The EASY COURSE in HOME RADIO

MAJ. GEN. GEO. O. SQUIER, EDITOR-IN-CHIEF

LESSON III:—TUNING AND WHAT IT MEANS

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FORMER PRESIDENT OF INSTITUTE OF RADIO ENGINEERS

ONE OF THE FOLLOWING SET OF SEVEN LESSONS
1. A GUIDE FOR LISTENERS IN. 2. RADIO SIMPLY EXPLAINED. 3. TUNING AND WHAT IT MEANS. 4. THE ALADDIN'S LAMP OF RADIO. 5. BRINGING THE MUSIC TO THE EAR. 6. HOW TO MAKE YOUR OWN PARTS. 7. INSTALLING THE HOME SET.

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LESSON THREE

Tuning and What It Means

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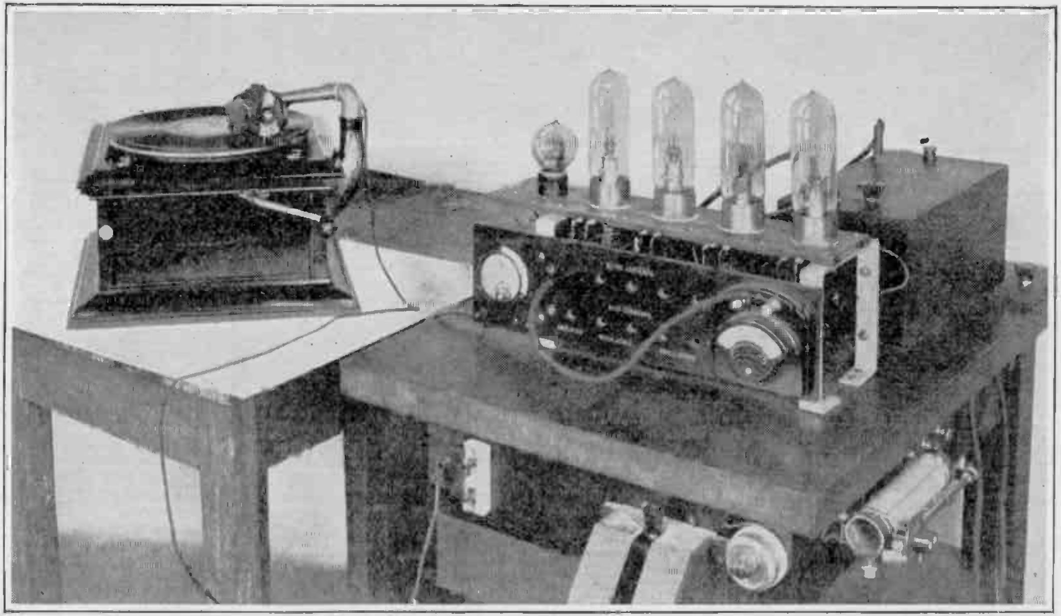


Photo by Bureau of Standards

Sometimes the broadcasting station will play phonograph music. This picture shows how the phonograph may be connected with a medium-power radio telephone transmitter. A microphone transmitter is used as a reproducer on the phonograph.

LESSON THREE

What We All Know About Tuning

TUNING in radio circuits seems a mysterious process. There is nothing supernatural about the operation, however, and we can easily get a clear idea of it by comparing its principles and its effects with other occurrences in our daily lives. We are all more or less familiar with the tuning of musical instruments; we know that when a player tightens a string of his violin, that string produces a note higher in pitch than it did before it was tightened. We have noticed that the longer and heavier strings of a harp or piano give off the lower musical tones. If we wish to tune a string to make a certain sound, say that of middle C on the piano keyboard, we will usually begin by getting its length and weight about right and then adjust its tightness until we have *tuned* it to the exact pitch we desire.

The Musical Scale

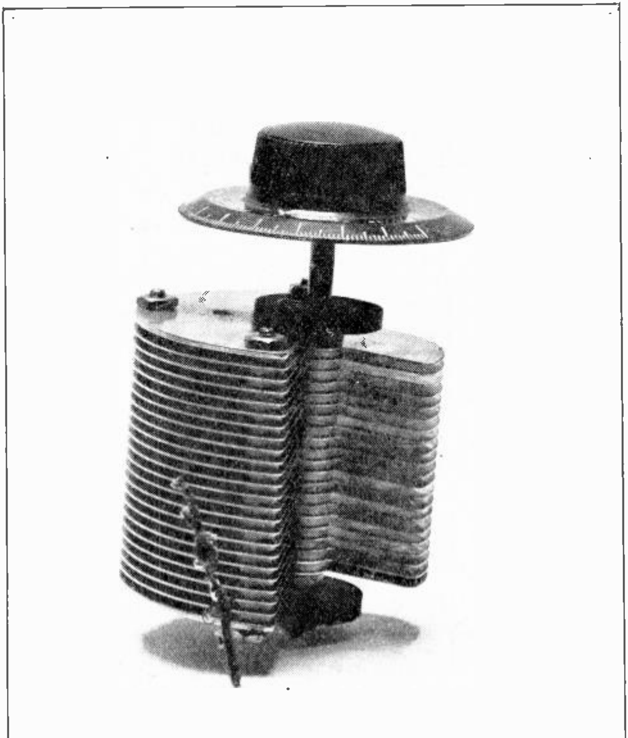
What is it that makes the notes of a piano have different pitches? What do we mean by high-pitched and low-pitched tones? The thing about a sound wave which tells us its pitch is simply the *rapidity* at which it vibrates. If the sound vibration is very rapid, it will produce the sensation of a high-pitched tone; if it vibrates comparatively few times per second, the tone will be low in pitch or frequency. The range of frequencies ordinarily used in musical compositions extends upward from about 32 vibrations per second, which is the third C below middle C on the piano. The highest note commonly heard is the fourth C above middle C, which has a frequency of 4,096 vibrations per second.

If we wish to produce a note of any particular pitch, say that of middle C (which vibrates 256 times per second) we need only to set up a stretched string or some other vibrating body, so that it may oscillate at this particular rate.

Sympathetic Vibration

Did you ever make the experiment of sitting before a piano, and, while holding down the "loud" pedal, singing or whistling some single note? Pressing the pedal lifts a damper from the strings, and leaves them free to vibrate. Whatever note you sing, you will find that the corresponding string of the piano will take it up and continue to sound that particular tone for a moment after you stop singing. By uttering in quick succession two or three loud but short tones, you can get the piano to respond to a complete chord.

What happens in this demonstration of sympathetic vibration is that your vocal cords produce air vibrations of the frequency corresponding with the note you sing. These air vibrations travel outward from your mouth as a sound wave, which spreads in all directions through the room somewhat in the form of an imaginary but huge and ever-expanding soap bubble. The air-wave strikes against



In receiving sets employing electron tubes most of the tuning is done with variable condensers of this type. For the reception of continuous waves, sharp tuning is required; for this purpose a variable series condenser may be used in the primary circuit, and a small variable condenser called a "Vernier" condenser, connected in parallel with it.

all the strings of the piano; some one of those strings is tuned to the same pitch (the same frequency of vibration) as the sound wave. This particular string is the only one that can swing back and forth in unison with the sound-wave, and, as we shall see later, is the one which can most

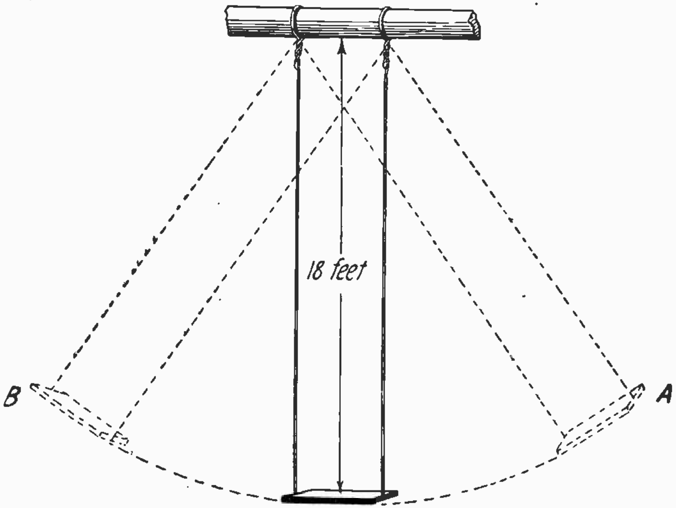


Fig. 1

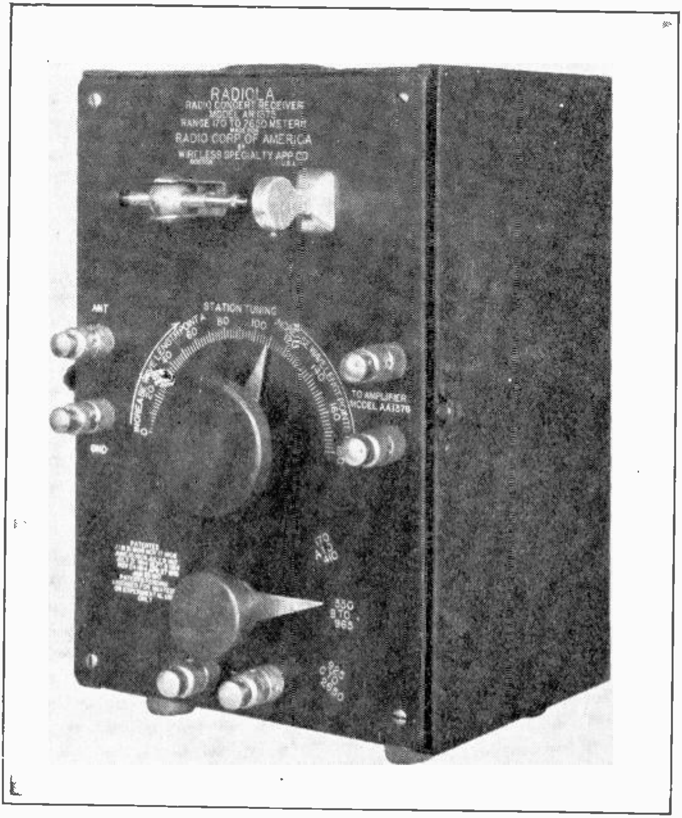
A child's swing; if the length is eighteen feet, it will take about five seconds to travel from A to B and back to A.

easily be made to move at that individual frequency or pitch. The sound-wave striking this string, and the successive impulses in the sound-wave coming along at just the right rate to hit the string exactly in step with its own vibrations, combine to make the string itself swing back and forth vigorously. When the sound-wave stops, because you stop singing, the string is going strongly; its oscillations cannot stop at once, and while they are dying away they produce new sound-waves of the original pitch which travel outward from the string and are heard by you as a reproduction of the tone you sang.

The Natural Frequency

Let us see how some of these same effects occur in other vibrating systems. Instead of considering sound waves, with their frequencies of from sixteen vibrations per second upward to thousands of oscillations in one second, let us study the action of a child's swing hanging from the limb of a tree. If the swing, as shown in Fig. 1, is eighteen feet long, it will travel from one high position to the other and back again in about five seconds. This time will be required to complete an entire double-swing from right to left and back, regardless of the distance through which the seat moves; if it is "swinging low" it will move comparatively slowly, and if "swinging high" it will automatically go fast enough to make each half-trip in two and one-half seconds.

The time required for any vibrating or swinging body to make a full or double swing is called its *time period,* or simply its *period.* The double-vibration itself is called a *cycle* of oscillation. The *frequency* of vibration is the number of cycles or complete vibrations that the system completes in one unit of time. In the case of sound waves the vibrations are so rapid that we measure the number in



A modern crystal detector set, with a range of about 40 miles under good conditions.

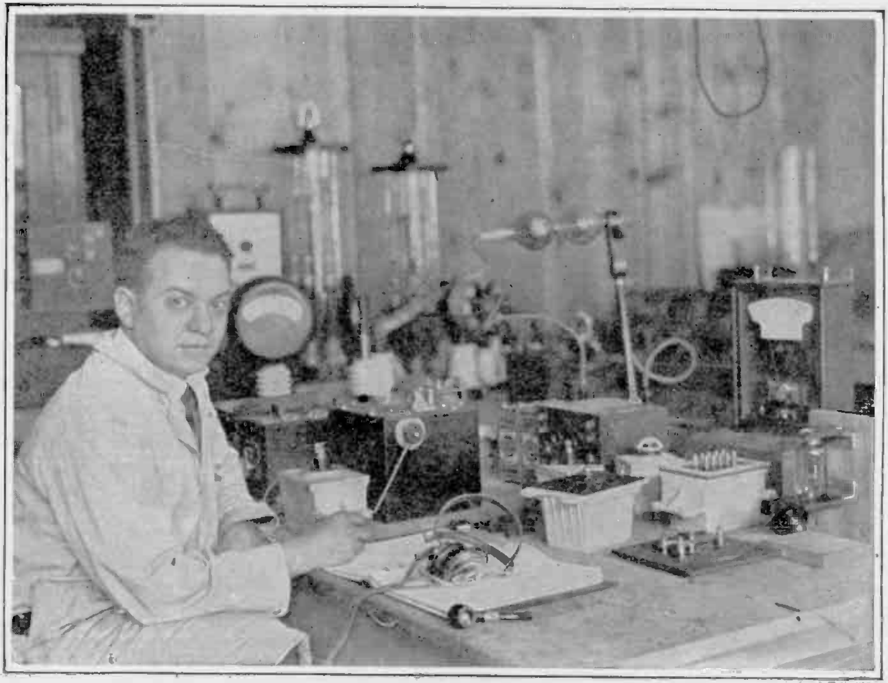
The simplest type of vacuum-tube detector set has a handle for tuning in and beside it a "tickler" knob for sharpening the tuning. The second knob shown (that next to the lamp-like tube) merely controls the current supplied to the filament.

one second, and speak of the frequency in *cycles per second;* for our swing which has a period of five seconds, it is more convenient to measure the frequency per minute.

