NATIONAL RADIO INSTITUTE

Complete Course in PRACTICAL RADIO

NRI

Radio-Trician

(Trade Mark Reg. U. S. Patent Office)

Lesson Text No. 9

3rd Edition

PRINCIPLES OF RADIO COMMUNICATIONS

Originators of Radio Home Study Courses

••• Established 1914 •••

Washington, D. C.

"Resolve to be Self Independence thyself; and know, that he who finds himself, loses his misery."—Coventry Kearsey Deighton Patmore.

ACCURACY HABIT

A Personal Message from J. E. Smith

Accuracy. The habit of accuracy is achieved by being careful. Inaccurate persons are usually careless. This habit can easily be formed because we have a ready check on it. The check is the number of mistakes made. Accuracy counts as much as or more than any other one thing. Mistakes mean dollars, serious mistakes may mean business failure. Accuracy is not limited to figures. It applies to principles as well.

How do errors arise? This depends on the kind of work being done. Fundamentally, all errors come from one or two sources. First, insufficient knowledge may be responsible for errors. The radio man should know where mistakes are liable to occur and be on the lookout at these points. Second, bad mental habits are responsible for most mistakes. The habit of skimming over one's work; the habit of inattention to details is the cause of much trouble.

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Radio-Trician's

(Trade Mark Reg. U. S. Patent Office)

Complete Course in Practical Radio

NATIONAL RADIO INSTITUTE WASHINGTON, D. C.

PRINCIPLES OF RADIO COMMUNICATIONS AND PRODUCTION OF RADIO WAVES

To obtain a good idea of the nature of the electric currents which are induced in a receiving antenna by **electromagnetic waves,** it is necessary to have a general conception of the principles of Radio communications.

Radio communications depend upon the travel of Radio frequency waves **from** the transmitting aerial **to** suitable apparatus

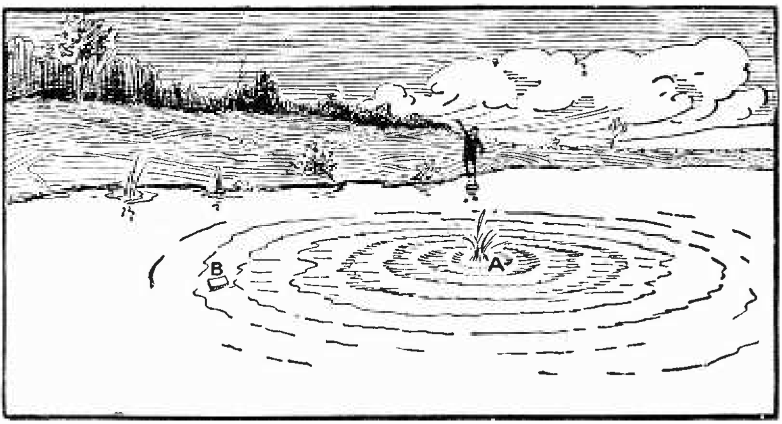

Fig. 1—Picture showing how waves are produced in a pond by throwing a stone in the water at "A." This stone starts a series of concentric ripples or waves, which spread out in all directions, affecting the piece of wood "B." The stone "A" may be compared to a Radio transmitting station and "B" to a receiving station.

at the receiving station. The receiving apparatus makes the signals, sent out from the transmitter, intelligible.

To understand how **code, speech, music** or **television signals** can be reproduced at a receiving station many miles away from the transmitting station, a study of wave **motion** and its characteristics is essential. A Radio wave may be defined as a propulsion of **motions** through a **medium** called the **ether.**

A false impression exists in many minds that it is the medium which actually travels away from the point of the original disturbance which caused the wave. It should be clearly understood that the **medium as a whole does not travel** and, except for an up-and-down or to-and-fro motion while a wave is passing, remains where it is.

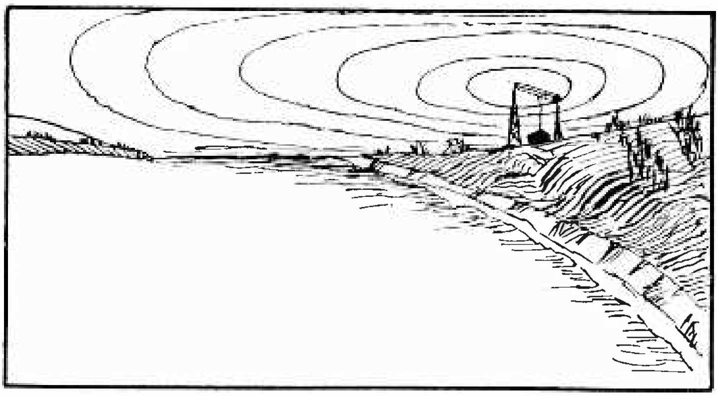

Fig. 1(a)—Picture illustrating how the electromagnetic waves from a Radio transmitting station, while not visible, are radiated in much the same manner as water waves.

Scientists have gradually realized that everything we see, hear and feel is due to waves generated in a **medium** which seems to be everywhere.

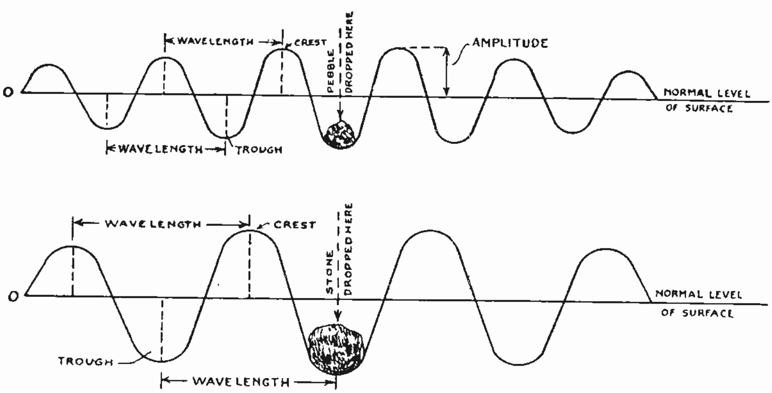

Fig. 2—Illustration showing what happens when a pebble and a large stone is thrown in still water. The pebble produces small waves; the large stone, large waves. Measured from crest to crest or trough to trough we obtain the length of the wave.

That such a substance actually exists has long been doubted, but the study of the phenomena in connection with the transmission of heat, light, and electricity shows that they are all due to wave action which cannot be explained unless we assume there is a medium through which, or on the surface of which, these waves travel.

PROPERTIES OF WAVE MOTION

Everyone is familiar with the "to-and-fro" motion of water, which we call "waves." When a stone is thrown into a quiet

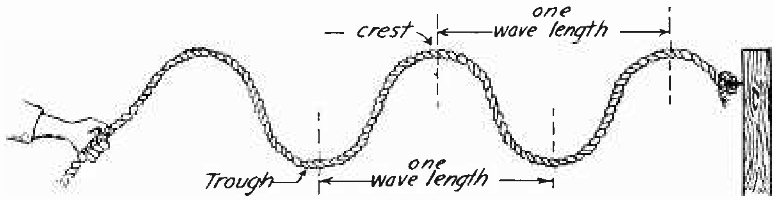

Fig. 3—Illustration using a rope to show a wave motion.

pond **little waves are produced,** which spread out from the starting point in all directions until they meet the shore, or die away. This is clearly illustrated in Figure 1.

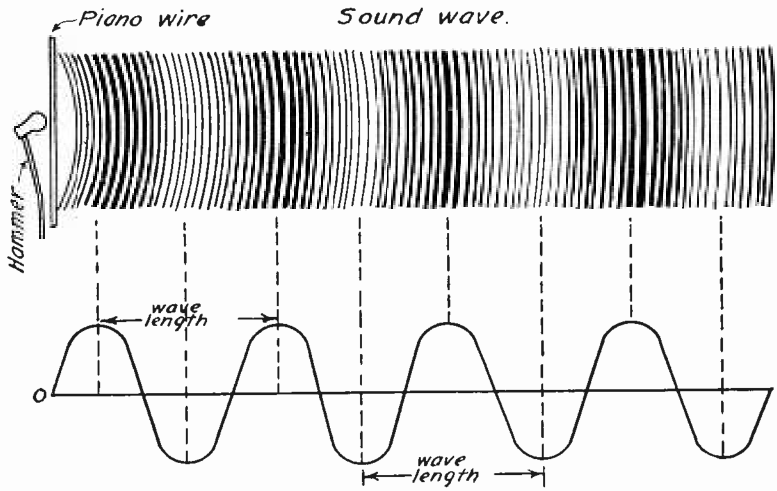

Fig. 4—Picture showing how a piano wire when struck by a hammer radiates waves set up by the vibrations of a wire.

