, be it understood, the essential merit of the regenerative circuit, with its introduction of the "beat," or heterodyne method, is that it adds almost indefinitely to the sensitiveness of the receiving mechanism. The "regenerated" current washes against the telephone diaphragm (if a crude but suggestive phrasing be permitted) with the augmented force of ocean waves driven against the shore by a freshened breeze. Radio messages that before were weak now become strong. Messages hitherto unheard now become clearly audible. Radio stations previously far out of range are brought within hearing distances when the receiving mechanism has been so reconstructed as to utilize the feed-back or regenerative principle.

It is not too much to say that the introduction of that principle gave sure augury of a new era in radio telephony.

CONTROVERSIAL ASPECTS OF THE DISCOVERY

It remains to be noted, merely in the interest of historical accuracy and completeness, that the position of Mr. Armstrong as originator of the regenerative circuit has not been conceded without abundant and even violent controversy. Eight years of legal controversy have led, however, to a final decision, handed down by the final court

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of appeal, giving the full recognition to the Armstrong patent.

This does not by any means prove that there may not have been other investigators who were hard on the trail of the same discovery. Nor does it even assure us that there may not have been others who independently made investigations that revealed to them the possibility of application of the feed-back principle. The Armstrong claims were contested by several investigators of acknowledged skill, even including Dr. DeForest himself. Professor Fessenden, of Columbia University, did not enter into the legal controversy, yet he is often mentioned as the originator of the heterodyne method. But of course the "feed back" may be used, and constantly is used, without utilization of the heterodyne effect.

From such controversial aspects the history of a great discovery is never free. Nor can it be expected in any case that the precise details of the growth of an idea or the evolution and application of a principle will be fully revealed—even to the inventors themselves. It must suffice for the present purpose to say that no one has questioned the originality of Major Armstrong's investigations, which led him to a practical development of the "feed-back" principle; and that the record of his discovery, bearing date of January 31, 1913, was accepted by one legal tribunal after another as giving him unequivocal priority. The impression as to the merit of the young inventor that was gained by the court is revealed in the words in which Judge Meyer touches the official verdict.

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After characterizing the case as "another contribution to the romance which has so often characterized the history of forward inventions," and reviewing briefly the inventor's activities from the time when "as a boy of fifteen he became interested in radio, and erected a radio station at his home," Judge Mayer says:

"It is important at this point to realize that Armstrong is a remarkably clear thinker. His modest demeanor belies his extraordinary ability. His achievement was not the result of an accident but the consummation of a thoughtful and imaginative mind."

And this unusual tribute is followed by the official legal verdict concluding thus:

"We think this excellent contribution to the wireless art should be accorded the full scope which the court below gave it in the decree. We think that the decree is not too broad, but properly describes what the inventor conceived and for which protection must be accorded to him."

PROFESSOR PUPIN'S ESTIMATE

Professor Michael I. Pupin, who should be in position to know all the facts of the case, has made an interesting comment, on the court decision, and on the invention itself which, altho we have previously quoted it in part, will bear repeating:

"I am perfectly astonished," he says, "after reading the opinion, at the wonderfully clear scientific analysis which the court exhibits in this decision.

"This decision refers to one of the most important inventions, if not the most important, in the

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wireless art. It is the invention of employing in connection with an audion a coupling which enables a local battery to contribute its energy to the amplification of a signal received in a wireless station. The contribution attained in this manner from the local battery or the local source of energy may be made as large as we please within certain definite limits. Armstrong was the first to employ this coupling, or, as it is called, the 'Armstrong feed-back circuit,' and he did it while he was still an undergraduate at Columbia University."

THE AUDION AS OSCILLATOR

In the article from which this quotation is made, which appeared in the *New York Tribune* of March 19, 1922, Professor Pupin goes on to say that a study of the regenerative principle led presently to realization of the possibilities of the audion tube in the rôle of transmitter of radio messages, whereas hitherto it had been thought of only as a receiver.

Still referring to Armstrong and the "feed-back" principle, Professor Pupin continues:

"The invention enabled him to make another most important step in wireless telegraphy and that is the construction of a vacuum-tube oscillator. When the feed-back circuit energized by the local source contributes more than a certain definite amount, then the system of circuits becomes an electrical oscillator, oscillating at the perfectly definite period which depends upon the inductance and the capacity of the controlling circuit. By varying either the inductance or the capacity we can produce any period of oscillation

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between a few periods per second and many millions per second, and the oscillation once established maintains its pitch indefinitely.

"It is a generator of electrical oscillation, maintaining its pitch with a degree of accuracy never before obtained by any apparatus constructed by man.

"The importance of the feed-back circuit in the reception of wireless signals and the importance of the electrical oscillators, not only in wireless telegraphy but also in wire telegraphy and other departments of applied electricity, can not be overestimated.

"It is admitted by those skilled in the wireless art that the ordinary electromagnetic generator of high power will before long be superseded by the vacuum-tube oscillator, which also will bring about more or less reconstruction of wireless transmitting stations. I am particularly pleased that this decision gives the credit for the invention to a man who is a former student of mine and a student of Columbia University, and who has made a deal of his work in the Marcellus Hartley Research Laboratory of Columbia University.

"It goes without saying that long-distance radio communication and radio phone broadcasting would be impossible without this invention."

AT THE TRANSMITTING STATION

In appearing as the chief performer at the radio-transmitting station, the three-electrode tube is certainly assuming a rôle apart from anything that its originator could have predicted for it.

The very name that Dr. DeForest gave his

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invention, the audion, suggests that it was supposed to be a detector of sounds—an auditor—and not a producer or speaker. Yet the amazing little implement, after proving itself supreme and unrivaled in the radio receiving field (not only detecting feeble messages but amplifying them thousands of times over), entered the transmitting field and in due course was to make itself as supreme at this end of the radio channel as at the other.

The words of Professor Pupin, as above quoted, convey a general impression of the way in which the audion is made to become a producer of oscillating currents. But when one attempts to visualize the activities within the magic tube during the process of generating radio messages, one encounters difficulties.

In our study of the audion as detector, we were led to visualize a stream of electrons flowing from the filament and grid to the plate, and thus establishing a current in one direction; the flow in the opposite direction being impeded. We were led thus to think of the audion tube as an apparatus that rectifies an alternating current, changing it into a direct current. Yet now we must think of the same apparatus, with its essential filament and grid and plate, as being able to perform what appears to be the precisely opposite feat of receiving a direct current and sending it out as an alternating or oscillating current (or, what come to the same thing, receiving an alternating current of one period and sending it out as alternating current of quite different period—either slowed down or indefinitely accelerated in its period of vibration).

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That the audion actually does this is demonstrated hourly at the radio transmitting stations, including those that do the radiophone broadcasting everywhere. Can we gain a really definite idea as to how the feat is accomplished?

It is by no means certain that the question can be answered in the affirmative. Certainly nothing can be said that will make the feat seem less wonderful. But perhaps an explanation may be attempted that will make it a shade less mystifying.

THE PHENOMENA OF OSCILLATION

We gain an inkling of the secret when we reflect that the audion tube is the point of juncture of several electrical circuits; and that these circuits have, jointly and severally, the so-called constants of resistance, inductance, and capacity. We learn that the rate of oscillation in the antenna, both at the transmitting and receiving ends, depends upon the mutual relations of inductance and capacity, one having to do with electromagnetic and the other with electrostatic phenomena; and that "tuning" consists essentially of the adjustments of these relations with the practical aid of induction coils of one type or another and of condensers, fixed or variable. We find our radio apparatus, even of the most primitive type, always associated with at least one induction coil; and if a simple receiving outfit may dispense with a condenser, we are reminded that the apparatus as a whole still has "capacity," because the antenna system itself acts as a gigantic condenser, with aerial for one plate and ground for the other and the air as dielectric.

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Unless these conditions obtain, there will be no oscillating current generated in the antenna at the transmitting station; and unless the same essential conditions obtain at the receiving station, there will be no oscillating current generated in response to the passage of the electromagnetic waves along the receiving aerial.

Now we have to think of the electric circuits of the audion tube as duplicating, in certain essentials, the conditions of inductance and capacity of the antenna system. In a word, the audion becomes, in this view, a miniature antenna. As such, it generates the oscillations that represent the mutual relations of magnetic and electrostatic fields and which, in practical terms, can set up electromagnetic or radio waves in the ether.

THE TRIODE CIRCUITS

It will be recalled that, among the alternative names or aliases given the audion, one of the most familiar is that which characterizes it as a "three-electrode tube." But a moment's reflection makes it clear that this characterization is inaccurate, inasmuch as the audion obviously has four electrodes—two for the filament, and one each for the grid and the plate. In the practical hook up of a radio outfit, it is of course necessary that both grid and plate should be brought into a circuit with the filament (by however tortuous a channel), since an electric current travels always in a circuit and has no tangible existence in a wire with a single pole.

We find, therefore, that in the practical receiving audion outfit, one electric circuit involving the filament, the current generated by what is called

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an A battery having, of course, like every other battery, a positive and a negative pole. We find, then, a plate circuit, actuated by a so-called B battery, the positive pole connected with the audion plate, and the circuit completed by connecting the negative pole with the audion filament, through linkage with the wire from the negative pole of the A battery. Then we have the grid bringing the current from the antenna; and we find that this is brought into a third audion circuit by linkage of the incoming wire with the same wire leading to the negative electrode of the filament that constitutes a part of the plate circuit. There may even be (altho this is exceptional in practise) a C battery introduced in the grid-filament circuit, just as the B battery was introduced into the plate-filament circuit.

We have, then, as our three audion circuits, (1) the complete filament circuit, (2) the plate-filament circuit, and (3) the grid-filament circuit.

A glance at any familiar hook-up of an audion radio-receiving set will make this perfectly clear; but it may not make it equally clear as to how the various circuits, which have one filament electrode in common, are mutually operated. We know that as a fundamental principle the flow of electricity is determined by the voltage. We know that in practise the A battery of the filament circuit is of low voltage and the B battery of relatively high voltage. We know also that the current coming to the filament may be an exceedingly feeble one. We have seen something, too, as to the way in which an additional induction coil may be brought into the plate-filament circuit (in the feed-back mechanism), and the various circuits

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thus coordinated. Yet the relations are obviously intricate, and not easy to understand. The balancing of inductances and condensers constitutes, indeed, a practical problem the solution of which determines the efficiency of operation of the entire apparatus. But it is clear that the action of the audion tube must be dependent on the joint action of the three systems which, in the larger view, becomes coordinated into a single system.

THE TUBE CIRCUITS AS AN OSCILLATING SYSTEM

It is implied in Professor Pupin's remarks, as above quoted, that it is the local battery B that becomes the determining factor in the development of oscillations in this system; since it is this battery that directly energizes the feed-back circuit. When the contribution from this source exceeds a certain definite amount, Professor Pupin says, the system of circuits becomes an electrical oscillator, with definite rate of oscillations depending upon the inductances and capacity of the controlling circuit.

It may be added that the tube does not always begin to oscillate when first energized. It may be necessary in practise to introduce what might be likened to an initial push with an alternating current; but when oscillations are started they continue indefinitely, as has been said, and with unvarying period of whatever range, so long as power is applied and the constants of inductance and capacity are not altered.

The current that flows from the oscillating transmitting tube under these conditions becomes, of course, through the medium of the aerial, the

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generator of undamped or continuous electromagnetic waves,—waves, therefore, that are suitable for radiotelephony as well as radiotelegraphy. There is no such interruption in the current as occurs where the spark system of transmission is employed; nor is there difficulty about producing a current that oscillates or alternates with exceeding rapidity, which, as we have seen, is one of the problems presenting practical difficulties where an electromagnetic generating motor is employed.

The magnetic alternator may still be used to supply current to the audion oscillator; but, as we have just seen, it is not this current but the conditions within the circuits of the audion itself that will determine the oscillation period of the current that will flow from the audion to the aerial.

In considering the flow of this current, we are obviously reversing the point of view that we have for the most part held in our previous discussions of the audion. Hitherto we have been concerned with a current that came from the receiving aerial and found its way to the audion by way of the grid; ultimately passing through the plate circuit to the receiving telephone. We are now concerned with a current which reverses this course, being generated at the transmitting station and passing through the circuit of the transmitting tone at audio-frequency, to receive the modulations of the speaking voice or other sounds, and thence passing into the audion tube, where the oscillations are increased to radio-frequency (without disturbance of modulations) and thus passed on to the aerial.

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A TENTATIVE THEORY OF ACTION

If, now, we endeavor to trace the course of this transmitting current, through the audion, we shall perhaps come a stage nearer to understanding the way in which the audion performs its magic feat of changing a direct current to an alternating one; in other words, just how the audion functions in the rôle of transmitting oscillator.

The secret appears to lie in the disturbance of inductance and capacity between the different circuits of the audion. The perpetual effort at readjustment, momentarily successful (with the instantly recurring maladjustment) results in a reversal of current, instantly readjusted, which in the aggregate constitutes a condition of oscillation.

In attempting to visualize this condition, we must think of a stream of electrons, which normally, in the receiving apparatus, pass from filament and grid to plate, as now reversing their course intermittently, and passing from plate to grid. There is nothing inherently anomalous about such a reverse flow. The accepted reason for the normal flow in the detector audion, from filament and grid to plate, and never in appreciable quantity in the opposite direction, is that the plate is always relatively cold and a positive pole, whereas the filament is always hot and hence a constant source of emission of negative particles or electrons. But now there is a capacity effect in the case of the oscillating transmission between plate and grid, and under conditions that now develop we must think of the tube as a condenser that perpetually stores electricity from the ener-

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gizing source (dynamo, probably *via* two-electrode rectifiers) and discharges it uninterruptedly into the antenna circuit, at a rate of alternation determined by the "resonance" (balance of inductance and capacitance) in the system.

We may thus gain at least a general idea of the way in which the electrons are made to surge back and forth through the audion in generating the oscillating current. It was suggested at the beginning of this explanation that we could not perhaps hope for a really satisfying visualization of the conditions. There is always an element of mystery about an electrical current; and at best our picture of the alternating or oscillating current, in which it is assumed that electrons perpetually reserve their direction and yet appear to progress, leaves a good deal to be desired. Even so, it has seemed worth while to attempt to gain at least an inkling of manner of operation of the oscillating tube, for mysteries enough remain in connection with the necromantic tube to excite wonderment of both specialist and layman, and for the casual observer it is scarcely superfluous to give assurance that the feats of the audion fall within the scope of natural phenomena and are not the work of a veritable Jinn like the one in the bottle that performed such miraculous feats for the fishermen of the Arabian Nights.

PRACTICAL TRANSMISSION

Theories aside, the transmitting audion is able to make the current that passes through it oscillate at any required degree of frequency. Its efficiency as a handler of alternating-current power is said to be normally rather low, in the sense that the

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output of current is only a fraction of the input. Professor Morecraft estimates that small tubes used, for example, in airplane telephony, give an efficiency of only about twenty-five per cent.; and the larger tubes, to get an output of 150 watts, require an input of about 300 watts.

He states, however, that the tube has no competitor as oscillator when a small amount of power is required at a frequency of 100 kilocycles or more, there being, indeed, no other satisfactory method of generating power at these frequencies.

When many kilowatts of power are required, and the frequency is not greater than perhaps 400 kilocycles, the Poulsen arc offers advantages as a generator. But where greater frequencies are required, the vacuum tube is supreme, and for small amounts of power the frequency of which is preferably variable, the vacuum tube is, in Professor Morecraft's opinion, probably better than any other device, no matter what the frequency may be.

Summing up the status of the audion as a radio-transmitting mechanism in a book published in 1922, Professor Morecraft said:

"It has been used as a source of power for transmitting up to several kilowatts of high-frequency output, but its application in such installations at present is of doubtful utility; unless the frequency desired is above the possible limits of a high-frequency alternator, it seems that a machine is preferable because of the high expenses for tubes and their short life compared with that of a machine. It seems quite likely, however, that new developments in high-power

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vacuum tubes will soon make them superior to any other type of high-frequency transmitter."

A few months later a 100-kilowatt triode had been exhibited, and a 1,000-kilowatt Fleming valve; and transoceanic radiotelephony with triode transmission was an accomplished fact. Then came the development of the heated cathode type of tube, and the vogue of the long-known screen-grid tube, which, in the words of Dr. De Forest himself, has "many times the amplification of the usual three-element tube, yet with an inherent simplicity of construction never before realized, introducing us to a new era in broadcasting possibilities."

Soon the short-wave vacuum-tube transmitter revealed possibilities hitherto hardly suspected by the general radio audience, and the supremacy of the tube over the Alexandrian alternator, the arc, and the spark transmitters for long-range transmission under many conditions was placed beyond controversy. The spectacular feats of the short-wave tube transmitter—as in keeping Admiral Byrd's Antarctic company in constant touch with New York—have given full publicity to the wizardry of the magic tube in the field of long-range transmission.

Commenting on this aspect of the subject, Dr. De Forest, writing as one of a symposium of experts in a book called *Radio and Its Future*, contrasts present with recent conditions in these words: "Time was when long-distance radio was a standing joke among cable men, whose best patrons were perhaps the luckless radio companies compelled to dispatch accumulated radio messages *via* the competing cables in the face of obdurate

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atmospheric interference. To-day, however, the tables are often turned. Radio circuits not only operate day in and day out, hour after hour, but actually handle messages at a far greater speed than is feasible even with the latest type of improved cable circuit. Short-wave transmitters fling messages between New York City and Berlin at 225 words per minute. During certain magnetic storms which have paralyzed the cable circuits, the short-wave radio circuits have continued to function, even given the cable a helping hand now and then."

As to further advance, Dr. De Forest looks to the development of directive transmission and reception, multiplex operation of single radio circuits, and perhaps new methods of radio propagation and reception. He speaks also of a developed technique for yet shorter wave lengths than those hitherto available and the perfection of compound or multiple tuning systems.

All these possibilities, it may be added, imply simply getting better and better service out of the magic vacuum tube, which remains in principle precisely what it was when first devised—as a three-element mechanism—by Dr. De Forest himself in what now seem the distant days of the first decade of our century.

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CHAPTER VI

A CHAT ABOUT WORDS, SYMBOLS, AND ABBREVIATIONS AND THE THINGS THEY STAND FOR

WHEN a new game or fad or social custom or science is developed, immediately there springs up in connection with it a new set of words and symbols which may be characterized as "slang" or as "jargon" or as "scientific terminology" according to the character of the innovation or the mental bias of the interpreter.

The new words must always be convenient short-cuts for the expression of ideas, else they will not gain vogue. Yet to the uninitiated they may convey no meaning whatsoever.

Current literature furnishes any number of illustrations. If you chance not to be a baseball "fan," you will gain scant information from reading a newspaper account of a contest between groups of individuals called, let us say, "Yanks" and "White Sox." If you know little about an automobile, an expert description of what lies under the hood of the vehicle might as well be delivered in Choctaw as in alleged English for all you will understand of it.

And now comes "radio" with its whole new vocabulary, thrust upon us suddenly and so insistently that we can scarcely evade it.

That certainly brings a new complication into many lives. The baseball columns we can skip if we so elect. Automobiles are made for us by the

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manufacturers, and, after learning a few elementary things about levers that practically control clutches that we need not very fully understand, we can take the interior mechanism largely for granted. But when we set out to secure a radio-receiving telephone outfit, to enable us to "listen in" on the broadcasting, we are at once reminded that it will be economical to assemble our own outfit; and even if we do not wish to do that, we are obliged to know something about putting it together and providing ourselves with an antenna system. Moreover, we must decide in advance whether we are to use a "crystal detector" or a "vacuum tube."

So we must very naturally consult a catalog. Here is one, for example, that deals, among other things, with vacuum tubes. Our eyes are arrested by a picture showing two electric light bulbs which seem to have some rather curious mechanisms inside them, and we think to find out something about them. Se we glance down at the descriptive text. And this is what we find:

"It is a well known fact that for maximum amplification the characteristics of an intervalve tone-frequency amplifying transformer must be such as to feed the output impedance of the preceding tube in a cascade amplifying set. There is an allowable variation of the constants of the transformer when loaded on the secondary by an amplifying tube——" and at about that point we decide to turn to another page.

Here we pause to inspect a very pretty lamp-bulb, and learn that it is "primarily intended for use with the 50-watt power tubes to produce a D. C. plate supply from an A. C. source." We

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learn further that "this rectifier is at a maximum when the load is such that the D. C. potential is between 900 and 1,100 volts. At no load under an A. C. voltage of 1,250 volts, the D. C. voltage will rise to about 1,750 on short circuit, the current will rise to about three-quarters of an ampere."

And all this has to do, as of course we are expected to understand, with "C. W. transmission at amateur wave lengths." Although of course I. C. W. or radiotelephony may be had from the same set, simply by shifting a few switches. And if crystal detectors are in question, "the grid circuit should be modulated by a rotary 'chopper', which is nothing more than a rotary interrupter, designed to interrupt the grid circuit of an oscillating tube from six hundred to one thousand times per second."