Since there are sixty seconds in one minute and since the swing uses five seconds to make a complete swing or cycle, it is quite evident that the swing will describe twelve round-trips in one minute. Thus, its frequency is twelve cycles per minute. This is the frequency that the swing will take if started and left to itself, and consequently it is called the *free* or *natural frequency* of the swing. Of course, we can force the swing to vibrate at any other rate we desire if we will hold on to it and move it by main strength; in that way we can force it to move back and forth only five or six times per minute, or we can speed it up to go even twenty times per minute. To do this, however, we will have to work hard and actually drive the swing at every point of its motion; for if we leave it alone for an instant it will begin to regain its natural frequency of twelve per minute.

On the other hand, we can keep the swing in motion at its natural frequency simply by pushing it slightly each time it passes us. Very little effort is required to keep it going at this rate, for we are taking advantage of its natural tendency to go back and forth at its own frequency. This natural frequency of vibration is the rate of swinging which is most easily attained by the system.

The middle C string of the piano has a natural frequency of 256 cycles per second. When an air-wave of this same frequency strikes the tuned string, the wave-impulses are able to set the string swinging back and forth strongly. It is a case very much like that of the swing,



Wm. Dubilier, who invented the pressed mica condenser which is now used widely for both transmitting and receiving radio communication.

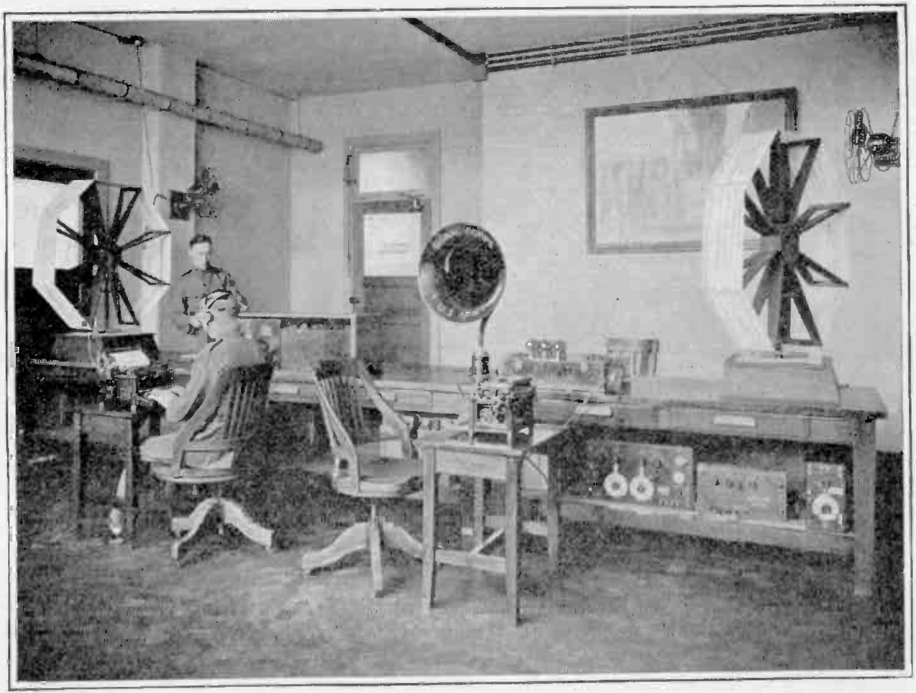


Photo by Bureau of Standards

The polygonal frames at the right and the left are loop-antennae. This is a Signal Corps intercept station. The loop antennae receive waves about 6000 meters in length.

for when the driving impulses pushing the swing are timed to the rate of twelve per minute (which is the natural frequency of our swing), it is easy to make the seat move higher and higher with each oscillation.

Changing the Natural Frequency

We have seen that we can change the natural frequency of a musical string, or *tune* it, to give off any desired note, merely by changing its size or its tightness. Let us now find out how the natural frequency of a mechanical system can be controlled.

The simplest slowly-oscillating mechanical arrangement which is capable of easy and flexible adjustment is probably the "twisting dumb-bell" or torsion pendulum shown in Fig. 2. This is nothing more than a vertical rod or stiff wire, clamped firmly at the upper end to prevent it from turning at that point, suspending a horizontal section which carries a weight at each end. The bottom part resembles a dumb-bell; for convenience in experiment it should be provided with interchangeable weights of several different sizes.

If we set up such a torsion pendulum with a rather thin vertical twist-rod and moderately heavy weights, it will have a fairly slow motion or low natural frequency. To set it going, you twist the dumb-bell around in a horizontal plane as far as it will move easily, and let go. The dumb-bell then swings back and forth, the weights moving in a horizontal circular path, first in one direction and then in the other, the motion gradually becoming less and less until the weighted arm finally comes to rest in its initial or undisturbed position. We may measure the time required for the weights to swing from one extreme position to the

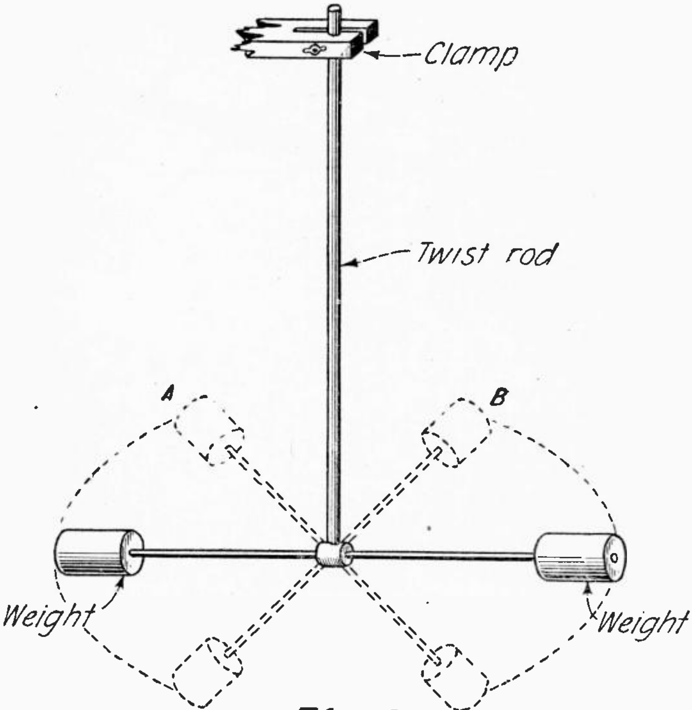
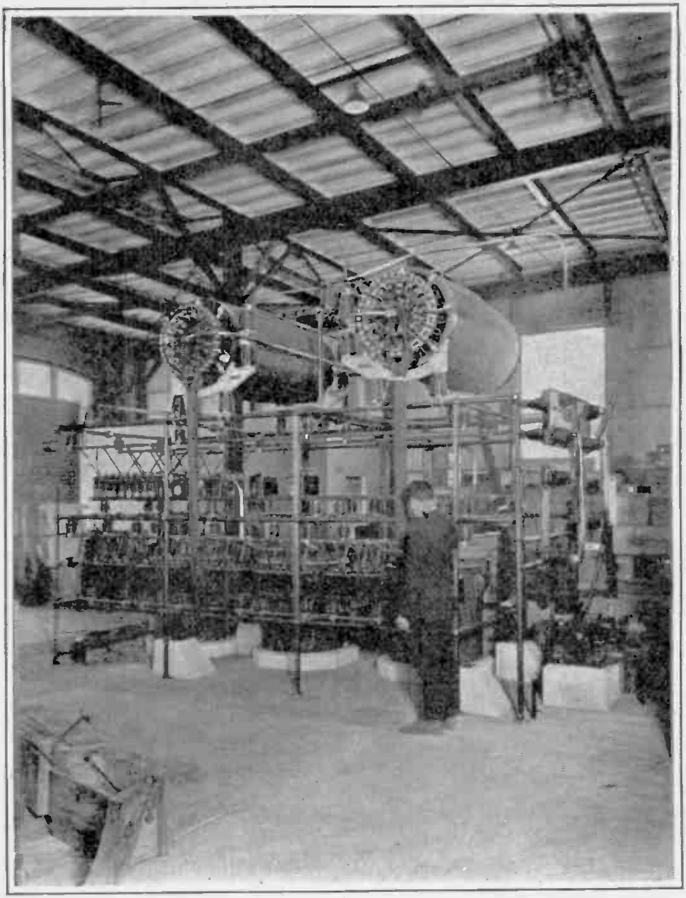


Fig. 2

A twisting Dumb-bell or Torsion Pendulum; the weights swing back and forth between A and B as indicated by the dotted lines.

other and back again. This time is, of course, the *period* of the pendulum. The number of double swings or complete cycles that it makes in one second or in one minute is the natural frequency per second or per minute. A typical



High frequency transformers and condensers for the Alexanderson alternator of the great station at Port Jefferson, L. I.

twisting dumb-bell of this sort will swing through a full cycle in one second; therefore its free or natural frequency is one per second or sixty per minute.

Suppose that we have such a torsion pendulum, with a natural frequency of sixty cycles per minute. If we take the twist rod between thumb and finger, about half-way down from the supporting clamp, and "roll" it slightly, we can move the swinging weights a short distance along their circular path. If, having given the pendulum such a feeble impulse, we allow the weights to swing back, their momentum will carry them past the position of rest and part away around in the opposite direction. The springiness of the twist-rod will soon arrest this motion, however, and the weights will once more swing in the direction in which we started them. We may now "roll" the rod between thumb and finger again, as before, and the second impulse will carry the weights a little farther away from the rest or neutral position. By impulsing the system once in each swing we can build up an oscillation of considerable size, in which the weights swing with a good deal of motion. But to do this, the driving force must be applied at the right time in each oscillation; in other words, its frequency must agree with the natural frequency of the driven system. If we desire the dumb-bell to oscillate at any other rate, we must either force it to do so by main strength (keeping hold of the swinging weights throughout their movements and not permitting them to oscillate freely) or we must change the natural frequency of the pendulum to the new value which we desire.

How can we change the natural frequency of such a twisting pendulum? What can we do to it that will cor-

Photo by Keystone

This antenna tower, one hundred feet high was constructed by two amateurs in Salt Lake City. With the antenna they have picked up radio music as far east as Schenectady, and as far west as Oakland.

respond with changing the size or the tension of a piano string, and so change its rate of vibration?

It should be almost self-evident that if the twist rod is made more flexible, or more flimsy, it will not have so much spring or restoring force and consequently it will not be able to swing back the weights so fast when they are displaced from the position of rest by turning them in one direction. Therefore the time period may be lengthened, and the natural frequency correspondingly decreased, by increasing the flimsiness of the torsion rod. If the rod is left without change, but heavier weights are put on the swinging arms, the restoring force of the rod will be insufficient to move the larger weights as rapidly as before. Consequently, increasing the mass of the pendulum weights in a twisting dumb-bell system will also reduce the frequency of natural oscillation. By a proper choice of flimsiness and mass we can make the natural frequency of the pendulum any value we desire within the practical limits of the structure. It is interesting to note that when we change the tension of a vibrating musical string we change the restoring force, and that alterations in the size of the wire change its mass for a given length; thus the control of the natural vibrating frequency of a piano wire is much like that of the torsion pendulum.

Tuning and Resonance

We have seen that in order to drive a vibrating system most effectively, the frequency of the driving impulses must be practically the same as the natural frequency of the driven system. This was true of the musical string,

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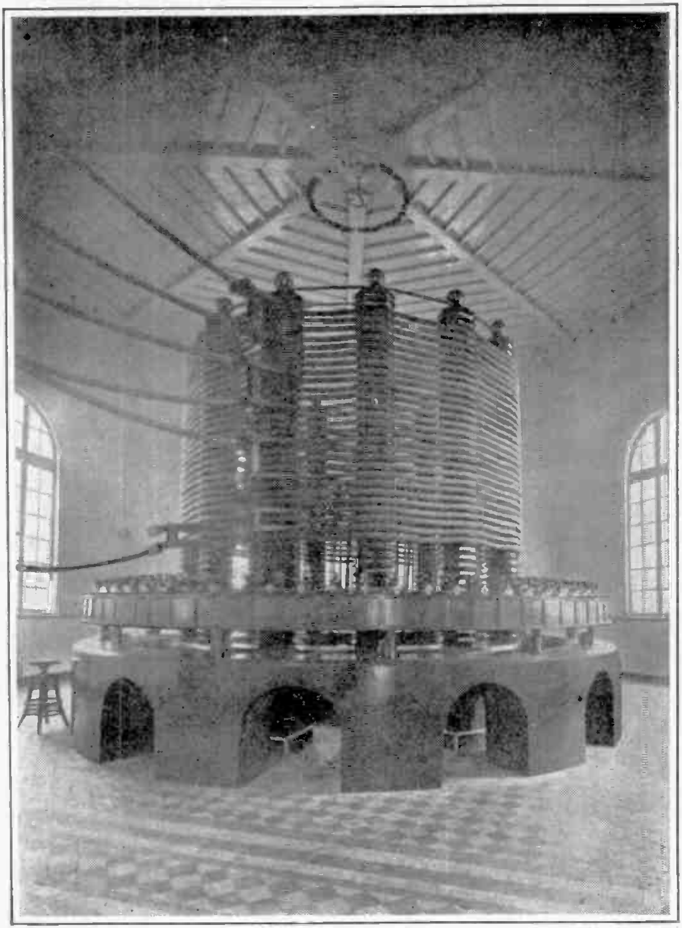
Tuning in—a process that consists in much more than turning a knob.

the child's swing, and the twisting dumb-bell. It is equally true of all other systems, mechanical or electrical, which are capable of natural or free oscillations and which consequently have natural frequencies of vibration. The agreement or practical identity of the frequency of the applied force and the system which it is intended to operate is what we call *resonance* or *syntony*. When the vibrating system has its natural frequency adjusted to agree with the frequency of the driving force, it is said to be *tuned* to that frequency.

