PRODUCTION OF SINGLE SIDEBAND FOR TRANS-ATLANTIC RADIO TELEPHONY*

By

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On January 5, 1923 the first public demonstration was made of the use of the single sideband eliminated carrier method of transmission applied to radio. The occasion of these tests was the transmitting to England of messages spoken by the officials of the American Telephone and Telegraph Company from their offices at 195 Broadway, New York. These tests, which were made possible by the co-operation between the engineers of the American Telephone and Telegraph Company and the Western Electric Company and the engineers of the Radio Corporation of America, have been described in a paper by Arnold and Espenschied.[1]

This single sideband eliminated carrier method of transmission has been in use on wires for several years. This method was invented by J. R. Carson. It is described in his patent[2] and is discussed in a paper by Colpitts and Blackwell.[3] The electrical filter which plays an important part in the system here described was invented by G. A. Campbell. Its advantages over the ordinary modulated carrier system of radio transmission are such as peculiarly to fit it for long wave radio telephone work.

The Single Sideband System

The general principles of the system, whether applied to wire or radio communication, are outlined in the papers just referred to and in one by Hartley, but as the application which I am about to describe is best understood by having a simple point of view, it is desirable to repeat a certain amount of what has been given in these papers.

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[1] "Journal of the American Institute of Electrical Engineers," June, 1923.

[2] United States Patent Number 1,449,382, also 1,343,306 and 1,343,307.

[3] "Journal of the American Institute of Electrical Engineers," April, 1921.

To begin with, we must consider the nature of our signals to be transmitted. The sound waves in speech are exceedingly complex. It has been found, however, that with a continuous band of frequencies extending from 200 cycles to 2500 cycles intelligible transmission of speech can be obtained. While entirely perfect reproduction of speech would require an extension in the frequency band in each direction, the range given above is sufficient for reasonably satisfactory communication. In reducing the construction of speech to this sustained wave basis we can use a method of handling the analysis of our system which is relatively easy in the present state of the art.

When several people speak simultaneously, frequencies occurring in their various voices all fall within the same range. Any system of communication built to transmit several conversations over the same wire or thru the same medium must provide means for sending several of these groups of frequencies without their mutually interfering at the receiving end. That is, if the frequency range representing conversation *A* in Figure 1 is a group occurring in one conversation, we must make it possible to keep this group separate from other groups that fall in the same range. What we call the single-sideband system provides a method for doing this as follows: Suppose we take the group *A* and shift it abruptly to the position marked *B* which is, say 25,000 to 30,000 cycles. A second conversation also falling in the region *A* is then shifted by another piece of apparatus up to the position *C* which runs from 20,000 to 25,000, and so on in like manner other conversations can be given positions *E*, *D*, and so on. Now with this shift in the frequencies to higher values, each conversation occupies its own frequency region and it is possible by the use of filters to separate one group from another. That is, at a receiving end group *B* will be selected by a suitable filter which discriminates against *E*, *C*, and so on, and when this group is shifted back to its original position it is understandable to the recipient. Simultaneously *C* and *E* selected by their respective stations are also moved back to the positions originally held at *A* and are also understood by their respective recipients. There is then no mutual interference between these various conversations.

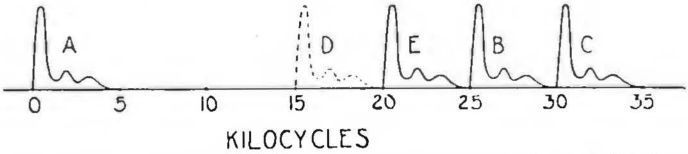

FIGURE 1—Shifted Speech Frequency Bands for Multiplex Communication

This system of communication has certain advantages over ordinary radio telephony. One is that the frequency band region which it occupies is only equivalent to that taken up by speech itself. It is one-half of the frequency band width which is taken up by the ordinary modulated carrier in radio, so that there is a doubling of the number of channels of conversation over what ordinary radio will allow. Another advantage is that there is no carrier transmitted. In the ordinary modulated wave at least two-thirds of the energy goes into the carrier which is not one of the intelligence-carrying frequencies. In this new system all of the energy goes into those frequencies which represent the speech frequencies and when converted back into speech frequencies at the receiving end provide those frequencies with the necessary energy. In view of the fact that the power used for trans-Atlantic communication runs up to the order of hundreds of kilowatts, it is highly desirable in the interest of economy that as little be put into the non-intelligence-carrying frequencies and as much be put in intelligence-carrying frequencies as is possible.

A third advantage is that with the narrowing of frequency range which occurs over what we get in ordinary modulated radio it is possible to work on sharper tuned antennas at long waves. This is of particular importance.

METHOD OF PRODUCTION

The sliding of a conversation band such as represented by frequency group A up to range B is accomplished by making use of well-known principles. When a sustained wave has its amplitude varied in accordance with an audio frequency signaling wave the resulting modulating wave represented by equation

$$i = A \sin \omega t (1 + \Sigma K \cos \phi t)$$

may be looked upon as a group of frequencies of steady amplitude. The principal frequency is the carrier frequency, $A \sin \omega t$, and on either side of this carrier, groups of frequencies known as sidebands occur. A sideband group of frequencies consists of an aggregation of frequencies having exactly the same frequency-amplitude distribution when measured from the carrier frequency position as has the speech signal $\Sigma k \cos \phi t$. That is, if conversation A modulates a carrier C in Figure 2 there are produced above frequency "C" a group of frequencies called the upper sideband having frequencies $\left(C + \frac{\phi}{2\pi}\right)$ and below frequency C another group called the lower sideband, having frequencies $\left(C - \frac{\phi}{2\pi}\right)$

These frequencies above and below the carrier occur simultaneously with the frequencies in the speech group and have relatively the same amplitude and variation in amplitude with the frequency. We, therefore, usually say the frequencies produced when a radio frequency wave is modulated are the carrier frequency, the carrier plus the speech frequencies, and the carrier minus the speech frequencies.

The ordinary process of modulating a carrier wave thus produces a group of frequencies such as *B* (Figure 2) having exactly the same frequency-amplitude arrangement as the original speech frequencies, but they occur in a totally different part of the frequency range. This gives us the shift in the speech band which we desire. The undesirable things about it, however, are that they are located close by a carrier frequency and the frequencies of the other sideband. To get the desired band isolated, it is necessary to discriminate against or eliminate entirely the carrier and the undesired sideband.