We are assured that "tests have demonstrated that a tube set modulated in this way gives the same receptive efficiency as a quench spark set of the same power to the antenna."

All of which is highly informative—to the previously informed. To the novice, it says just about nothing at all. And yet the novice must learn to deal with such a vocabulary if he is to acquire an intelligent understanding of radio. It is possible, to be sure, to ignore all technicalities, and to learn to operate a radio-receiving telephone set just as many people operate motor cars, with only bare knowledge as to a few dials to be consulted and levers to be turned.

But readers of this book are not likely to be satisfied with that sort of craftsmanship. And, whereas all technical terms are explained in the

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text as we come to them, it may be a convenience, even at the cost of repetition, to present here, in condensed form, an interpretation of certain of the more or less technical words that are part of the every-day vocabulary of radio; together with some of the abbreviations that we are assumed to know, and the symbols that are invariably used to represent essential parts of the radio apparatus in the "circuit diagrams" or "hook-ups" that are constantly brought to our attention.

"WIRELESS" VERSUS "RADIO"

At the outset something should be said about the word "radio" itself. Everyone must have noticed that this word has almost altogether supplanted the once-familiar word "wireless."

The change has both convenience and logicality in its favor. It always did seem rather absurd to describe by the word "wireless" a method that everywhere and always involved the use of systems of wires. But since these wires, in connection with certain other mechanisms, develop radiating waves in the ether that constitute the essential and novel features of the method, the short-cut "radio" has obvious applicability.

At Mr. Hoover's conference in Washington (1922), the consensus of opinion favored "radio" unequivocally, and the word may thus be said now to have semi-official status.

The word is not quite ideal, because there are sundry radiation phenomena (connected with radium, for example) with which it has no association; but it would be useless to attempt to quarrel with "radio" on that or any other ground. The word has taken the world by storm, and has come

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to stay. If you talk about radio in future, everyone will understand that you are referring to the transmission and reception of messages by the method originally introduced by Marconi under the name of "wireless," or by some modification of that method; and it is no longer necessary to put quotation marks about the new word.

RADIOPHONE AND RADIO RECEIVER

We have, then, radiotelegraph and radiotelephone; and as a matter of course an obvious short-cut will be taken, giving us "radiophone." Already this word has become a part of familiar speech; but there is as yet certain ambiguity in its application. Up to the present, general usage among experts has applied the word "radiophone," to the transmitting apparatus only. The receiving apparatus is spoken of as a "radio-receiver." The publications of the U. S. Bureau of Standards make this distinction.

On the other hand, the public at large is pretty certain to speak of the radio-receiving apparatus as a "radiophone." There would seem to be no valid objection to the adoption of the word "radiophone" as applicable to either the transmitting or the receiving apparatus. Certainly either one is quite useless without the other; and as no ambiguity is involved, general usage will probably give us "transmitting radiophone" and "receiving radiophone," the latter being more explicit than "radio-receiver," which obviously might imply a receiving telegraph outfit, not adapted for the reception of telephone messages.

In the present book, as the reader will observe, the phrase "radio-receiving telephone" is some-

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times substituted with "receiving radiophone." Again "radio-receiver" is used by itself, in cases where the context removes all ambiguity. "Radiophone receiver" is perhaps the ideal term.

"ANTENNA" VERSUS "AERIAL"

As to the name or names to be applied to the wire-system that constitutes the most conspicuous feature of the ordinary radio mechanism, there is unfortunately not quite the same uniformity of usage.

The word "antenna" (plural antennæ or antennas), used from the outset in the Marconi system, has become familiar, and will almost certainly be retained.

But there is a certain ambiguity as to just what constitutes an antenna. Almost at the outset we learn that the "resonance," or receptiveness to certain ether waves, of the radio apparatus, is not dependent solely on the conspicuous wire or wires that are strung high in the air, but on the wire that leads in to the radio apparatus on our table, and also on the other wire that completes the circuit by being "grounded."

We learn, further, that we can modify the conditions of resonance, in order to receive shorter or longer waves, by "tuning," and that the tuning mechanism may include one or several coils and condensers, all of which may be thought of, in a comprehensive view, as part of the antenna system.

Having these things in mind, technical and semi-technical writers have tended more and more to include all parts of the resonance-apparatus just outlined within the implications of the word "an-

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tenna" or "antenna system." More and more the question has prevailed of referring to the obvious up-in-the air part of the system as the "aerial." That word has seemed to be clearly descriptive, and in most respects satisfactory.

Now, however, it appears that the Washington conference favors a reversal of terms, suggesting the word "aerial" to include the entire tuning mechanism, from sky to ground; and the word "antenna" for restricted application to the wire-system up in the air, which writers who pride themselves on the discriminative use of words have come to speak of so generally as the "aerial."

It was further suggested at the Washington conference that the older and more familiar type of wire-system should be spoken of as an "open antenna," and the newer form, in which the wire is wound into a closed loop for indoor use (as in the radio compass) should be called a "loop antenna."

It remains to be seen which usage will prevail. A good deal might be said in favor of each. The word antenna, meaning "feeler," always seemed a pretty good one as applied to a receiving mechanism; but never had obvious applicability when applied to the transmitting mechanism. But it was obviously convenient to use the same word for both mechanisms, and usage sufficiently justified the slightly strained application.

The introduction of the word "aerial," however, seemed a distinct advance. It became possible to use the word antenna in a comprehensive sense. Speaking, for example, "of the fundamental wave length," of an antenna, it would be understood that reference was made to the entire

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resonance system. Meantime, when one spoke of the aerial, it seemed obvious enough that one referred to the wire or system of wires up in the air.

It certainly does not seem so logical to use the word aerial to include not only the part of the wire that is up in the air, but the part that comes into the house and is included in a box on your table; and also a part that connects with the water-pipe or runs down the side of the house and is buried deep in the ground. An antenna, or feeler, may logically enough include anything that helps in the feeling process; but it is hard to persuade oneself that an "aerial" should include the ground as one of its essential parts. Air and earth seem rather to be opposing entities.

Perhaps the matter is not vitally important. Words quickly come to take on any meaning that usage ascribes to them, and as between antenna and aerial, there will probably be no great ambiguity. The context of any sentence in which either word is used will generally supply the interpretation.

The present writer's preference, however, as doubtless the preceding paragraphs reveal, is for the use of the word antenna in the more comprehensive sense; and the restriction of the word aerial to the part of the antenna that is usually stretched in the air. In this sense the words are usually employed in the present book; altho occasionally the words may be used interchangeably, and quite generally, in the interest of clearness, the compound "antenna-system" may be employed when emphasis is to be laid on the fact that the resonance of the entire apparatus is in question.

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ABOUT ETHER WAVES

The word resonance itself, as here employed, requires brief interpretation. The usual explanation seeks analogy with the piano string or the tuning-fork, which responds to the sound-waves of a particular length.

Ether-waves are very different from air-waves that produce sounds; but the two have this important resemblance,—in each case a certain apparatus, and a certain condition, will produce waves of a given length only.

A piano string must have a given length and a certain degree of tension in order to produce, let us say, waves interpreted as the note "C." And the antenna system must have a certain electrical conductivity (partly determined by length of wire) and electrostatic capacity in order to produce ether waves of a given length, say 200 meters.

And in each case what applies to the producing mechanism applies also to the responsive mechanism. Only a piano string of the same length and degree of tension that produces waves for the note "C" will respond to those waves; and only a radio-antenna system having the same electrical constants (so-called inductance and capacity) as the one that produced 200-meter waves will respond to those waves.

In each case the word "resonance" may be applied as indicating the accord between transmitting and receiving mechanisms. And in each case it is convenient to use the word "tuning" to describe a method of bringing the two complementary systems into resonance.

The waves with which radio deals are called electromagnetic waves because they are developed

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by the joint action of electric and magnetic fields in and about the antenna system. These waves pass through the ether of space (or through space itself, if you wish to challenge the ether hypothesis) at a uniform speed of about 186,000 miles (300,000,000 meters) per second, and the individual waves or oscillations or pulsations or cycles or whatever you may wish to call them follow each other in regular sequence and at measurable, even if infinitesimally short, intervals.

As the speed is always the same, it is obvious that the distance between the wave-crests will be determined by the intervals of emission. If, for example, waves traveling three hundred million meters per second are sent out from an aerial at such intervals that the distance between crests is two hundred meters, there must obviously be 1,500,000 such waves per second.

We have merely to divide the 300,000,000 (meters) by the length of a single wave or cycle to have the number of waves or cycles.

This formula obviously applies to waves of any length whatsoever. Always the rate of progression is 300,000,000 per second, so there must be a simple reciprocal relation between length of wave and number of waves.

Secretary Hoover's radio conference at Washington apportioned (provisionally) the various wave lengths to different classes of radio operators. The wave lengths in question range from 150 meters in length to 6,000 meters; representing respectively 2,000,000 oscillations per second and 50,000 oscillations per second. Even the latter figure is far beyond the range of vibrations that the human ear can detect. So all these radio

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waves are spoken of as being of radio-frequency; in contradistinction to pulsations of not more than about 10,000 per second, which the ear can detect, and which therefore are spoken of as having audio-frequency.

The terms radio-frequency and audio-frequency, with the implications just presented, will come frequently to our attention. They constitute important items in the new vocabulary we are acquiring.

DAMPED AND UNDAMPED WAVES

Whereas the electromagnetic waves, otherwise known as radio waves, that pass out from the transmitting aerial of a radio apparatus at a given time are thus always of a given length, dependent upon the resonance, at the moment, of the antenna system, these waves are not necessarily of uniform amplitude; nor are they of necessity sent out continuously.

On the contrary, in the early day of radio, the waves produced were never uniform or continuous. A so-called spark-gap system was introduced by Marconi, and used for a good many years exclusively, which involved the discontinuous action of the electric currents that produced the radio waves; owing to the fact that the discharge of a condenser, which regulated the electric pulsations, is not a uniform phenomenon, but an alternating discharge of diminishing intensity, followed by a period of complete intermission while the condenser is being charged anew.

The radio waves that resulted were called "damped" waves because they came in "wave trains" that began suddenly and rose to maximum

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amplitude and then faded away and presently were obliterated or "damped" altogether—this process being repeated over and over.

Such damped waves, however, have many disadvantages. Their discontinuity serves no useful purpose; and in particular the lack of uniformity of amplitude is exceedingly bothersome, because the pulsing current produced lacks clearness of definition. It is relatively weak at best, because so much of the time the waves are feeble or altogether lacking; and sharp "tuning" is difficult or impossible because of the inherent imperfections of so variant a wave-system.

Naturally enough, then, efforts were made to produce a more uniform system of electromagnetic or radio waves. Elsewhere we have occasion to inquire just what efforts were made. Here it suffices to note the success of the efforts. There are a number of methods, beginning with the Poulsen arc and culminating with the oscillating electron tube, whereby success was attained in the development of a high-frequency electrical current in the antenna system that would result in the sending out of a continuous stream of radio waves of uniform amplitude.

This result, however attained, is spoken of as continuous-wave radio; and the abbreviation C W has gained universal currency in radio literature. It is possible to break these continuous waves into groups of wave trains with the aid of a "buzzer" or some form of "rotary grid chopper," in which case they are spoken of as interrupted continuous waves, known to the sophisticated as I C W.

Again these waves may be modulated by the microphone transmitter for radio telephone trans-

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mission. Such modulation (sometimes furthered by the use of a special "magnetic modulator") implies the variation of amplitude of the constantly flowing stream of waves to represent varying tones or modulations of the human voice or of musical instruments.

Such modulated continuous waves may be received by crystal detectors, which are therefore suitable for use in the radio-receiving telephone (tho by no means competing with the electron tube, or triode, on terms of equality); but the crystal detector is not able to interpret the C W waves used for radio telegraphy unless they are chopped up or modulated by buzzer or chopper at the transmitting station and thus made into I C W waves.

The electron tube, on the other hand, is able to handle all types of waves. Moreover, the electron tube when used as oscillator at the transmitting station, is able to send out C W waves or I C W waves or telephonic waves at will of the operator, simply by the shifting of a few switches.

THE ELECTRIC CURRENTS THAT GENERATE RADIO WAVES

It is important to make a very clear distinction between the electromagnetic waves or oscillations that convey the radio messages through space and the electric currents that generate these waves at the transmitting station and are in turn generated by them at the receiving station. There is obviously the closest reciprocal relation between the two types of phenomena; but they are of quite different orders.

The electromagnetic wave rushes off into space

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in every direction at a speed of 300,000,000 meters per second, apparently unhampered by the atmosphere and not greatly hampered even by solid structures such as buildings or the bodies of human beings; altho to some extent hindered by hills and mountains and masses of trees.

No medium but the ether of space (or space itself if you prefer), is required as a channel of transit for the electromagnetic waves.

Electric currents, on the other hand, can make no such venturesome leaps through space. Their existence is bound up with such substantial structures as solids and liquids. Even gases do not afford them free transit. A thin layer of dry air will block the passage of a powerful electric current as effectively as a mountain blocks the passage of electromagnetic waves;—more effectively, in fact, inasmuch as the electromagnetic wave may find its way over or around the mountain, in part at any rate, whereas the electric current (unless a circuitous channel or highway of solid liquid presents itself) is stalled absolutely.

Yet this electric current can make its influence felt in regions that it can not penetrate. Indeed, it always carries with it a so-called "field" of influence penetrating the space about the wire or other conductor to which it is bound. This field of influence is in the ether, and grips the ether, or perhaps constitutes itself part of it; otherwise there would be no electromagnetic waves to convey radio messages.

Moreover, the kinds of influence thus exerted by electric currents are of two different types. One we term magnetic influence. It has to do with a current moving in one direction. The other we

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term electrostatic or merely electric influence. It has to do with a current of electricity that oscillates or moves first in one direction and then in the other, changing its course with vibratory rapidity.

"D. C." VERSUS "A. C."

We think of electricity nowadays in terms of electrons. The current that moves in one direction, whether by continuous flow or in pulsations, is called a direct current, and no sophisticated person ever thinks of writing out its full name. It is known as D. C. and some writers do not even dignify the abbreviation with capitals, writing merely, d. c.

The current that oscillates or vibrates, perpetually changing its course, is spoken of as an alternating current; and of course here also the initials must do service for the full name. We write A. C. or merely a. c. with entire familiarity, and take it for granted that everyone will know what we mean.

But D. C. electricity and A. C. electricity are by no means to be thought of as belonging to different worlds. Both of them owe their existence to (or in their very essence consist of) electrons in motion. In the case of D. C. the electrons move always in one direction, altho perhaps by intermittent rushes; whereas in the case of A. C. they appear to jostle in one direction or the other.

The electron, as we know, is the unit structure of electricity. It is negatively charged, and carries about it a magnetic field. Indeed the electron itself may be thought of as a tiny magnet. As the electron moves, it creates a magnetic dis-

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turbance in the ether. When it changes its course suddenly, the character of its influence changes. A negative phase becomes a positive phase; and this reversal goes on at a rate precisely in keeping with the oscillations of the electrons themselves.

These oscillations may take place thousands of times, or even millions of times, per second; yet obviously there must be an infinitesimal pause between each change of direction; and this pause, during which the electron is static, is associated with an environing condition called an electric or electrostatic field.

In this field, which may comprise air only or some other substance that the electric current can not penetrate (called in either case a dielectric), electric energy is stored.

When the dielectric is surcharged with this energy, the electrons are apparently forced to attempt to move on, along any available conducting surface. They may even break through a dielectric, when no conductor is available, as evidenced in a lightning flash.

The same thing occurs on a small scale in a radio apparatus, when a condenser is discharged through a spark gap; or in the perpetual charging and discharging of condensers that takes place in the antenna system, constituting the A. C. of high-frequency (many thousand oscillations per second) that enables the electrostatic field, in cooperation with the magnetic field of the moving electrons, to stir up the commotion in the ether that we call electromagnetic or radio waves.

If you do not quite clearly understand this, neither does anyone else in the world. We can visualize the activities of the electrons, and we

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know that the "fields of force" about them are actualities. We can even demonstrate the looped directions of the "lines of force" of the magnetic field by the familiar experiment with a magnet and iron filings. But when we attempt to visualize the lines of force or the fields of force themselves, as we visualize the electrons, we find the task futile because the ether in which these fields of force reside has no point of contact with our sense-organs except through the activities of the electrons themselves.

The electrician draws for us a picture of the fields of force, in which the lines of magnetic force are in loops longitudinal to the direction of movement of the electric current; whereas the lines of electrostatic force are in transverse circles about the wire. He gives us assurance that these respective fields represent energy, in definite and measurable quantities, that is emanating from the electrons and radiating into space in all directions, as manifested by electromagnetic waves. He assures us that the strength or amplitude of these electromagnetic waves is dependent on the energy of the storage battery or dynamo that generated the electricity of the so-called "input" current.

And if all this is not quite fully satisfying, at least it is helpful as enabling us to get somewhere near the confines of the mysterious radio territory.

UNITS OF MEASUREMENT

The current in the aerial that sends out the radio waves is thus always an A. C. But the current that came into the radio-transmitting apparatus connected with the aerial may have been

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a D. C. Or it may have been, and in modern amateur practise it very generally is, an A. C. that is "rectified" in a "Fleming valve," and then is fed as D. C. into an "oscillating" electron tube and thus converted into an A. C. of predetermined frequency of oscillation or alternation.

In case there are several oscillating tubes in sequence or "cascade," in order that the strength of the current may be amplified, there may be a "master-oscillator" tube to fix the rate of vibration and insure its unvarying regularity. But in any event this rate of oscillation must be determined by the so-called electrical constants of the antenna system, these constants being measured by the electrician in terms of "Resistance," "Inductance," and "Capacity."

"Resistance" is a self-explanatory word, and the thing itself is measured in "Ohms."

"Inductance" has to do with the flow of current in the antenna system, as determined by the mutual relations of the resistance and the pressure or "voltage" of the current. Inductance is modified by the length of wire of the antenna system; and in particular by the coils of wire that enter into that system (and indeed are placed there for the purpose of modifying inductance), which go by the name of "induction coil," "loose-coupler," "vario-coupler," "variometer," "honeycomb coil," "spider-web coil," and the like, according to their particular forms; but all of which act on the same principle, and are comprehensively classified as "inductances," or "tuning coils."

The unit of measurement of the energy of inductance is the "henry." As the radio operator deals with very small quantities, the inductance of

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his antenna system is usually measured in "microhenries"—a microhenry being the millionth of a henry; or even in "micromicrohenries."

"Capacity" is the word used to express the power of the antenna system to store a greater or less quantity of electrostatic energy. The "condenser" is the apparatus in which such storage chiefly occurs. The antenna system as a whole constitutes a relatively gigantic condenser, with aerial for one plate and ground (or counterpoise of wire) for the other, and with intervening air for dielectric.

Small condensers, made of alternate plates of conducting and non-conducting substances (tinfoil and mica for example) are introduced into the system, to modify "capacity"; and such condensers may be either "fixed," in which case the amount of energy they can store is predetermined and not subject to alternation; or they may be "variable," in which case their storage-capacity may be modified at will within predetermined limits. The variable condenser, as will readily be understood from what has been said, is an important element in the tuning apparatus, as an aid to the modifying of the mutual relation of inductance and capacity upon which the "resonance" of the antenna system depends. It consists usually of series of revolving plates separated by air.

"Capacity" is measured in farads, or rather, for the purpose of the radio operator, in terms of "microfarads," or millionths of a farad. The adoption of so small a unit suggests the relative weakness of the "capacity" with which the radio operator has to deal.

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POWER FOR RADIO TRANSMISSION

The power for the transmitting radio apparatus comes, directly or indirectly, from a power plant similar to or identical with that used for generating electric light and power for trollies, elevators, and the like.

The amateur may draw on the ordinary electric light current, at 110 volts, either D. C. or A. C., of about 60 cycles. In the latter case, as already explained, he may use a "rectifier" before passing the current on to his oscillating tubes—tho this is not absolutely essential.

He may use induction coils to modify the voltage of the current, or instead of that a local battery for the "filament circuit," which carries the current that brings the filaments of the electron tubes to incandescence.

He may require one or more "transformers," which are induction coils with different numbers of turns of wire on "primary" and "secondary," to raise the voltage of the current as it is fed to the oscillating tubes.

Such a transformer is said to "step-up" the current. A "step-up" transformer has more coils of wire on the secondary than on the primary—the primary being the coil through which the original current flows. Were the conditions reversed, so that the secondary coil has the fewer turns of wire, we should have a "step-down" transformer, lowering the voltage. The minor coil used to reduce the part of the current to a voltage suitable for the filament (say from 110 volts to 6 volts) in the amateur transmitting radiophone we are considering, is such a step-down transformer.