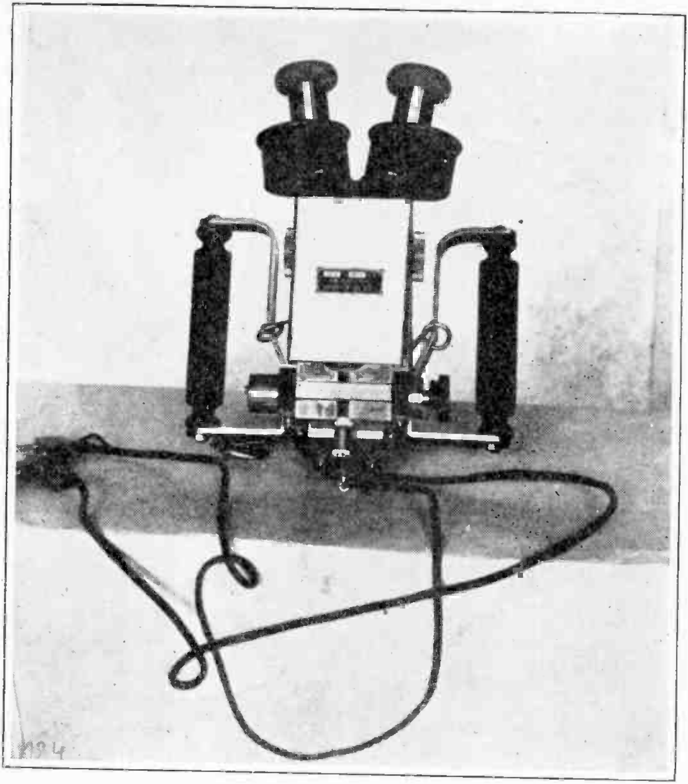
In this connection we must not overlook the fact that any oscillating system may be forced to vibrate at frequencies which are different from its natural or resonant rate. But, as in the case of the swing, such non-resonant vibrations must be maintained by the use of excessively large power (by main strength, as we said) since they do not take advantage of the tendency of the system to swing back and forth at its natural frequency. These non-resonant vibrations are called *forced* vibrations, to distinguish them from the natural or free vibrations of the system.

Electrical Vibrations

One might well ask what the preceding discussion of music and pendulums has to do with electricity and particularly with radio. The answer is simple; in a word, everything. All the phenomena that we have considered from the mechanical viewpoint are reproduced in electrical circuits and are used in radio communication. We have merely to work out the electrical counterparts of the various mechanical effects to understand the basis of



The largest radio transmitting coil in the world—that of the Lafayette Station near Bordeaux.



In the early stages of the war, observers found it difficult to receive radio telegraph signals with the telephone headsets because of the roar of the engine. Hence this instrument was used. The observer looked through a pair of glasses and saw dots and dashes of the code in the form of flashes longer or shorter duration, a filament or string being electrically heated. Later this ingenious instrument was displaced by telephone sets so constructed that the observer could hear easily.

tuning and resonance in radio circuits. Although the oscillations in an electric circuit are not visible, as they are in the case of a pendulum, they nevertheless occur in the same way and are subject to the same sort of control as to natural frequency, intensity of vibration, etc.

Let us first get a general idea of an electric circuit with electric current flowing in it. Suppose that the positive end of a battery is connected by a piece of wire with a current-indicating meter, that the meter is connected with

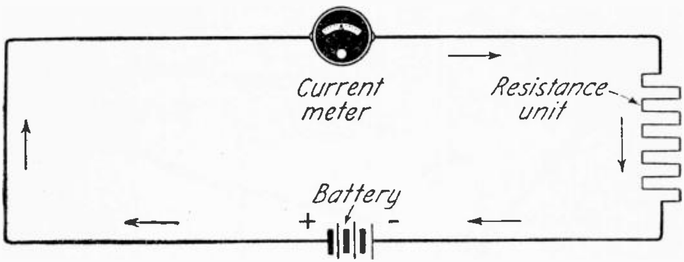
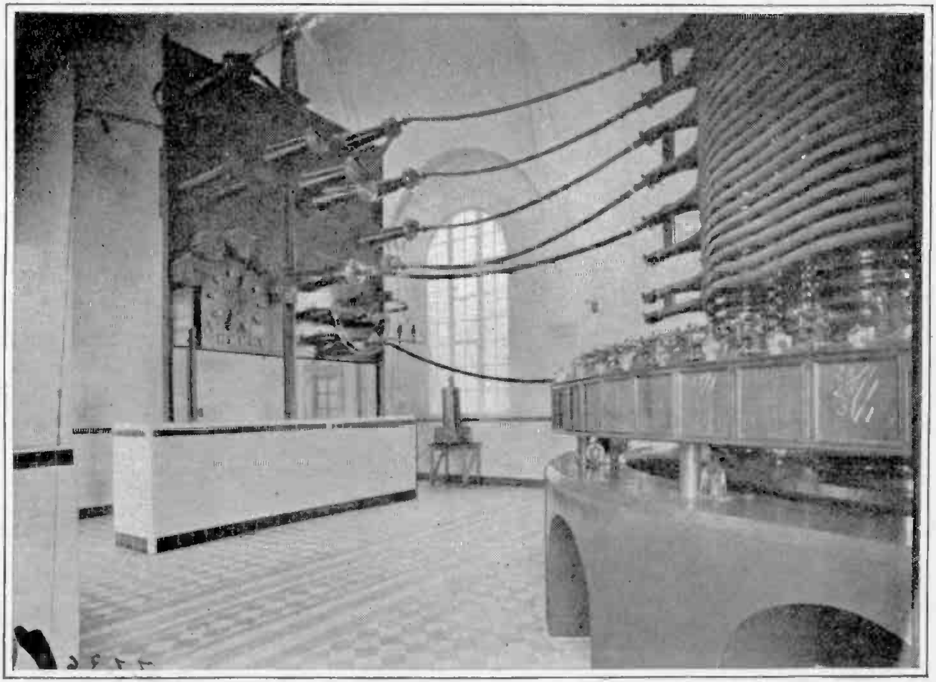


Fig. 3

A simple battery circuit; direct current flows through the wires in the direction indicated by the arrows.

one end of a resistance unit, and that the other terminal of the resistance is wired back to the negative side of the battery, as illustrated in Fig. 3. The battery is something like a pump for electric current; it produces between its terminals an electric pressure which tends to cause a flow of electric current when the terminals are connected by a wire or other conductor. The positive end of the battery, indicated by a plus sign, is the high-pressure end; the difference in electrical pressure or potential between the bat-



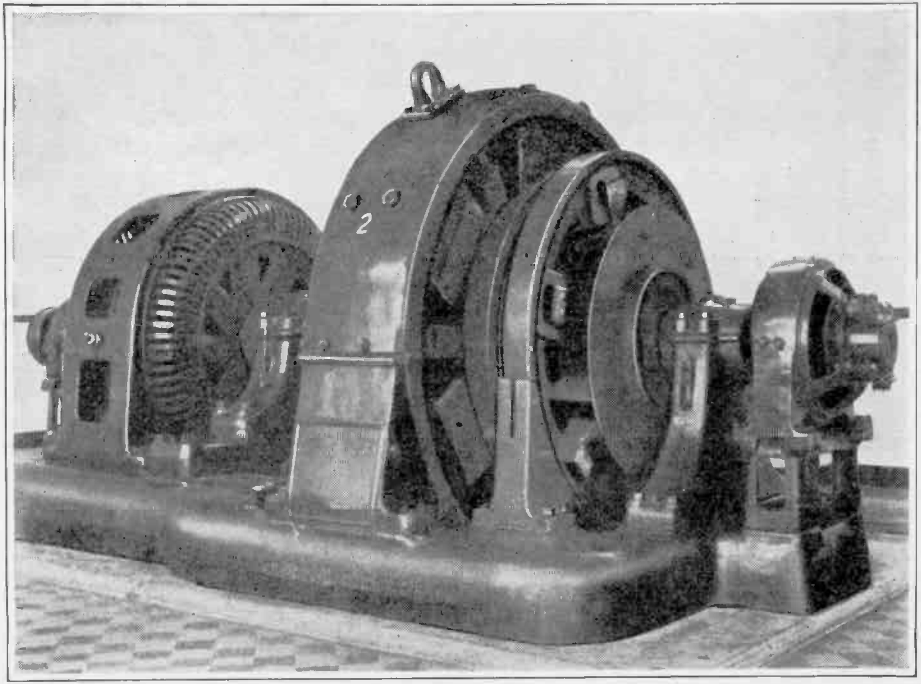
Interior of the Lafayette Station. The size of the wire is an indication of the amount of antenna current. To the right a high-power tuning **coil.**

tery terminals is measured in *volts,* and the higher the voltage the higher the electrical pressure.

In the circuit that we have imagined, a path for current-flow from one end of the battery to the other is provided through the resistance unit and meter. The battery pressure will force a current to pass through the circuit; the amount of current will be registered in *amperes,* and will depend upon the pressure of the battery and the resistance of the circuit. The resistance is measured in *ohms,* which is merely that property of a wire which holds back electric current. In this circuit the current flows only in one direction, from high to low potential (or plus to minus ends of the battery, according to the conventional expression adopted many years ago); it is therefore called a unidirectional or *direct current.*

Suppose that the battery were connected into the circuit with its terminals reversed. The current would still flow from high potential or positive to low potential or negative, but its path through the wire would be in the reversed direction. If the battery in such a circuit were regularly and rapidly turned end for end, being connected with the wires each time, it is not hard to see that the current in the circuit would flow first in one direction and then in the other direction. In other words, the current would no longer be unidirectional or direct, but would change its direction of flow at regular intervals, going first one way and then the other. Such a regularly reversing flow is called an *alternating current.*

Alternating currents are not produced in practice by reversing the terminals of a battery, but instead by means of an alternating current dynamo or *alternator.* This dynamo machine automatically sets up electric potentials



Alternating current dynamos can produce the electric waves used in radio. But the dynamos must be of special construction in order to generate currents with a frequency of thousands of cycles per second. This is the alternator of the great Lafayette station built by the American army in France during the war. The station is one of the most powerful in existence.

across its terminals, first in one direction and then in the other. The fluctuating potentials cause corresponding alternating currents in any electrical circuit connected from one of the alternator terminals to the other, such, for example, as that of Fig. 4.

It is not hard to see that electric currents which flow first in one direction and then in the other, that is, alternating currents which swing back and forth in a circuit, must have something in common with mechanical

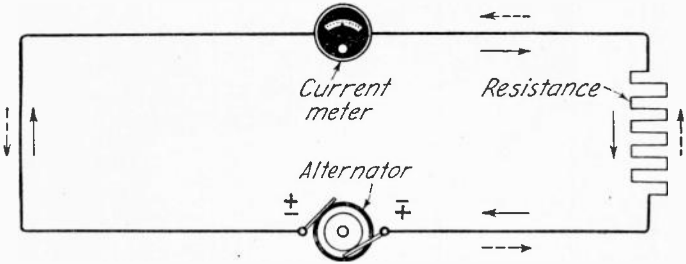
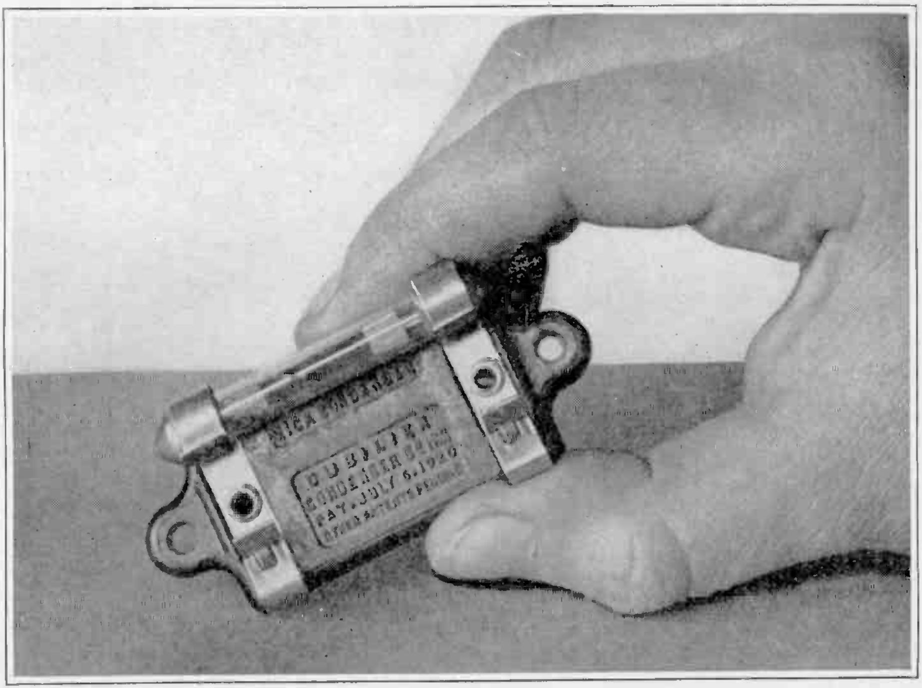


Fig. 4

Alternating current circuit; when the left-hand terminal of the alternator is positive the current flows as indicated by the solid arrows. The dotted arrows show the direction of current flow when the right-hand terminal is positive.

oscillations. They are evidently electrical vibrations, just as the swings of a pendulum are mechanical vibrations. The electrical swings, of course, require a definite length of time to complete one double-oscillation or cycle; this length of time is, as before, called the *period*. The number of complete electrical cycles of alternating current in one second is, as in the mechanical case, the *frequency* in cycles per second.

