Connecting up a receiving set is no mean wiring job, even if this is called wireless telegraphy

These cardboard tubes, wound with numerous turns of wire, are called loading coils, and serve to build up wavelength

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Experimental Wireless Telegraphy and Telephony—I*

Elementary Principles Regarding Apparatus and Means Employed in Radio Telegraphy and Telephony

By Louis Gerard Pacent and Austin C. Lescarbours

As in most other fields of applied electricity, one cannot delve deeply into radio communication without encountering formidable mathematical calculations. Indeed, it is the presence of intricate formulæ in many works on the subject that has caused laymen to turn away in despair; yet, as a matter of cold fact, it is possible to experiment in the field of radio communication without troubling one's self with the mathematics thereof. It resolves itself down to a matter of interesting one's self in the practical use of the apparatus with little regard to the theory, particularly such theory as requires the extensive use of mathematics to explain a bit of action or to measure currents or waves.

Because of the lack of space and because the scientific world is already overtaxed with works on elementary principles of electricity and magnetism, the authors have omitted going into the details of fundamental electricity and magnetism. It is taken for granted that the reader is acquainted with the simple electrical terms and theories which will be referred to; and if he is not so acquainted, it is taken for granted that he will gather the necessary basic information from the numerous works available.

It is with the object of guiding the layman through the various phases of radio communication that the authors have prepared this work. In so far as is practicable, they have endeavored to eliminate mathematical formulæ, working on the idea that in this instance the layman wishes to purchase and operate apparatus for the purpose of receiving and transmitting messages and for experimental purposes. That is

*This article is the first of a series by these authors. The entire series will cover every phase of the amateur radio art not only serving as a handy guide to the installation and operation of amateur apparatus, but as a stepping stone to commercial practice. (Copyright, Scientific American Publishing Co., 1919.)

to say, the layman here is considered in the same light as the man purchasing an automobile: he is interested in the pleasure the equipment will furnish him, primarily; and he is somewhat interested in how his automobile functions, because that enables him to get the most service out of it. But when it comes to analyzing the formulæ and curves and abstruse theories of automobile engineering, he prefers to leave that side of motoring to the automobile engineer.

While limiting themselves to a simplified explanation of radio communication and radio apparatus, the authors have made every effort to incorporate the latest ideas in this work. The war has resulted in many radical departures in radio communication; so much so, in fact, that wireless telegraph and telephone equipment is now broadly classified as pre-war and post-war types. And reflecting the developments brought about in naval and military equipment, the amateur instruments likewise have been changed to no little extent.

Among the new developments now available to the wireless amateur and which will be covered in subsequent chapters of this series are:

- (a) Radio telephony using vacuum tubes for the generation of undamped high-frequency oscillations.
- (b) Barrage receiver for duplex radio operation and for the elimination of interference and static or strays (atmospheric electricity).
- (c) Weagant's system for the elimination of strays.
- (d) Loop receivers, which possess remarkable characteristics such as direction-finding.
- (e) Loop transmitters.
- (f) Underground systems of long-distance reception.
- (g) Direction-finders of various types.
- (h) Various ways of modulating the high-frequency systems for radio telephony.

ELECTROMAGNETIC WAVES THAT TRAVEL THROUGH SPACE.

When a pebble is thrown into the smooth water of a pond it starts a series of concentric ripples or waves, which spread out indefinitely with a speed of a few hundreds of a meter per second. Similarly, an electrical disturbance caused by a wireless transmitter starts electric waves, which spread out in all directions. These waves affect receiving stations at distant points, and that, in brief, explains the principle of radio communication.

Now the pool in which wireless waves are created and propagated is the ether. It is a well-known fact among scientists that all space and matter contain ether—a medium for the conduction of electromagnetic waves. Although the ether, which is not to be confounded with the ether employed by surgeons, is invisible, odorless, and otherwise does not indicate its presence by the usual means, it is claimed to be as essential to our existence as the air which we breathe. Scientists tell us that the universe is one vast ocean of ether.