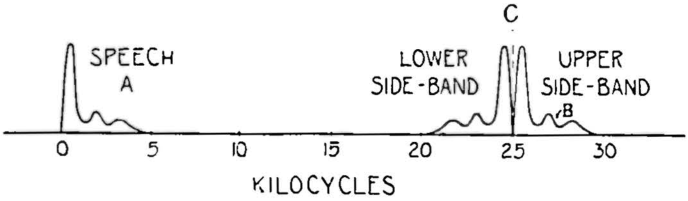

FIGURE 2—Sidebands Produced When a Radio Frequency Carrier Wave is Modulated by speech

The elementary system of a single sideband radio telephony is, therefore, to modulate a carrier with speech, put the modulated wave thru a filter which will eliminate the carrier and undesired band and then amplify the desired band and put it into the antenna. Practically, it is not so simple. In its application to line wires the carrier is first eliminated by balanced tube circuits. In the application of it to radio further complications become necessary.

The difficulty is apparent when we consider that the upper and lower sidebands lie quite close together. If we wish to use a sideband near 50 000 or 60,000 cycles we would find a satisfactory filter prohibitively costly to build in the present state of the art. Also, if we rely on a single filter to accomplish our selection, either the filter must be adjustable or else transmission must be restricted to one frequency. It would be an obvious hardship in radio not to be able to change wave length to avoid interference, and on the other hand adjustable filters are difficult and costly to construct. We, therefore, resorted to the process of double modulating[5] in addition to using a balanced modulator for carrier elimination in order to get around both the difficulties mentioned above.

CARRIER ELIMINATION

To eliminate the carrier we can use several circuit schemes. For instance, in Figure 3 is shown a bridge arrangement in the plate circuit of a modulator. The bridge contains one arm tuned to the carrier, and is balanced for it. The carrier will not be present in the output of this bridge network or on the grid of the amplifier. For the sideband frequencies, however, the bridge will be unbalanced and they will be impressed by means of the transformer, *T*, on the amplifier. Or we might use the circuit shown in Figure 4, where the output of the modulator tube *M* is impressed on the circuit "*Q*." A coil *P* connected to the oscillator couples with an inductance in circuit "*Q*" and introduces enough of the carrier in opposite phase to neutralize the carrier from the tuned circuit "*O*." In the case of the side frequncies produced

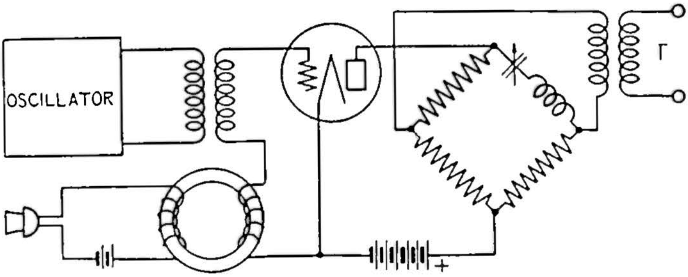

FIGURE 3—Modulator Tube with Bridge Circuit to Eliminate the Carrier

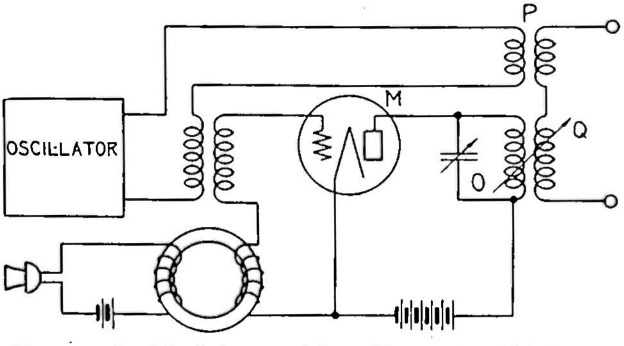

FIGURE 4—Modulator with a Circuit in Which the Carrier is Neutralized

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[5] Espenschied, United States Patent Number 1,447,204.

by the modulator tube and delivered through the circuit *"O,"* there will be no emfs. to balance them out and they will be impressed upon the amplifier. Or we might make use of the balanced modulator shown in Figure 5. In this case two modulator tubes are used. The carrier is put on from the oscillator to the two grids in parallel while the speech comes in on the grids in opposition. The transformer *C* in the output circuit will therefore, not transmit any of the carrier but it will transmit the sidebands. There are other modifications of these circuits which will accomplish about the same results, but these are the principal ones and the one in Figure 5 is the one we have used in our work.

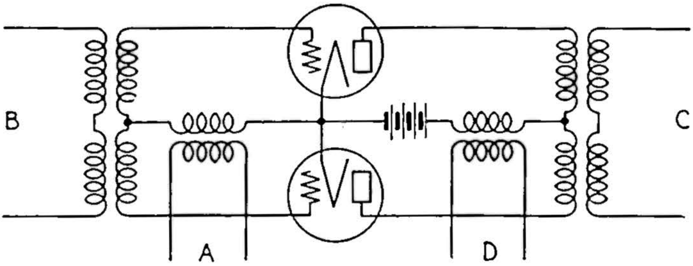

FIGURE 5—Balanced Modulator Showing the Two Places for Introducing the Speech and Carrier, and Two Places for Securing the Output

The degree to which the carrier must be eliminated is not so great as for the undesired sideband. It gives trouble only in proportion to its magnitude relation to the locally supplied carrier at the receiving end. That is, the amplitude of any audio frequency beat note it produces is

$$A = C\,S\,k$$

where *C* is the carrier amplitude received and *S* is the sideband amplitude received. The locally supplied carrier *C′* will produce a beat note of

$$A' = C'\,S\,k$$

and this always is much greater. The trouble comes only if *C* and *C′* do not have identical frequency values. If the ordinary detector is used in receiving, it is necessary to make *C* as small as possible so that *C′* does not have to be exactly in synchronism. If we use a balanced detector the magnitude of *C* is of secondary importance as the circuit will automatically eliminate *A* but not *A′*.

In keeping our carrier down to a minimum we make use of both the balanced modulator and of the filter. The balanced modulator reduces the carrier to a very considerable extent and by placing the carrier about half way up the side of the filter attenuation curve, it is reduced a considerable amount more. The final value is then a fraction of a percent of the value it would have if not reduced at all. In order to eliminate the carrier sufficiently a proper proportion of the carrier and speech amplitude must be made. The magnitude of the sideband is proportional to the product of the carrier and signal amplitudes, while of course any unbalance and frequency selection in the carrier elimination circuit will give a carrier output proportional to the carrier input, so that we do not want to make the carrier too large, because any unbalance will allow a proportionately large amount to get thru.

THE BALANCED MODULATOR

A little further information on balanced modulators will probably not be out of place at this point. Suppose we take a circuit as represented in Figure 5 and add a transformer in the position D. We then have two places in which to impress voltages on the grids A and B and two places to take the power out of the circuit, C and D.