3



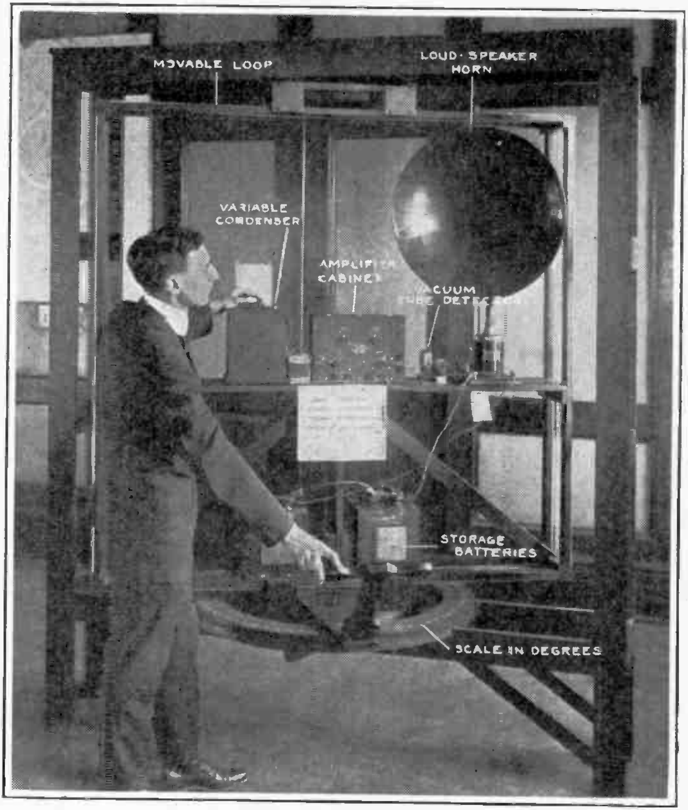
Small Dubilier receiving condenser. The tube contains the grid-leak.

Everyday electric alternating current used for house lighting has a frequency of 60 cycles per second, or a time period of 1/60 second. This is a much faster vibration than either the swing or the pendulum we have considered, but is right in the musical frequency range and corresponds to a tone about two octaves below middle C.

Free Electrical Oscillations

The alternating currents we have just considered are not free or natural electrical vibrations, for their frequency of alternation is determined by the frequency of the voltages developed by the dynamo machine. The current that flows through the circuit connected to this alternator is forced to follow the voltage which sets it up, both as to direction and amount of flow, and hence as to frequency. It is, true enough, an electrical vibration, but it is a forced vibration. The dynamo voltage forces the current to flow in a given direction, and with a given intensity, by main strength.

There is another sort of alternating current generating system, however, in which the electrical oscillations are not forced. If we connect an electrical *condenser* in circuit with a coil of wire, which has the electrical property called *inductance*, we make a system which is capable of freely oscillating electrically. If such a circuit is provided with a battery and a charging switch, as shown in Fig. 5, as well as with a discharging switch, it may be used for the purpose of generating alternating currents. The working of such an arrangement, complicated as it may appear at first sight, is not hard to understand if one considers each portion of the system separately.



Loop which when turned indicates the direction from which waves are coming. Such a loop constitutes what is called a radio-compass. By its means ships can find their way through fogs and starless nights.

Some coils used in radio receiving sets have more than one layer. Here we have a coupling coil with a type of winding resembling a lattice. This type of coil is variously called "lattice wound," "celular," "basket wound," "honeycomb." In this type a winding of given inductance occupies a smaller space than if a single-layer winding were used, and the distributing capacity of the winding is small. The type doesn't give very satisfactory results on wave lengths less than 2,500 meters.

In the first place, let us look at the battery, the charging switch and the condenser. The electrical condenser is merely a pair of electrical conductors of somewhat large surface arranged so that their faces are close to, but not in contact with each other. Two sheets of tinfoil placed on opposite sides of a sheet of thin glass will make an excellent condenser for many purposes; two plates of copper each about two feet square, hung freely in the air about half an inch apart, give us another useful form. The glass in the first type and the air between the plates in the second arrangement, serve to keep the two plates electrically apart so that current cannot flow directly from one to the other. Yet the two comparatively large surfaces are allowed to act upon each other so as to develop the outstanding property of an electrical condenser, namely, *capacitance.*

This *capacitance* (formerly called capacity) measures the electrical size of a condenser, and shows the quantity of electricity which may be stored in a condenser at any given voltage or electrical pressure. A condenser is to electricity about what a toy balloon is to gas; one can charge a condenser with electricity just as one can blow up a rubber bag with gas. Electricity is stored in a charged condenser; gas is stored in an inflated balloon. If a gas-bag is filled from a pump producing some certain definite pressure, it will be possible to store a certain amount of gas in the balloon, and no more; the restoring force produced by the stretched walls of the bag will at some point be equal to the force of the pump, and no more gas will go into the balloon. The amount of gas that can be stored at some particular pressure will measure the size of the balloon for storage purposes. In the same way, if

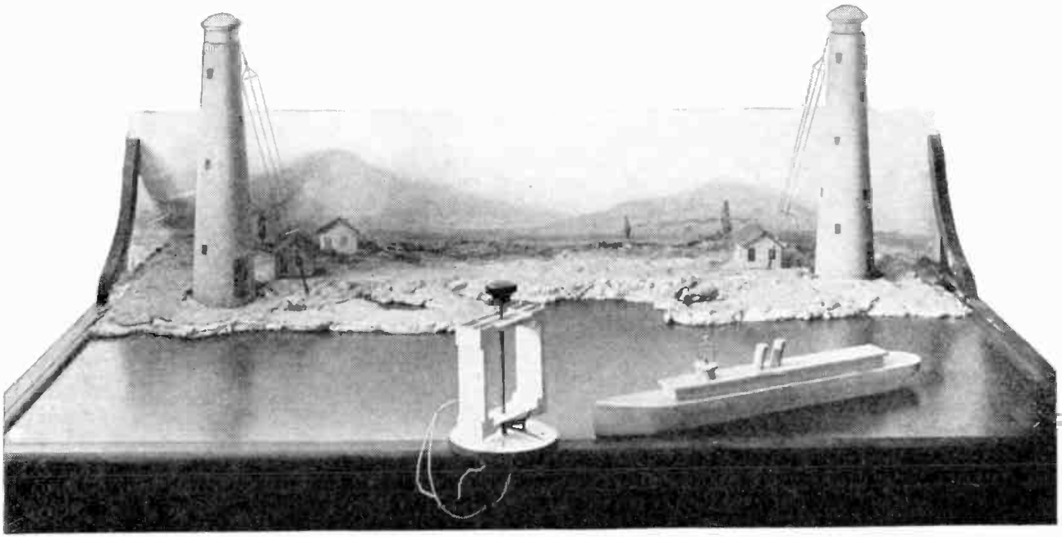


Photo by Bureau of Standards

This model was built to show how the radio compass which is dependent on a loop (in the foreground) can help ships to find their way through fogs. The system illustrated is that developed by the Bureau of Standards.

a condenser is charged at a definite electrical pressure or voltage, it will hold just so much electricity and no more; the restoring force developed in the condenser will prevent more electricity from entering as soon as the force becomes as great as the charging pressure. Thus, the quantity of electricity that a condenser will hold at some definite voltage will measure the size or capacitance of the condenser for storage purposes. In general, the capacitance is larger the greater the oppositely exposed surfaces of the

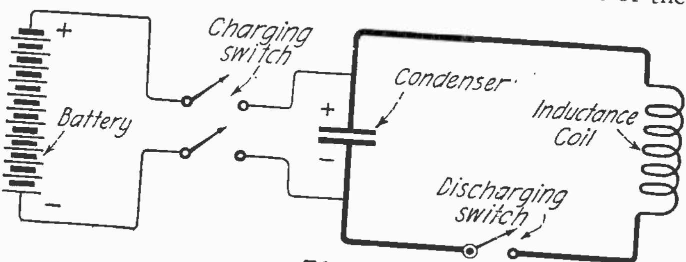
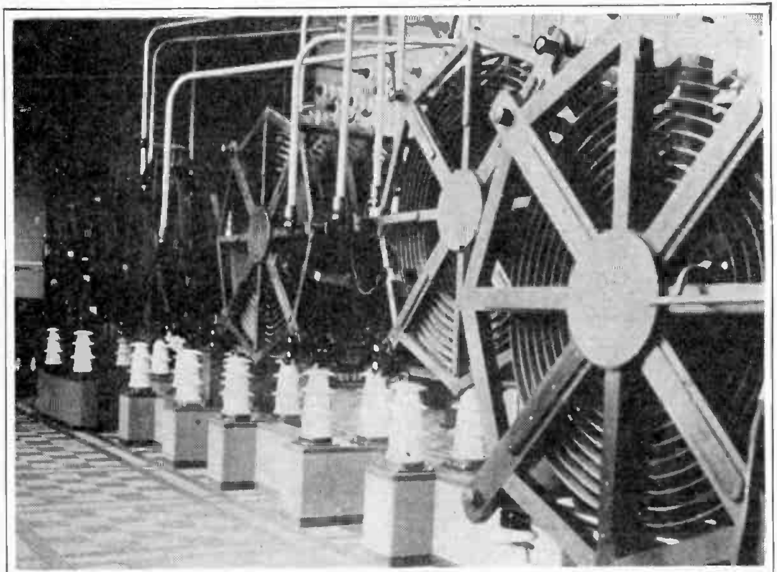


Fig. 5

A condenser-coil or oscillatory circuit, provided with charging battery and switch in addition to a discharging switch. Oscillations are produced in the inductance coil circuit shown in heavy lines.

condenser plates and the closer the separation between them.

We should now be able to see that if the charging switch between the battery and the condenser in Fig. 5 is closed, a certain amount of electricity will flow into the condenser from the battery. This amount will be greater the larger the capacitance of the condenser and the higher the potential or voltage of the battery. For the condenser to charge in this way, however, the discharging switch



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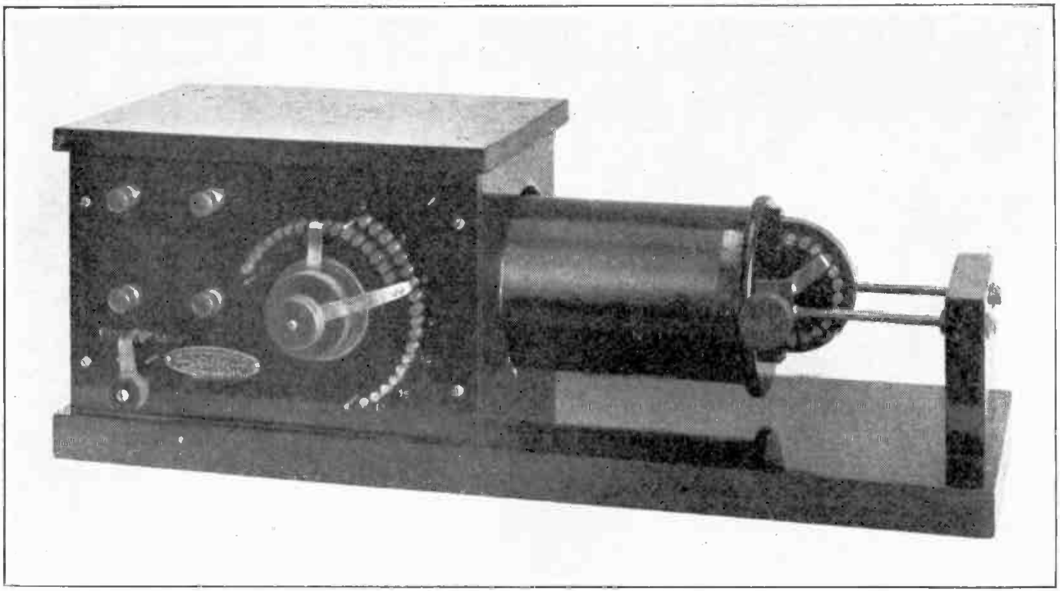
The variable inductors of the great radio-station at Nauen, Germany.

also shown in Fig. 5 must be open, so that current cannot flow around the condenser through the wires leading to the inductance coil shown.

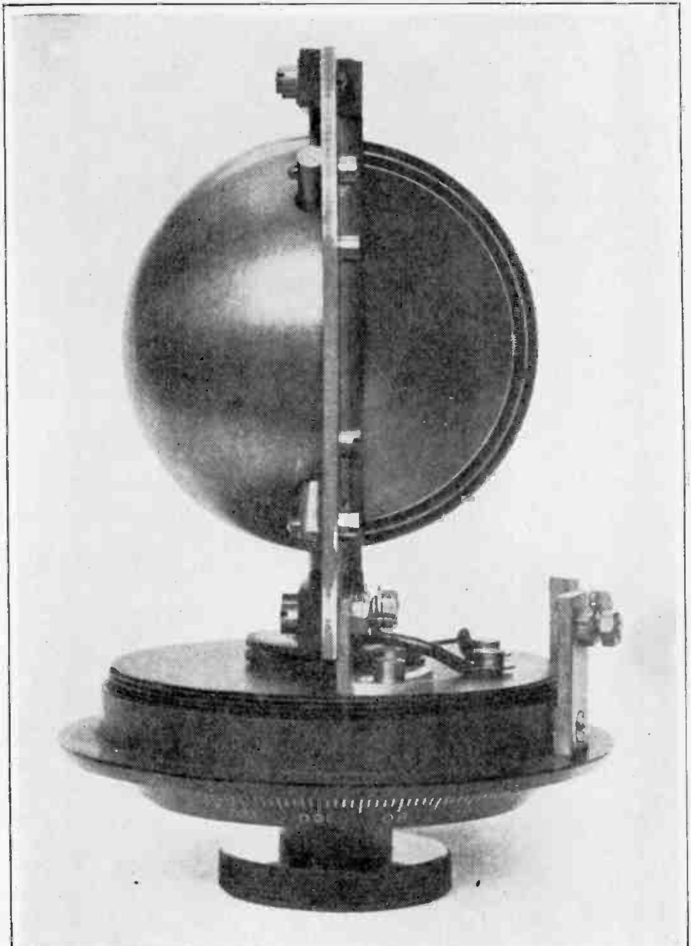
Having charged the condenser, we may open the charging switch. This leaves the condenser filled with electricity. The upper plate (Fig. 5), which was connected to the positive terminal of the battery, is of high potential; the lower plate is of low potential; the potential difference of the two plates is the same as the voltage of the charging battery. In fact, this charged condenser is just like a battery provided with only a limited quantity of electricity; it can, by reason of its charged voltage, set up a current in any electrical circuit connected across its two plates or terminals, but the amount of current which will flow is limited by the amount of charge that the capacitance of the condenser permitted it to draw from the charging battery.