So it follows that the function of a wireless transmitter is to set up waves in the ocean of ether, just as the stone thrown in the pool creates ever-spreading waves. The waves in radio communication, which travel at the rate of 186,000 miles per second, are created by the discharge of a condenser of some type or other across a spark gap through a self-inductance coil, and this simple circuit in which the periodic discharges occur is connected either directly or indirectly to the antenna system and ground. The antenna and ground serve to propagate the waves into the ether at the transmitting end, and detect the waves at the receiving end. The antenna and ground may be looked upon as a hinged paddle dipping in the pool of still water already referred to. If this paddle is worked back and forth, the power exerted is converted into

Wireless telephony has progressed to a point where it is applicable to an automobile

The wireless telephone enables the motorist to keep in touch with his home station

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waves which travel in all directions through the pool. Now if another similar paddle is placed some distance away, it will begin oscillating as the waves from the first paddle reach it. These oscillations, in turn, can be made to strike a bell, run a pencil back and forth across a sheet of paper, or otherwise indicate that the paddle is being affected by surface waves. All of which is precisely what aërials and grounds do in radio communication. The aerial and ground go together, it being necessary to employ elevated wires for the aerial, as well as some form of connection or relation with the earth to complete the electrical arrangement, except in special instances which will be covered later on.

Everyone who has studied electricity in even an elementary way is familiar with the discharge of a condenser, such as a Leyden jar, charged by any one of several methods available. The discharge across the spark gap appears as a single spark, but in reality it is composed of a great many sparks following each other in rapid succession. Indeed, the condenser discharges its accumulated energy first by a tremendous rush of current across the gap in one direction, and then another discharge somewhat less powerful in the opposite direction, and still another discharge in the first direction, and so on, back and forth, just like the action of a pendulum, with each discharge weaker than the preceding one until the condenser is completely discharged or emptied of its original accumulated charge. Yet the complete series of discharges takes place in an almost immeasurable fraction of time, depending on what is termed the oscillating or radio frequency. And it is the rapidity of discharge that causes the creation of high-frequency alternating currents, as compared with the very low frequency currents used for power and lighting purposes.

The value of this oscillating or radio frequency depends on the measure of the propagated waves. The term wavelength is employed in giving the value of

The analogy of small and large stones dropped in water, showing the formation of waves of varying power

radio waves. The wavelength is the result of the oscillating frequency; oscillating or radio frequency, in turn, is the result of the capacity and inductance values in the oscillating circuit. As in alternating current practice, one complete reversal in the spark discharge, that is to say, one discharge in one direction and another discharge in the opposite direction, constitutes what is known as a cycle. Various standard wavelengths are herewith given, together with their equivalent frequencies:

200 meters		1,500,000	cycles per second
300 "		1,000,000	" " "
600 "		500,000	" " "
1,000 "		300,000	" " "
1,500 "		200,000	" " "
3,000 "		100,000	" " "
5,000 "		60,000	" " "
10,000 "		30,000	" " "

Under the prevailing wireless laws in the United States the wireless amateur station is limited to a wavelength of 200 meters for the transmitter except in special cases. Ship-station transmitters operate on a wavelength of 300 or 600 meters, while Government and long-range stations operate on longer wavelengths. Wavelengths above 18,000 meters are never employed except in experimental work, because the frequency then becomes too low to be practical while the aerial system has to be of such vast proportions and the power necessary to charge it must perforce be great.

In order to make use of radio waves for the practical purpose of sending messages and then receiving them at a distant point, it is necessary:

- To produce regular electrical disturbances in a circuit which starts the waves. (These disturbances are electric currents which reverse rapidly in direction, as already outlined).
- To get the waves out into surrounding space, through which they travel with great speed. (This is done by means of the transmitting antenna.)

- By means of these waves, to set up electric currents in a receiving circuit at a distant station. (The device which these waves strike as they come in, and which turns them over to the receiving circuit, is called the receiving antenna or aerial.)

- To change these currents so that they may be detected by electric instruments. (The operator usually receives the message through signals in a telephone receiver.)

Analogy for damp and sustained waves as produced in water by a stone and a paddle

METHODS OF PROPAGATING RADIO WAVES AND INTERCEPTING THEM.

Taking up first the methods of producing electrical disturbances, it may be said that there are numerous arrangements now available even to the amateur as compared with one or two in the early days of the art. Formerly the amateur produced the wireless waves by the simplest means, namely, a spark coil or transformer, a condenser, a simple inductance, and a spark gap of plain design. The spark coil or transformer served to charge the condenser, which in turn discharged through an inductance and across a spark gap, thus creating oscillations, which were transferred either directly or indirectly to the aerial system.

Today the amateur has a wide choice of transmitting apparatus. Aside from spark coils and transformers, which may be used with improved forms of gaps, such as quenched and rotary gaps which will be described further on, he can make use of simple vacuum tubes which generate radio waves for telegraph and telephone purposes. Indeed, the vacuum tubes, as we shall read later on, have more or less revolutionized radio communication. Then there is the arc generator, which is little more than a carbon arc connected in circuit with condenser, inductance, and other accessories. The arc generates currents suitable for either wireless telegraphy or telephony. Again, there is the high-frequency alternator, which is a modified form of alternating-current generator capable of producing currents of high frequency, which in turn can be used for creating waves.