If there are impressed a carrier voltage E_1 and a speech voltage E_2 we write the equation of current as:

$$\begin{aligned}
i &= a_1 (E_1 \cos \omega t + E_2 \sin \phi t) + a_2 (E_1 \cos \omega t + E_2 \sin \phi t)^2 + \dots \\
&= a_1 E_1 \cos \omega t + a_1 E_2 \sin \omega t + a_2 E_1^2 \cos^2 \omega t \\
&\quad + a_2 E_2^2 \sin^2 \phi t + 2 a_2 E_1 E_2 \sin \phi t \cos \omega t + \dots \\
&= a_1 E_1 \cos \omega t + a_1 E_2 \sin \phi t \\
&\quad + \frac{a_2 E_1^2}{2} + \frac{a_2 E_1^2}{2} \cos 2 \omega t \\
&\quad + \frac{a_2 E_1^2}{2} - \frac{a_2 E_2^2}{2} \cos 2 \phi t \\
&\quad + a_2 E_1 E_2 \sin (\omega + \phi) t \\
&\qquad a_2 E_1 E_2 \sin (\omega + \phi) t + \dots
\end{aligned}$$

for tube number 1. If we had both the carrier and the speech frequencies impressed on transformer B, the current in tube number 2 would be identical except that the signs of E_1 and E_2 would be reversed. The current taken out thru transformer C would be the difference of these two currents, while the current taken out thru transformer D would be the sum of the two. If, however, we both put the speech and carrier in at transformer A, the signs of E_1 and E_2 in the equations for the currents will be the same, and the sum and difference currents coming out thru transformers D and C will be quite different. There are thus totally different currents to be secured at these two outputs depending upon where the inputs occur. Also E_1 and E_2 may be put in at separate transformers A and B, respectively or vice versa, and in that case still different results occur. The four combinations possible are shown in table A.

TABLE A

	Speech in at	Carrier in at	Out at C	Out at D
1	A	A	0	$\phi, \omega, 2\phi, 2\omega, \omega-\phi\ \omega+\phi$
2	A	B	$\omega, \omega+\phi, \omega-\phi$	$\omega, 2\phi, 2\omega$
3	B	A	$\phi, \omega+\phi, \omega-\phi$	$\omega, 2\phi, 2\omega$
4	B	B	ϕ, ω	$2\phi, 2\omega, (\omega-\phi), (\omega+\phi)$

All odd harmonics of ω and ϕ come out with these respective frequencies, and the even harmonics come out where 2ω and 2ϕ, respectively, are shown.

If our only purpose is to eliminate the carrier $\omega/2n$ we can use either combination 3 or 4 from the table. We would take the sidebands out thru transformer D if using combination 4. However, the second and even harmonics come out with the sidebands in combination 4 while only the speech frequencies (and odd harmonics if present) come out with the sidebands in combination 3. As the transformer to handle the side frequencies will be inefficient for the speech frequencies, we can secure the sidebands free of other frequencies more easily with combination 3 than with any of the others.

FILTERING

The principal reason why we do not use the more simple process of producing the single sideband is that it is too expensive to build filters sufficiently sharp to separate one sideband from another at carrier frequencies up in the neighborhood of 60,000 cycles. In order to get a single sideband at 60,000 we resort to the process of modulating twice. That is, we secure our single sideband at a low enough frequency to separate it easily from the carrier and the other sideband and then by a second modulation process we move it to the desired point. This is represented in Figure 6. The speech band represented by A is used first to

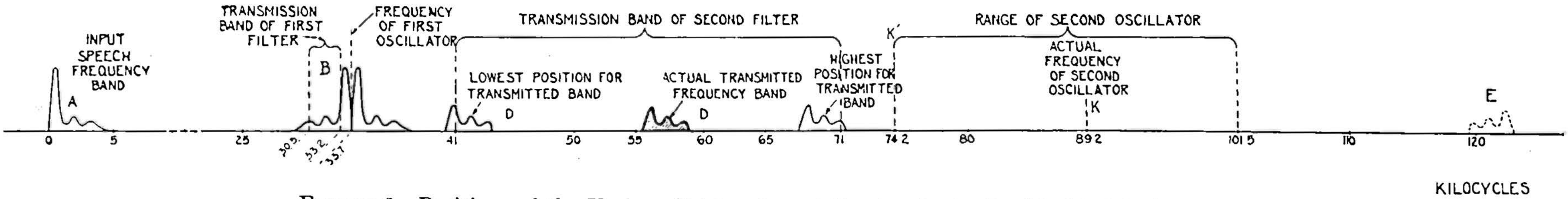

Figure 6—Positions of the Various Sidebands and Carriers in the Double Modulation Process

modulate a carrier such as 33,700 cycles. There are then produced an upper and a lower sideband at that frequency. It is comparatively easy to separate the bands at this frequency. In this particular case we pick out the lower sideband, that is, we use a filter which transmits the frequencies running from 30,500 to 33,200. For this purpose the filter is built with a good steep slope on the upper side. The filter which we use has an attenuation characteristic as shown in Figure 7. Now we take this desired sideband located at *B* in Figure 6 and put it into a second modulator where we modulate a second frequency of about 89,200 cycles. There will then be produced two new sidebands, one shown at *D* running from 56,000 to 58,700 and one shown at *E* running from 119,700 to 122,400. The new *D* and *E* sidebands are very far apart and also 30,000 cycles removed from the second carrier, and it becomes a very easy matter to build a filter which selects the desired band *D* and discriminates against the 89,200 cycle carrier and sideband *E*. This filter does not have to have anywhere near the steepness of attenuation slope that the first one does because of the relatively greater separation between the bands and the carrier *K*.

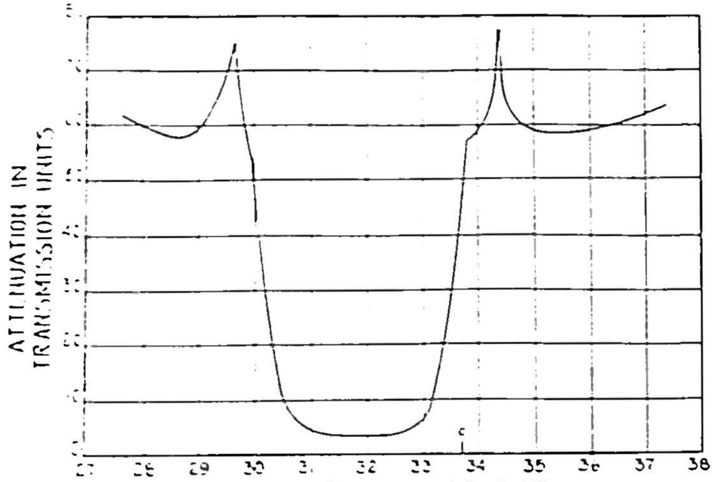

Figure 7—Attenuation Curve of the First Filter

By this double modulation process we also provide ourselves with a flexibility in frequency range which we could not attain by the simple scheme except at prohibitive expense. That is, if we build our second filter to transmit frequencies between 71,000 and 41,000 cycles we can cause our desired band *D* to fall anywhere within this range such as *D′* by merely moving the second carrier *K* to *K′*. If that carrier is removed down to 74,000, the lower sideband then falls between 41,000 and 44,000. If we move the carrier *K* up to 101,000, the sideband runs from 68,000 to 71,000. We thus secure a flexibility in frequency range for the placing of our sideband *D* with the use of fixed frequency band filters, which, for work such as we have been doing, is of vital importance.