We can **produce** "waves" in water by various methods, but whatever method we use, it is always done by something that will cause the surface of the water to move up and down. In other words, we must have some contact between a moving body and the water. For instance, wind will produce waves in water. The moving air comes in contact with the water and imparts motion to it.

If a rope supported at one end is shaken briskly up and down, a wave-like motion is given to it, which will travel down its length. If the rope is shaken twice, two waves will be started which travel away to the other end, keeping always the same distance apart. If the shaking is repeated rhythmically, a con-

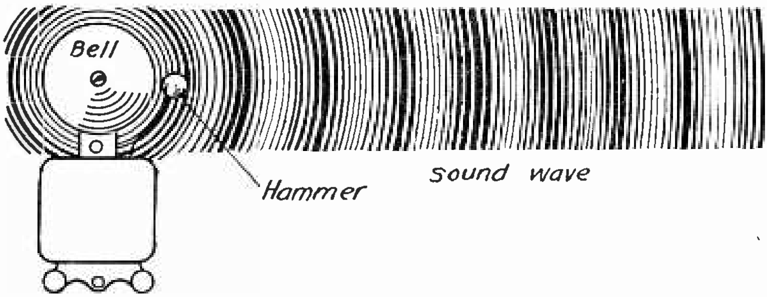

Fig. 5—Sound waves spread out in all directions from a bell.

tinuous wave motion is started which transmits the energy imparted by the hand to the other end of the rope. The **high points** of the wave are called the **crests;** the low ones, the **troughs.** The **distance between two successive crests is the wave length. The height of the crest above the normal or the**

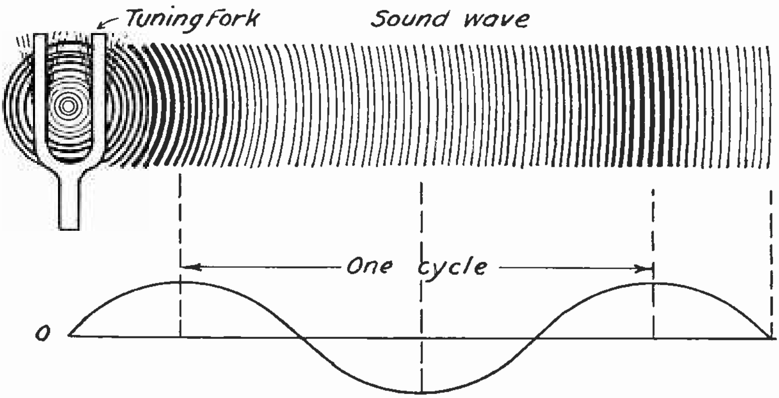

Fig. 6—Illustration showing how sound waves may be represented by using an alternating curve.

depth of the trough below normal is the amplitude, while the number of cycles (complete waves **per second) at which the waves apparently travel is called the frequency.** The latter is sometimes expressed by the number of waves passing a given point each second. Many of the most familiar phenomena of every-day life are caused by wave motions. Sound is transmitted by means of waves in the air. Every musical note is produced by causing the air to vibrate a certain number of times per second. Light and heat are transmitted by exceedingly short waves (high frequency).

NATURE OF RADIO WAVES

Radio waves in the ether are produced in a similar way to water waves—by the motion of something that affects the ether. The only known thing that is capable of affecting the ether is the **electron** and the only way that electrons can produce waves in the ether is by moving rapidly to-and-fro. Thus, to produce a Radio wave we must have a rapid to-and-fro movement of electrons. The moving electrons produce Radio waves and the

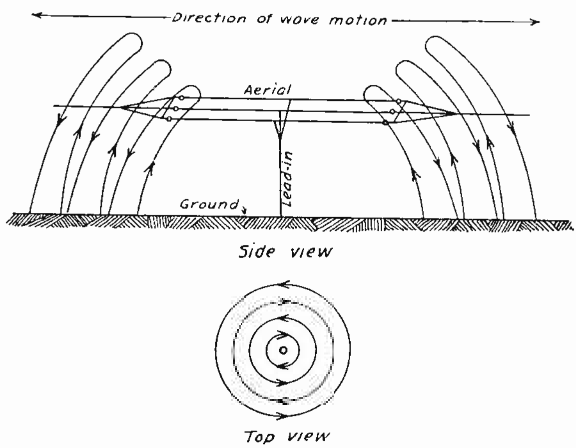

Fig. 7—Drawing illustrating how Radio waves are produced around a transmitting aerial.

Something very similar to the waves on a pond. If in some way they could be made visible they would look like this when looking down from above upon the aerial also from the side view.

Radio waves produced are similar in every respect to the motion of the electrons producing them. In other words, the Radio waves used for communication are **produced by electrical energy,** which is caused to move up and down in the transmitting aerial system so as to send out these waves in all directions. These waves become weaker the farther they go from the transmitting station, just as water waves become weaker the farther they go from the point where a stone is dropped in a pond.

To make electrical energy move up and down in an aerial system, the proper transmitting equipment must be used so as to cause a high frequency alternating current to flow in the aerial. This is another way of saying that the transmitting apparatus causes powerful electrical oscillations to be set up in the antenna, at very high frequency. When the electrical energy is in the antenna, it produces an **electric field** between the aerial and ground which is at right angles to the direction of motion of the wave. When the electrical energy moves it produces a **magnetic field.** Thus, it produces both the **electric** and **magnetic disturbances** that go to make up the **electromagnetic waves.**

Figures 7 and 8 give two good illustrations of what is meant by the above paragraph.

Waves of all kinds travel with a **definite velocity.** However, the velocity of different kinds of waves vary to a great degree. Sound waves travel in air with a velocity of about 330

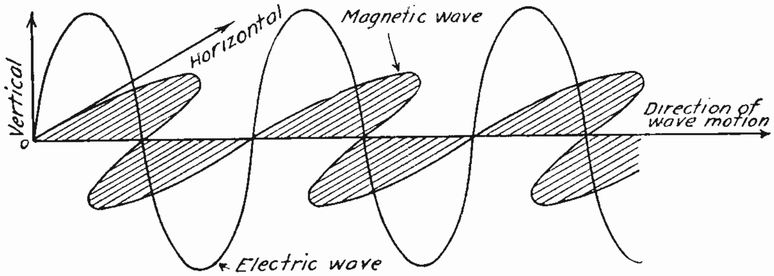

Fig. 8—Drawing showing how Radio waves are theoretically imagined to split into electric and magnetic components.

meters per second, or about 1,083 feet per second. The velocity of light waves in space is 300,000,000 meters (to be more accurate 299,820,000) per second, or about 186,300 miles per second.

It has been demonstrated in many ways that Radio waves are transmitted with the same velocity as light waves and the waves that constitute heat radiation, and that the three, Light, Heat, and Radio, are the **same kind** of waves, but **differ** in frequency. Electric waves, including Radio waves, light waves, and radiated heat waves, are all referred to by the general term **electromagnetic waves.**

ANTENNA SYSTEMS

In order to produce electromagnetic waves by using high frequency alternating current and have these waves radiated into space, it is necessary to use a radiating system known as the antenna.

(1) The condenser antenna. (See Fig. 9.)
(2) The coil antenna. (See Fig. 10.)