The circuit in which the electrical disturbances or oscillations are produced is known as the oscillating circuit. This circuit is connected or coupled to the antenna or aerial circuit in such a manner as to transfer the disturbances or oscillations to the aerial circuit. If the coupling between the two circuits is close in the electrical sense, it is known as a close-coupling, and the set is said to be closely-coupled; whereas if it is loose, still speaking in the electrical sense, the coupling is said to be loose-coupling, and the set is loose-coupled. The relative effects in close-coupled and loose-coupled arrangements will be dealt with later. These arrangements are also employed in receiving.

Transmitters generate one of two kinds of waves, known as undamped or continuous waves, and damped waves. The undamped waves, as will be noted by studying one of the accompanying sketches, can be compared with a simple water analogy. If a paddle is kept moving, it produces steady waves all of about the same peak. In wireless, the effect is the same; the transmitter produces waves of constant power or am-

This diagram shows how the wireless telegraph and the wireless telephone transmit the vowels

plitude. In damped waves, on the other hand, the best analogy is that of a pendulum. The pendulum receives an impulse every so often, and sets swinging with big strokes at first but with each stroke shorter than the preceding one. If the impulses are applied at long intervals, the pendulum stops in between. So in wireless, a damped wave is one in which the impulse is applied every so often, and the cycles soon die down, as shown in one of the accompanying sketches. A group

of these cycles caused by a single impulse is known as a train. Every time the transmitting key is pressed, a large number of trains are sent out through space, and at the distant receiving station it is the trains which set up the audible indications or buzzes in the operator's receivers. Damped waves may be either moderately damped or highly damped, depending upon the spark gap and other features of the transmitter.

Wireless telegraphy and telephony differ in that one makes use of a telegraph code of dots and dashes, while the other uses the voice. In the case of the first, the generated waves are merely interrupted to form the dots and dashes, by means of a telegraph key. In the second the waves, which must be of the undamped variety, are sent out continuously, but the power or amplitude of the continuous train of waves is altered, in the manner shown in one of the sketches.

Now then, the aerial or antenna circuit comes up next for consideration. As already mentioned, the aerial circuit consists of the aerial proper, and a ground or earth connection in most instances, although there are systems of aërials where no ground is employed. The aerial proper consists of a number of insulated wires, either elevated some distance or lying close to the ground or even buried. The elevated aerial may be arranged in several ways; for instance, it may consist of one long wire running between a tall house and a low house, with the connection taken off the lower end. Again, it may consist of a number of wires between masts and poles, as on shipboard. Still another arrangement is known as the umbrella aerial, in which one pole is used as the center, with the wires radiating in all directions and terminating in short poles at their lower end.

ODDITIES IN AERIAL SYSTEMS.

And in these days of advanced practice, an aerial need not necessarily be an aerial, in the accepted sense

Received wireless wave and how a detector rectifies it for the telephone receiver worn by the operator

of the word. It may be a buried wire, such as has been used during the war for long-distance reception. It may be a loop of many turns of wire about three or four feet in diameter for amateur purposes, and larger for commercial work, known as a loop receiver or transmitter and used indoors or outdoors, as may be most convenient. Again, it may be the conventional telephone line, tapped through a small condenser so as not to interfere with the electrical system of the service. It may be a large metal object or collection of objects, such as a metal bedstead, a fire-escape, a large stove-pipe or metal chimney, and so on; for, after all, the aerial is merely an insulated mass which serves to intercept the radio waves as they spread out in all directions from the transmitter, and to lead them through the receiving set down to the earth connection.

One more word about the loop antenna. This form has a decided advantage over the usual high elevated antenna system, because of the fact that, being only exposed electromagnetically and not electrostatically—no ground connection being used—it is affected but little by atmospheric electricity which gives rise to the troublesome interference known as "static." At times the static noises are so loud and so persistent in the receiving apparatus that it is impossible to hear and "read" signals from a transmitting station. That is why, in the past, long-distance stations have often been unable to transact their business for hours at a time. In short, static has been the curse of the radio engineer. Of course, with a loop antenna the signals are weaker than they would be with a large aerial system, and must be amplified for proper audibility in many instances.

Direction-finding is another advantage of the loop antenna. As will be described in that part of this work dealing with aerial systems, the loop receives signals loudest when it is properly adjusted to receive them from one particular direction. This feature of the loop makes for no end of interesting experiments.