The question may be asked why we picked the lower sideband at 33,700 and used it to modulate another frequency and then again picked the lower sideband. The reasons for this are partly circuital and partly psychological. We could have picked the upper sideband at 33,700 and then modulated about 93,000 cycles and located a sideband in the same region where we have *D* as represented. In that case the sideband would be reversed. There is no electrical reason for desiring the band as we have used it, over reversing the band, as either will give just as good quality, but it seemed simpler to maintain the frequency arrangement in the same order in which it occurs in the voice. There is an objection to producing the sideband *D* by using one of the sidebands near 33,700 to modulate a second carrier of about 21,800 which would again place the sideband *D* in about the same position. The objection here lies in the fact that there is some likelihood of harmonics, especially second harmonics, giving some trouble if the balance is not perfect. It seemed desirable in a first experimental installation to keep all the frequencies and bands totally separate and not have them overlapping in such a way as possibly to give rise to any harmonic trouble. We, therefore, chose the lower sideband in both cases, which altho it means turning the frequency band over twice, yet finally places it in the desired position and gives us the flexibility which is of value.

REPLACING THE CARRIER

At the receiving station it is necessary to replace the carrier It is not necessary to replace the auxiliary carriers used at the transmitting station: 33,700 and 89,200, but only the resulting or final carrier 55,500. It is interesting to note that this final carrier which is "eliminated" is not generated at the transmitting station at all. It is generated only if the first modulator is unbalanced and some of the first carrier gets into the second modulator. In practice the carrier is considered eliminated if reduced in amplitude to a few percent of its original value.

The accurate replacing of the carrier is sometimes of great importance. This is particularly true in receiving music, as otherwise overtones would not be overtones at all. As far as receiving speech goes, if the carrier is placed too close to the sideband, the voice sounds low and guttural, while if placed too far away, it appears very high pitched, but in either case the articulation is reduced from what is secured when the carrier is correctly placed. It is, therefore, necessary for satisfactory operation to place the carrier as near as possible to the theoretical point.

If our carrier is to remain within say 20 cycles of the theoretical point, that means that both the suppressed carrier and the replaced carrier must remain constant within 10 cycles. If our carrier has a value of say 55,500 cycles and we wish to keep the frequency within 10 cycles, that means that it has to stay within 1/55 of a percent of the desired value at all times even tho temperatures in the room change or the voltage supply fluctuates slightly. To secure this constancy is a job all by itself. Ordinarily an oscillator changes its frequency when either the plate voltage or filament voltage changes, or when the temperature changes affect the constants in the circuit, and steps had to be taken to prevent these changes or minimize the effects.

PRESENT SYSTEM

The system which we have in use at Rocky Point is outlined schematically in Figure 8 and the circuit is given in Figure 9.

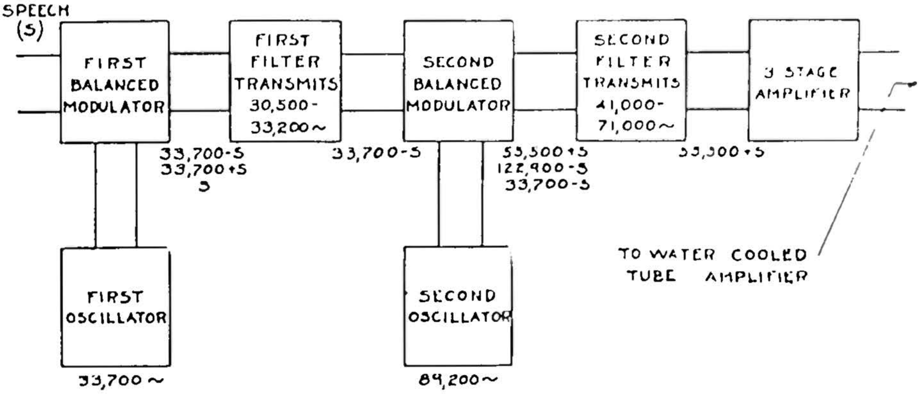

FIGURE 8—Schematic Arrangement of the Constituent Elements in the Single Sideband Apparauts

The first carrier is 33,700 cycles. As previously stated, a relatively low frequency was chosen to give us good elimination of the undesired sideband. The oscillator generating this frequency is usually referred to as the first oscillator. The first carrier is impressed upon the grids of the balanced modulator tube by means of two transformers. It is impressed on the two grids in the same phase (equivalent of position *A*, Figure 5) so that when we use the differential transformer in the plate circuit, the carrier is largely eliminated. The speech comes in from the line or from an amplifier, and is impressed on the grids of the modulating tubes in opposition (position *B* in Figure 5). In the plate circuit of the modulator the differential transformer passes the sidebands and the speech. By using a transformer here which is inefficient for the speech frequencies but efficient for the sideband, the speech frequencies will be discriminated against. The sidebands with a small amount of the signal frequencies then go into the first filter. The transmission characteristic of the first filter is shown in Figure 7. Its impedance characteristics are shown in Figure 10. This filter, tho having the theoretical cut-off at 33,200 does not cut-off sharply. The attenuation begins to increase rapidly at that point, so that frequencies 500 or 600 cycles higher are not entirely eliminated but are reduced somewhat in amplitude.

