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Complete Course in PRACTICAL RADIO

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Lesson Text No. 19
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HETERODYNE RECEPTION OF RADIO WAVES

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There are certain common things that everyone needs for effective study. For example, everyone needs fresh air. One cannot do any kind of work successfully in an ill-ventilated room. The effect is probably more noticeable in mental work that requires some degree of originality.

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Radio-Trician's
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Complete Course in Practical Radio

NATIONAL RADIO INSTITUTE WASHINGTON, D. C.

HETERODYNE RECEPTION OF RADIO WAVES

No one can have any contact with radio communication today without hearing very frequently the term **"Heterodyne."** Newspaper articles discussing the general subjects of radio regulations and interference make frequent use of the term. It is also extensively used in descriptive matter with respect to radio sets and certain types of radio reception. The term "Super-Heterodyne" is applied to a particularly well-known receiving set which depends for its operation upon the heterodyne principle. This principle is so deeply involved in the science of radio communication and in so many ways that we are going to discuss it very fully in this text. When we have finished you should thoroughly understand the terms and the phenomenae with which it is associated.

THE PRODUCTION OF BEATS

If you have access to a piano you can perform the following experiment: Strike the white key which is known as middle C. This produces a sound frequency of 256 cycles per second. Referring to this white key as key number one, the eighth key below is low C. The frequency produced by striking it will be one-half of 256 or 128. Now referring to this as key number one, the eighth key below this might be referred to as extra low C. The frequency produced by striking it will be 64 cycles. Now strike the key which is just below extra low C, as we have called it. The frequency which would be produced by striking this key is approximately 60 cycles per second.

You have now located a white key upon your piano, which when struck produces a frequency of 64 cycles and a second white key next to it which when struck will produce a frequency of 60 cycles per second. Strike the two keys simultaneously. You will at once notice a distinct throbbing sensation which is somewhat unpleasant to the ear. The intensity of the sound produced appears to go up and down periodically. The phenomenon which you have just observed is known as the production of beats. The throbbing which you have noticed is caused by a variation in intensity in the tone as heard by your ear.

Referring now to Fig. 1, let us assume that the upper time graph labeled A represents a pure tone of 64 cycles and that the time graph B represents a pure tone of 60 cycles. If we add the ordinates of curve A to those of curve B and plot underneath a third curve, we have a graph such as is shown by curve C of Fig. 1. The number of cycles shown in each curve of Fig. 1 in each case is the number which would be produced in ½ second. The graphs would have to be twice as long to show the total number per second.

You will note that the curve C is not constant in amplitude. The intensity first rises and then falls. It is this rise and fall in intensity which produces the throbbing you have noticed. If the frequency of one of the piano keys is 64 cycles and of the other is 60 cycles, then there will be four amplitude peaks per second in curve C, or, as we usually refer to the phenomenon, the *beat frequency* produced will be the *difference* between 64 and 60 cycles which is 4 cycles.

Let us now assume that we are one hundred or more miles distant from a radio broadcasting station whose carrier frequency is 1,000,000 cycles (1,000 kc) and that a hundred or more miles in the other direction from us there is located another radio broadcasting station whose carrier frequency is 1,001,000 cycles (1,001 kc). We will also assume that receiving conditions are such that if either station were operating alone, we would have no difficulty in hearing it. If, however, both stations are operating simultaneously, we will notice in our receiving set a very strong whistle or note which makes it impossible for us to receive a satisfactory program from either station.

There are two characteristics of this note which are worthy of mention. In the first place, its frequency remains fairly constant, providing, of course, the carrier frequencies in use by the two stations are held constant. In the second place, the note is often louder than the program from either station. We are becoming acquainted with a type of interference known as "heterodyne" interference and the phenomenon we are studying is very similar to that we studied by the aid of the piano.

In our piano experiment, we were dealing with two frequencies, one 64 cycles and the other 60 cycles, both of which lie within the range of audibility of the human ear. The beat frequency which was produced by "interference" between these two audible frequencies was so low as to be inaudible. It, therefore, manifests itself as a throbbing in intensity of the tone as received by the ear. The two frequencies we are now dealing with are well above the range of audibility. The ear will not respond directly to a frequency of 1,000,000 cycles, nor will it respond to a frequency of 1,001,000. However, the simultaneous reception of these two frequencies by a particular receiving set, and the action of the detector when the two frequencies are applied to it produce a third frequency in the detector circuit and in the audio-frequency amplifier which is equal to the difference be-

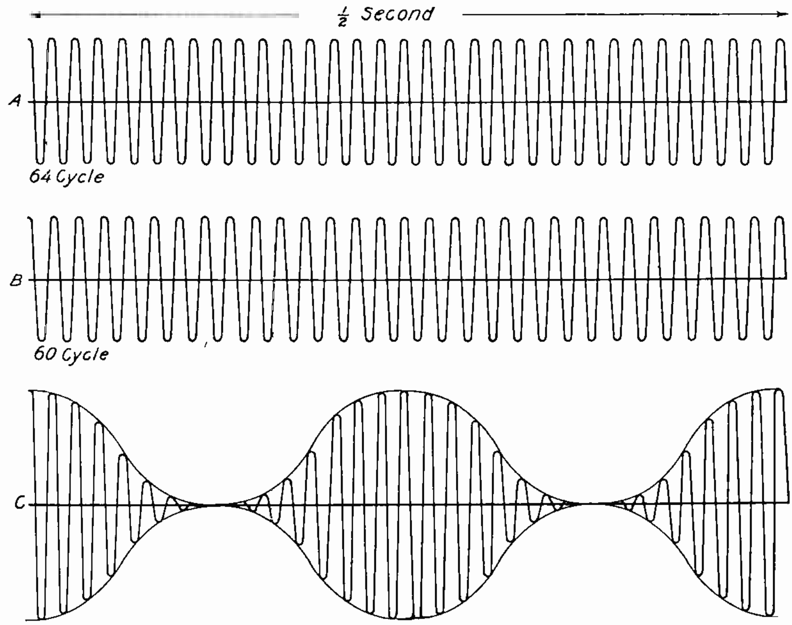

Fig. 1—Curves showing how two audio frequencies combine.

tween the two incoming frequencies. In other words, the detector will, from the 1,000,000 cycle voltage and the 1,001,000 cycle voltage present, produce a third alternating voltage having a frequency equal to the difference between these two, which is 1,000 cycles. The 1,000 cycle alternating voltage produced by the detector will then be amplified by the audio-frequency amplifier, passed through the head-set, or loud-speaker, and produce the very disturbing note which we have found.

It is of importance to note that the action of the detector is essential to the production of the beat frequency. This is a fact which is often but inadequately understood. If we were to amplify a 1,000,000 cycle voltage and a 1,001,000 cycle voltage by means of a perfect amplifier, the output of this amplifier would contain only the two frequencies with which we started. It is only by the aid of a detector that we can produce a frequency equal to the difference between the two. The fact that the two primary frequencies are well above the range of audibility does not in any way prevent the beat frequency produced by detector action from producing an audible sound when passed through a loud-speaker.