The **condenser type of antenna** consists of a system of wires suspended above the earth or above a counterpoise (a somewhat

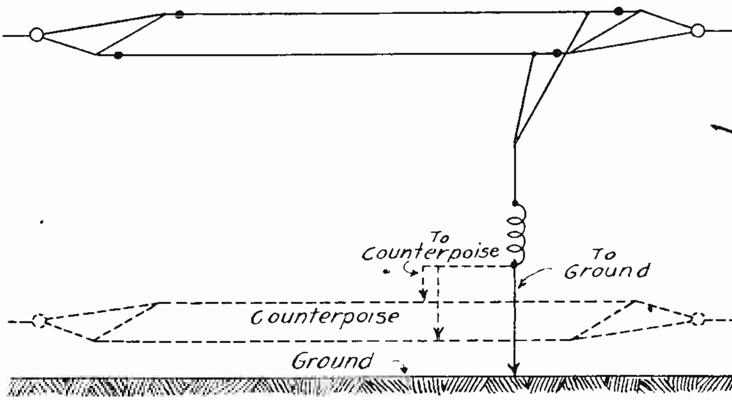

Fig. 9—Condenser antenna.

similar system of wires suspended below the antenna and insulated from the earth) as shown in Figure 9.

The elevated system of wires used in the condenser type of antenna is often called the aerial. The physical dimensions of

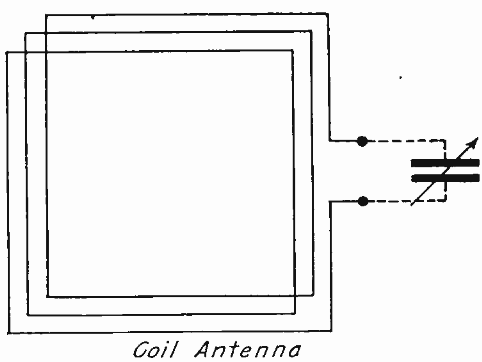

Fig. 10—Coil antenna.

a condenser antenna system will depend upon the use to which this system is to be put, whether for long or short waves (low or high frequency). **Coil antennas** consist of one or more turns of wire, such as illustrated in Figure 10, of varying dimensions and shapes, depending upon the frequency or wave length and use to which they are to be put. Coil antennas having only one turn of wire are usually referred to as loop antennas, although this term is often loosely used to designate coil antennas of any number of turns.

TYPES OF RADIO WAVES

Radio Communication, considered from the standpoint of the waves by which communication is established between stations, may be divided into two classes.

Undamped or continuous waves. (See Fig. 11.)

Damped waves. (See Fig. 14.)

Transmitters employing **"undamped waves,"** made use of Radio frequency waves which form a **continuous series of waves of constant amplitude.** As the generated wave is continuous, this system is also known as the continuous wave system, frequently abbreviated to CW system.

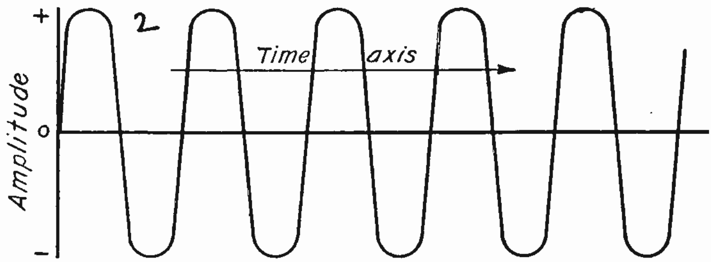

Fig. 11—Continuous (Class A) wave.

PRODUCTION OF UNDAMPED WAVES

There are **three main ways of producing undamped waves,** namely, with a very **high frequency alternator,** with the **oscillating arc,** and with the **vacuum tube oscillator,** the latter being most used at the present time. The theory, operation and construction of Radio transmitters will be taken up in advanced lessons. Undamped waves can be used for telephony and telegraphy. For telegraphy, the undamped or continuous waves are merely **interrupted** (I. C. W.) at intervals, in the form of dots and dashes of the International Telegraph Code (see Fig. 12). A short series of complete cycles of high frequency alternating current comprises a dot, while a longer period would form a dash. In telephony, the undamped waves are **modulated,** that is, **their amplitude periodically varies in accordance with the**

sound vibrations impressed on them by the action of the **microphone** (see Fig. 13) and modulating circuits connected to the vacuum tube oscillator.

A transmitter using **damped waves** for communication sends out a series of waves or wave trains, as they are often called. Each of these trains consists of a **group of damped Radio frequency waves.** (See Fig. 15.)

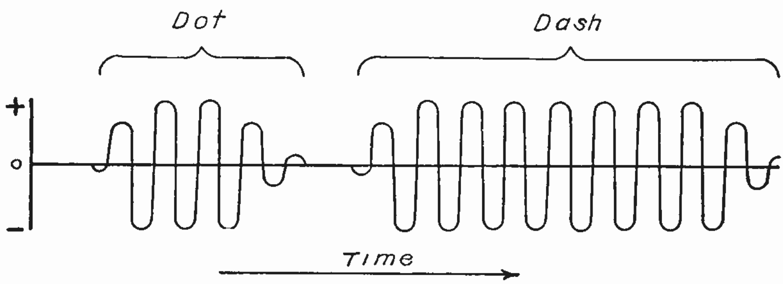

Fig. 12—Key modulated (Type A1) wave representing the letter A.

The **term damped** as used here means that the succeeding waves in the wave train are of **decreasing amplitude.** This type of wave is produced by the discharge of a condenser through a spark gap and an induction coil, one **train of damped waves** occurring for each spark or condenser discharge.

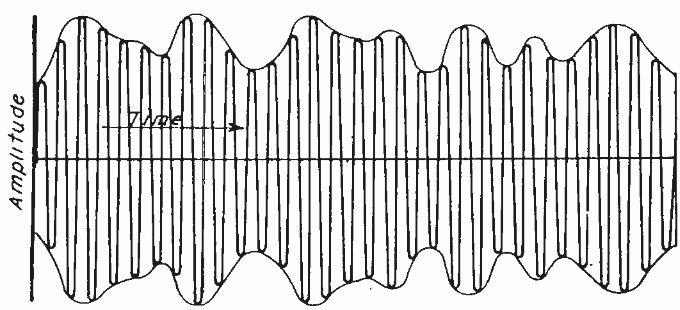

Fig. 13—Type of wave radiated by a radiophone transmitter during modulation (Class A3).

The operation of the entire arrangement is controlled by a transmitting key, which opens and closes the electric circuit. As long as the key circuit is open, nothing occurs. But as soon as the key closes the circuit, the high frequency oscillations are set up due to the rapid condenser discharge through the spark gap and induction coil. This sends waves out from the transmitting aerial. These waves are broken up into trains or groups, however, the trains do not overlap, or even join their neighbors.

An analysis of the radiation as produced by current in an antenna from a damped wave transmitter would show that a very **wide band** or **channel** in the ether is occupied. This band is many times wider than that produced by the modulated continuous waves of a Radio telephone transmitter. For this reason, spark transmitters, as they are called, which produce damped waves cause a great deal of interference even on frequencies widely removed from that alloted to the transmitting station. As a result, transmitters of this type are being rapidly replaced by more modern equipment radiating either an interrupted continuous wave or a continuous wave modulated at audio frequency.

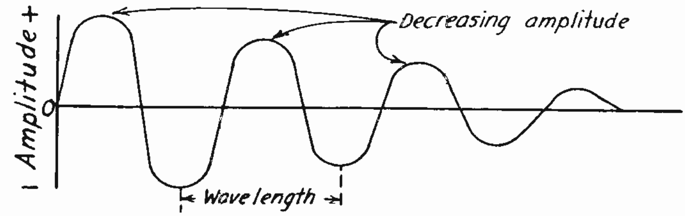

Fig. 14—Damped wave (Class B).

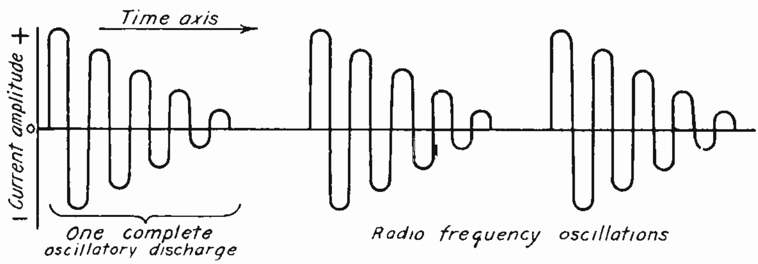

Fig. 15—Graph showing three complete oscillatory discharges as produced by a damped wave transmitter (Class B).

