THE HETERODYNE RECEIVING SYSTEM, AND NOTES ON THE RECENT ARLINGTON-SALEM TESTS.

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Much interest has been shown in the heterodyne receiver since its use in the recent test between the Fessenden stations of the U. S. Navy at Arlington, Virginia, and aboard the cruiser, Salem. These trials mark the first public use of the heterodyne system, which has often been called the greatest of Professor Fessenden's inventions; but, as a matter of fact, the method has been utilized in the National Electric Signaling Company's plants for a number of years.

It is the purpose of the present paper to explain the heterodyne principle, and to describe the apparatus by means of which it is put into practice. Since the invention involves a number of points which are quite outside the range of observation of the average worker in radio signaling, an introductory consideration of the fundamentals of receiving instruments in general is desirable.

Every radio receiver is composed of two main parts; an energy absorber and an indicator. In some special forms of apparatus these two elements may be physically combined, but functionally they remain as distinct as before. The relation between the energy received and the response of the indicator, together with the process whereby the receipt of that energy effects the indication, probably serves as the best basis for classifying receivers in radio signaling.

In the receiving instruments originally used (which were mainly various arrangements of coherers with auxiliary apparatus), there was provided a local source of potential energy which was capable of operating the indicating mechanism, but was not allowed to do so because of the presence of some obstruction. In general, the energy of the received waves overcame this obstruction and allowed the stored local energy to give a signal upon a sounder, a buzzer, a bell, or some other indicator.

After each action of the indicator the obstruction was automatically set up once more so that the cycle of operations described might recur. This method of reception is typical of the so-called relay-operating receivers, in which the received energy serves only to release energy from a local source, and in which the final indication is not proportional to the received signal intensity. It is true that some forms of "local energy" or indirectly acting devices, such as microphones, restore themselves very quickly, and may give roughly proportional responses; but in all receivers of the relay type a group of received waves operates to change local conditions at the receiver so that energy from a local source may operate the indicator.

The relay class of receivers has been practically abandoned and almost all modern equipments have instruments in which the indication is made by the energy of the received wave itself. This statement may seem somewhat startling to some, for there still persists the old conception that the power received at radio stations is infinitesimal, and can be discovered only by the use of a "very sensitive" apparatus called a detector. Of course, the fact is that the power of the received radio signals is often of the order of magnitude of the largest rates of energy delivery occurring in line telephony, and that the detector of a radio receiving system is ordinarily a much less efficient device than the magnetic telephone used in connection with it.

Almost all receivers used in modern radio stations have as their basis of operation some instrument which rectifies electrical currents. The rectifier may be of the gaseous, liquid or solid type, but in any event it acts solely as an energy transformer linking together the wave absorbing system (the antenna) and the indicating mechanism (which is usually a telephone). In these arrangements the energy which moves the telephone diaphragm is actually received from the transmitting station by radio, and local sources of energy are not relied on to operate the indicator. The result of this type of action is a response very different from that of the relay receivers, for now the signals are proportional to the received power, and are therefore characteristic of the stations sending.

Practically all arrangements proposed or used for the reception of radio signals may be classified as either relay or transformer devices, in accordance with the above outline. The filings coherer with its battery and relay is typical of the first division;

the "crystal" rectifier operating without battery is obviously representative of the second type. It has been experimentally demonstrated that the liquid "barreter" (electrolytic detector) and solid rectifying detectors are of the direct energy-transforming type, the only effect of a local battery on their operation being a change of sensitiveness, but no alteration in the principle of operation.

It is evident that if we could secure a better relay detector than the coherer it would be possible to use radio communication in many ways not now practicable. Unfortunately all detectors of this class seem to become very delicate so soon as their sensitiveness to incoming signal is made great. This delicacy results in false operation by static; and, together with a general instability in the instruments, makes them far inferior to the transformer type detectors. This is true in spite of the fact that all instruments of the second class are limited in their response by the amount of energy actually received from the given transmitting station. The ability to give responses proportional to, and characteristic of, the transmitting station seems to be the feature which has given the transformer or convertor detectors their tremendous superiority. And radiotelephony is strictly dependent on such detectors.

It has been attempted to overcome the energy limitation of the transformer receivers by arranging them to control a microphonic relay which would modulate the current from a battery at the receiving station in accordance with the received signals. All instruments of this sort have increased the delicacy of adjustment at the receiving station and have made operation difficult on account of their large amplification of atmospheric and other false signals. It is apparent that what is needed is a quantitative receiver which permits the use of local energy to assist in giving the indication, but which will operate only upon persistent received waves; that is to say, a *selective* amplifier is needed in order to increase the effectiveness of radio receiving stations.