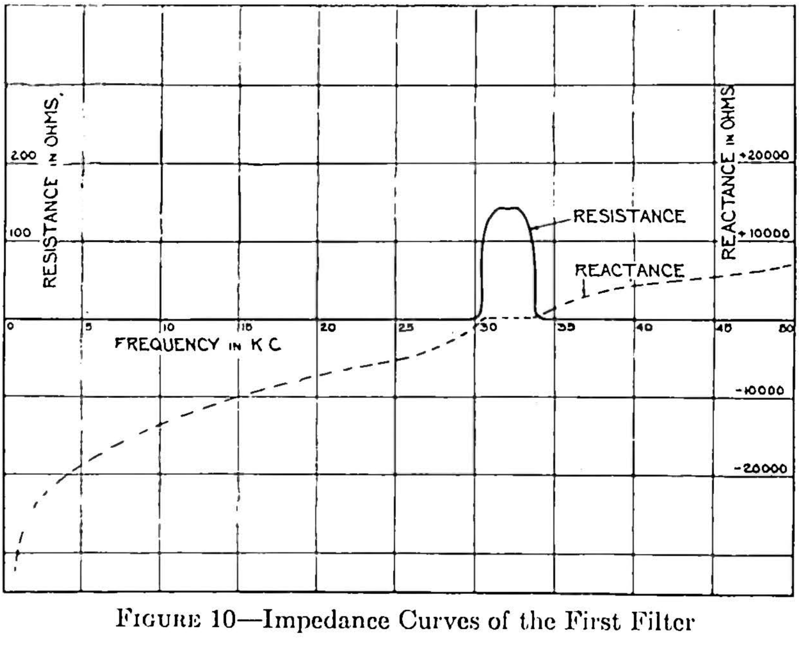

FIGURE 10—Impedance Curves of the First Filter

From the filter the single sideband passes to the second modulator. This second modulator is also of the balanced type in order to reduce the amplitude of the second carrier and not overload the filter. The second carrier is supplied from the second oscillator in Figures 8 and 9 which operate at about 89,200 cycles. The modulating frequencies now run between 30,500 and 33,200 and are impressed in opposite phase on the grids of the two modulating tubes. The 89,200 cycle carrier is impressed on the two grids in phase. The transformer in the output is differentially connected so as to eliminate the carrier, but it transmits the sidebands and the modulating frequencies.

The two sidebands pass from the modulator into the second filter. The transmission band of the second filter is from 41,000 to 71,000. The attenuation curve for it is shown in Figure 11. Only one of the sidebands falls within this range. The impedance characteristic of this filter is shown in Figure 12. It will be observed that the impedance of this filter is quite low in the neighborhood of 30,000 to 33,000 cycles. The resistance outside the band, of course, is practically zero and the reactance curve crosses the axis at this point. The purpose of using a filter having this reactance characteristic is to allow the modulators to function properly, as it is a well-known fact that in order to get modulated power out of the Van der Bijl type of modulator, the impedance in the plate circuit for both the modulating and modulated frequencies must be low. The impedance is, therefore, made a minimum for the modulating frequencies which, in this case, lie between 30,500 and 33,200 cycles. It is not necessary to make it either zero or a minimum for the modulated frequency of 89,200 in the arrangement which we are using, for the reason that the differential connection of the transformer eliminates the filter from the circuit. In the case of the first modulator, the same requirements hold. The differential transformer connection eliminates the filter from the circuit for the carrier frequency, but not for the speech frequencies. The filter used has not the desired low impedance at the speech frequencies, so we take advantage of the inefficiency of the transformer at these frequencies to provide the low attached impedance.

The transmission characteristics of the second filter are such as to give us considerable flexibility in frequency range. The lowest position where it will allow the placing of the desired sideband is between 41,000 and 44,000 cycles. The frequency of the second oscillator in this case would be set at 41,000+33,200 or 74,000 cycles. This point is well up on the upper side of the attenuation curve, so that the second carrier frequency would be kept out of the amplifier and the antenna. The degree to which this muct be kept out is very great for the reason that in a high-powered set, it does not take a very large input to put several watts into an antenna even tho it is off tune. The highest position where we would possibly place the desired sideband is around 68,000 to 71,000 cycles. The frequency from the second oscillator would then be about 101,000 cycles. The upper sideband in both of these cases would be at 100,000 cycles or above. The second filter will easily eliminate this upper sideband.

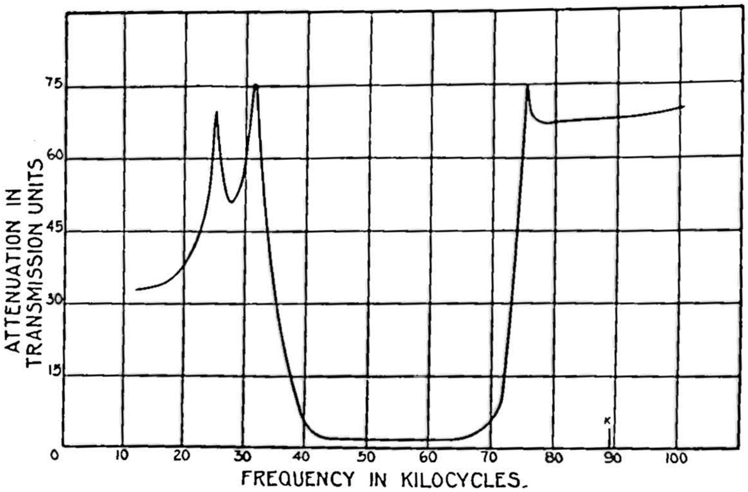

FIGURE 11—Attenuation Curve of Second Filter

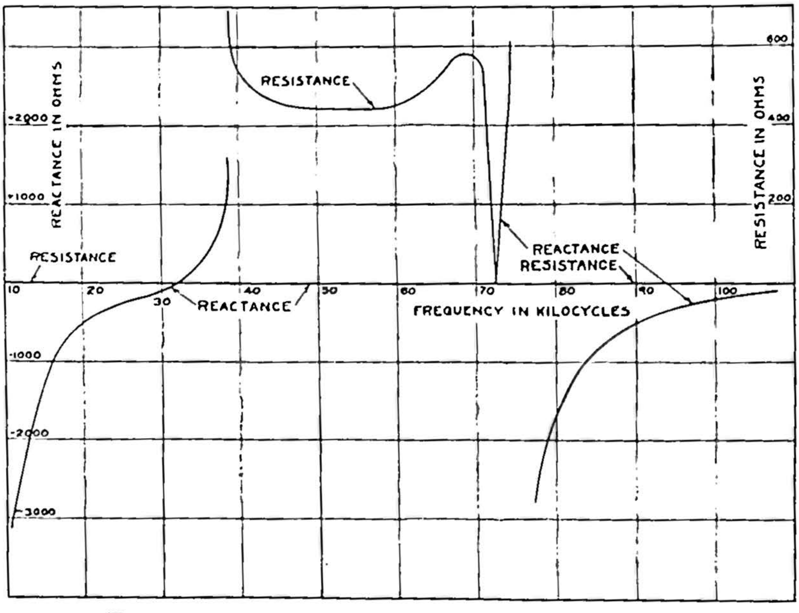

FIGURE 12—Impedance Curves of Second Filter

The second filter is built to have a very high attenuation between 24,000 to 35,000 cycles, because it is in this region that the modulating frequencies of the second modulator lie. The arrangement of the second modulator is such that the modulating frequencies pass thru both tubes and the second transformer readily into the second filter so that it is not impossible, if the second filter does not eliminate them, for them to produce in succeeding amplifier tubes second harmonics which might lie directly in the range of the desired sideband. That is, since our first sideband lies between 30,500 and 33,200, the second harmonics from it would lie between 61,000 and 66,400, and if we try to use this latter region as the position of a sideband for communication, we might find that some of these harmonics would fall within the band and give disturbing noises.