Suppose now that we close the discharging switch. This act provides a direct electrical circuit from one side of the condenser through the inductance coil to the other side, as shown in Fig. 5. The electricity stored in the condenser must discharge through this circuit as a current from the high potential plate to the low potential plate, passing through the inductance coil.

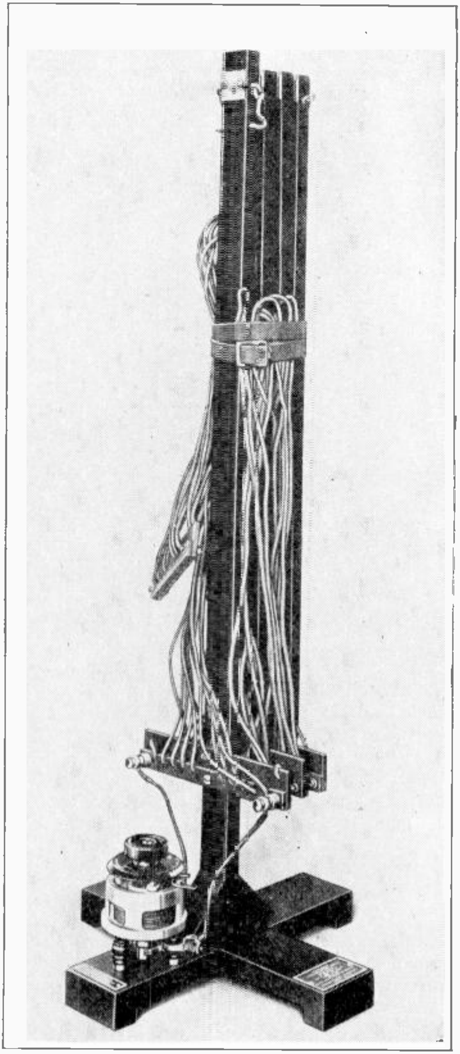
We come now to what is probably the most interesting thing about condenser-coil circuits of this sort. If the circuit is a good one, that is, if it has not such high resistance that electricity will not flow freely through it; the effect of the coil will cause the current to keep on going after the condenser is fully discharged. The current in passing through such a coil will gain a sort of momentum; it will not die away when the condenser



In this receiving transformer, one primary switch has thirty-four turns between points, and the other switch has two turns between points. The secondary switch adjusts by groups of turns, fine tuning is accomplished by a variable condenser. The coupling between the primary and the secondary is loosened by pulling the secondary out of the primary. The switches of the transformer are adjusted until the approximate wave length range of the station which it is desired to receive, is reached. The secondary circuit is then turned by a variable condenser to the station which it is desired to receive.



Another view of the British Government's ball condenser with one of its hemispheres partially turned.

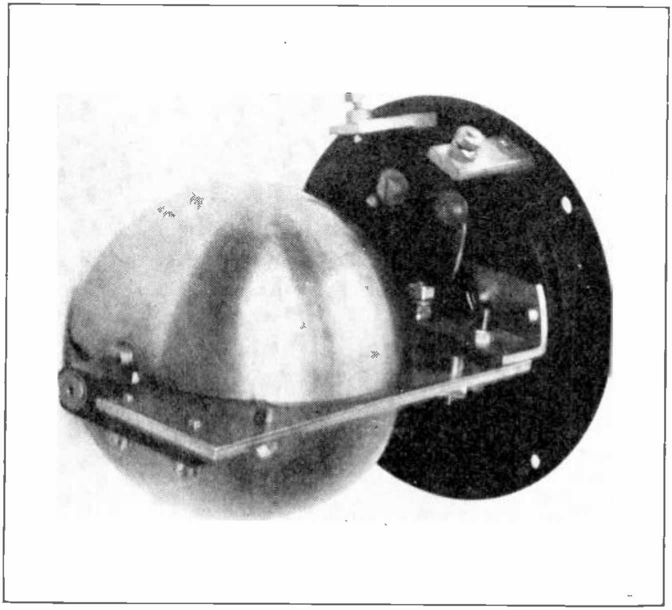


A collapsible loop-antenna in its "knocked - down" position.

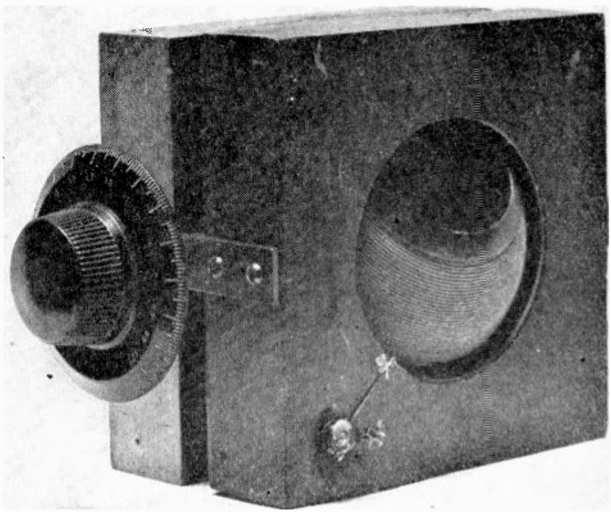
voltage has fallen to zero, but will overshoot and pile up on the condenser plates in the opposite direction of charge. By reason of this peculiar action, the condenser will again become charged, but in the opposite sense; the upper plate will now be negative and the lower plate positive. However, some electricity will have been lost in passing through the circuit, and the new charge will be of somewhat smaller potential than was the initial charge. Otherwise the conditions will be as they were when the charging switch was opened and the discharging switch closed; the new reversed charge in the condenser will discharge through the coil in the opposite direction, and will again overshoot enough to charge the condenser a third time. Now the polarity will be as it was originally; the upper plate will be positive and the lower negative, but the amount of electricity in the condenser will, of course, be still less.

It is easy to see that the co-operative action of the coil and the condenser will cause, for a single initial charge, a long series of discharges which alternate in direction and which gradually die away in intensity. Thus there is produced in the condenser-coil circuit an oscillatory discharge, an alternating current which persists for many complete cycles but which finally dies away and which cannot thereafter be renewed until the condenser is again charged from the prime source (in this instance the battery). The number of complete oscillations produced by such a discharge may easily be several hundred, before the current falls off to small values.

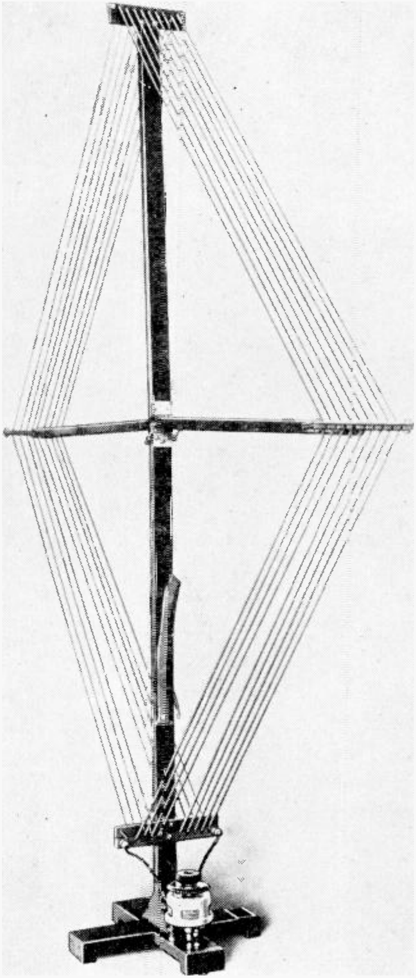
What is it about an ordinary coil of wire that will cause a current through it to show a sort of inertia or momentum effect? Why does the condenser discharge current, passing through the coil, keep on going after the



The British Government during the year introduced this ingenious ball condenser. It consists of three concentric hemispheres which can be rotated to vary the capacity. Once adjusted the capacity is permanent; no sag is possible.



This is a Variometer of the usual type used in ordinary radio practise.



The collapsible loop-antenna extended for connection with the receiving set.

condenser voltage has become zero, so as to charge the condenser again in the opposite direction? The answer to both of these questions lies in the property of *inductance,* which is possessed by any conducting wire, but which appears in more concentrated or exaggerated form when the wire is coiled up into a spiral. This electrical property of inductance is analogous to the mechanical property of *mass;* it gives rise to inertia or the tendency to keep things as they are. Mass in a pendulum causes the weight to swing past the position of rest, so as to travel part way against the restoring force and prepare for the next swing. Inductance in an electrical circuit causes the current to persist beyond the condition of zero voltage, so as partly to charge the condenser for the succeeding discharge. Any coil of wire possesses inductance; the more turns, the closer the turns to each other, and the greater the area enclosed by each turn, the greater the inductance of the coil.

Natural Electrical Frequency

When a condenser-coil circuit such as that shown in Fig. 5 produces electrical oscillations or alternating currents of gradually decreasing intensity, what governs the frequency of these oscillations? Reasoning that the inductance of the circuit corresponds with the mass of the torsion-pendulum weights, and that the capacitance of the electric example is comparable to the flimsiness of the spring in the mechanical case (since the condenser is what supplies the restoring force in the electric circuit), one might conclude that the frequency of vibration would depend upon the amounts of inductance and capacitance

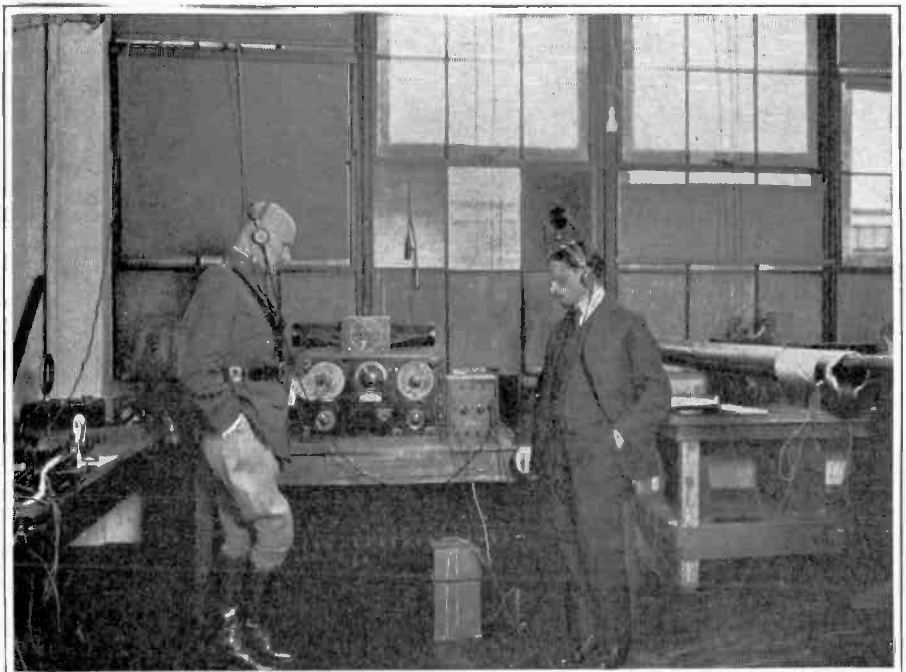


Photo by Bureau of Standards

"Static" is the bugbear of radio. In the receiver it sounds like frying fat. It is caused by lightning and other electric discharges. General Squier is here shown experimenting with a "static eliminator."

which are effective in the electric circuit. This conclusion would be exactly right; the analogy is close and complete. We may make the natural frequency of a condenser-coil circuit almost what we will, merely by changing the size of the condenser and of the coil. Since the natural electrical discharge of the condenser through the coil is always of the free frequency of the circuit, by changing the inductance and the capacity, or either of them, we may vary the frequency of the oscillations generated by such a circuit.

The arithmetical rule for finding the natural frequency is simply to multiply the inductance in henrys (the practical unit) by the capacitance in farads, take the square root of the product, multiply this root by 6.28 and find the reciprocal of the new product. This reciprocal is the natural frequency of a circuit having the effective capacitance and inductance used for the calculation. The practical value of such a rule is that it enables us to find the natural frequency when we know the size of the coil and the condenser, and that it shows us that the frequency becomes higher and higher as the size of the coil and of the condenser are decreased.