The only receiver of this selective type is the heterodyne, the name of which (from the Greek words *HETEROS* and *DYNAMIS*, meaning "other" and "force") describes its method of action; viz., to give an indication by using energy both from the received wave and from a local source. The telephonic relay amplifiers which have so far been proposed, act like valves

turning on and off a direct current in amounts approximately proportional to any received impulse. The heterodyne acts by the conjoint operation of two alternating currents which mutually add and subtract according to the physical laws governing the interaction of wave motions. These interactions will be next considered.

It is an interesting fact that the same laws of interference or wave addition hold whether one considers periodic displacements in water, air, "ether," or any other medium. If two wave motions occur in the same medium at the same time, the resulting action may be determined graphically by adding the ordinates of curves representing each of the separate waves. These curves are usually drawn to show displacement at a given point as time goes on, or else to show the wave form in a certain region of space at some assumed and definite instant of time. It is unnecessary actually to draw the curves, since the algebraic addition of expressions which give the displacements due to each of the component wave motions as functions of time or space will result in an equation expressing the resultant displacement.

The clearest conception of interacting wave motions may be gained from graphical considerations. Figure 1 represents two sine waves, A and B, progressing thru the same medium, and combining to give a resultant larger wave C. From the curves it is seen that frequencies of the fundamental waves are the same, and that the amplitudes are the same. Since both start at the same instant, they always remain in phase, and their effects are mutually additive, so that the resultant wave has an amplitude twice as great as either of the component waves.

Using the following notations, we can easily express the mathematical relations for the addition of the waves shown in Figure 1: t = time, n_1 = frequency of the wave shown on axis A, i_1 = instantaneous amplitude on curve A, I_1 = maximum amplitude on curve A. The same letters, but with subscript 2 refer to corresponding quantities of the wave plotted along the B axis. The curve A is represented by

$$i_1 = I_1 \sin \omega_1 t \quad (1)$$

and that of B is given by

$$i_2 = I_2 \sin \omega_2 t \quad (2)$$

where ω_1 and ω_2 are equal respectively to $2\pi n_1$ and $2\pi n_2$.

The sum of these two expressions will result in an equation of which the curve C is the locus, namely:

$$i = i_1 + i_2 = 2 I_1 \sin \omega_1 t \quad (3)$$

Fig. 1

Figure 1

Fig. 2

Figure 2

Fig. 3

Figure 3

In the case shown in Figure 1, the waves travel, so to speak, hand in hand, and therefore always assist each other. If the wave B had started slightly later than A, for certain portions of time they would be opposing each other. A case of this sort is shown in Figure 2, in which the wave B starts 90° (or $\frac{\pi}{2}$ radians) later than wave A. This angular difference of starting is called the phase displacement of the second wave, and is represented by the letter θ .

By graphically adding the curves A and B, that of C is arrived at, and it is seen that in this case the maximum amplitude instead of being twice as great as that of the component waves is only 1.41 ($=\sqrt{2}$) times as large. The frequencies and original amplitudes have remained as in Figure 1. The reason for the change of the amplitude of the resultant wave is, of course, that for Figure 1 the maxima of the resultant waves occurred at the same time, whereas in this case they do not. The graphical result may be confirmed mathematically by a process similar to that for Figure 1. The following expression:

$$i = I_1 \sin \omega_1 t + I_1 \sin (\omega_1 t - \theta) \quad (4)$$

shows the addition of two terms, the first representing curve A, and the second, curve B. By a simple trigonometric and algebraic transformation, equation (4) becomes

$$i = I_1 [\sin \omega_1 t (1 + \cos \theta) - \cos \omega_1 t \sin \theta] \quad (5)$$

For the case of Figure 2 we have assumed the phase displacement 90° , therefore $\sin \theta = 1$ and $\cos \theta = 0$. So that equation (5) becomes

$$i = I_1 (\sin \omega_1 t - \cos \omega_1 t) \quad (6)$$

$$= I_1 [2 \cos 45^\circ \sin (\omega_1 t - 45^\circ)] \quad (7)$$

$$= 1.41 I_1 \sin (\omega_1 t - 45^\circ) \quad (8)$$

Expression (8) exactly agrees with the graphical results of Figure 2.