From this second modulator the desired sideband *D*, which is shown in Figure 6, is passed into the low power amplifier. This low power amplifier is a three-stage amplifier consisting of 5-watt, 50-watt, and 750-watt steps. These are the power ratings of the tubes. The actual power secured in the various amplifier stages is not these values, but is considerably lower. Power efficiency in this part of our set is not of importance, but quality is, so these three stages are built for reproducing the desired sideband faithfully and at a sacrifice of power. The last two stages are purely voltage step-up stages, or choke coil amplifiers. The power secured from the last amplifier is about 500 watts maximum.

INSTALLATION

Photographs of the single sideband apparatus are shown in Figure 13. The apparatus is built on two racks. Each elemental circuit is also on its own panel. The first rack contains all the single sideband producing apparatus and the second rack contains the three-stage amplifier with the testing and measuring panels.

The power comes from several sources. The modulators and oscillators have their plates supplied from the 220-volt direct current circuit in the station. The amplifiers are supplied from a 1,500-volt generator. All filaments are lighted by alternating current. The negative grid potentials for the amplifiers are secured by potentiometer arrangements from the 220-volt circuit while for the modulators, a battery is used.

The arrangement of this apparatus at Rocky Point is shown in Figures 14 and 15. Figure 14 shows the single sideband producing rack and Figure 15 shows the preliminary amplifier rack. In locating this apparatus in the station, precautions had to be taken to prevent singing. The power supplied from either oscillator to the modulators is of the order of one one-thousandth of a watt. The power delivered by the water-cooled tubes to the antenna runs up over 100 kilowatts. The ratio of these powers is about 1 to 100,000,000. It would not do to leave this apparatus operated by such small voltages in such a position that the high-powered equipment could disturb it. This apparatus was, therefore, all mounted inside a copper-screened cage. The screen was placed on the floor and ceiling as well as on all four sides. Even

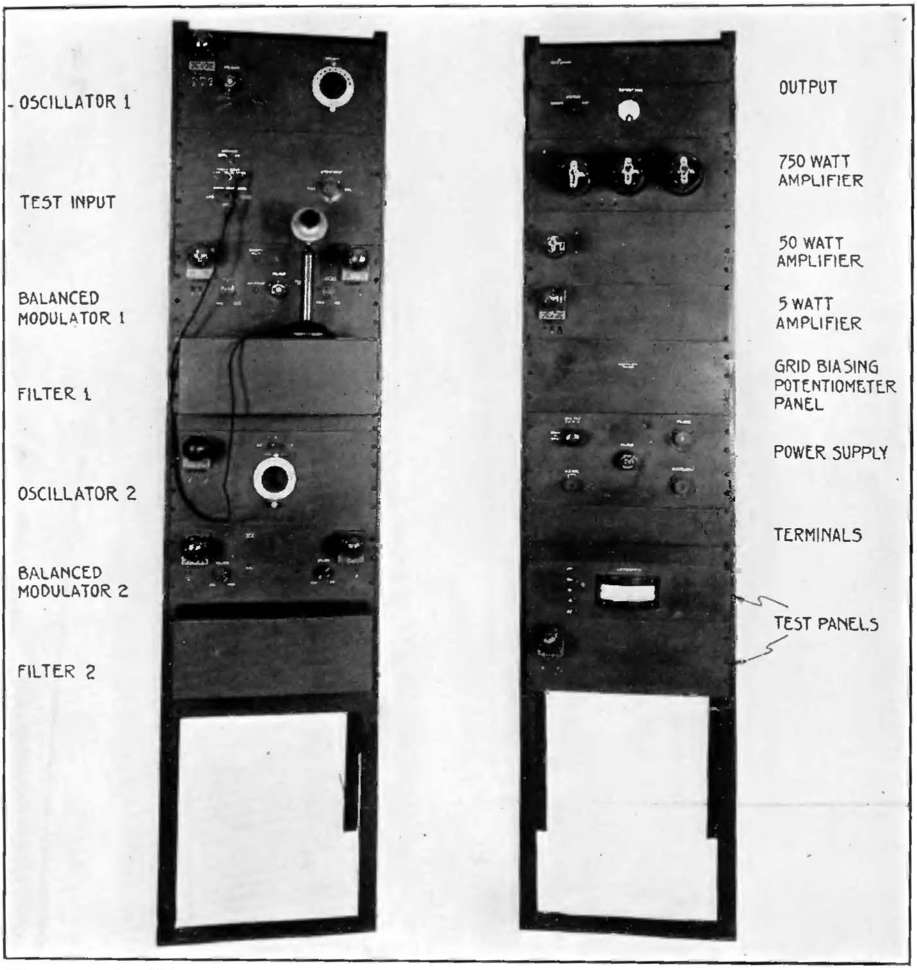

Figure 13—Photograph Showing the Panel Type of Construction. The Left Hand Rack Contains the Oscillators, Modulators, and Filters. The Right Hand Rack Contains the Three-stage Amplifier which Delivers the Single Sideband at About 500 Watts Maximum

a screen door was provided, tho it has not always been necessary to close the latter. Shielding is sufficiently well done, so that any voltages introduced in the wiring of the set from the high-powered apparatus are small compared to the driving voltages from the oscillators.

There is also located in this cage a Vreeland oscillator which provides frequencies over the audio range for much of the test work. It may be observed in Figure 14 behind the sideband rack.