CLASSIFICATIONS AND TYPES OF RADIO WAVES

According to the Radio Telegraphy Convention and General Regulations between the United States and other powers, Radio emissions are divided into two classes (A) Undamped or Continuous Waves, (B) Damped Waves.

Waves of Class "A" include the following types, which are defined here:

Type A-1, Unmodulated continuous waves. Continuous waves, the amplitude or frequency of which is varied by means of telegraphic keying.

Type A-2, Continuous waves modulated at audio frequency. Continuous waves, the amplitude or frequency of which is varied in a periodic manner at audible frequency, combined with telegraphic keying.

Type A-3, Continuous waves modulated by speech or by music. Continuous waves, the amplitude or frequency of which, is varied according to the characteristic vibrations of speech or music.

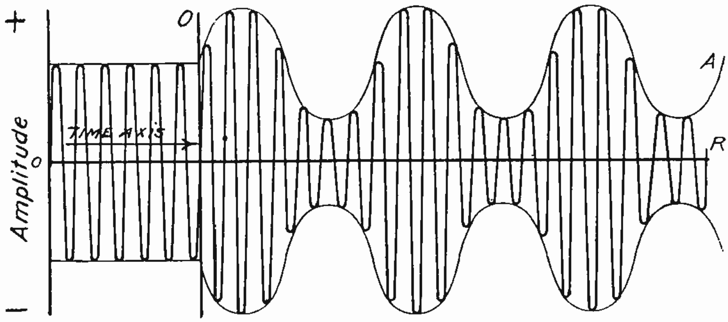

Fig. 16—Sine modulated Radio frequency type A-2 wave.

Let us consider briefly these types of Radio waves with regard to the way in which they are produced. If the high frequency current flowing in the transmitting antenna is a pure **sine wave** (a wave having amplitude of each separate cycle or oscillation as high above zero as the trough is below) of a single frequency such as shown in Figure 11, and if no peculiar fading phenomena disturb the transmission of energy from the transmitter to the receiving station, then the Radio wave is known as a Class "A" wave (continuous wave).

The drawing shown in Figure 11 may be considered as illustrating the variations of the current in the transmitting antenna as a function of time, or it may be considered as showing the variations of the intensity of the Radio waves as a function of time either near the transmitting station or at the receiving station. The amplitude, of course, will be much less at the receiving station, than close to the transmitting station. It is interesting to note that while the power radiated by a transmitting station may be as high as 50,000 watts (50 kilowatts), the power in the Radio waves at the receiving station is ordinarily only a few millionths of a watt. In other words, the Radio waves rapidly grow weaker as they travel from the transmitter.

KEY MODULATED CONTINUOUS WAVES

Class "A" waves as previously stated are **sub-divided on the basis of modulation.** By modulation we mean a variation in the amplitude (intensity) or frequency of the waves. Radio telegraphy, using continuous waves, is ordinarily accomplished by using dots and dashes made by interrupting the current somewhere in the transmitting system by means of a key. When the amplitude or frequency of a continuous wave is varied by means of telegraphic keying, these waves are known as Type A-1 waves. Figure 12 illustrates a typical Type A-1 wave so keyed as to transmit the letter A in the **International Radio Code.**

AUDIO FREQUENCY MODULATED WAVES

Figure 16 illustrates a second type of wave known as Type A-2, which we must give consideration as it is a continuous wave modulated at a single audio frequency. The portion to the left of the line O has been left unmodulated. If you follow curve A which determines the amplitude of this wave, you will note that this also is a sine wave, but of much lower frequency than the Radio wave. Such a continuously modulated wave is obtained by superimposing upon a Class "A" wave, a frequency somewhere within the range of the human ear. It is essential to consider the characteristics of Type A-2 waves in detail prior to the consideration of waves which have been modulated at different audio frequencies by speech and music.

The line to the left of the axis O, in Figure 16, represents the high frequency unmodulated wave. To the right of O, the line marked A, corresponding to the sine wave single audio frequency which is superimposed upon the Radio frequency wave. For the purpose of explanation, let us give specific values to the Radio frequency and audio frequency waves. Let us assume that the Radio frequency curve represents a wave having a frequency of 1,000,000 cycles per second. Let us further assume that the audio modulated component has a frequency of 5,000 cycles per second. Figure 16, therefore, represents a Radio frequency current of 1,000,000 cycles modulated by an audio frequency of 5,000 cycles.

Sound waves produced by the vibrations of the human voice and musical instruments as stated previously do not follow a pure sine wave like that shown in Fig. 16. Sound vibrations are made up of numerous frequencies (harmonics) and overtones resulting in the transmission of a wave of varying amplitude. Thus, the wave form of a single vowel sound, as pronounced by the vibrations of the voice, must produce a curve similar to that shown in Figure 17(A). In many cases the wave form is even more complicated, but it invariably repeats itself at regular intervals.

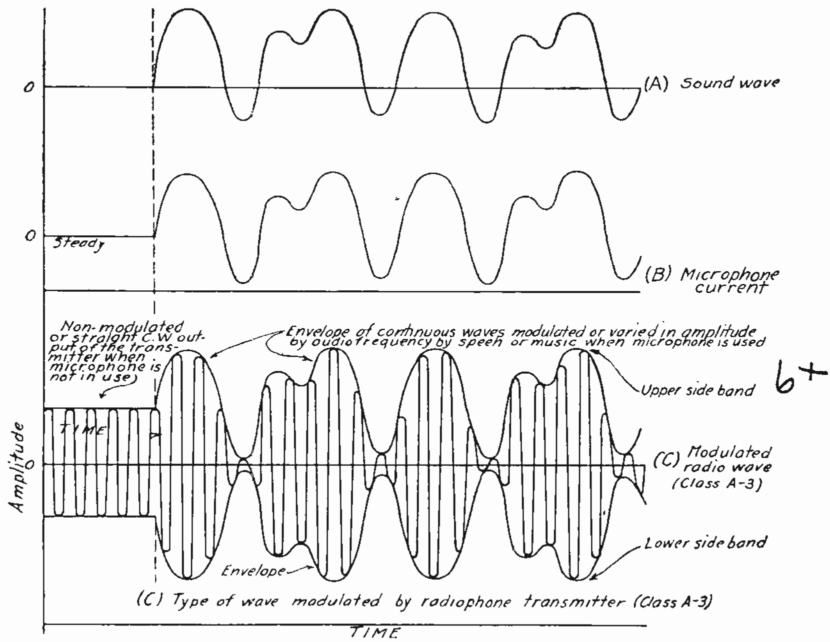

Fig. 17—This drawing shows how the high frequency oscillations are modulated according to the characteristics of the audio frequency sound waves impressed upon them from the microphone.

In the communication of **speech** or **music** by Radio, these complicated waves must be **exactly transmitted** and again **reproduced** at the **receiving station.** This would be practically impossible were it not for the great **difference in frequency** between **Radio waves** and **sound waves.**

The continuous high frequency waves act as the **carrier** of the **low frequency sound waves.** This is accomplished by varying the amplitude of the continuous high frequency waves and thus the variations in amplitude conform to the frequency in wave form of the sound waves.

The illustration shown in Figure 17(C) shows how the sound wave form and frequency are carried by the Radio wave. This type of wave is known as Type A-3.

At the transmitting station the transmitting apparatus **generates** and **radiates a constant stream of Radio waves of high frequency.** The **fluctuations** of the **microphone current** (see Fig. 17(B)), produced by the voice or music are **amplified** and applied to the generator of Radio waves in such a way that the amplitude of the **Radio waves rise and fall** at this **applied frequency**, thus preserving the **wave form** and frequency of the sound waves. In other words, the amplitude of the Radio frequency waves is varied only while sound waves are striking the microphone. At the receiving station the modulated high frequency wave is induced on the receiving antenna, amplified by the receiving vacuum tubes, the detector tube irons them out so to speak and leaves the audio frequency wave to be amplified so as to enter the loud speaker reproducing the audio signals. Reception of various waves and different receiving systems will be taken up in detail in advanced text-books.

MEASUREMENTS OF WAVES

In determining the character of the various Radio waves, we usually speak of their frequency expressed in **cycles** or **kilocycles** per second, or their **wave length,** which is the distance between successive wave crests measured in meters.