In addition to the beat frequency equal to the difference between the two incoming frequencies, there is produced by the detector another frequency which is equal to the sum of the two incoming frequencies. Thus, the combination of our 1000 kc and our 1001 kc frequencies produces in addition to the 1 kc (1000 cycle) beat note which is audible, another frequency of 2001 kc which is well above the range of audibility. This frequency has been used in certain types of receiving sets of an experimental character.

HETERODYNE RECEPTION OF CONTINUOUS WAVES

Let us now consider how the principles we have been discussing can be applied to the reception of radiotelegraph signals from a continuous wave transmitting station. As you have learned in previous lessons, continuous (CW) waves are produced by transmitting stations which produce pure sine waves, that is to say, the amplitudes of the succeeding oscillations are all the same. These waves may be produced by a vacuum tube oscillator, by a high-frequency generator, or by other methods. For telegraphic purposes, the waves are broken up into dots and dashes at the transmitting stations by means of a key. Referring to Fig. 2, curve (a) let us assume that this represents a dash as is made by closing the key for a given period of time and then lifting it as shown on the curve. Let us assume that we are located at some distance from the transmitting station at which this is done, and further that we are equipped with a radio receiving set, the circuit for which is shown in Fig. 3. The upper portion of Fig. 3 shows a conventional crystal receiving set, the operation of which we are already familiar with. In the lower portion of the figure, we have included a generating device for producing an undamped radio-frequency voltage, which voltage may also be applied to the crystal receiving circuit as is shown. We are not at this particular time concerned with the details of operation of this local generating circuit.

It might, however, very probably be a vacuum tube oscillator

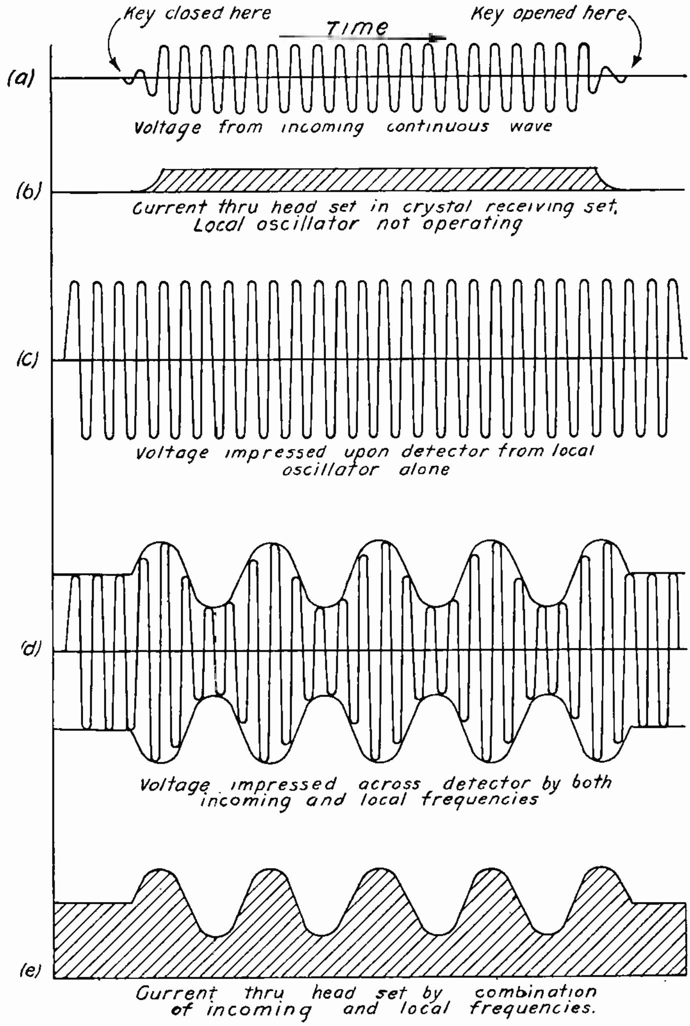

Fig. 2—Combination of incoming and local frequencies in heterodyne reception of continuous waves.

so constructed and so operated that the beat frequency produced by it could be varied at will.

For the purpose of our explanation, let us assume that the frequency produced at the distant transmitting station is 500,000 cycles (500 kc). This frequency is one which is very often used by radiotelegraph stations on ships or communicating with ships.

We have, therefore, selected a very suitable frequency for our illustration. Suppose now that before we start the local frequency generator shown in Fig. 3, we listen in the head-set of our crystal receiver while the operator at the distant transmitting station closes the key, transmits a dash and lifts the key to conclude the dash as shown in curve (a) Fig. 2. Before the incoming signal arrives, no current will, of course, flow through the head-set. When the signal does arrive, however, a voltage as is shown in curve (a) is applied to the crystal rectifier system and a steady current as is shown by curve (b) Fig. 2 will flow through the head-set.

When the key is closed at the transmitting station, a slight click will be heard in the head-set. This is due to the rise in the value of current through the head-set due to the application of the voltage as shown at the beginning of curve (b) Fig. 2. After the current through the head-set reaches this new value, it remains steady until the key is lifted at the end of the dash. This steady current will maintain tension upon the receiver diaphragm, but as the current and, therefore, the tension do not change, no sound will be heard until the key is lifted, when another click similar to the one heard at the beginning of the dash will be produced. If the operator at the transmitting station is transmitting dots and dashes in accordance with the continental code, then we will only hear a series of clicks at the beginnings and ends of the dots and dashes. Often due to the presence of other noises in the head-set, these clicks can not be readily identified.

From the above discussion, you can readily see that an ordinary crystal receiving set is not suitable for receiving radiotelegraph signals transmitted by a continuous wave transmitting station. This would also be true if a vacuum tube receiving set of the type ordinarily used for radiotelephone reception were under consideration. We must, therefore, include something else in our receiving set, if we are interested in receiving signals of the type shown in curve (a) Fig. 2.

Let us now throw into operation our local generator circuit and let us adjust the frequency produced by this generator to have a value fairly close to that produced by the distant transmitting station, say 501 kc. Curve (c) Fig. 2, shows the voltage which will be impressed upon the detector from this local oscillator alone. Since we can control the design of our generator, the voltage impressed upon the detector from it can readily be made considerably greater than will be that impressed by the incoming signal from the distant station.

