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INTERNATIONAL UNION FOR SCIENTIFIC RADIO TELEGRAPHY
U. R. S. I.

LONG DISTANCE RADIO RECEIVING MEASUREMENTS IN 1924*

By
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(LABORATORY FOR SPECIAL RADIO TRANSMISSION RESEARCH, WASHINGTON D. C.)

(Conducted jointly by the Bureau of Standards and the American Section of the International Union for Scientific Radio Telegraphy.)

Two stations, Monte Grande (LPZ), Argentina, and Cayey (NAU), Porto Rico, have been added during the year to the number of those regularly measured in Washington. Monte Grande is interesting; first, because it is 2,000 km. farther away than the European stations, and second, because the waves travel in a south-north direction from the southern to the northern hemisphere; thus encountering entirely different seasonal conditions from those encountered in the transmission from Europe to America. The station gives nearly the same morning intensity as Nauen, Germany, and the ratio of average observed to calculated values is about three to one. Unfortunately, Monte Grande does not send in the afternoon.

Cayey has been observed partly because its frequency, approximately 33.8 kc. (8,870 m.), is considerably higher than the other stations and partly on account of its nearly south-north direction of transmission, which at certain seasons lies nearly parallel to the sunset shadow wall. It was thought that this might cause eccentricities in reception at about sunset, but no peculiarities have been observed on the rather limited number of occasions when transmission took place at that time.

The mean monthly values of the field intensities of the signals from the various stations, and of the corresponding atmospheric disturbances, are shown in the tables and curves.

Table I gives the approximate data concerning the transmitting stations, as far as known.

*Received by the Editor, February 20, 1925. Published by permission of the Director of the Bureau of Standards of the United States Department of Commerce.

TABLE I

APPROXIMATE TRANSMISSION DATA

	Frequency f kc.	Wave Length λ m.	Antenna Current I amp.	Effective Height h m.	Distance d km.
Nauen POZ[1]	23.4	12,800	390	145	6,650
Bolinas KET	22.9	13,100	420	51	3,920
Cayey NAU	33.8	8,870	150	120	2,490
Monte Grande LPZ	23.6	12,700	610	150	8,300
Lafayette LY	15.9	18,900	475	180	6,160
Ste. Assise UFT	20.8	14,400	380	180	6,200
Ste. Assise UFU	15.0	20,000	475	180	6,200
Malabar PKX	19.0	15,800	500	320	14,700
Cavite NPO	19.3	15,500	180	120	11,800

Tables II and III give the monthly averages of the received field intensities and of the corresponding atmospheric disturbances in microvolts per meter. It is to be remembered that the signals received in Washington at 10 A. M. from Europe have an all-daylight path, tho during the short days of winter they are probably disturbed by being transmitted too close to the European sunset time. The 3 P. M. signals are sent during the evening hours and during the winter considerable parts of their paths lie in darkness.

TABLE II

AVERAGE SIGNAL AND ATMOSPHERIC DISTURBANCE INTENSITIES IN 1924 FOR LAFAYETTE (LY), STE. ASSISE (UFU), AND EL CAYEY (NAU) IN MICROVOLTS PER METER

1924	A. M.			P. M.			A. M.		P. M.	
	LY	UFU	Dist.	LY	UFU	Dist.	NAU	Dist.	NAU	Dist.
January	130.0	63.5	21.2	160.0	89.6	26.5	....	....	....	....
February	153.0	64.2	39.3	125.7	71.5	70.6	....	....	....	....
March	117.5	50.3	30.2	88.3	46.7	70.4	....	....	....	....
April	136.7	50.9	65.8	88.2	34.7	166.5	73.2	17.7	59.3	47.3
May	107.5	52.2	97.3	75.8	34.7	180.0	79.8	23.3	59.9	64.4
June	120.0	45.8	105.4	77.3	36.6	605.0	57.3	35.4	43.5	170.0
July	113.6	47.1	56.0	61.8	22.5	267.0	112.5	30.0	66.5	137.0
August	93.5	40.3	87.0	52.5	17.7	294.0	57.0	42.0	73.2	157.0
September	119.7	55.3	50.0	88.6	35.3	151.0	100.2	19.0	92.5	88.0
October	113.7	54.4	46.0	137.4	57.0	110.0	87.0	10.0	67.6	31.0
November	87.8	37.4	38.3	180.9	66.3	66.0	62.8	10.8	65.1	14.0
December	87.6	50.3	30.2	151.5	64.2	35.9	56.1	7.1	62.1	7.8
Average	115.0	50.9	55.5	107.3	48.0	170.2	76.2	21.7	65.5	79.6

Figure 1 shows the monthly averages of the 10 A. M. signals from Bordeaux for the years 1922, 1923, and 1924. Figure 2 gives similar 10 A. M. curves for Nauen. Figure 3 shows the

[1] During the year Nauen has used at times an antenna with $h = 175$ m. and a current varying between 300 and 480 amperes for its 23.4 kc. frequency.

TABLE III

Average Signal and Atmospheric Disturbance Intensities in 1924 for Ste. Assise (UFT), Bolinas (KET), Nauen (POZ), and Monte Grande (LPZ) in Microvolts per Meter

1924	A. M.					P. M.				
	UFT	KET	POZ	LPZ	Dist.	UFT	KET	POZ	LPZ	Dist.
January	37.3	....	16.5	....	17.7	39.3	....	24.0	....	22.1
February	41.8	80.4	19.3	....	32.8	37.4	69.6	21.8	....	61.3
March	40.7	59.9	35.7	40.1	24.0	32.5	54.4	37.0	....	58.9
April	39.6	56.3	28.5	33.6	53.3	21.2	47.4	17.8	....	136.0
May	34.3	57.4	22.5	27.2	77.3	21.4	40.6	13.1	....	158.0
June	37.0	55.4	27.1	26.1	90.4	21.5	35.0	18.9	....	531.0
July	43.1	53.5	30.3	33.3	50.0	22.6	26.1	15.1	....	238.0
August	40.4	24.5	34.9	41.3	78.0	21.8	36.3	15.7	....	306.0
September	59.5	58.9	49.6	39.3	54.0	36.5	50.8	31.2	....	148.0
October	49.9	62.7	31.2	42.3	31.0	44.0	59.8	32.0	....	81.0
November	24.3	49.3	14.5	38.4	26.0	39.0	61.2	43.8	....	56.0
December	32.7	54.2	21.7	46.7	23.5	41.4	54.1	39.4	....	25.9
Average	40.0	55.6	27.6	36.8	46.5	31.5	48.6	25.8	....	156.0

morning signals for Cayey and Monte Grande. Figure 4 shows the variations in the monthly disturbance averages at 3. P. M. for three frequencies. The marked difference between the disturbances at 24.0 kc. and 33.3 kc. is noticeable. In Figure 5 the 3 P. M. disturbances for a frequency of 24.0 kc. (12,500 m.), are plotted for the years 1922, 1923, and 1924. Figure 6 gives similar curves for a frequency of 15.0 kc. (20,000 m.), for the same years

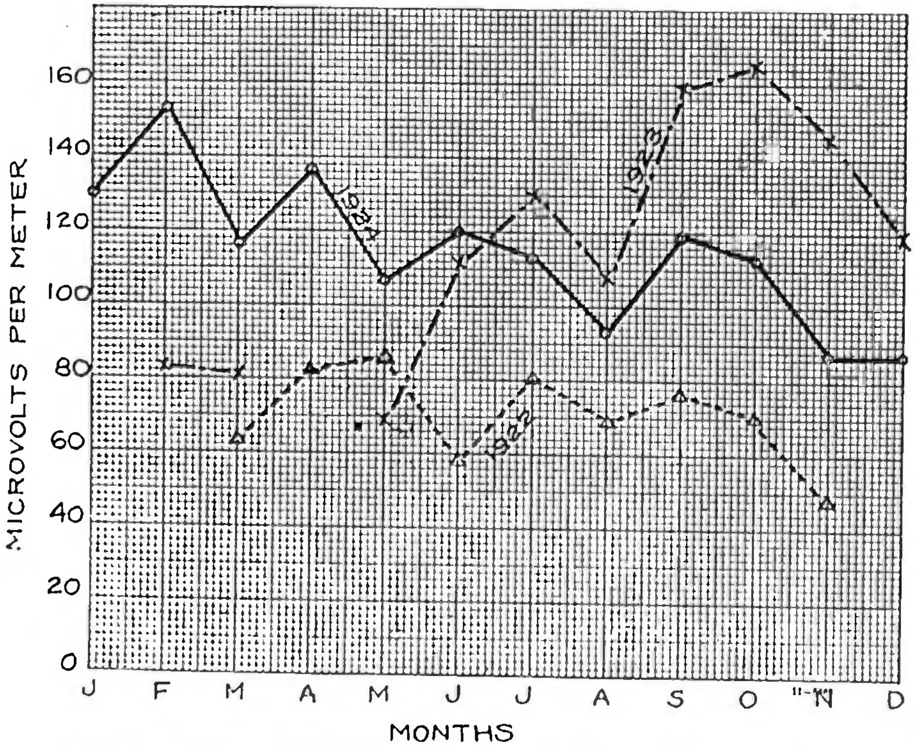

Figure 1—Lafayette (LY) Average Signal 10 A.M. 1922–1923–1924

These curves for 1922, 1923, and 1924, are given merely as information. It is too early to attempt to draw any definite conclusions from their variations.

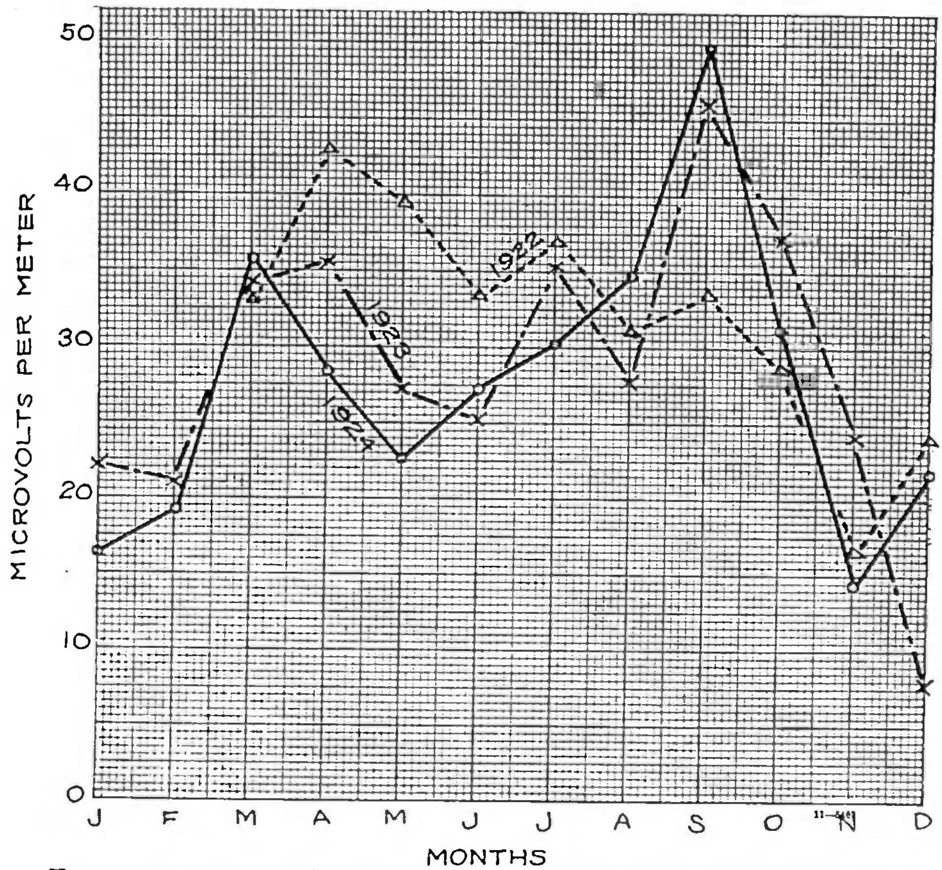

FIGURE 2—Average Signal for Nauen (POZ) 10 A.M., 1922–1923–1924

Field intensity measurements were made during August and September at San Diego, California, on the high-power arc stations, Cavite, Philippine Islands, and Malabar, Java. The distance from Cavite to San Diego is approximately 11,800 km. (6,400 nautical miles), with a difference in time of eight hours, while the distance from Malabar is 14,700 km. (8,000 miles), with a difference in time of nine hours. This is about the greatest distance which can be attained for all daylight and approximately all water communication with the present high-power stations of the world. Even in this case there are only about two hours during the day available for observation without too close approach to sunset or sunrise at one station or the other. The observations were taken with the telephone comparator and the apparatus calibrated with a radio-frequency generator and attenuation box as in the Western Electric method of measuring signals.

The final results were as follows:

	Cavite	Malabar
Observed averages	2.04 μv./m.	4.02 μv./m.
Calculated (Austin-Cohen formula) . .	0.69	1.83

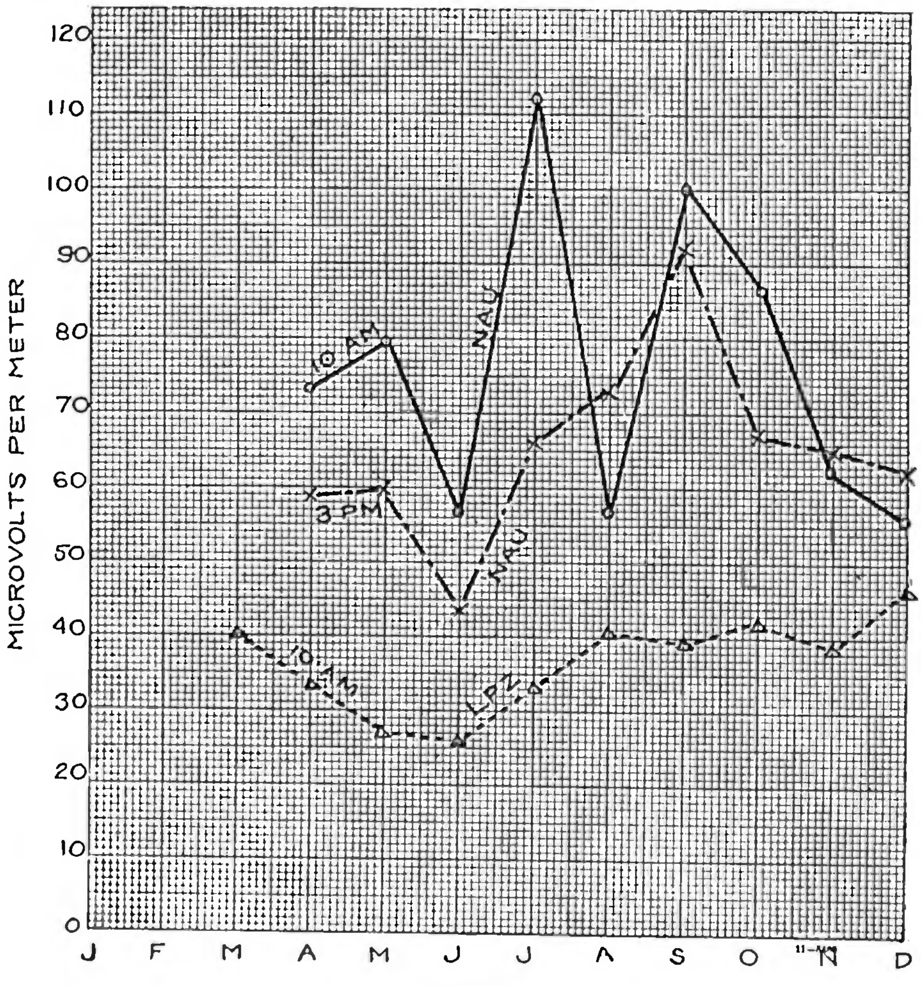

Figure 3—1924 Signal Averages of El Cayey (NAU) and Monte Grande (LPZ)

During the year experiments have been carried on to determine the effect of heavy atmospheric disturbances on the observed values of the strength of signals by making measurements on the telephone comparator, first with an artificial antenna and then with an elevated antenna on which the disturbances were coming in. It was found: (1) That if the disturbances were separated by intervals of comparative silence, the readings were independent of the intensity of the disturbances provided the telephones were removed from the ears sufficiently to prevent the deafening effect of the crashes. (2) If the disturbances were

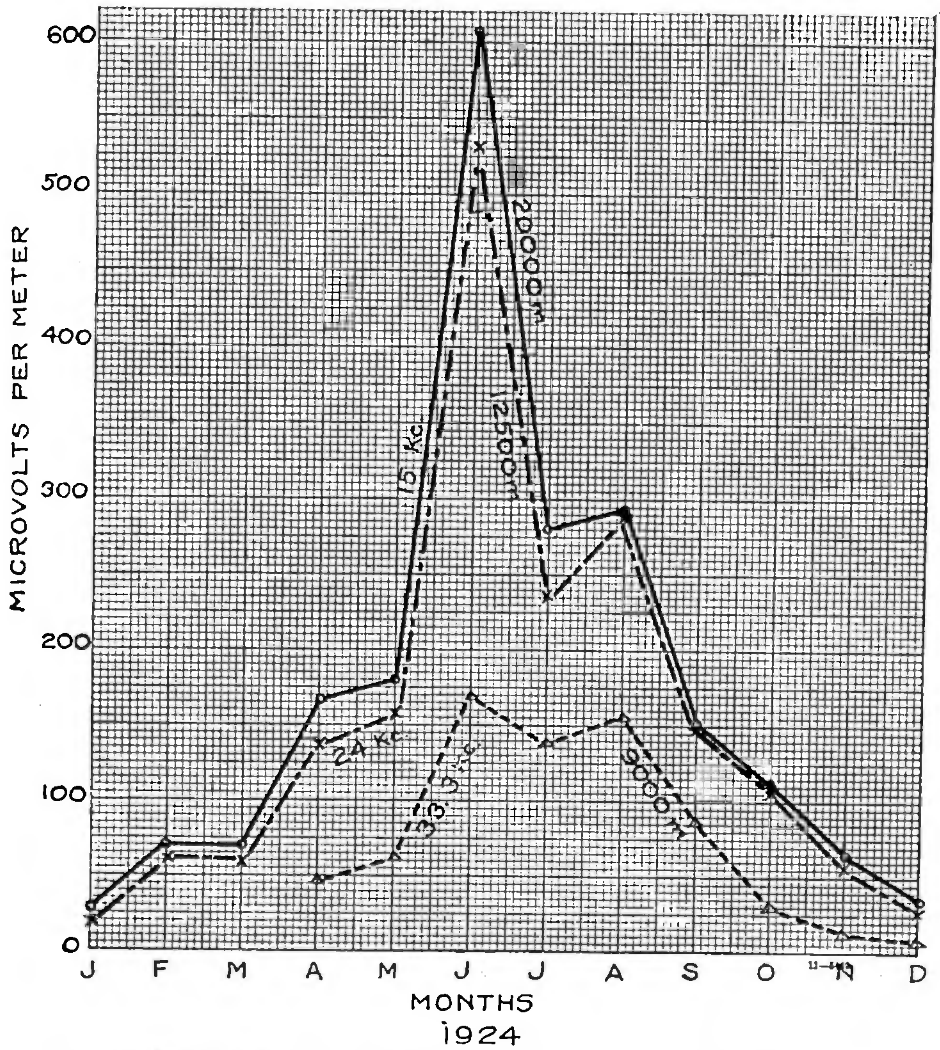

FIGURE 4—1924 Average Atmospheric Disturbances 3 P.M. for 15 kc. (20,000 m), 24 kc. (12,500 m), and 33.3 kc. (9,000 m)

practically continuous but less than about seven times the strength of the signal, the observations were unaffected. (3) With the continuous disturbances between seven and sixteen times the strength of the signal the observed values are too low. (4) When the disturbances are more than sixteen times the signal strength, the signal is not heard. These experiments have made it possible to make estimates of the signal strength of the weaker stations on the summer afternoons instead of arbitrarily throwing them out, or considering them inaudible. This is a matter of some importance for the determination of the summer afternoon fading. The application of these corrections to the afternoon observations of 1922 and 1923, practically doubles the average values of the summer afternoon readings of the weaker stations, like Nauen.

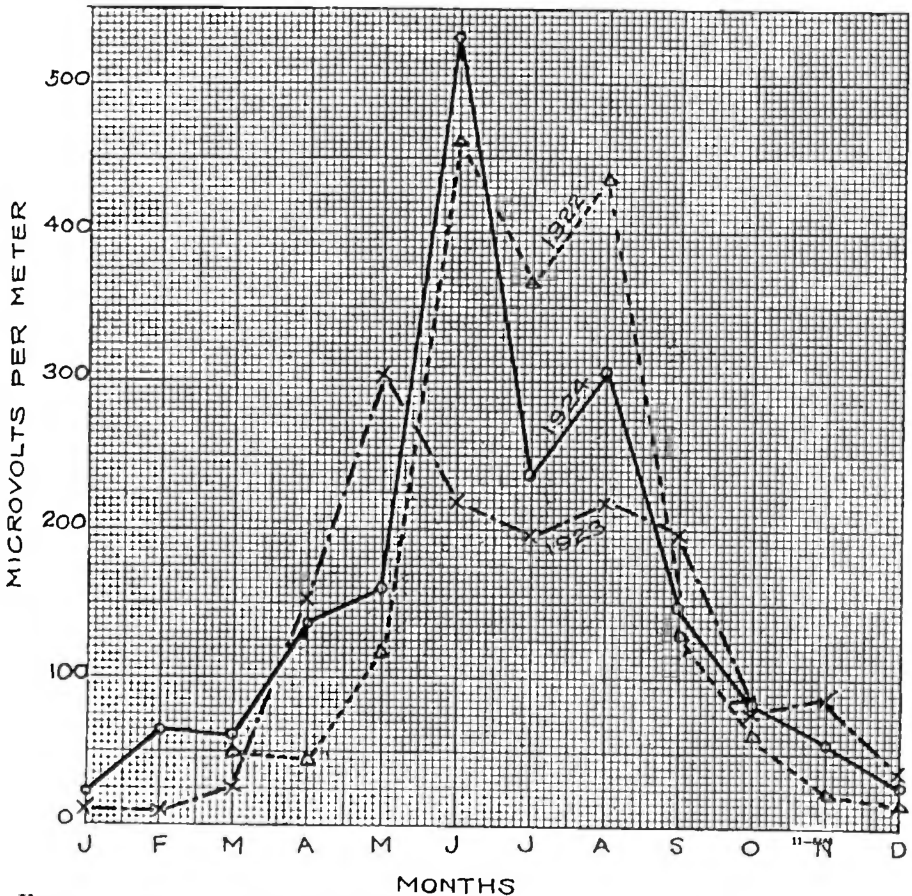

FIGURE 5—Average Atmospheric Disturbances 3 P.M. for 1922–1923–1924
$f = 24$ kc. (12,500 m)

Some work has been done during the year on the weakening of the European stations at about the time of the European sunset. This plays a part in the production of the weak signals observed at 10 A. M., in November, December, and January, and in the afternoon fading observed on the 3 P. M. signals in summer. On account of the limited personnel of the laboratory, it has not been possible to complete this part of the work for presentation.

The similarity in the monthly average intensity curves taken

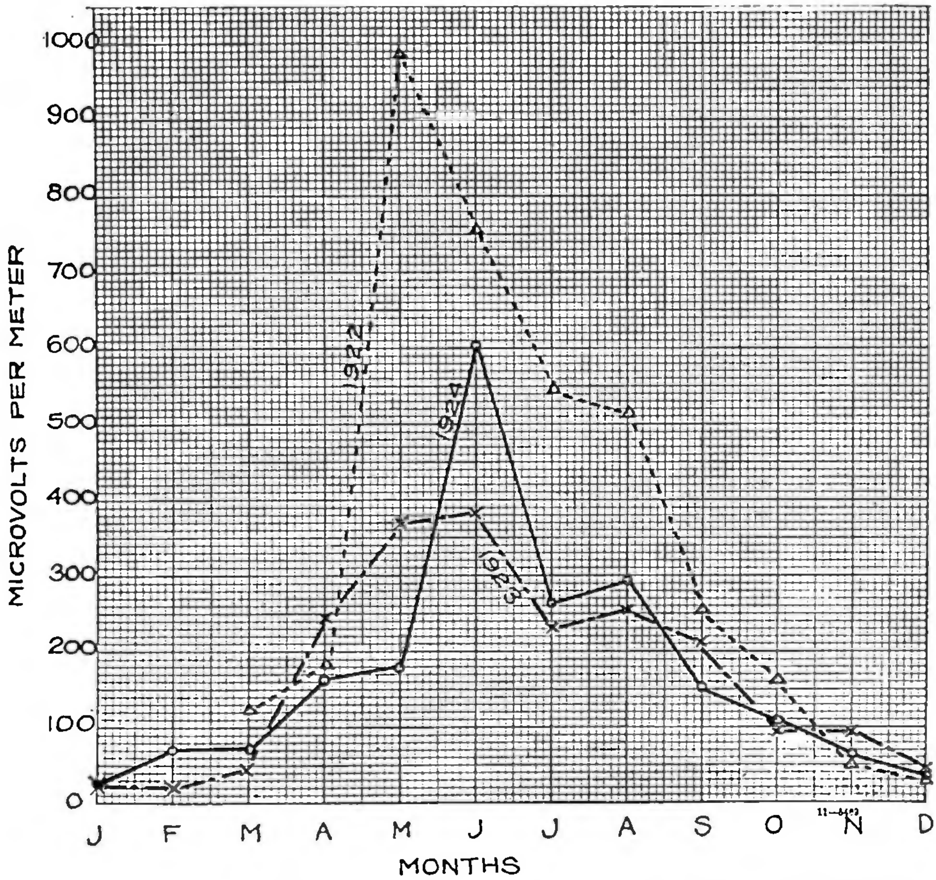

FIGURE 6—Average Atmospheric Disturbances 3 P.M. for 1922–1923–1924 f = 15 kc. (20,000)

at Meudon and in Washington on the U. R. S. I. signals sent out from Bordeaux (LY) at 3 P. M., Washington time, has continued to be worthy of note. This similarity began to be observed at the time of Bordeaux's change in frequency from 12.8 kc. (23,400 m.), to 15.9 kc. (18,900 m.), in May, 1923, as was mentioned in last year's report. Similar, nearly simultaneous readings have also been taken on Rocky Point, L. I. (WQL) at Meudon and Washington, but in this case no definite correspondence between the two reception curves has been found.

Bureau of Standards,
January, 1925.

SUMMARY: The paper gives a resumé of the measurements of 1924. Observations were taken twice a day on the following stations: Lafayette (Bordeaux), Ste. Assise (Paris), Nauen (Berlin), Bolinas (California), Monte Grande (Argentina), and Cayey (Porto Rico). In addition, measurements were made in August and September at San Diego, California, on signals from Cavite, P. I., and Malabar, Java, respectively, 11,300 and 14,700 km. distant. The tables and curves show the monthly averages of signal and corresponding atmospheric disturbance strength for the various stations and also some comparisons of these quantities for the years 1922, 1923, and 1924.

PRODUCTION OF SINGLE SIDEBAND FOR TRANS-ATLANTIC RADIO TELEPHONY*

By

R. A. Heising

(Western Electric Company, New York)

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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*Presented before The Institute of Radio Engineers, New York, March 19, 1924. Received by the Editor, January 10, 1925

[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.

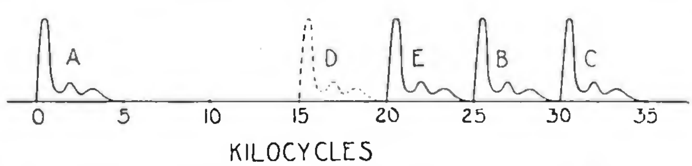

FIGURE 1—Shifted Speech Frequency Bands for Multiplex Communication

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.

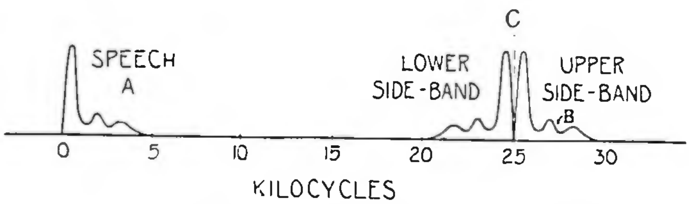

FIGURE 2—Sidebands Produced When a Radio Frequency Carrier Wave is Modulated by speech

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

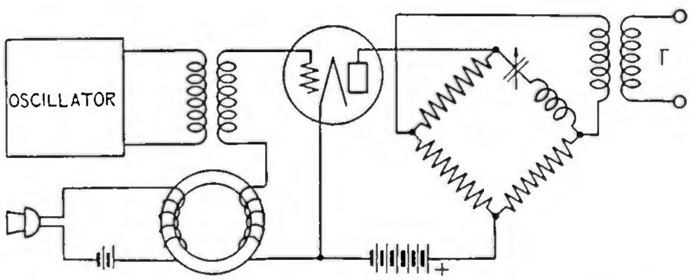

Figure 3—Modulator Tube with Bridge Circuit to Eliminate the Carrier

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

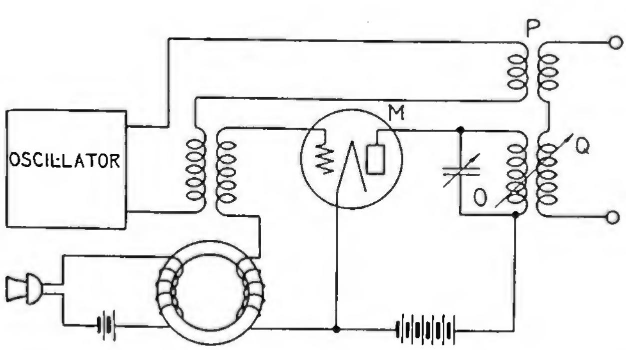

Figure 4—Modulator with a Circuit in Which the Carrier is Neutralized

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

[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.