It is seen that as the phase displacement is increased, the two component waves oppose each other for larger portions of the total time. From this it would be expected that for some value of θ the two waves might completely neutralise, and there would be no resultant action. That this may occur is shown in Figure 3, where two waves of the same frequency and amplitude as in Figures 1 and 2, but having a phase difference of π radians or 180° are shown. The sum of these two waves is zero at all points. Indeed, if we substitute for θ in equation

(5), the value 180° , we obtain immediately for the resultant:

$$i = 0.$$

Evidently the addition of two sine waves of the same frequency, but of different phases, will produce a new sine wave having an amplitude lying between the difference and the sum of the component amplitudes as the phase difference varies from 180° to 0° .

However, if the frequencies of the A and B waves are not equal, the amplitude of the resultant wave will not be constant, but will be affected by the constantly varying difference of phase of the component waves. The complete mathematical solution of this case is somewhat complicated, but a clear idea of the phenomena involved can be obtained by the graphical method. It will be found that in general, the result of the addition (which includes subtraction or negative addition) of two waves of different frequencies is to produce a third wave having a fundamental frequency of the same order, but varying in amplitude from the difference of the component amplitudes to their sum. This variation in the size of the resultant wave is periodic, and occurs at a frequency equal to the difference of the frequencies of the component waves.

This regular, periodic variation of amplitude forms the basis of the entire science of harmony in music. The waxing and waning of a wave resulting from the addition of two notes of slightly different pitches form what are called "beats." Figure 4 represents two waves of different frequencies, together with the resultant wave found by adding them point by point. The A wave, shown on the top axis, is taken to have a frequency of 250 per second, while the B wave is of frequency 200. The amplitudes are seen to be the same, say 10; and the difference in frequencies is 50 per second. On the three diagrams, the axes extend for a distance representing one-tenth of a second, so that 25 of the higher frequency and 20 of the lower frequency waves are shown. Examination of the C axis shows that, as was to be expected, there are 5 complete beats or periodic variations, which correspond to a beat frequency of 50 in one second.

In every case so far considered, the component waves have had the same amplitude. Figure 5 shows the addition of two waves having the same frequencies, as in Figure 4, but with amplitudes of 10 and 2 respectively. It should be noted that the variation of amplitude is from $I_1 - I_2 = 8$ to $I_1 + I_2 = 12$, and that

the beat frequency is the same as in Figure 4. It should also be noted that whereas the smaller component wave B has an effective amplitude of only 2, the variation in the resultant wave is twice that. These theoretical considerations of the addition of wave motions may be verified experimentally.

We may take two organ pipes and connect them to a tank of compressed air thru separate valves, so that they may be blown individually or together. One of the pipes is of variable pitch, its frequency being alterable thru a considerable range. If both pipes adjusted to equality of pitch are blown simultaneously, a note of this pitch and of a volume twice as great is secured. If it were possible to blow both pipes so that they vibrated in opposite phase, it would be possible to secure complete neutralization of sound, that is, silence. This cannot be done experimentally with organ pipes. However, a somewhat similar effect may be secured by moving one of the pipes back and forth, and so changing the loudness of the resultant sound (due to direct transmission and indirect reflection from the wall) in some parts of the room. This indicates a change in the degree of addition or neutralization due to a variation in phase difference. These beats are also shown even more perfectly by the use of the clear tones produced by ordinary singing flames.*

If the two organ pipes have slightly different frequencies, the conditions of Figure 4 will hold. One pipe has been adjusted to 500 vibrations per second, corresponding roughly to the note C' and to a wave length in air of 0.6 meter (2.2 feet). If the other has a slightly different pitch, when both are blown together, there will be produced a tone which shows a slow increase and diminution of volume, the number of beats per second being determined by the difference of the frequencies of the organ pipes. If the difference of pitch is slightly increased, the beats increase in frequency, and if the difference of frequency of the pipes is still **further increased**, the beat frequency increases till finally the fluctuations can no longer be heard. When both organ pipes produce sounds of the same intensity, the beats are very marked. But even when the tone from one pipe is made very weak by shutting off part of the air supply, the beats are still very distinct, as would be expected from inspection of Figure 5. As a rule, the beats are more prominent than the weaker of the two component

*(The experiments herein described were performed at the original presentation of this paper before the INSTITUTE. Editor.)

Figure 4

Figure 5

Figure 6

tones, and this fact is often made use of by engineers working in acoustic problems to determine the presence of a weak tone which cannot itself be heard because of other noises.