Let us now assume that the operator at the distant telegraph station again transmits a dash by means of the key. We will now have present in the crystal detector circuit not only the voltage impressed by the local oscillator of 501 kc, but also the incoming voltage of 500 kc. These two voltages when added together will give a voltage such as is shown by curve (d) Fig. 2. Note the similarity between this curve and the one shown in one of our previous lessons describing the various types of waves. You will note that this is now a sine modulated wave. The varia-

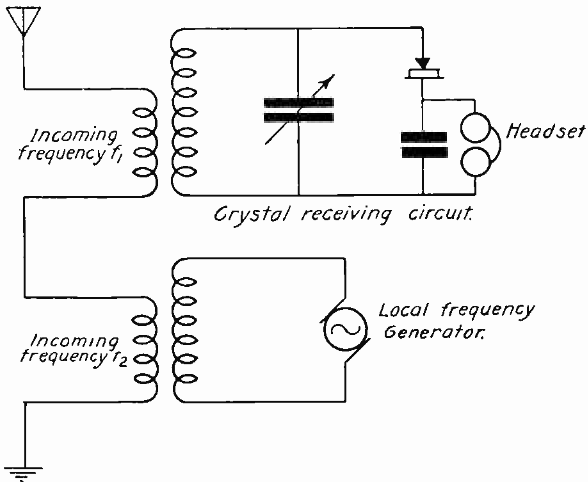

Fig. 3—Explanatory circuit to show principles of heterodyne reception of continuous waves.

tions in amplitude due to the combination of the two frequencies are of a frequency equal to the difference between the two frequencies, namely, 1 kc or 1000 cycles.

The application of a voltage to our crystal detector as is shown by curve (d) Fig. 2, produces a current through our headset such as is shown by curve (e) Fig. 2. Note that until the key is closed at the transmitting station, the current through the head-set is steady and, therefore, the receiver diaphragm is under constant tension. This steady current is, of course, produced by the local oscillator. When the voltage impressed upon the detector begins to vary in amplitude due to the effect of the incoming voltage, then we have the current through the head-set varying as is shown in curve (e). These variations will take place at a frequency of 1000 cycles as we have described, and this will cause the head-set diaphragm to vibrate at this frequency. Since 1000 cycles is well within the range of audibility, a 1000 cycle tone will be produced in the head-set.

There are a number of important deductions which can be made from the curves shown in Fig. 2. In general, the amplitude of the incoming voltage will be quite low because the transmitting station is a long distance away. The amplitude of the local voltage can be made many times this. You will readily notice that the amplitude of the 1000 cycle tone produced in the head-set by heterodyne reception as shown by curve (e) is considerably greater than the amplitude of the clicks occurring at the beginning and end of the graph as shown by curve (b). This is due to the effect of the local frequency voltage. We discover here a very astonishing fact. *By the use of heterodyne reception, we can introduce great amplification into our signal.* The amplitude of the resulting signal in the head-set from the incoming voltage alone is usually assumed to be proportional to the *square* of this voltage. However, the amplitude of the signal produced in the head-set by the combination of the incoming voltage and the local voltage is proportional to the *product* of the two voltages. Since the local voltage may be many times greater than the incoming voltage, this *product* of the two voltages may be many times greater than the *square* of the incoming voltage. Heterodyne reception possesses this great advantage over other types of reception—*the process of heterodyning in itself introduces great amplification.*

The purpose of the circuit shown in Fig. 3 is to show the principles involved in heterodyne reception, and not to give a working diagram. The circuit for the local generator has therefore been omitted, and a crystal receiving circuit has been included in place of the more commonly used vacuum tube circuit because it is somewhat easier to explain the detector action involved. Until very recently the great majority of transmitters used on ships and in land stations operated for communication with ships have been of the damped wave type. However, the great amount of interference which transmitters of this type cause with other radio services and their inefficiency has led to their gradual abolition and to the use of modern continuous wave vacuum tube transmitters in their place. Some of these transmitters are of the pure continuous wave type while others radiate continuous waves modulated at audible frequency classified as Type A-2.

Continuous wave transmitters are now very extensively used in amateur stations. These stations range in power from a fraction of a watt up to about 500 watts and operate upon frequencies which are confined to narrow bands near 1,800, 3,750, 7,150, 13,000 and 28,000 kilocycles. The bands lying near the first four frequencies listed above are probably the most used by amateurs. In a later lesson we will discuss in considerably more detail the many interesting things which amateurs are doing. We are, in this lesson, only concerned with the fact that most amateur transmitting stations are of the continuous wave or modulated continuous wave type and, therefore,

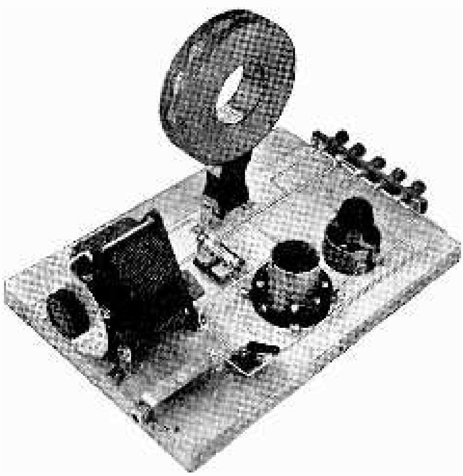

Fig. 4—A long wave receiving set for code practice.

amateur receiving sets are practically all such as to permit reception of signals from these stations by means of heterodyne reception.

A SIMPLE AUTODYNE RECEIVING SET

Most radio receiving sets used for heterodyne reception are, of course, of the vacuum tube type. In practically all such sets the same vacuum tube circuit used for detection is also used to produce the local frequency which is to be combined with the incoming frequency. This is done by using a regenerative circuit and by making the regeneration so great that the circuit actually produces oscillations. Since it is necessary only to retune the receiving set ever so slightly to make the local frequency different from the incoming frequency by an audible amount, say 500 or 1000 cycles, the fact that the receiving set is producing one frequency and receiving another does not to any appreciable extent impair its efficiency. When a particular vacuum tube circuit produces the local frequency and at the same time functions as a detector, reception is said to be by the *"autodyne"* method.

Circuits of this kind are open to one objection and this is the fact that inasmuch as they are producing oscillation they also act as small transmitters. They may, therefore, produce interference in other receiving sets trying to receive signals from the same transmitting station or from another station radiating nearly the same frequency. However, as heterodyne reception is today used most frequently in connection with commercial and Government radiotelegraph stations, the number

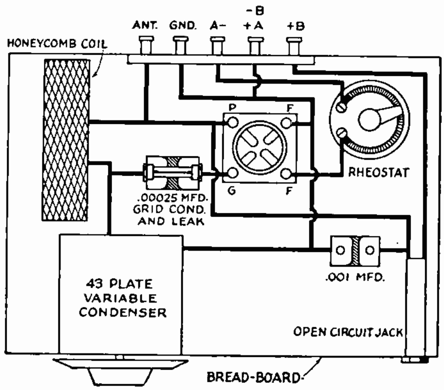

Fig. 5—Bread board mounting of a long wave receiving set.

of operators interested in this type of transmission is limited and the radiating properties of their receiving sets do not therefore ordinarily cause much trouble.

Fig. 4 shows a single circuit long wave receiving set which can be very easily constructed at small expense and which is very useful for listening to long wave stations for the purpose of learning the International Continental Code.* Trans-Atlantic radiotelegraph stations using continuous waves are continually sending on frequencies lying between 60 and 15 kilocycles (5000 and 20,000 meters). Many of them use tape transmission and therefore their sending is perfectly regular. These stations send at a speed depending upon receiving conditions at the time of transmission. It is usually possible to select a station going at about the desired speed for code practice.