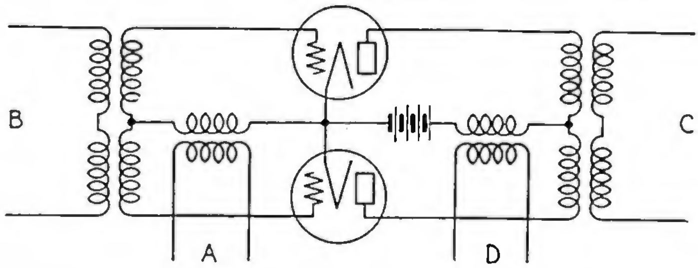

FIGURE 5—Balanced Modulator Showing the Two Places for Introducing the Speech and Carrier, and Two Places for Securing the Output

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:

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

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 $2\,\omega$ and $2\,\phi$, 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

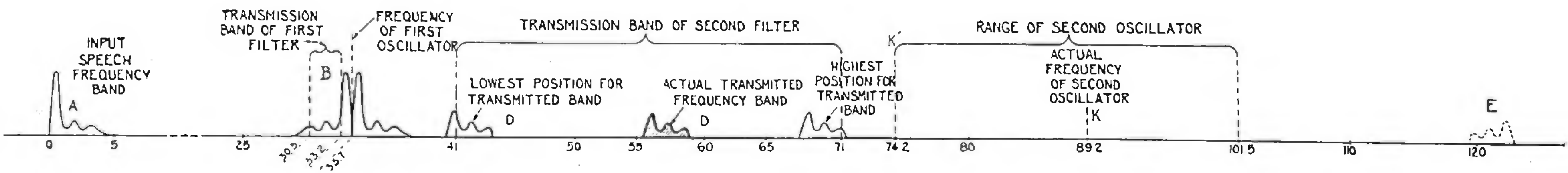

FIGURE 6—Positions of the Various Sidebands and Carriers in the Double Modulation Process

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*.

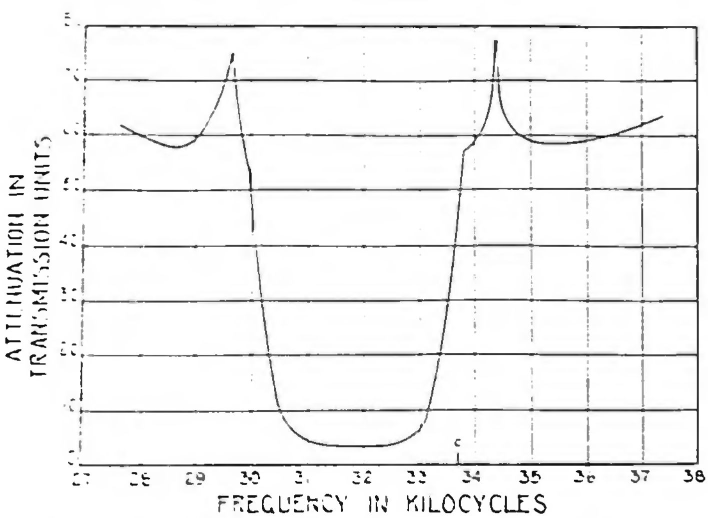

FIGURE 7—Attenuation Curve of the First Filter

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 gutteral, 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.

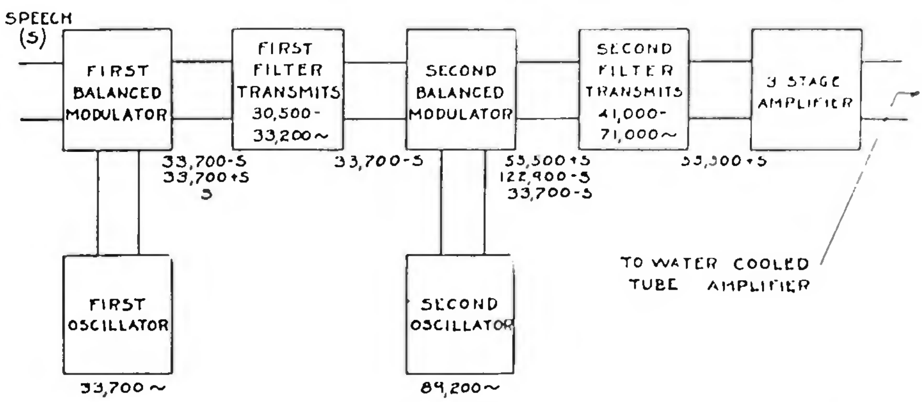

Figure 8—Schematic Arrangement of the Constituent Elements in the Single Sideband Apparauts

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.

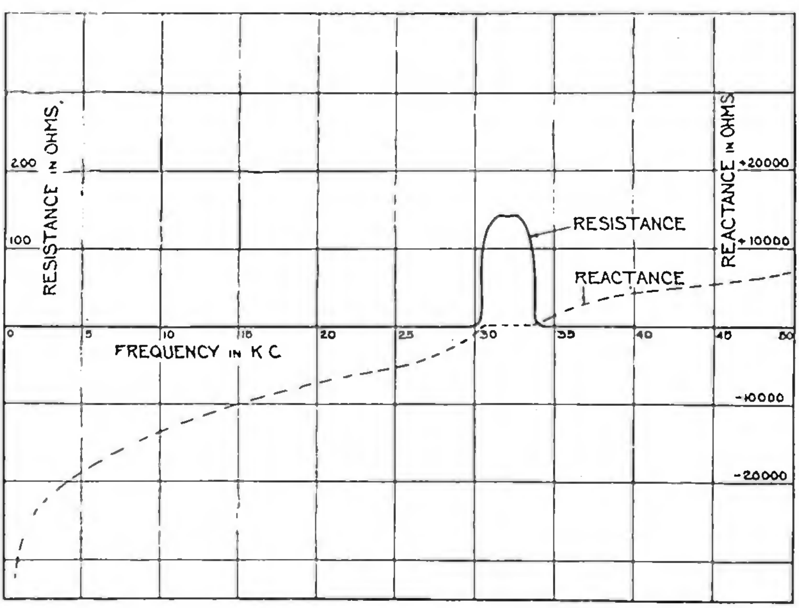

Figure 10—Impedance Curves of the First Filter

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.

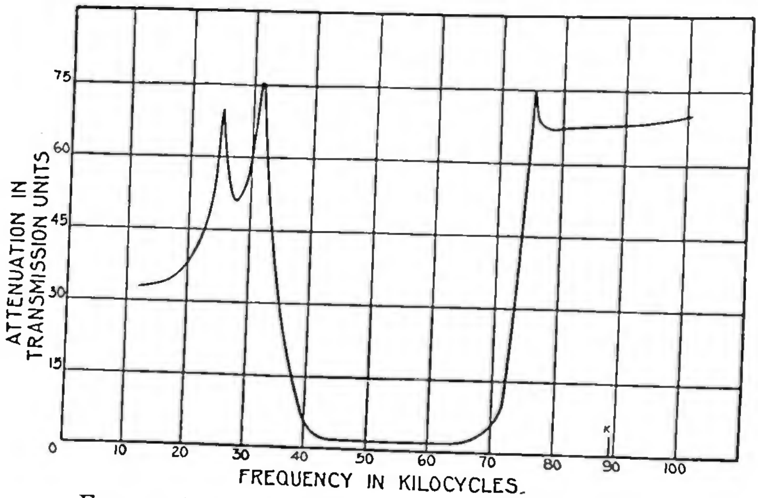

FIGURE 11—Attenuation Curve of Second Filter

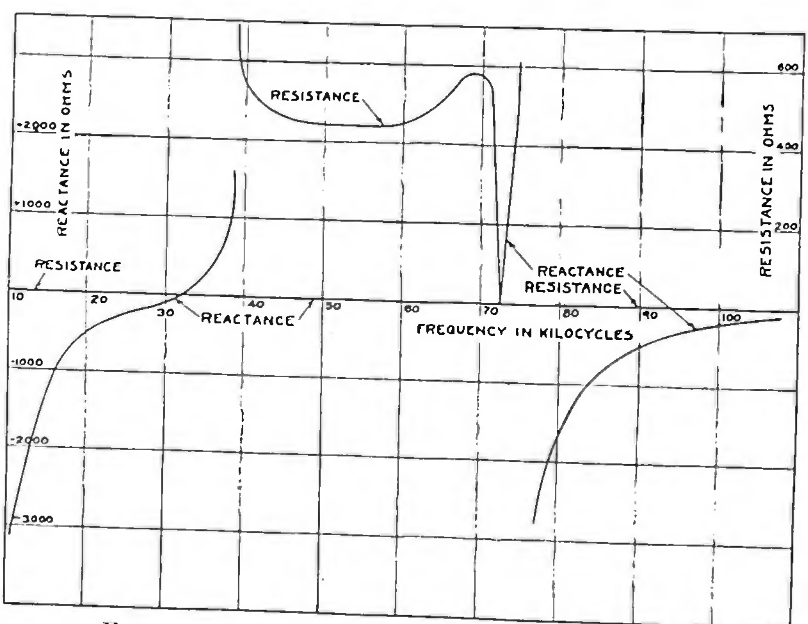

FIGURE 12—Impedance Curves of Second Filter

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

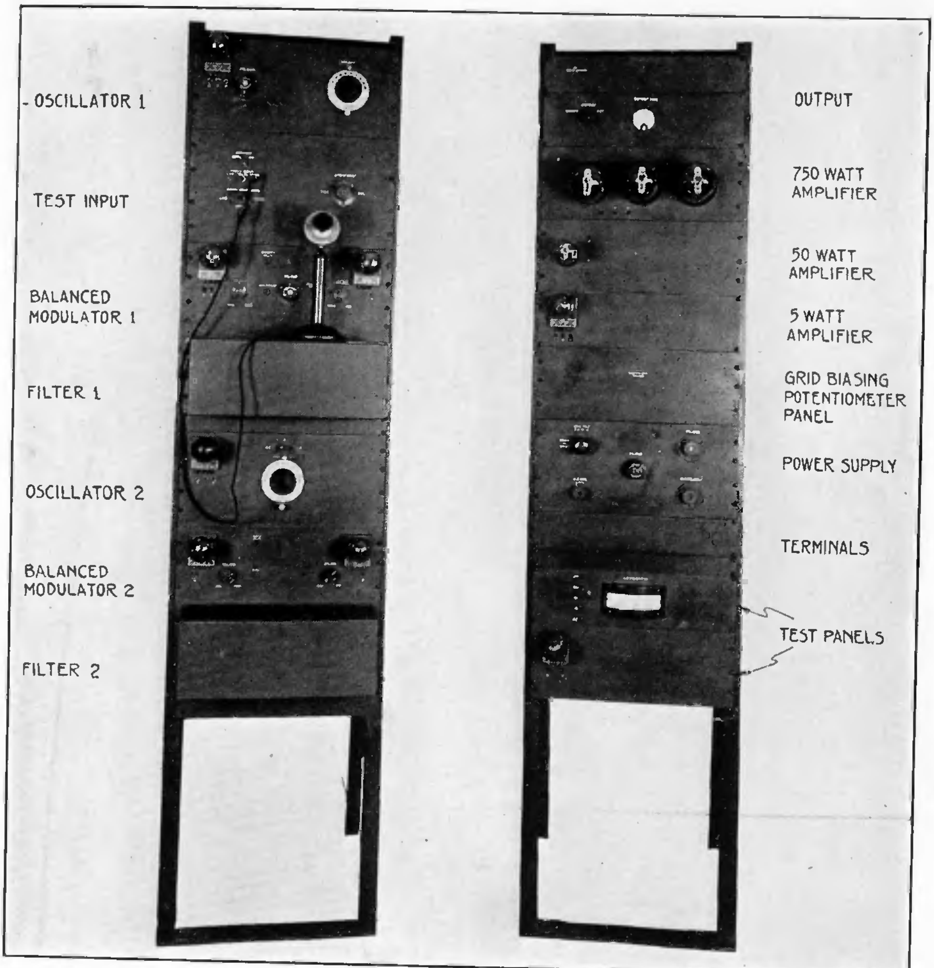

FIGURE 13—Photograph Showing the Panel Type of Construction. The Left Hand Rack Contains the Oscillators, Modulators, and Filters. The Right Hand Rack Contains the Three-stage Amplifier which Delivers the Single Sideband at About 500 Watts Maximum

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

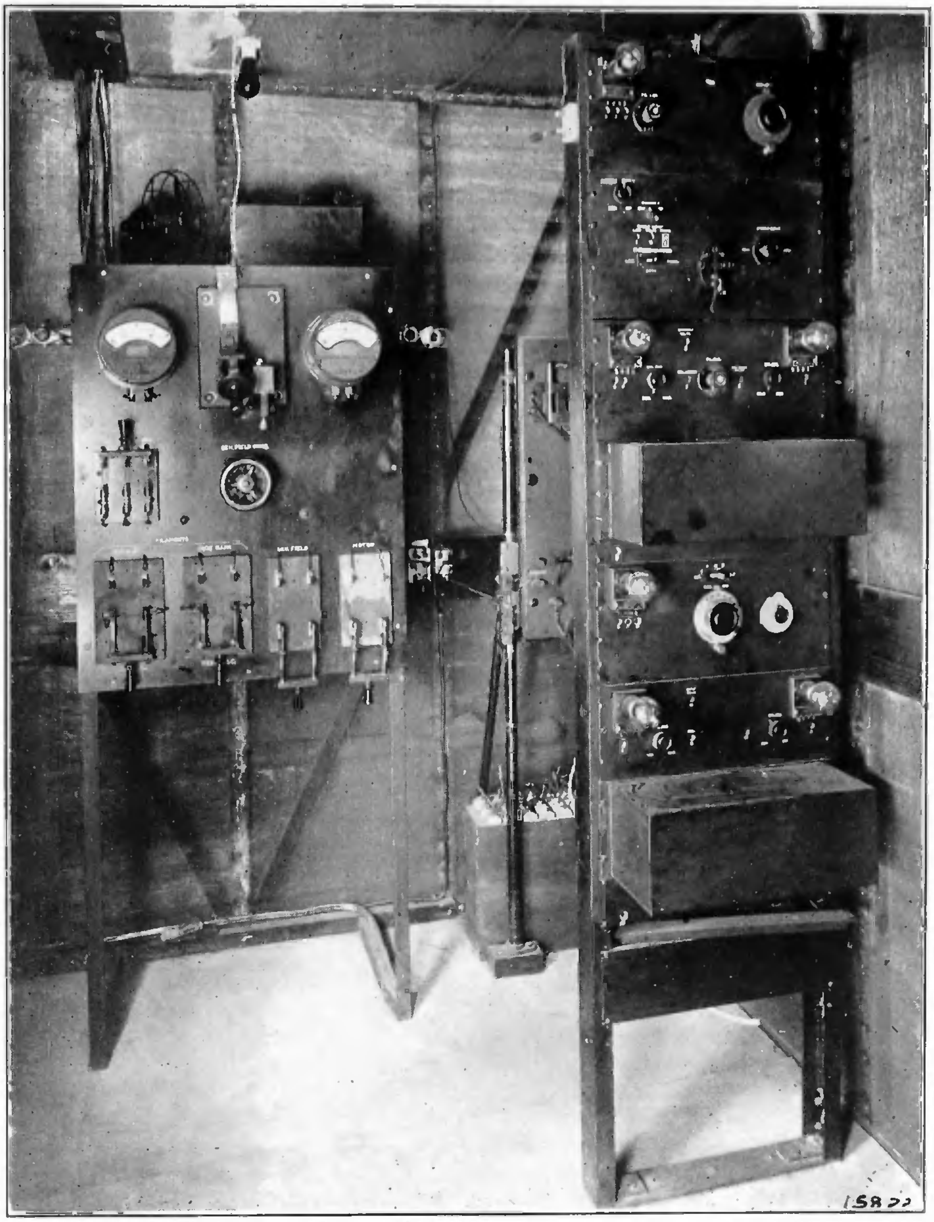

FIGURE 14—Photograph Showing the Oscillator-Modulator Rack Located in the Shielded Cage

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.

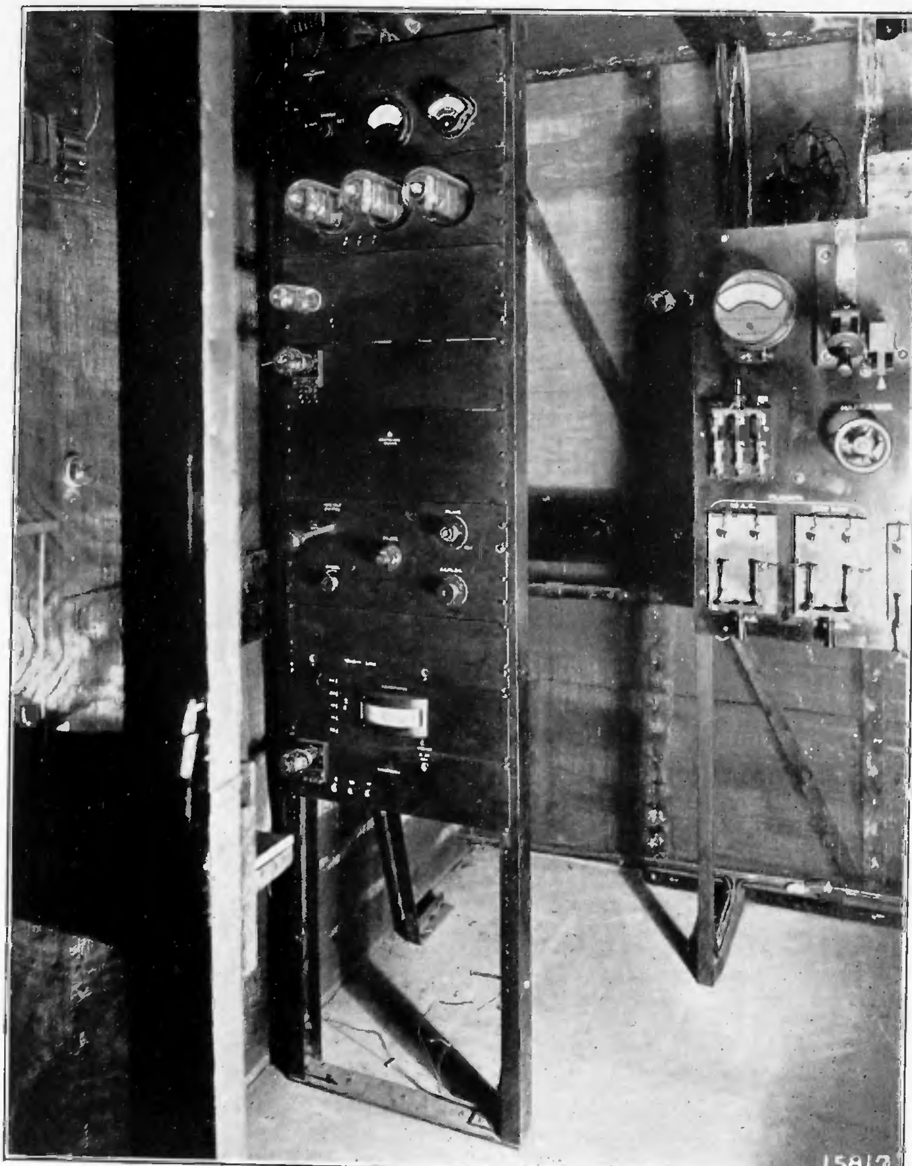

FIGURE 15—Photograph Showing the Preliminary Amplifier Rack Located in the Shielded Cage

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.

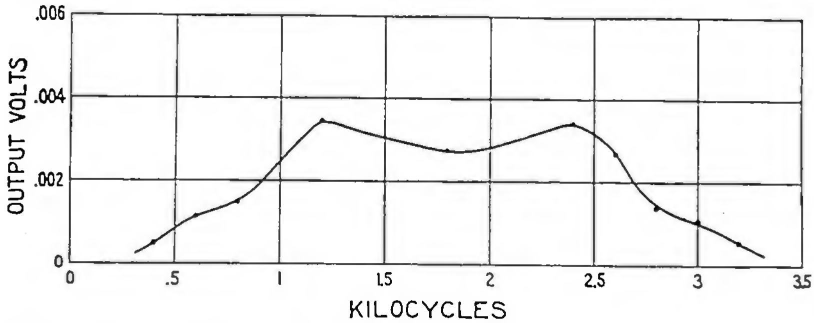

FIGURE 16—Amplitude of the Sideband Frequencies at the Output Terminals of the First Filter as a Function of Modulating Frequency. Input at All Frequencies Constant

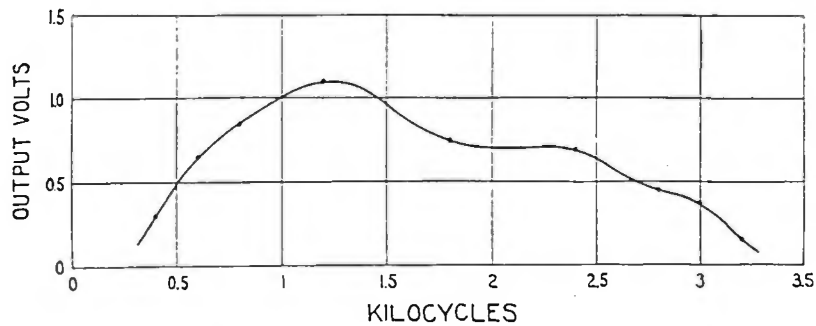

FIGURE 17—Amplitude of the Sideband Frequencies at the Output Terminals of the Second Filter as a Function of Modulating Frequency

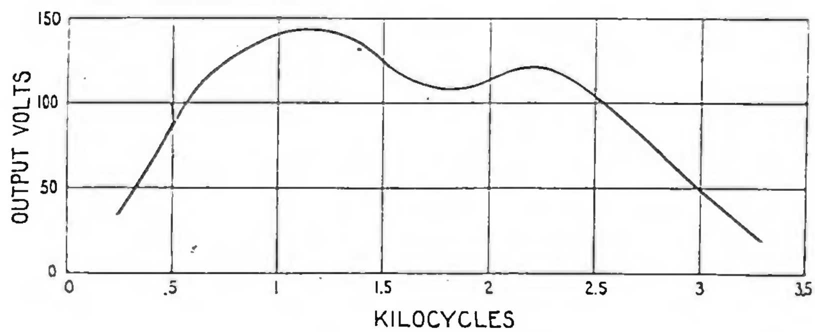

FIGURE 18—Amplitude of the Sideband Frequencies Delivered by the Set to the Water-cooled Amplifying Tubes as a Function of Modulating Frequency

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.

October 9, 1924.

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.

POWER AMPLIFIERS IN TRANS-ATLANTIC RADIO TELEPHONY*

By

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and

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Introduction

It has long been recognized by engineers interested in telephone service over great distances that radio transmission offers the most promising medium thru which commercial trans-oceanic voice communication may be realized. It is now fairly well established that, both from the viewpoint of the conservative use of the ether and from the consideration of financial costs, the most economical radio system requires the development of the useful signal element by modulation and filtration at very low power values and subsequent amplification to the levels necessary for successful transmission. Convincing proof of this statement is found in the successful application and operation of such a system during the trans-atlantic telephone experiments in 1923.

It is not within the scope of this paper to enter into a complete discussion of these experiments or even to describe the operation of the system as a whole. Papers have already been published[1] which present the over-all results attained during recent tests and which describe the general system and methods employed.

For the present purpose it will suffice to say that one of the objects of the experiments in 1923 was to demonstrate the efficacy and the practicability of radio transmission by means of the single-sideband eliminated-carrier method. With this method

*Presented before The Institute of Radio Engineers, New York, May 7, 1924. Received by the Editor, December 11, 1924.

1 "Trans-oceanic Wireless Telephony," by Dr. H. W. Nichols, "Journal of the Institution of Electrical Engineers," volume 61, number 320, July, 1923 "Transatlantic Radio Telephony," by H. D. Arnold and L. Espenschied "Journal of American Institute of Electrical Engineers'," August, 1923.

the narrowest possible frequency band is employed in the ether and all of the radiated energy has maximum effectiveness in transmitting the signal. As mentioned above, the single side-band currents of the desired frequency are prepared at low power and then amplified to the required magnitude for application to the transmitting antenna. A paper has been given recently which described the low-power modulating system in considerable detail.[2] The present paper deals entirely with the power amplifiers. Material concerning other parts of the system will only be introduced when it contributes to the definition of the amplifier functions or when it seems essential to a clear conception of the requirements imposed on the amplifier.

Characteristics of Single-Sideband Signal

It is well known that, when an alternating carrier current is modulated by telephone currents, the resultant wave is distributed over a frequency range[3] which may be conveniently considered in three parts: (1) the carrier frequency itself, (2) a frequency band extending from the carrier upward, and having a width equal to that of the frequencies appearing in the modulating wave, and (3) a band extending from the carrier downward, and having a similar width.

These relationships are shown by the three spectra plotted in Figure 1. The rectangle B with the frequency limits S_1 and S_2 represents the voice frequency band essential to the transmission of intelligible speech. The frequency f_c is that of the alternating carrier current which is being modulated. The products of modulation are spread over a region comprising the original carrier frequency f_c and two bands B_1 and B_2, known as the lower and upper sidebands. These two bands have the same width as the band B and furthermore each transmits power which contains all of the elements necessary to reproduce the original speech. Since most of the radio telephone transmitters now in use radiate all of the products of modulation shown in Figure 1, it will be convenient to employ the term "ordinary" to designate systems in which none of these products are suppressed.

The ordinary radio telephone sends out the carrier f_c continuously and adds to this the bands B_1 and B_2 whenever speech or other similar signals are transmitted. The total transmission

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[2] By R. A. Heising, entitled, "Production of Single Sideband for Trans-atlantic Transmission," presented at a meeting of The Institute of Radio Engineers, on March 19, 1924.

[3] "Relations of Carrier and Sidebands in Radio Transmission," by R. V. L. Hartley, Proceedings of The Institute of Radio Engineers, February, 1923.

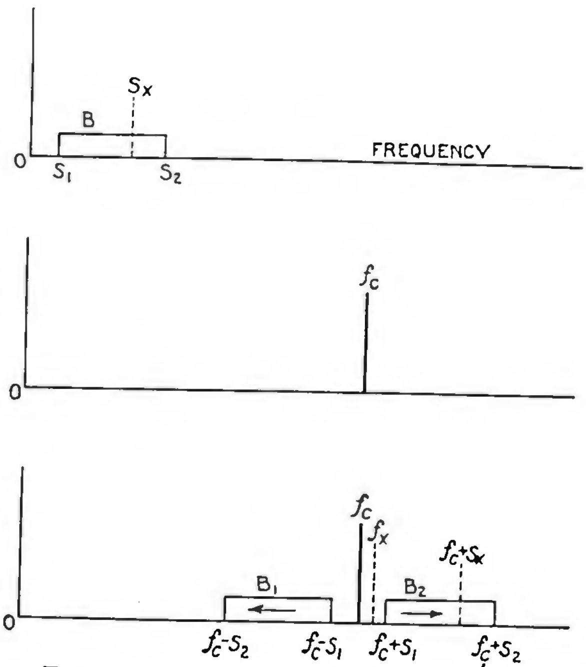


FIGURE 1—Frequency Spectra in Radio Telephone Modulation

frequency range extends from f_c-S_2 to f_c+S_2 and is therefore equal to 2 S_2.

In the single-sideband eliminated-carrier method of transmission no power is radiated except when signals are being transmitted. A combination of modulators and electrical filters are employed to eliminate the carrier and one sideband. Thus in Figure 1, currents of all the frequencies less than f_x are prevented from reaching the output circuit of the modulation system. The total transmission frequency range extends from f_c+S_1 to f_c+S_2 and is therefore equal to S_2-S_1. This is slightly less than one-half the frequencies employed by the ordinary method. Modulation becomes a simple frequency transformation in which all the signal frequencies in the band B are stepped up an equal amount f_c to produce the band B_2.

If a pure sine wave potential of frequency S_x be applied to the input terminals of a single-sideband system, the resultant output will be a continuous wave of frequency f_c+S_x. Hence a single-sideband radio telephone system can be converted into a continuous wave telegraph system without any change in apparatus other than replacing the microphone with a single frequency generator.

Thus far the comparison of the single sideband signal with that of ordinary radio telephone signal has emphasized the difference in frequency ranges. There are other important differences between the two signals which have a direct bearing on the requirements of the transmitting apparatus. Such differences will now be considered with the assistance of the diagrams shown in Figure 2. In these diagrams no effort has been made

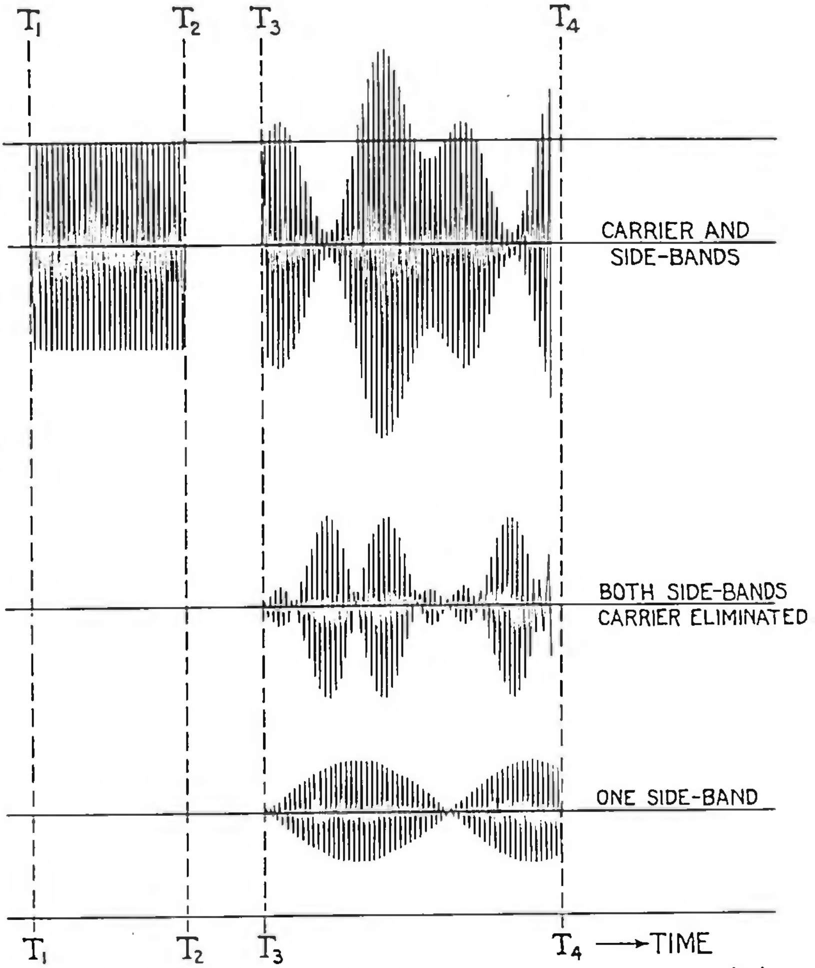


FIGURE 2—Wave Radiated in Three Systems of Transmission. In interval T_1—T_2 there is no modulation. In T_3—T_4 there is modulation by two audio frequencies, a fundamental and its second harmonic

to represent correctly each radio frequency cycle, but the envelopes of the radio frequency instantaneous peak values are properly related. The signal condition shown during the time interval from T_1 to T_2 is that which occurs when no voice message is being transmitted, for example, during a pause between words. The signals shown during the interval from T_3 to T_4 represent conditions when a voice message is in process of transmission and the audio frequency wave conforms to the envelope of the upper curve. The signals represented by the upper curve are those radiated by the ordinary radio telephone transmitter. In this case a continuous wave signal is sent out during the interval T_1 T_2 and the wave, transmitted during the interval T_3 T_4, may vary in amplitude from zero to twice the amplitude of the continuous wave signal radiated during the interval T_1 T_2. The signals represented by the lower curve are those sent out by a single-sideband radio telephone transmitter. No signal of any sort is radiated during the interval T_1 T_2 and the maximum amplitude during the period T_3 T_4 is considerably less than that for the case where the carrier is transmitted. Even disregarding the advantages possessed by the single-sideband system, that there is less interference due to the sharper tuning permissible in the receiver and that the received signal strength is subject to less variation due to changes in the ether conditions, this system has the advantage of lower power consumption for given results. The maximum power capacity requirement is one-fourth of that for the usual transmitter. It is important to remember that the power output of a single-sideband transmitter is zero when no speech is transmitted and that the output varies from zero to approximately full load each time a word is spoken. This characteristic has an important bearing on the power supply and amplifier requirements.