The acoustic effects described have their exact analogues in electricity. If we had two small alternators independently driven and with separate controlling resistances (so that their frequencies, phases, and amplitudes might be changed at will), it would be possible by varying the several resistances to secure all the effects shown in the preceding figures.

Changing the frequency of the interesting waves does not affect the production of beats so long as the difference between the frequencies is kept constant, except as the component or fundamental frequencies affect the responding mechanism. Responders or indicators are of two broad classes, polarized and non-polarized. A polarized indicator is one in which a displacement in one direction will produce a motion in a certain direction, and a displacement in the other direction will produce a motion in the opposite direction. Examples of this class are the ear and the ordinary magnetic telephone. In non-polarized indicators a motion is produced in a certain direction regardless of the polarity of excitation. That is to say, a positive displacement will produce the same motion as an equal negative displacement. Examples of this type of indicator are the static telephone and the magnetic telephone having no permanent magnet. Referring to Figure 4, and considering a wave motion in air represented by the C wave affecting a polarized indicator such as the ear, it is evident that the ear drum follows exactly the curve of excitation. It is also evident that as the frequency is increased indefinitely a point will be reached at which the ear drum cannot follow in its movements the rapid fundamental vibrations, tho it could move at a frequency corresponding to the beats. Air vibrations which approach and even pass this upper limit of audible vibration frequency may be produced by the use of a Galton whistle, and by moving this instrument back and forth in front of a reflector, beats in the high frequency note can be produced because of the interference between the direct and reflected waves. It is found that beats of sound can be heard up to the limit of audibility, but so soon as the whistle produces an air wave which cannot itself be heard, the beats become inaudible.

The reason for this can be seen from Figure 4 C. When the note frequency is so high that the inertia of the ear mechanism

prevents any response to individual half waves, the applied wave energy alternates so rapidly that its effects are alternately equal and opposite, and there is no tendency toward motion of the drum. When the fundamental wave itself produces no motion regardless of its intensity, it is quite evident that variations in this intensity will produce no effect, and therefore that beats are inaudible under these conditions. The beats really exist none the less, and this may be proved by noting that even tho they are inaudible to some persons, others whose ears have a higher limit of audibility can still hear the variations in amplitude of the fundamental whistling tone.

The conditions are completely changed, however, if, instead of a polarized device, there is used one which is non-polarized, or one in which there is given an effect proportional to the integrated applied energy, regardless of the polarity or direction of displacement. Figure 6 applies to an instance of the second sort. In this diagram, the curve along the C axis is exactly like that of Figure 4. If motion in the same direction is produced for either positive or negative displacements, such motion will be shown by the curve D of Figure 6, which is the curve C rectified. A little consideration will make it clear that in this case, as the frequency of the component tones is increased (provided their difference is kept the same), there will still be a motion corresponding to the frequency of the beats even tho the responding mechanism can no longer follow the individual waves. The motion which will result is shown along the E axis.

The possibility of building a radio receiver based on the beats principle should now be evident. If two radio frequency currents of slightly different periods are allowed to interact, there will be a periodic variation of amplitude of the resultant radio frequency current, and this variation or beat frequency will be equal to the difference of the two fundamental frequencies. As is well known, it is not possible to indicate the existence of a radio frequency current by means of a polarized indicator such as the magnetic telephone of the usual type, since the wave frequency is beyond the upper mechanical limit of response of such indicators. An air core telephone, or one without a permanent magnet, would give an indication when such currents passed thru it, since it belongs to the non-polarized class and operates in a manner analogous to that shown in curves D and E.

The development of the heterodyne receiver by Professor

Fessenden and the engineers of the National Electric Signaling Company may now be considered. Figure 7 shows the first device in which the heterodyne principle was employed. Here A and A' are separate receiving antennae, B and B' loading coils, and C and C' additional coils so arranged that their resultant field will act upon the diaphragm D. If, at a transmitting station two sustained waves of slightly different frequencies are sent out, and at the receiving station one antenna is tuned to each, their conjoint action will result in a motion of the telephone diaphragm corresponding to the difference of their frequencies. Signaling may be effected by sending short or long groups of both waves simultaneously, or one wave may be generated continuously and the signals sent by starting and stopping the other one. It is evident that an economy may be brought about by transmitting only one wave, and generating the second frequency at the receiving station. Figure 8 shows the apparatus arranged for this method of operation, and in this sketch G represents a radio frequency generator, and F and H tuning inductance and condenser respectively. The local generator G is under the control of the receiving operator, and therefore the difference between its frequency and that of the waves received from the transmitting station may be varied so as to give vibrations of the diaphragm D corresponding to any musical note which the operator may prefer.