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In the radio-receiving telephone apparatus, conditions of resistance and induction and capacity obtain, as a matter of course; but here the current is generated in the receiving aerial, through contact of the radio waves which have come through space from the transmitting aerial; and, feeble tho they are, they may pass on through the apparatus and bring their message to the ears of the listener without augmentation. The extreme sensitiveness of the diaphragms of the radio-receiving telephone ear-pieces makes this possible.

The simplest form of radio-receiving telephone thus requires no local battery. But of course the range of such an apparatus is limited. The range can be extended only by amplifying the current that is generated in the receiving aerial antenna.

The particular application of electricity through which this is brought about will be considered in connection with the study of the all-important part of the mechanism called the "detector" system, to which we now turn.

CRYSTAL VERSUS TUBE

The "detector" is one of the three absolutely essential parts of any radio-receiving mechanism, —the other two being the antenna (which, in its very most elementary form need have neither coil nor condenser) on one hand, and the telephone ear-piece on the other.

The detector is absolutely essential, because the current generated in the antenna is an A. C. of radio frequency; and if such a current were to reach the magnets of the telephone receiver unmodified, it would cause them to pull at and release the diaphragm in such rapid sequence that the

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diaphragm could not respond at all (being pushed back before it has time to start forward, so to speak); and even if a diaphragm sufficiently sensitive to respond were provided, the result would be nugatory, because the human ear-drum can not respond to pulsations of such rapidity.

The "detector," then, must be inserted in the circuit between antenna and telephone to "rectify" the current; that is to say, to change it from A. C. to D. C.

The simplest form of "detector" is a little crystal of "galena" (a lead-sulfur compound) or "carborundum" (an artificial product) or "molybdenite," or one of several other crystalline substances having the curious property of letting the electric current pass freely in one direction but not in the other. A fine wire called a "catwhisker," with its end adjusted against the surface of the crystal, directs the current to the spot that has been found to be most sensitive, such determination being usually effected with the use of a local "buzzer," which is a little induction coil of the kind used to sound call-bells in house and office.

The crystal, however, is a relatively primitive and insensitive type of detector, and the user of the radio receiver is usually not long content with it. He wishes to hear a more distant station, or to hear better, or to introduce a "loud speaker," so that several persons may listen at the same time to the message; and to meet any and all of these ends, it is necessary that he should provide himself with a new type of detector in the form of an "electron tube."

The electron tube is a marvelous instrument,

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made in various forms, and characterized by various names. It is essentially an electric light bulb into which one or two additional electrodes have been sealed. There is always the filament, to be made incandescent by an electric current when the tube is operated; and for purposes of the radio operator this filament is made of tungsten.

Such an electric light bulb becomes an "electron tube" in the radio sense when an additional electrode, in the form of a platinum plate or cylinder is introduced. This so-called "plate" being connected with the positive pole of a battery, the incandescent filament will send electrons across the vacuum space to the plate; but electrons will not pass in any considerable number, if at all, in the opposite direction, from the relatively cold plate to the hot filament.

THE FLEMING VALVE

Such a tube, it will be observed, performs in its way the function of the "detector" crystal, permitting the flow of current in one direction only. Its action might be compared to that of a valve which permits a current (as of water) to flow in one way only; and as the name "ions" is sometimes applied to the electrons (more properly to partly dissociated molecules or atoms acted on by the electrons), the apparatus is sometimes spoken of as an "ionic valve."

Inasmuch as energy (the equivalent of heat), conveyed by the electrons, passes from the hot filament to the cold plate, the apparatus is sometimes spoken of as a "thermionic valve."

As the inventor and patentee of the apparatus

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PROF. J. H. MORECROFT OF COLUMBIA UNIVERSITY COMPARING AMERICAN 20-KILOWATT WATER-COOLED TUBE (HELD IN LEFT HAND) WITH BRITISH AIR-COOLED TUBE OF ONE-HALF KILOWATT

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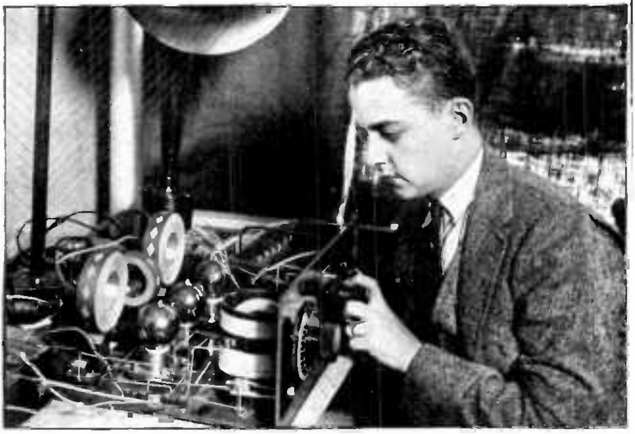

SUPER-REGENERATIVE SET USING HONEYCOMB COILS (BELOW), AND CONTRAST BETWEEN LARGE LOOSE-COUPLER OF 1910 AND COMPACT VARIO-COUPLER OF 1923 THAT REPLACES IT

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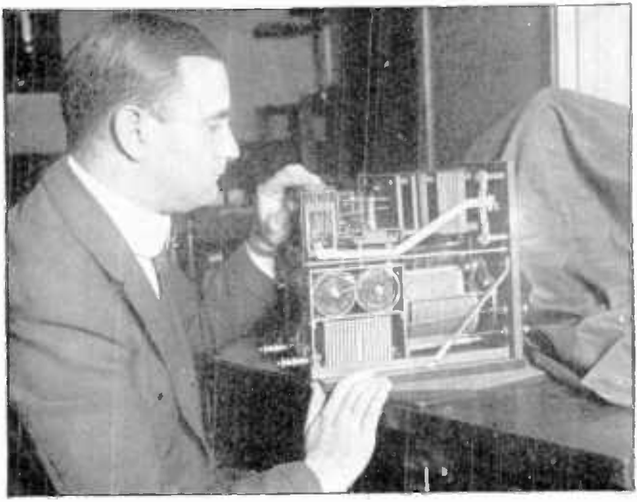

DR. ALFRED N. GOLDSMITH WITH COMPACT UNI-CONTROL RECEIVER (BELOW), AND LARGE INDUCTANCE USED IN TRANSOCEANIC TRANSMISSION AT THE COLLEGE OF THE CITY OF NEW YORK

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CHARLES J. McCARTHY USING POWERFUL RADIO-TELEGRAPH TRANSMITTER IN PROF. MORECROFT'S RADIO LABORATORIES AT COLUMBIA UNIVERSITY

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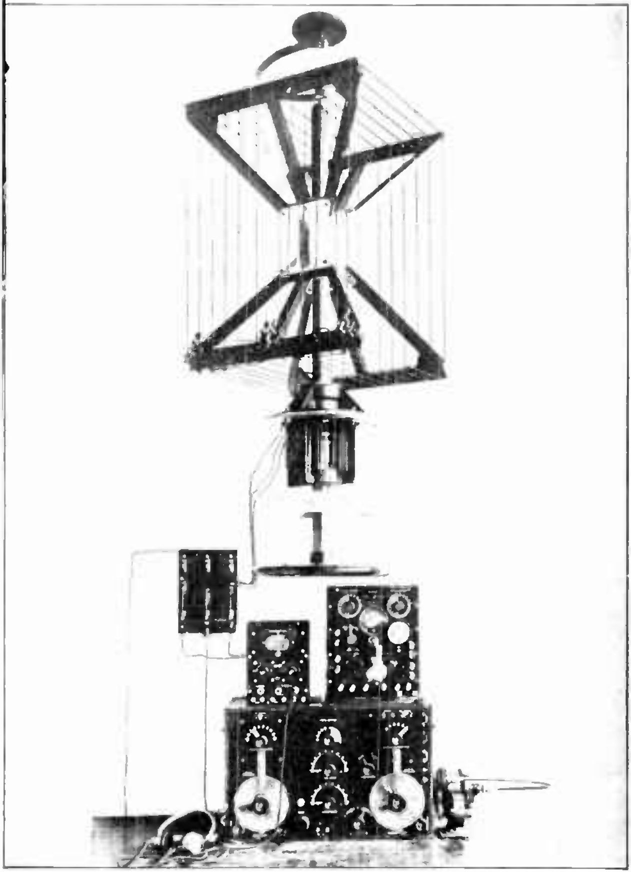

UNITED STATES NAVY RADIO COMPASS. THE DIRECTIONAL EFFECT BEING DUE TO THE LOOP AERIAL

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Photograph by Brown Brothers

BROADCASTING POPULAR ORCHESTRA MUSIC FROM A WELL-EQUIPPED STUDIO IN NEW YORK

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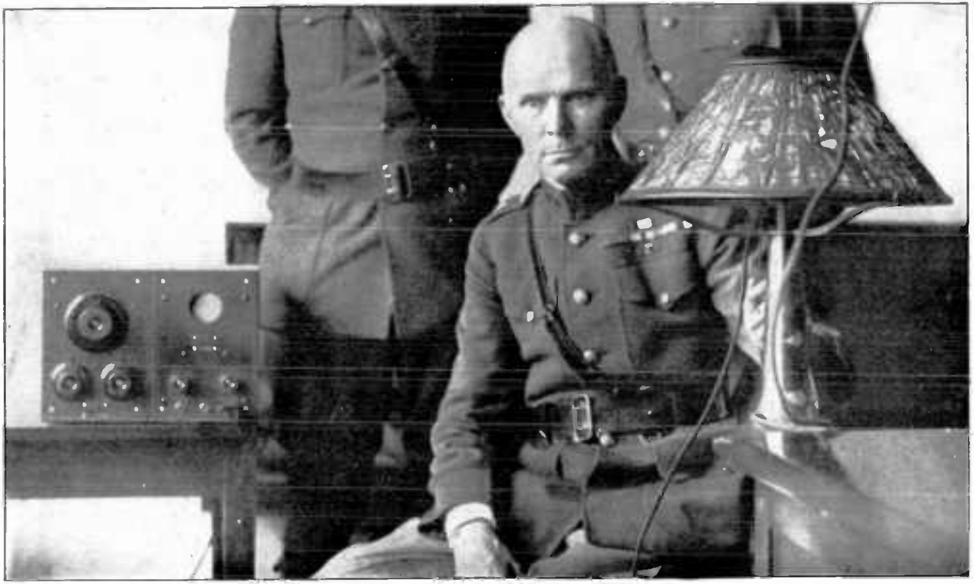

MAJOR GENERAL SQUIER GIVING A DEMONSTRATION OF "WIRED WIRELESS"

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Photograph by Brown Brothers

BROADCASTING FROM A BIG AIRPLANE WHILE FLYING ABOVE THE CLOUDS

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was Dr. J. A. Fleming, the name "Fleming valve" has obvious propriety.

Various special forms of the tubes, notably one for rectifying an A. C. in connection with radio transmission, have been developed. But any and all the forms fall within the generic designation "two-electrode electron-tube."

The two-electrode tube, however, is not used in the modern radio-receiving apparatus. The "electron tube" in question here, and the apparatus that is responsible for most of the seeming miracles of modern radio, is the invention of Dr. Lee DeForest. It consists essentially of a Fleming valve into which a third electrode, in the form of a mesh of wire or a metallic perforated "grid," has been introduced between the filament and the plate.

This "grid," whatever its form, is the wonder-working little structure that transforms the "Fleming valve" into a veritable Aladdin's lamp.

THE DEFOREST AUDION

When Dr. DeForest first constructed such an apparatus, he named it the "audion."

The name was suggested, doubtless, by the fact that the little modified electric light bulb, utilized as a detector in the radio circuit, proved far more sensitive than any device previously available, and enabled a listener to hear messages that otherwise would have been inaudible.

But the invention involved Dr. DeForest in a patent suit, or a series of patent suits, with Dr. Fleming and others; and while the controversy was dragging through the courts, other uses were found for the audion. It was found to be not

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merely a detector or rectifier of A. C., but an amplifier of currents (with the aid of a local battery); and (under proper conditions) an oscillator, that could transform D. C. into A. C. of enormously high frequency, thus proving the ideal instrument not merely at the receiving station but also (for the purposes of the amateur at any rate) at the transmitting station as well.

And so the names "detector" and "amplifier" and "oscillator" came to be applied to different types or modifications of the audion; and the comprehensive term "vacuum tube" came to be pretty generally employed to designate the apparatus in all of its varieties.

Vacuum tubes they all are, of course; but there are plenty of vacuum tubes that are not used for radio purposes in the present significance of the word (X-ray tubes, for example, and ordinary electric-light bulbs, and the tubes used in high-frequency electro-therapy), so it could hardly be expected that this name would gain official sanction. But neither, it appeared, was there any probability that Dr. DeForest's original selection, "audion," would gain approval.

The suggestion made at the Washington Conference, which appears to be fairly plausible, is that all vacuum tubes of the types we are now discussing should be known as "electron tubes." The tube of the Fleming valve type is to be called a "two-electrode tube." Tubes of the DeForest audion type (those, namely, that have the all-important grid introduced as a third electrode), however modified, are to be designated by the name "triode."

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THE VERSATILE TRIODE

"Triode," then, may be expected to become a very familiar word.

It is an obvious short-cut for "three-electrode tube," and the reader will understand that the terms "audion," "electron tube," "De Forest tube," and even "vacuum tube," as synonyms, will be encountered frequently in radio literature.

We shall learn also that a "soft tube," or one of relatively low vacuum, serves best as a "detector"; that various types of "hard tubes," or tubes of high vacuum, serve as radio-frequency and audio-frequency amplifiers; and that tubes of special construction, but in nowise modified as to essentials, constitute transmitting "oscillators" that are in many ways unrivaled.

In a word, then, when one has learned to recognize the De Forest tube in all of its guises and many aliases, one has gained a fair introduction to modern radio procedure and has acquired a technical vocabulary of some significance.

This multiplicity of names applied to the "Aladdin's lamp" in its entirety may prove somewhat confusing. Fortunately there is no confusion whatever about the terms applied to its essential parts. "Filament," "plate," and "grid" are names that have no ambiguity. The word "grid" in particular is ever-recurrent in radio literature; and no possible doubt ever attaches to it. In radio parlance, "grid" means the third and all-important electrode in the most important piece of apparatus with which radio deals; and it means nothing else.

When we study the kind of drawing called "a circuit diagram," or "hook-up," of a radio appa-

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ratus, we find here and there a little circle within which are three characteristic symbols—a loop, representing the filament; a straight line representing the plate; and a zigzag line representing the grid. Sometimes the circle is omitted, only the symbols remaining; but the symbols by themselves reveal the triode unequivocally; and as we observe the lines running in this direction and that, representing various electric circuits, we are again reminded that this is indeed the very heart of the radio system. Everything about the operating of the radio apparatus depends on the way the electric currents flow through the filament and grid and plate of this all-important electron tube, the triode.

TUBE CIRCUITS AND BATTERIES

If you examine a simple circuit diagram or hook-up (a complicated one will serve the same purpose, only it would be more difficult to follow), you will note that lines representing the channels of an electric circuit make loops having respectively (a) the plate and the filament and (b) the grid and the filament at their ends. Also, of course, there is a circuit that includes the loop of the filament itself.

These circuits are known respectively as (a) the plate-filament circuit, (b) the grid-filament circuit, and (c) the filament circuit.

It will be noted that there are batteries associated with these circuits; and here it should be explained that the battery that actuates the filament circuit is called the "A" battery, and is a storage battery of not more than 6 volts; whereas the battery that actuates the plate-filament circuit

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is known as the "B" battery and is a 22½-volt battery, comprising a group of dry cells.

Incidentally it may be added that the "A" battery is a good deal of a nuisance, as all storage batteries are, requiring to be recharged from time to time.

A "rheostat," or "variable resistance," with dial for adjustment, is arranged in the filament circuit, so that the current may be regulated in such a way as to bring the filament to mild incandescence, without overheating. There may be a "voltmeter" in the plate-filament circuit, the object of which, as the name implies, is to determine the voltage and power of the current.

In the grid-filament circuit (which includes the part of the inductance coil of the simplest antenna, or the secondary coil of the loose coupler or its equivalent) there is sure to be a small condenser, and about this a grid-leak, which consists essentially of a channel for an overflow current, so to speak.

This channel may be provided by the mark of an ordinary lead pencil on a piece of paper, affording a conducting highway which may be modified by the use of an ordinary rubber eraser. A less primitive grid-leak is a little wire-like carbon resistance in a glass tube perhaps an inch in length.

THE REGENERATIVE CIRCUIT

If we examine a more elaborate hook-up, showing a "regenerative" circuit, we shall see that the plate-filament circuit is looped back in such a way that a coil inserted in it is in the neighborhood

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of one of the coils, probably the secondary, of the chief antenna inductance, or tuning mechanism.

This implies that there is opportunity for inductive transfer of current between the plate-filament circuit and the grid-filament circuit. As the current in the former is relatively strong, the effect is to "feed back" a certain amount of current flowing there from the antenna, and conveying the radio message, is fortified, or amplified, or regenerated.

The coil in the plate circuit that accomplishes this is called a "tickler" coil; the arrangement as a whole is said to utilize the "feed-back" principle and to constitute, as already stated, a "regenerative" circuit.

The possibility of utilizing the local current in this way to this end was discovered by Major Edwin H. Armstrong, who in consequence bears the popular sobriquet of "Feed-back Armstrong."

The possibility of modifying the "input" current in this way, through the inductive influence of current from the local battery, is enormously important. Strangely enough, the input current retains its original modulations, being equally magnified as to all its parts; so that no distortion of the message occurs. Meantime it is possible, by regulation of the plate-circuit current, to modify the conditions of inductance and capacity in such a way that the detector tube will "oscillate." And the oscillations may be regulated in such a manner that they almost, but not quite, coincide with the oscillations of the high-frequency current that is coming to the grid from the aerial.

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THE HETERODYNE OR "BEAT" PRINCIPLE

When this is done, we have what is called a "heterodyne" or "beat" effect, the result of which is altogether notable.

To illustrate: The "carrier" current coming to the grid from the antenna is oscillating, let us say, 1,500,000 cycles per second, representing a wave length of 200 meters; and the local oscillation in the detector tube is developed to 1,499,000 cycles. The result is that all but 1,000 oscillations are neutralized or annulled; and a radio-frequency current (1,500,000 cycles) is transformed into an audio-frequency current (1,000 cycles), which is rectified in the detector tube simultaneously with its production and passes on into the plate circuit as a current of 1,000 pulsations (not alternations) per second, admirably adapted to move the diaphragm of the telephone receivers.

And this forward-pulsing audio-frequency current retains all the modulations of the original alternating high-frequency current.

When the principle of reduction from radio-frequency to audio-frequency is carried out in this way, the "beat" effect is said to be produced by the "autodyne" method, as just stated. The Washington Conference suggested, as a substitute for this word, the term "self-heterodyne."

There is another method of producing the same effect, in which oscillation is set up in a triode not otherwise directly associated with the radio-receiving mechanism, the local oscillating current being blended with the input grid current to produce the "beat" effect as before.

This is spoken of as the "outside heterodyne" method.

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As a refinement of the method, there may be amplifying tubes in connection with the local oscillator and a graded reduction of the frequency, a "super-heterodyne" receiver being developed. A full explanation of this highly efficient method is given in a later chapter.

THE QUESTION OF AMPLIFICATION

The simplest detector triode is far more sensitive than the best crystal detector; but the capacity of the modern radio-receiving apparatus is not gaged by the possibilities of a single electron tube. To get the full effect, the current must be augmented by passing through one or more "amplifiers."

Were a single triode in question (as in the simplest outfit), the rectified current would pass from the plate along the circuit that includes the receiving telephones; but when "amplification" is to be practised, the current passes through the primary coil of a step-up transformer, and is thus passed on inductively, amplified in force, to the grid of an amplifying triode.

From the plate of this amplifier the current may pass either directly to the telephones, or by way of another transformer, to the grid of a second amplifier.

It is possible to introduce a third amplifier, and yet another and another; altho of course practical difficulties of manipulation are multiplied. The apparatus is spoken of as a "one-stage amplifier," a "two-stage amplifier," etc., according to the number of amplifying electron tubes used.

A modification of this method applies the amplification principle to the radio-frequency vibrations

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of the input current, using one, two, or three stages of such amplification before passing the current through the rectifying detector tube; and then using one, two, or three stages of audio-frequency in addition before the current is passed on to the microphone. There are certain difficulties attendant on such use of the amplifying principle when applied to the modulated current of the radio telephone message. But these have been overcome, and for long-distance reception the use of multiple radio-frequency amplification plus audio-frequency amplification now constitutes the standard method.