Although it is easy to build vibrating electrical circuits having natural frequencies within the range of musical tones, those used in radio signaling ordinarily have much more rapid rates of vibration. Whereas the musical scale runs from about 16 to about 4,000 cycles per second, and while frequencies even lower and higher than these are audible and hence come within the range of so-called "audio frequencies," the radio frequencies are usually considered to begin at about 10,000 cycles per second and run on up to several millions per second. By proper choice of coils

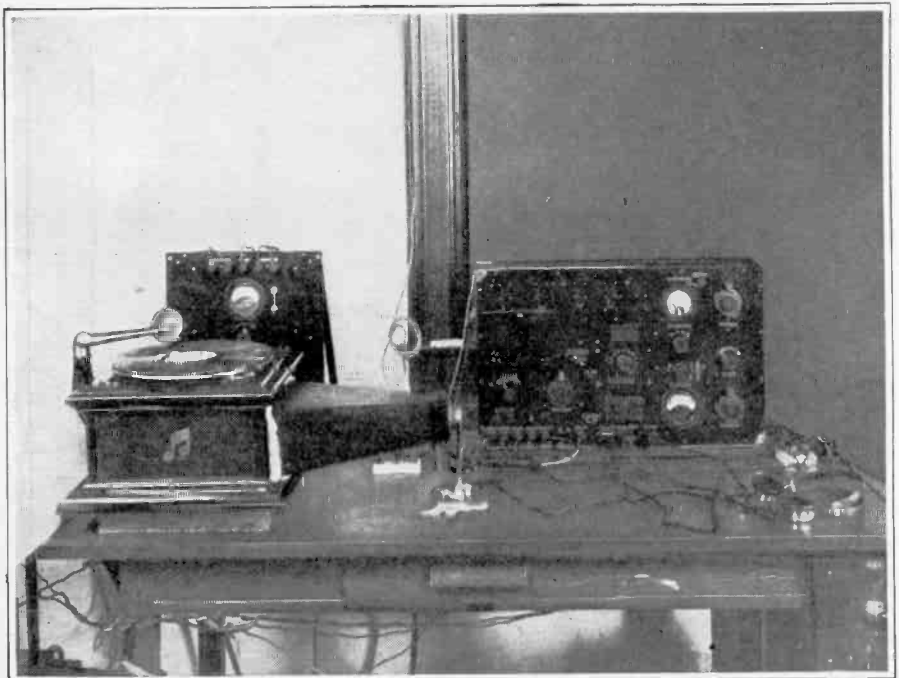


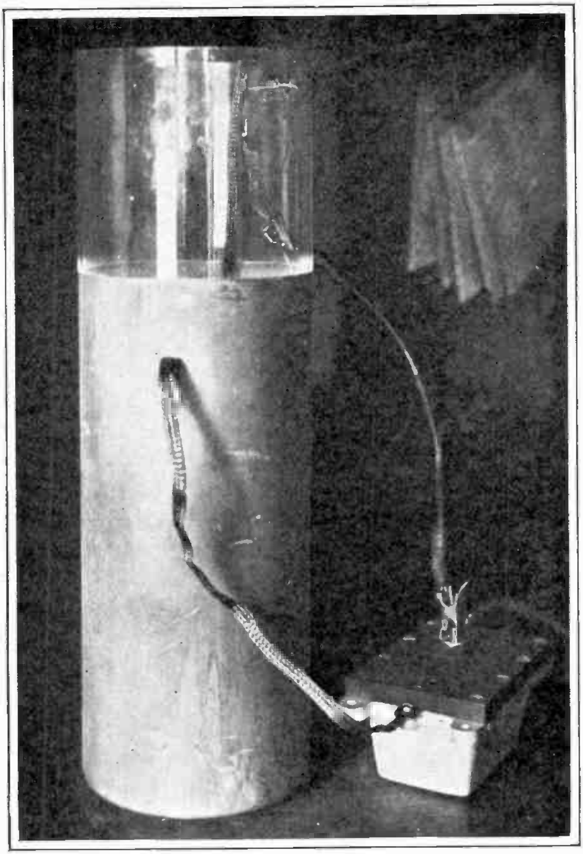
Photo by Bureau of Standards

Instead of using a microphone transmitter in place of the reproducer of a phonograph an extension may be built on the horn of the phonograph. This extension is connected with a telephone transmitter, as here shown.

and condensers it is not difficult to set up oscillating electrical circuits with natural frequencies even as high as these. Thus we have found a way to produce free electrical oscillations with these enormously high frequencies that are used in radio.

The Radio Frequency Generator

The discharge of a condenser through a coil in an oscillatory or resonant circuit is not the only way we have to produce these radio frequency currents, however. In spite of the fact that the ordinary power alternator generates alternating current of only 25 or 60 cycles per second, it has been found practicable to increase the speed of special dynamos to the extent that they can directly produce alternating currents of 100,000 or even 200,000 cycles per second. Such high frequencies are entirely suitable for use in radio transmission. The electrical currents made by such generators are forced oscillations; they are constant in intensity, and do not die away and require renewal charges ever so often. In addition to the alternator of radio frequency, which is due primarily to Professor R. A. Fessenden and in its present-day detail to E. F. W. Alexanderson and others, there have been discovered several ways to keep a condenser-coil circuit operating constantly and to prevent its oscillations from decreasing in intensity. Among these is the Poulsen arc, which takes the place of the discharge switch in Fig. 5, and the Armstrong regenerative circuit for the vacuum tube, which is described by Professor Morecroft in the present series of pamphlets. All of these generators pro-

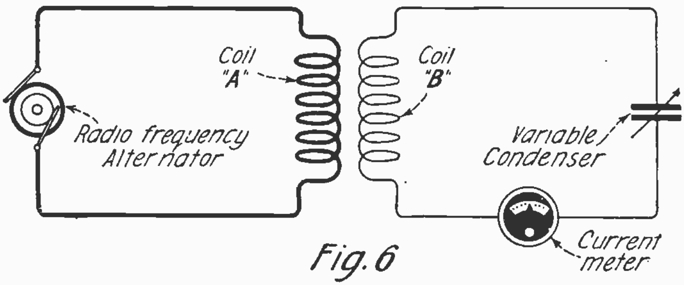


To the left is the standard Leyden jar which was long used in radio; to the right is the modern Dubilier mica condenser which has taken the place of the old Leyden jar throughout the world. The old Leyden jar was fragile. Sometimes it was broken by a salvo on a battleship with the result that the entire wireless set was rendered useless. It was also responsible for what are called brush charges, which generated ozone gas and induced headaches. All these objections are overcome by the modern mica condenser.

duce in effect a smooth alternating current of controllable radio frequency. With the alternator, the frequency is changed by altering the speed of the machine; with the arc and vacuum tube, the frequency is controlled by varying the capacitance or inductance of the oscillating circuit.

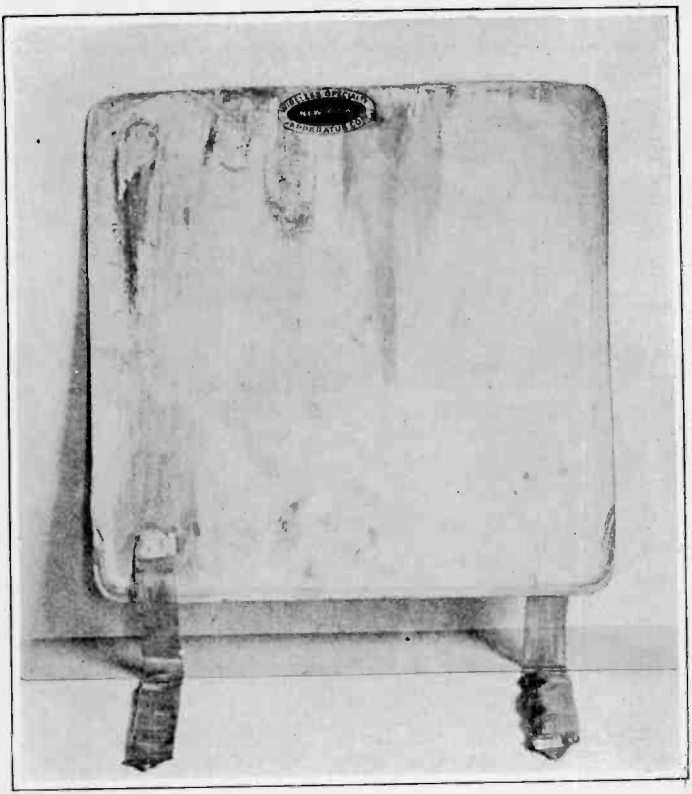
Coupled Radio Circuits

Let us now consider a circuit such as that shown in Fig. 6. Here a generator of radio frequency currents is shown

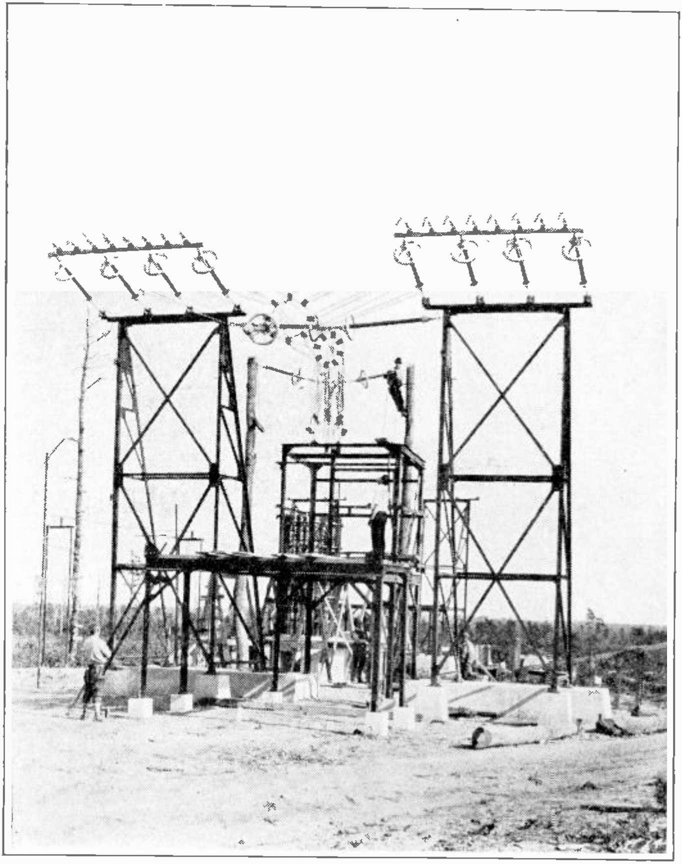


How a high-frequency dynamo may be arranged with a two-coil transformer to produce radio currents in a coupled condenser-coil circuit.

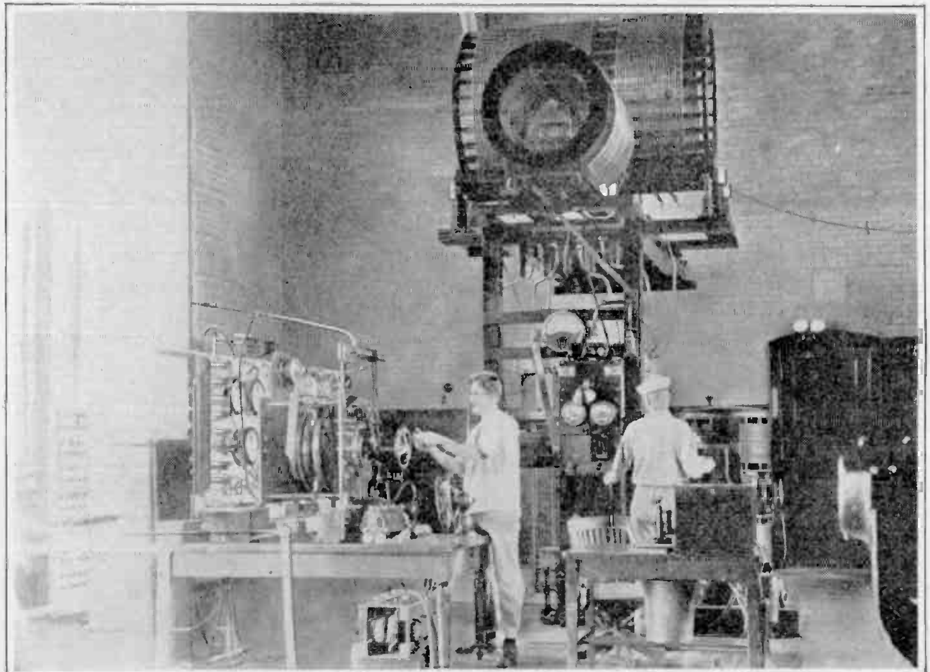
at the left, connected to an inductance coil marked A. The alternating voltages produced by the generator will force alternating current of corresponding frequency through coil A. The magnetic field around this coil will induce voltages of the same frequency in coil B, which is connected in series with a current indicating meter and a condenser whose capacitance may be varied. What will



A Leyden jar consists of a thin glass vessel coated inside and out with metal foil. Connection is established between the two coatings to charge and discharge the jar. When it was discovered that the electricity is connected by the coatings, condensers were made in the form of glass plates, as here shown. These are called parallel plate condensers and consist of alternating layers of dielectric (glass in this instance) and conducting material (metal foil).



Wires leading in from aerial to large outdoor tuning coil at the Port Jefferson station.



Large tuning coil in the Arlington Station (Washington). To the left a small transmitting set.

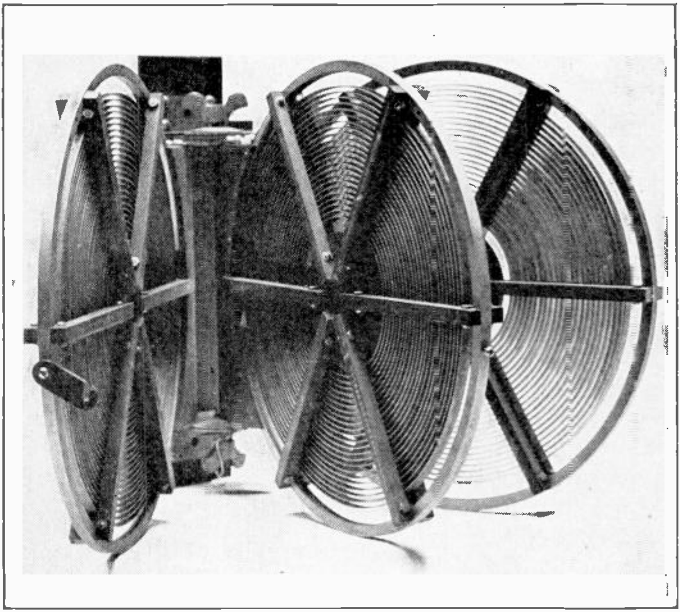
happen in this second circuit, containing coil B and the condenser?