The form of telephone shown in Figures 7 and 8 was found not to be a very efficient receiver, so that the sensitiveness of the entire system was improved by the use of a thin insulating diaphragm carrying one coil, this being placed in the field of the second fixed coil C, Figure 9. With this arrangement the effect is the same as in Figure 8, except that the repulsion between the coils as well as attraction is used. A still further increase in sensitiveness was attained by substituting for the dynamometer type a delicate static telephone as shown in Figure 10. This arrangement, together with one equivalent to it (in which the static telephone was placed in a coupled circuit) has been used by the Company for some time, and is effective. The arrangement gives a sensitiveness equal to that of the usual detector for persistent waves, yet the selective power is much higher and the response to static far less. With the arrangement shown in Figure 10, I have personally received signals over distances of approximately 3,000 miles (4,800 km.), altho the static telephone

Fig. 7.

Fig. 8.

Fig. 9.

Fig. 10.

Fig. 11.

is notoriously insensitive, and such results might appear incredible.

A further reference to Figure 10 will serve to show how the effective receiving power of the static telephone is increased by the application of the heterodyne principle. From the sketch it is clear that any current flowing in the antenna by way of the static telephone D will cause a motion of the diaphragm. The sound energy produced by this action will be proportional to the electrical energy, that is, to the square of the antenna current. If we consider the received wave as setting up the antenna current, it is seen that if the former is of audible frequency and sufficiently powerful, the diaphragm will give an audible indication of frequency twice that of the received wave. If the frequency is increased beyond that to which the diaphragm can respond, motion will be produced only at the beginning and ending of the trains of waves, and during all the time radio frequency current is passing, the diaphragm will remain in a state of steady strain. If such radio frequency waves are received in groups, there will be a pull on the diaphragm for each group, and the group tone will be produced with a strength proportional to the square of the antenna current. If we assume that no waves are being received, but that the generator G is in operation, the effects produced will be the same as outlined above. So long as the generator produces a stream of sustained radio frequency current, the diaphragm will remain strained toward the fixed plate, and motion will be produced only when the generator current is altered in value. If a stream of waves is received by way of the antenna, and at the same time the local generator is operated to produce currents of a slightly different frequency, the effects in the antenna may be considered to be those shown in Figure 4, where A represents the locally generated current, and B shows that from the received wave. These two series of alternating impulses acting simultaneously on the static telephone produce effects corresponding to the rectified form shown in Figure 4 C. Since attraction of the telephone diaphragm results from any increase of the electromotive force, regardless of the polarity, the tendency toward movement is shown by Figure 6 D. Inasmuch as the inertia of the diaphragm prevents the indication of the individual waves, its actual motion is shown in Figure 6 E. If the incoming wave has a frequency of 100,000 cycles per second (corresponding to a wave length of 3,000 meters) and that

of the generator is 101,000, a musical beat tone of frequency 1,000 will be produced by the static telephone and the intensity of this sound will be *proportional to the square of the beat variation*.

What value this action has in increasing the strength of signals may be determined from a brief consideration of a mathematical explanation which has been proposed. Assuming a receiving current of i_1 milliamperes, it is clear that if the train be started and stopped by some form of interrupter the signal will be measured by $(i_1)^2$ audibility units since the response is proportional to the square of the antenna current. If, instead of interrupting the incoming wave, there is induced in the antenna a second locally generated radio frequency current of i_2 milliamperes, the resulting instantaneous value will be

$$i = i_1 + i_2 \quad (10)$$

The component of the antenna current measured by i_1 varies from zero to its full value as the signals are started and stopped, but the value of i_2 , which is generated at the receiving station, remains constant. If the audible response were proportional to the current, there would be no increase in it due to adding i_2 . But since this response is proportional to the energy, or current squared, it is proportional to

$$i^2 = (i_1)^2 + 2 i_1 i_2 + (i_2)^2 \quad (11)$$

Considering now the various components of this antenna energy factor, the part represented by $(i_1)^2$ starts and stops with the signal dots and dashes, but is of inaudible frequency, and therefore does not add to the tone signal in the static telephone. The component $(i_2)^2$ is constant, and therefore forms no part of the signal. The remaining component, $2 i_1 i_2$ measures the signal, since it represents the beat itself. The response is proportional to the energy of the beat variation, that is, to