THE TRANSATLANTIC TESTS

When Mr. Paul F. Godley went to Scotland, in December, 1921, and made his famous demonstration that amateurs using low-power apparatus and short waves could transmit messages across the Atlantic, he used a "super-heterodyne" receiver with five stages of radio-frequency and two heterodyne tubes, supplemented by audio-frequency amplification. His success in hearing the signals of more than a score of American amateurs proves the value of that equipment.

Meantime, it is worth recalling, that several British amateurs heard some of the signals. The most successful of these was Mr. W. R. Burne, of Sale, Cheshire, who heard the signals of seven American stations, and who relied chiefly on from three to six stages of radio-frequency amplification; followed by a detector operating on the heterodyne principle, and one stage of audio-frequency amplification.

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The step-up transformers used for the radio-frequency valves (triodes) were so-called "open core" or "air core"; whereas the one used for the audio-frequency amplifier and the second one placed between the amplifier and the receiving head-phones were "closed core"—in accordance with the usual American procedure. (Mr. Godley used resistance coils instead of transformers between his radio-frequency amplifiers.)

We find this comment on Mr. Burne's achievement in the *Wireless Age:*

"The aerial used by Mr. Burne is an inverted L supported by one mast on his house and in an adjoining garden. It is 56 feet high at the house and 45 feet high at the other. The antenna is within the limited size allowed by the General Post Office, being only 45 feet long. The usual water-pipe was used as a ground for the receiving set.

"The set used in the record-breaking reception was mostly of home construction. Mr. Burne states that a friend of his classified it as a 'veritable collection of junk.' Some junk!

"The set consists of the usual tuning devices, radio-frequency amplifiers, transformers and condensers, detector, and audio-frequency amplifiers. On the first two nights of the test 4 ES valves were used, making a total of five with a separate external heterodyne. On the third night five tubes were used as radio-frequency amplifiers, in addition to the heterodyne. On the succeeding nights six radio-frequency valves were used, with the occasional addition of one or two steps of audio-frequency amplifiers."

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BRITISH AMATEUR METHODS

The periodical *Q S T* notes that the total length of wire used in Mr. Burne's aerial is well within the British limit of 140 feet; the 45-foot length of aerial proper being supplemented by a down lead of 50 feet. Further comment as to details of equipment of Mr. Burne and several other British amateurs who shared with him the distinction of hearing the American signals, as presented by an editorial writer in *Q S T*, is worth quoting.

"The radio-frequency transformers are so particularly interesting and are of the semi-tuned type. The transformer 'formers' were tuned out of solid 1¾-inch ebonite rod, a groove one-eighth of an inch deep containing the primary and secondary windings consisting of 30 and 35 turns of N. 38 D. S. C. copper wire, the secondary wound over the primary. These transformers were good for 180 to 325 meters with the shunted variable condensers made for the occasion.

"The second prize winner, Mr. H. H. Whitfield, who heard 1AFv, LBCG, and 2ZL, had a particularly interesting arrangement which contained some rather unusually constructed apparatus. His receiver used two steps of radio-frequency amplification, a detector and two steps of audio-amplification. A three-coil tuner with single layer coils was used with long wooden handles to vary their couplings. All of his apparatus was home-made and especially for the occasion.

"Mr. Corsham of London, joint third prize winner, used a detector and two steps of audio-amplification, being very similar to the arrangements in general use in this country. Mr. R. D.

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Spence, the other third prize winner, used three steps of transformed coupled radio-frequency amplification, a detector and two audio amplifiers.

"The apparatus of Mr. J. R. Forshaw, also a prize winner, consisted of one step of radio-frequency amplification, a crystal detector and one step of audio-frequency amplification. 1 BCG was heard by Mr. Forshaw and he reports fading signals when a steam train passed by his house which he attributes to the cloud of steam and smoke emitted from the engine.

"The English amateurs are certainly to be complimented on their fine work and we only hope that they will now be able to hear American signals frequently and in the very near future that we may be in direct communication with them."

HOW AMERICAN AMATEUR STATIONS ARE LISTED

Another very entertaining article in the journal *Q S T*, under heading "Interest in France," tells of the enthusiasm with which the successful trans-atlantic tests were heralded in Europe. In particular, it refers to the code messages that Mr. Godley sent, and the way in which they were interpreted. I am minded to quote the account in full, not only because of its inherent interest, but because it is peculiarly pertinent from the standpoint of the present discussion in that it brings out in a graphic way the system of numbering and lettering through which American amateur sending stations are identified.

"The French amateurs," we are told, "took an intense interest, copying each morning Mr. Godley's daily reports of listening, creating what Dr.

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Pierre Corrot, editor of the amateur magazine 'La T. S. F. Moderne,' calls 'a most palpitating romance.' Their only information was second-hand and they were rather hard put to it to make heads or tails of the cryptic radiograms they copied from MUU. Thus we find them wondering what in the world a 'beverage' antenna might be, their dictionary saying that a 'beverage' means a 'drink' or a 'potation.'

"In Godley's second telegram, his statement, 'Heard one able yatch during free-for-all period sink gap fading,' completely got their animal. Quoting Dr. Corrot, '. . . a most remarkable sentence. It appears that Mr. Godley heard very well indeed during the open-for-all period an accomplished or able yacht! He therefore heard nothing from America. It is not astonishing under the prevailing atmospheric conditions.'

"Two days later Godley reported 1BCG. 'This time here we are! A warm rain is falling; the wind has calmed and the atmospherics have diminished in intensity. And Mr. Godley has heard one boy cast George who called him on continuous waves. . . . But who might this "Boy throws George," who confirms success of the transatlantic test? What a peculiar language Mr. Godley talks.'

"And then, fellows, do you remember Godley's long message, the one with the thrill:

"'One London—TC—American Relay League Hartford Conn. U. S. A.—Heard one ram unit two fox pup two boy mike love stop Code words of these three verified by Coursey stop Also heard cables from following spark one able ram yacht one boy dog tare two boy king two dog nan three boy pup also following continwave one able ram

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yacht one boy cast george one boy dog tare one boy george fox one yacht king one xray mike two fox dog two easy have eight able cast fox eight xray vice stop Strong and reliable—Godley.'

"Dr. Corrot continues: 'Here is a puzzle for us! A correspondent writes us: "I'll be damned if I understand anything of this mystery where rams, dogs, foxes, yachts, and even X-rays play such an important part!!! Might this not be a code?"

"'Yes, it is one. Let us consider the second part of this telegram. "Code words of these three verified Coursey." This shows us that the preceding sentence treats of the transmission of three American amateurs, prearranged words transmitted by whom have been verified by Mr. Coursey.

"'And if we remember that the calls of the American amateurs are all issued with a number followed by two or three letters; if we notice that in the first sentence there are exactly three numbers (1, 2, 2), each one followed by two or three words; if we remember the story of Fritz, Karl, Walter & Company and that of the telephone girls, "A like Andre, B like Bertha, C like Cecily"—we are immediately led to think that in order to avoid errors in reception they have replaced each letter of the calls received by a word beginning with that letter; A like Able, B like Boy, C like Cat, D like Dog, E like Easy, . . . etc. And now all at once we discover that the pretended yacht which was so accomplished, "one able able yacht," heard on the night of December 8th, is the code station of the American amateur 1AAY . . . and that the remarkable "one boy cast George" that called Mr. Godley on continuous

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waves on the night of December 10th is none other than the station whose call is 1BCG.

" 'There still remain the words "sinkgap fading" which are most incomprehensible even when we know that sinkgap is an abbreviation for synchronous rotary spark gap. It just confirms in us once more the idea of an international language which exists and which is used with success, and which is the necessary complement to radiotelegraphy and even more so to radiotelephony. What good do the words we receive do us if we don't understand them?

" 'The puzzle telegram of December 12th reveals to us in its turn that on the memorable nights of the 10th and 11th the following were heard: 1RU, 2FP, and 2BML, whose code words were verified by Mr. Coursey, also the calls (cables is certainly a mistake; Mr. Godley must have written calls, perhaps not very legibly) of 1ARY, 1BDT, 2BK, 2DN, and 3BP, and finally the CW stations 1ARY, 1BCG, 1BDT, 1BFG, 1YK, 1XM, 2FP, 2FD, 2EH, 8ACF, and 8XV, eighteen stations were heard on the same night (strong and well), of which one, 1BCG, was heard the night before and two, 1ARY and 1BDT, were heard on spark and on CW.' "

The editorial writer in *Q S T* takes up the theme with applause:

"Good for the Frenchman!" he cries. "They figured it out exactly right, and give them credit, fellows. They will be good chaps to work with when international radio becomes a commonplace. And, by the way, it gives us great pleasure to record that possibly largely as a result of our own A. R. R. L. transatlantic tests, the bars have been

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let down in France and amateurs there are being licensed to use 200 meters and 100 watts of CW. Soon we hope that they, like the British, will be ready to test to us and give us the privilege of repaying them for their kindness in listening for our signals.

"Once having discovered the 'system,' 'La T. S. F. Moderne' had no more trouble and proceeded in its articles to interpret the succeeding Godley messages without difficulty. When Mr. Coursey let it be known that American stations were heard as well by the British amateurs, they said: 'Bravo, British amateurs! You have shown that without special installation Old Europe in spite of its hindrances can show itself to the haughtiness of young America."

In further elucidation of the abbreviations designating American amateur sending transmitting stations, it is necessary only to add that the numbers 1, 2, 3 refer respectively to districts into which the United States is charted officially for purposes of such classification. The first district includes the New England territory; the second district, the New York, and so on.

In the case of this year, 1922, more than five hundred broadcasting stations were established in this country, every state in the union being represented, and of course there are several thousand amateur transmitting stations, each with its numeral and series of letters in unique sequence.

Amateur fans are so familiar with the abbreviations used to designate the various stations that thev usuallv consider it quite superfluous to mention names, or even locations, in writing about their own achievements. Thus we find Mr.

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Godley in his long and highly interesting article in the *Wireless Age*, describing the results of his transatlantic test, without mentioning the names of the successful senders, or the locations of their stations.

He simply takes it for granted that when he says "1BCG" everybody will instantly understand that this means a certain station at Greenwich, Connecticut, operated by a group of well-known amateurs, including Mr. Edwin H. Armstrong. And so with all the other stations.

THE AMERICAN RADIO RELAY LEAGUE

This feat of spanning the Atlantic by amateurs was spoken of as "the greatest scientific sporting event ever undertaken." It did more, perhaps, than any one other thing to advertise the American Radio Relay League to the general public. It aroused the interest, also, of the military authorities, and prepared the way for the development, under the leadership of Mr. Hiram Percy Maxim, of the International Amateur Radio Union.

After that, in Mr. Maxim's words, the pace was fast and furious. Soon the United States Navy came forward with a really amazing offer. They asked the loan of the communications manager of the amateur organization, Mr. F. E. Schnell, and offered to give him free hand to demonstrate what might be done with short waves over long distances.

The Amateur Relay League consented to give Mr. Schnell leave of absence, and prepared eagerly to cooperate in every way. Mr. Schnell

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accompanied the Pacific Fleet to the other side of the world. Let Mr. Maxim tell the sequel:

"Schnell covered himself with glory. The Navy was astonished at the amateur organization and its enthusiasm. Direct communication between the fleet and the American continent was maintained by this amateur with naval as well as amateur stations, even when the fleet was anchored in Australian and New Zealand harbors, a feat that had never before been accomplished by the Navy with its standard long-wave transmitters and receivers. There could not have been a more convincing demonstration of organized amateur radio."

THE TRIUMPH OF SHORT WAVES

It became increasingly obvious that the province and possibilities of the short wave in radio had been quite misunderstood or unappreciated. Now the short wave was to come into its own—somewhat at the expense of the amateurs who hitherto had had this field, or a significant part of it, largely to themselves. Aforetime waves below 200 meters were given to the amateur because no one else wanted them, and the amateur had to put up with what he could get. But now there was a scramble for the short waves, which were by way of becoming the most valuable of all.

When it had been demonstrated that with frequencies of 6,000 to 12,000 kilocycles (waves of fifty to one hundred meters), messages could be sent ten thousand miles—as from Melbourne, Australia, to Washington, with a power of only 200 watts—the radio world not unnaturally took notice. Experiments with higher and higher fre-

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quencies went forward, and new knowledge as to the characteristics and potentialities of waves from 25 to 13 meters was forthcoming. A report by Mr. A. Hoyt Taylor, Superintendent of the Radio Division of the Naval Research Laboratory, states that waves from 25 to 13 meters are best adapted to long-haul daylight communication, and not at all well adapted for night work, apparently because the Kennelly-Heaviside Layer of the upper atmosphere is not always dense enough in free electrons at night to reflect these very short waves.

Still shorter waves, down to 3 meters (generated by currents of 100,000,000 frequency) are within the experimental domain, and may be used with success between points not obstructed by material obstacles. Such waves have somewhat the character of magnified beams of light. An airplane has communicated with a station on a mountain top 200 miles away, using these very short rays.

A highly important particularity of short radio waves is that they lend themselves to directional propagation. Mr. Taylor states that it is easy to build simple beam systems either by use of specific antenna arrays or by the use of reflectors behind the antenna, or even possibly, as the Japanese are doing, with directors in front of the antenna.

The physical dimensions of such apparatus, he tells us, are proportional to the wave length. For relatively long waves generated by a 700-kilocycle current, enormous structures higher than any existing building and of great lateral extent would be needed. But a very concentrated beam of 5-meter waves can be gained with a structure only

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about 150 feet in diameter. It is obvious that a directed radio beam takes on some of the advantages of a wire-directed current.

BROADCAST RECEPTION

The short-wave work has important bearings on broadcasting programs, because messages and speeches sent across the ocean on short waves may be transposed into middle-wave impulses for distribution to the general radio audience—as when America listens to Britain's King or Europe to America's President. But of course it is the moderate-wave message with which the millions of listeners, familiarly spoken of as the "radio audience," are directly concerned. The manufacture of receiving sets for this audience became a major industry during the decade following the introduction of broadcasting as a doubtful experiment.

The principles involved in radio reception did not change, but the practicalities of receiving sets were rapidly modified after the expiration of patents permitted radical cuts in the price of electron tubes. The crystal detector ceased to be a factor in the consideration of the average radio listener. And very soon it became the rule rather than the exception to employ receiving sets with five or more tubes. By the time of opening of the second decade of general broadcasting, standardization of receiving sets had so far advanced that there was little to choose between multistage amplifiers of a variety of makes. Radio-frequency amplifiers were a matter of course, and superheterodyne amplifiers had attained great popularity.

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A very striking modification in the practical use of the radio receiver came with the introduction of so-called Battery-Eliminators, which permitted the use of current from the ordinary electric supply in place of the cumbersome, costly, and impermanent A and B batteries. No new principle was invoked, but a system of transformers and rectifiers of current, so adapted as to feed to each of the receiver circuits electric current of the right voltage.

Soon the battery eliminator as a separate and relatively bulky device was itself eliminated. The four-element or shield-grid tube further facilitated amplified reception; and the electro-dynamic loud speaker superseded the old electromagnetically driven horn. Presently the receiving set of seven or eight tubes—two or three stages of radiofrequency amplification. detector, audiofrequency amplifiers, and power tube—with the electrodynamic loud-speaker equipment, took on the appearance of a compact piece of cabinet furniture, much like a moderate-sized clock; the similitude being enhanced sometimes by the placement of an electrically driven clock mechanism with ordinary dial at the front of the radio-receiver case.

The four-element vacuum tube just referred to is a modified De Forest audion, or triode, the essential change consisting of the introduction of an additional electrode, in the form of a wire shield, which is kept at a positive potential and neutralizes the capacity between the control grid and the plate. The shield increases the efficiency of action of the tube without modifying the principle of its action. The same device in tubes at the broadcasting station is said to save the op-

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erator many troublesome adjustments, and to insure or facilitate perfect operation.

All these practical betterments change the status of radio as a household convenience and pleasure-giver, but it is worth repeating that they involve no radical discovery or fundamental advance upon the radio equipment of earlier years. The city dweller perhaps needs to be reminded that millions of satisfactory receiving sets necessarily are still operated with batteries, in regions where commercial line-current is not available.

It may be of interest to note, further, that whereas the crystal detector has been so largely superseded by the vacuum tube, a crystal frequency control continues to be an important element of the transmitting apparatus at the broadcasting stations. The curious certitude of action of a quartz crystal in this capacity seems not to be challenged by even the magic four-element vacuum tube—tho of course the latter performs many functions in the transmitting set that the crystal could not pretend to emulate.

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CHAPTER VII

MEASURING RADIO WAVES AND ELECTRIC CURRENTS

IF I should wish to prove to you that a young athlete of my acquaintance is a very fast sprinter, I would tell you that he can "do the hundred in even time."

I would mean by that, of course, that the young athlete can run one hundred yards in ten seconds. Comparatively few athletes in the world can accomplish that feat. To be able to "do the hundred in ten flat" has long been the standard test of supreme sprinting speed. Not more than half a dozen men have ever lived who proved themselves able to run faster than that; and these swiftest of human beings cut only a fraction of a second from the record.

We may fairly say, then, that ten yards—thirty feet—represents approximately the extreme distance that the human body may be propelled by its own muscular energy in a second's time. Thirty feet per second becomes a standard gage of speed. Any human runner who approaches this standard is running very fast indeed. Any animal that can move faster than that can readily escape the fleetest human pursuer who depends on his legs alone.

Of course man, being an ingenious animal, has learned to supplement his legs. First he requisitioned the speed of animals, notably the horse, as a carrier; and then sundry wheeled vehicles, some of them, like the bicycle, even propelled by his own

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legs; others, yet more speedy, propelled by engines actuated by steam or gasoline. With such aid, we are able to move along the earth's surface at the rate, say, of a mile a minute. Making the simple computation, we find that that means about 88 feet per second—almost exactly three times the speed of the fleetest runner.

Even that is not man's supreme effort. Motorcycle and locomotive and motor car, on occasions, have accomplished two miles a minute—156 feet per second. And now we hear of airplane attaining the almost terrifying speed of 180 miles per hour, or three miles a minute, or 264 feet per second. More than eight times the speed of the runner.

That is going very fast indeed, as anyone will admit,—much faster than most of us would care ever to travel.

Now human ideas are, of necessity, conditioned on human experiences. So when we think of things being fast or slow, we must necessarily make comparisons in terms of human observation. Consciously or unconsciously, we get back to that standard of thirty feet or thereabouts per second as representing a test of speed. But of course we are early taught to understand that things may move much more rapidly in the inorganic world. We know that a falling body, dropping sixteen feet the first second, drops more and more rapidly until the eye can not follow it. We are familiar, too, with projectiles such as bullets and cannon balls that move far too rapidly to be seen; and we accept the statement of experts to the effect that such projectiles may have a muzzle velocity of,

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let us say, 3,000 feet per second—100 times the speed of the runner.

Such a projectile is moving faster than sound waves, which accomplish only 1,040 feet per second; so that the victim of a bullet, standing at whatever distance, might be stricken by the missile before he heard the sound of the discharge.

THE SPEED OF LIGHT

Everyone who has been much in the country has had the experience of watching some laborer at a distance engaged in the task, let us say, of chopping wood; and has been mildly surprized to note that the sound of each successive blow of the ax comes to the ears at a noticeable interval after the eye has seen the blow delivered.

That observation tells us that sound travels much more slowly than light. In fact, if we gage things by our own senses, it would be hard to convince us that light takes any time at all in its transit. It would be hard to persuade an uneducated man that he does not see the movement of the ax in the precise instant that it occurs; and, indeed, for all practical purposes of human experiences this intuition is substantially correct. When a physicist measures the speed of light, he is obliged to use planetary bodies—the moons of Jupiter and the like—to aid him, or to devise apparatuses of exquisite delicacy the action of which the ordinary man can scarcely comprehend.

And when, as a result of such measurements, the physicist tells us that light moves 186,000 miles per second (or three hundred million meters per second, to use the modern standard), the words convey no definite meaning.

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It does not help us at all to say that light travels so fast that it requires only eight minutes in coming to us from the sun; and if we confine attention to terrestrial distances, we can only reflect that a beam of light, were it to follow the earth's surface, would go round and round the entire globe in a great circle almost eight times during the second that the human runner requires to compass thirty feet. At each and every stride of the runner, the beam of light would circle the world anew and again overtake him.

A speed like that lies so far away from human experience, that we gain only a vague notion of what 186,000 miles per second means, even from such an illustration.

RADIO WAVES HAVE THE SPEED OF LIGHT

And yet it is with that particular standard of speed—the speed of light—that the radio operator constantly deals.

The electromagnetic waves that convey the radio messages from transmitting station to receiving station are cousins-german to light waves, and move at the same speed. They, too, would pass almost eight times round the world while the runner is making his thirty feet;—not only could but actually do accomplish this, since the radio waves, unlike light waves, do follow the curves of the earth's surface.