* Figures 4 and 5 are taken from "The Radio Amateur's Handbook," published by American Radio Relay League at Hartford, Conn.

The following is a list of material necessary to construct a long wave radio receiver such as is shown in Fig. 4:

1 1500-turn honeycomb coil (5000 to 15000 meters).
1 standard single coil mounting (not pivoted).
1 good variable condenser having a maximum capacity of .001 microfarads.
4 brass angles to support the condenser.
1 good tube socket.
1 30-ohm rheostat.
1 .001-microfarad mica by-pass condenser.
1 .00025-microfarad mica grid condenser.
1 2-megohm grid leak.
10 feet No. 14 tinned bus wire.
1 single jack, open-circuit type.
1 terminal block, 2″ x 4¾″ x ¼″ bakelite.
1 wood baseboard, 1″ x 7½″ x 12″.
6 8/32 binding posts or machine screws with two hex nuts each.

Honeycomb coils and coil mountings can be obtained from radio parts dealers or from supply houses.

For the commercial ship and shore stations which operate upon 500 kilocycles and the frequencies which lie near this, a 150-turn honeycomb coil may be used. For the 250 to 115-kilocycle bands (1200 to 2600 meters), a 400-turn coil may be used. A 750-turn coil will bridge the gap between 115 and 60 kilocycles. These coils may be added as desired and by plugging them into the coil mounting, the wave-length range of the set may be changed. With the smaller coils, you can hear Arlington press as it is broadcast by telegraph for the use of the Navy as well as many low-powered ships and shore stations.

Figure 5 shows how the various parts may be mounted upon a plain pine board while Fig. 6 shows the wiring diagram, as well as the arrangement of apparatus. (The wiring diagram shown in Fig. 6 is somewhat different from that for the set pictured in Figs. 4 and 5 and will probably give somewhat better results. Note that it is necessary to tap the honeycomb coil.) If a 201-A type tube is used, then a 6-volt storage battery must be connected between the —A and +A terminals. The plate voltage should be supplied by one or two banks of 22½ volts each.

SUPER-HETERODYNE OR INTERMEDIATE AMPLIFIER RECEIVING SET

The same principles we have been discussing are used in a type of receiving set which is known to the great majority of radio listeners as the Super-Heterodyne. Briefly the theory of operation of this receiving set is as follows: Assume that it is desired to receive a radio broadcasting station which is operating on a carrier frequency of 1000 kc. In most receiving sets of this type, the signal energy is usually collected from the wave present at the receiving location with a coil antenna, such as is shown in Fig. 7. This signal is applied to a vacuum tube circuit which operates as the detector and to which we will refer as the *first detector.*

A voltage from a local oscillator is also produced in the coil antenna as shown in Fig. 7. This oscillator is ordinarily of the vacuum tube type and the frequency it produces can be varied at will by means of a tuning condenser. Now, instead of making the difference between the incoming frequency and the frequency produced by the *local oscillator* some frequency which is within the range of audibility, as was done in the receiving set we described for straight heterodyne reception of telegraph signals, the difference between the incoming frequency and the local frequency is made to possess some value considerably *above* the range of audibility. Let us assume that this difference is equal to 35 kc. If the incoming frequency were 1000 kc then the local frequency might be made 1035 kc. There would then be produced in the plate circuit of the first detector a beat frequency of 35 kc, together with upper and lower side bands extending to about 40 kc in one direction and down to 30 kc in the other direction.

The *intermediate frequency amplifier* shown to the right of the first detector unit in Fig. 7 will consist of two or more tubes together with associated apparatus so designed and adjusted that it will amplify frequencies lying between 30 and 40 kc much more readily than it will frequencies lying outside this band. You can readily see the reason why this amplifier is called an *intermediate frequency amplifier.* It is particularly designed to amplify a band of frequencies which lie *between* the *radio* frequencies ordinarily used for radio broadcasting and the *audible* frequencies present in speech and music. The intermediate frequency amplifier acts just exactly as it would in the event that the radiotelephone transmitter were operating at a carrier frequency of 35 kc (approximately 8571 meters) and the amplifier were connected up directly to a receiving antenna.

After the band of frequencies lying between 30 and 40 kc has passed through the intermediate frequency amplifier, the voltages are applied to the *second detector*. This functions as any detector circuit with the exception that its input will always consist of a carrier frequency of approximately 35 kc and side bands as produced by modulation extending up to approximately 40 kc and down to 30 kc. The fact that this range of frequencies is considerably lower than those lying in the broadcast band itself necessitates certain special considerations in connection with the design of this second detector circuit as we shall see in a later lesson.

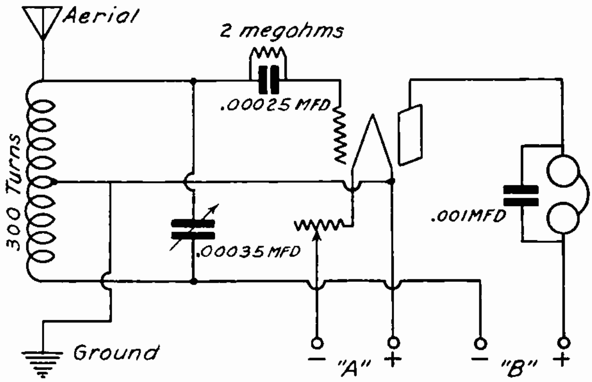

Fig. 6—Wiring diagram of a simple long wave receiving set.

The audio-frequency amplifier connected to the output of the second detector functions as would any such amplifier, its purpose being to raise the level of the speech and music frequencies to a point where they will satisfactorily operate the head-set or loud-speaker.

A Super-Heterodyne such as is shown in Fig. 7 would ordinarily use 8 tubes, one for the local oscillator, one for the first detector, three in the intermediate frequency amplifier, one for the second detector and two in the audio-frequency amplifier. In certain types of Super-Heterodynes, however, one or more tubes are made to do double duty thus reducing the total number required. To illustrate, the oscillator tube may be made to function as a detector or some other combination of functions may be made.

It should be understood that the circuit given above is not a practical one. There are, in fact, objections to coupling the local oscillator to the antenna system as is shown, inasmuch as the local oscillator will then produce energy in the antenna, which energy, when radiated, may cause interference with other receiving sets located in the immediate vicinity. The purpose of Fig. 7 is to show how the Super-Heterodyne works. We are not showing the circuit in so detailed a fashion as to distract your mind from the fundamental principles we are considering. Detailed information concerning specific Super-Heterodyne and intermediate frequency amplifier circuits will be given in a later lesson devoted specifically to this subject. We are concerned here only with the theory of operation.

There are a number of features in connection with Super-Heterodynes which you can readily appreciate after the very simple explanation we have just gone through. Regardless of the incoming frequencies, they can all be reduced to the band lying between 30 and 40 kc by the proper adjustment of the local oscillator. For instance, assume that the incoming frequency is 550 kc. If the frequency of the local oscillator is then made 585 kc or 515 kc, the beat frequency produced will still be 35 kc, and the side bands will lie to the sides of this frequency as before. The fact that the Super-Heterodyne can be made to reduce the signals from any station operating in the broadcast band to a 10 kc band of frequencies considerably lower but always the same makes it possible to design the intermediate frequency amplifier so as to operate most efficiently for all frequencies in this particular lower band. In other words, if tuned circuits are used in the intermediate frequency amplifier, they may be tuned by means of fixed inductances and condensers, and once tuned by the builder of the set, they do not need to be varied.