It should be evident that we have here an electrical case which may be compared with the torsion pendulum driven by rolling the twist-rod between the thumb and finger. The condenser-coil circuit at the right is an electrical system having its own natural frequency, which frequency we may control by changing the size of the condenser. This system is impulsed periodically by the alternating voltages induced upon the coil B from the forced electrical vibrations or currents flowing from the generator through coil A. We should expect that it would be difficult to produce a current in the circuit of coil B unless its natural frequency agreed with the frequency of the driving or applied electrical forces, and this is exactly the case. The natural frequency of the coil B circuit may be varied by changing the capacitance of the condenser; as this frequency is brought more and more exactly into agreement or resonance with the frequency of the alternator, the current in the coil B circuit will increase to a maximum value.

Thus we see that to produce the greatest current in a second circuit associated with or coupled to another in which an alternating current is flowing, we must adjust the natural frequency of the second circuit to agree with the frequency of the driving current. This is called *tuning* the second circuit.

The Antenna or Aerial Circuit

So far we have considered only coil and condenser circuits, in connection with their natural frequencies. Nevertheless, what we have learned may be applied to any elec-



A Navy loose coupled tuning coil used in portable or pack sets.

trical circuit which possesses the properties of inductance and capacitance, whether or not it contains either coils or condensers. For instance, instead of the inductive effect being produced by a coil of several turns, it is possible to supply the requisite inductance by means of a single turn loop enclosing a considerable area. Instead of using a two-plate or multiple-plate condenser, the necessary capacitance may be found in a network of wires supported above the earth and connected to it through the circuit. Clearly, such an elevated group of wires will take the part of one condenser plate while the surface of the earth (which is a good electrical conductor) will act as the other plate of the condenser. The fact that wires are

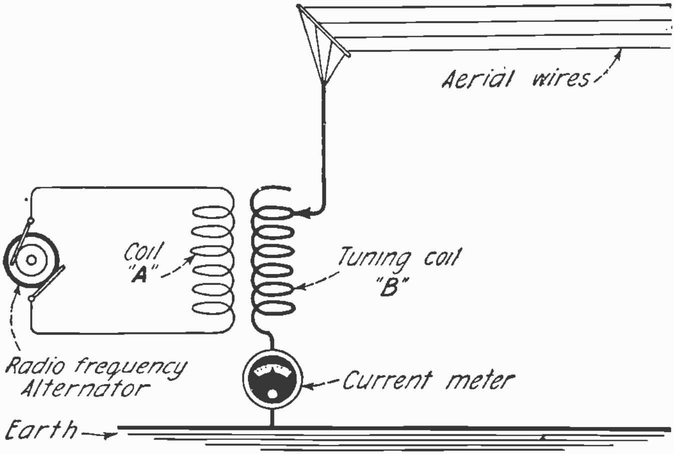
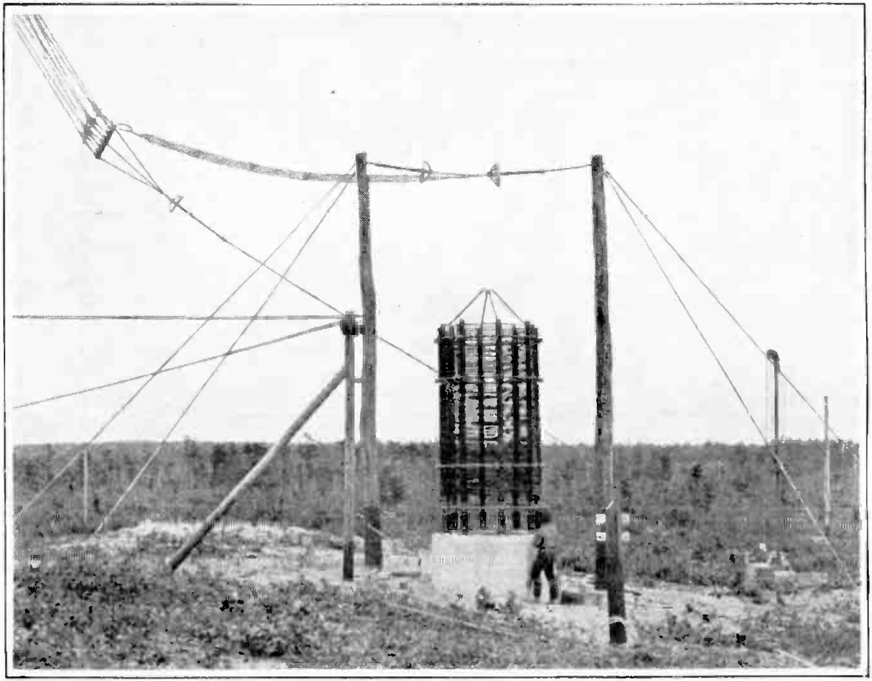


Fig. 7

As shown here, an elevated antenna wire system and earth connection may be substituted for the condenser of a resonant circuit.



The outdoor coil for tuning the antenna of the great trans-Atlantic station at Port Jefferson, L. I.

hung quite high above the ground will necessarily reduce the capacitance of the system, but this will largely be compensated for by the great extent of the aerial wires (which may be several hundred feet in length) as compared with the size of ordinary condenser plates.

With this in mind, we may re-draw Fig. 6 in the form of Fig. 7, where the condenser connected to coil B has been replaced by an aerial and ground corresponding to the upper and lower plates of the condenser. Because of the capacitance of the aerial with respect to the ground, taken in connection with the inductance of the coil B, such a system will have a definite natural electrical frequency just as had the condenser-coil circuit. However, the capacitance is now fixed by the size of the particular aerial employed, and so in order to vary the natural frequency of the circuit it is necessary to make the inductance of the coil B adjustable. This is indicated by the arrow-tipped connection, which may be moved from turn to turn until the best value of inductance is found. When the inductance coil is made adjustable in this way, it is usually called a *tuning coil.* By changing the amount of inductance, the antenna circuit may be brought into resonance with the frequency of the driving alternator, as already explained in the case of the condenser circuit, so as to secure the greatest possible current flow at radio frequency between aerial and ground.

Creating Radio Waves

Whenever rapidly-alternating or radio frequency currents flow in an aerial-and-ground system such as that

How the antennae are connected with the great Lafayette Station in France.

shown in Fig. 7, they produce radio waves in space around the aerial. These waves shoot off in all directions from the aerial, and pass outward over the surface of the earth at the speed of 186,000 miles per second. The waves are electro-magnetic disturbances of the all-pervading medium of transmission that we call the *ether* of space, and, except for their frequency, are similar to light and heat waves that travel through this same ether. The frequency of the radio waves is exactly the frequency of the currents that produce them; if the radio frequency alternator of Fig. 7 is operating at 100,000 cycles per second, the currents in the antenna or aerial circuit will be of 100,000 cycles per second; the radiated waves will also be of this same radio frequency.

We imagine the radio waves to spread outward from the sending station in ever-increasing hemispheres, somewhat as indicated in Figs. 8 and 9. Fig. 8 shows roughly a side view of the antenna and the waves leaving it in opposite directions, as indicated by the arrows. Fig. 9 is

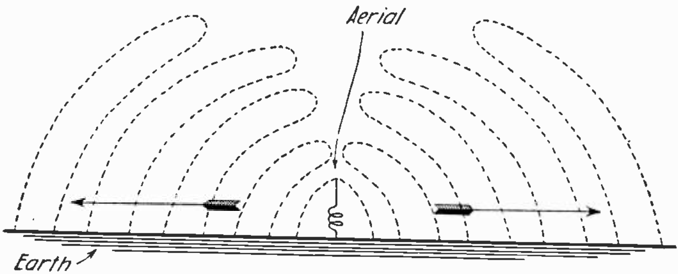
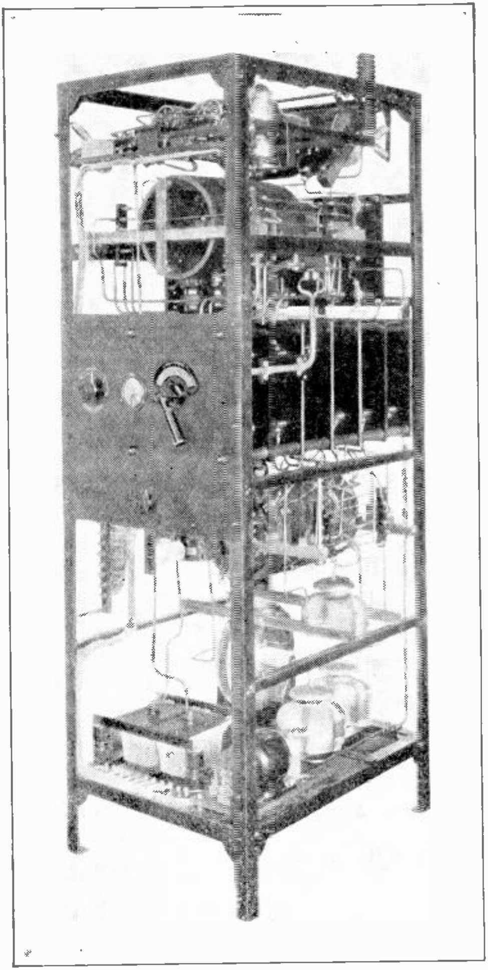


Fig. 8

This illustration shows how the radio-waves are imagined to pass out over the earth's surface from a sending aerial.



Duplex radio telephone transmitter radio unit, showing tuning inductance (coil at the top) and wave changer (handle on panel) for tuning to different wave lengths. By "duplex telephony" is meant telephony that makes it possible to talk and listen with the same apparatus.

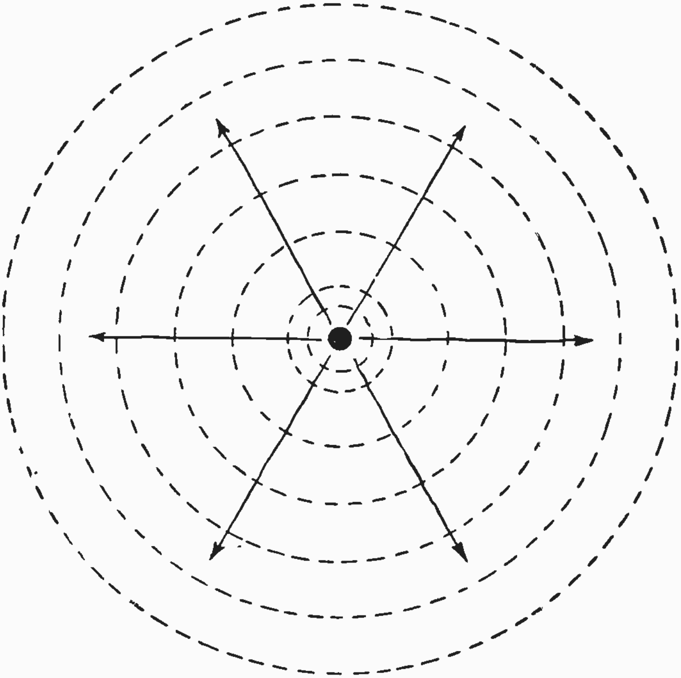


Fig. 9

Looking down from directly above a radio station. The waves are found to spread outward in all directions, as suggested by the arrows and ever-widening circles.

a plan representing the way in which the waves spread out in all directions from a radio station. At the tremendous speed with which they travel, radio waves will cover nearly 200 miles in 1/1000 of a second.

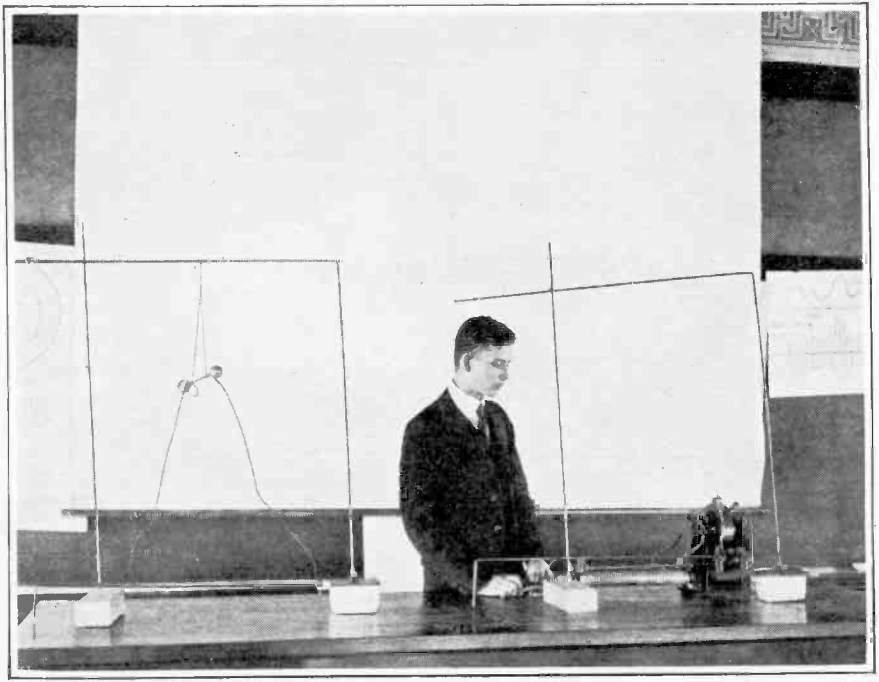


Photo by Bureau of Standards

Model built by the Bureau of Standards to illustrate how an electric circuit can produce waves of high frequency, which waves are received by another circuit tuned to resonance. The box-like casings on the table from which the poles protrude up are Dubilier mica condensers.