(Continued on page 16)

ing industry were especially heavy and genuine lignum-vitæ stocks were short on account of limited shipping facilities, an inferior substitute, known as "Panama lignum-vitæ" or "yellow guayacan" was used by the Emergency Fleet Corporation. This came about largely through confusion of names. The Panama wood in question is locally known as "guayacan," a name also applied to the genuine wood, although the two are of entirely different families of trees and are wholly unlike in structure and properties. Yellow guayacan (*Tabebuia* sp.) seems to be lacking in the essential properties of genuine lignum-vitæ and is probably no better suited for stern bearings than our native beech which was formerly used in a small way.

Regarding the use of yellow guayacan, the Bureau of Construction and Repair of the U. S. Navy Department advises the writer in a letter dated March 29, 1919, that it "made one purchase of *Tabebuia* with the expectation that this material would be suitable for the same uses for which the genuine lignum-vitæ is required. Tests have proven that this material has sufficient strength and hardness but is lacking in oil content which prohibits its use for stern bearings which require wood of self-lubricating properties."

The writer was recently informed by a person familiar with the timbers of Central America that at least 40 different kinds of woods are locally called "guayacan." The experience with the Panama wood shows the danger lurking in that name and emphasizes the need for discrimination on the part of users and buyers of lignum-vitæ if they would avoid being imposed on, whether intentionally or otherwise.

Experimental Wireless

(Continued from page 13)

On airplanes, dirigibles, and other aircraft in general, the antenna system consists of a trailing wire in most cases. While the aircraft is in flight, a wire several hundred feet in length is paid out from a reel. A stream-lined weight is fastened to the free end of the wire, so as to keep it trailing behind the aircraft. When the aircraft is about to land, the wire is taken up on the reel. In some airplanes the aerial consists of wires stretched between posts on the top wings, or between other members. In the case of at least one dirigible, namely, the C-5 of the United States Navy, which was blown to sea after a successful flight to Newfoundland, the aerial wires were placed inside the gasbag.

A live tree makes an excellent antenna for receiving. In fact, during a recent U. S. Signal Corps demonstration at Washington, D. C., a live tree was employed in receiving messages from powerful stations in Europe. Of course, most of these improvised aeriels are only suitable for receiving purposes, because in transmitting it is imperative to have a good aerial in order to impart the waves to the ether in the most efficient manner. However, it must not be inferred from all that has been written, so far, that one aerial is required for the transmitter and another for the receiver. If an aerial is of the proper design and size, it may be employed for receiving and transmitting; and for this purpose a switch is employed which permits of connecting either set with the aerial at will.

As for the so-called ground or earth connection, this is merely a matter of a good electrical connection with the ground, or a capacity effect. On shipboard the problem is merely one of securing a connection with the metal hull, or if the ship is of the wooden design, having a plate in the water. In the city, the ground is merely a connection with a water or gas pipe, preferably the former. In the country the ground may be a special one, prepared with little trouble. In localities where it is next to impossible to make a good contact with the earth, such as in sandy or rocky regions, one resorts to the capacity ground or so-called counterpoise, which is nothing more than an arrangement of wires laid on the ground or supported a short distance above the ground, arranged very much after the fashion of the antenna but much lower, of course. Still another form of counterpoise is a piece of wire netting, spread on the surface. In the case of aircraft, the ground is also of the capacity of counterpoise type. The wires of the rigging are used to form a capacity ground.

Hence it becomes obvious that the term "ground" is a misleading one, particularly in cases where there is no ground connection at all. However, it is the accepted term and must therefore be abided by.

Coming to the receiving side of wireless communication, we find the situation just the reverse of the transmitter. The currents induced in the aerial by the intercepted radio waves flow down through the aerial circuit, and are transferred to the receiving circuit, where they operate certain instruments which in turn give the operator some indication of their passage.

Practically speaking, a receiver does not take away

from the power of the transmitter; that is to say, whether a thousand or ten receiving stations are receiving a message at one time, the effect on the transmitter is the same. Indeed, it is never known whether one's transmitted signals are being picked up or not, unless one receives an acknowledgment. The transmitted waves spread out in all directions to be picked up or not, growing weaker and weaker the farther they go away from the transmitter. A receiver which is sufficiently sensitive may be made to intercept the waves within the range of the transmitter. It follows that the farther a receiving set is from a given transmitter, the more delicate it must be. That fact explains why almost any kind of aerial—even a common umbrella or a short length of stove-pipe—and a crude receiving set may be used for receiving nearby signals.

THE IMPORTANT MATTER OF TUNING.