Only two tuning controls are necessary, the first is the variable condenser shown in Fig. 7, which must, of course, be tuned to the incoming signal. The second tuning control is the variable condenser which determines the frequency produced by the local oscillator. Receiving sets which have only two tuning controls are practically as good as those which have only one. In fact, there are those who believe that from a psychological standpoint, a receiving set with two controls is better than one possessing a single control. They argue that with a single control receiving set, one of the operator's hands has nothing to do and is, therefore, likely to be operating controls which should be left constant and not adjusted at all, such as, for instance, the filament control. However, whether or not there is any logic in this argument, no one can deny that it is practically as easy to operate a two-control receiver as a one-control receiver.

In our illustration we have assumed that the intermediate frequency amplifier is designed to handle a band of frequencies lying between 30 and 40 kc. The beat frequency produced by the combination of the signal from the local oscillator with that from the incoming signal will then be 35 kc. Such a receiving set would be referred to as a *35 kc Super-Heterodyne* and the intermediate frequency amplifier as a 35 kc amplifier. For radiotelephony it must, of course, handle a band of frequencies extending 5 kc each side of this. Different designers design their intermediate frequency amplifiers to handle different frequencies. The one we have selected for the purpose of

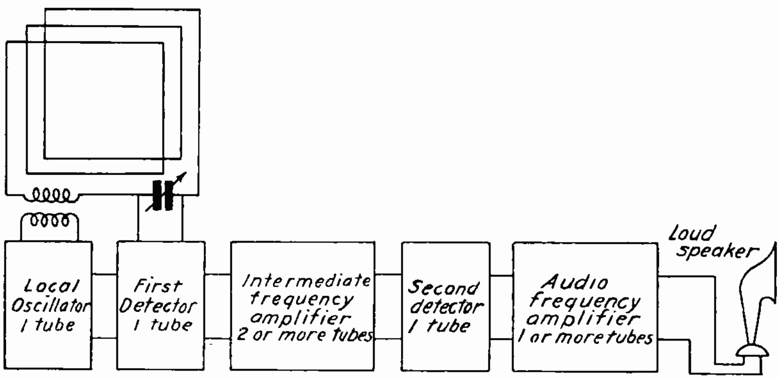

Fig. 7—Block diagram for a Super-Heterodyne or intermediate frequency amplifier type radio receiving set.

illustration is about as low as can be used without producing intermediate frequencies which will lie within the range of audibility. Some designers have built intermediate frequency amplifiers to operate when the beat frequency produced between carrier and local frequencies is as high as 340 kc. There is a distinct tendency now to use intermediate frequencies above 100 kc.

Let us note one or two peculiarities with respect to the operation of Super-Heterodynes. We will continue to assume that the intermediate frequency used in the Super-Heterodyne shown in Fig. 7 is 35 kc. If we are receiving a radio broadcast station whose carrier frequency is adjusted to 550 kc, then we can produce the intermediate frequency of 35 kc by adjusting the frequency of our local oscillator 35 kc below 550 kc; that is, 515 kc. Since the beat frequency produced is equal to the difference between the two frequencies we might also produce a 35 kc intermediate frequency by adjusting the local oscillator to produce a frequency of 585 kc. In other words, having tuned the antenna circuit by the aid of the condenser shown in Fig. 3 for 550 kc, we find that there are two places on the dial controlling the frequency produced by the local oscillator at which we can in general receive equally satisfactory signals. One of these is when the local oscillator is adjusted for 585 kc, the other when it is adjusted for 515 kc. This characteristic of the Super-Heterodyne is not possessed by any other type of receiver.

Let us assume that the station to which we are listening is transmitting on a carrier frequency of 550 kc, and is located at some distance from us. Let us, however, assume that much nearer to us is a broadcasting station whose carrier frequency is 620 kc. There will then be present in the coil antenna signals from two stations, one 550 kc, the other 620 kc. Were it not for the fact that our antenna system is tuned to 550 kc, the energy from the nearer 620 kc station would, of course, be many times that from the 550 kc station. However, in spite of tuning, it is quite possible that a considerable voltage will be produced at the input connections of the first detector circuit by the nearer 620 kc station. In addition to producing a 35 kc beat note with the incoming signal from the 550 kc station, the local oscillator will also produce a 35 kc beat note with the signal from the station transmitting a carrier frequency of 620 kc, since the difference between 585 kc and 620 kc is also 35 kc. We may, therefore, experience interference from the 620 kc station.

The phenomenon we have discussed is at times very troublesome in Super-Heterodyne receivers which are not so designed as to eliminate it, particularly in communities like Chicago and New York where there are many broadcasting stations. Less difficulty is experienced when a stage of tuned radio-frequency amplification is used between the coil antenna and the detector. The addition of this stage of tuned radio-frequency amplification and the introduction of the local signal after it has the added advantage of preventing the radiation of the local signal.

The interference we have described is also minimized by designing the intermediate frequency amplifier transformer for frequencies somewhat different than those we have used in our illustration. If our intermediate frequency amplifier is designed to handle a beat frequency of 37 kc and the two side bands as produced by an incoming signal and local oscillator, then the local oscillator would be tuned to 587 kc instead of 580 kc. The difference between 587 kc and 620 kc is 33 kc which is 4 kc lower than the 37 kc for which the amplifier is designed. However, this method of attempting to eliminate the interference is not as successful as might be supposed, due to the fact that the intermediate frequency amplifier cannot be highly selective, otherwise it will amplify the frequencies near the carrier frequency better than those removed 5 kc with the result that the signal will be distorted.

In view of the number of tubes necessary in Super-Heterodyne receivers, their circuits are often very complicated. Detailed information concerning these circuits and their operation will, as has been previously said, be given in a later lesson. The fundamental principles that we have discussed should make it comparatively easy for you to understand their operation.

Before closing our discussion, there is one principle which should be again emphasized. As you have already learned, *heterodyning in itself introduces great amplification.* In addition, since the frequencies handled by the intermediate frequency amplifier are comparatively low, it is possible to make this amplifier relatively efficient. As a result of the great amplification introduced by heterodyning and the high efficiency of the intermediate frequency amplifier, a Super-Heterodyne will operate satisfactorily even though the voltage delivered to the first detector by the signal collecting device is relatively low. In other words, Super-Heterodynes are very sensitive. They are, therefore, ordinarily used with coil antennas. Coil antennas do not deliver anywhere nearly as large voltages to the detector as do the larger antennas, but they are more selective and to some extent less subject to atmospheric disturbances.