Any wave whatsoever, a Radio wave in the ether, a sound wave in the air, a water ripple on the surface of a pond, consists of a succession of pulsations moving along one after another. Most waves will have a succession of regular crests and troughs like ocean waves or like the electric waves as illustrated in Figure 18.

The part of the wave measured from the **crest of one wave to the crest of the next** following wave is called **one complete wave** or cycle. Its length, that is, the distance between successive wave crests, is one **wave length.**

The **frequency** of a wave is merely the number of crests in a complete wave that pass in one second, or what is the same thing, the number of **wave lengths** in the distance the wave moves in one second.

For example, let us consider the arrival of a moving wave at some fixed point, such as the arrival of a sound wave at your **ear.**

The wave reaches your ear as a succession of regularly timed pulsations, one pulsation for each wave crest. Each pulsation pushes slightly against your ear drum. This causes the drum of the ear to vibrate; inward for each pulsation, outward again during each interval between pulsations. The number of these back-and-forth vibrations of the drum a second is the same as the number of pulsations of the wave that arrive a second; that is, it is the same as the frequency of the wave. The higher the frequency, the higher the pitch of the sound seems to your ear.

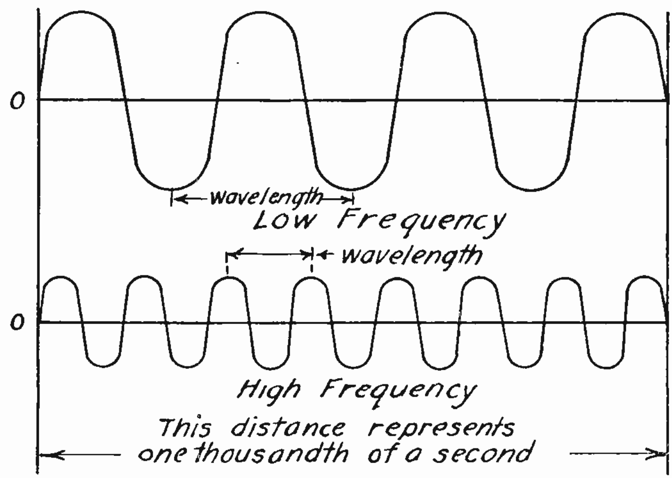

Fig. 18—This drawing illustrates the relation of frequency to wave length, The higher the frequency the lower the wave length. the lower the frequency the higher the wave length.

What you really hear, then, is the frequency, not the wave length. Frequency, indeed, is always a more characteristic property of waves than is length. **Wave length depends on the frequency of the wave,** and the speed depends not only on the kind of wave but on the medium in which the wave is traveling. For example, sound waves move faster in water than they do in air. The wave length of a sound wave will be greater in water than in air, but its frequency will be the same. It is the frequency, not wave length that is important to us.

Similarly, when you modulate or impress a sound wave onto a Radio frequency wave, the wave length of the two waves do not matter, because what is impressed on a Radio carrier wave is not a wave length—it is a frequency. The **"Radio"** wave is a high frequency wave in the ether. The **sound wave** is a low frequency wave in the air. The factors that really determine the relation of the two waves, the factors that you need to take account of in modulation calculations, are the respective frequencies of the two waves.

This is one reason why frequencies are used at the present time instead of wave lengths. The use of frequencies makes all kinds of waves directly comparable. Modulation calculations are easier. Interference, harmonics and all other mutual relations of waves are more directly discoverable.

A **cycle** is a reversal from zero to positive, to zero—then from zero to negative and back again to zero, when speaking of the path of electricity in an alternating current circuit or the impulses creating the field of a Radio wave. "Cycles" used as a measure of the rapidity of these changes implies always per second, and "kilocycles" is simply a short expression for thousands of cycles per second.

The **kilocycle,** therefore, is merely a unit of frequency, just as the meter is a unit of wave length. In electrical terms, a cycle means one complete wave, measured, as usual, from one crest to the next following one. The frequency may be expressed, therefore, in cycles. It is the number of cycles a second. An alternating current, for example, may have 60 cycles a second, which means the same as the frequency of 60 cycles.

One kilocycle is merely 1,000 cycles, just as one kilometer is 1,000 meters or one kilowatt is 1,000 watts. To say that a station is transmitting on a frequency of 1,000 kilocycles means that it is using a frequency of 1,000,000 cycles, that is 1,000,000 complete waves a second. In other words, it means that there will be one million double changes per second in the polarity of the Radio wave as measured at any point in its progress.

WAVE LENGTH FREQUENCY CONVERSION

To calculate the frequency or wave length requires a knowledge of the velocity or speed of the waves. Radio waves move with the speed of light. According to the most accurate experimental determinations, this speed (in vacuum) is 186,300 miles a second, or 299,820,000 meters a second. For ordinary calculations, Radio engineers use a round number of 300,000,000 meters a second.

A train of waves that has 1,000 kilocycles (which is the same as 1,000,000 complete waves) a second will move in that second 300,000,000 meters. The length of each wave will be,

TABLE NO. I.

TABLE OF ALL THE ETHER WAVES NOW KNOWN

		FREQUENCY	WAVE LENGTH	
		.02 KILOCYCLE (20 VIBRATIONS PER SECOND)	15,000,000 METERS	
AUDIO FREQUENCY VIBRATIONS	10.6 OCTAVES			THE AUDIO FREQUENCY AND THE RADIO FREQUENCY OVERLAP
		30 KILOCYCLES	10,000 METERS	
USUAL RADIO WAVES	6.7 OCTAVES			HERE BELONG ALL ORDINARY RADIO WAVES.
		3,000 KILOCYCLES	100 METERS	
SHORT ELECTRIC WAVES	16.7 OCTAVES			THESE WAVES HAVE BEEN USED ONLY EXPERIMENTALLY. HERE BELONG, ALSO, THE RADIO HEAT WAVES RECENTLY DISCOVERED BY DR. E. H. NICHOLS. ALL THESE WAVES WILL PROBABLY BE QUITE IMPORTANT IN THE FUTURE.
		300,000,000 KILOCYCLES	.001 METER (10,000,000 ANGSTROM UNITS)	
HEAT WAVES	10.3 OCTAVES			ALSO CALLED THE INFRA-RED RAYS.
		387,000,000,000 K.C.	7750 ANGSTROM UNITS	
LIGHT WAVES	1 OCTAVE			
		759,000,000,000 K.C.	3900 ANGSTROM UNITS	
ULTRA-VIOLET LIGHT	3.7 OCTAVES			
		10,000,000,000,000 K.C.	300 ANGSTROM UNITS	
X-RAYS	11.6 OCTAVES			RAYS THAT PENETRATE MOST KINDS OF MATTER.
		30,000,000,000,000,000 K.C.	.1 ANGSTROM UNIT	
GAMMA RAYS	3.3 OCTAVES			FROM RADIUM
		300,000,000,000,000,000 K.C.	.01 ANGSTROM UNIT	
UNEXPLORED REGION. WAVES STILL SHORTER THAN GAMMA RAYS				

(Note)—The Angstrom Unit used in the above table is the common unit for the length of light waves, equals one ten billionth of a meter. It is named after Dr. K. A. Angstrom who was the first to study and chart the spectrum of sunlight.

therefore, 300,000,000 meters divided by 1,000,000. This means the "crests" will be at points 300 meters apart along the path of a 1,000 kilocycle wave. We have here the idea of simple waves, corresponding to waves in water with approximately equal spaces between their tops or crests.

Here are the "rules" for conversion from "wave length" to "frequency" and vice versa.

To convert the wave length in meters into the frequency in kilocycles divide the wave length into 300,000.

$$F = \frac{300{,}000}{WL}$$

The reverse rule is the same:

To convert the frequency in kilocycles into the wave length in meters, divide the frequency into 300,000.

$$WL = \frac{300{,}000}{F}$$

The speed or velocity of Radio waves in air and in non-conducting materials is nearly the same as in a vacuum.

These "rules," therefore hold for all ordinary calculations.

By way of comparison, the speed of sound waves in air under ordinary conditions is about 1,083 feet a second (330 meters a second) not much over one millionth of the speed of Radio waves. The speed of sound waves in water is about 1,500 meters a second.