The generality of radio waves, to be sure, passing out in all directions from the transmitting aerial, probably move in straight lines, and pass off into interminable space. But it happens, as we are aware, that certain parts of these waves are so deflected that they follow the earth's sur-

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face, and thus actually make such a circuit as the waves of light were supposed to make in the rather fantastic illustration just given.

If radio waves could be seen, we might actually observe them hurtling by us again and again, each time after circling the world, during the critical second in which the sprinter, making a supreme effort, moves thirty feet along the cinder path.

Since the radio waves can not be seen, this illustration perhaps appears scarcely less fantastic than the other. But let me cite an illustration of less intangible kind (briefly presented in the first chapter) that will perhaps prove more convincing.

SOUND VERSUS RADIO-WAVES

This time we are to deal not with imagined possibilities, but with realities. Let us suppose that you are a member of the throng of people who have gathered about the platform to hear President Hoover deliver his inaugural address. As it chances, you have been very fortunate and have secured a place well toward the front, only thirty feet from the platform on which the speaker stands. You are listening with eager interest, and of course every word of the address comes to your ears loud and clear. As you watch the speaker's lips, you certainly would say that you hear each word at the precise instant when it is spoken.

Would it astonish you, then, to be told that there are people in New York, in Chicago, in Denver, in San Francisco, who hear each successive word of that speech before you hear it?

Such, at any rate, is the astonishing fact. Each and every wave-sound coming from the speaker's

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lips has required three-one-hundredths of a second to reach your ears—a time to you quite inappreciable. Yet in that same tiny fraction of a second, sound waves from the same impulse of the speaker's lips have made their impression on a little microphone receiver and have been transmuted into electromagnetic waves and flashed off in every direction through space, and retransmuted into sounds that have come to the ears of each and every radio-telephone listener within a distance of *5,000 miles* before the original sound can have crossed *thirty feet* of space between the speaker's lips and your ears.

Word by word the address may be heard in Paris and London before you hear it!

JUGGLING WITH TIME AND SPACE

On a still more recent occasion the President spoke into a telephone tube and his words were flashed out from the great Radio Central station on Long Island to the representatives of twenty-one nations in all parts of the world. And had you stood at the far end of the room in which he spoke, his words would not have come to your ears until after they had reached the ears of the listeners at the capitals of each and every one of the twenty-one nations—to the farthest corners of the world.

The listener in Tokio was, in a sense, nearer to the President than you were, tho you stood there in his very presence. The vast stretches of intervening space—the breadth of a continent and the sweep of an ocean—had vanished before the magic of radio.

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Who does not stand abashed in the presence of such mysterious phenomena?

And yet, from another point of view, the radio waves are not mysterious. We know how they are generated and we can produce them at will. We know not only how fast they travel but how to intercept them at any stage of their journey. We can measure the exact distance from crest to crest of the waves, despite the incredible speed of their flight. We not only can do this, but we must do it if we are to be practical users of radio. Government regulations provide that if you are to generate electromagnetic waves with a radio-transmitting apparatus, you shall produce waves only of specified length. As an amateur, you may not send out waves shorter than 150 meters nor longer than 275 meters.

The ether is a public domain, and you may no more run amuck in it than you may run amuck on a public highway in your automobile.

Meantime if you are to receive messages with your radio-receiving telephone you must "tune" the mechanism for the reception of radio waves of a particular length, else you will have small measure of success. It is true that the apparatus you are using may have been purchased ready made, and nothing more may be required of you than to turn the pointer of a dial in order to accomplish the "tuning." But even so you are aware that the designer of the instrument must have known how to measure the radio waves, else he could not have provided for such adjustment.

And if you have thought at all about it, you must have wondered how it was possible for any-

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one to measure waves that are hurtling by so fast that each successive crest rushes clear round the world in a small fraction of a second.

The more you reflect on the subject, the more wonderful the feat of measuring radio waves will seem. You have been told that these waves, whatever their length, move at uniform speed,—and that this speed is the speed of light. Since the excessively minute light-waves and the long radio-waves have the same rate of motion, it would appear as if no other rate of movement is possible in the ether.

WAVE SPEED AND WAVE LENGTH

Be that as it may, we have no knowledge of any ether-waves that do not conform to the same speed rule. And so, if we know the distance between crest and crest of successive waves of any given series, it is a matter of simple arithmetic to determine how many of these wave crests will pass a given point in space in a given period of time—say one second.

The computation is most readily made if we use the generally recognized modern standard of length, the meter; which, as every one should know, is a little more than the length of a yard-stick—about 39 inches. But for our present purpose we are not concerned with individual meters. It suffices to know that the distance of 186,000 miles, which is the distance traveled by each radio wave in a second, may be otherwise stated as 300,000,000 meters.

If, then, in a given instance, the radio waves passing us are 300 meters from crest to crest, it

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is obvious that precisely 1,000,000 such waves will pass in each successive second of time.

If the waves were 150 meters in length there would be, just as obviously, 2,000,000 of them per second. If, on the other hand, the waves were long ones, say 3,000 meters from crest to crest, only 100,000 waves would pass per second.

In a word, we have but to use the uniform speed of radio waves, 300,000,000 meters per second, as a dividend, and the length of the individual waves of a series as a divisor, in order to learn the number of waves per second.

Meantime we are already aware that these electromagnetic waves are generated by an electric current in the transmitting aerial; and that each wave, with its crest and hollow, represents a single complete pulsation (call it alternation or oscillation or cycle as you prefer) of an alternating electric current. Such a current, it is well to recall, is always designated in technical writing by the initial A. C.; to distinguish it from the direct current, designated D. C. The technician, as we have learned, may not even bother to use capitals in making the designation.

This alternating current, as we know, may be thought of as represented by a backward and forward surging or oscillation of the electrons along the wire. The forward surging is spoken of as the positive phase, the backward surging as the negative phase of the current. The two together make up a complete oscillation or alternation or cycle, and each such cycle, as we have just seen, corresponds to the electromagnetic cycle, with crest and hollow, constituting a radio wave.

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ETHER WAVE AND ELECTRIC CURRENT

When the electromagnetic or radio wave, coursing through space, washes along the aerial of a receiving radio station, it will set up in the wire an alternating electric current corresponding precisely to the generating current in the transmitting aerial by which the radio waves themselves were set in motion. Each successive electromagnetic wave that passes will cause the electrons in the aerial wire to oscillate, with positive phase or forward push to correspond to the wave-crest, and with negative phase or backward surge to correspond with wave-hollow.

It is highly important to bear in mind always these reciprocal relations between the alternating current in the antennæ and the electromagnetic, or radio waves proper, in the ether.

The two sets of phenomena belong to quite different orders. The alternating electric current may be visualized as movement of electrons, which are part of the physical structure of the antenna wire. Except under very exceptional conditions (in the narrow chamber of the audion or electron tube) the electrons can not leave the immediate vicinity of the wire. They have about them lines of magnetic and electrostatic forces, constituting an electromagnetic field about the wire; and the movement of these lines of force, as the electrons oscillate, is what causes the disturbance in the ether that manifests itself in electromagnetic waves—just as an oscillating movement of your hand may set up waves that move along the surface of a pond.

To give perhaps a better illustration: The vibrations of your larynx produce the sound waves that

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pass off through the air and are heard by someone at a little distance. The ear-drum of the listener vibrates in unison with the air waves; but it would be absurd to suggest that the sound-waves, which thus have a curious reciprocal relation with larynx and ear-drum, are not in themselves something quite different from either larynx or ear-drum.

A still closer analogy, and the one usually chosen, is that furnished by two piano strings, precisely equal in length and sensitiveness. When one string is struck, a certain sound is given out, which is caught up responsively by the other string at a distance. the two strings then vibrating in unison.

No one fails to discriminate between the strings themselves and the sounds that are generated by one and caught up by the other.

There is just as much difference between radio antennæ, transmitting and receiving, and electromagnetic (radio) waves, as there is between piano strings and sound-waves.

The sounds that come out from the piano string are due to the oscillations of molecules that make up the physical structure of the string; and the response of the second piano string is due to the setting up of corresponding oscillations in its molecules. But molecules are one thing and sound-waves are quite another—despite the reciprocal relation. And just as radical is the distinction between the oscillations of electrons that make up the physical structure of the antenna wires and the ether waves that pass through space from one aerial to the other.

I carry the illustration to tiresome length, be-

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cause it is of such fundamental importance that everyone who would have a clear notion of radio should fully understand the distinction between radio waves and the high-frequency electrical oscillations by which they are generated at the transmitting station and in terms of which they are interpreted at the receiving station.

The electric current is the direct servant of the radio operator. It can be controlled, held to a definite and predetermined physical highway of wires; made to oscillate at a given period; obliterated or reproduced at will.

The electromagnetic wave, on the other hand, is a free and untramelled voyager of the ether;—child of the electric current, if you will, but subject to no human guidance or control when it has started on its voyage; forever out of touch with the world in which we live, except that some chance remnant of an attenuated wave may wash against a receptive antenna, and stimulate responsive electrical activities. From a human viewpoint, the exception is all important—otherwise there would be no such thing as practical radio. But when we consider the entire series of electromagnetic waves that go out from a transmitting aerial, it must be obvious that the arrival of a stray waif of a radio messenger at here and there an antenna constitutes a phenomena that can hardly be thought of as other than fortuitous.

It is humiliating to think that human ingenuity, after so cleverly controlling the electrical current that generates the electromagnetic waves, is so helpless to govern the electromagnetic waves themselves. And yet, from another viewpoint, it might be made to appear as the cause of gratula-

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tion rather than humility, inasmuch as human ingenuity has sufficed to catch up the infinitesimal energy represented by the attenuated radio wave that reaches the receiving aerial, and to fortify and magnify it until it reveals to the ear the full import of a message that might well have been supposed to be hopelessly lost.

PRACTICAL MEASUREMENTS

It is difficult in contemplating such phenomena to keep one's feet squarely on the earth. But we are dealing with practical radio, and so must come back to practicalities. And the particular practicality that concerns us at the moment is associated with the fact of the very definite reciprocal relation between the electrical current in the antenna system and the electromagnetic waves with the aid of which communication is established between transmitting and receiving stations. In particular, we are concerned with the salient fact that each electrical oscillation in the transmitting aerial produces a single electromagnetic wave; and that the length of the electromagnetic wave may thus be predetermined by control of the alternating electric current.

If we generate and send into the transmitting antenna an electric current which will produce 1,000 electromagnetic waves per second; as these waves will rush off into space at a speed of 300,000,000 meters per second, there will obviously be 300,000 meters between each successive wave crest.

But practical radio can not deal with waves of such length; so we must produce an electric current of far more rapid oscillations. A current of

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10,000 cycles (which chances to be about the limit of audibility for the human ear) will produce radio waves of 30,000-meter lengths. Such waves are still much too long.

We must increase the oscillations of electric current to something like 50,000 cycles per second, representing radio waves of 6,000 meters, before we are dealing with messengers reduced to something like reasonable conformity with the relatively small size of the world on which we are operating.

Somewhat longer waves than this may be used, to be sure; but it will be recalled that at the radio conference in Washington, when allocation of wave lengths was made, the longest waves specifically dealt with were those from 5,000 to 6,000 meters, which were reserved for transoceanic radio-telephone experiments.

Meantime, as will also be recalled, the wave-lengths that have to do with more familiar radio phenomena are of far less ample proportions, the suggestive range for the waves used in private and toll broadcasting being from 310 to 435 meters; and the waves that amateurs may use ranging from 150 to 275 meters.

It is the last-named group, of course, that chiefly concerns us. A brief computation already made has shown us that waves of 150-meter length represent 2,000 vibrations per second. Making a similar computation for the 275-meter wave length that represents the amateur's future maximum, we find that these are generated by a current oscillating 1,090,909 times per second. The 200-meter waves that the amateur has hitherto for the most

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part dealt with represent 1,500,000 vibrations per second.

Every amateur, therefore, who would make himself eligible for a permit to transmit radio messages must provide himself with a radio-transmitting mechanism that can produce oscillating electrical current of more than a million oscillations per second at the lowest, and must be able to make sure that the oscillations do not run above 2,000,000 per second.

And at once the practical question arises: How is the radio operator to meet these conditions; and how is he to know that he has met them?

A million vibrations per second, at *slowest!* A rate of vibration a hundred times beyond the upper limit of audibility. A lightning-change far beyond anything that we can definitely conceive or imagine. Must not the inconceivable be also immeasurable?

UNTHINKABLE BUT NOT IMMEASURABLE

Fortunately not. The mind may balk in the attempt to conceive the possibility that an electron may change its course, interrupt itself, surge backward and forward, a million times per second; yet the mind that is abashed in the simple contemplation of such a phenomenon can nevertheless satisfy itself that the phenomenon exists; can not only measure such bewildering activities on the part of the electron, but can even predetermine these activities.

In other words, it is practically feasible to produce a one-million cycle or a two-million cycle electric current at will; and to measure such cycles, and distinguish them from the slower ones

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or the far more rapid ones that may also be produced at will.

We have now to inquire how this is accomplished in practical radio work.

As preliminary to answering the question, it may be recalled that the production of a high-frequency (rapidly oscillating) current has been one of the standing difficulties with which the radio operators have been confronted. We are aware that several more or less satisfactory solutions of the problem have been advanced, but that for purposes of production of an extremely rapid and uniform oscillation, the audion, or electron tube, has no known competitor. Our present concern, however, is not with the operation of the oscillating tube, or any other form of generator, but with measurement of the oscillating current itself, once it has been generated.

Our immediate viewpoint is that of the amateur who has installed, or is about to install, a radio-receiving telephone set and who wishes to make sure that he receives messages at a given wave length.

RESONANCE OF THE ANTENNA SYSTEM

The important thing for such an amateur to understand at the outset is that what may be called the normal receptivity of his outfit is determined by certain conditions of the antenna system.

These conditions are electrical conditions, which may seem rather odd when it is considered that there is no electrical equipment of any kind associated with the antenna, or with any other part of the receiving apparatus, if the outfit is of the simple kind using only a crystal detector. The

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explanation is that electrical conditions will be developed in the antenna system when the electromagnetic or radio waves come in contact with it (as an earlier discussion has shown us), and that the antenna system must be adjusted to make a certain response, somewhat as the piano string of one of our illustrations was adjusted to respond to certain sound-waves.

The analogy holds fairly well notwithstanding the radical difference between an electrical current and sound-producing vibrations.

In the case of the antenna, as in case of the piano string, a very great deal depends upon the length of wire involved. So true is this that it is customary to speak of a certain length of antenna wire as representing the "fundamental" wave length,—the reference being, of course, to the electromagnetic or radio waves to which that particular antenna is inherently adapted to respond.

The "fundamental" responsiveness of any particular antenna, however, may be modified in practise by linking aerial and ground with a coil of wire of greater or less extent, as in the simple induction coil with which we are already familiar. Indeed, it has previously been explained that the purpose of such a coil is to modify the responsiveness of the antenna—the process being described as "tuning." The purpose of the other types of induction coils (loose coupler, vario coupler, variometer, and honeycomb coil) is in part to make still better tuning possible; and the condensers further modify the receptivity of the antenna system, the variable condensers in particular being important parts of the tuning mechanism.

It is possible, however, to make an absolutely

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simple antenna system, comprising aerial and ground, with the detector adjusted between and a telephone receiver attached; and to receive untuned messages at a given wave length, or more or less blurred messages, over a considerable range of wave lengths. With such an untuned apparatus, the length of the antenna wires would be a paramount consideration.

In a general way, computation as to the "fundamental" wave-length-receptivity of a given antenna may be made by following very simple rules. In Radio Communication Pamphlet No. 40, issued by the Signal Corps of the U. S. Army, the following directions are given:

"*Measurement of Antenna Wave Length.*—For a simple vertical wire-grounded antenna the fundamental wave length is slightly greater than four times the length of the wire. The constant is often used as 4.2 and applies approximately also to flat-top antennas (*L* or *T* types) with vertical lead-in wire, the total length being measured from the transmitting apparatus up the lead-in wire and over to the end of the flat top. It is usually easier, and certainly more accurate, to measure the wave length radiated from an antenna directly by the use of a wave meter. The wave-meter coil needs merely to be brought somewhere near the antenna or lead-in wire and the condenser of the wave meter adjusted to give maximum current in the wave-meter indicator. The wave length corresponding to the wave-meter setting is then the length of the waves radiated by the antenna. The 'fundamental' wave length of the antenna may be determined by gradually decreasing the number of turns in the loading coil, measuring the wave

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length for each setting of the loading coil, and plotting a curve showing the wave length corresponding to the various numbers of turns of the loading coil. The 'fundamental' is the wave length corresponding to zero turns, and corresponds to the point where the extension of the curve cuts the wave-length axis.

"The amateur is required by law to transmit on a wave length not exceeding 200 meters [provisionally increased to 275 at the Hoover Conference] and is interested to know the kind of antenna to use. It is impossible to give an exact rule for constructing an antenna for a particular wave-length, because many local conditions peculiar to each case must receive consideration. An approximate rule which will be found convenient in constructing an antenna which is to transmit on a wave length not exceeding 200 meters is that the over-all length of the circuit from the ground connection through the entire path which the current follows to the end of the antenna must not exceed 120 feet. This distance, 120 feet, includes the distance from ground up the ground-lead to the antenna-switch, from the antenna-switch to the oscillation transformer and back to the antenna-switch, through the antenna lead-in to the antenna top, and along the antenna top to its end. This approximate rule applies to the various types of antennas ordinarily found at amateur stations, including inverted *L*, *T*, and fans. In the case of an antenna for which the lead-in is taken off the antenna top at an intermediate point, as in a *T* antenna, the distance along the antenna top should be measured to the most distant end of top, if the lead-in is not con-

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nected at the middle of the top. If an antenna is constructed in which the distance measured as described does not exceed 120 feet, it is probable that with suitable transmitting apparatus and no loading it will be possible to transmit on less than 200 meters, but if loading inductances are used or equivalent changes made in the transmitting apparatus the emitted wave-length may, of course, considerably exceed 200 meters."

THE TUNING SYSTEM

Even the most primitive radio apparatus that is actually employed has a tuning device, as we have learned; so of course the antenna has a measure of flexibility. The chief thing necessary is to make sure that in the original installation there is not so important a maladjustment as to prevent the tuning apparatus from bringing waves of a certain length—for example that of some important broadcasting station—within range. There is little danger of violating this rule if the aerial wire, with its lead-in wire, is kept within such limits as a minimum of forty or fifty and a maximum of 125 to 150 feet.

The induction coil, whether simple or in the modified form of the loose coupler, vario-coupler, variometer, or honeycomb coil, constitutes a direct physical continuation of the aerial, and of course adds to its length. If condensers, fixed or variable, are used (as they are in all but the most primitive apparatus) these further modify the electrical conditions of the antenna system.

The tuning of that system, as we know, can be affected by modifying the conditions of either induction coil or condenser or both. The induction

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coil has primarily to do, as the name suggests, with inductance, which is concerned with resistance to the flow of an electric current along the wire. The condenser is concerned with the storage of electricity and its periodic oscillating discharge. The antenna system as a whole is concerned with such storage no less than with the matter of inductance; since the aerial is in effect one plate of a condenser, the ground being the other, the air between serving as so-called dielectric or non-conductor. This function of storing electricity is spoken of technically as the capacity of the antenna system.

Inductance and capacity are the so-called constants with which the radio operator is perpetually concerned. They bear a reciprocal relation to each other in any given antenna system; and by this relation is determined the rate of oscillation of the electric current in the system that generates the electromagnetic or radio waves.

Reverting to the convenient even if not closely homologous comparison with the piano string, it might be said that "inductance" is comparable to the length of the piano string and "capacity" to its tension. The mutual relations of the two factors determine the length of the radio wave on one hand and of the sound wave on the other. In one case as in the other the amplitude of the waves ("strength" or "loudness" of the message) is determined by the force applied (electrical in one case, physical in the other), but in neither case does this modify the rate of vibration.

The wave length of the piano string is ordinarily gaged, as everyone knows, by comparison with the sound produced by a tuning fork of

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known pitch. The wave length of the antenna system, on the other hand, is gaged by measuring the electrical conditions of the intenna system that produces or receives it, not by observation of the waves themselves. Even here, the difference is more apparent than real; for of course the ear that gages the sound produced by the piano string does not directly measure the waves, but only sends the vibrations from ear-drum to brain cells that interpret the result of the impact of those waves.

In this view, the analogy might be said to be almost perfect; only in the case of the radio apparatus we must supply an artificial ear-drum and brain cells to make the interpretation.

THE WAVE METER

The artificial ear-drum takes the form of what is technically called a wave meter; and the interpretative brain cell within this apparatus is known as a hot-wire ammeter. At the risk of pressing the analogy too far, we may add that this essential mechanism, the hot-wire ammeter, is a little platinum wire or filament that might be likened by an imaginative physiologist to the nerve filament that is believed to be the essential receptive structure of the brain cell that (in cooperation with its fellows) interprets sounds coming from piano string or elsewhere.