The power supply of all this equipment was handled thru a

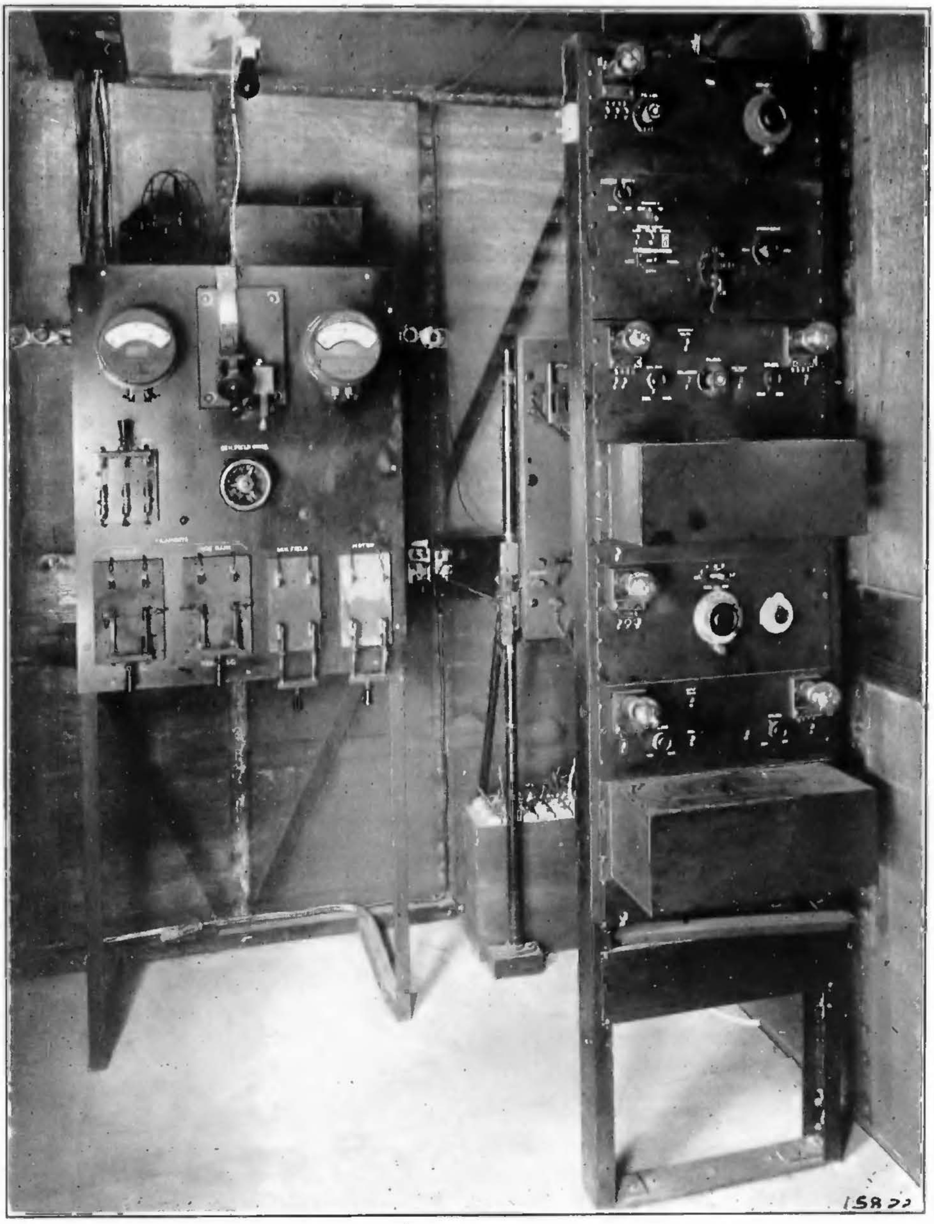

FIGURE 14—Photograph Showing the Oscillator-Modulator Rack Located in the Shielded Cage

switchboard also located within the cage. The motor-generator which supplies the power at 1,500 volts for the three 250-watt tubes is started and controlled from this panel. The direct current power circuits for supplying the 220 volts to the small tubes is also run thru this switchboard. Other pieces of apparatus used in testing such a wave meter and monitoring receiving set, are also usually kept in the cage tho they are not shown in any of the pictures.

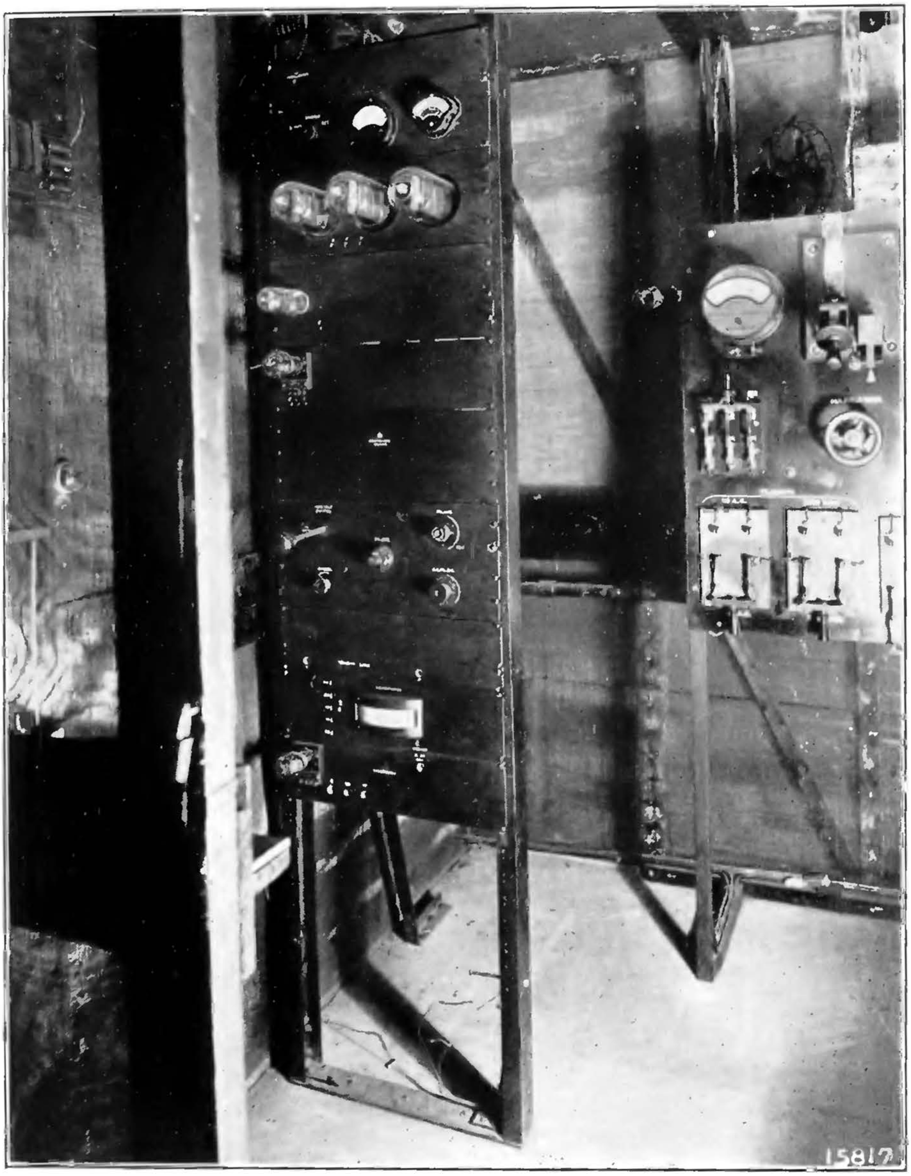

FIGURE 15—Photograph Showing the Preliminary Amplifier Rack Located in the Shielded Cage

PERFORMANCE

In a study of the performance of the single sideband apparatus the first element we look for is quality. We get our idea of quality primarily from an amplitude-frequency performance curve. This is based upon our previously stated theory that if all sustained frequencies between 200 and 2,500 cycles are transmitted without any appreciable frequency discrimination, the quality will be satisfactory for the purpose. Our quality tests, therefore, take the form of a set of curves plotted between input frequency in the audio range and output amplitude from the last amplifier. The amplitudes of the input frequencies are kept constant, that is, we supply the same power at all audio frequencies. The voltage or current of the single sideband resulting is measured for each one of the signal frequencies and the curve plotted. We also find it desirable to take measurements at various points in the set in order to locate the position of the various distortions if possible. In Figures 16 to 18 are a set of these curves which were taken in the manner described.