Operational Classification of Amplifiers

Vacuum tube amplifiers, like most electrical apparatus, may be classified in a number of ways. For the present purpose it will be convenient to group them in three classes, according to their mode of operation, defined as follows:

Class I comprises amplifiers in which operation is confined to the substantially linear portion of the tube characteristic curve.

Class II consists of those in which the anode current never ceases to flow, but operation extends beyond the linear portion of the tube characteristic.

Class III comprises amplifiers in which the anode current ceases to flow during a portion of each cycle.

Telephone repeaters and similar audio frequency apparatus, in which distortionless amplification is a prime consideration, are usually amplifiers of the first class. When some distortion is permissible and power efficiency is important, amplifiers of the second and third classes are employed. High efficiency radio frequency power amplifiers are all of the third class.

Typical anode current and potential relations for each class of amplifier are shown in Figure 3. The curves at the left show the static characteristic and also the dynamic characteristics for a load at unity power factor. Those at the right are the corresponding current and voltage relations with time as abscissa when a simple sinusoidal voltage is applied to the grid. In an

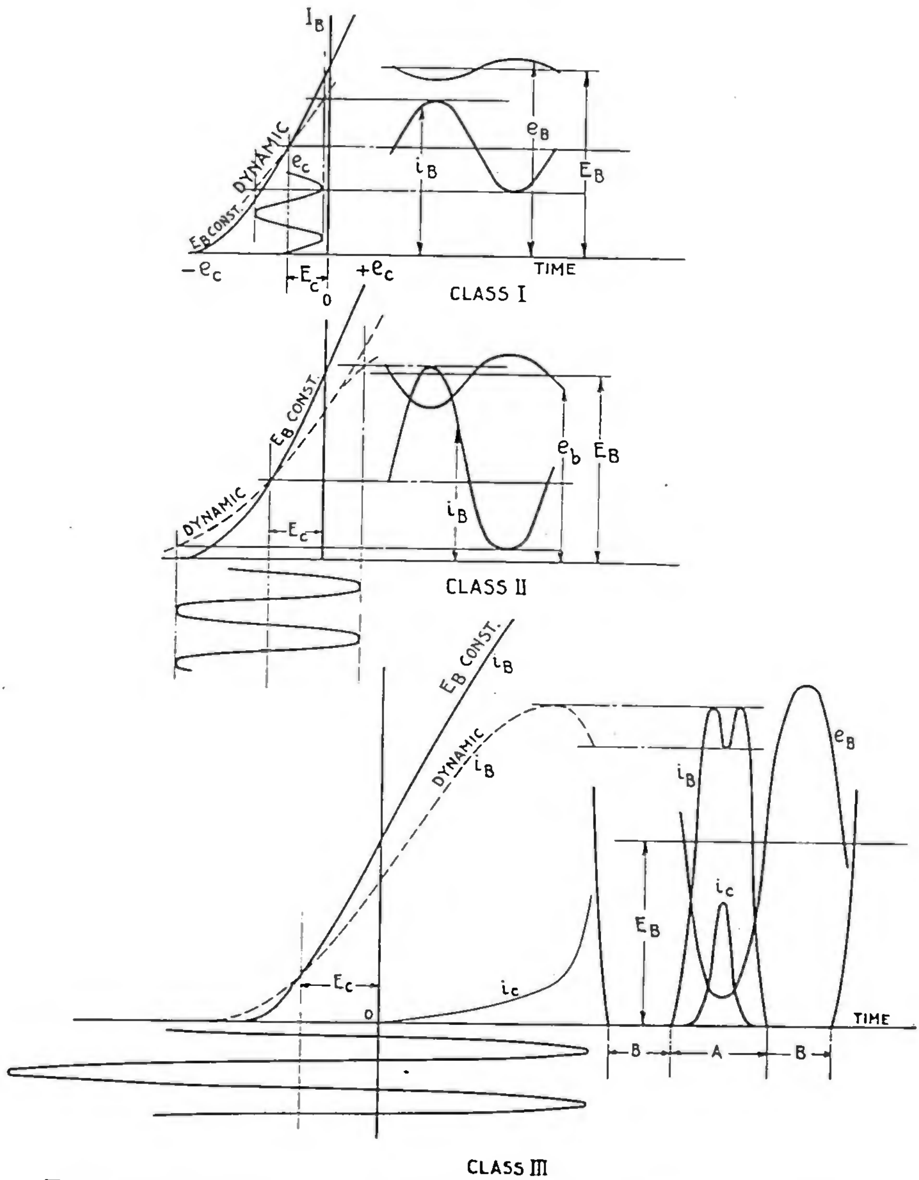


FIGURE 3—Typical Characteristics of the Three Classes of Amplifiers

amplifier of the first class the grid polarizing potential E_c is selected so that the alternating emf. applied to the grid operates on the linear portion of the dynamic characteristic. The peak value of the applied alternating grid voltage e_c is always less than the polarizing potential E_c. The alternating components of anode potential and current very closely approximate sine waves and may be considered so for all practical purposes. In the case of amplifiers of the second class, the peak value of applied alternating grid potential may exceed the grid polarizing potential, but is never sufficient to bring the anode current to zero. The anode current i_b departs considerably from a sine wave. Distortion may occur in i_b due to the flow of grid current when the grid assumes positive values. Amplifiers of the third class are driven by comparatively large alternating grid potentials. The value of grid polarizing potential is selected at or near the point of anode current cut-off. For some purposes it may be made much greater than the cut-off value. It is usually the case that during each cycle the grid swings positive to such an extent that there is an appreciable grid current. The anode current is pulsating and flows only during the time A. The energy dissipated in the anode is represented by the integrated product of e_b i_b. Since i_b is zero when e_b is large, this mode of operation results in much higher power efficiencies than can be obtained otherwise. While discussing this question of efficiency it may be pointed out that for amplifiers of the third class a considerable advantage is gained by limiting the flow of anode current to a half cycle or less. This condition is obtained by establishing the grid polarizing potential at values equal to or greater than the value required for anode current cut-off and exciting the grid with correspondingly large values of alternating emf. Improved efficiency may be obtained in this manner for the case of continuous wave telegraphy and that of carrier radio telephony without serious disadvantage in other respects. However, in the case of single-sideband transmission other considerations make it desirable to employ grid polarizing potentials slightly less than the anode current cut-off value. The foregoing definition of third class amplifiers includes those in which the grid and anode potential wave form are distorted for the purpose of obtaining high efficiency or high power. The essential characteristic common to all members of this class is that the current becomes zero for a finite portion of the cycle.

Amplifiers of the Third Class Applied to Radio Telephony

Since the anode current in an amplifier of the third class is pulsating, energy is delivered to the output circuit in similar form. Therefore, it is usually advantageous to employ an output circuit containing elements which tend to store the energy as received from the tube and power source and to deliver this energy to the load in sinusoidal form. Furthermore, altho the presence of harmonics in the anode circuit contributes to the attainment of high efficiencies, it is obvious that, where a third class amplifier is used as the final stage of a radio telephone system, the radio frequency harmonics must not be allowed to reach the antenna. The importance of harmonic current suppression in a high power radiating system can scarcely be over-emphasized. One of the best ways to accomplish both the foregoing results is to employ a circuit which by-passes harmonics thru a low impedance path and, by virtue of its resonance to the fundamental, receives energy at that frequency. Such a circuit is shown in Figure 4.

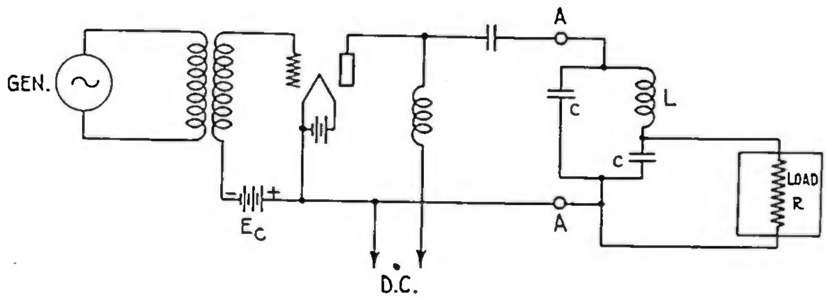


FIGURE 4

During a portion of each cycle the circuit CL, which is tuned to the frequency of the driving generator, receives one or more current pulses. These impulses add energy to that being cyclicly interchanged between the electrostatic fields of the capacities and the magnetic fields of the inductances. The movement of energy between C and L continues during the period when the anode current is zero, and the alternating potential across the terminals AA of CL completes each cycle approximately as a sine wave. It follows that the load current is not greatly affected by the pronounced distortion of the anode current.

Referring to Figure 5, e_c is the alternating emf. applied to the grid, and i_b is the anode current. In this case the grid polarizing potential E_c was selected to cut-off the anode current at $e_c=0$. The anode current consists of distorted half waves, but the circuit CL, Figure 4, functions to give the load current a sinusoidal form. The anode current, Figure 5, may be resolved into a direct current component, a radio frequency fundamental and a large number of harmonics.

Since the dynamic characteristic is a function of input amplitude[4] the behavior of the system is somewhat different when a

[4] R. A. Heising "Modulation in Radio Telephony," (Appendix), PROCEEDINGS OF THE INSTITUTE OF RADIO ENGINEERS, August, 1921.

modulated radio wave is applied to the grid, but the underlying principle of operation is unchanged. The variations in dynamic characteristic change to some extent the radio frequency distortion in the anode circuit.

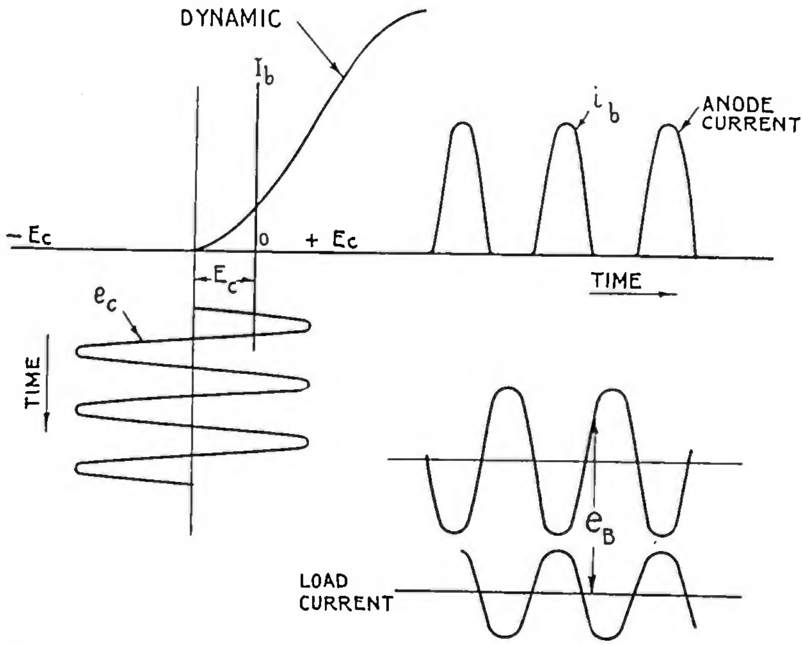


FIGURE 5—Current and Voltage Relations in Typical Amplifier of the Third Class

When a modulated radio wave such as the upper curve in Figure 2 containing the carrier and both sidebands is amplified, the anode current contains a constant direct current component corresponding to the carrier and a large number of audio frequency components corresponding to the original voice currents. Provision is usually made to by-pass these voice currents around the direct current power source. The load on the power source fluctuates at syllable and word frequencies within a relatively narrow margin at approximately full load value.

On the other hand, when a radio wave comprising a single-sideband signal, such as the lower curve in Figure 2, is amplified, the anode current does not contain a constant direct current component in addition to the radio frequency currents, but does have large currents within the voice frequency range, plus large low frequency components corresponding to words and syllables. Hence the load on the power source fluctuates between zero and full load at syllable frequencies. This is an important consideration in designing the power source for a single-sideband amplifier.

The oscillograms in Figure 6 were taken for a power amplifier operating as the last stage of a single sideband transmitter, with the vibrators connected as shown in Figure 7. Number 1 vibrator recorded the anode input voltage; number 2 vibrator recorded the anode input current, and number 3 vibrator recorded rectified antenna current. Number 4 is a 60-cycle timing wave. The exposure was made during the transmission of the word "Bordeaux." The conditions at both the beginning and the end of the exposure are those occurring between words. At such times the antenna current is zero and the anode current input is small. The latter contains alternating current components due partly to the rectifier ripple and partly to room noises entering the microphone. The syllabic variations of load mentioned in the preceding paragraph are clearly illustrated.

As mentioned above, the harmonics in the plate circuit of a third class amplifier are apt to cause serious interference unless

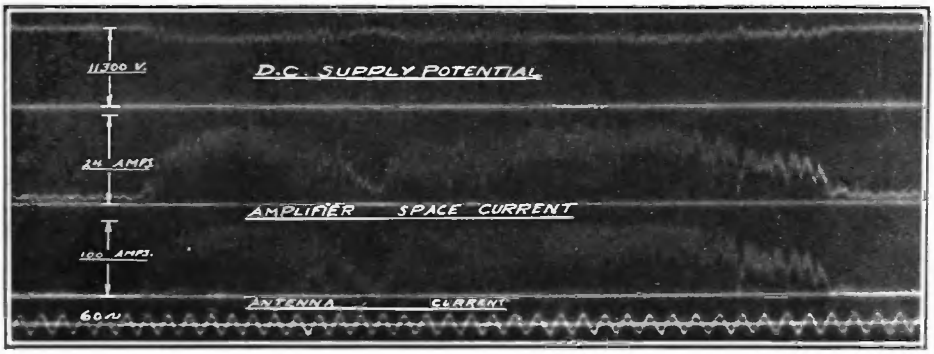


FIGURE 6—Oscillogram Taken During Transmission of the Word "Bordeaux." Note particularly that before and after the word there is but little amplifier space current and no antenna current. This oscillogram was taken with a dummy antenna

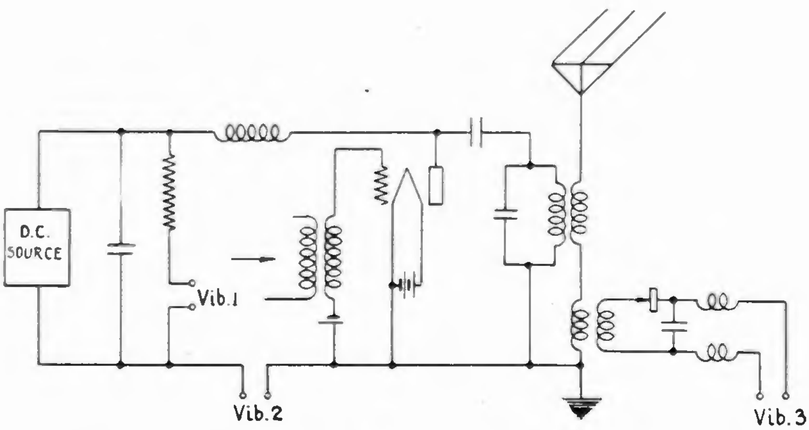


FIGURE 7—Connection of the Oscillograph Vibrators Used in Taking Figure 6

special precautions are taken to eliminate them from the antenna. One well-known method of balancing out the even harmonics is by means of the push-pull amplifier. The odd harmonics, however, are not affected and hence the method of itself is not sufficient, altho it is helpful. In a radio transmitting system this reduction of the even harmonics is the main virtue of the push-pull amplifier. As regards the reduction of distortion in the speech signal which is being transmitted, little if any advantage is gained. When the output circuit is such as to have negligible impedance for the predominant harmonics, there is no difference whatever between the amplitude characteristics of these two types of amplifier.

In the case of the present trans-atlantic experimental installation, the introduction of a push-pull amplifier presented certain minor problems. While these were by no means difficult to solve, the advantage to be gained did not justify discarding the more simple method of connecting all of the power tubes in parallel.

Water-Cooled Tubes

At the time when the decision to build a trans-atlantic telephone transmitting set was made, a suitable vacuum tube had already been developed in this laboratory. The principles which have led to the adoption of the type employed have already been fully discussed by Dr. W. Wilson in the "Bell System Technical Journal," volume 1, number 1.

For those who have not followed recent progress in the development of tubes of high power it will be sufficient here to say that in this type the anode, which forms a part of the containing envelope, is immersed in water. Continuous circulation of the latter carries away the power dissipated in the copper anode, the temperature of which is thus maintained well below the boiling point of water. Instead of the tube being inserted in a socket it is placed in a jacket so designed that water, entering from below, flows about the cylindrical anode with a rapidly whirling motion.

The type of tube employed in the experimental installation is capable of dissipating continuously ten kilowatts with an ample factor of safety. Such a tube will develop ten kilowatts in a suitable oscillating circuit. The operating voltage is 10,000. The ten-kilowatt output can readily be obtained with a direct current in the anode circuit of 1.4 amperes or less. The grid current is between 0.1 and 0.3 amperes. As a rule it is desirable that the filament emission of an efficient radio power tube be about five times the direct current to the anode. This means that in the present case about seven amperes are needed, a requirement which is readily met with a filament current of 41 amperes at 22.5 volts. Pure tungsten wire 0.035 inches in diameter is used. The grid must usually be able to dissipate from 200 to 250 watts. This condition is fulfilled by the water-cooled tube with a large factor of safety. The amplification constant is about thirty-eight. This signifies that the negative potential which we must apply to the grid in order to reduce the anode current at 10,000 volts to zero, has a value of about 260 volts, that is $10,000/\mu$.

When large numbers of high power tubes are operated in parallel it is desirable that separate protection be provided for each one. If this is not done, an open grid circuit, a burned-out filament or some other abnormal circumstances, may operate not only to destroy the tube completely but to injure other apparatus as well. Under such circumstances the overload protection for the tube bank as a whole would not be of much value. Therefore each tube is provided with a small overload relay. When the anode current exceeds a certain average value the relay contacts are opened. In this way the no-voltage release circuit of the power line breaker may be opened or the holding current of a remotely controlled switch may be interrupted, directly or thru the agency of an intermediate relay. Such a closed circuit system is preferable in this type of installation to the open-circuit type.

It will be obvious that if the flow of water in the cooling jacket is interrupted, the tube may suffer serious damage, resulting in loss of vacuum. In extreme cases the anode may be punctured. Hence, in a permanent installation some sort of alarm which operates when the flow is less than a certain amount is necessary. There are devices on the market which operate on water pressure rather than flow. These are satisfactory for certain cases, but do not afford complete security under all conditions. Two different types of alarm depending on flow have been developed. The one now in use is shown in Figure 8. Two views are presented, that at the left being an assembled alarm and that at the right being an "exploded" view. One feature of this design is the air dome formed by the cap. The imprisoned air prevents the water from reaching the electrical contacts. The advantage thus obtained in maintaining clean contacts is obvious. Such a device can readily be made to open the main circuit breaker, as well as to operate some audible or visible type of alarm.

The copper anode is safe providing that the temperature of every part is below the boiling point of water. However, to insure this condition, the temperature of the water at the outlet must be well below 100° C. This is particularly true when several water jackets are connected in parallel and only the average temperature of all is measured. No one outlet temperature can be

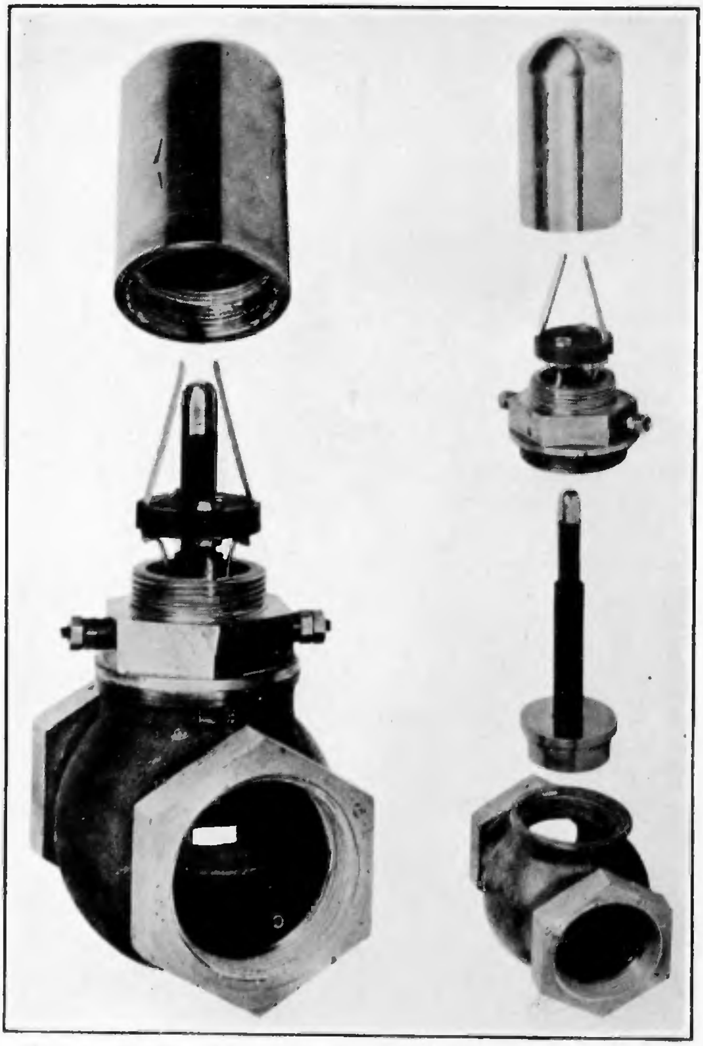


FIGURE 8—Partially Assembled and Exploded Views of Waterflow Alarm

specified for all cases since this depends on the rate of flow and the inlet temperature. It is entirely safe to operate a ten-tube unit with an outlet temperature of 60° C. when the inlet is at 25° C. and the water flow per jack is one gallon per minute.

Normally, however, the temperature is considerably less than 60° C. Means are provided to insure that this temperature is not exceeded. A thermometer having contacts which close when a certain temperature is reached, may operate an alarm thru suitable relays or it may open the circuits which supply the anode and filament power.

Initial Development of a Two-Tube Amplifier

Preliminary experiments devised primarily for the purpose of determining the utility of the present type of water-cooled tube as a power amplifier for telephone purposes were undertaken and extended into the early part of 1922.

This set will be briefly described, not only because it is used in the trans-atlantic tests, but because it possesses certain features of general interest. The assembled laboratory equipment is shown in Figure 9. From left to right may be seen the amplifier unit, the rectifier unit and the power control panel. The low power equipment is not shown. On the amplifier may be seen several meters, a thermometer for determining the outlet temperature of the cooling water, a flow indicator and relays for the individual protection of the tubes. There are also electrically-driven clocks for automatically recording the total time that filament and plate voltage have been applied.

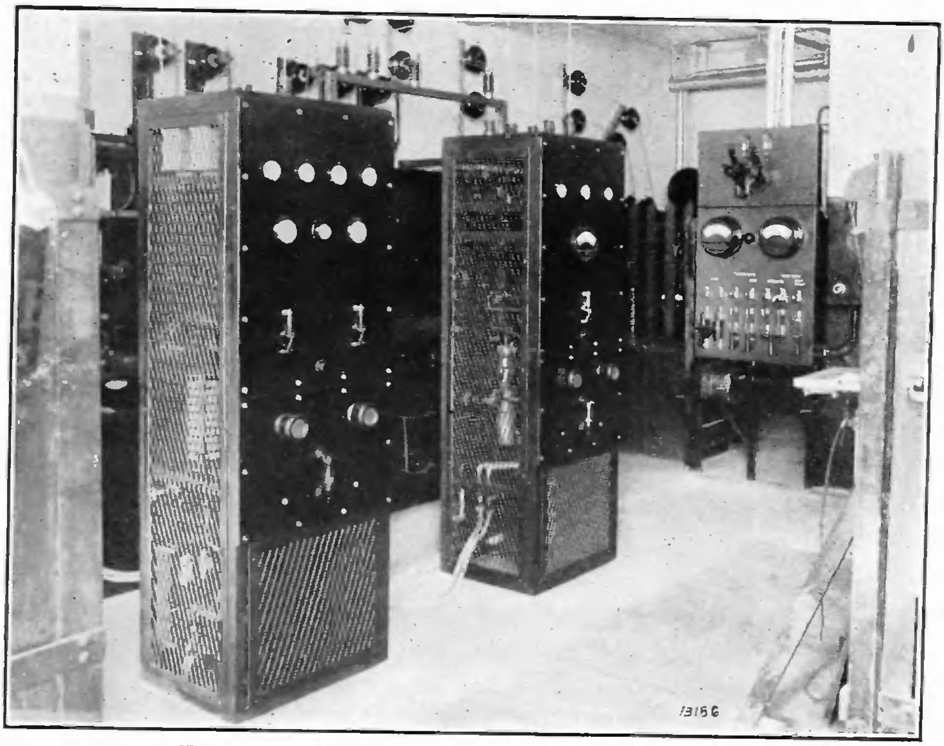


Figure 9—Amplifier and Rectifier Assembly
The former employs two amplifier tubes, the latter two rectifier tubes, all water-cooled

Figure 10 is a rear view of the amplifier. The space behind the panel is enclosed with expanded metal so that while the tubes are visible there is no danger that the operator will accidentally come into contact with a high potential conductor. The filament transformers, one for each tube, and such other apparatus as the potentiometer and filter used in connection with the grid polarizing circuit, are also located in this enclosed space.

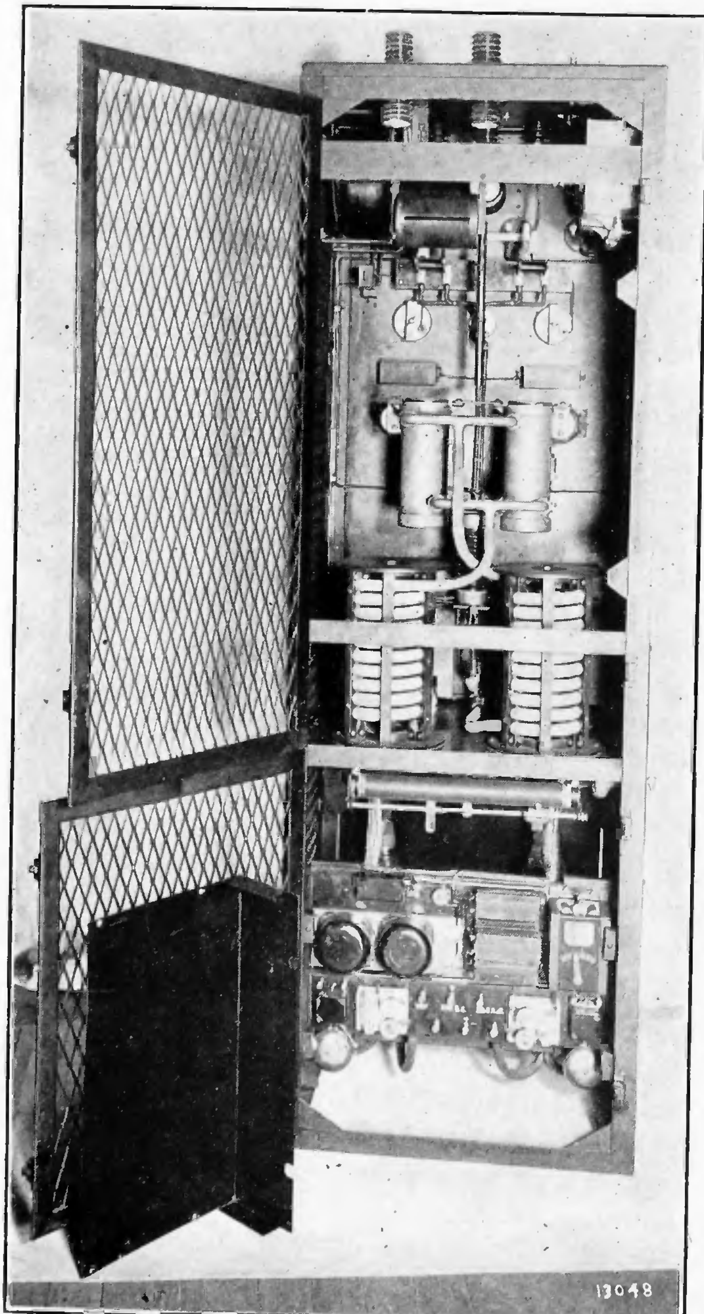


FIGURE 10—Rear View of Amplifier Set Shown in Figure 9

Just beneath the tubes are placed the insulating hose coils thru which cooling water circulates. These are necessary because the anodes operate at high voltage and the water supply is at earth potential. The general belief is that ordinary tap water, undistilled, is a fairly good conductor. Calculations made of the resistance of a half-inch hose a few feet in length filled with tap water show the resistance to be in the neighborhood of a megohm. Because of this rather high resistance these water columns need not be very long.

The rectifier was of the whole-wave type, two two-element water-cooled tubes being employed. From Figure 9 it is seen that these were mounted in a unit similar to the amplifier. A rear view is shown in Figure 11.

In a finished set the power control apparatus and the units containing the low power oscillators, amplifiers and modulators would be lodged in panels of the same height and general appearance. They would be placed adjacent to one another along the same line so that all of the routine adjustments which could be made with power on would be made from the front of the set.