Analogies aside, the so-called wave meter that is adjusted in a circuit of, let us say, the receiving apparatus is a very interesting and important piece of mechanism; doubly so, perhaps, because of its essential simplicity.

It is called a wave meter appropriately enough, since its dial registers wave lengths; yet as already

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stated it has nothing to do with the direct measurement of waves, being solely concerned with measurement of an electrical current that, under the right conditions, will produce the waves.

That the dial registers wave lengths instead of electric-current frequencies, or oscillations, is a matter of convenience. It is rather simpler to speak of a 200-meter wave than of an electric current oscillating 1,500,000 times per second; and the two statements, as we have seen, imply precisely the same thing. Here again one is tempted to make comparisons with the piano string, for the tuner deals directly with molecular vibrations, but records his results in terms of sound—"C Sharp," or what not.

The most important part of the wave meter has been named as the hot-wire ammeter. An ammeter is an instrument for measuring amperes; the ampere being the unit of current of electricity—technically defined as "that flow of electrons which will deposit 1.118 milligrams of silver per second from a silver nitrate solution in a standard volt meter." The hot-wire ammeter has its essential little thread of platinum adjusted about a pulley wheel, and held tense by a spiral spring. The pulley wheel has a pointer connected with a dial. When an electric current is passed along the little strand of wire, the wire is heated thereby and of course expands. The coiled spring keeps it tense, taking up the slack, so to speak, and in so doing turns the pulley wheel more or less according to the amount of lengthening of the wire.

The heating of the wire is due, of course, to the resistance that its molecules offer to the passage

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of an electric current; and this resistance, granted a certain strength of current (electromotive force as the technician describes it), varies with the degree of frequency of oscillation of the alternating current. The higher the frequency, the greater the relative resistance—and therefore the grater amount of heat in the wire, and a correspondingly greater lengthening.

Obviously, then, if we can make sure that the electromotive force of the current we send through the mechanism is uniform, we have only to watch the pointer on the dial connected with the pulley wheel, and we can gage the frequency of the current that is passing along the wire and heating it.

And as the manufacturer of the apparatus has been good enough to mark the dial with a wave-length scale, we read the result directly.

The little wire is tingling with the rush along its surface of electrons oscillating backward and forward at the rate of, let us say, 1,500,000 vibrations per second; and the pointer on the dial of the ammeter registers 200-meter waves.

It seems a far cry from electrons thus oscillating along the tiny filament of wire to the ether-waves coursing endlessly through distant space; but we are fully informed as to the manner in which these two series of phenomena are associated; and as 200-meter waves are the ones we wish to intercept, we read the dial record with satisfaction, and proceed to "listen in."

If, on the other hand, we wish to intercept radio waves of some other length, we must readjust inductances or capacities (condensers) in order to change the "resonance" of our antenna system, and make further tests with the hot-wire ammeter.

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ADJUSTMENT BY RULE OF THUMB

Of course the average user of a radio-receiver does not have a wave meter at all. He uses an outfit originally constructed to receive waves within a comparatively restricted range; and the dial that he operates is connected with the tuning apparatus. He modifies inductance and capacity of his antenna system, perhaps without clearly knowing what he is doing, according to formula; and, listening in meantime, is guided by results. Presently he has so changed the resonance that he secures a message and knows that he is tuned to the proper wave-length.

This rule-of-thumb method of operation serves every practical purpose for the average amateur who is a receiver of messages only; but it will be obvious that the transmitter of radio messages must be able to operate in a more scientific manner. The receiver's mechanism may be tuned for any wave-length whatsoever, so far as any legal constriction is concerned; but the transmitter, whether amateur or professional, must keep within certain prescribed bounds. If an amateur, he must hold to short waves, and he can by no means "trust to luck" or adopt mere rules-of-thumb as to the resonance of his transmitting aerial. He must use the hot-wire ammeter or its equivalent; and as a rule he will find the wave meter just described the instrument best suited to his convenience. He is of course provided also with sundry voltmeters to register the voltage of the generating current that is the chief source and of the minor coils and batteries that supply current to the vacuum-tube filaments.

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LOCAL BATTERIES OF THE RECEIVING APPARATUS

The main supply of current for the transmitting radio stations may come from a dynamo of greater or less power or a storage battery, according to the size and intended range of the sending apparatus itself.

The operator of a radio-receiving telephone is concerned with certain local batteries that constitute an indispensable part of every such apparatus that has been developed beyond the crystal-detector stage,—that is to say every receiving apparatus that is equipped with an electron tube used either as detector or as amplifier.

The simplest radiophone received, as we know, has only a crystal for detector and is devoid of amplifying mechanism; and for such an apparatus no local battery or other electrical equipment is required. But the possessor of such an apparatus is pretty sure, sooner or later, to wish to reach out to wider fields. In order to do so, as we have seen, he must either supplement the crystal with an amplifying vacuum tube, or supplant it altogether with a detector tube; and in either event he will now require two local batteries, one to light the filament of the tube or tubes, and the other for the plate circuit. Unfortunately the requirements are such that they can not be met satisfactorily by the use of a single battery.

According to conventional usage, the current for the filament is supplied by a storage battery. This is called the "A" battery. It is of low voltage (six volts being the usual maximum), and, as listed by the manufacturer, is built to deliver a certain current for a definite number of hours. The rating is stated in volts and ampere-hours;

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Photograph by Brown Brothers

LOOP ANTENNA ON UPPER DECK OF STEAMSHIP *LEVIATHAN*

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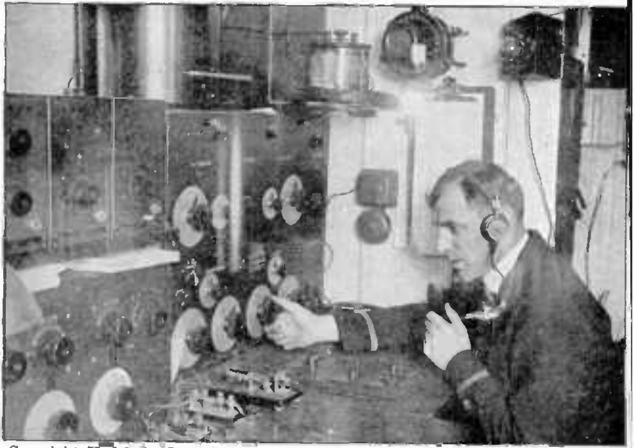

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PRESIDENT H. B. THAYER OF THE AMERICAN TELEGRAPH AND TELEPHONE COMPANY TALKING TO LONDON BY RADIOPHONE FROM HIS NEW YORK OFFICE (BELOW), AND OPERATOR F. E. BLACK OF THE S. S. *AMERICA* TALKING TO WASHINGTON WHILE FAR AT SEA

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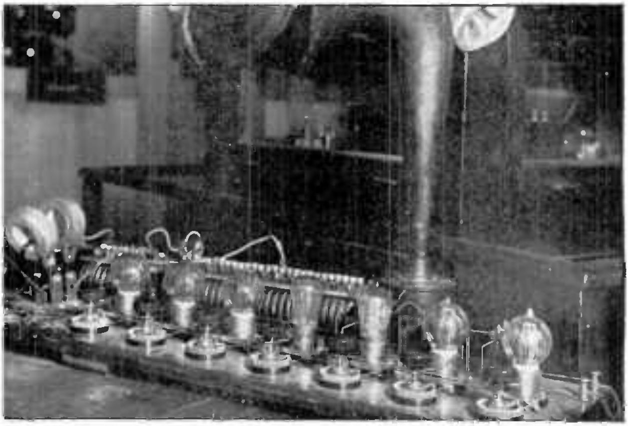

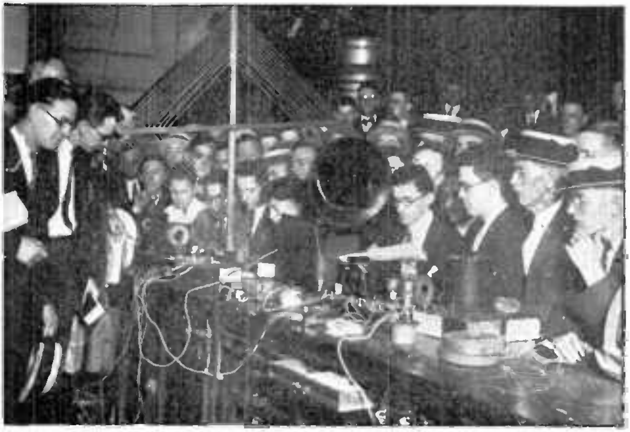

MAJOR E. H. ARMSTRONG'S SUPER-REGENERATIVE (BELOW) AND SUPER-HETERODYNE RECEIVERS

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TUBE TRANSMITTING SET OF S. S. *VAUBAN* WITH RANGE OF 1,500 MILES USING CURRENT OF ONLY ONE AND A HALF KILOWATTS

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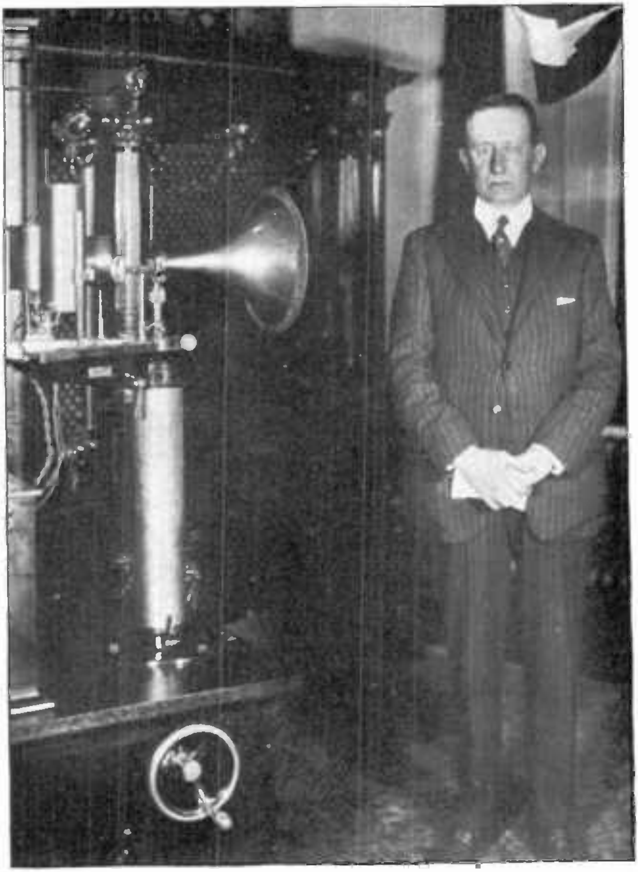

SENATOR MARCONI BROADCASTING FROM THE GENERAL ELECTRIC STATION AT SCHENECTADY

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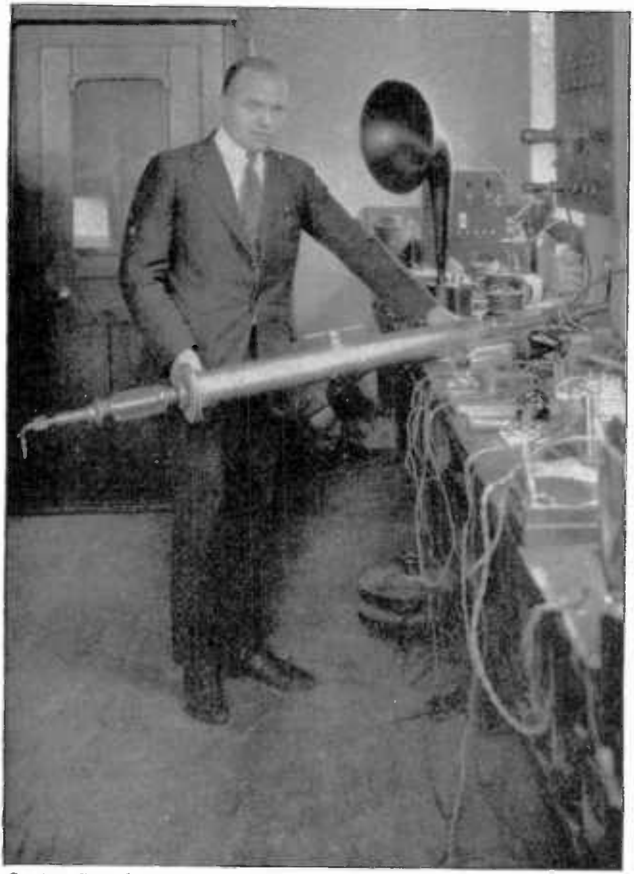

Courtesy General Electric Co.

THE MILLION-WATT TWO-ELECTRODE VACUUM TUBE DEVELOPED BY J. H. PAYNE, JR., IN THE RESEARCH LABORATORY OF THE GENERAL ELECTRIC COMPANY

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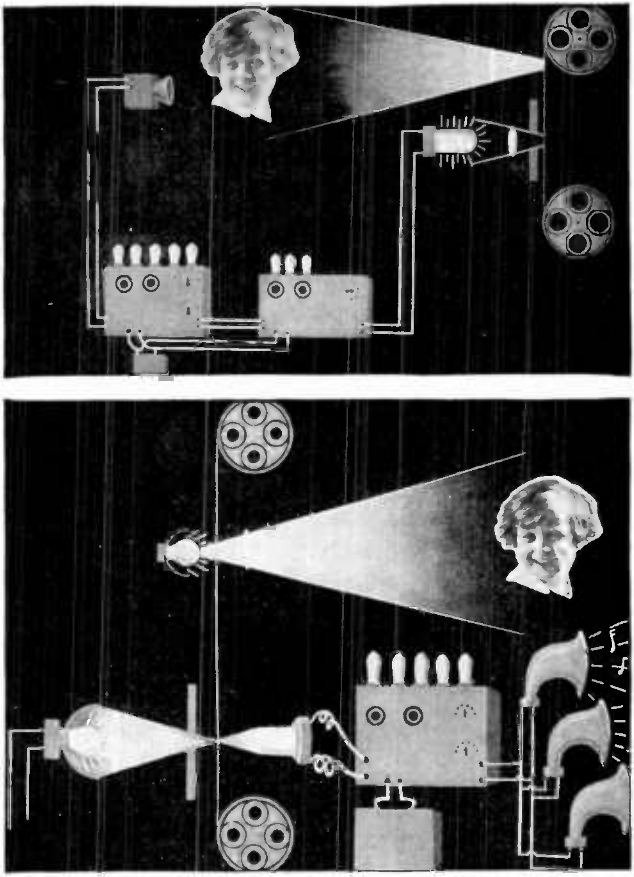

DR. LEE DE FOREST'S PHONO-FILM OR "TALKING MOVIE" SHOWING SCHEMATIC VIEWS OF RECORDING (ABOVE) AND REPRODUCING PROCESSES

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DR. LEE DE FOREST WITH PHONO-FILM RECORDING APPARATUS, AND A STRIP OF FILM MAGNIFIED FIVE HUNDRED TIMES TO SHOW RECORDS OF THE VOWEL SOUNDS

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meaning that the battery will deliver one ampere per hour for the length of time stated.

When the electron tube is operated, the filament should be brought to moderate incandescence only. Too strong a current will not improve the operation of the tube, but will greatly shorten its life. A rheostat should be provided in the filament circuit, to regulate the strength of the current from the storage battery.

As already stated, the storage battery of low voltage can not be used for the plate circuit which required a much stronger current. The so-called "B" battery provided to supply this high-voltage current usually gives far less trouble than the A battery. The conventional apparatus is a dry cell battery supplying 22½ volts. Where amplifying tubes are used, the plate batteries commonly aggregate one hundred volts or more. A potentiometer, or voltage-divider is also used, as a rule, to regulate the potential of the grid circuit. A so-called "C" battery, otherwise known as a "bias battery," may serve the same purpose, being introduced in the grid-filament circuit.

THE BALANCE OF INDUCTANCE AND CAPACITY

The introduction of electron tubes, with associated batteries, of course modifies the electrical "constants" of the entire system. Electricity, like water, seeks its level; and of course where there is no obstruction the tendency is to produce uniformity throughout a series of connecting circuits, however intricate.

In the radio mechanism, however, there are obstructions and modifying influences in the forms of inductances and conductors and "resistances" and "grid-leaks" and (in case of amplifiers) transformers, to say nothing of the electron tubes themselves. So different circuits in the mechanism, altho all linked inductively, may differ as to their local conditions. The amplified current that comes from the plate of the last electron tube, for example, is of magnified voltage as compared with the current that came to the grid of the first tube.

But always and everywhere there is the same balance between conditions of inductance having to do with the flowing current, and conditions of capacity having to do with stored electricity. And these mutual relations, which determine the "resonance" of the circuit (the rate of oscillation of the alternating current traversing it) are independent of the voltage or pressure of the current.

Period of oscillation (and so of course wave length) may always be stated in terms of inductance and capacity.

A simple formula, used by the technicians, presents an equation according to which wave length, in meters, is equal to the square root of the product of inductance, stated in microhenries, into the capacity, stated in microfarads; multiplied by a constant, the number 1885. It follows that if the wave length to which a given radio apparatus is tuned is known, and either the inductance or the capacity of the circuit is known or measured, the other constant (inductance or capacity as the case may be) can be calculated.

The verification of this formula does not here concern us, but it is perhaps desirable to say a few words about the standards of measurements named as "microhenries" and "microfarads."

The henry is the unit of inductance in a given

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circuit—just as the unit of current is the ampere and the unit of electromotive force is the volt. These names were given in honor of three pioneer workers in electricity: Joseph Henry, an American; Andre Ampere, a Frenchman; and Alexandra Volta, an Italian. Most readers are probably aware that the names of various other units of measurements used by the electrician—for example, "ohm" the unit of resistance; "coulomb" the unit of quantity (a one-ampere current flowing for one second); "joule" the unit of work; and "watt" the unit of power—have been given in honor of other pioneer workers. It may not be so generally known that the word "farad," representing the unit of capacity, is an abbreviation of the name of the no less famous Faraday.

When we have to deal with very small quantities of electricity, it is convenient to have smaller standards; and in some cases the prefixes "mille" or "micro" are used to indicate unit quantities of one-thousandth or one-millionth, respectively, the size of the original. Thus the microhenry and the microfarad (millionth-henry and millionth-farad) appear in the tests of inductances and capacity in the radio apparatus, as we have just seen. Opposite conditions may call for large standards, as in the familiar "kilowatt," representing a thousand watts, used in measuring the current of power-plants. It may be noted, too, that the same expedient is adopted in referring to high-frequency currents and the rapidity of oscillation of radio waves.

It is convenient, for example, to speak of a current or wave of 1,500 kilocycles instead of saying 1,500,000 cycles.

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Actual measurement of the power of individual inductances and condensers will scarcely fall within range of the average amateur's activities. A general idea of the power of the different inductances will of course be gained from the amount of wire used in making the coils; and the capacity of a condenser may be roughly judged from the size and number of the plates. But the aggregate effect will for the most part be tested by practical tuning, at most supplemented by the use of a wave meter. The amateur who goes beyond this is likely to have training an an electrical engineer, implying familiarity with technicalities of electrical measurements beyond what is essential for the ordinary user of the radio-receiving telephone.

Meantime the outfits purchased fully assembled from the dealers comprise all necessary tuning devices, requiring scarcely more skill in their manipulation than the setting of a watch; and where individual parts are purchased, as, for example, condensers, tests have been made in the factory and the capacity of the apparatus is clearly stated in price list and catalogs. Such legends as "twenty-three plate condenser, .0005 MFD" and "43-plate condenser .001 MFD," are familiar. The initials represent, of course, the abbreviation for "microfarad."

As we have already learned that the microfarad is only the millionth of a farad, it will be obvious that the radio condenser, rated at from five-ten-thousandths to the one-thousandth of a microfarad, deals with very small quantities of electricity indeed.

Whenever considerable quantities of electricity

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were in question in connection with the radio receiving apparatus, they are supplied solely by the local batteries. The current generated in the aerial by the passage of the message-bearing radio waves is always infinitesimal.

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CHAPTER VIII

AMPLIFICATION AND SUPER-REGENERATION

THE PROBLEM OF AMPLIFICATION

THE most fundamental of radio problems is the problem of amplification. A mere ripple in the ether, almost infinitely attenuated by distance, cuts across the almost spaceless outline of the wire we call an antenna, and sets up in it an almost infinitely tenuous electrical oscillation. No ordinary instruments are sufficiently delicate to detect that current. Yet the radio-receiving apparatus is called upon to transmute it into vibrations in the air that are powerful enough to impinge on our ear-drums with the force of what we term audibility.

The radio apparatus performs this miracle. Two essential mechanisms are involved in the transformation: (1) A rectifier, to change the alternating current more or less fully into a direct current; and (2) an electromagnet operating a diaphragm to transform energy into mechanical energy.