$$(i_1 + i_2)^2 - (i_1 - i_2)^2 = 4 i_1 i_2 \quad (12)$$

The effective amplitude is one-half of this. It is therefore clear that with the heterodyne receiver it is possible to get a signal y times as loud as with the plain static telephone, where y is defined by

$$y = \frac{2 i_1 i_2}{(i_1)^2} = \frac{2 i_2}{i_1} \quad (13)$$

From (13) it is seen that if the current drawn from generator G , (Figure 10) is less than one-half that received, there will be no improvement in the signal, but as soon as more is taken

from the local circuit an increase in effective sensitiveness is had. Values of current for an actual case may be taken as $i_1=1$ milli-ampere and $i_2=100$ milliamperes, which gives a value of $y=200$. In other words, under these conditions the signals received by the heterodyne will be 200 times as loud as tho the plain static telephone were employed with no local excitation. Since such a ratio of i_2 to i_1 is not at all out of the ordinary, the increase of sensitiveness which makes possible reception over distances of 3,000 miles (4,800 km.) may easily be understood.

It should be noted that the theoretical amplification factor expressed by y in equation (13) holds only for the interaction of two sustained sine waves. If damped waves are used, the beats will still be generated, but they will become weaker as the decrement of the received wave is increased, since as the beats tend to build up, the decreasing amplitude of one of the component waves will tend to reduce them. With highly damped discharges such as those produced by atmospheric disturbances, only a portion of a beat is produced, and therefore the response to static is small. But with the waves of a well-adjusted spark station of the synchronous rotary or fixed quenching gap types the amplitude ratio may reach comparatively large values. This obviously provides a means for selecting persistent signals and eliminating undesired atmospheric disturbances.

The heterodyne receivers described above are limited in practise by the low sensitiveness of the indicator, but this handicap has been removed by the adoption of the type now in use. This last arrangement is shown in Figure 11, where A and E represent antenna and ground, and where B' and B'' are coils forming the antenna-to-ground circuit. I is a secondary coil and J a tuning condenser, K and L are respectively rectifier and telephone condenser, and M represents a magnetic telephone of the usual type. F G H shows the ordinary local generating circuit, coupled to the antenna thru the coils B'' F. In this apparatus the action is exactly as described above, the rectifier-telephone combination taking the place of the other non-polarized receivers. Referring to Figure 6 the action may be explained by considering that the C curve represents the currents in the radio frequency circuits, while rectified currents pass thru the telephone windings and produce a motion of the diaphragm corresponding to E. It is clear that in this arrangement of apparatus the amplifying power of the heterodyne system may be combined with the

sensitiveness of the normal rectifier and telephone. The difficulty due to the delicacy of the usual detector has been overcome, and it is possible to get tremendous amplifications of sustained waves and very valuable increase of signal intensity even when receiving from spark transmitters.

NOTES ON THE RECENT ARLINGTON-SALEM TESTS

Heterodynes of the type last described were installed at Arlington and aboard the Salem for the recent tests between those stations, and were used as the extreme distances were approached. During these trials the greatest amplification factor measured was 12 times, and the average thruout the test was about 5. That is to say, spark signals from Arlington or from the Salem were received on the heterodyne an average of 5 times louder (as measured by the audibility factor) than upon the electrolytic detector operating alone. This increase in effective sensitiveness, together with auxiliary apparatus of especially efficient design, made possible the great communication distances attained, altho even without the heterodyne new records for consistent communication between ship and shore would have been established. In connection with reports of this test which have appeared in various newspapers and scientific periodicals, it should be noted that the spark transmitter and Fessenden receiver were used for all official communication trials, but that a number of other receivers, including a ticker, were placed aboard the Salem by the Navy Department for some special tests. In some of these experiments an arc transmitter which had been temporarily installed at Arlington was used. A statement has been made to the effect that signals from the arc were received further than those from the spark transmitter, and this in itself is true, altho it leads to an erroneous idea as to the reasons for the occurrence. The explanation is simply that the heterodyne was used for receiving all signals at long distances, whether from the arc or from the spark transmitter, the ticker receiver having been abandoned by the Navy engineers within the first few days of the cruise, since results from it were not to be compared with those obtained with the heterodyne.* The heterodyne amplifies sustained waves such

* Dr. Austin is of the opinion that the rotary ticker used on the "Salem" was probably in some way defective, as it did not appear more sensitive than the electrolytic even, altho ordinarily it shows a sensitiveness of from three to ten times greater.—Editor.