Not only Radio waves, but all kinds of ether waves are designated most conveniently by their frequencies. Table No. 1 gives in convenient form for reference all the ether waves now known with their frequencies and the corresponding wave lengths. The term **"octave"** is borrowed from music. **One octave means all the waves between any particular frequency and a frequency twice as great.** For example: The first octave includes all the waves between a frequency of 20 cycles a second and a frequency of 40 cycles a second; the second octave is from 40 to 80 cycles a second, and so on.

The entire series of ether waves, from the longest Radio wave to the shortest **gamma rays** is shown in the table No. I.

The divisions of the waves into Radio waves, heat waves and light waves are made merely for convenience. All the waves belong, really to one unbroken series. Many of the divisions overlap, just as the heat waves overlap the short Radio waves and the X-rays overlap the ultra violet. There is a similar overlap of the audio frequency and the Radio frequency waves.

The ether waves that have been most studied by scientists are those of light. These differ from the longer and shorter waves only in that they can be perceived by the human eye. Physically all the waves are the same. The color of light depends upon its frequency, and hence also upon its wave length.

ALLOCATION AND USE OF FREQUENCIES (WAVE LENGTHS) AND TYPES OF EMISSIONS

The Federal Radio Commission at Washington, D. C., assign the frequency or wave length for each individual station. Broadcasting stations in the United States are today assigned to frequencies which lie between 550,000 and 1,500,000 cycles per second approximately; that is, between 550 and 1,500 kilocycles (kc). We speak of those frequencies lying between 550 kilocycles and 1,500 kilocycles as lying within the broadcasting **band, or spectrum.** The broadcasting spectrum now consists of frequencies as indicated above, which correspond to wave lengths ranging from approximately 545 meters down to 200 meters. The entire Radio **spectrum** assigned to various services such as Ships, Aircraft, Army, Navy and Amateur Stations, etc., may be considered as extending in wave lengths from 30,000 meters down to about 5 meters, or in frequencies, extending from 10 kilocycles to 60,000 kilocycles per second.

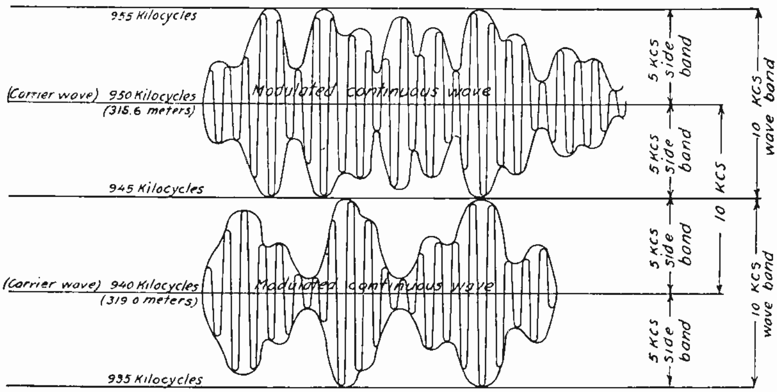

Fig. 19—Illustration showing the upper and lower side bands of modulated continuous waves and the relation of wave bands to each other.

UPPER AND LOWER SIDE BANDS

When a transmitting station sends out an **unmodulated** Class "A" wave, as stated previously, we are transmitting only

one single frequency. Thus, the energy radiated by a wave having the form given to the left of the axis O, as illustrated in Figure 16, consists of one frequency only and that frequency on the basis of our illustration is 1,000,000 cycles or 1,000 kilocycles per second. If, however, we were to analyze completely the frequencies present in such a wave, as shown to the right of the axis O, we would find an entirely different state of affairs existing. If the Radio frequency or carrier frequency, as it is usually called, is 1,000,000 cycles (1,000 kilocycles) and the modulating frequency is 5,000 cycles, then it can be proven that the wave radiated actually consists of **three separate frequencies.** These frequencies will be (1) 1,000,000 cycles known as the **carrier frequency,** (2) 1,005,000 cycles known as the **upper side frequency** and (3) 995,000 cycles per second, known as the **lower side frequency.** A very good illustration of the above statement is shown in Figure 16.

The fact that the modulation of a carrier wave tends to change the transmission from its single frequency characteristics and to consist of at least three frequencies, one on either side of the carrier frequency, as shown in Figure 16, is of great importance to Radio today. Every transmission takes up a good proportion of the Radio frequency spectrum. The width of the portion or channel occupied, will, of course, depend upon the kind of transmission, more particularly upon the nature of the modulating frequencies which are superimposed on the carrier wave. From this it can be seen that when we modulate a carrier wave by speech or music, there will be an **upper** and **lower** band of frequencies, one band on either side of the carrier frequency. It is this fundamental fact which definitely limits the number of Radio broadcasting stations which can be simultaneously operated between 200 and 545 meters (1500 and 550 kilocycles), without interference with each other. This fact is of such great importance to an understanding of the operation of Radio transmitting stations that we will now proceed to devote further consideration to it, particularly to the operation of Radio broadcasting stations.

AUDIO SIGNALS IMPRESSED ON THE CARRIER WAVES

When we consider the types of Radio waves which are transmitted from a broadcasting station, we must take into consideration the characteristics of speech and music and also the characteristics of the human ear. We have seen that we can associate the terms "frequency" and "wave length" with the Radio waves which are transmitted from a transmitting antenna. Wave lengths and frequencies are associated and one can be computed by making use of known formulas, as given in this text book. Since sound is a wave motion, we can do practically the same thing with sound waves. However, in this case, the transmitting medium is different. Radio waves are transmitted through a medium which we call ether, at a certain velocity per second. Sound waves can be transmitted through air, liquids and solids. The velocity of sound in air is approximately 1,083 ft. per second. The velocity will, to some extent, depend upon the temperature and pressure.

Another difference between Radio waves and sound waves

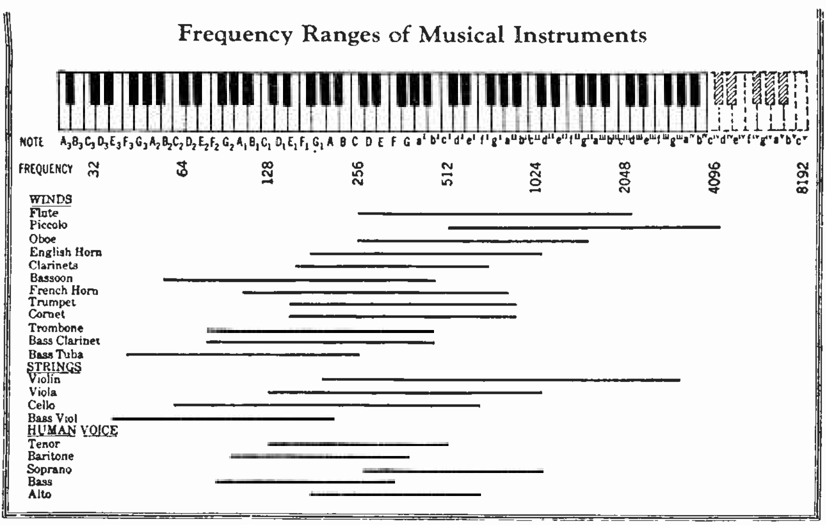

Fig. 20—Relation between frequency ranges of musical instruments, voice and the piano keyboard.

is the range of frequencies which are utilized. Radio waves can be considered as being produced by electrical disturbances of frequencies between 10 kilocycles and 60,000 kilocycles. Sound waves, however, are produced by vibrating mechanical bodies and the range of frequencies which we can classify as sound is considerably less and is composed of frequencies much lower than those given for Radio waves.

The sound spectrum must be confined to those frequencies capable of affecting the average human ear. The deepest organ pipe which can be heard produces a frequency of 16 cycles per second. The highest frequency which can ordinarily be heard by the human ear is somewhat around 15,000 cycles per second. The ability of various individuals to hear frequencies as low as 16 cycles a second and as high as 15,000 cycles per second varies greatly and these may be taken as extreme limits. But, few people can hear, or detect as sound, frequencies as low as 16 cycles, although a relatively large number can hear frequencies as high as 15,000 cycles.