Now all wireless waves are not alike; they have different wavelength values as already indicated. Wavelengths vary from 40 to 18,000 meters, the longer values being used in long-distance, high-power stations, while the shorter wavelengths are employed by the Government, ship stations and amateurs.

This matter of wavelengths is a most important one in radio communication. All transmitters emit signals of varying wavelengths, and all receiving stations may be adjusted to receive signals of any wavelength, and hence signals from any transmitter. Thus if transmitter A is emitting signals on a wavelength of 300 meters, and transmitter B is emitting signals of 600 meters, a receiving set can be adjusted for 300 meters to receive from A, or 600 meters to receive from B. It is this matter of transmitting signals of a given wavelength and picking them up at the receiving station which is known as tuning. And it is this tuning which permits several transmitters and receivers to operate in a given locality at one time, without unduly interfering with one another.

Indeed, the most practical example of the value of tuning is offered in the regulations applying to amateur wireless in the United States, which specify that amateur transmitters must be tuned to wavelengths below 200 meters. In this manner the commercial and Government transmitters, operating on longer wavelengths, can communicate with their respective receiving stations without interference of the shorter wavelength transmitters.

In practice, tuning is not as perfect as one would hope for. That is to say, even despite a wide difference in tune, one transmitter may seriously interfere with another. This is usually the case when one transmitter is quite close to a receiving station, while the desired transmitter is some distance away. Even though the receiving station is tuned for the distant transmitter, the signals of the nearby transmitter force themselves on the receiver. This result is known as forced oscillations.

Tuning is a matter of varying the oscillating or radio frequency of wavelength. Most transmitters, unless they are of the "fixed" variety, can be generally tuned to any desired wavelength over a considerable range, by varying the capacity and inductance in the oscillating and the aerial circuit, while the receiving set can also be varied by varying the capacity and inductance in the aerial and associated circuits.

The currents induced in the receiving aerial by the passage of signal waves are transferred to the receiving circuit proper. Between the two circuits there may be a close or loose coupling, according to requirements. These currents, being of the high-frequency alternating current category, cannot be detected by ordinary electrical apparatus. A telephone receiver, for instance, while sensitive in the extreme and responsive to weak electrical currents, will not respond to these high-frequency currents. The reasons why a telephone receiver cannot be connected to the high-frequency circuit are: In the first place, the little magnet coils contained in the receiver exert a choking effect upon the currents of such high frequency, which effectually blocks their passage. Low frequency and of audible nature, intermittent direct currents and continuous direct currents will readily pass, producing a sound each time there is any change in their value. Hence it becomes necessary to convert the high-frequency alternating currents into some form of current that can operate the telephone receiver.

Various methods are available for converting and detecting high-frequency currents in a receiving circuit, among these being ingenious rectifying devices, sensitive modifiers which modify a telephone circuit in accordance with the varying strength of the antenna currents, electric lamps of special construction known as vacuum tubes, and so on. The device that converts the antenna currents so that they may be detected with a telephone receiver, is known as the detector.

The purpose and action of most types of detectors are to act as a valve, allowing the current to pass through in one direction only, or offering what is known as a uni-lateral conduction to the current. The action is clearly shown in the last of the remaining sketches, depicting first the high-frequency current, and then the same current after passing through the detector.

The average receiving set comprises tuning instruments, for varying the antenna and receiving circuit so as to bring the receiving apparatus in tune with the desired signals, a detector, a pair of telephone receivers, and the miscellaneous equipment necessary to round out the installation. Sitting before his tuning instrument, the operator can, by the mere turn of a knob or two, search through the entire range of wavelengths, picking up the various signals then passing through space as he gets in tune with them. Indeed, that is one of the greatest fascinations of radio—this matter of eavesdropping, so to speak, on all transmitting stations at will, while being instantly able to concentrate on any one by sharp tuning.

So much for a broad introduction to the subject of radio communication. In subsequent chapters the actual installation and operation of radio equipment are taken up in proper turn.

SCIENTIFIC AMERICAN SUPPLEMENT

Founded 1876

Published by Scientific American Publishing Co.

New York, Saturday, July 5, 1919

Munn & Co., 233 Broadway, New York

Charles Allen Munn, President; Orson D. Munn, Treasurer; Allan C. Hoffman, Secretary, all at 233 Broadway

The Scientific American Publications

Scientific American Supplement (established 1876) per year \$5.00
Scientific American (established 1845) 5.00
The combined subscription rates and rates to foreign countries, including Canada, will be furnished upon application.
Remit by postal or express money order, bank draft or check.

Scientific American Publishing Co.

233 Broadway, New York

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