HETERODYNE INTERFERENCE

It will be our object as we discuss the fundamental principles underlying various phases of radio communication to at the same time discuss the practical application of these principles. Thus in this lesson, after discussing in detail the production of beats, we have considered two practical applications of this phenomenon. We learned that the combination of two frequencies to produce a frequency equal to the difference between the two introduces great amplification. Two very useful applications of this principle are the use of heterodyne reception in receiving sets designed to receive continuous wave radiotelegraph signals and the use of the same principle in somewhat modified form in the Super-Heterodyne or intermediate frequency amplifier receiving set. In both of these cases, the fact that heterodyning introduces great amplification is a tremendous advantage. We are now going to consider in some detail a situation in which this amplification imposes a very serious limitation upon the use we can make of a radio station, particularly a radio broadcasting station.

As you are well aware, the range of a radio broadcasting station depends to some extent upon the power in use at the station. It also depends upon many other factors such as atmospheric conditions, the time of day or night, the season of the year, and the possible presence of disturbing influences at the receiving location. In general, however, it is possible to state figures with respect to the range of a radio broadcasting station in terms of power and miles which, while not accurate, do give a general idea of the results which can be expected.

Let us assume that a particular broadcasting station is operating upon a particular channel 10 kc wide, say the channel having its carrier frequency at 1000 kc. The approximate range of a 100-watt station is 15 miles, of a 500-watt station 30 miles, of a 5,000-watt station 100 miles and of a 50,000-watt station 300 miles. We do not, of course, mean that a 5,000-watt station will never be heard if the receiving set is located more than one hundred miles away from it. We mean that the average range of this station under normal day and night conditions throughout the year will probably run around one hundred miles. It is, of course, true that under very favorable conditions at night, a 5,000-watt station may be heard one, two or even three thousand miles away, but it is also true that under certain conditions the station cannot be satisfactorily heard at a distance of forty or fifty miles, so we will take the figure 100 miles for the 5,000-watt station as being its average good broadcast range. In other words, the radio listeners who will receive good reliable service from the 5,000-watt station under consideration will in general reside within a circle of 200 miles diameter having the station in question at the center of the circle.

An inexperienced listener might think that if the people receiving good service lie within the above described circle drawn around a station operating on 1,000 kc, a second broadcasting station operating on 1,000 kc could be located at a city two, or possibly three hundred miles distant from the first city, and that the power in use by this station might also be made 5,000 watts. If you have had any experience at all with radio receiving apparatus you know that such is certainly not the case. Even though you might be only 10 or 15 miles from the first 5,000-watt station, the operation of a second 5,000-watt station on the same carrier frequency assignment located two or three hundred miles distant from the first would completely destroy your reception from the nearer station. You would, as you well know, have a very strong heterodyne beat note produced in your receiving set which would result from the fact that without special equipment the carrier frequencies in use at the two stations would not be exactly the same, but would differ by an amount which would lie within the audible range. In fact, it is quite possible that even though the two stations in question were separated by much greater distances, you would still experience excessive interference. We might state our conclusions as follows: *While the service range of a 5,000-watt station is of the order of 100 miles, its interference range, due to the limitations imposed by heterodyning, is far greater, probably about two or three thousand miles.*

The fact that the interference range of a station is so much greater than its service range imposes some very peculiar limitations. In general, one 5,000-watt station cannot be located upon the same channel as another 5,000-watt station with a separation of less than three or four thousand miles if we are to prevent serious heterodyne interference occurring in the normal service area of either station. This means that in general it is impossible to assign the same channel in the United States to more than one station of 5,000 watts without introducing the possibility of serious interference.

Some figures have been compiled to show the maximum number of stations of given powers which can be operated simultaneously upon the same channel in the United States without serious interference due to heterodyning. These figures are as follows:—if the station is of 5,000-watt power or more, not more than one station can be operated per channel in the United States—two or three stations separated from each other by eighteen hundred miles can probably be operated simultaneously without excessive interference if the power does not exceed 1,000 watts—five or six stations separated from each other by twelve hundred miles can be operated simultaneously without excessive interference if the power does not exceed 500 watts per station—nine or ten stations separated by six hundred miles can be operated simultaneously without excessive interference if the power does not exceed 100 watts per station.

It is possible to draw a number of rather interesting conclusions from the figures which have been given. Table 1 contains approximate figures for the service radius of stations of given powers, and the number which can be operated simultaneously upon the same channel without excessive interference. These figures are, of course, only approximate and will undoubtedly vary from time to time as conditions change. Let us calculate, for the purposes of discussion, the number of square miles served by stations of various powers. These figures resulting are also shown in Table 1.

TABLE 1

Areas served upon a given broadcast channel assuming the simultaneous operation of the maximum possible number of stations of given power without excessive heterodyne interference.

Power watts	Service radius miles	Service area square miles	Maximum number simultaneous operation	Total area served by simultaneous operation square miles
100	15	707	10	7,070
500	30	2,827	6	16,964
1,000	45	6,361	3	19,085
5,000	100	31,416	1	31,416
50,000	950	2,827,440	1	2,827,440

If we assume the figures giving the ranges of broadcasting stations are correct, and that the figures showing the maximum number of stations which can be simultaneously operated upon a given channel without excessive interference are also correct, then there are certain logical conclusions which it is difficult to escape. Table 1 shows that more than twice as many square miles of area are given service by the operation of six 500-watt stations properly placed throughout the United States than by the operation of ten 100-watt stations. The table also shows that a slightly greater number of square miles are served by three 1,000-watt stations than by six 500-watt stations. However, we can serve approximately fifty per cent more square miles by the operation of one 5,000-watt station than by the operation of three 1,000 stations. The most astonishing fact, however, is that one 50,000-watt station will serve nearly three million square miles, while one 5,000-watt station will serve only thirty-one thousand square miles. In other words, the area served by the one 50,000-watt station is nearly one hundred times as great as that served by one 5,000-watt station, although the increase in power has only been ten times.

The reason for the larger area served here by an increase in power, is, of course, the fact that while it is possible to operate only one 50,000-watt station in the United States without interference, it is still not possible to operate more than one station without interference even though the power is only 5,000 watts. The obvious conclusion is that if the power is 5,000 watts at a particular broadcasting station, there is no reason why that power should not be increased to as large a value as is practicable. Since the interference range already extends beyond the United States, this increase in power will not materially produce more interference, although it will, of course, produce some difficulties in the receiving sets of those who desire to receive distant stations located at frequencies near that of the 50,000-watt station and who reside close to the 50,000-watt station.

The figures contained in Table 1 are worthy of a great deal of study. They are excellent illustrations of data such as the radio man is continually being called upon to produce. Such data are not strictly accurate mathematical calculations resulting in strictly accurate and irreputable conclusions. A great many of the phenomena with which we must deal in the field of radio communication are difficult of analysis. The factors affecting the transmitting range of radio broadcasting stations are many and varied. Let us, therefore, examine the conclusions we have drawn in the preceding paragraph and see if there are any factors which we have neglected or if there are others which we have over-emphasized.