The result of this development was a power amplifier unit which operated in the range of wave lengths now used for broadcasting and which could be readily converted to operate at any other suitable radio telephone frequency. Altho the power supply was a sixty-cycle single-phase rectifier, the filter circuit built to eliminate the large ripple reduced it to about one percent of the supply voltage. Had it been necessary, an increase in the size of the filter could have been made to attenuate the ripple to a lower value without making the equipment unduly bulky or costly.

Amplifier Requirements for Experimental Trans-Atlantic Installation

Since the generation of a single-sideband signal is most readily accomplished at low power levels (of the order of 500 microwatts) the complete amplifier system must receive energy at this level and increase the power to very large values. For the purposes of the present experimental installation, a maximum power output of 150 kilowatts is required from the last vacuum tube bank. This represents an over-all power amplification ratio of the order of three hundred million.

Obviously the first stages of such an amplifier system are small sensitive devices operating at low potentials and requiring careful electrical shielding. As the amplification progresses a

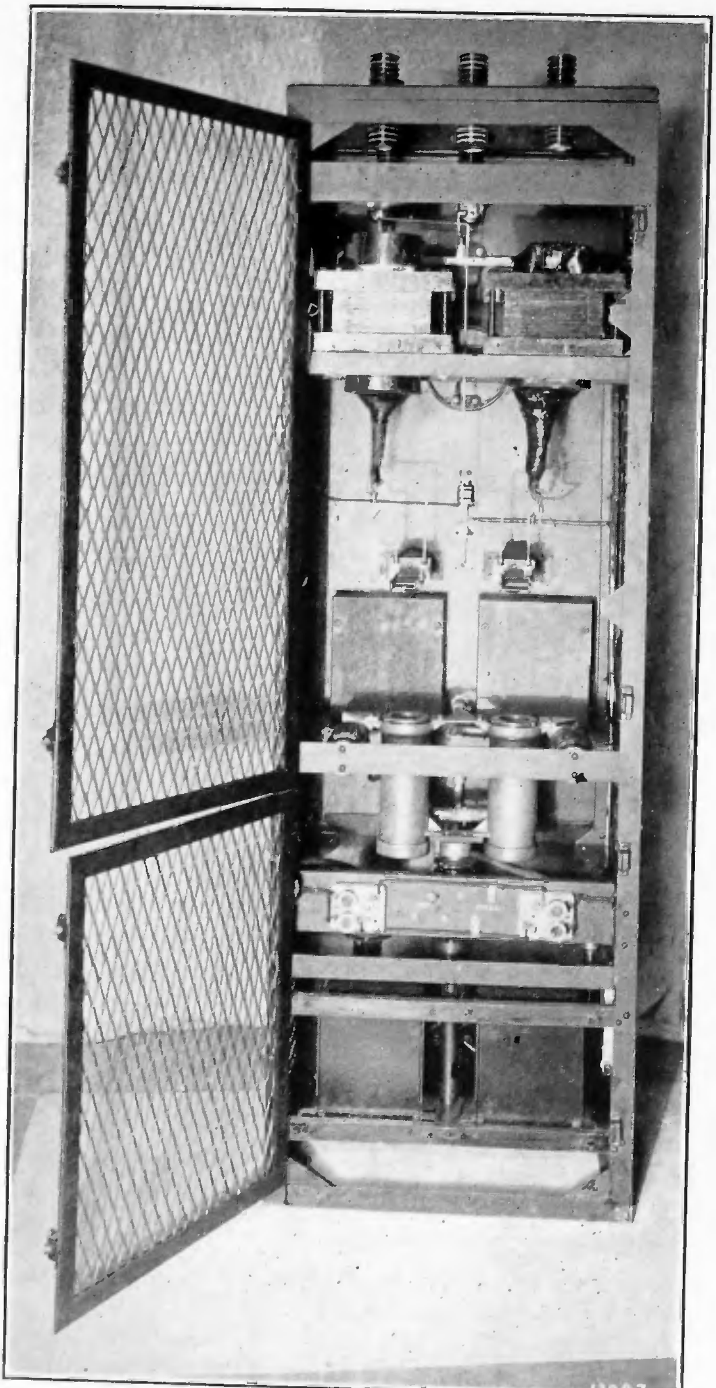


FIGURE 11—Rear View of Single Phase Whole-wave Rectifier Shown in Figure 9

point is reached where shielding becomes less important and a large upward step is taken in anode potentials of the amplifiers. The entire type of apparatus design may change at this point. Hence it is logical and convenient to divide the system into two distinct amplifier units operating in tandem. The low voltage stages will be termed the intermediate amplifier and the high potential stages will be referred to as the power amplifier. Only the latter will be given detailed consideration.

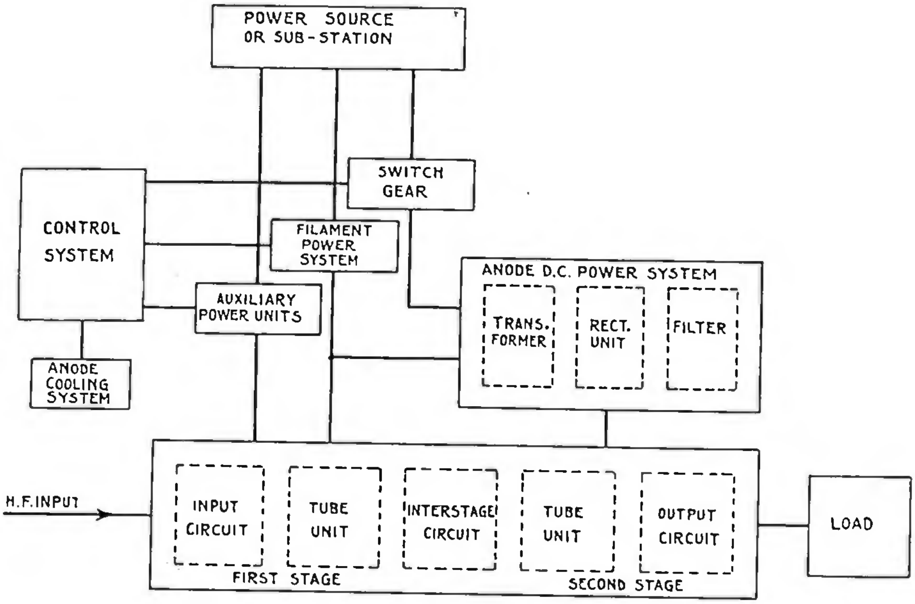
In the present installation the division between intermediate amplifier and power amplifier, expressed in terms of power level, occurs in the range 300 to 500 watts. Hence the amplification requirement of the power amplifier for the experimental system may be stated as 400 watts input and 150 kilowatts output. If there is to be no distortion the amplification ratio must be uniform thruout the transmission frequency band for all amplitudes.

An outstanding advantage of the single-sideband eliminated-carrier method of transmission lies in the fact that the frequency band over which uniform amplification is desired is reduced to slightly less than one-half of that usually required and this greatly simplifies the amplifier design problem, particularly in the case of trans-oceanic transmission where relatively low radio frequencies are employed. This matter will again be considered when discussing the amplifier circuit design.

Block Schematic of Power Amplifier System

Due to the large power capacity and the relatively high operating potentials, the design and construction of the experimental power amplifier system involved a number of new problems. The size and weight of various parts precluded the ordinary procedure of mounting the vacuum tubes and the associated apparatus in a single self-contained unit. The arrangement adopted was not unlike that for other types of power apparatus where the system comprises a number of complete units, separately located and controlled from a central position. Altho, in the case of an amplifier system the design of each unit is closely associated with the others, it will be convenient to consider them independently and to subdivide and restate the problem as applied to each part. For this purpose the block diagram shown in Figure 12 has been prepared.

The general problem of the power amplifier system has already been stated; viz., to receive a single-sideband signal of approximately 400 watts maximum power, distributed over a frequency band of 2,500 cycles, in the frequency range of 55,000 cycles to 60,000 cycles, to amplify this signal with minimum distortion to 150 kilowatts maximum power and to deliver the amplified signal to an antenna system. This requires a power amplification ratio of 375.



BLOCK DIAGRAM
TWO STAGE POWER AMPLIFIER
FIGURE 12

When dealing with power outputs of 150 kilowatts, operating efficiency is an important item. High efficiency is obtained without undue distortion by employing amplifiers of the third class, but since the grids of such amplifiers are driven positive, an appreciable power is expended in the grid circuit of each stage, thereby limiting the amplification per stage to ratios much less than those secured with amplifiers of the first class. In power amplifiers of the third class a ratio of 375 requires two stages. It may be possible to obtain the same amplification at these levels by means of a single stage, but more tubes will be required.

In Figure 12 these two stages are divided into five units. The tube units comprise mountings for the tubes in each stage, means for supplying cooling water and filament heating current, and such individual protection as each tube may require. They do not contain the radio frequency power circuits common to all the tubes in a unit. These radio circuits are designated as the input circuit, the interstage circuit, and the output circuit.

The input circuit serves to connect the grid-filament terminals of the first tube unit with the line carrying the signal which is to be amplified. One of the functions of this apparatus is to receive efficiently the incoming signal energy and to convert it to the proper potential for operation of the power tubes; that is, to match the effective grid-filament impedance with that of the line thruout the signal frequency transmission band. Another function is to introduce the desired grid polarizing potential and to provide amplification control. The interstage circuit serves a similar purpose between the anodes of the first tubes and the grids of the second.

The output circuit connects the anodes of the second tube unit with the load. It acts as a conversion circuit which efficiently transfers the radio frequency power to the load circuit, which is, of course, the antenna system. The output circuit is required to eliminate radio frequency harmonics, and in cases where the impedance characteristic of the antenna is unsatisfactory, the output circuit must be designed to correct the difficulty. This last requirement cannot always be completely met, but some correction is usually possible, as will be shown later.

The anode direct current power system must convert the available supply into direct current power at the proper voltage; it must suppress noise from the power source, and it must provide a path to by-pass the large voice frequency components generated in the anode circuits of the amplifier.

The functions of the remaining blocks shown in the diagram of Figure 12 are self-explanatory. Their requirements are largely detail matters relating to control and protection, both for the power units and the tubes. Since the tube circuits are supplied with power thru three lines and are dependent upon the proper circulation of cooling water, it is apparent that the control circuits must possess interlocking features, which prevent incorrect applications of power when starting the plant and which avoid damage to the system by switching off power whenever an abnormal condition is established during operation. Further than this, the control system should signal the attendant and give some indication of the kind and location of trouble. It should also include suitable safety devices designed to prevent the attendant from accidentally examining high potential parts without shutting off the power. All of these things can usually be accomplished in a number of different ways and the exact arrangement is determined by the particular conditions.

150-Kilowatt Amplifier for Trans-Atlantic Experiments

It has been shown that a two-stage system is required to amplify a 400-watt signal to a 150-kilowatt signal efficiently and economically. Hence the experimental system was constructed on the basis of two 10-kilowatt tubes for the first stage and twenty 10-kilowatt tubes for the second. Since a two-tube unit is capable of delivering 20 kilowatts, there is an ample margin in power capacity, and advantage is taken of this to adjust the circuit for improved efficiency and better quality. The reasons for using twenty instead of fifteen tubes in the last stage will be more apparent later when the design of the output circuit is considered. It will be sufficient at this point to say that the load power factor at the edges of the telephone transmission band may depart considerably from unity and that this effect, in combination with the anode circuit impedance characteristic, necessitates the extra volt-ampere capacity.

The two-tube unit which was developed shortly after the first experiments with the present water-cooled tube and which has already been described was available for the first stage of the power amplifier. The single-phase rectifier unit was not required. The tube panel as installed for the first stage is shown at the right in Figure 13. In the middle of the picture is shown the central control panel for the power amplifier. This panel does not include remote control of the radio frequency tuning apparatus because the cost of such control is not warranted in an experimental plant.

The twenty power tubes for the second stage were arranged in two panel type units each containing 10 tubes. The object in constructing two separate tube units was to provide greater flexibility both for experimental and routine testings. There are several operating advantages to be gained by dividing the tubes into two groups such, for example, as running at reduced power with one tube unit, while repairs are being made to the other unit. The suppression of undesired oscillations becomes more difficult as the number of tubes in a single bank is increased. During the course of the initial testing of the 150-kilowatt stage there were numerous occasions when the division of the tubes into two banks proved to be a valuable aid.

The two ten-tube units for the second stage of the power amplifier are shown at the left of Figure 14. Mounted on the upper panel are two auxiliary control buttons for use in emergencies, and a thermometer with electric contacts to ring an alarm in case the cooling water temperature exceeds a safe limit. The plate glass panel gives the attendant a full view of all the tubes and of the scale of the ammeter used for checking individual anode currents. This meter is located at the forward end of the high voltage rack about seven inches behind the glass panel. The meter is switched into and out of each anode circuit by means of jacks operated by a metal plug on a long insulated rod. The

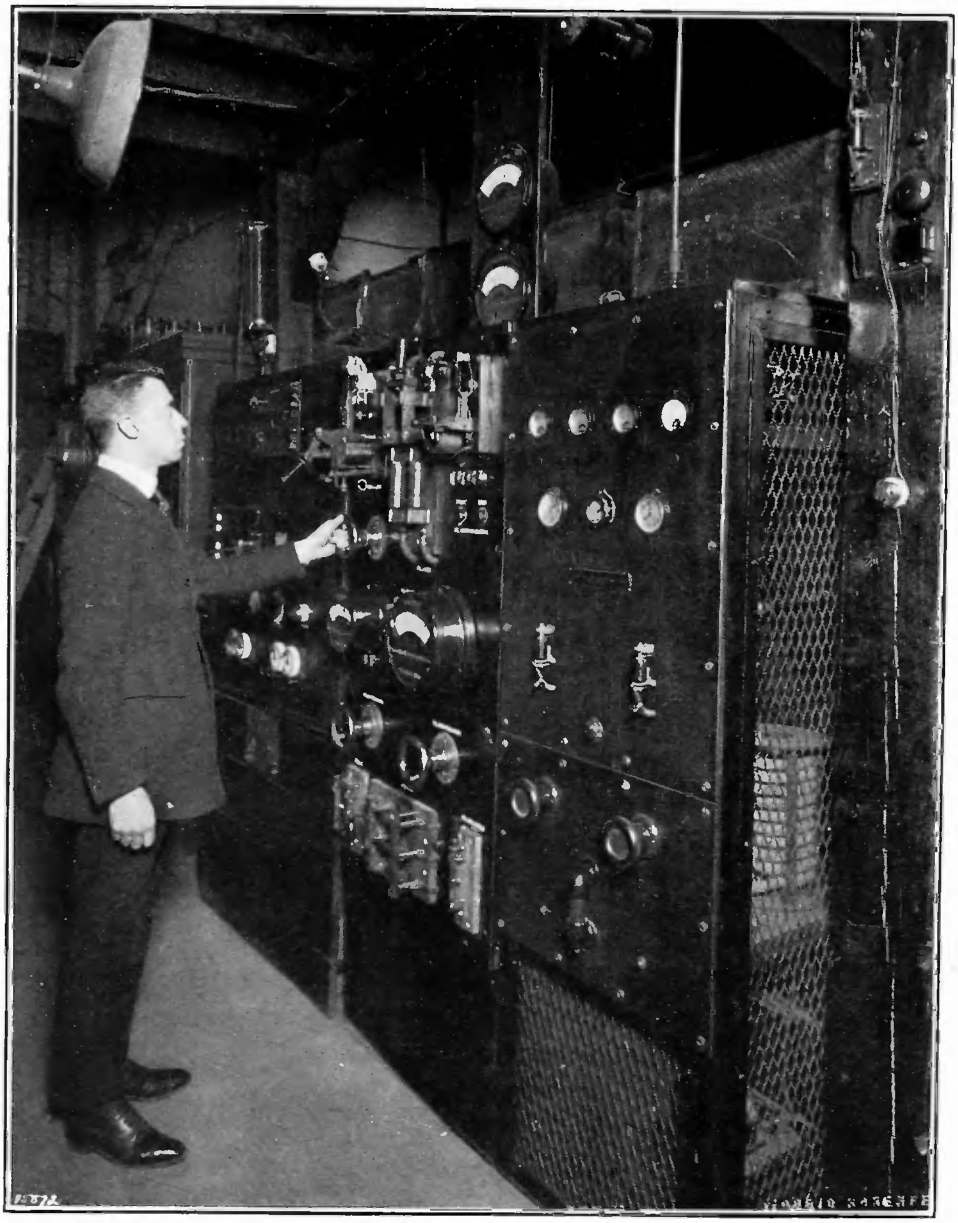


FIGURE 13—Amplifier Shown in Figure 10 Installed as the First Stage of the Power Amplifier. The Second Stage is Shown in Figure 14

two lower panels carry the rheostats and switches for individual control of filament currents.

The jackets for the ten-tube unit are arranged in two rows of five tubes each as shown in Figure 15 and Figure 16. Compact arrangement of tubes is highly desirable both from an electrical and mechanical viewpoint. Cooling water is circulated thru common inlet and outlet headers so arranged that the flow is equalized for all tubes. The connection between each jacket and the header contains a very short length of rubber hose for the purpose of providing a high resistance electrical path between jackets. The reason for this will be evident when the intertube electrical circuit is described. No valves are provided to shut off the flow to individual jackets. In case it is desired to operate without a complete set of tubes, metal disc stoppers are substituted for tubes. It is not necessary for this stopper to have the same shape as the anode because the pressure drop thru the jacket is small compared to that in the connections to the headers.

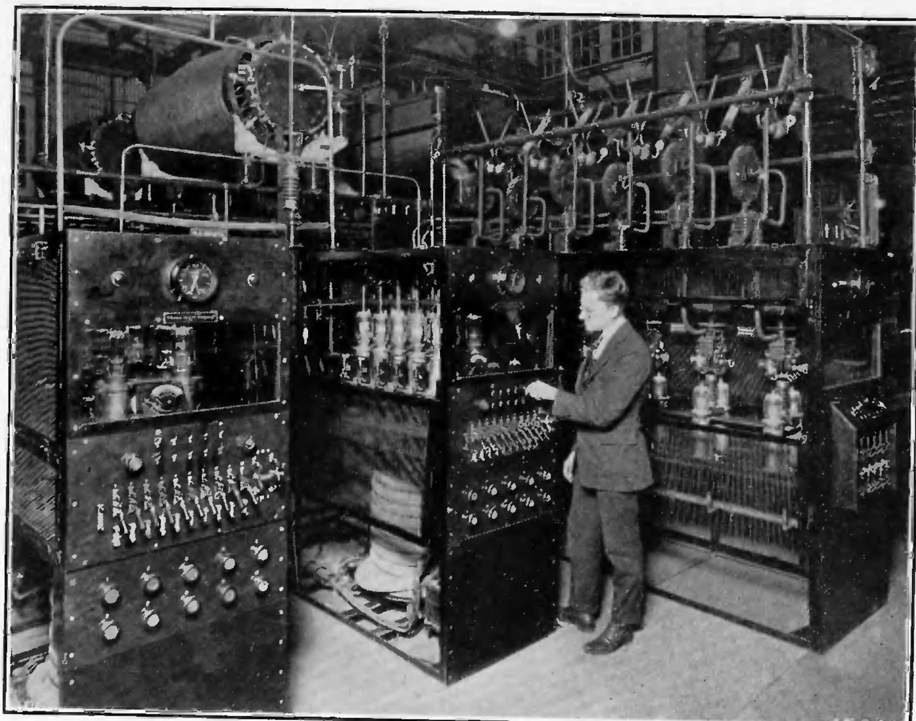


FIGURE 14—Last Stage of Amplification. Two ten-tube sets are shown, also the six-phase rectifier at the right

Since the cooling jackets and the common intake and outlet headers are at the same potential as the anodes, it is necessary to bring the water to and from headers by means of hose coils as previously explained when describing the two-tube unit. These hose coils are located directly under the insulated frame supporting the water jackets. The intake and outlet lines are wound in parallel on the same frame. One coil is clearly visible in Figure 14.

The water jackets are insulated from each other for comparatively small voltages and are mounted on a main frame which is insulated for the full anode potential. This frame also supports the radio frequency bus, the individual by-pass condensers,

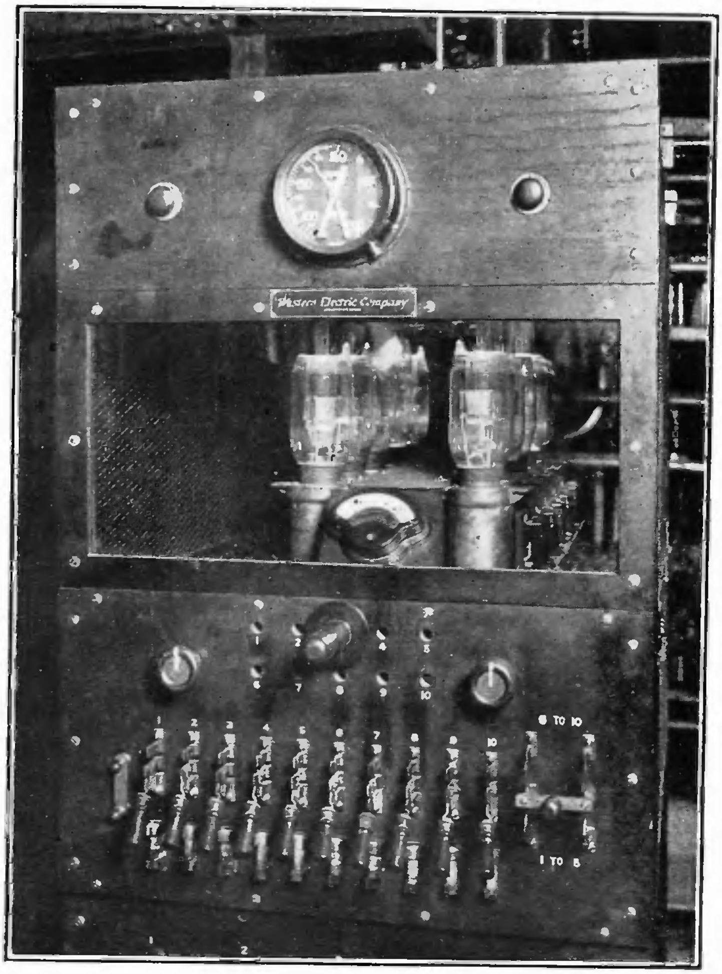


FIGURE 15—Front View of One of the Amplifier Units

the individual anode circuit overload trip-coils, the network for the suppression of inter-tube oscillations and the meter, jacks and cables necessary for checking the individual anode currents.

The grids are connected directly to a common grid bus as shown in Figure 16. One side of the filament is connected in like manner. The other side of each filament is connected to a rheostat and switch controlled from the front of the panel unit. Filament heating current is supplied to the ten tubes by a transformer placed on the floor between the hose coil and lower panel board.

Adequate protection against high potentials is provided by expanded metal screens arranged for quick removal to facilitate repair work. These screens also introduce a certain degree of electrical shielding between the banks. Altho such shielding does not appear to be essential, its presence undoubtedly helps to stabilize the anode-filament capacity relations.

A schematic diagram of the electrical circuit comprising one ten-tube unit of the second power amplifier stage is shown in Figure 17. It will be noted from this that the problem of connecting ten power tubes for parallel operation involves considerably more than merely connecting the terminals to a common bus system.

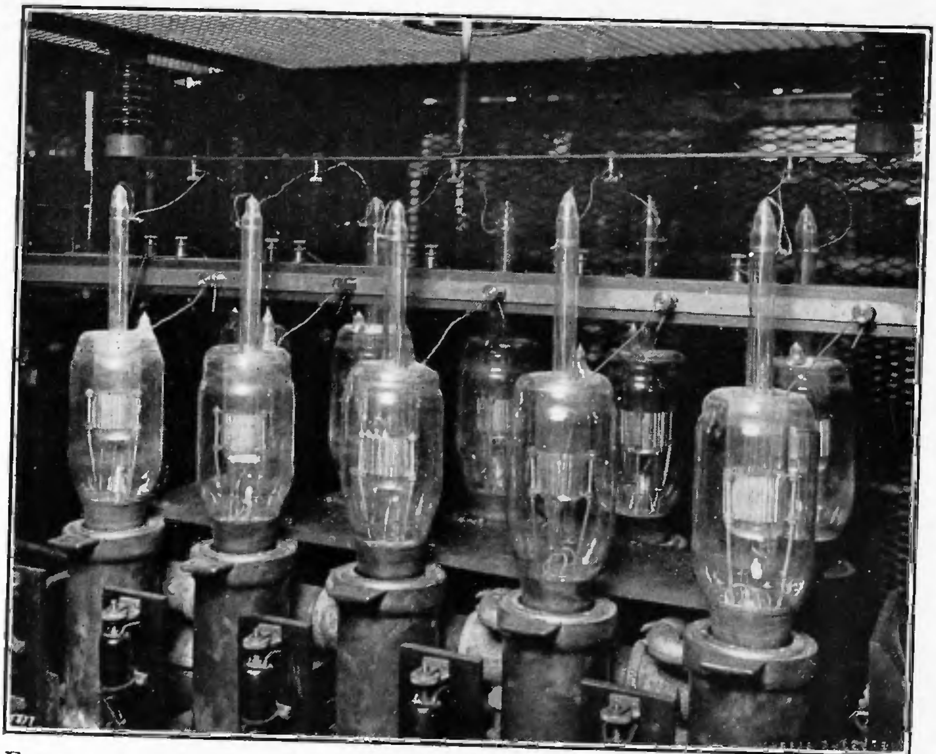


FIGURE 16—Side View of One of the Amplifier Units, Showing Tube Arrangement

Beginning with the filament circuit, there are two buses connected to the terminals of the heating transformer secondary. These are provided with the usual bypass condensers. The direct current from the anode circuit passes thru the transformer winding to ground. In order to balance the direct current thru the two halves of the transformer winding it is necessary to place five filament rheostats in the lead to one bus and the remaining five in the lead to the opposite bus.

It will be recalled that in describing the arrangement of water jackets and inter-connecting water lines it was stated that the jackets were insulated from each other. The jacket, of course, corresponds to the anode in Figure 17. In order to eliminate certain types of inter-tube oscillation, all of the anodes are connected together thru a resistance network so designed that sub-

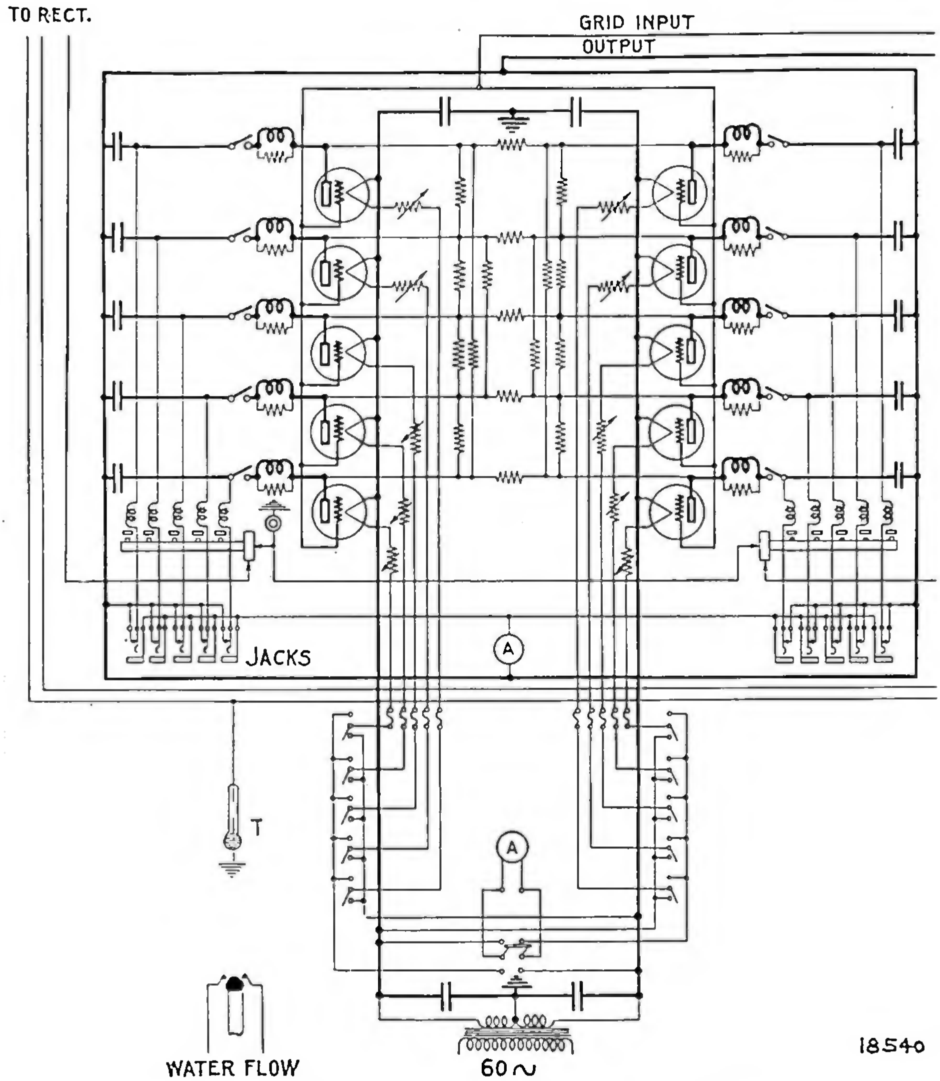


FIGURE 17—Schematic of the Electrical Circuit of One Ten-tube Amplifier Unit

stantially equal resistance paths exist between any two jackets. Each anode is connected to the main bus thru a path including a resistance and a choke coil in parallel. The latter passes the normal radio frequency. The underlying principle of the network is to provide a low impedance path for the normal radio signal and a non-oscillatory resistance path for undesired oscillation. The inductances lower the resonant frequencies of the circuits involved in the tube-to-tube oscillations to such an extent that the grid coupling, which is due to the inductance of the grid leads, is insufficient to sustain oscillations when damped by the resistance as described. Such a network is equally effective when placed in the grid circuit insofar as suppression of undesired oscillation is concerned, but there are other reasons for not doing this. For example, since the grid is driven positive during a large part of each cycle, there is an appreciable grid current and every impedance in the path of this current tends to increase the non-linearity of the input-response characteristic of the amplifier. Then again, obstructions in the grid circuit will presumably tend to aggravate any effects due to secondary emission or to unusual gas conditions. The latter occurs only in exceptional cases when a tube develops a slow leak, but the consequences may prove very injurious to the adjoining good tubes.

The direct current component flowing to the anode passes thru overload trip coils associated with an auxiliary control circuit. Experience thus far has shown that such devices give valuable protection. The jacks connected in series with these trip coils are so arranged that the insertion of a cordless plug switches an ammeter into the plate circuit. The information concerning tube performance obtained by observing the individual anode currents more than justifies this slight switching arrangement.