PURE TONES AND HARMONICS

A vibrating source producing sound waves of a single frequency is best to produce a **pure tone.** The **frequency** of the fundamental **sound waves determines** the **pitch.** Musical tones, however, as produced by striking a piano string or bowing a violin string **do not** consist of pure tones, but ordinarily consist of a particular or **fundamental frequency** and in addition a number of other frequencies known as **harmonics.** Harmonics are frequencies which are **multiples of a given frequency** known as the fundamental frequency. Thus, if we strike a piano note, the fundamental frequency of which is 500 cycles, there are present in the air sound wave frequencies of 1,000, 1,500, 2,000, 2,500, etc., cycles. In Radio work, we refer to the frequency having the value twice that of the fundamental frequency as the second harmonic, the frequency having a value three times the fundamental frequency as the third harmonic, and so on.

PITCH AND TIMBRE OF MUSICAL TONES

While the **pitch** of a musical tone is determined by the frequency of the fundamental, **the tone quality or timbre,** as it is often called, depends upon the ratio of the amount of energy in the various harmonics to that in the fundamental. It is these ratios which enable you to determine, even though you may not be able to see the instrument, whether or not the tone is produced by a piano, violin, or a singer. A chart is shown in Figure 21, giving the relative amount of energy in the fundamental frequencies and the harmonics of a musical tone as produced by bowing a violin in a particular way. If the fundamental frequency produced by striking a piano string is 256 cycles per second (middle C in the musical scale), then the second harmonic will be 512 cycles, the third 768 cycles, and the fourth 1,024 cycles, etc.

LOUDNESS OF TONES

As we have pointed out, there are two characteristics of musical tones, pitch and timbre or quality. **Pitch**, as we have learned, depends upon the frequency of the fundamentals. **Timbre** depends upon the relative energy in the fundamental frequency and in the harmonics. There is, however, a third characteristic which we must be acquainted with and that is the term **loudness.** The **loudness** of a tone, of course, will depend upon the amplitude of the vibrating source which produces it. As far as the ear is concerned "loudness" depends upon the amplitude of the sound waves striking the drum of the ear.

When a musical selection is played by an orchestra, or an organ, it requires the utilization of a large number of fundamental frequencies. The range of these fundamental frequencies

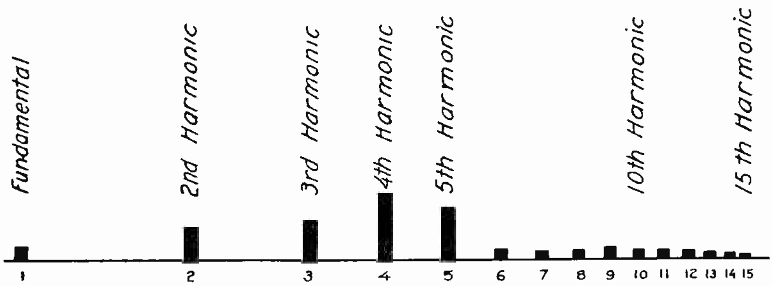

Fig. 21—Distribution of energy among fundamental and harmonics of a musical tone produced by bowing a violin.

which must be transmitted in the reproduction of a musical selection will ordinarily range from 30 cycles per second up to about 4,000 cycles per second. The satisfactory transmission of a selection of music over any Radio transmission system will require that the **harmonics of these frequencies be transmitted as well as the fundamentals, otherwise, the reproduction will not possess the characteristics of the original.** Speech does not require as wide a range of frequencies for intelligibility as does music. Engineers, therefore, have extensively studied the range of frequencies which must be accompanied by any system to meet various standards of reproduction.

FIDELITY

At this time it is well to discuss a term which we will use from time to time in describing the characteristics of Radio transmission, broadcasting equipment, receiving apparatus, etc. It is the term called **fidelity.** You often hear people who own

Radio receiving sets refer to the quality of reproduction of their sets. The term "quality" in this case is not a very good one. For example, suppose that a broadcasting station is putting on the air a very poor program and that you are listening to that program with an excellent receiving set. Would you say that the receiving set was reproducing a good quality program? The quality of a Radio program depends just as much upon what is put into the microphone as it does upon the characteristics of the receiving set. To avoid this rather ambiguous use of the term **quality**, Radio engineers today make use of the term **fidelity** to describe the faithfulness of reproduction of receiving apparatus. A very poor broadcast program may be faithfully reproduced by an excellent receiving set. You may, therefore, say that the fidelity of the receiving set is good, without saying that the quality of the program is good.

On the basis of the above discussion, let us consider briefly the standards which engineers generally agree to with respect to the range of frequencies which must be transmitted by a broadcasting station if "fidelity" is to be obtained. Extensive tests have shown that if a transmitting system is concerned only with the transmission of speech and if intelligibility only is desired, frequencies lying between 200 cycles and 2,000 cycles only need to be accommodated. The ordinary desk telephone, and all telephone exchange equipment as used for land line telegraphy are designed only to accommodate frequencies which lie between these two limits. When we come to consider the frequencies which must be transmitted for the satisfactory reproduction of music, we find it necessary to set rigid limits. A broadcasting system or a receiving set which satisfactorily handles all audio frequencies lying between 30 cycles and 10,000 cycles would give excellent fidelity. Such a receiving set would in general give satisfactory results, and there is no question but that the most highly trained musician would be entirely satisfied with its fidelity characteristics. In view of the present engineering limitations of broadcasting apparatus and governmental requirements receiving sets capable of satisfactorily reproducing all frequencies lying between 50 cycles and 5,000 cycles per second will be found to be entirely satisfactory to the average person. Accordingly, a large share of our Radio apparatus is today engineered to accommodate the frequencies which lie between these two limits. For the purpose of our study, we will, therefore assume in the next few pages of this text-book that a musical program as transmittd by a Radio transmitting station consists of a large number of frequencies lying between 50 cycles and 5,000 cycles. On the basis of this, let us now turn our attention to speech and music modulated waves which will be transmitted from a Radio broadcasting station.

SPEECH AND MUSIC MODULATED WAVES

If we consider that over a period of time a musical reproduction consists of a great number of frequencies lying between 50 and 5,000 cycles per second, then the Radio wave transmitted by a Radio broadcasting station must be somewhat similar to type A-2 wave illustrated in Figure 16, except that it will be much more complex due to the fact that the envelope as determined by the modulating frequencies will be continually varying

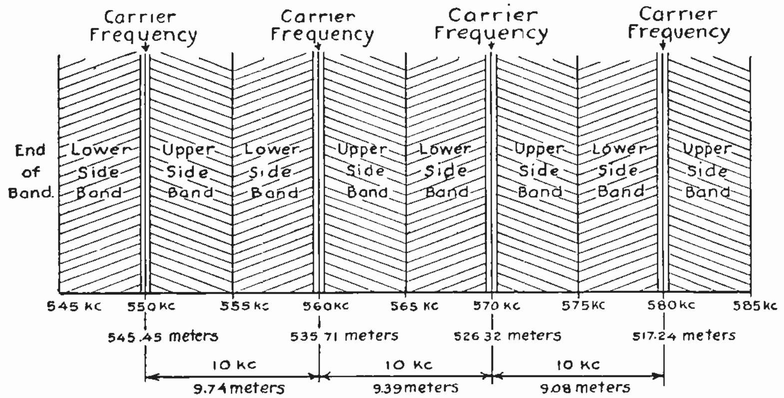

Fig. 22—The broadcast channels at the lower end of the frequency band.

and will take all possible values lying between the limits we have selected. Instead of consisting of a single frequency with an upper side frequency and a lower side frequency, the wave transmitted is said to consist of a **single frequency** and an **upper side band** and a **lower side band.**

Let us assume again that the carrier frequency transmitted by a broadcasting station is 1,000,000 cycles (1,000 kilocycles). And instead of being modulated by a single frequency of 5,000 cycles, the station is used to transmit a musical program such that over a period of time all possible frequencies lying between 50 and 5,000 cycles are present in the program.