In the first place, we must admit that our figures showing service range as a function of distance are distinctly approximate and that they depend upon the type of radio broadcast service in which we are interested. You might very properly point to instances where radio receiving sets located three hundred miles from a 5,000-watt broadcasting station had received almost daily service from that station. You might likewise indicate one or two instances where receiving sets located closer than one hundred miles, say fifty miles, from a 5,000-watt station found it impossible to secure satisfactory reception from that station. Our figures are, therefore, merely average figures. Assuming these to be correct, however, our calculations of service area immediately follow since all we have had to do is to compute the areas of circles of known diameter.

We now come to the fourth column in our table which shows the maximum possible number of transmitting sets which can be simultaneously operated assuming the transmitting stations to be of a given power. If we attempted to so place our stations through the United States that the maximum number is possible, we would probably find that at some locations where we desired to place our stations there would be no cities and probably no sources of program material available. Because of this we can probably only operate a smaller number of stations of a given power on a given channel than is shown by our table. On the other hand, we might find that transmission across mountain ranges or in particular directions is not as good as it is in other directions with the result that we might not need as great a separation between stations as we have previously decided. Taken as a whole, therefore, the figures we have given in the fourth column may be considered as good enough for our purposes. The figures in the fifth column, of course, follow from those in the previous column.

Now, if you have been thinking intently upon the subject matter we have been discussing you have already put your finger upon the weakest point in the argument presented. It is as follows: We are not interested primarily in broadcast service to *areas*. We are primarily interested in building up a broadcasting structure which will serve the *maximum number of people*. Our figures might be unimpeachable if every square mile in the United States possessed the same density of population. Such, however, is not the case. It might, therefore, be possible to place a 1,000-watt station near a large city and then to place another 1,000-watt station some distance away on the same channel near another large city and have the total number of radio listeners served by the two stations greater than could possibly be served by the operation of one 5,000-watt station at either location. This, of course, would be due to the concentration of population at these two points. While we have taken into account several of the factors involved in the delivery of good broadcast service on a particular channel, we have not taken into account all of them.

The above discussions should be sufficient proof of the necessity of carefully scrutinizing all of the factors involved in the deduction of any set of conclusions from a given accumulation of data, particularly where the data are approximate in nature and in some instances open to question. Coincidence is very often taken for connection, let us illustrate—last Monday night radio receiving conditions were very poor. Last Monday night the wind was from the East. Therefore, when the wind is from the East we can expect that radio reception will be poor!—perhaps the wind had something to do with receiving conditions but the chances are that it had nothing at all to do with them. It was merely a coincidence that the wind was at the East at the same night receiving conditions were poor. As you become more and more acquainted with the radio field, you will find that there are more superstitions about radio reception and radio operation in general than almost any other science. This is due to the fact that there are so many factors involved which are exceedingly difficult to analyze. We must, therefore, be very careful not to draw conclusions from too little data.

INTERFERENCE FROM RADIATING RECEIVING SETS

In the early days of radio broadcasting, a certain type of interference was very prevalent which fortunately has now practically ceased to exist. This type of interference also owes its existence to the principles we have been discussing in this lesson and is known as interference from radiating receiving sets. In the early days of broadcasting, a great majority of radio receiving sets were of the single circuit regenerative type. In tuning such a receiving set, the operator manipulates a tuning control and a regeneration control. The greatest sensitivity exists when regeneration is brought almost to the point where oscillations are produced. In attempting to adjust a set for weak signals, it is a very common occurrence for the operator to increase the regeneration beyond the point where oscillations are produced with the result that during the time when the operator is tuning, his set itself will be radiating high-frequency energy. The frequency of these radiations will be that for which the set happens to be tuned at the particular instant in question. Since the operator is invariably looking for stations when his set is producing oscillations, this frequency will not be constant but will be continually varying.

The high-frequency alternating current produced in the receiving antenna of the regenerative set will produce voltages in other receiving sets located nearby. Sometimes the interference may exist one-half to one mile or more away. If the frequency radiated by the receiving set is sufficiently close to that of the carrier from the distant transmitting stations to which nearby operators are listening, then the two frequencies will combine and a heterodyne beat note will be produced equal to the difference between the two. Inasmuch as the transmitting station desired is usually a long distance away, while the interfering receiving set is nearby, the electric field intensities from the two sources will be of the same order of magnitude. The beat note or "squeal" which results is very objectionable.

Many radio listeners have difficulty in differentiating between heterodyne beat notes as produced by the simultaneous operation of two broadcasting stations upon carrier frequencies too close together and the operation of a regenerative receiver on a frequency too close to the transmitting station to which they are endeavoring to listen. It is very easy to differentiate between these two types of interference. Since the frequencies used by broadcasting stations remain fairly constant, the beat note produced by the operation of two broadcasting stations on carrier frequencies too close together is practically always fairly constant in frequency. On the other hand, since a regenerative receiving set operator is usually engaged in tuning his set during the time when it is producing oscillations, the beat note produced by a combination of his signal with that of a distant transmitting station will be varying continuously.

Interference from the operation of regenerative receiving sets was very serious in the early days of broadcasting when the great majority of sets were of this type. However, the increasing use of tuned radio-frequency sets and more modern sets of other types has practically driven the regenerative sets out of existence. The situation was somewhat aggravated by the fact that in tuning for a distant station, it is somewhat easier to do so with a regenerative receiving set when the set is producing oscillations, although after the station has been found, regeneration must be decreased below the oscillation point, otherwise satisfactory reception of the speech and music cannot be obtained.

Some very humorous situations used to arise in the old days as a result of a lack of understanding on the part of the public of this peculiar phenomenon which we call fading, particularly when a large number of people in a given city were listening to signals from a fairly distant broadcasting station. Due to fading the signal would probably be changing somewhat in intensity. It would first be very strong for three or four minutes and then slowly fade out until the station could not be heard at all or was very weak. In a few minutes it would again be as strong as ever. During the period of time when the signal was strong all would be well. Large numbers of people would be listening to the station and enjoying its program. As the signal began to fade out, those unfamiliar with the phenomenon assumed that something had gone wrong with their receiving sets and they immediately began to retune. The wise listener, however, knew that the signal was fading and that nothing he could do to his receiving set would change the situation but he also knew that if he would be patient and wait a minute or two the intensity would rise to its former value.

The actions of the large number of listeners who became alarmed at the decrease in intensity of the signal and their attempts to find the station again with their receiving sets producing oscillations produced a very amusing effect. The oscillations produced by their receiving sets would, of course, beat with the frequency from the incoming station although that signal might be so weak as to prevent satisfactory reception of the speech or music. The whole effect as produced in the receiving set of the listener who did not change his set was that of listening to a swarm of bees which had been suddenly disturbed by poking a stick into the hive. This state of affairs would exist until the signal began to increase in intensity again and then one by one the listeners who had been so seriously disturbed by fading would find the station again and would for a few minutes more settle down to listen to the program. The effect of this settling down was very much as though the swarm of bees had again gradually settled down into a new hive. In a few minutes, however, the signal would begin to fade out again and numerous listeners would again become disturbed and the whole story would be repeated. While this state of affairs did not make for the best reception for the man who knew what was going on and who knew enough to leave his receiving set alone, it did undoubtedly furnish him with a great deal of amusement.