A simplified overall schematic of the power amplifier system is given in Figure 18. The input circuit to the first stage is simple because the output impedance of the intermediate amplifier, which supplies the signal at the 400-watt level, is approximately equal to the correct input impedance for the grids of the two-tube unit. Under these circumstances direct resistance coupling is satisfactory. A slightly greater output could be obtained from the first power stage by driving the grids thru an input transformer, but the additional power is unnecessary. The resistance coupling arrangement has a very desirable transmission characteristic and requires no difficult adjustments. A large inductance connected in parallel with the resistance coupling element bypasses the direct current component of the grid current. The polarizing potential is supplied from a generator connected thru a potentiometer and a filter.

The interstage circuit consists of a parallel tuned circuit designed to match the impedance of the two power amplifier stages. The resistance element flattens the impedance characteristic, thus making the circuit suitable for the transmission of telephone signals, and it also assists in preventing the generation of spurious oscillations at frequencies of the same order as those of the signal. The grid polarizing potential is supplied thru a filter system the impedance of which is made low to prevent a blocking action which may occur under certain conditions. The direct current to the grid is from one to three amperes and, in order to avoid distortion caused by changes in the grid polarizing potential which result from variations of this current, the impedance of the potentiometer from which the polarizing potential is taken must be relatively low. For this reason about 2.5 kilowatts are expended in the potentiometer.

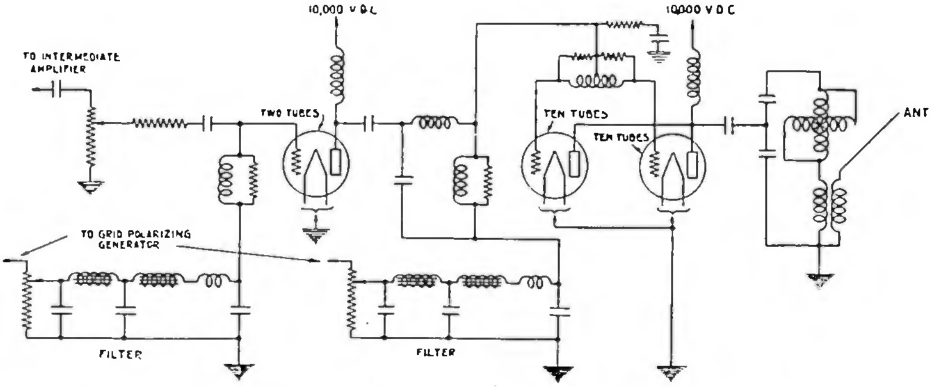


FIGURE 18—Simplified Over-all Schematic of the Power Amplifier System

The grid buses of the two 10-tube units are connected to the common grid circuit thru a mid-tapped reactance coil having a high mutual coupling between the two halves. The signal frequency currents pass thru this coil in opposite directions and are impeded only as a result of the leakage reactance. A resistance is connected in parallel with the coil. Any disturbances tending to establish oscillations between the two tube-banks encounter the full impedance of the coil with its shunted resistor. In doing this they are suppressed because of the large resistance component of this impedance. The same device can be applied in the anode circuit. In this case the coil must have a very much larger current carrying capacity.

The Output Circuit and Load

In subdividing the amplifier problem with reference to Figure 12 the output and load circuits were defined. It will be recalled that one of the functions of the output circuit is to match the impedances of the power tubes and of the load. That is, having given an amplifier capable of delivering a certain amount of radio frequency power and an antenna with certain characteristics, it is necessary to design an intermediate circuit which satisfies the impedance requirements both of the power tubes and of the antenna. A second condition which the output current must satisfy is that the power at all frequencies in the band must receive substantially the same amplification in passing thru the system to the antenna. In addition, in order to prevent interference, currents of harmonic frequencies must not be allowed to flow in the antenna.

From the foregoing requirements it is obvious that in order to design the output circuit it is necessary to know something about the characteristics of the antenna. One of the multiple tuned antennas at the Radio Central Station of the Radio Corporation of America was used. It is located at Rocky Point, Long Island. For a discussion of multiple tuned antennas the reader is referred to articles by E. F. W. Alexanderson and E. E. Bucher, in the "General Electric Review" for October, 1920, and to one by Alexanderson, Reoch, and Taylor in the American Institute of Electrical Engineers "Proceedings" for July, 1923.

The resistance component of the antenna impedance as viewed thru the feed current downlead, that is, the series resistance of the antenna, is a function of the loading in the various downleads. An experimental curve is shown in Figure 19. As

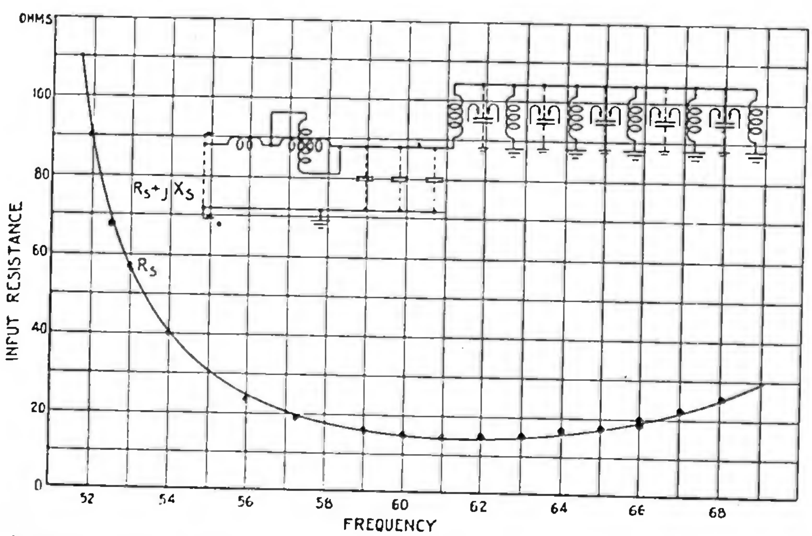


FIGURE 19—Resistance Characteristic of Multiple Tuned Antenna

the frequency increases from the lowest shown in this curve the resistance decreases sharply at first, passes thru a flat minimum and begins to rise again. At the frequency used (57 kc.) the multiple resistance of the antenna is approximately 0.76 ohms. The radiation resistance, taking account of the directive effect, is 0.32.[5] The radiation efficiency is therefore about forty percent.

[5] The effective height as determined from field strength measurements is 85 meters. The value obtained when the directive effect is neglected is 0.41 ohms. The radiation efficiency would thus be nearly fifty percent. As a result of the directive effect there is a saving in total antenna power of about 12 percent for equal signals along the axis of transmission.

This low antenna resistance is of itself most desirable, but it results in a narrow resonance curve which for telephony leads to certain complications not encountered in the telegraph service for which the antenna was designed. When the antenna is tuned to 57 kc. the band width is 1,150 cycles. (See Figure 20.) The band width is here arbitrarily taken as the difference between the two frequencies for which the impedance of the tuned antenna circuit is double the minimum value. It will be seen that the transmission of high quality speech under such conditions presents a difficult problem in spite of the fact that the system is favored by the single-sideband method.

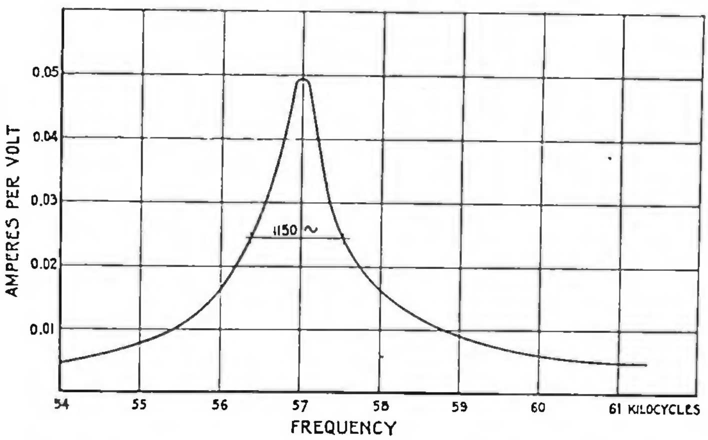


FIGURE 20—Antenna Input Admittance of the Antenna when Tuned to 57 kc.

Figure 20 does not indicate the total antenna current but only that in the downlead thru which power is supplied to the antenna. The ratio of the former to the latter is shown in Figure 21, curve *A*. The ordinate gives the sum of the six downlead currents divided by the feed current as measured in the station at *M* in the diagram. Between the station and the first loading coil there is a lead the capacity of which to earth, plus that of the coil itself, is of the order of 0.001 microfarad. Hence the current in the downlead itself is less than that in the station by an amount which is by no means negligible. Curve *B* gives the feed ratio referred to the feed current in the downlead beyond the loading coil at *N*. The difference in the present case is large because the loading inductance at *M* is a large fraction of the total loading of the first downlead. In Figure 22 are plotted the currents in the downleads divided by that at *N*. Their intersection at a frequency of about 58 kc. is the result of a proper choice of the inductances of the various downleads. The divergence above and below this point is due to the inductance of the flat-top.

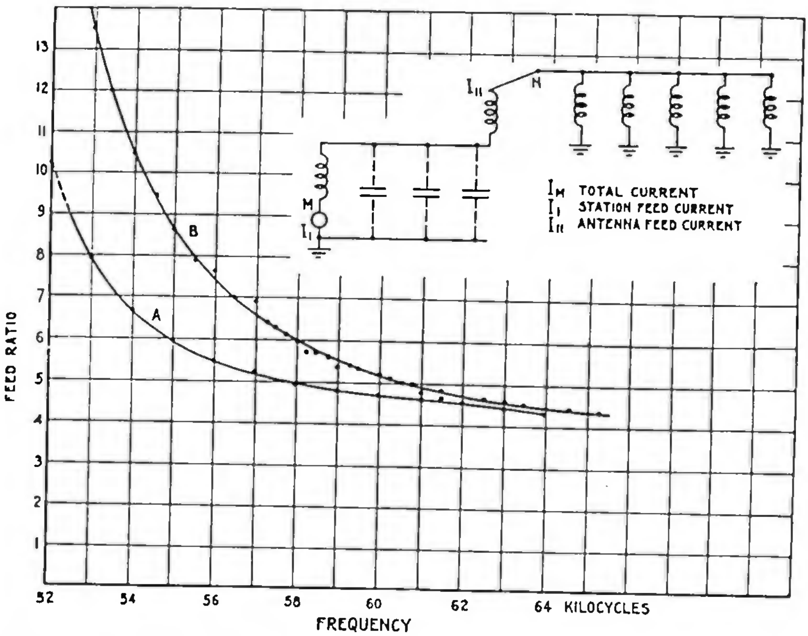


FIGURE 21—Feed Ratio Characteristic of the Antenna. The ordinates of A are the ratios of I_M to I_1. Those of B are the ratios of I_M to I_{11}

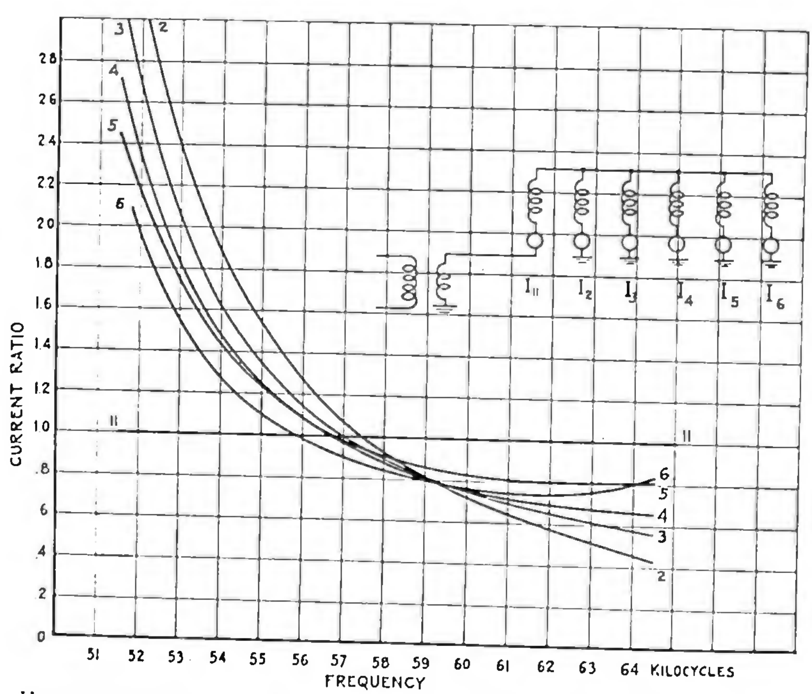


FIGURE 22—Ratio of Currents in the Various Downleads to I_{11}

There are several forms in which the output circuit may be arranged. In addition to the conditions previously mentioned, convenience, ease of adjustment, and availability of apparatus should be considered in the design. A schematic of the circuit employed is shown in Figure 18. It consists of a capacity branch which provides a low impedance path for harmonics and an inductive branch, coupled inductively with the antenna circuit. The latter is tuned at 57 kc. The primary circuit is usually adjusted so that at 57 kc. the phase angle of the load into which the amplifier works is approximately zero; that is, its power factor is unity. All of the adjustments necessary in routine operation can be made by means of variometers and a variable coupling coil.

In a single-sideband eliminated-carrier system this tuning frequency of 57 kc. is an upper sideband frequency corresponding to a 1,500-cycle audio signal applied to a 55.5 kc. carrier. Since 1,500 cycles is approximately at the middle of the voice frequency band which it is desired to transmit, it follows that the antenna and output circuits when tuned to 57 kc. are in correct adjustment for the middle of the upper radio frequency sideband. Hence the initial electrical design considerations are centered about this frequency.

Having fixed upon the type of output circuit, the electrical design procedure consists of two steps: first, the preliminary determination of circuit constants on the basis of a single tuning frequency as stated above and, second, an examination of the frequency impedance characteristic thruout the band for the purpose of modifying the constants so as to obtain the most practical input-response-frequency characteristic for the amplifier system.

Referring to Figure 23, let the antenna reactance, X_s, be

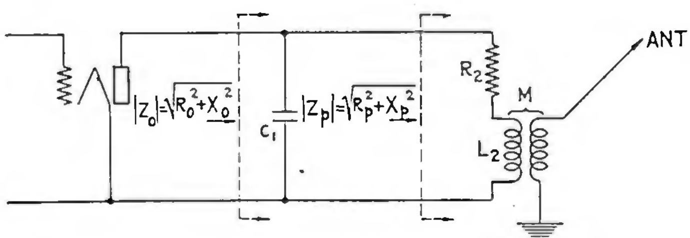


FIGURE 23

zero for the frequency f_t. Let R_s equal the corresponding antenna resistance and R_{s_2} equal the resistance component introduced into the inductive branch of the output circuit thru the coupling M. Let R_2 represent the total resistance of the output circuit alone and assume that it is lumped in the inductive leg. This assumption introduces very little error because the coil losses are usually several times greater than the condenser losses. The total resistance of the inductive leg is therefore

$$R_p = R_2 + R_{s2}$$

Since the antenna reactance is zero, the reactance component, X_{s2}, introduced into the inductive branch of the output circuit is also zero and X_p is equal to X_2, where X_2 is the reactance of the inductive branch alone. In the simple case shown in Figure 23, X_2 is equal to $2\pi f_t L_2$. In general the impedance, Z_o, of the output circuit as seen by the tubes has both a resistance component R_o and a reactive component X_o. It is apparent that if the tubes are to work into a pure resistance, X_o must equal zero for the frequency f_t, in which case $Z_o = R_e$ where R_e is the particular value of R_o corresponding to the frequency f_t. The conditions for unity power factor are satisfied when

$$R_p = \frac{X_1^2 R_e}{X_1^2 + R_e^2} \tag{1}$$

and

$$X_2 = \frac{-X_1 R_e^2}{X_1^2 + R_e^2} \tag{2}$$

where X_1 is the reactance of the capacitive branch of the output circuit. The design is started by fixing the numerical value of R_e. The correct determination of R_e requires previous experimental knowledge concerning the type of tube to be employed because it involves the effective internal tube resistance and the latter in turn is a function of the anode mode of operation. If N is the number of tubes connected in parallel, then $R_e = \frac{K}{N}$ where K is constant for a given application. When water-cooled tubes of the type already described are supplied with direct current at 10,000 volts and are operated as single frequency amplifiers of the third class, 5,000 ohms is a good value for K. If transmission occurs over a band of frequencies, then the choice of the value of K at the middle of the band will depend upon the way in which the impedance varies for higher and lower frequencies. If the output circuit is to prevent anode circuit harmonics from reaching the antenna, such currents must pass thru condenser C_1. The impedance of C_1 to the second harmonic should be of the order of one-fourth of the impedance offered by the output circuit to the fundamental. That is

$$C_1 = \frac{1}{\pi f_t R_e} \tag{3}$$

Having fixed the value of R_e and C_1, the necessary data is available to solve equations (1) and (2) for R_p and X_2. R_2 can be determined approximately from coil design data, and the coupling is obtained from the expression

$$M = \frac{\sqrt{R_p R_{s_2}}}{2 \pi f_t}$$

The impedance frequency characteristic can now be calculated. It is well known that the impedance, Z_{s_2}, introduced into the output circuit inductive branch by the antenna is given by the expression.

$$Z_{s2} = R_{s2} + j X_{s2} = \frac{\omega^2 M^2 R_s}{R_s^2 + X_s^2} - j \frac{\omega^2 M^2 X_s}{R_s^2 + X_s^2}$$

Since the impedance Z_2 of the inductive branch alone is $R_2 + jX_2$ the total impedance is

$$_p = R_p + j X_p = Z_2 + Z_{s2} = [R_2 + R_{s2}] + j[X_2 + X_{s2}]$$

The output circuit impedance, Z_o, and the power factor are obtained from the usual expressions for parallel tuned circuits:

$$|Z_o| = \sqrt{R_o^2 + X_o^2}$$

$$R_o = \frac{R_p X_1^2}{R_p^2 + (X_1 + X_p)^2}$$

$$X_o = \frac{X_1 X_p (X_1 + X_p) + R_p^2 X_1}{R_p^2 + (X_1 + X_p)^2}$$

$$\text{Power factor} = \frac{R_o}{|Z_o|}$$

In Figure 24 a measured and a calculated impedance curve is shown for the case where the antenna band width is relatively narrow. As a result of the fact that coupled circuits are involved, there may be one, two, or three frequencies within the transmission band at which the tubes work into a pure resistance. This is clearly shown by the power factor curve in Figure 25. The impedance at two of these frequencies is apt to be very high.

These relations will probably be made clearer by further reference to Figure 24. The full lines represent the impedance of the output circuit while the dotted lines is the resonance curve of the antenna alone. One way of expressing the reason for the two peaks of impedance is as follows: At 57 kc. the antenna introduces only resistance into the primary circuit. For lower frequencies, positive reactance is introduced and at the frequency of point B this inductive reactance is such that the output circuit becomes anti-resonant and the impedance passes thru a maximum. For frequencies higher than 57 kc., capacity reactance is added to the inductive leg of the output circuit, making the latter anti-resonant at the frequency of the peak, *C*. The impedance at these peaks is high because the resistance introduced into the primary from the antenna both above and below 57 kc. is much lower than at the tuning frequency.

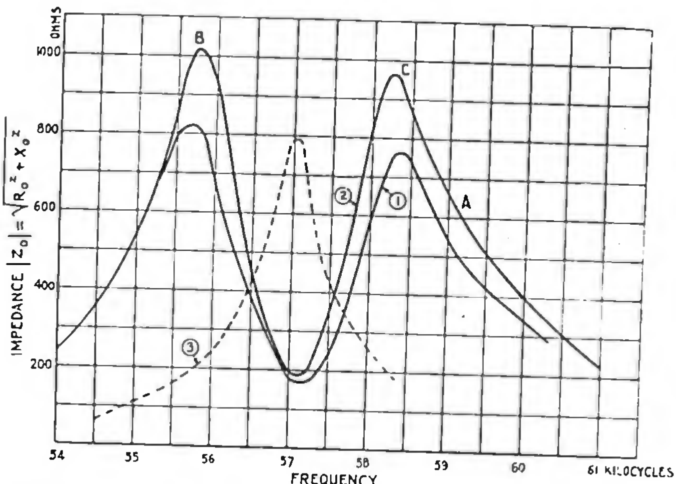


FIGURE 24—1. Impedance of the output circuit as a function of frequency, measured values. 2. The same, calculated values. 3. Resonance curve of antenna

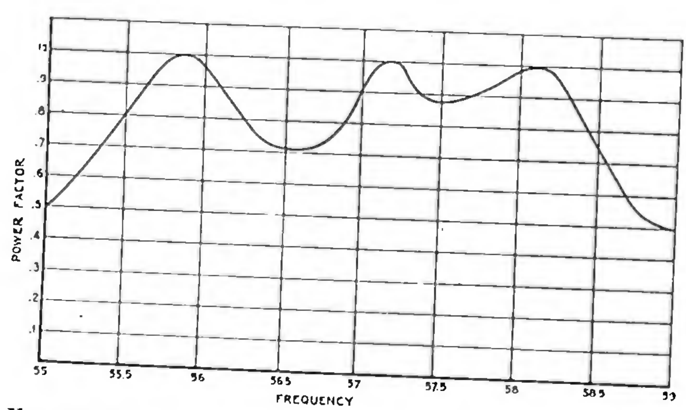


FIGURE 25—Power Factor of the Output Circuit. The middle maximum corresponds to the tuning frequency, the other two to points *B* and *C* of Figure 24

Let us now see how this is related to the antenna current-frequency characteristic, assuming that we apply a constant voltage of varying frequency to the grid of the last stage. If the impedance of the tubes were zero, this would be equivalent to the application of a constant voltage equal to μe_c (amplification constant times alternating grid voltage) to the output circuit. The antenna current characteristic would not differ very radically from the resonance curve of the antenna. Now taking account of the fact that the impedance of the tubes is finite, we find that the same potential is not applied to the output circuit for all frequencies, but is greatest for the frequencies at which the output impedance is greatest. Hence there is a tendency to depress the antenna current characteristic at points of low output impedance. If, therefore, the tube impedance is sufficiently great this characteristic may possess two distinct maxima, one above and one below 57 kc. and the band width may thus be made several times as great as the resonance band of the antenna. The adjustment finally adopted must, of course, be one for which the efficiency of the amplifier is satisfactory. The effect of tube resistance as a factor in determining the band width is illustrated in Figure 26, in which

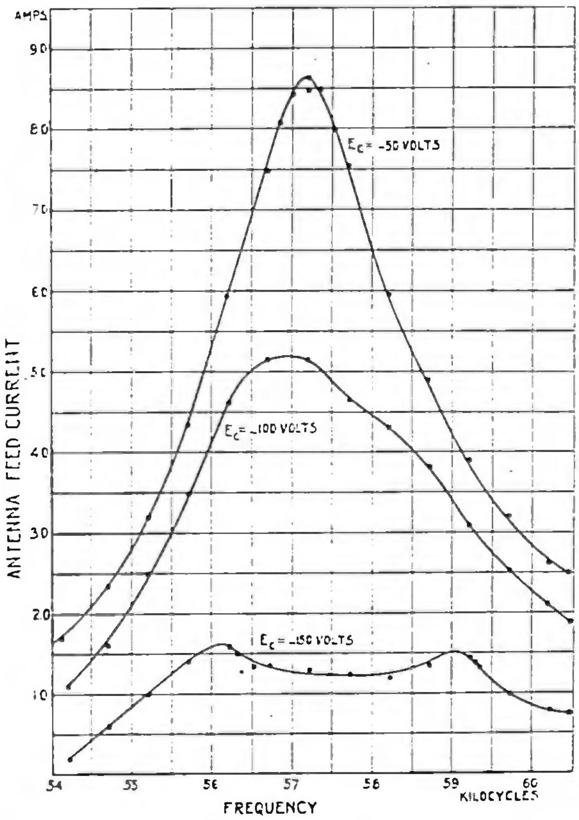


FIGURE 26—Effect of Tube Impedance on the Transmission Characteristic at Low Amplitudes

three curves for different values of grid polarizing voltage are shown. The upper one is for $E_c = -50$ volts. The tube impedance is therefore lower than usual. The middle and lowest curve corresponds to -100 and -150 volts, respectively. The formation of a second maximum at 59 kc. may be traced. Even in the upper curve this tendency can be seen, but not until the tube impedance is that corresponding to the lowest curve does the new maximum become equal to the first. It will also be noted that the position of the original peak has apparently been shifted to the left.

The characteristics which have just been discussed were taken at low amplitude such that the operation of the amplifier was probably as one of the first class. When the grid input is so large that the grid during a portion of the cycle assumes high positive values and the highest power output is obtained, the characteristic corresponding to the low amplitude curves does not in general have the same shape. This is due to the fact that under such conditions the tube impedance is not constant but depends on the alternating grid and plate potentials as well as upon their relative phase. This is illustrated by Figure 27 in which Curve 1 is for low amplitude and Curve 2 for high.[6] In curve 1 there are tendencies to form maxima at 56 and at 58.5 kilocycles. In passing to Curve 2 the tube impedance at these frequencies becomes much greater than at 57.4 kilocycles because of the tendency for the anode to assume small or negative values when the grid potential is positive.[7]

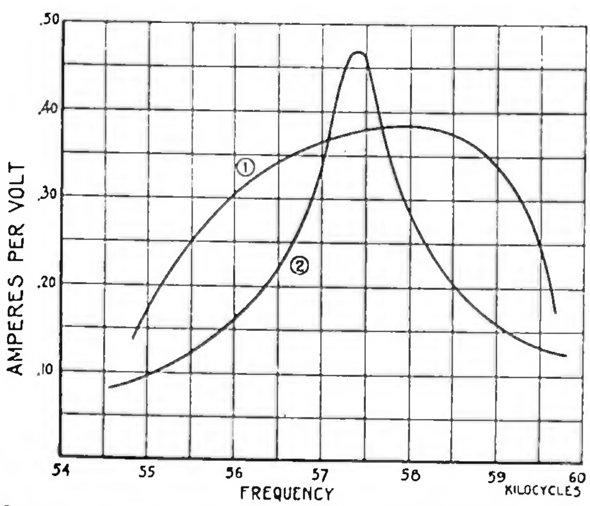


FIGURE 27—Transmission Characteristics. 1. Low Amplitude. 2. High Amplitude

[6] This figure should not be compared quantitatively with others in this paper since it is for a different circuit adjustment.

[7] In speaking of the "impedance" of a tube operating as a third class amplifier, we are thinking in qualitative terms only. Tube impedance does, of course, have a real and useful significance for an amplifier of the first class, but for the third class great care must be taken lest we beguile ourselves into thinking that we are talking about a constant. This mistake, however, is often made.

In Figure 28 is plotted the antenna current as a function of grid input, the frequency being constant at 57.2 kc. Altho this is not a straight line, as is desired for perfect reproduction, it is nevertheless a fair approximation to this up to the knee of the curve. This will be seen by comparison with the dotted line. The problem of obtaining a straight amplitude characteristic is one which is not met in building an ordinary telegraph transmitter. This is because only two amplitudes are of interest, viz., maximum and zero,[8] Hence, it is somewhat more difficult in telephony to obtain the best efficiency because the grid polarizing potential must be less than the value which, in the absence of alternating grid input, reduces the anode current to zero.

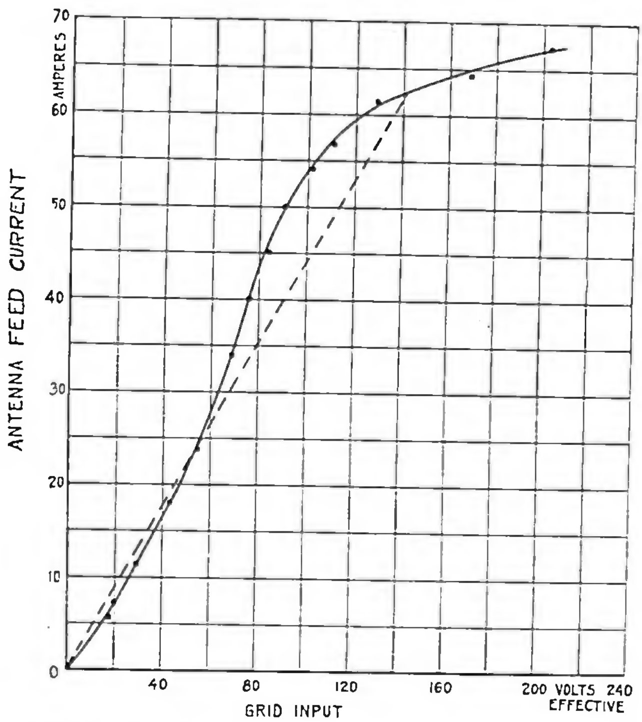


FIGURE 28—Input-response Curve at Constant Frequency

It has been mentioned that in an output circuit such as has been described, the impedance at points in the transmission band may be very high. This fact results in one advantage and one disadvantage. The advantage is the widening of the input-response-frequency characteristic. This has been discussed above. The disadvantage results from the fact that the widening is accomplished only at the expense of a diminished factor of

[8] This statement should not be taken to include a telegraph repeating system which receives and retransmits a signal without relays.

safety. For with increase of output impedance there is a corresponding, tho not proportional, increase in the alternating component of the anode potential. The result is that during a portion of the cycle the anode becomes negative by a value which may be as much as one-half the voltage of the direct current supply. There is no danger in this, at least under ordinary circumstances; but in the other half of the cycle, since the wave is symmetrical, the potential is of the order of 2½ times the supply voltage. In fact, there have been cases in which even greater potentials have been measured with a peak voltmeter. Hence, if the same factor of safety is to be maintained, a lower supply voltage must be employed and a decreased tube power rating therefore must follow. Thus in Figure 29 a case is illustrated in which this phenomenon takes place. Note in particular that at a frequency of 59.5 kc. the alternating peak is 15 percent more than the supply voltage. This difference may be increased by augmenting the grid input voltage.