We term the rectifier a "detector," and the electromagnetic apparatus a telephone receiver. The wired structure that brought the message-bearing electric current to these apparatuses is called an antenna system. It has certain elements of what the electrician calls inductance and capacity, and it may be more or less complicated in appearance; but for the present purpose it may be thought of

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as a unit structure. Our radio-receiving apparatus has, then, three essential parts: (1) An antenna system, (2) a detector, and (3) a telephone receiver. The first and third of these exercise a purely passive function. They can receive and manipulate the message-bearing current that comes to them, but they have no power to transform its essential character. If a feeble current comes to the antenna, it is passed on as a feeble current to the detector. If a feeble current comes (by way of the detector) to the telehone receiver, it can give no other than a feeble impulse to the diaphragm, with concomitant feeble sounds. If amplification of the current—actual increase of energy—is to be effected, the detector-element alone must be looked to for the accomplishment of this feat.

THE CRYSTAL DOES NOT AMPLIFY

If we are to understand the problem of amplification, we must get the force of this analysis clearly in mind. We must further reflect that the crystal detector, used without a local battery in the ordinary simpler receiving outfit, can no more add energy to the current than can the antenna and the telephone.

It follows that the radio-receiving outfit using a crystal detector only, without "booster" battery, has no power of amplification. It can merely accept and tend to interpret the radio message that comes to it; and the limitations of its efficiency are determined absolutely by the power (expressed in terms of output energy and of distance) of the transmitting station from which the message comes.

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That is why we commonly speak of the crystal detector outfit as having a range of only from fifteen to twenty-five miles. We mean that the amount of energy that comes to the ordinary antenna from average broadcasting stations at a distance of from fifteen to twenty-five miles (varying somewhat with atmospheric conditions and local intervening topography) is just adequate to move the telephone diaphragm sufficiently to produce audible air-vibrations.

Experiments have tested the force of this minimum current, and have found that, for the very best crystal detector under favorable conditions, the minimum is about ten microamperes; or the one-hundred-thousandth of an ampere. An ordinary crystal, under ordinary conditions, is deaf to any current that is not about five times as strong as this. Feebler currents in infinite variety, from weaker or more distant stations—voyaging criss-cross round the world from multitudes of transmitting stations—wash perpetually against the antenna; but the currents they induce either can not penetrate the resistant surface of the crystal or do not suffice to make an audible knock at the door we call a telephone diaphragm. If these feeble currents are to be brought to the plane of audibility, new energy must be supplied them within the radio-receiving apparatus. And, as we have just seen, neither antenna system nor crystal detector nor telephone receiver can be looked to for such aid. (There have been recent reports of alleged successful use of an amplifying relay with the crystal detector, but the practical ultility of such an apparatus awaits further demonstration.)

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THE TRIODE AS AMPLIFIER

But if we take out the crystal detector and put in its place the little Aladdin's lamp which Dr. Lee De Forest, its inventor, called the audion, but which is now semi-officially named triode, the complexion of affairs is radically changed.

Now we have an apparatus that can supply new energy to the input current. It is an apparatus, indeed, that can not function without supplying additional energy. It is true we speak of "detector" tubes and "amplifier" tubes as if they were things of different orders; and doubtless many users of the detector tube do not realize that it is also amplifying even while it "detects." Yet a moment's consideration of the manner of action of the triode shows that this is inevitable.

One tube may amplify more than another, and we may purposely modify conditions so that the function of detection (rectification) is emphasized or minimized respectively; but if the tube works at all, it sends out through the plate circuit a more powerful current than the one that came to it through the grid circuit.

The reason is that the triode can not operate at all except as it is actuated by local batteries; and at these batteries supply a quantity of energy compared with which the energy of the input (message-bearing) current is negligible. Everyone knows, for example, that the filament of the tube is made incandescent by a current of about one ampere. But it was just noted that the radio current that comes from the antenna was measured in microamperes—millionths of an ampere.

We saw that the minimum current that the best

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crystal detector could handle effectively consists of ten microamperes. Now we note that this is a current one hundred thousand times more feeble than the current that lights the filament of the triode and prepares that apparatus for functioning. And we know also that there is a relatively enormous additional supply of energy in the plate circuit impressed by the "B" battery of 22½ volts.

If we understand the elements of action of the tube, we know that the essential thing that happens within it is transfer of electrons from filament to plate, so that current may circulate through the telephone; and that the function of the little grid that Dr. De Forest adjusted between filament and plate is merely to introduce the feeble message-bearing current from the antenna so that its alternations may constitute it an electric valve, accentuating the flow of electrons from filament to plate during its positive phase, and retarding that flow during its negative phase.

A very small valve in a water system may control reservoirs of water; and so the little grid, with its insignificent oscillating current, controls the flow of relatively enormous quantities of energy in the plate-telephone-filament circuit.

THE TRIODE LIKENED TO A WATER-VALVE

Just as the water-valve may be fully opened at one time and at another time fully closed, or made to fluctuate between intermediate points; so the grad current fluctuates or intermits, and impresses its changes on the flow of electrons from filament to plate in the triode. The fluctuations, corresponding to modulations of currents in the trans-

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mitting radio outfit, mold the plate current in the manner just described; and it is the ever-varying changes of amplitude thus impressed that can alone affect the telephone diaphragms.

Just as the water in the pipe would be negligible were it not for the reservoir back of it; so the feeble current in the grid current would be utterly futile to convey messages were it not for the reservoir of energy in local "A" and "B" batteries that induces a relatively enormous current in the telephone circuit.

Some faint idea of the torrential flow of the plate-filament circuit may be gained if we recall the technical estimate to the effect that at least a billion electrons per second must flow from filament to plate in order that the current should measure one billionth of an ampere. It requires only simple arithmetic to assure us that the actual number of electrons flowing when the triode is in operation would be represented, if we attempted to set down the unmeaning figures, by arrays of numerals and ciphers that would spread clear across the printed page.

There is no need to attempt to name numbers so far beyond human comprehension; but it was worth while to let imagination stand appalled in their mystic presence for a moment, to bring out, at least in a general way, the contrast between the rivulet of energy in the message-bearing grid current and the Niagara-flow of (also message bearing) output current in the plate circuit.

And all that, of course, to make clear why it is that relatively enormous powers of amplification are inherent in the action of the detector triode.

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"SOFT" VERSUS "HARD" TUBES

But if all triodes are amplifiers, why, then, do we apply the name "amplifier" specifically to certain types of tubes:

The answer is altogether simple. Our automobiles develop a certain amount of speed; but certain automobiles we speak of specifically as "speedsters." They all move in the same way, but some go faster than others. So with triodes. All amplify, but some are adapted to specialize in amplification. There are triodes and triodes.

The difference, however, between one triode and another is, fundamentally, slight almost to the vanishing point. In principles of mechanical construction, each individual triode is like every other triode. All are vacuum tubes with filament, grid, and plate. But in some the air is more nearly evacuated than in others. "Vacuum" as the practical mechanician uses the word, is a relative term. In the most complete vacuum that can be made, about a hundred million molecules of gas remain, so it is estimated, to each cubic centimeter of space.

But for practical purposes this is a "complete" vacuum; and a triode thus evacuated is termed a "hard" tube. A less completely evacuated one is termed a "soft" or "gassy" tube.

It has been found in practise that the "soft" tube is a good detector, in the radio-receiving apparatus, with relatively small efficiency as an amplifier. It is a reliable rectifier, but only a moderate booster.

Contrariwise, the "hard" tube is not, under ordinary conditions, as good a detector; but specializes in amplification. It is built for speed. The

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reason appears to be that electrons can flow much more freely through a vacuum than they can through air. The electron is about eighteen hundred times smaller than an atom of hydrogen; and from the standpoint of such a midget a molecule of air is an enormous obstruction.

An electron colliding with an air-molecule is like a meteor plunging into a planet.

The air molecules that have thus collected electrons are negatively charged, and thus add to the negative charge in the triode, further tending to obstruct the flow of electrons from filament to plate.

Like quantities of electricity repel each other, as everybody knows, so a negative charge in the triode tends to drive the escaping electrons back to the filament. The relatively air-free "hard" tube accumulates a negative charge less readily, and so permits a relatively free flow of electrons. And of course free flow of electrons means amplified current.

THE "CHARACTERISTIC CURVE" OF THE TRIODE

Experimenters have tested various triodes, as regards their greater or less tendency to facilitate such electron-flow; and have charted the results of experiments, producing what is spoken of as the "characteristic curve" of the triodes.

There are, indeed, several such curves; but the one that chiefly concerns us is that which shows certain fixed relations between "grid voltage" and "plate current." In reality, it merely interprets the conditions that we have been discussing, and gives us a graphic presentation of the relations that obtain between the grid in its alternating

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phases, representing oscillations of the input current, and flow of electrons from filament to plate, representing plate current.

In such a diagram, drawn in the usual fashion, the horizontal direction represents grid voltage (with reference to filament, in the circuit which includes the secondary coil), positive phases to the right and negative phases to the left. Meantime vertical direction represents plate current (flowing in plate-filament circuit, through the telephone), which, as we know, is determined by electron flow in the triode. At a glance, we see that the line representing plate current slopes upward slowly at the bottom, and then at a very acute angle, not far from the perpendicular; curving over again at the top.

As we consult the scale at the foot of the diagram, we see that the accentuation of plate current thus depicted corresponds to changes of voltage in the grid through which it becomes more and more positive.

Recalling what take place within the triode, we understand this situation; but the notable thing about it, now that we inspect the chart, is that a relatively slight change in the grid potential results in a relatively enormous change in the plate current.

Such changes, however, are by no means uniform. At the southwest corner of our diagram, where the grid is rather strongly negative, no plate current is flowing. As the grid potential changes toward the position by one volt, there is only slight flow of plate current; but change of another volt brings about a great acceleration; and beyond

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that the acceleration continues at a uniform rate for a time.

A moment's reflection will show that if, in practise, a tube were operated at the point indicated by the letter "A" in the diagram, a two-volt oscillation of potentials in the grid (accentuated by the input, or message-bearing, current) would result in grading the plate current down to zero during the negative phase, and lifting it to about two milliamperes at the climax of the positive phase.

And it is clear that this would represent a pulsing or rectified current; the pulsations corresponding in frequency to the alternations of the grid current.

Obviously, a tube operating thus is acting as a "detector." It is amplifying incidentally, because the current makes quite a jump upward when the grid potential is in positive (or less negative); but the primary consideration is that it shuts off the current in large measure, or altogether, during the alternate phase of the grid potential.

Suppose, however, that the triode with which we are experimenting has the balance of its electrical circuits so adjusted that it is operating at the point marked "B" on the chart. Now we see that when the grid shifts to its positive phase, there is an even larger jump in the plate current; but that when the grid potential shifts to its negative phase, the plate current by no means approaches zero as before, but is represented by a negative phase matching (in amplified proportions) that of the grid.

In other words, the current that now flows in the plate current, under influence of shifted grid potentials, is an amplified alternating current, pre-

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cisely corresponding in frequency to the frequency of the grid (message-bearing) current.

Thus our speedster has shown its quality. It has magnified the current without rectifying it, thus justifying its name of amplifier.

USE OF POTENTIOMETER AND "C" BATTERY

It is obvious, then, that by manipulating the grid-filament current, in such wise as to determine the voltage relation between grid and filament, we can modify the action of the triode, making it "detect" or not as we wish; and determining a greater or less degree of amplification.

In practise, such modifications of grid potential are determined either by the use of a voltage-divider, commonly called a "potentiometer" or "stabilizer"; or by the uses of a third battery, called a "bias" or "C" battery, introduced in the circuit, with negative pole toward the grid.

A more familiar method is to introduce a grid condenser, before the detector tubes, to emphasize the modulated character of the input current; together with a grid-leak to carry off the input changes of electrons that would otherwise accumulate on the grid and block the action of the triode by obstructing the flow of electrons from filament to plate.

When the triode is acting as amplifier only, the grid condenser is omitted, but the bias battery and potentiometer then have special utility.

At the very best, however, there are obvious limitations on the amount of amplification that can be brought about by such manipulations of the grid current. The diagram showing the characteristic curve reveals these, inasmuch as it de-

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picts, toward the top, a maximum at which the line representing plate-current no longer ascends, even obliquely, but turns abruptly to the right, indicating that it has reached its highest flight.

Beyond that, no increase of grid potential is availing. The flow of electrons within the triode has reached saturation point. In electrical terms, there is a balance between positive and negative resistancies. In mechanical terms, as we visualize conditions within the triode, the plate is absorbing all the electrons that the incandescent filament throws off, except such as are caught by the grid, the latter of which set up an undesirable grid current, as they flow away through the input circuit.

AMPLIFICATION BY REGENERATION

In ordinary practise, however, with a receiving outfit that has neither potentiometer nor "C" battery, this point of maximum amplified current would not be reached, inasmuch as the fluctuatings of grid potentials are too slight to bring about maximum effects.

There remains, however, an expedient for manipulating the grid current far more effectively than can be done with potentiometer or bias battery. The latter expedients deal with direct currents, and avail only to adjust the balance of potentials in the grid circuit, without modifying the essential character of the input current itself.

But the new expedient now in question does more than this. It amplifies the input current itself, so that the grid potential shifts through a far wider range; while at the same time maintaining the frequency of alternation and the

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modulations of amplitude as they were in the original current.

This new miracle is called regeneration. It is accomplished by "feeding back" into the grid circuit part of the energy of the plate current, after that current has been made, through action of the triode, to take on the alternations and modulations of the message-bearing input-current.

The radio waves in question, in a given instance, are, let us say, of 200-meter length; representing, therefore, a generating current of 1,500,000 cycles per second. The receiving apparatus of course can generate a current of the same frequency; and the plate current is of necessity synchronous, the alteration having been impressed on it through action of the grid in the triode, as we have seen. Now we bring this amplified, synchronous plate-current into inductive relation with the feeble input-current, and something of its power is transferred to augment the feeble current while maintaining its essential characteristics of frequency and modulation.

To do this is to accomplish something radically and fundamentally different from what we have hitherto considered. It implies actual amplification of the input-current before it reaches the triode; something that theoretically seems almost impossible. It was impossible until a young American amateur, Edwin H. Armstrong by name, found a way to accomplish it, about ten years ago, and so gained world-wide fame as discoverer of the "feed-back" principle.

There are several practical ways in which the miracle may be done. And, after young Armstrong had shown us how, anyone could do it.

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One simple method is to put a coil in the plate circuit, near enough to the secondary coil so that the electromagnetic fields of the two interlock, permitting inductive transfer of energy. Any coil will answer. The honeycomb coil has the merit of easy manipulation.

An alternative method that is also popular, calls for the introduction of a variable resistance, in practise usually a variometer, in the plate circuit. Now the current is not sent back inductively, but the variometer coils offer resistance to change of plate potentials (resistance to change being characteristic of all inductances), so that there is rhythmical modification of capacitance within the tube itself, the component parts of which constitute a miniature condenser.

This boosts the grid current by what is technically called capacitive coupling. Sometimes the effect is enhanced by putting another variometer in the grid current.

An arrangement that has come to be spoken of as a standard regenerative system utilizes a vario-coupler in the antenna circuit, and two variometers in the positions just suggested.

Details of method aside, the effect of the "regenerative" current is to establish a curious and almost magical new relation, in which the increased variation of potentials in the grid results in boosting the plate current; which in turn gives another boost (through the "feed-back") to the grid current; which once more passes on its enhanced power to effect still greater amplification of the plate-current pulsations.

One gets a little giddy in attempting to visualize this tit-for-tat effect; and at first it is not clear

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why there should be any upward limit at all to this endless cycle of mutual pushes. We envisage a circuit that seems to suggest perpetual motion with ever-increasing power.

And when we operate the regenerative outfit, there seems tangible promise of all but infinite amplification. The sounds are built up gradually with delightful crescendo effect that seems to promise everything. But unfortunately there comes a time presently when the volume of sound no longer increases; and if we attempt to force it by manipulation of tuning dials, an unwelcome hubbub greets our ears in place of the desired message.

Regeneration, under the conditions that obtain in that particular outfit, has reached its limit.

Various explanations may be offered. It is sometimes said that negative and positive resistances within the triode have reached their balance, so that further advance is impossible. It is sometimes said that the flow of electrons has reached a saturation point, at which the entire possible output of the incandescent filament passes to and is absorbed by the plate.

It may be doubted whether either explanation or any similar one is correct. What actually happens, it may be surmised, is that there comes a time, after successive transfers of energy from plate circuit to grid circuit, when the oscillations in the two circuits have ceased to synchronize perfectly. If, for sake of convenience, we think of the alternating current as representing a wave movement, we may say that the crests and hollows of the successive waves are no longer in precise alinement. With each successive transfer of

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energy there is a slight maladjustment, and ultimately this becomes sufficient to result in conflict between the two sets of waves; which conflict reveals itself as a discordant sound that does not require telephone receivers for its interpretation.

The squeals and squawks that the tube sends out under such conditions are not only painfully audible to the operator of the apparatus, but may be radiated from the receiving antenna for the edification of users of other radio receivers anywhere within range.

That such failure of complete coaptation between the waves of the grid circuit and those of the plate circuit should occur is no wonder, when we reflect that the oscillations themselves are coursing along the wire at the rate of 1,500,000 cycles per second (assuming that 200-meter radio waves are still in question; in other words, that we are handling an ordinary amateur radio message). How could we hope for absolute accuracy of adjustment between two sets of oscillations of such unthinkable rapidity?

What has actually happened is comparable to what happens when different beams of light are brought together in such a way that there is interference among their rays, resulting in the revelation of the colors of the spectrum. Squeals and squawks are the spectrum of that other form of high frequency oscillation which we term a radio current—a rainbow effect if you will.

MAKING THE WAVES FIT

It is obvious that the more rapid the oscillations of the current with which we deal, the greater

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will be the difficulty of obtaining exact coaptation between the two sets of oscillations.

If, for example, we were handling a message that came to our aerial on 2,000-meter waves, the oscillations in the current of our grid and plate circuits would have a frequency of only 150,000 to the second. We are now dealing with waves ten times the length of 200-meter waves; and it is clear that a specified degree of maladjustment will be far less significant in this case than in the other.

Twenty meters, for example, would represent only one per cent. of the long waves, but ten per cent. of the short waves. A one per cent. maladjustment might be negligible, and a ten per cent. maladjustment disastrous.

That is why, in practise, it is far more difficult to amplify radio messages transmitted on short waves than those on long waves. Viewed from another angle, that is why radio-frequency amplification is more difficult than audio-frequency amplification. And, viewed from yet another angle, that is why radio current modified by utilization of the super-heterodyne principle, on one hand, or the super-regenerative principle on the other (both due to Major Armstrong) are susceptible of amplification to a degree not practicable under limitations imposed by direct handling of the carrier current with multi-stage amplifiers, with or without simple regeneration.

ROLLS-ROYCE VERSUS FLIVVER

It is with the last-named aspect of the problem of amplification that we are here concerned. The super-heterodyne apparatus and the super-regen-

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erative apparatus, represent the last word, to date, in radio-receiving mechanisms. The inventor himself, in his address before The Radio Club of America, spoke of the super-heterodyne as the de luxe outfit, the Rolls-Royce of the radio world; the new, compact super-regenerator being the flivver outfit in contrast,—marvelously efficient for its cost, but not fully entering into competition.

This humorous comparison is worth citing, for the enlightenment of those enthusiasts who have supposed that Major Armstrong expects the new super-regenerative receiver to supplant all antecedent mechanisms. His own comment seems to make it obvious that he has no such expectation. The patent merit of the super-regenerative receiver is that it makes one tube do the work of three. With three tubes, it rivals the nine-tube super-heterodyne. With two tubes, it outrivals the apparatus of standard equipment of one detector with regenerative circuit and two stages of audio-frequency amplification.

These are transcendent merits, and they lead us to feel that Major Armstrong was unduly modest when he made the facetious estimate just quoted. One does not recall seeing a four-cylinder flivver in successful competition with a double-six. And we shall see presently that super-regeneration, as Major Armstrong uses the term, involves the introduction of an altogether new principle, supplementary to the original feed-back principle, that brings out in the triode powers of amplification hitherto unrevealed.

The super-heterodyne method and the super-regenerative method have this in common, that

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they in effect break up the inordinately rapid oscillations of the carrier current into manageable groups; so that the short-wave current takes on, for purposes of amplification, the characteristics of a long-wave current. But the two methods accomplish this in quite different ways; tho both depend for their operation upon the oscillations generated in the same apparatus,—and this no new mechanism, but our old, familiar friend, the triode, adjusted in a tuned circuit.