The **carrier wave** transmitted from the Radio station will then be something like that shown in Figure 17. That is, it will consist of the carrier frequency as before but in place of the upper and lower side frequencies, we will not have upper and lower side bands. The upper side band will extend from 1,000,000 cycles (1,000 kc) upward to 1,005,000 cycles (1,005 kcs). The lower side band will extend downward from 1,000,000 cycles (1,000 kc) to 995,000 cycles (995 kcs). In other words, every broadcasting station capable of transmitting audio frequencies which extend as high as 5,000 cycles (5 kcs) may be considered as occupying space in the ether 10,000 cycles (10 kcs) wide, that is, twice the highest modulated frequency.

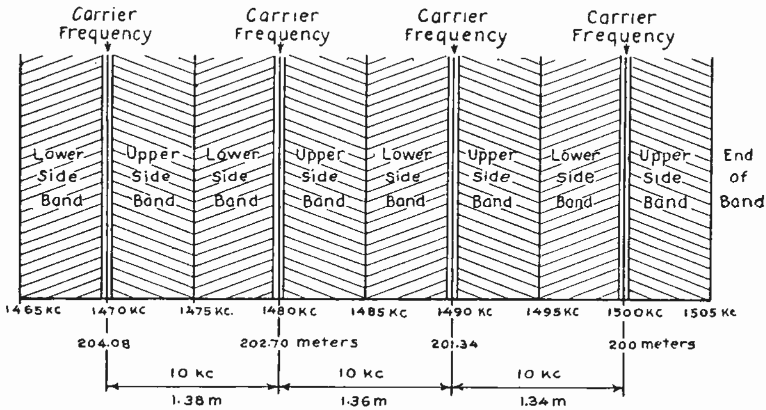

Fig. 23—The broadcast channels at the upper end of the broadcast band.

THE BASIS FOR BROADCASTING STATION ASSIGNMENT

Consider for a moment a Radio broadcasting station whose carrier frequency is assigned to be 550,000 cycles (550 kilocycles). Speaking in terms of kilocycles, the lower side band will then extend downward to 545 kilocycles and the upper side band up to 555 kilocycles. If the waves transmitted from this station are not to overlap those from a certain station which it is desired to operate simultaneously with the first, then the second station cannot be assigned a carrier frequency less than 10 kilocycles, removed from the first. In other words, the carrier frequency of the next station cannot be closer than 560 kilocycles, in which case the lower side band associated with it would just touch the upper side band of the station whose carrier frequency is 550 kilocycles.

To make the above statement clear, Figure 22 shows in graphic form the four broadcast channels nearest the lower end of the broadcast band (referring to the frequency band). The

TABLE NO. II.

Table for converting frequency assignments in the broadcast band to wave lengths.

Frequency in Kilocycles	Wave Length in Meters	Frequency in Kilocycles	Wave Length in Meters	Frequency in Kilocycles	Wave Length in Meters	Frequency in Kilocycles	Wave Length in Meters	Frequency in Kilocycles	Wave Length in Meters
550	545.45	750	400.00	950	315.79	1150	260.87	1350	222.22
560	535.71	760	394.74	960	312.50	1160	258.62	1360	220.59
570	526.32	770	389.61	970	309.28	1170	256.41	1370	218.98
580	517.24	780	384.61	980	306.12	1180	254.24	1380	217.39
590	508.47	790	379.75	990	303.03	1190	252.10	1390	215.83
600	500.00	800	375.00	1000	300.00	1200	250.00	1400	214.29
610	491.80	810	370.37	1010	297.03	1210	247.93	1410	212.77
620	483.87	820	365.85	1020	294.12	1220	245.90	1420	211.27
630	476.19	830	361.45	1030	291.26	1230	243.90	1430	209.79
640	468.75	840	357.14	1040	288.46	1240	241.93	1440	208.33
650	461.54	850	352.94	1050	285.71	1250	240.00	1450	206.90
660	454.54	860	348.84	1060	283.02	1260	238.09	1460	205.48
670	447.76	870	344.83	1070	280.37	1270	236.22	1470	204.09
680	441.18	880	340.91	1080	277.78	1280	234.37	1480	202.70
690	434.78	890	337.08	1090	275.23	1290	232.56	1490	201.34
700	428.51	900	333.33	1100	272.73	1300	230.77	1500	200.00
710	422.53	910	329.67	1110	270.27	1310	229.01		
720	416.67	920	326.09	1120	267.86	1320	227.27		
730	410.96	930	322.58	1130	265.49	1330	225.56		
740	405.40	940	319.15	1140	263.16	1340	223.88		

carrier frequency of the station assigned to the lowest channel should be kept at a frequency of 550 kilocycles. Its upper side band will then extend just to the point reached by the lower side band of the station whose carrier frequency should be set at 560 kilocycles. The next station then should have its carrier frequency set at 570 kilocycles, and so on. You can, therefore, see that for all practical purposes the space between 545 and 555 kilocycles is occupied by the broadcast station whose carrier frequency is adjusted to 550 kilocycles.

For reference, the wave length corresponding to the frequencies 550, 560, 570 and 580 kilocycles have been calculated and are given below the frequency in Figure 22. Note that while the carrier frequencies are spaced 10 kilocycles apart, in this illustration, the difference between the wave length of these carrier frequencies draws progressively less as we move from the lower frequencies towards the high end of the spectum, that is, from the higher wave length towards the lower wave length. The carrier frequencies 550 and 560 kilocycles are 9.74 meters apart. The carrier frequencies 560 and 570 kilocycles are 9.39 meters apart and the carrier frequencies 570 and 580 kilocycles are 9.08 meters apart. This decrease in separation between carrier frequencies in wave lengths draws progressively less and less until the high frequencies in the broadcast band becomes less than two meters apart.

In Figure 23 we show in graphic form the broadcast channels at the upper end of the broadcast band. You will note that the wave length corresponding to 1500 kilocycles is 200 meters, while that corresponding to 1,490 kilocycles is 201.34 meters. The separation in wave length between these two frequencies as shown by the Figures is 1.34 meters. Actually, however, a 10 kilocycle channel at the upper end of the broadcast band is just as wide as 10 kilocycle channel at the lower end of the band. The difference in separation, based on wave lengths, does not give a true picture of the situation which exists.

From the above explanation we are quite sure that you will fully understand why Radio engineers today recommend the use of frequencies to designate the transmission of Radio waves in place of wave lengths. It is surprising to note the confusion in the minds of many the relation between kilocycles and wave lengths and why kilocycles are used in allocating transmitting stations. If we were to confine ourselves to the term "wave length," we would have a cumbersome system of numbers to deal with and would find it necessary to make an involved calculation every time we wish to find the position of a particular broadcasting station in the spectrum. If we speak in terms of frequencies, we find our problem very simple. The entire situation can be described in a nut-shell by stating that the carrier frequencies in use by Radio broadcasting stations extend from 550 kilocycles up to 1,500 kilocycles and are spaced 10 kilocycles apart. With this information you can very easily calculate that there are 96 broadcast channels, available within this band if 1,500 and 550 kilocycle assignments are used.

Table No. II shows the carrier frequency assignment used for Radio broadcast stations in the band extending from 550 to 1,500 kilocycles, together with the corresponding wave lengths based on the use of the conversion factor, 300,000. If you are using a Radio broadcasting receiver which is calibrated in terms of meters, you will find the conversion factor given very useful.

TEST QUESTIONS

Number Your Answer Sheet 9—3 and add Your **Student Number.**

Never hold up a set of lesson answers until you have another set ready to send in. Send each lesson in by itself before you start on the next lesson.

In that way, we will be able to work together much more closely; you get more out of your course and better lesson service.

1. Name and describe briefly the two types of antennas in common use.
2. Draw a diagram of an undamped or continuous wave, and also a damped wave.
3. Name the three ways of producing undamped Radio waves.
4. How are damped waves produced?
5. What is the fundamental objection to the use of damped waves for Radio telegraphic purposes, and why are transmitters which radiate such waves being rapidly discontinued?
6. Draw a diagram of a type A-3 Continuous Wave, and mark the details on the drawing.
7. Explain briefly the meaning of side bands.
8. What determines the pitch of a musical sound?
9. Define the meaning of the term "fidelity" of a receiving set.
10. Why is it better to designate assignment to Radio transmitting stations on the basis of frequencies rather than on the basis of wave length?

RADIO BY MAIL

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