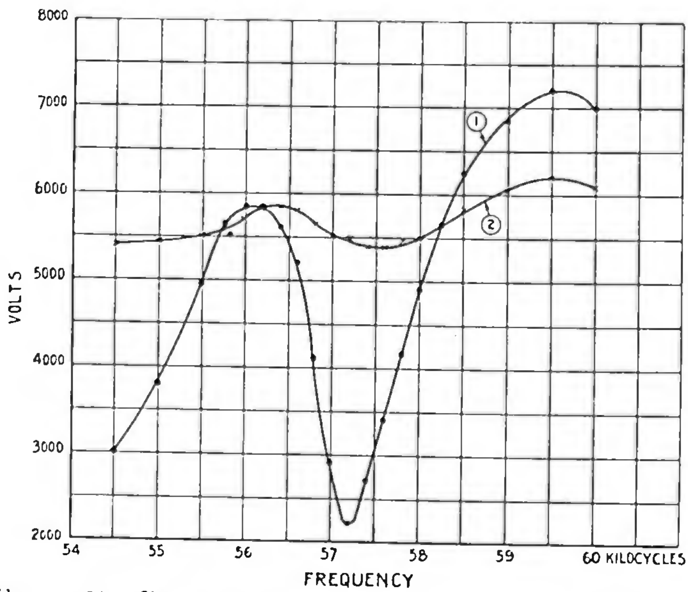


FIGURE 29—Curves Illustrating the Variation in Alternating Anode Voltage When Working Into an Output Impedance Having a Characteristic Similar to That Shown in Figure 24. Constant Grid Input Voltage. 1. Alternating peaks. 2. Supply voltage as read on direct current voltmeter

A further disadvantage in permitting the anode potential to assume negative values during a part of the cycle is that this is usually accompanied by a sudden increase of harmonics. The reason, of course, is that in this interval there is no anode current, and the abrupt changes in current at the beginning and end of the period result in strong harmonics of a fairly high order.

These may, of course, be prevented from penetrating to the antenna by suitably designed circuits.

It has been mentioned above that these impedance peaks may be so pronounced as to cause trouble. Readjustment of the inductance, capacities, and resistances of the circuit will, of course, remedy this difficulty, but such changes have the effect of narlowing the input-response-frequency curve. One method is to insert resistance in the primary circuit. This will discriminate against the peak frequencies because the corresponding currents in the primary circuit exceed those for frequencies at which the impedance is low. However, the reduction in the peak impedance results in a narrower transmission band and a less efficient circuit. If the reduction is accomplished by changing the inductances and capacities, the effect on the transmissions band is the same. In other words, if the antenna resonance band-width is less than the requisite transmission band-width the impedance peaks are essential to the attainment of increased band-width. Hence there must be a compromise between power output and transmission band-width. The best remedy is to remove the difficulty at the place where it is introduced, that is, in the antenna. This would require increasing the capacity in proportion to the increase of band-width desired.

The Anode Direct Current Power System

Before describing the rectifier actually employed it may be well to state some of the considerations involved in supplying direct current to the anodes for telephone purposes. There are at least three important general requirements which should be met by such a source of direct current, namely,

1—Small ripple.

2—Low impedance of the source to currents generated in the load, unless such currents are purposely impeded as in the Heising system of modulation.

3—Reasonably good regulation.

The relative importance of these desiderata depends upon the system of telephony used. This will be discussed later.

For this undertaking a source of direct current at 10,000 volts capable of delivering 200 kilowatts or more was required. This was obtained from the three-phase sixty-cycle power supply by means of thermionic rectifiers. Two-element copper anode tubes are employed as the rectifying elements. These are the same as the amplifiers with the grid omitted. All the advantages secured by employing water-cooling in connection with the radio power tubes are given to the rectifiers by a similar construction.

The power supply at Radio Central Station is three-phase sixty cycles at 22,000 volts. A six-phase rectifier was employed. The circuit is shown in Figure 30. It will be seen that the six

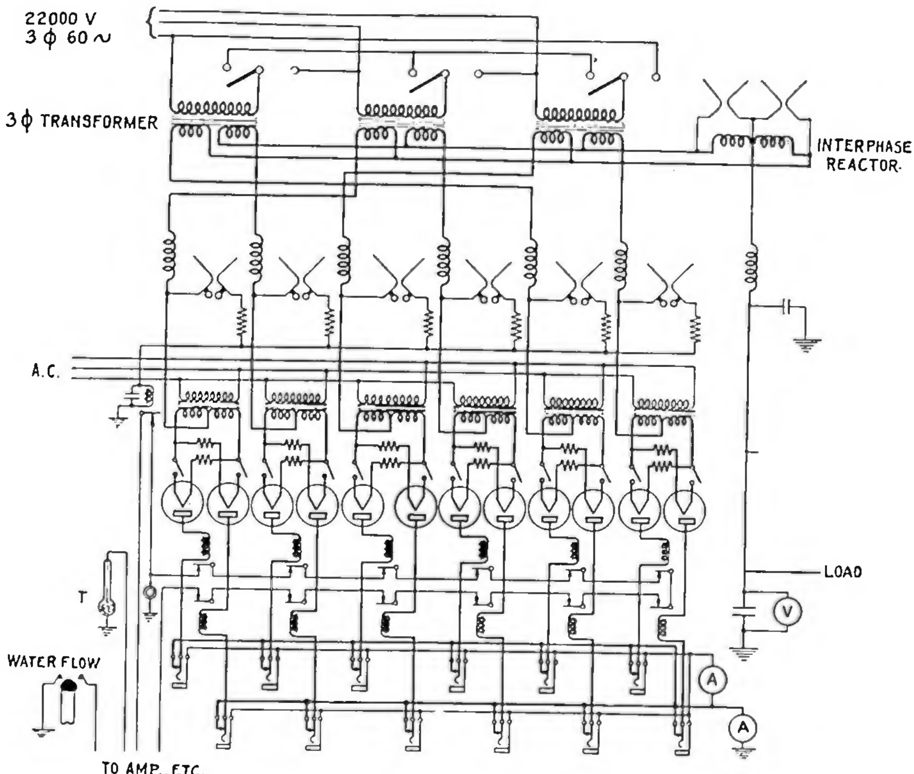


FIGURE 30—Schematic of Six-phase Rectifier Circuit

phases are connected in two groups, each a three-phase star. The neutrals of these stars are joined by an interphase transformer or reactor having a center tap from which the load is taken. The potential from these two neutrals to earth, besides having a direct voltage component, contains frequencies of 180 cycles (the third harmonic of 60 cycles) and integral multiples of 180. It is easily seen that in a symmetrical system the corresponding components of the two stars are equal for the even multiples and opposite for the odd. Since the voltage of the mid-point of the reactor is the average of those of the two ends, the components 180, 540, and so on, do not appear in the output while the 360, 720, and so on, are present with values the same as in each star. The resulting percentage ripple is quantitatively the same as that to be expected in a simple six-phase system. The even harmonics of 180 cycles can be reduced by the use of an inductance in series with the load, as shown in the diagram.

The advantage of the interphase reactor is therefore not to be sought in any marked effect on the ripple. Its usefulness results from its action in lengthening the time when current flows thru the tubes. Among the advantages gained by its incorporation in a six-phase system are the lower thermionic emission required for a given output, less power dissipation in the anodes and better regulation. There are certain disadvantages, but they will not be discussed now.

If the rectified output from a group of phases is made constant, as for example by suitable chokes, and if during a part of the cycle one of the phases carries the whole load, it is well known that the wave form of each phase has a flat top. The statement that the wave form is rectangular is, however, incorrect. As is to be expected, it more closely resembles a trapezoid. In the oscillograms of Figure 31, we have the actual wave form of the potential of the filaments with respect to the anodes for a pair of rectifiers connected directly in parallel forming one of the six phases of the system shown in Figure 30. Below it is the approximately trapezoidal current through these tubes. From the oscillogram it may be found that the maximum current is slightly more than three times the average, as we should expect. The flow of current lasts 0.46 cycles instead of 0.33 cycles as it would were the transformer and tube impedances negligible. The maximum voltage across the tube is about 2.1 times the average, which also is in accordance with theory.

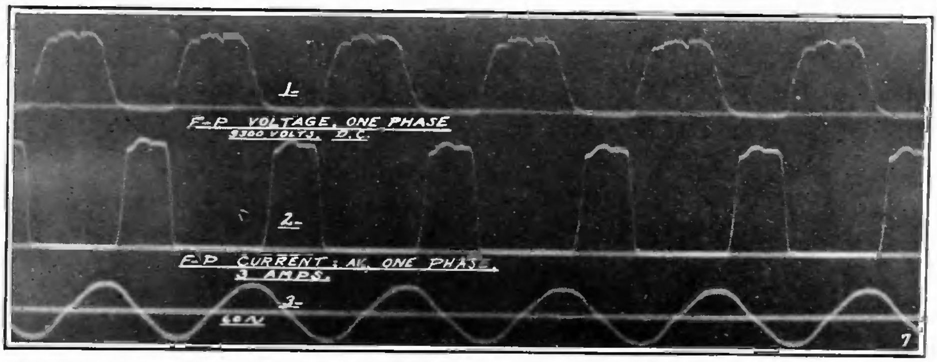


FIGURE 31—Oscillogram Showing Current and Voltage for the Rectifier Tubes in One of the Six Phases

The filter consists merely of a series inductance in the neutral and a large capacity in shunt with the load. The ripple frequencies in the output of a balanced system of ϕ phases are multiples of ϕf, where f is the frequency of the power supply. Their approximate amplitudes are readily found from the expression[9]

[9] A similar expression has been derived by D. C. Prince and probably by others who have worked with polyphase rectifiers. See this journal, October, 1922.

$$\text{ripple voltage} = \frac{2}{\phi^2 n^2 - 1} \times \text{average voltage}.$$

This expression refers to the voltage applied to the filter. It does not apply under some conditions of light load when the current in the neutral is interrupted during a portion of the cycle. For any assumed filter design the percentage of ripple applied to the load may thus be readily calculated. This procedure was employed in the design of the filter for the single-phase rectifier previously described and for the six-phase source which we are now considering. The method has been found to be of value. In the present case the 360-cycle ripple frequency is predominant. Its amplitude as applied to the filter is 5.7 percent. The filter employs an inductance of one-half henry and a capacity of three microfarads. With these constants the 360-cycle component is reduced to about 0.8 percent, while still higher frequencies are attenuated to values which are negligibly small for most purposes.

The general question as to how much ripple is permissible in the power supply of the last stage has considerable general interest, particularly since the requirements of the ordinary system and those for single-sideband transmission differ so radically. In the former the disturbance manifests itself primarily as a continuous note of the same frequency. Its presence is particularly objectionable during lulls in the modulation. In the latter system there is no effect in the absence of modulation, since there is then no radio frequency to act as a carrier. It is only during modulation that the disturbance appears, and then it is due less to the ripple tone itself than to components the frequencies of which are those of modulation plus and minus that of the ripple. It has been found experimentally at Rocky Point that with the six-phase rectifier the presence of the normal ripple in the plate supply was not a serious matter. Calculations indicate that even with a four-phase system this distortion would be permissible for many purposes, but that one of only three phases would not be satisfactory without a filter.

The second of the general requirements enumerated above relates to the impedance which the power source presents to the flow of the low frequency currents generated in the amplifier. It has been indicated that this consideration is of no importance in the case of a radio frequency amplifier of the first class, since for such there are no low frequency components in the anode current. When, however, we pass to class two and particularly to class three this question becomes one which must be considered, for unless precautions are taken, distortion may be introduced and abnormal voltages may be produced in certain parts of the system. Since in the case of single-sideband telephony the power source ripple is not as troublesome as in the usual system, investigation may prove that it is best to reduce or omit certain elements of the filter if they are such as to increase the impedance to load circuit currents. In estimating this quantity in the case of a rectifier, we are at once confronted by the complication that it depends upon the load, on account of the curvature of the tube characteristics, and that it differs in different parts of the cycle of the supply current, because the number of phases carrying the load is not constant. However, the order of magnitude of the impedance may be ascertained by assuming simple conditions. For instance, in the six-phase rectifier discussed it might be postulated that one and only one of the phases of each delta carry current at a time. The tube impedance would be fixed by the fact that each of these phases would then carry half of the load. It is desirable that this impedance be small compared with the resistance of the load into which the rectifier delivers power at all frequencies that are apt to arise in the amplifier.

The above-mentioned impedance requirement is usually easier to meet in the system employing carrier and both sidebands than in the single-sideband system. In the discussion of amplifiers of the third class as applied to radio telephony, it was shown that in the case of the former the predominant frequencies generated in the amplifier are those of the voice signal itself, and this is strictly so if the anode direct current is proportional to the effective grid input. Hence, it is not far wrong to say that large currents the frequencies of which are lower than those of the signal are not present. There is thus a fairly definite lower limit below which the filter impedance may be high. On the other hand, with a single-sideband the low frequency anode currents are determined by differences of speech frequencies and therefore the impedance must be low for all from zero to a frequency numerically equal to the band width transmitted.

Of the three general requirements stated above, the last relates to regulation. When a third class amplifier is used in the ordinary radio telephone system, the fluctuations in the direct current load due to changes in modulation are usually not very large. The opposite is true when the carrier is eliminated, and therefore the decrease in voltage which results when the load is increased should be made small for obvious reasons. It is therefore important in designing a rectifier system for this purpose to use tubes of low resistance, to make the transformer leakage reactance as small as permissible, and to employ means which allow the currents in the various phases to flow for a large fraction of a cycle. It is usually desirable in the design of the transformer to make the coupling between the whole of the primary and each half of the secondary as close as possible.

A photograph of the six-phase rectifier unit is shown in Figure 32. Twelve two-element tubes, two in parallel for each phase, are employed. Their anodes are mounted in jackets which are connected thru means for measuring the anode current and thru protective relays to earth and are hence substantially at earth potential. This practice has been followed in all the rectifiers employing water-cooled tubes on account of the simplification of design that results. The large individual hose coils which would otherwise be necessary are dispensed with. The jackets, meters and protective relays need not be mounted on high voltage insulators. It becomes necessary, of course, to provide separate filament transformers for each phase, and insulation between primary and secondary must be increased to withstand the higher voltages. However, the problem of obtaining suitable air-cooled transformers is not a serious one when the direct potential required is 15,000 volts or less. The filament transformers are mounted directly over the rectifier tubes. A thermometer for measuring the outlet temperature is mounted above the glass window in the front of the set. Below is a board with twelve jacks, one corresponding to each tube. When the plug is inserted the corresponding anode current is read on the small ammeter at the right. Under these jacks are the twelve relays which afford protection against an excessive load in any tube.

Above the rectifier set, Figures 14 or 32, can be seen six "pancake" choke coils. Their purpose is to prevent injury to the main transformer as a result of surges, such as might be set up by the failure of a rectifier tube. The six spark gaps are in series with resistances consisting of short pieces of hose containing a dilute solution of potassium nitrate. One terminal of each gap is connected to the filaments of one phase. The other terminal is connected to earth thru the resistance and a relay. The latter is common to the six gaps. These spark gaps and the relay are so adjusted as to operate when an excessive voltage surge is set up. The opening of the relay breaks the control circuit and shuts off the power. The objection may be raised that such an arrangement will result in frequent interruptions of service which might be avoided by the use of lightning arresters which relieve the surge and then open the circuit. Experience, however, has shown that interruptions due to this are rare and that when they do occur they are usually accompanied by a disturbance elsewhere in the system which of itself would be sufficient to cause an interruption.

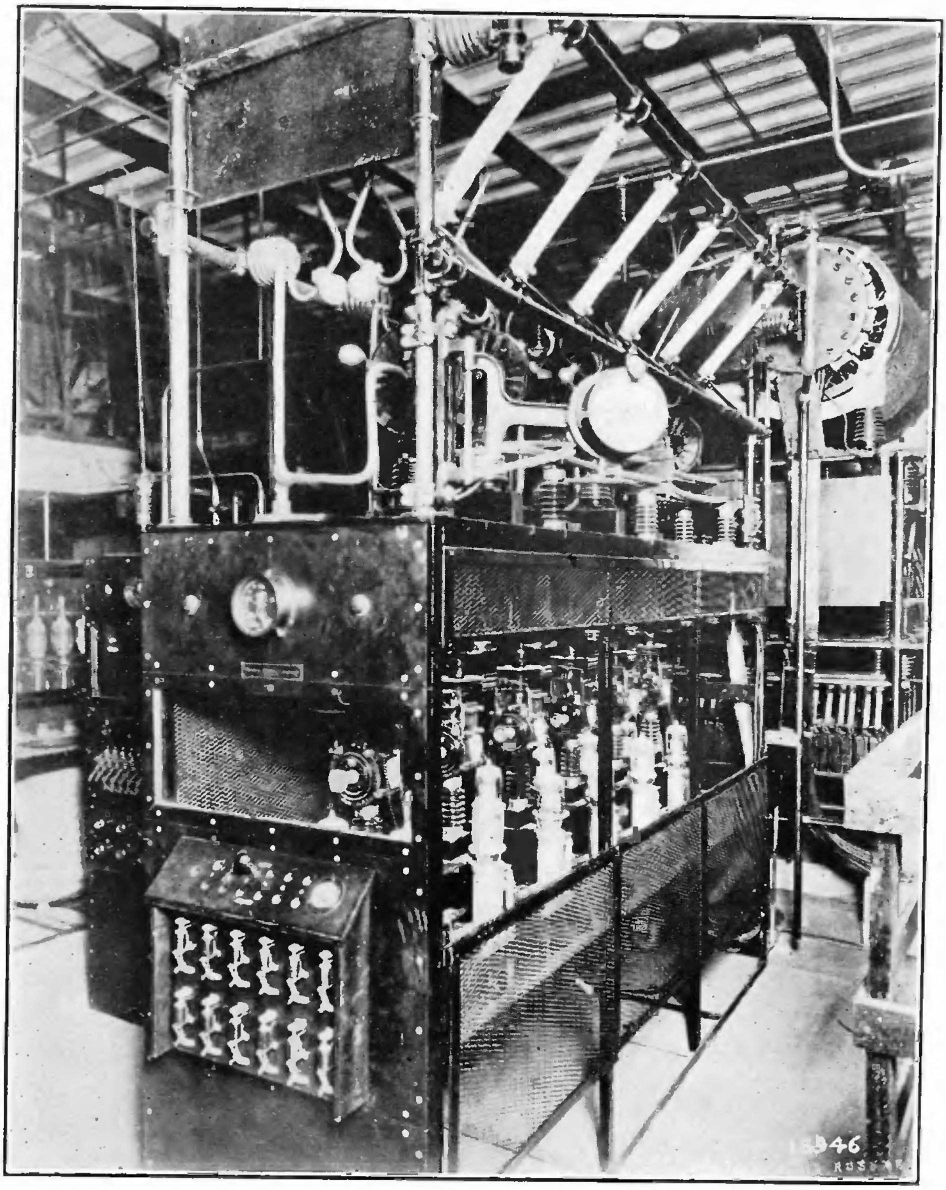


FIGURE 32—Six-phase Rectifier

Figure 33 shows the three-microfarad smoothing condenser, capable of withstanding 17,000 volts. It is made up of about 2,600 standard paper telephone condensers.

In Figure 34 is shown the 300 kilovolt-ampere 22,000-volt power transformer. The six terminals of the three-phase primary are brought out separately to permit of either delta connection for normal, or star for reduced potential. There are seven bushings for the secondary, one for each phase and one for the neutral.

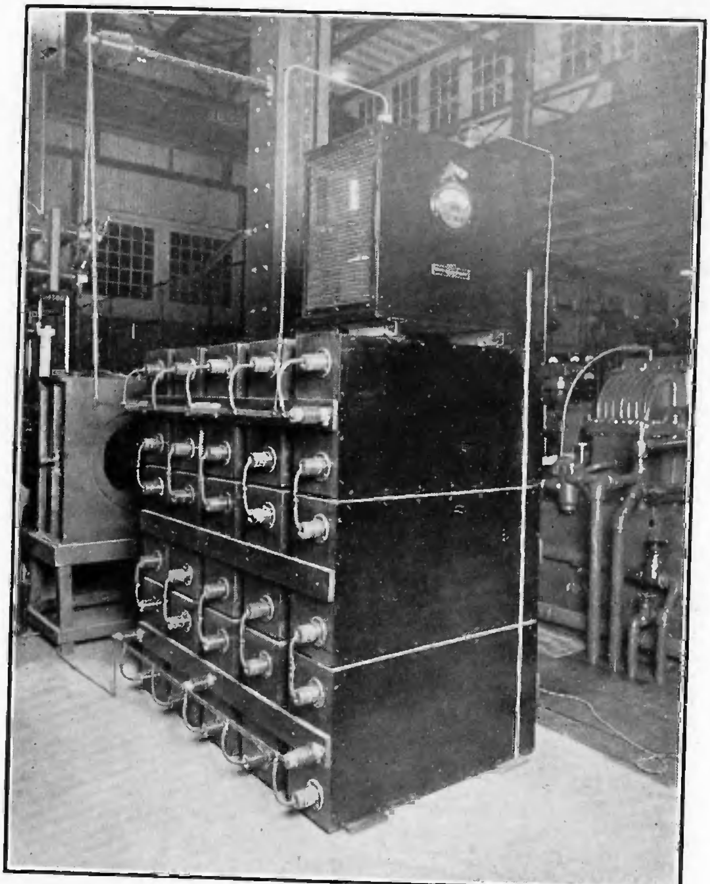


FIGURE 33—3-microfarad Smoothing Condenser

OVER-ALL SYSTEM

The complete amplifier system is shown in Figure 35. This includes the power apparatus and the control circuits. Figure 36 is an overall frequency-response characteristic for the entire power amplifier beginning with the input circuit of the first stage and ending with the total antenna current. The curve was taken for the condition of constant input voltage applied to the first stage at the maximum signal amplitude.

For purposes of comparison, the antenna resonance curve is shown dotted. It will be noted that the transmission band width of the antenna alone is about one-half that of the whole combination. This is a good example of the possibilities of band width improvement by properly proportioning circuits. However, it will be recalled from the discussion of the output circuit, that such expansion of band width is accomplished at the expense of the vacuum tube capacity. Therefore, the kilovolt-ampere rating for the tubes must be somewhat greater than the maximum kilowatt output. Since the antenna systems for trans-

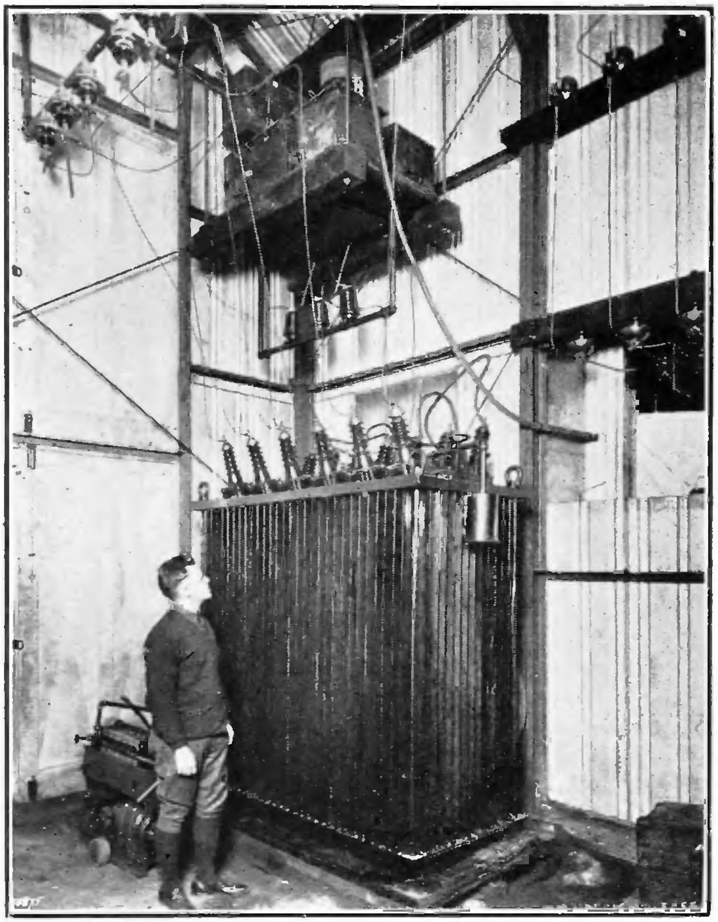


FIGURE 34—Six-phase 300-kva. 22,000-volt Transformer and Filter

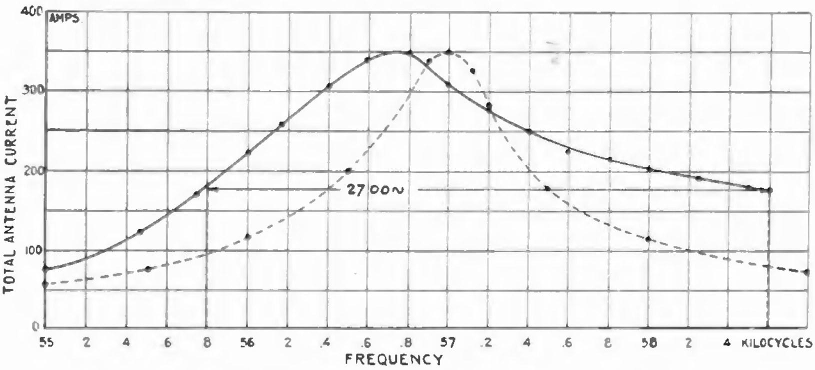


FIGURE 36—Over-all Transmission Characteristic. The resonance curve of the antenna is shown in dotted lines

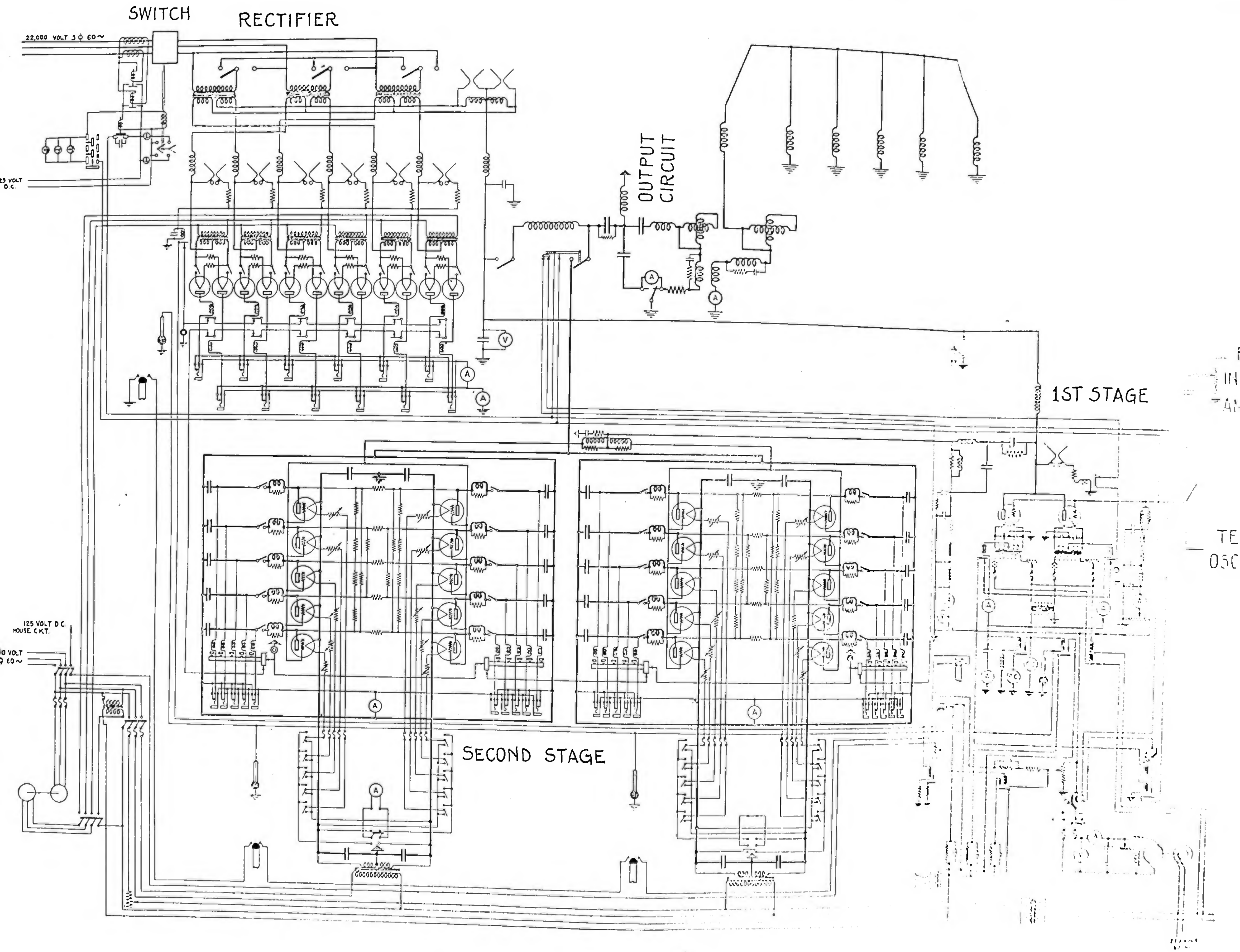


FIGURE 35—Schematic of Complete Rectifier and Power Amplifier System

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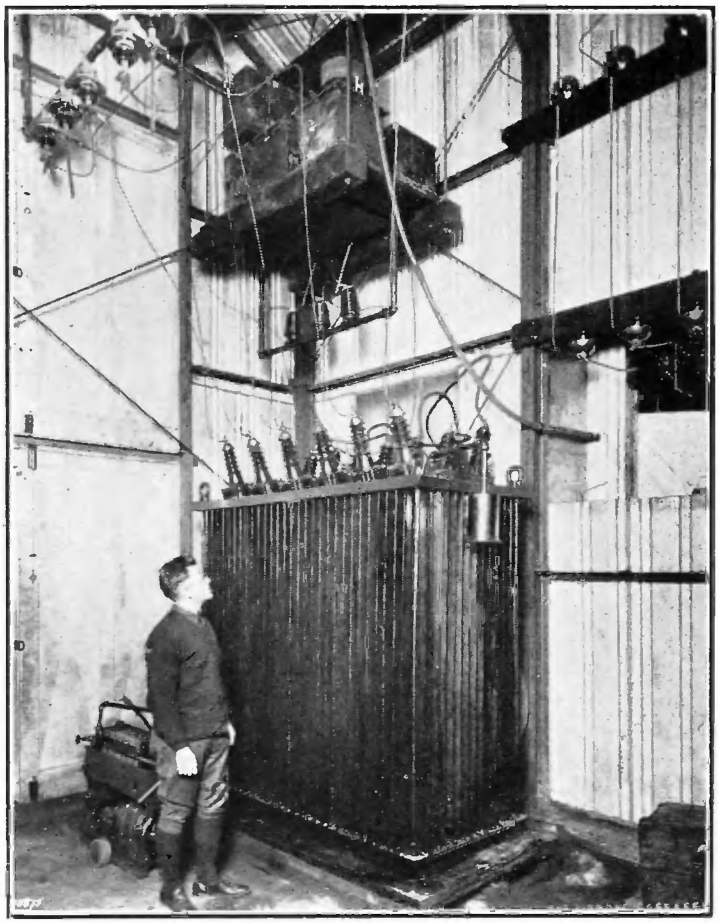