ADVANTAGES AND DRAWBACKS OF THE HETERODYNE

The heterodyne principle has long been familiar. It is a directed interference method, in which an oscillating current bearing the message in the grid circuit has imposed upon it another oscillating current of comparable (but not identical) frequency; with the result that the major part of the oscillations are obliterated through neutralization, and the residual oscillations give their character to the current, producing the "beat" effect.

As originally suggested by Professor Fessenden, and ordinarily employed, the heterodyne method is utilized to reduce a current of high frequency to a current of low or audible frequency. If, for example, the input current (holding to our previous illustration) is alternating at 1,500,000 cycles per second, the heterodyne current may be made to oscillate at 1,499,000 cycles per second; and the resultant current will oscillate at the residual frequency of 1,000 cycles,—which of course is an audible frequency, when the oscillations are rectified in the detector tube.

The heterodyne effect may be developed in a

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tube outside the regular receiving outfit series, in which case it is called an external heterodyne; or it may be developed by the detector tube itself, which is then spoken of as exercising the self-heterodyne (autodyne) effect.

The super-heterodyne method, as introduced by Major Armstrong, applies the heterodyne principle in a modified way, in that the locally developed current is made to differ from the input current by perhaps 50,000 or even 100,000 cycles per second; so that the residual current is still of radio-frequency, altho of far more manageable type than the original. Since the obliterated oscillations represent lost energy, it is obvious that a super-heterodyne method conserves energy (as compared with the single heterodyne), while at the same time supplying material for application of the principle of radio-frequency amplification.

That there are advantages in the latter type of amplification, notably through the elimination of audio-frequency intrusions, has for some time been recognized; but the difficulties of radio-frequency amplification, particularly where regenerative circuit was in question, were no less patent than its theoretical advantages.

The super-heterodyne method enabled Major Armstrong to introduce six stages or more of radio-frequency amplification, as in the receiving outfit used by Mr. Paul Godley in the famous transatlantic tests; whereas radio-frequency amplification without this modification usually proves impractical (or at least very difficult to handle) beyond the third stage.

There is, however, a disadvantage inherent in

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the heterodyne method in that the obliteration of so large a proportion of the oscillations of the input current must weaken and to some extent modify its character. The heterodyne current of course supplies new energy; but at best it adds this energy to a remnant of the original current. Might it not be possible to modify the original current through the influence of a local triode, without annulling any of its original characteristics?

THE SUPER-HETERODYNE

I am not sure that the problem presented itself to Major Armstrong in this form; but at least that is one way in which the problem might be presented. And an effective solution of the problem was given when Major Armstrong conceived the super-regenerative principle and put it into application.

The method proposed and put into effect involves the development of a local oscillating current, just as in case of the heterodyne; but in this case a current in no wise comparable in frequency to the input current upon which it is to be imposed. Regardless of whether that input current is operating at 1,500,000 cycles or half or twice that, the local oscillation will be developed at a frequency only slightly above the range of audibility, somewhere between 12,000 and 20,000 cycles per second. Current of this relatively low frequency is imposed on the input current, in effect breaking it into pulsations of, say, 20,000 to the second, while retaining the far more rapid original oscillations as minor vibrations within the larger waves.

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Such imposition of the local super-audible oscillation upon the input current is effected either (1) by way of an ordinary tickler coil, as in a simple regenerative circuit; or (2) by the introduction of a new coil in direct series with the grid circuit; or (3) by the combination of both these methods in the same outfit.

ADVANTAGES OF THE NEW METHOD

The result, stated in a word, is that the new input current thus produced, consisting essentially of 20,000-cycle oscillations molded about the smaller original vibrations of the input current, can be amplified without distortion to an extent quite unapproachable before such modification was effected.

The large oscillations of the 20,000-cycle current in effect represent waves 150,000 meters in length; and there is little danger of maladjustment of consequence between successive series of such waves if sent back over and over to the grid circuit in the way with which earlier study of regenerative principle has made us familiar.

If minor janglings occur among the vibrations of the original input current, these are subordinated by the dominant 20.000-cycle waves. They are like insignificant dimplings on the surface of a great ocean billow.

And yet these minor oscillations have given the character of their varying amplitudes to the larger current, so that it retains the essential modulations without which it would serve no useful purpose, however amplified, when it comes to the telephone magnets.

Since it has been shown in practise that the

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local 20,000-cycle current can thus be set back upon an input current of any frequency, it follows there is no longer any limitation upon the use of radio currents of very high frequency.

The exceptional value of these high-frequency waves for long-distance transmission has been mentioned. The explanation rather generaily accepted is that these waves are reflected peculiarly well from the so-called Kennelly-Heaviside layer of the upper atmosphere, which is believed to be a stratum exceptionally supplied with free electrons from ionization of the atmospheric gases. The ground waves are absorbed much more quickly than those of lower-frequency messages. But the reflected waves are much more important than direct ones, especially for long distance communication.

At a relatively short distance from the transmitting station, ground waves may be altogether absorbed and it may chance that the effective reflected rays have not returned to the earth's surface—accounting for the "skip distance" (silent region) which, in the early day of radio broadcasting, seemed altogether inexplicable. Under other conditions (for example, a lower-lying Kennelly-Heaviside layer), there may be interference between direct and reflected waves, causing heterodyning or "fading." The obvious reason for such interference is that the reflected rays travel a longer distance, and thus get out of step with the direct rays. Interference may take place, also, in case of very delicate receiving instruments, between waves coming directly or by reflection from the station and corresponding waves that have traveled around the globe.

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CHAPTER IX

THE AGE OF THE TRIODE

THE PROGRESS OF DISCOVERY

IN the field of invention and discovery, as elsewhere, progress is by evolution, almost never by sudden vaulting. Each inventor builds on the work of earlier inventors. Almost never is it possible for contemporary judgment to apportion justly, as between rival discoverers, credit for an innovation; for almost always several people are working along the same line, and within reaching distance, so to say, of the same discovery.

Equally difficult is it to say what constitutes a valid discovery, and what is merely the application of a principle already known. That is why the patent office experts have so much difficulty and why the courts are clogged with litigation over alleged inventions and infringements thereof.

Making application to the present case, it is probable that experts would differ radically as to apportionment of credit for discovery and application of the principles associated with the amplification of radio messages in the receiving outfit. Without attempting to gage the relative importance of the different steps of discovery, however, an attempt has been made in the preceding pages to point out the steps of progress involved, and in so doing to state the essentials of the principles that appear to involve new conceptions without which successive advances would not have been

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made in the manner or in the order in which they actually were made. Let us now summarily list these principles, by way of recapitulation.

AMPLIFICATION AND REGENERATION

(1) The principle of the triode relay, made operative by the introduction of the grid into the electron-tube. This discovery and its application may unequivocally be ascribed to Dr. Lee De Forest, who first put a grid in a vacuum tube about the year 1906, inasmuch as practically all subsequent development in the radio art from that time to this has been dependent on or associated with the advantages of this principle, and would be nullified if the grid-bearing tube were non-existent.

Dr. De Forest's discovery must be ranked as the greatest one in radio history since Marconi's first triumph.

The history of radio progress from 1906 to 1932 might be summarized under the title: "How men learned to use the De Forest audion."

(2) The principle or regeneration; consisting essentially of the "feeding back" of energy supplied by a local battery to all parts of the input current with impulses synchronized solely through action of the De Forest grid-bearing electron tube.

This discovery is officially credited to Major Edwin H. Armstrong, whose priority of invention was established in the courts after a long legal battle.

The regenerative or "feed-back" principle revealed new potentialities of the triode in the way of: (a) amplification of the message-bearing current to an extent not otherwise attainable with

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a single tube; (b) oscillation of the triode current independently of the input current, so that the heterodyne or "beat" principle, first suggested by Professor Fessenden, could be applied effectively as an aid in the reception of messages in general and of short-wave messages in particular; and (c) oscillation of the triode at any desired rate of frequency to generate high-frequency current for transmission of radio messages, so that the instrument originally supposed to be only a receiver proved the most important of radio-transmission instruments as well.

SUPER-HETERODYNE RECEPTION

(3) The principle of super-heterodyne reception; a special application of the heterodyne principle, in which the adjustment of frequencies is such between the input current and the locally developed current that the residual current is not at audible frequency but of relatively low radio-frequency,—say 50,000 or 100,000 cycles per second.

This principle, obviously, applies only to short-wave (that is, very high-frequency) reception, inasmuch as the carrier current in long-wave work is originally at a frequency corresponding to that of the residual current in the super-heterodyne.

A frequency of 50,000 cycles, for example, corresponds to the wave length of 6,000 meters, which is that used by some high-powered commercial stations. Other commercial stations use a 30,000-cycle current, representing waves of 10,000 meters.

These relatively low frequencies are handled to advantage by successive amplifying tubes.

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The object of the super-heterodyne method, as just stated, is to reduce high-frequency waves to such relatively low frequencies that they are similarly manageable.

The objection to the heterodyne method is that it requires very careful adjustment, and that at best it is wasteful of energy, inasmuch as a preponderant number of oscillations of the carrier current are obliterated, only a fraction of the energy being utilized.

As an illustration, suppose that the super-heterodyne method were employed in the reception of messages from an ordinary broadcasting station, operating at 360 meters. This implies an input current of 834,000 cycles. With a local current of 800,000 cycles, a 34,000 residual current would remain, to be amplified. But it is obvious that for each unit 34,000 cycles remaining, no fewer than 800,000 cycles have been neutralized or obliterated. This, obviously, is an exceedingly wasteful procedure; justified only by the observed fact that the reduced current can be amplified without distortion to a degree not feasible with the original current.

Super-heterodyne reception is to be credited unequivocally to Major Armstrong.

MULTI-STAGE TRIODE AMPLIFICATION

(4) The principle of multi-stage amplification, using successive triodes linked together either by inductances, capacitances, or resistances; and used either with or without the cooperation of the regenerative principle.

Full possibilities of radio reception are never brought out without the addition of one or more

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amplifying tubes to the receptor unit ("cascade" effect). Audio-frequency amplification (handling the rectified current) is more facile, the modulated groups of pulsations being handled by iron-cored transformers with step-up ratio of from three to ten. The amplification-constant of each magnifying triode may be from four to ten or more; so that the aggregate amplification of the current when three or more stages are utilized, is enormous.

Radio-frequency amplification is more difficult, especially when high frequencies are in question, and the difficulties are exaggerated if attempts are made to use a regenerative circuit as well. Radio-frequency transformers are of open core, and have variously modified windings, to adapt them to reception of current of different frequencies. The amplifying tubes used in radio-frequency reception should be of minimized inherent capacitance. Tubes that answer excellently for audio-frequency amplification may be unfitted for radio-frequency amplification, because of their high capacitance.

Specific credit for conceiving the idea of using successive triodes in cascade to increase the amplification of the carrier current must be given to Dr. De Forest himself.

Inasmuch as a measure of amplification is inherent in the action of the triode even when it is used primarily as a detector, the idea of linking triodes in series to accentuate the amplification could hardly be overlooked. Yet the practical application of the idea has such tremendous significance as to rank among the great, significant

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stages of progress in the unfolding of the potentialities of the necromantic tube.

Without thus marshalling triodes in support of one another, no long-distance radio work, in the present-day acceptance of the term, would be possible; radio broadcasting would not be attempted; and the "loud-speaker," as applied to radio reception, would not have come into existence.

SUPER-REGENERATION

(5) The principle of super-regeneration, as introduced in 1922 by Major Edwin H. Armstrong, the original discoverer of the regenerative principle, and the originator of the super-heterodyne.

Super-regenerative reception utilizes the principle of regeneration, in that it feeds back energy from plate circuit to grid circuit. The current may be sent back inductively, through a tickler, or directly into the grid circuit, or through both channels simultaneously; but the current thus imposed on the input current is radically different from that used either in simple regeneration or in heterodyne reception.

In simple regeneration, the feed-back current coincides in frequency with the input current; in heterodyne reception, the feed-back is made purposely to approximate, but not to coincide with, the frequency of the input current; and all but a determined number of the oscillations are obliterated.

In super-regeneration, the feed-back current is of frequency totally different from that of the input current; it is just above the range of audibility, say at 20 cycles, so that its modulations

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neither coincide with nor interfere with those of the input current, but merely superimpose a frequency of a new order, comparable to that used in super-heterodyne reception, but having the very great advantage of preserving all of the energy of the original current.

The super-regenerative current, with its 20,000-cycle oscillations, may be thought of as an envelop about the original input current, molded in accordance with the modulations of that current, but having such power as to blot out discordances due to minor discrepancies of coaptation of the individual waves of the input current and the corresponding waves of the ordinary feed-back current,—the latter being still operative, inasmuch as simple regeneration and super-regeneration go on simultaneously.

Thus we have radio-frequency amplification comparable to that of the super-heterodyne method, together with regeneration, with simultaneous rectification or detection; and it is possible so to arrange the circuit that all three functions are performed by a single triode.

A somewhat more satisfactory method is to let one tube serve the purposes of amplification and detection while a second tube acts as oscillator, imposing the super-regenerative current.

These circuits, however, require very careful adjustment; and simplicity of operation is attained, paradoxical tho that may seem, by the addition of a third tube to act as audio-frequency amplifier.

The results attained with three tubes rival those attained with nine tubes of the super-heterodyne receiver; which is comprehensible when we reflect

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on the great loss of energy inherent in the use of the heterodyne principle.

The latent possibilities of the super-regenerative method should be brought out, it would seem, when sundry stages of amplification are applied without regard to economy of material, as is done in the super-heterodyne outfit.

Major Armstrong's problem at the moment was to demonstrate what could be done with one or two or at most three tubes; but doubtless other aspects of the problem have not escaped him.

In particular, it is known that the possibilities of super-regeneration in the development of short-wave radio work have been given consideration, and made the subject of enthusiastic prophecies. Such prophecies, it should be added, do not emanate from Major Armstrong himself, he being wisely content to give publicity to what he has actually accomplished, keeping his ambitions to himself.

MODULATION OF THE CARRIER CURRENT

(6) Modulation of the oscillations of the carrier current, at the transmitting station, to provide for accurate and undistorted reproduction of the sounds at the receiving station.

This is, of course, only an extension of the method of mechanical interruption of continuous waves with buzzer or chopper in radiotelegraphy. The so-called magnetic modulator is a comparatively recent device; but the process of modulation at the broadcasting station is now carried out with the aid of the triode, and the circuit of choice is that devised by Mr. Reginald Heising. Through action of the modulating tube, the carrier

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current, at a frequency determined by the oscillating operating triode from which it has just issued, and of course already modulated by action of the recording microphone in accordance with the words or music represented, is further molded to meet the needs determined by previous experience with the receiving apparatus.

The operator of the Heising circuit listens-in with a local receiver at the transmitting station, thus putting himself in the position of the distant and widely scattered audience; and the success of his efforts at adjustment of the modulation-apparatus largely determines the quality of the radio performance.

DIRECTIONAL RECEPTION

(7) The principle of directional reception of radio waves. It has been observed that the ordinary receiving aerial operates somewhat better when the radio waves are coming from the direction in which it points. This is particularly true of a long aerial; and it will be recalled that when Mr. Godley made his famous demonstration in Scotland, he erected his antenna, about 1,300 feet in length (approximately two wave-lengths) in such wise that it "pointed toward Chicago."

Important directional effects, however, are chiefly observable in connection with the loop-aerial. This apparatus is so directional in reception that it can be used as a "compass" pointing directly toward the transmitting station.

Messages are loudest when the edge of the loop points toward the station; they lessen in strength as the loop is rotated, and they may dis-

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appear altogether when the plane of the loop is at right angles to the line of the radio waves.

So accurate is this action that the loop-aerial may be used, and is used, in connection with an ordinary compass to determine the positions of ships at sea. The "radio compass" is a practical mechanism in actual operation, enabling the navigator to determine his position, with the aid of shore transmitting stations, when weather conditions do not permit ordinary observations. An adaptation of the same apparatus is used on airplanes.

General Squier and his associates have demonstrated directional receiving capacities of an induction coil used in connection with "wired wireless." The inherent possibilities of this type of directional reception have apparently not yet been developed beyond the experimental stage.

DIRECTIONAL TRANSMISSION

(8) Directional transmission of radio waves. The possibility of such transmission, through reflection of the radio waves, has been demonstrated by Senator Marconi, and his associate Mr. Franklin, where very short waves are in question.

It is said that waves as short as one meter in length have been used; and Mr. Franklin has demonstrated the possibility of sending and receiving messages accurately directed, to the distance of 100 miles.

Senator Marconi is said to have declared that in order to insure similar direction of long waves, an electrically operated reflecting apparatus several miles in length would be required. That in itself would be no barrier, it would seem, when

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we consider the magnitude of such plants as Radio Central, Long Island; but presumably the principle of the reflection of the electromagnetic waves must be developed through many experimental stages before it can be expected to have application on a commercial scale.

Even as at present developed, in the experiment just referred to, the discovery seems to give augury of tremendous development of the radio art in a new direction.

Hitherto the great defect of the art has been the fact that messages were of necessity broadcasted, for free reception of all the world. Directional transmission would make possible a degree of secrecy hitherto supposed to be unattainable; and at the same time would free the air of the meshwork of intermingling radio waves that so hampers at present the development of radio as a public utility.

If the directional sending were possible, for example, a station might send out fifty or a hundred messages in all directions simultaneously, on the same wave length, without mutual interference; or any number of stations, for example along the Atlantic seaboard, might send messages to a single point in Europe, say London, at the same time and on the same wave length without interfering with one another.

With such possibilities of directional radio-sending in view, and with the new possibilities of utilization of short waves, or high frequencies, making unprecedented selectivity possible, as implied in the application of the super-regenerative principle, it would appear that a new chapter of radio history is about to be opened up. The

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progress of recent years has been spectacular, but it is more than likely that the progress of the immediately ensuing years will be even more phenomenal.

WIRED WIRELESS, OR LINE RADIO

(9) In the matter of transmission of various messages without interference, there is even now available a method of great practical utility in the "wired-wireless" method, otherwise known as "line radio," introduced by Major-General George E. Squier.

Here the high-frequency current is sent directly along the course of a wire, which may be the ordinary electric-light wire; the radio program being put on the wire at the powerhouse source. Messages at different frequences may be sent along the same wire simultaneously. The wire does not act as an antenna, as has sometimes been supposed, but as a direct guide for the carrier waves.

Messages are interpreted, at the receiving end, with the ordinary radio-receiver, plugged into the ordinary electric-light socket. With a number of radio-receivers, adjusted to different sockets and variously tuned, a variety of programs might be received simultaneously in the same house, even in the same room.

It will be obvious that the possible applications of General Squier's method are almost limitless.

THE TALKING MOVIE

Among recent developments, one that establishes a new relation between radio and a companion art, is the method of recording sounds

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for reproduction on a photographic film. The record occupies only a thin strip, and may be run at the side of an ordinary moving picture negative. Picture and accompanying words or music being thus recorded simultaneously, the problem of synchronism, which hitherto has been the *bête noir* of the would-be producer of a "talking movie," is solved.

Of the many persons who have been working on this problem, at least three are reported to have reached a solution almost simultaneously. Two of these, Dr. Lee De Forest himself and Mr. Charles A. Hoxie, have recently exhibited their respective apparatuses, giving satisfactory demonstrations of the practicality of the method. Mr. Hoxie's device is called the pallo-photophone; Dr. De Forest's the phono-film.

In Dr. De Forest's apparatus, modulations of sound in the transmitting microphone are represented by variations of electric current that correspondingly modify the brilliancy of light in a bulb which projects its beams through a slit one-two-thousandth of an inch wide upon the film. The record thus made is reproduced by reversing the process, so that the fluctuating light modifies the electric conductivity of a medium on which it plays. An ordinary amplifying series of audions (triodes) is used to magnify the sounds, actuating a loud-speaker, so that a large auditorium is filled.

It is impossible to say how many variants upon the earlier methods of thus producing "talking" films have been developed, but the same general principles apply to them all. The practical results are familiar to every patron of the "talkie"

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theaters, which seem by way of superseding the earlier homes of the "silver screen." It must be admitted that the large-scale reproductions of the human voice in these now familiar presentations has left something to be desired.

The newest attempt to improve on the quality of sound-production for theaters and other large auditoriums is the "resonator" of the Danish-American physicist, Dr. Christian A. Volf, Jr. This consists of a group of tubes, suggestive of organ pipes, of varying sizes, each designed to handle sound waves of a determinate length. There is no amplification of volume (as to which the ordinary loudspeakers are adequate), but a freedom from distortion not hitherto attainable, the inventor believes, by any other method.

The particularity of the resonator, in addition to the tubular system just noted, is that the apparatus operates above a surface of water which in effect acts as a sounding-board of very exceptional quality. A public demonstration of the resonator, made in one of the largest theaters in New York in 1931, was highly satisfactory. It appears that the "sound film" reproduction of both speech and music, on any scale, has attained a degree of perfection which, considering the newness of the art, is surprizing.

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