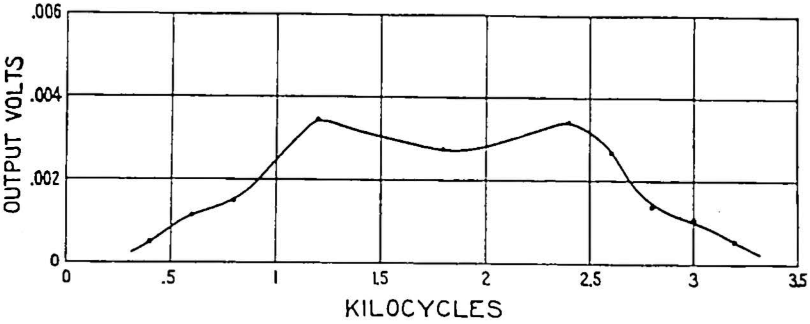

Figure 16—Amplitude of the Sideband Frequencies at the Output Terminals of the First Filter as a Function of Modulating Frequency. Input at All Frequencies Constant

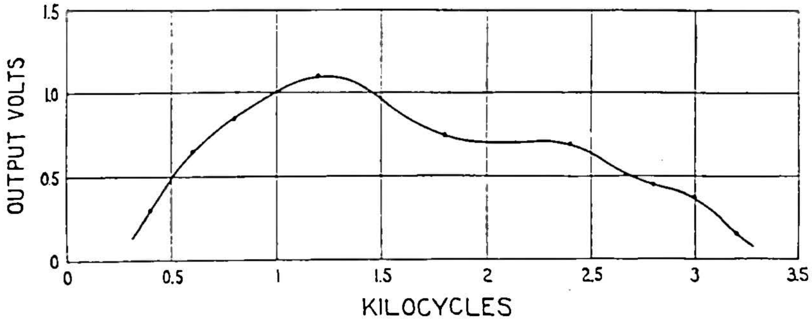

Figure 17—Amplitude of the Sideband Frequencies at the Output Terminals of the Second Filter as a Function of Modulating Frequency

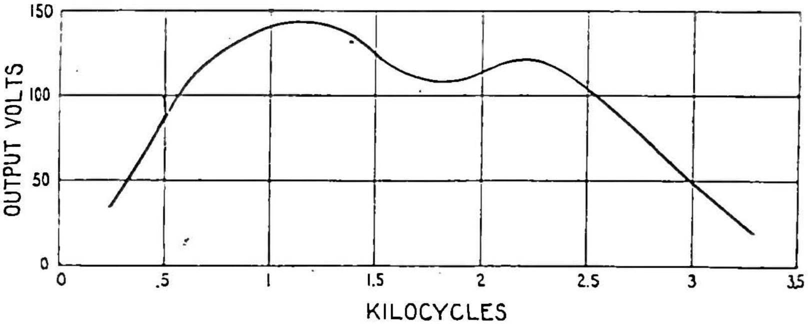

Figure 18—Amplitude of the Sideband Frequencies Delivered by the Set to the Water-cooled Amplifying Tubes as a Function of Modulating Frequency

Figure 16 is a curve showing the output of the first modulator and filter. In Figure 17 is shown the output curve of the second filter. Some additional distortion has evidently occurred over what is produced in the first one. However, it does not produce any serious reduction in quality. In Figure 18 the over-all characteristic is shown. Further distortions occur, some parts being worse and some parts better. This curve is still one which indicates we should get adequate quality.

That the quality resulting from the set is good is indicated by the fact that in the public demonstration across the Atlantic, the speakers' voices were recognized and reporters had no trouble in getting every word using the head telephones or a loud speaker. We have received word from some nearby listeners who said the quality was not good, but their troubles were located in their sharp receiving circuits. The distortion that a good long wave telegraph receiver will cause is enormous. When this fact was pointed out and proper circuits used, their bad quality disappeared.

The operation of this apparatus has been quite satisfactory. It has been in use for a year and a-half. It was operated continuously during the early trials and development and during the last year during all weekly tests. Changes have been made from time to time, as can be seen if Figures 13 and 14 are compared. Photograph 13 was taken just before the apparatus was shipped to Rocky Point and Figures 14 and 15 after it has been in use some time. The continued operation could not help but cause certain modifications to be made to improve operation or facilitate adjustment or control. All changes made, however, were of a minor nature, as no departure was made from the fundamental system which we had in mind when starting out. The operation is reliable in every way, as evidenced by the regular week-end trans-Atlantic tests which are carried out and the absence of necessity of tinkering between times.

Research Laboratories of the American Telephone and Telegraph Company and Western Electric Company, Incorporated, New York.

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SUMMARY: This paper describes in detail the equipment and circuit used in the production of the single sideband for trans-Atlantic radio telephony in the experiments at Rocky Point. The set consists of two oscillators, two sets of modulators, two filters, and a three-stage amplifier. The oscillators and modulators operate at power levels similar to those in high-frequency communication on land wires. The three-stage amplifier amplifies the sideband

produced by these modulators to about a 500-watt level for delivery to the water-cooled tube amplifiers.

The first oscillator operates at about 33,700 cycles. The modulator is balanced to eliminate the carrier; and the first filter selects the lower sideband. In these trans-Atlantic experiments the second oscillator operated at 89,200 cycles, but might operate anywhere between 74,000 and 102,000 cycles. The second modulator, which is also balanced, is supplied with a carrier by the second oscillator and with modulating currents by the first modulator and first filter. The second filter is built to transmit between 41,000 and 71,000 cycles, so that by varying the second oscillator, the resulting sideband, which is the lower sideband produced in the second modulating process, may be placed anywhere between these two figures. Transmission curves for the filters are given as well as some amplitude-frequency performance curves of the set.