Intercepting Radio Waves

The radio wave travelling outward through the ether is a combined magnetic and electric disturbance that gradually grows weaker as it passes farther and. farther from the sending station. So long as it retains enough strength to be recognizable, however, it will induce electric pressures or voltages in any conductor which it strikes. Just as a water wave will float a bit of wood up and down as it passes by, so will a radio wave set up electrical motions or currents in any circuit through which radio-frequency currents can readily flow. This is the property upon which we rely to receive radio messages. Antenna wires are thrust upward into the air and provided with ground connections; in them feeble currents are produced by the passing radio waves, and these currents are used to operate the radio receiving instruments. The aerial conductors may be of any form whatever; a single wire dropped from a flag-pole, a T-shaped group of wires, or an enlarged umbrella-like structure will operate satisfactorily. Major-General G. O. Squier has discovered that living trees possess sufficient electrical conductivity to intercept and bring down strong enough radio frequency impulses for practical reception of messages by wireless. Even a coil or loop of wire within a building, forming what is known as a loop aerial, will pick up enough power to operate the most sensitive modern radio receivers.

What can we do to get the greatest amount of current in our receiving aerial systems, so as to make their effects as large as possible? The answer to this follows from what has gone before. Once more we have an electrical circuit which is impulsed by a radio frequency electrical

Photo by Bureau of Standards

Here a large resonance-wave coil-antenna (Rolling Pin type) is shown, mounted for transmitting.

force, the force in this case being in the arriving wave. We have learned that to secure the greatest response to such an alternating force, we must tune the driven system. In our present problem, then, we must provide the receiving aerial system with capacitance and inductance in such proportion that its natural frequency will be the same as the frequency of the wave which we desire to receive. The receiving aerial already supplies us with the necessary capacitance; consequently we need only to insert the proper amount of inductance as a tuning coil between the aerial and the ground connection, as indicated in Fig. 10. By adjusting this coil, the aerial system may be tuned so that its natural frequency will be the same as the frequency of the arriving waves; under this condition we will secure the largest possible radio frequency current in the aerial for a given voltage induced by the waves. The receiving instrument used may be connected directly to this tuning coil, or, as suggested in Fig. 10, another tuned condenser-coil circuit may be coupled to it and the converter and receiver (to be described in a later pamphlet) connected to that circuit.

Interference

When the natural frequency of the receiver agrees with the frequency of the received wave, the greatest current is generated in the receiving system by that wave. Other waves from other transmitters, at different frequencies, will produce less than the greatest or maximum resonant current; hence their effects on the receiver will be less-

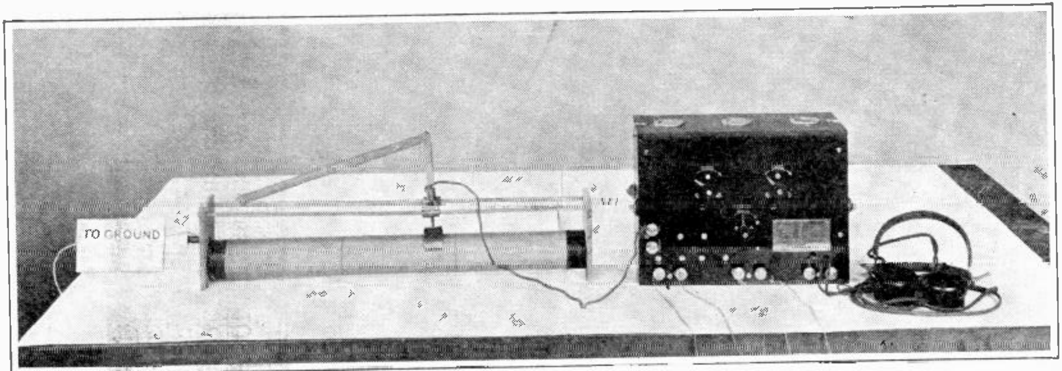


Photo by Bureau of Standards

Here we see the "Rolling Pin" antenna—a compact cylindrical multi-turn coil—with amplifier for receiving.

ened, and we have a simple means (in the tuning of radio circuits) to reduce "interference," as the unwanted signals heard from disturbing transmitters are called.

If we use a second tuned circuit coupled to the antenna circuit of our receivers, as in Fig. 10, we gain the selective power of two tuned adjustments in succession. In this

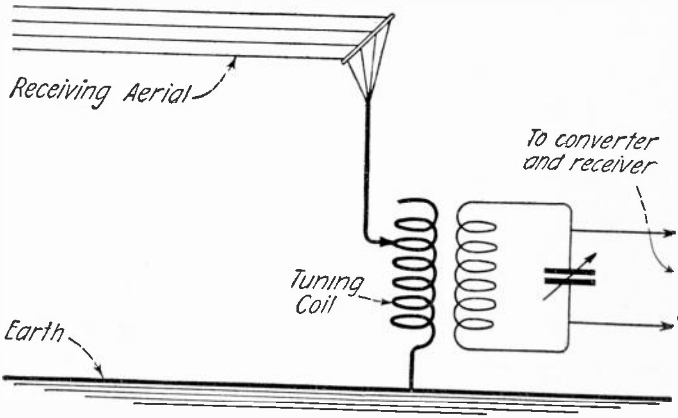


Fig. 10

A receiving system of this kind combines an aerial tuning coil with a closed resonant circuit so as to produce a highly selective arrangement.

way it is possible to secure sharp resonant effects, in which the desired or tuned incoming waves produce a relatively large current while interfering waves of slightly different frequency set up little or no current. Under these conditions the selectivity of the receiver is said to

General Squier some years ago made the discovery that the electric wires that enter our homes act as antennae. Here he is shown seated at an electric lamp which is connected with the receiving apparatus on the table in the background.

be high, or the tuning sharp. The less electrical resistance in any resonant radio circuit, the sharper will be its tuning; a two-circuit or coupled receiver permits control of the effective resistance conditions, and, although more difficult to adjust, is capable of greater selectivity or discrimination between desired and unwanted signals of slightly different frequency.

There is another kind of interference, however, which does not arise from other radio stations transmitting waves of definite frequencies differing from that which it is desired to receive. This is "atmospheric" or "static" interference, produced by electrical discharges in nature, by lightning storms, etc. Static interference does not appear to have a definite wave frequency, and hence it cannot be tuned out by simple resonant methods. Fortunately, these natural disturbances do not persist all year long nor at all times of day. Neither are they powerful enough to cause trouble in normal broadcast radio reception, except under extreme conditions or when the incoming signals are weak. There is less static interference, in Northern latitudes, in Winter than in Summer; frequently there is less in the early evening than during the day, even in Summer. All of this favors broadcast radiotelephone operations.

Radio Frequency and Wavelength

In this pamphlet we have considered mainly the *frequency* of the radio waves, because that is the characteristic most closely associated with tuning effects. There is another term much used in describing radio waves, however, viz. *wavelength*. The wavelength is simply the dis-

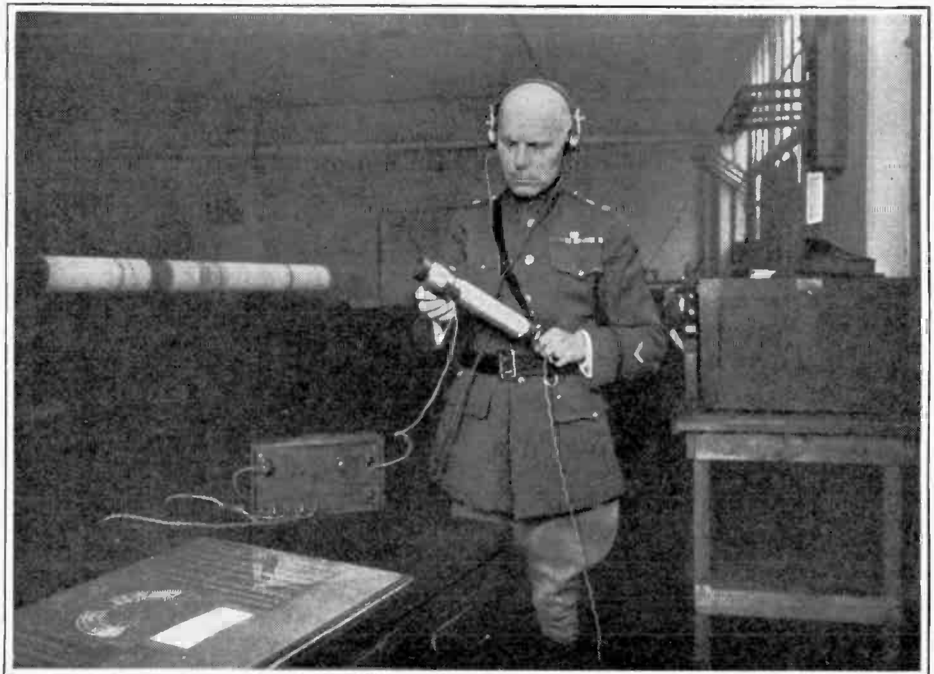


Photo by Bureau of Standards

General Squier is here shown, holding in his hands what is called a "Rolling Pin" type of antenna because of its characteristic shape.

tance from crest to crest of the radio wave we imagine in the ether; it is usually measured in meters (one meter equals 39.37 inches) instead of in the more common English unit of feet. The wavelength is intimately connected with the wave frequency; either constant of a radio wave may be found from the other by dividing into the wave velocity factor of 300,000,000 meters per second. A wave of frequency 833,000 cycles per second has a length of 360 meters. A 1,000 meter wave has a frequency of 300,000 cycles per second. Other corresponding values are given in the following table:

Wave Frequency	Corresponding Wavelength
10,000 cycles per second	30,000 meters
20,000 " " "	15,000 "
30,000 " " "	10,000 "
50,000 " " "	6,000 "
100,000 " " "	3,000 "
150,000 " " "	2,000 "
200,000 " " "	1,500 "
300,000 " " "	1,000 "
400,000 " " "	750 "
500,000 " " "	600 "
600,000 " " "	500 "
750,000 " " "	400 "
833,000 " " "	360 "
1,000,000 " " "	300 "
1,500,000 " " "	200 "
2,000,000 " " "	150 "
3,000,000 " " "	100 "

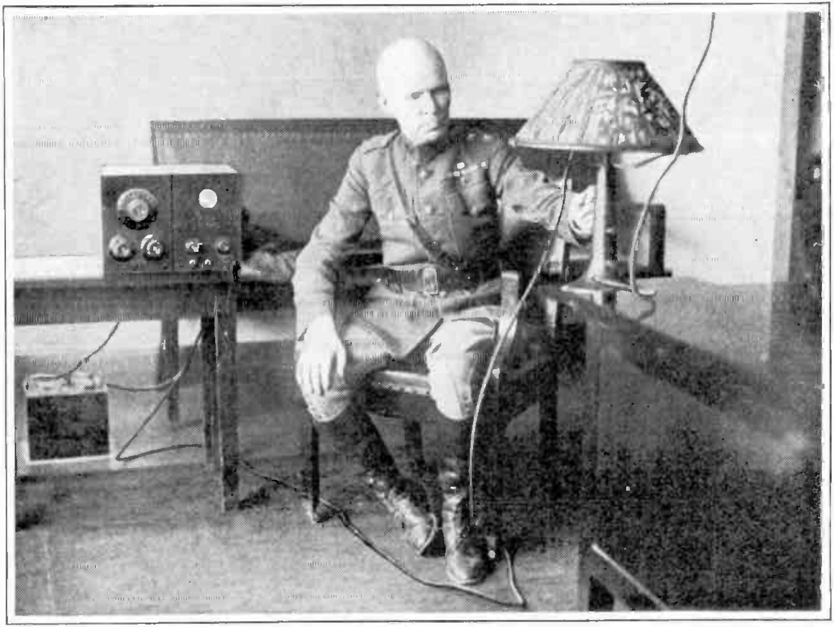


Photo by International

Major - General Squier has discovered that any electric light wire is an antenna. Simply connect your receiver with a lamp-socket, through the medium of a suitable condenser and you hear just as well as you would with an antenna. The General is here shown seated at a lamp with which the proper connections have been made with the set on the table behind him.

There is, of course, a multitude of wavelengths and frequencies between the limits of the above table, where only those in round figures are given. Each different wave frequency provides a channel for communication by radio, but even under ideal practical conditions the closest adjacent frequencies cannot be used for simultaneous operation without setting up interference. With good modern apparatus, however, independent and non-interfering signaling can be carried on upon frequencies differing by 10,000 cycles or more, so long as the difference in intensity at the receiving station (where resonant selection must, of course, be accomplished) is not too great.

Survey of the Tuned System

Tuning is evidently an essential throughout the entire radio sending and receiving system. At every point we are dealing with alternating electric forces, and always we desire to produce the maximum effects consistent with the voltage and power available. Consequently we tune the transmitting antenna to coincide in frequency with the generator, and we tune the receiving antenna to coincide with the wave frequency. From the beginning to the end of the radio circuits the working frequency remains the same in ordinary practice; if our generator delivers a frequency of 833,000 cycles per second, this also will be the frequency of the sending antenna current and of the radio waves it produces. The receiving aerial will be tuned to 833,000 cycles, and the currents flowing in it will have that frequency. If it were not for the principle of resonance, as exemplified by the timing of pushes to agree with the natural rate of the child's swing, radio in its modern forms would be a practical impossibility.

You have now seen how a stream of waves can be produced at a radio sending station, how the waves will spread outward for miles in every direction, and how their effects may be intercepted at any point within range of the transmitter. In order to understand how this system is used for the transmission of messages either by the dots and dashes of the Morse code (in wireless telegraphy) or by the spoken word (in radio telephony) you need only to grasp the idea of how the signals themselves are impressed upon and carried by the radio waves, and how, at the receiving station, they are first separated from the radio frequency currents which the waves produce and then applied to a responding instrument. This general topic of signaling is the subject of the next pamphlet.