INTERFERENCE FROM HARMONICS FROM RADIO TRANSMITTING STATIONS

We have discussed two types of heterodyne interference, namely, heterodyne interference produced by the operation of two broadcasting stations upon frequency assignments which are too close together and heterodyne interference due to the operation of regenerative receiving sets. Before leaving this subject, we must consider a type of heterodyne interference which is identical in characteristics with that produced by the operation of radio transmitting stations on assignments too close together, except that it is produced by the harmonics of one or both of these stations. We must, therefore, briefly consider the production of harmonics by radio stations.

As you already know from previous lessons, *harmonics* are frequencies which are *multiples* of a frequency known as the fundamental. You will remember that in describing the production of musical sound, you learned that associated with a fundamental musical tone there were certain harmonics which gave to the tone its quality or timbre. Thus a musical tone having a fundamental of 1,000 cycles would have associated with it harmonics having frequencies of 2,000, 3,000, 4,000, 5,000 cycles, etc. Harmonics may also be produced in radio transmitters. Thus if a continuous wave transmitter is operating upon, let us say, 250 kc, it may also produce and radiate energy at frequencies of 500, 750, 1,000, 1,250, 1,500, 1,750, etc., kc. However, while musical instruments may produce as many as ten or more harmonics and while the energy content of these harmonics may be greater than that of the fundamental, fortunately with radio stations not so many harmonics are produced nor is the energy in them nearly so great in proportion to that in the fundamental. Were this not the case the type of interference we are about to discuss would present a problem far greater than is the case.

It is possible for a radio broadcasting station operating on a carrier frequency of 600 kc to radiate a second harmonic on 1,200 kc of such amplitude as to cause a serious heterodyne beat note with the signal from a broadcasting station whose carrier frequency is assigned to 1,200 kc. If a radio listener is located fairly close to the 600 kc broadcasting station and is some distance removed from the 1,200 kc broadcasting station, he may find it impossible to obtain satisfactory reception from the more distant 1,200 kc station due to the presence of energy at approximately 1,200 kc produced by the second harmonic of the signal radiated from the nearby station which should properly confine all of its energy to the 10 kc band having its carrier frequency at 600 kc. Interference may also be produced between the higher harmonics of an interfering and the fundamental of a desired station.

You can readily see that it is only those broadcasting stations whose carrier frequency assignments lie on or below 750 kc which can produce second harmonics lying within the broadcast band and only those stations having assignments lying between 1,100 and 1,500 kc, inclusive, are liable to receive interference of this sort. Fortunately, however, interference of this type within the broadcast band is not particularly troublesome due to the fact that the more modern transmitters have apparatus incorporated in them for the suppression of harmonics, and to the fact that energy radiated on broadcast frequencies is fairly rapidly damped out as it travels over the earth. Harmonics from broadcasting and other stations can, however, produce serious interference with communication on the higher frequencies unless the transmitters in question are carefully designed and correctly operated. Consider for instance the operation of a radio broadcasting transmitter in which the harmonics have not been suppressed upon a carrier frequency assignment of 900 kc. Unless this transmitter is properly equipped with apparatus for suppressing harmonics, and unless it is properly operated, a second harmonic will exist at 1800 kc, a third at 2700 kc, a fourth at 3600 kc, a fifth at 4500, a sixth at 5400, a seventh at 6300 and an eighth harmonic will exist at 7200 kc. Now, due to the fact that the higher frequency waves usually travel over the earth's surface with much less attenuation or damping than do the longer ones, these harmonics may cause very serious disturbance with the operation of other radio services in no way associated with radio broadcasting. The second harmonic lies within a band now assigned to amateurs and used by them for radiotelephone. The seventh harmonic (6300 kc) lies within a band assigned to mobile services. It is quite probable, for instance, that this band might be utilized for communication with aircrafts. The eighth harmonic lies within the amateur band which is most used for international communication. The presence of harmonic signals from broadcasting stations in this band will be almost certain to cause serious interference with the operation of amateur stations.

I think you can see from the above discussion why it is essential that radio stations be required to suppress the harmonics which are produced by the normal operation of their transmitters. It is, of course, possible for other transmitters to produce harmonics. One of the most prolific sources of interference of this type is the arc transmitter often used for high-power long-distance communication on low frequencies. Arc transmitters are prolific producers of harmonics, and those who use such transmitters have had to devote a good deal of time and attention to the elimination of these troublesome sources of interference.

Before we finish this text there is one matter which you should thoroughly understand. Harmonics are always frequencies which are *higher* than the fundamental. Thus a station operating on 500 kc cannot produce a harmonic of 250 kc. If the station were radiating energy at 250 kc, then its *fundamental* would be 250 kc and 500 kc would be the second harmonic. You may have heard a listener complain, perhaps, that when his receiving set was tuned for a frequency of, let us say, 600 kc, he heard a station which was supposed to be transmitting on 1200 kc. He, therefore, maintained that the transmitting station is radiating energy upon a frequency one-half of that which it was assigned. This is not possible. The transmitting station cannot, if its fundamental is 1200 kc, radiate energy at 600 kc. However, when a receiving set is tuned to 600 kc, it may receive some energy at 1200 kc.

If you are operating a short-wave radio receiving set for amateur purposes, you may find it interesting to explore the waves above 1500 kc to see how many broadcasting stations you can listen to on their harmonics. You may at times, due to the peculiarities of transmitting conditions at the higher frequencies, receive certain stations better on their harmonics than you can on their fundamentals.

TEST QUESTIONS

Number your answers 19—2 and add your **Student Number.**

Never hold up one 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'll get more out of your course, and better lesson service.

1. If one broadcasting station is operating on a carrier frequency of 600 kc and another several hundred miles away is operating upon a frequency of 597 kc, what will be the frequency of the beat note produced in a receiving set which is receiving signals from both stations simultaneously?
2. Why is it advantageous to use heterodyne reception for continuous wave radiotelegraphy?
3. A Super-Heterodyne radio receiving set uses an intermediate frequency amplifier designed to amplify a frequency of 45 kc. At what two frequencies can the local oscillator be set for receiving signals from a broadcasting station transmitting with a carrier frequency of 700 kc?
4. What is meant by autodyne reception?
5. Name two types of interference of the heterodyne type.
6. Give five harmonics such as might be radiated from a transmitting station improperly constructed or operated whose fundamental frequency is 730 kc.
7. Why is it not possible for broadcast stations operating on carrier frequencies lower than 1100 kc to have their reception subject to interference from harmonics produced by other stations operating in the broadcast band which extends from 550 to 1500 kc inclusive?
8. Why is it not possible for broadcast stations operating upon carrier frequency assignments higher than 750 kc to generate harmonics which will cause interference with the reception of programs from other broadcasting stations operating within the broadcast band?
9. Why are coil antennas usually used with Super-Heterodyne receiving sets?
10. Can a station operating on a certain frequency in Kcs produce a harmonic of a frequency lower than its fundamental frequency?

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