FIGURE 34—Six-phase 300-kva. 22,000-volt Transformer and Filter

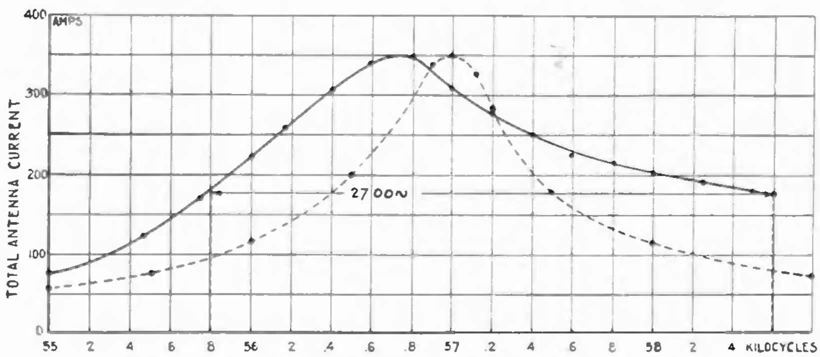


FIGURE 36—Over-all Transmission Characteristic. The resonance curve of the antenna is shown in dotted lines

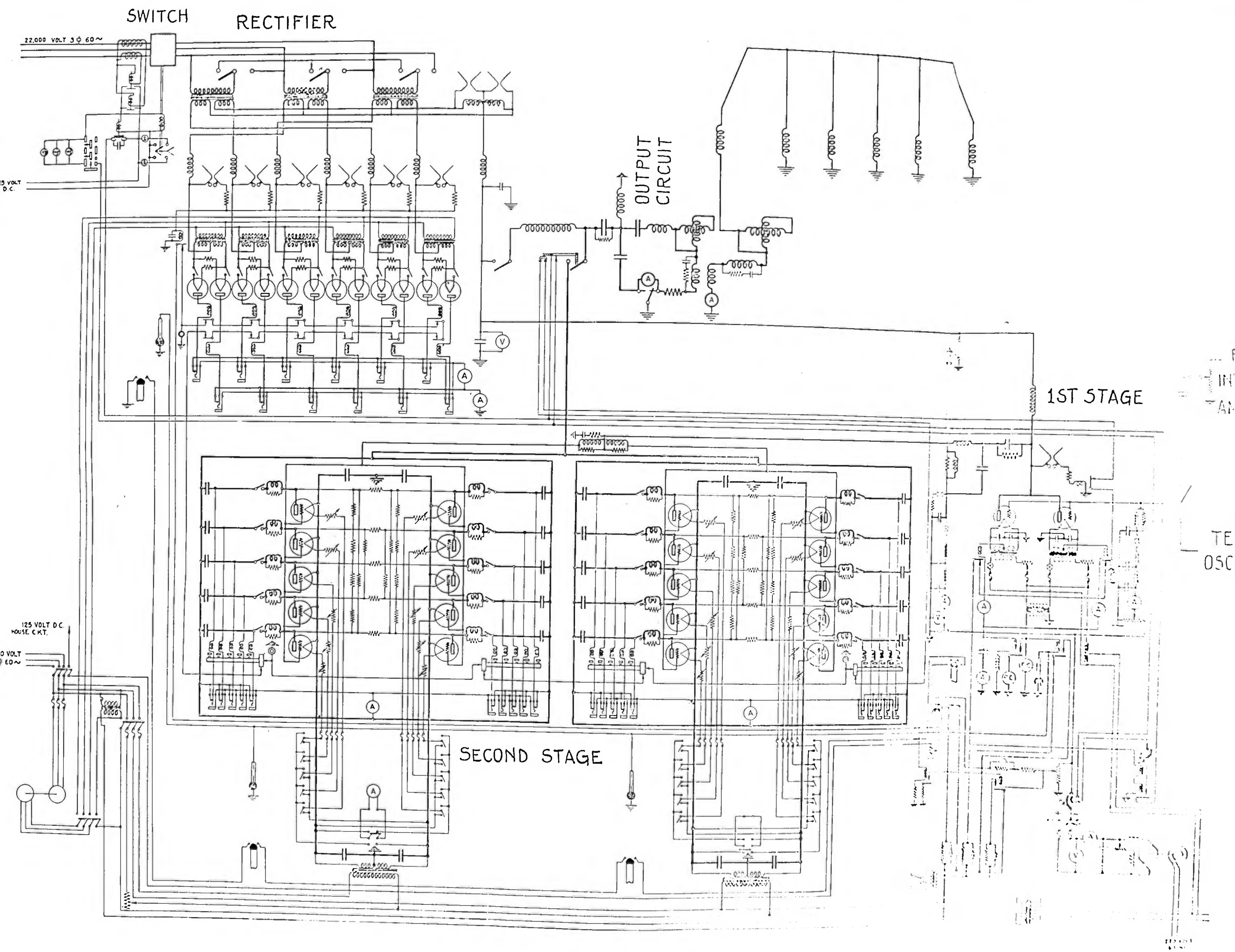
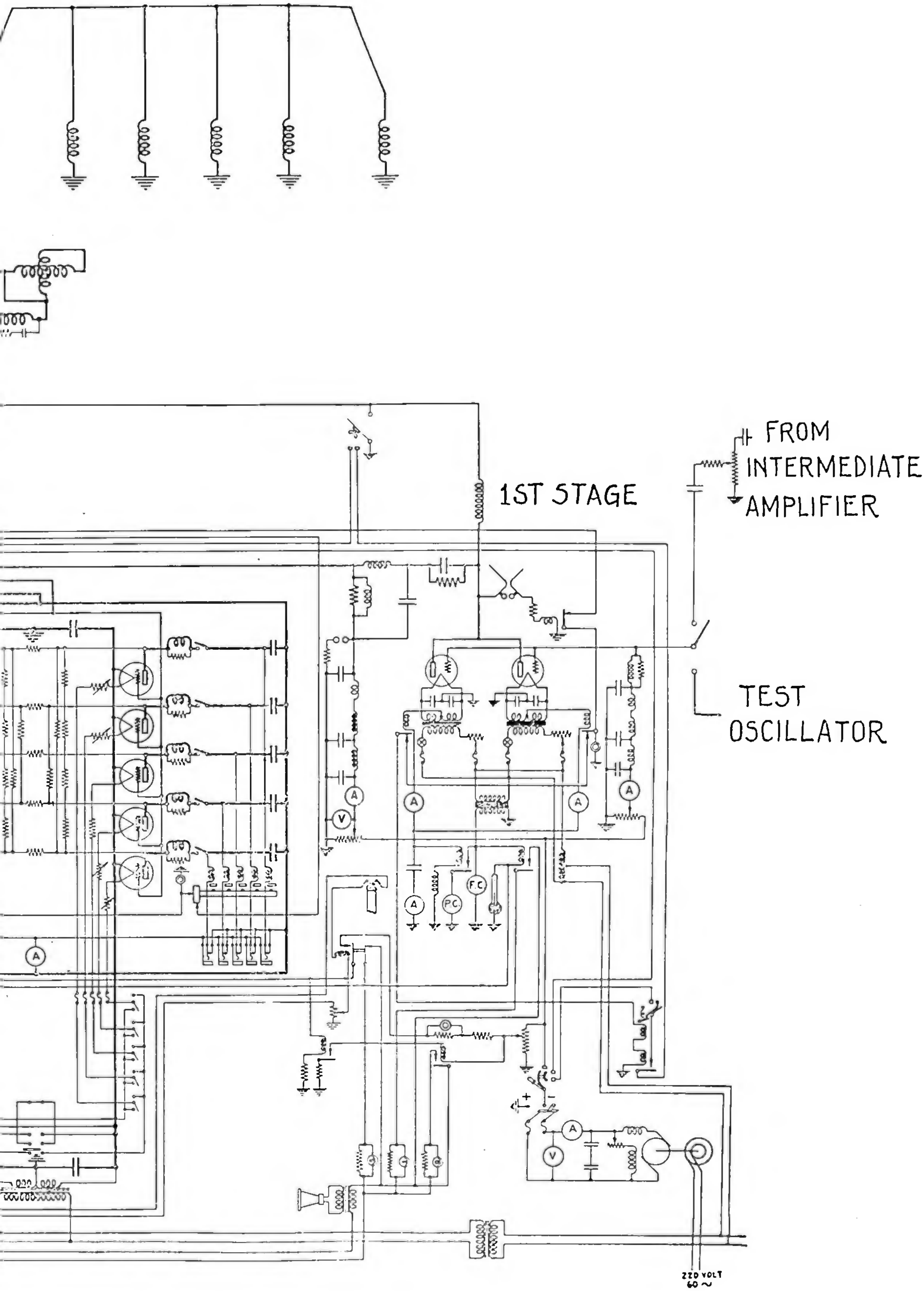


FIGURE 35—Schematic of Complete Rectifier and Power Amplifier System



r and Power Amplifier System

oceanic telephone stations are expensive structures, it is obvious that for a specified transmission band width the most economical system will be one in which tube replacements and power costs are balanced against antenna carrying charges.

In closing, the writers wish to acknowledge the valuable engineering assistance of Messrs. H. R. Knettles, J. P. Schafer, M. E. Fultz, and E. J. Sterba, who participated in the design, construction, and experimental operation of the system. We are also indebted to Mr. C. W. Hansell, of the Radio Corporation of America, whose experience with high power radio plants made his many suggestions of great value to us during the construction period. We are also indebted to the operating personnel at Radio Central station for their excellent and whole-hearted co-operation thruout the work.

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

June 7, 1924.

SUMMARY: The paper describes the development of a 150-kilowatt (output) radio frequency amplifier installation built for trans-atlantic telephone tests. The characteristics of the single-sideband eliminated-carrier method of transmission are discussed with particular reference to its bearing upon the design of the power apparatus. A classification of amplifiers is proposed in which there are three types distinguished from each other by the particular portion of the tube characteristic used. The water-cooled tubes employed in these tests are briefly described, special consideration being given to their use in a large installation. The system is then shown in outline by means of a block diagram, the elements of which are subsequently discussed in greater detail. The theory, electrical design, and mechanical construction of the last two stages of the amplifier are outlined, including the output and antenna circuits. Means employed to prevent spurious oscillations are described. The method used in increasing the transmission band width to a value much greater than that of the antenna is explained. The power requirements of a single sideband installation are outlined and a description of the six-phase rectifier used as a source of high potential direct current is given, together with a brief theoretical treatment of its operation. Circuit diagrams, photographs, and a number of characteristic curves are discussed.

RE-RADIATION FROM TUNED ANTENNA SYSTEMS*

By

Henry C. Forbes

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Introduction

A tuned receiving antenna which is in the field due to a distant transmitting station, produces, by reaction, disturbances in the magnitude and direction of that field in the immediate vicinity of the receiving antenna. These reactions become important in studies of re-radiation and of the effects which they produce upon nearby coil antennas used for direction-finding purposes. The following investigation was undertaken to determine the magnitude and characteristics of such reactions for cases of reception wherein local oscillation does not occur. The results have led to a rather simple method of measurement of the equivalent height of an antenna system.

Theoretical Characteristics

Radiation Formula

It has been shown by J. H. Dellinger[1] that the vertical component of the field strength at the earth's surface at any point due to a current flowing in a flat-top antenna is:

$$H=\left[\frac{2\pi}{\lambda}\frac{hI}{10\,d}+j\frac{hI}{10\,d^2}\right]a \qquad (1)$$

where

H = field strength
h = antenna height
d = distance from antenna
λ = wave length
I = antenna current in vertical portion
a = absorption factor.
$j=\sqrt{-1}$

*Received by the Editor, December 5, 1924.

[1] "Principles of Radio Transmission and Reception with Antenna and Coil Aerials," J. H. Dellinger, S. P. of Bureau of Standards, Number 354, 1919.

The field strength is expressed in gilberts per centimeter when I is in amperes, and all lengths are in centimeters. Effective values of H and I are used in this paper.

The absorption factor, a, is a function of the wave length, the characteristics of the earth's surface, the season of the year, and so on, an empirical value given by L. W. Austin[2] for day-time transmission over salt water being:

$$a = \varepsilon^{-0.000047 \frac{d}{\sqrt{\lambda}}} \tag{2}$$

The first term of equation (1) represents the radiation field, and the second term the induction field, due to the current in the vertical portion of the transmitting antenna. At small distances from the antenna the induction field predominates, and at large distances the radiation field predominates, the two fields being equal at the distance $\frac{\lambda}{2\pi}$.

This field, equation (1), will induce a voltage in a receiving antenna:

$$E = c\, h_r\, H\, 10^{-8} \tag{3}$$

where

E = induced voltage
c = velocity of propagation of field
h_r = height of receiving antenna

The current which will flow in the receiving antenna at resonance is then:

$$I_r = \frac{E}{R} \tag{4}$$

where

R = effective resistance of receiving antenna.

These expressions have been derived by Dellinger on the following assumptions:

(1) The current distribution in the vertical portions of both transmitting and receiving antennas is uniform.

(2) The flat-top contributes nothing to the field at a distance from the antenna.

(3) The earth's surface is non-conducting, that is, no image of the antenna is formed.

(4) The distance from the antenna is large compared with the antenna height.

Under practical conditions, the current is not strictly uniform thruout the vertical portion of the antenna, particularly in short wave antennas where the flat-top is small. The fact that

[2] "Quantitative Experiments in Long Distance Radio Telegraphy," L. W. Austin, "Bulletin Bureau of Standards," 7, October, 1911, page 315.

the earth is a partial conductor, and a partial image may therefore be formed, tends, as pointed out by Dellinger, to offset the first discrepancy. It is impossible, however, to take account mathematically of the effects of masts, trees and buildings upon the radiating properties of the antenna, and these factors introduce some uncertainty into calculations.

In practice, the fact that the current distribution is not uniform is taken into account by assigning an effective height to the antenna, this height being defined[3] as the product of the maximum height of the antenna above the ground, and the form factor. The form factor is defined[3] as the ratio of the average value of the current thruout the vertical portion of the antenna to the maximum value of the current in that portion. By using the effective height in the radiation formulas, however, we have still disregarded the effects of any nearby objects upon the field strength, and also the effects due to the fact the earth's surface may be a partial conductor and hence may form a partial image of the antenna.

It seems desirable, therefore, to define a term—the *equivalent height* which may be obtained by measurement, and which will take into account all of the above-mentioned factors. The *equivalent height* of an antenna will be defined as the height of an ideal antenna having a current equal to that at the base or anode of the actual antenna. The ideal antenna is considered as a vertical antenna with a uniform current distribution, erected on a non-conducting surface with no masts or other nearby structures. The equivalent height, which will be designated by h', is then that height, which, if substituted in the above formulas derived for the ideal antenna, will make the observed values of field strength agree with the calculated values. If this height is determined by observation near an antenna, the field strength at any point may be determined by calculation if the attenuation due to the absorption by the earth's surface is known. In an antenna system having directional properties, the observed equivalent height will be different in various directions, whereas the effective height as defined above does not determine this property. The observed equivalent height may be greater than equal to or less than the effective height, depending upon the magnitude and nature of the disturbances produced by the flat-top, the semi-conducting earth's surface, and by nearby absorbing or re-radiating structures. The difference between the equiva-

[3] The Institute of Radio Engineers—"Report of the Committee on Standardization for 1922," pages 10 and 12.

lent and effective heights in any particular case will be a measure of the effects produced by these factors.

These same considerations also apply to the receiving antenna, and it is necessary to use the equivalent height in the equations for the total induced voltage.

Inasmuch as this discussion concerns particularly the field strength in the immediate vicinity of the antenna, it is now proposed to find corrections for the above radiation formula, equation (1), when the distance from the antenna is not large compared with the antenna height.

Field Strength Near An Antenna

At short distances from the antenna, the induction field predominates, as previously mentioned, and so we may calculate the correction factor for the induction field and assume that it applies also to the radiation field without serious error.

Case I. Vertical Antenna, Uniform Current Distribution

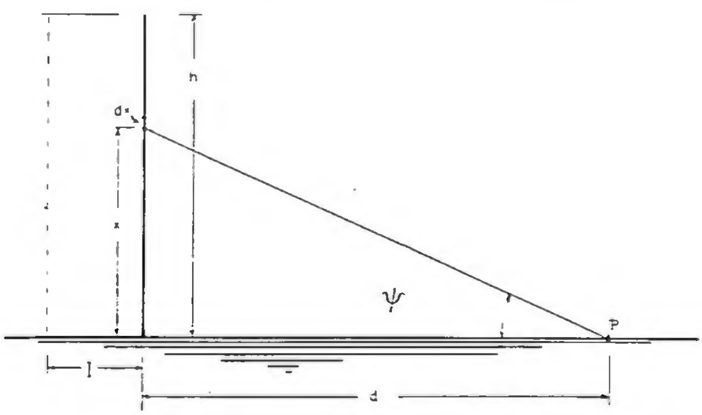


Figure 1—Vertical Antenna—Uniform Current Distribution

At the point P:

$$dH = \frac{I \cos\psi \, dx}{10(x^2+d^2)}$$

But $$\cos\psi = \frac{d}{\sqrt{x^2+d^2}}$$

Hence $$H = \frac{I d}{10}\int^h \frac{dx}{(x^2+d^2)^{3/2}}$$

or $$H = \frac{I h}{10 d^2} \cdot \frac{d}{\sqrt{h^2+d^2}}$$

the correction factor then being:

$$K_1 = \frac{d}{\sqrt{h^2+d^2}} \tag{5}$$

When d is large compared to h, K_1 becomes unity, and the expression for H reduces to that given for the induction field in equation (1). This correction is the equivalent to the form factor previously defined.

CASE II. VERTICAL ANTENNA, LINEAR CURRENT DISTRIBUTION

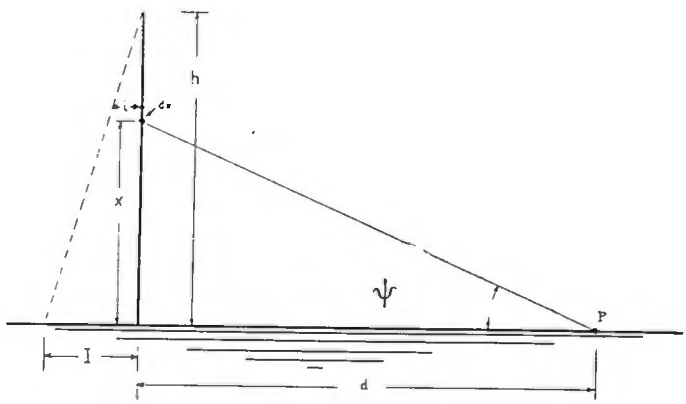


FIGURE 2—Vertical Antenna—Linear Current Distribution

At the point P:

$$d\,H = \frac{i \cos \psi \, d\,x}{10(x^2+d^2)}$$

But
$$\cos \psi = \frac{d}{\sqrt{x^2+d^2}}$$

$$i = \frac{h-x}{h} I$$

Hence
$$H = \frac{I\,h}{10\,d^2} \int_o^h \left[\frac{h}{(x^2+d^2)^{3/2}} - \frac{x}{(x^2+d^2)^{3/2}} \right] d\,x$$

or
$$H = \frac{I\,h}{10\,d^2} \cdot \frac{d}{h} [\sqrt{h^2+d^2} - d]$$

The correction factor is then:

$$K_2 = \frac{d}{h} [\sqrt{h^2+d^2} - d] \tag{6}$$

which reduces to

$$K_2 = \frac{1}{2}$$

as d becomes large compared with h.

Case III. Flat-top Antenna, Linear Current Distribution

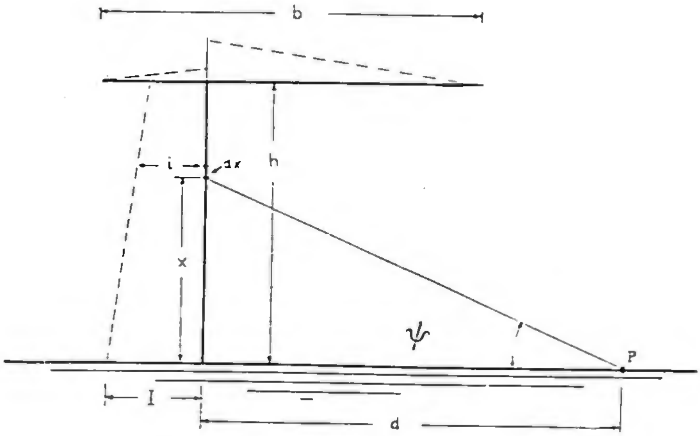


Figure 3—Flat-top Antenna—Linear Current Distribution

At the point P, neglecting the effect of the current in the flat-top:

$$dH = \frac{i \cos\psi \, dx}{10(x^2+d^2)}$$

But $\cos\psi = \dfrac{d}{\sqrt{x^2+d^2}}$

$$i = \frac{h+b-x}{h+b} I$$

Hence $$H = \frac{Id}{10(h+b)} \int_o^h \left[\frac{h+b}{(x^2+d^2)^{3/2}} - \frac{x}{(x^2+d^2)^{3/2}} \right] dx$$

or $$H = \frac{Ih}{10\,d^2} \cdot d \left[\frac{h(h+b)+d^2-d\sqrt{h^2+d^2}}{h(h+b)\sqrt{h^2+d^2}} \right]$$

The correction factor then being:

$$K_3 = d \left[\frac{h(h+b)+d^2-d\sqrt{h^2+d^2}}{h(h+b)\sqrt{h^2+d^2}} \right] \tag{7}$$

which reduces to

$$K_3 = \frac{h+b}{2h+b} \tag{8}$$

as d becomes large compared with h.

Under this condition,

$$\left.\begin{array}{ll} \text{If } b=0, & K_3 = 1/2 \\ \text{If } b=h, & K_3 = 2/3 \\ \text{If } b \gg bh, & K_3 = 1 \end{array}\right\} \tag{9}$$

Distortion of Field By a Tuned Receiving Antenna

Consider a receiving antenna of any type and of any current distribution, which may be replaced by an ideal antenna of height h' with uniform current distribution, the currents at the nodes being the same in both cases. Assume this antenna to be situated in the field from a transmitting antenna which is at such a distance that the field is substantially uniform in magnitude and direction in the immediate vicinity of the receiving antenna. Let H be the effective value of this field. Over a small area in the vicinity of the receiving antenna, H may be represented by a vector the direction of which is at right angles to the line pointing to the transmitting antenna (Figure 4).

This field will induce a current in the receiving antenna (equation (3)):

$$I_r = 3\times 10^{10}\frac{h_r'}{R}H\times 10^{-8} \tag{10}$$

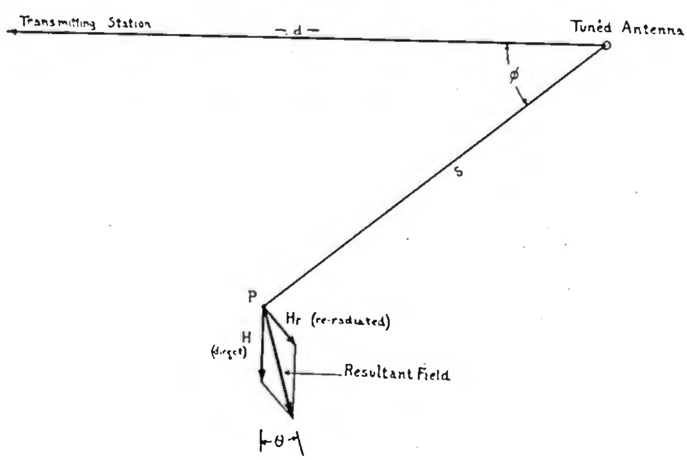


FIGURE 4—Field Distortion Due to Re-radiation

where h_r' is the equivalent height of the receiving antenna. Due to the current flowing in the vertical wires, the receiving antenna then becomes a miniature transmitting antenna, and a secondary or re-radiated field will be set up about it. The vertical component of this field at the earth's surface, and at a distance δ from the receiving antenna will be, by equation (1):

$$H_r = \left[\frac{2\pi}{\lambda}\frac{h_r' I_r}{10\,\delta} + j\frac{h_r' I_r}{10\,\delta^2}\right]K_1 \tag{11}$$

the induction field predominating at points near to the antenna. The absorption factor is of course unimportant for this case. The correction factor, K_1, used for proximity to the antenna is that for a vertical antenna with uniform current distribution, equation (5).

The resultant field strength at any point near to the receiving antenna will be a combination of the direct field, H, with the re-radiated field, H_r, with proper regard to the time and space phase relations of the two components. For points within the distance $\lambda/8$ of the receiving antenna, the two components will be closely in time phase with each other, and we may therefore make the simple space vector combination shown in Figure 4.

If this procedure is carried thru for a number of points in the immediate vicinity of the antenna, the resultant field is as shown in Figure 5, which has been calculated for the values shown. This distortion is similar to that produced in a uniform unvarying field by a wire carrying a direct current.[4]

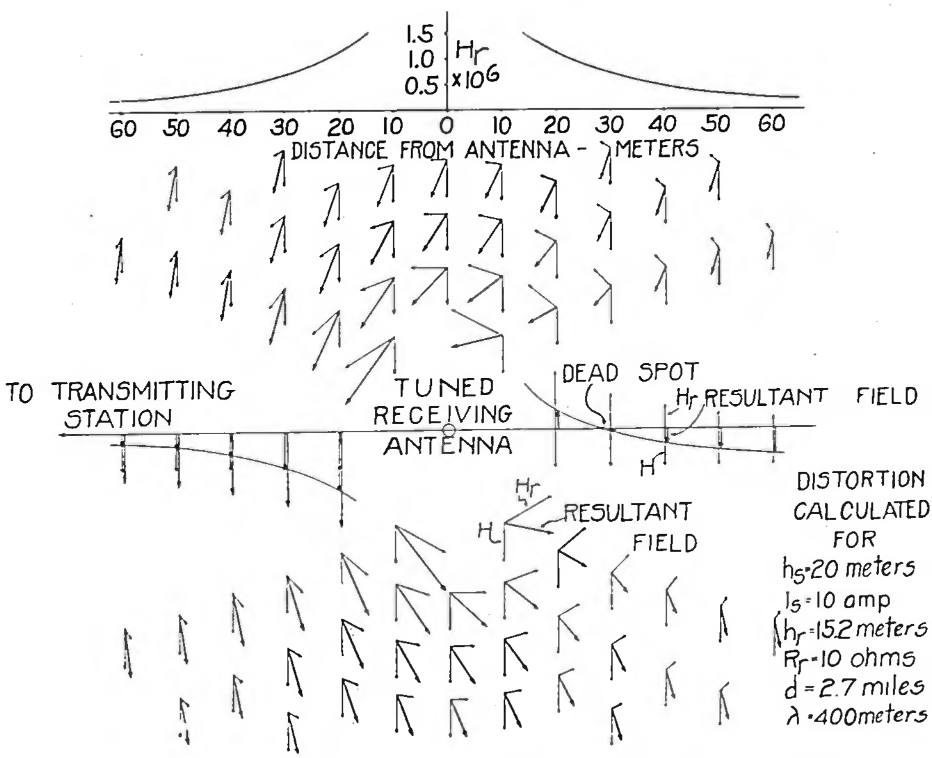


FIGURE 5—Calculated Field Distortion Near a Tuned Receiving Antenna

For points at greater distances from the receiving antenna, the phase relations due to time must be considered. The mathematical expression for the resultant field under such conditions will not be attempted here, but it may be pointed out that at a distance of $\lambda/8$ from the receiving antenna and between it and the transmitting antenna, the field component due to re-radiation

[4] See illustration, Figure XVII, in "A Treatise on Electricity and Magnetism," James Clerk Maxwell. Oxford, Clarendon Press, 1904. Volume II, 3rd Edition.

will be 90° out of phase with that due to the direct field. At right angles to the line of direction to the transmitting station, the components are 90° out of phase at a distance of $\lambda/4$ from the receiving antenna. On the side of the antenna opposite to the transmitting antenna, the two components are always in time phase with one another. The locus of the points of equal time-phase displacements for this case is a parabola, with its focus at the receiving antenna, and its major axis the line of direction to the transmitting antenna.

Characteristics of Field Near a Tuned Receiving Antenna

Observation of Figure 5, calculated for an ideal antenna of the constants indicated, and for distances within $\lambda/4$ from the receiving antenna, leads to several interesting facts. It is seen that in "front" of the antenna the field strength is considerably reinforced, due to the re-radiated component. To the "rear" of the antenna, and close by, the field is entirely due to the re-radiated component, and is therefore opposite in direction to the direct field. As the distance from the antenna in this direction increases, the field intensity passes thru a zero value, and becomes larger in the original direction, always, however, remaining less in magnitude than the original value of the direct field. At all other positions relative to the antenna, the resultant field is displaced at an angle to the direct field, and in general has a magnitude different from the original field.

Directly in the "rear" of a tuned receiving antenna we should then expect to find a position of zero field intensity, or "dead-spot" for the transmitting station to which the receiving antenna is tuned.

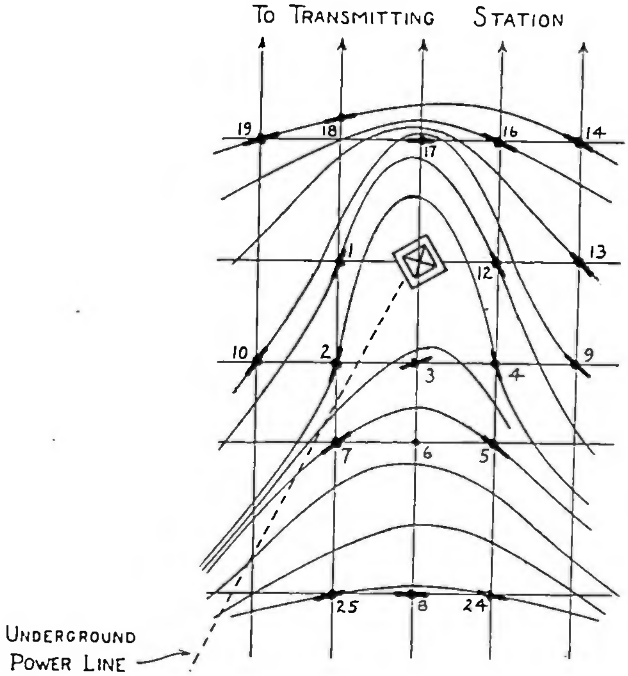
Comparison With Bureau of Standards Tests on Washington Monument

The Bureau of Standards have published[5] the results of tests made to determine the distortion produced by the Washington Monument in Washington, D. C., upon the field from a distant transmitting station. Maximum distortion was found to exist at a wave length of 800 meters, and it was assumed that this was the natural wave length of the monument considered as an antenna. The resultant field at 625 meters was also plotted and is herewith reproduced in Figure 6. It is very similar in general appearance to that calculated above, Figure 5. All distances

[5] "The Radio Direction Finder and Its Application to Navigation," F. A. Kolster and F. W. Dunmore, S. P. of Bureau of Standards, number 428, page 550, 1922.

shown in Figure 6 are within the distance $\lambda/4$ from the monument.

It should be noted that position number 6, directly to the "rear" of the monument is marked "dead." This is then the approximate position of the "dead-spot" noted above, and shown in Figure 5.



Position	Angle
1	+ 91°
2	+ 80
3	+ 18
4	− 80
5	− 40
6	DEAD
7	+ 38
8	0
9	− 36
10	+ 55
12	− 70
13	− 45
14	− 31
16	− 25
17	− 3
18	+ 24
19	+ 19
24	− 8
25	+ 10

FIGURE 6—Field Distortion Caused by Washington Monument
(From S. P. Number 428: "The Radio Direction Finder and Its Application to Navigation," Bureau of Standards)

DISTORTION NEAR UNIVERSITY ANTENNA

A series of observations similar to those made by the Bureau of Standards were taken in the immediate vicinity of the antenna at the University of Minnesota. A small coil aerial of six turns on a form one meter square was mounted on a surveyor's transit, Figure 7, and observations were made on the apparent direction of a local broadcast station both with and without the receiving antenna being tuned. The broadcasting station (WLAG) is about two and one-half miles (4 km.) distant, and the field was therefore substantially uniform over the region investigated. The results of the measurements are shown in Table 1, which gives the observed directions together with the signal audibility before and after tuning the antenna to resonance. The angle of distortion and the audibility ratio are also given. Figure 8 shows the observed field distortion for the points taken, and the results are

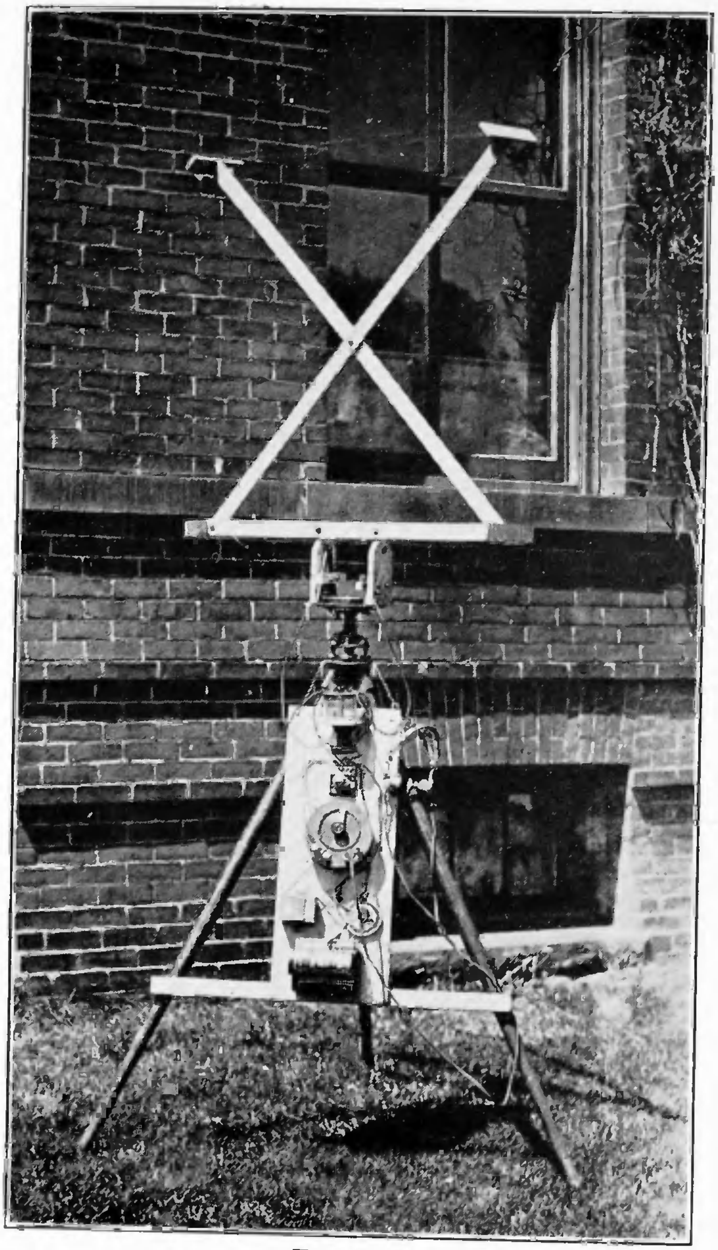


FIGURE 7

seen to be similar to those given in previous illustrations. The audibility measurements, while only very rough indications, show that the audibility is quite substantially increased in the direction of the broadcast station, and is reduced on the opposite side. The general position of the dead-spot is indicated. The presence of alternating current power wires prevented the taking of observations on the north side of the antenna.

TABLE I

FIELD DISTORTION PRODUCED BY TUNED ANTENNA AT UNIVERSITY OF MINNESOTA

Position (Figure 8)	Antenna Not Tuned				Antenna Tuned				Angle of Distortion	Audibility Ratio
	Minimum A	Minimum B	Apparent Bearing	Average Audibility	Minimum A	Minimum B	Apparent Bearing	Average Audibility		
A	N 74° E	N 110° W	N 108° W	15	N 61° E	N 116° W	N 117.5° W	18	9.5° S	1.2
B	N 82.5° E	N 97° W	N 97° W	30	N 30° E	N 147° W	N 148.5 W	350	51.5° S	11.7
C	N 85° E	N 96° W	N 95.5° W	350	N 83° E	N 101° W	N 99° W	800	3.5° S	2.3
D	N 64° E	N 111° W	N 111° W	50	N 69° E	N 107° W	N 109° W	80	2° N	1.6
E	N 78° E	N 110° W	N 106° W	40	N 52° E	N 123° W	N 125.5 W	4	19.5° S	0.1
F	N 50° E	N 130° W	N 130° W	12	N 50° E	N 124° W	N 127° W	10	3.0° N	0.8
G				0	No Minimum		N 95° W	4		
H	N 52° E	N 131° W	N 129.5° W	30	N 70° E	N 110° W	N 110° W	45	19.5° N	1.5
I	N 69° E	N 109° W	N 110° W	35	No Minimum		N 110° W	250	0	7.2
J	N 90° E	N 87° W	N 91.5° W	10				0	Dead Spot	0
K	N 70° E	N 111° W	N 110.5° W	15	N 60° E	N 118° W	N 119° W	35	8.5° S	2.3
L	N 75° E	N 103° W	N 104° W	6	N 63° E	N 115° W	N 116° W	12	12° S	2.0
M	N 72° E	N 105° W	N 106° W	7	N 52° E	N 124° W	N 126° W	15	19.5° S	2.1
N	N 60° E	N 118° W	N 119° W	80	N 57° E	N 122° W	N 122.5° W	120	3.5° S	1.5
S	N 78° E	N 99° W	N 100.5° W	22	N 87° E	N 90° W	N 91.5° W	40	9° N	1.8

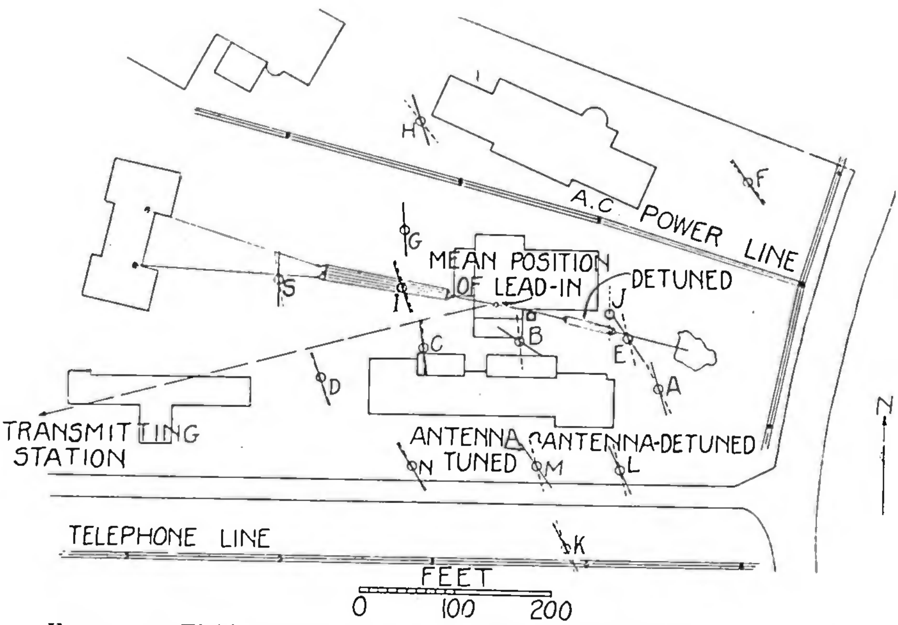


FIGURE 8—Field Distortion Due to Tuned Antenna at University of Minnesota

APPLICATION OF CHARACTERISTICS OF DISTORTED FIELD TO PRACTICAL USES

ELIMINATION OF INTERFERENCE

It is possible to utilize the "dead-spot" associated with a tuned receiving antenna for the purpose of eliminating interference from a powerful local station when it is desired to receive a distant station operating exactly on or near to the same wave length. The antenna is tuned to the interfering station and a coil antenna, or other antenna of small dimensions, is located in the resulting dead-spot, and used in the reception of the distant signal. All stations in the direction of the interfering station and operating on or near the same wave length are shielded from the coil antenna. Used in this manner, the antenna is merely a device for providing shielding for signals of one wave length and from one direction.

LOCATION OF COIL ANTENNAS FOR DIRECTION FINDING PURPOSES

The angle of deviation of the resultant field from the direct field has been shown to be the greatest in a direction approximately at right angles to the direction of the transmitting station. In locating coil antennas for direction finding purposes, this fact should be considered. If necessary to determine the direction of a station from a position near a large structure which is likely to produce distortion thru re-radiation, the direction-finder should be placed directly between the structure and the transmitting station, as determined by repeated observation, relocating the position of the coil aerial after each observation.

Broadening of Minimum Signal Position of Coil Antenna

When using a coil antenna near a re-radiating structure, the re-radiated field component will not, in general, be in time phase with the direct field. In observing directions at a distance from the structure such that the re-radiated component is neither exactly in phase nor 180° out of phase with the direct field component, no zero position will be obtained because both field components will not pass thru the zero value at the same instant of time. The re-radiated field component will generally be small compared to the direct component, however, so that the only effect produced will be a broadening of the minimum signal position similar to that produced by the "antenna effect."[6]

Transmission Without Local Source of Power

The fact that the receiving antenna becomes a miniature transmitter when tuned to resonance with a distant transmitting station, led to a test to determine how far from the receiving antenna these re-radiated effects might be observed. It has been determined that a local broadcast station (WLAG) produced a total voltage of about 0.50 volts in the antenna at the University of Minnesota. When this antenna was tuned to resonance with this station, its total resistance was about eleven ohms, and the current was therefore about forty-five milli-amperes. An interrupter and a telegraph key were also included in the antenna circuit, and the interrupter was arranged to break the circuit at an audio frequency. When using a coil antenna and a crystal detector, the re-radiated signals from this antenna were clearly readable thru the modulation of the broadcast station up to a distance of about one-half mile (0.8 km.). When no modulation was taking place, it was possible to transmit readable signals a distance of three miles (4.8 km.) to a non-regenerative receiver connected to a small indoor antenna, in the direction indicated in Figure 9. This transmission used no power except that received from the broadcast station 2.7 miles (4.3 km.) distant. By inserting a carbon microphone directly in series with the tuning inductance in the receiving antenna, speech was successfully transmitted a distance of 1.3 miles (2 km.), as is also shown in

[6] "S. P. Bureau of Standards, number 354," J. H. Dellinger, 1919, page 487. "S. P. of Bureau of Standards, number 428," Kolster and Dunmore, 1922, page 541.

Figure 9. The signals from the interrupter were also clearly audible at this distance.

The possibilities of development of this system for short range work where simplicity of apparatus is essential are apparent.

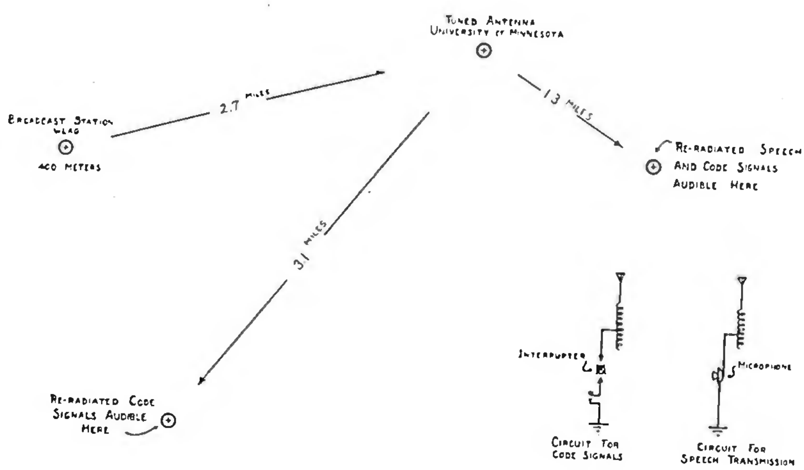


FIGURE 9—Transmission Without Local Power by Re-radiation

MEASUREMENT OF EQUIVALENT HEIGHT OF AN ANTENNA

Referring again to Figure 4 and recapitulating, consider a tuned antenna in the field of a distant transmitting station. Let the field intensity near the tuned antenna due to this transmitting antenna be designated by H. The current flowing in the vertical portion of the tuned antenna due to the voltage induced therein by the field H, will be, as above:

$$I_r = 3\times 10^{10}\frac{h_r'}{R} H \times 10^{-8} \qquad (10)$$

where h'_r is the equivalent height of the antenna. The tuned antenna then becomes a miniature transmitting antenna, producing a re-radiated field, the vertical component of which, on the earth's surface and at a distance δ from the antenna, may be expressed:

$$H_r = \left[\frac{2\pi h_r' I_r}{\lambda\ 10\,\delta} + j\frac{h_r' I_r}{10\,\delta^2}\right] K_1 \qquad (11)$$

where

$$K_1 = \frac{\delta}{\sqrt{h_r'^2 + \delta^2}} \qquad (5)$$

The magnitude of this re-radiated field is:

$$H_r = \frac{h_r' I_r}{10\sqrt{h_r'^2+\delta^2}}\sqrt{\frac{4\pi^2}{\lambda^2}+\frac{1}{\delta^2}} \qquad (12)$$

which, by substitution of equation (10) becomes:

$$H_r = \frac{30\, h_r'^2}{R\sqrt{h_r'^2+\delta^2}}\sqrt{\frac{4\,\pi^2}{\lambda^2}+\frac{1}{\delta^2}}\, H \tag{13}$$

Assuming that δ is sufficiently small so that the two components are practically in time phase with each other, we may write, by geometry from Figure 4, the following expression relating H and H_r:

$$H_r = H\frac{\sin\theta}{\sin(\phi-\theta)} \tag{14}$$

Substituting (14) in (13), we have:

$$\frac{\sin\theta}{\sin(\phi-\theta)} = \frac{30\, h_r'^2}{R\sqrt{h_r'^2+\delta^2}}\sqrt{\frac{4\,\pi^2}{\lambda^2}+\frac{1}{\delta^2}} \tag{15}$$

which is an expression relating h_r' with the distance δ, the wave length λ, the total antenna resistance R, and the angles ϕ and θ. A rather simple method of determing the equivalent height of any antenna thus arises.

The above expression, equation (15), cannot be solved explicitly for h_r' in simple form, but since h_r' enters the factor $\sqrt{h_r'^2+\delta^2}$ as a correction, its value may be estimated and a preliminary solution made. A second calculation using the new value is generally sufficient to determine h_r' within the accuracy of the method.

Solving, then:

$$h_r' = 0.1826\sqrt{\frac{R\sin\theta}{\sin(\phi-\theta)}}\sqrt{\frac{\sqrt{h_r'^2+\delta^2}}{\sqrt{\frac{4\,\pi^2}{\lambda^2}+\frac{1}{\delta^2}}}} \tag{16}$$

the value of h_r' on the right-hand side to be estimated as a first approximation. Any one set of units may be used for all lengths.

Equation (16) permits the measurement of the equivalent height of any antenna, by noting the apparent change in direction of a distant transmitting station as observed by a coil aerial near the antenna to be measured, as the antenna to be measured is tuned to resonance with the distant transmitting station. The other factors required for the determination are the distance of the coil aerial from the antenna to be measured, the wave length, the total antenna resistance, and the angles ϕ and θ of Figure 4.

In order that an angle θ may exist, it is necessary that the angle ϕ be made different from 0° or 180°. In order that θ may be large, the angle ϕ should be near 90°, and preferably somewhat larger than this value. If ϕ is made 90° for the determination, the factor $\frac{\sin\theta}{\sin(\phi-\theta)}$ of equation (16) becomes $\tan\theta$, and we have, if $\phi = 90°$:

$$h_r' = 0.1826\sqrt{R \tan\theta} \sqrt{\frac{h_r'^2 + \delta^2}{\frac{4\pi^2}{\lambda^2} + \frac{1}{\delta^2}}} \qquad (17)$$

Any transmitting station may be used as a source for the measurement, and the results are independent of the characteristics and distance of the transmitting station, provided the distance is sufficiently great so that the field is uniform near the antenna to be measured. The coil antenna may be located up to a distance of somewhat less than $\lambda/4$ from the vertical portion of the antenna to be measured, at approximately right angles to the direction of the transmitting station relative to the antenna.

If necessary to determine the equivalent height for various directions from the antenna, the use of more than one transmitting station may be necessary. The equivalent height thus determined is that for the particular wave length used.

It should be noted that this measurement does not take into account the effect of the current in the antenna flat-top upon the field strength at the point in question. Any such effect, altho usually small, will be credited to the lead-in by using this method of measurement, and will cause an apparent increase or decrease in the apparent equivalent height according as this effect adds to or subtracts from the field component due to the vertical portion. If observations are made at increasing distances from the antenna, the observed values of equivalent height will either increase or decrease slightly with distance, and asymptotically approach the true value due to the current in the vertical portion alone, since at great distances there will be no vertical field component due to the current in a horizontal wire.

This method is more particularly applicable to measurements of the equivalent height of antennas of symmetrical and definite characteristics, such as the vertical types, the inverted *L* and the *T*. Antennas which do not have a strictly defined vertical portion are difficult to measure because of the uncertainty of the determination of the distance of the coil antenna from the vertical portion.

In order to secure accuracy in the measurement, the angle θ should be of the order of 10°. Smaller values are difficult to measure accurately, and with larger values the value of the function $\frac{\sin\theta}{\sin(\phi-\theta)}$ is changing rapidly. The distance δ should be as large as possible consistent with remaining within the region wherein the direct and re-radiated field components are substantially in time phase. This means that the angle ϕ should preferably be somewhat greater than 90°, say in the neighborhood of 110°. The total antenna resistance, R, must include the resistance of the tuning devise.

While not a particularly admirable method of measurement, largely because of the necessity for making the observations so close to the antenna, it is quite practical for approximate results. It may be noted that the accuracy of the calculation is quite good, due to the fact that the equivalent height enters into the equation twice, once as a receiving factor, and again as a re-transmitting factor. Any errors in the measurement of R, θ, ϕ or δ then show only approximately as the square root in the resulting values of equivalent height.

Application of Method

This method of measurement of equivalent height has been applied to the data of Table 1 and Figure 8, which was obtained near to the antenna at the University of Minnesota. From the data for position M, which is closely at right angles to the antenna relative to the direction of the transmitting station, and is at a distance of 170 feet (51.8 meters) from the lead-in, we find by equation (17):

$$h_r'{}_{(M)} = 16.7 \text{ meters} = 54.8 \text{ feet.}$$

From the data of position K, where $\delta = 263$ feet (80.2 meters) and $\phi = 90°$.

$$h_r'{}_{(K)} = 15.0 \text{ meters} = 49.2 \text{ feet.}$$

Similarly at position L, where $\delta = 217$ feet (66.2 meters) and $\phi = 114°$, we have by equation (16):

$$h_r'{}_{(L)} = 15.6 \text{ meters} = 51.2 \text{ feet.}$$

The true equivalent height for this wave length and for this direction is probably about 49 feet (15.0 meters). Position M was entirely cut off from the antenna by the building shown in Figure 8, and at position K only the top of the antenna was visible.

Current measurements in a coil aerial near to this antenna, and based on the radiation formulas of the early part of this paper, give the following values for the equivalent height:

South — 16.7 meters (= 54.8 feet)
Southwest — 16.0 meters (= 52.5 feet)

These figures are for a wave length of 279 meters, whereas those given above are for the 400-meter wave length.

It is interesting to note that the application of this equation to the data given in Figure 6 of the Bureau of Standards' observations near Washington Monument, give the following values for the equivalent height of that structure:

Position number 9

$$h_r' = 13.5\sqrt{R} \text{ meters}$$
$$= 44.3\sqrt{R} \text{ feet}$$

Position number 13

$$h_r' = 16.2\sqrt{R} \text{ meters}$$
$$= 53.0\sqrt{R} \text{ feet}$$

Position number 14

$$h_r' = 14.2\sqrt{R} \text{ meters}$$
$$= 46.5\sqrt{R} \text{ feet}$$

Pierce's Tables[7] give the radiation resistance of a vertical antenna at the fundamental wave length as 36.6 ohms. Considering that the wave length of 625 meters is about 20 percent off resonance, a total impedance of the order of 50 ohms seems probable for this structure. If this value be assumed, the numerical values of the equivalent height determined above become:

Position number 9

$$h_r' = 313 \text{ feet}$$

Position number 13

$$h_r' = 374 \text{ feet}$$

Position number 14

$$h_r' = 328 \text{ feet}$$

$$\text{Average} = 338 \text{ feet}$$

The other observations cannot be used because of the disturbance produced by the underground cable. Since the total height is 532 feet, the form factor is 0.635 by this determination, which is rather too close to the theoretical value for a vertical antenna with sinusoidal current distribution, $2/\pi$ (0.637), to be entirely convincing. At any rate, the equivalent height of this structure is apparently closely equal to the effective height, a fact that would be expected, due to the absence of a flat-top and any nearby structure.

ACKNOWLEDGMENT

The writer wishes to express his appreciation of the assistance and co-operation of Professor C. M. Jansky, Jr., Mr. R. A. Braden, and others of the faculty of the Department of Electrical Engineering of the University of Minnesota, in the conduct of these experiments.

[7] "Electric Oscillations and Electric Waves," G. W. Pierce, McGraw-Hill, 1920, page 509.

SUMMARY: This paper considers Dellinger's treatment of the radiation from antenna systems, and applies correction factors thereto for the field strength near to the antenna. The term "equivalent height" is suggested and is differentiated from effective height. The expressions are then applied to the case of a tuned receiving antenna to determine the distortion produced in the field of a distant transmitter by re-radiation from the receiving antenna. The calculated results are then compared with the field distortion found by the Bureau of Standards near the Washington Monument, and also with measurements made near a typical antenna. The distorted field is found to have practical application as a means of eliminating interference; in short distance transmission without a local source of power; and in providing a means of measurement of the equivalent height of an antenna system.

Nomenclature

The following nomenclature has been used in this paper:

H = Field intensity due to a transmitting antenna.

H_r = Field intensity due to a re-radiating antenna.

h = Maximum height of an antenna.

h_r = Maximum height of a receiving antenna.

h' = Equivalent height of an antenna.

h_r' = Equivalent height of a receiving antenna.

x = Height to a differential element in vertical portion of an antenna.

ψ = Vertical angle of differential element above ground as observed at a distance d.

I = Maximum current in vertical portion of antenna.

I_r = Maximum current in vertical portion of a receiving antenna.

i = Current at height x in vertical portion of an antenna.

d = Distance from vertical portion of an antenna.

δ = Distance from vertical portion of a re-radiating antenna.

E = Total induced voltage in a receiving antenna.

R = Total effective resistance of a receiving antenna.

b = Length of antenna flat-top.

K_1 = Distance correction factor, vertical antenna, uniform current distribution.

K_2 = Distance correction factor, vertical antenna, linear current distribution.

K_3 = Distance correction factor, flat-top antenna, linear current distribution.

c = Velocity of propagation of field from antenna.

θ = Angle of distortion of field due to re-radiation.

ϕ = Direction angle of observer relative to distant transmitting antenna.

α = Absorption factor.

ε = Constant, 2.718....

$j = \sqrt{-1}$

DIGESTS OF UNITED STATES PATENTS RELATING TO RADIO TELEGRAPHY AND TELEPHONY*

ISSUED MARCH 3, 1925—APRIL 28, 1925

BY

JOHN B. BRADY

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1,520,129—E. H. Loftin and H. H. Lyon, filed April 5, 1920, issued March 17, 1925.

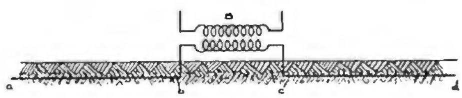


Fig 2

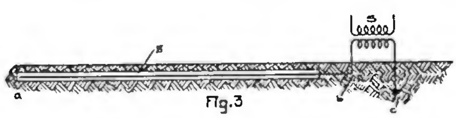


Fig.3

NUMBER 1,520,129—Radio Signaling System

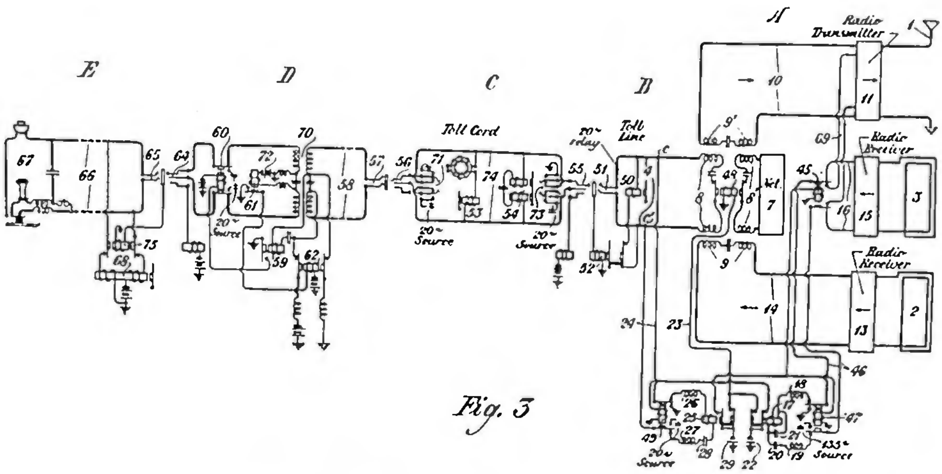
RADIO SIGNALING SYSTEM utilizing low extended antennas. The optimum length of the low horizontal antenna is described as being of the order of one-tenth the wave length of an operating signal and adjusted in resonance with the signaling wave. The invention is described with reference to underground and underwater antenna systems.

1,520,452—C. E. Willey, filed August 28, 1922, issued March 17, 1925.

RADIO DETECTOR of the cat-whisker crystal variety wherein a crystal holder is provided consisting of a cylindrical container adapted to receive a plug of soft metal in which a crystal is imbedded. The cylindrical container is open at both ends and fits over the head of a correspondingly shaped nut. In this manner, the crystal container is frictionally secured in position.

*Received by the Editor, May 12, 1925.

1,528,010—C. S. Demarest and M. L. Almquist, filed December 31, 1923, issued March 3, 1925. Assigned to American Telephone and Telegraph Company, New York.



NUMBER 1,528,010—Radio Signaling System

RADIO SIGNALING SYSTEM combining the advantages of line wire radio communication. Separate receiving circuits are provided for the reception of speech-modulated and signal-modulated carrier currents. The arrangement of the receiving circuits is such that a large amplification of the particular detected frequency or range of frequencies, which it is intended to secure may be received. The patent describes a terminal circuit which may be connected to a transmitting or receiving antenna with either speech currents or telegraph signaling currents. The switching means is actuated by signaling currents transmitted over the line for connecting the modulating circuit in desired relation to the antenna system and control circuits.

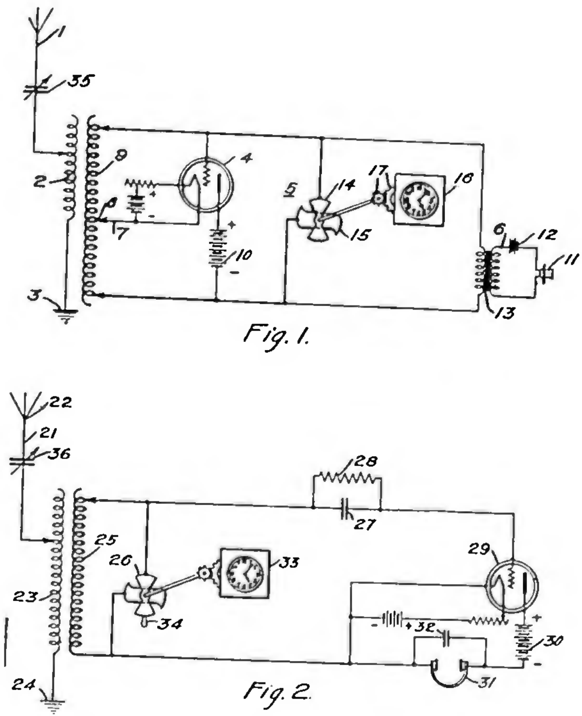
1,536,039—J. T. Bradley, filed April 3, 1923, issued April 28, 1925.

"NO-CAPACITY CONTROL" FOR CONDENSERS, in which the condenser plates may be moved for coarse adjustment and then moved for finer adjustment by means of gearing contained within the control knob secured to the condenser shaft.

1,528,011—C. S. Demarest and M. L. Almquist, filed December 31, 1923, issued March 3, 1925. Assigned to American Telephone and Telegraph Company, New York.

RADIO SIGNALING SYSTEM for slectivity signaling a particular station in a group of radio stations. In order that each station of the system may be able to maintain telephone or telegraph communication with every other station and a particular station to the exclusion of other stations, a band of frequencies is employed in the system. Each receiving station includes a detector which is so tuned that it will almost oscillate when the frequencies of one of the bands are applied to the detector. The receiving circuits are thereby operated selectively, enabling the several stations in the system to communicate without interference.

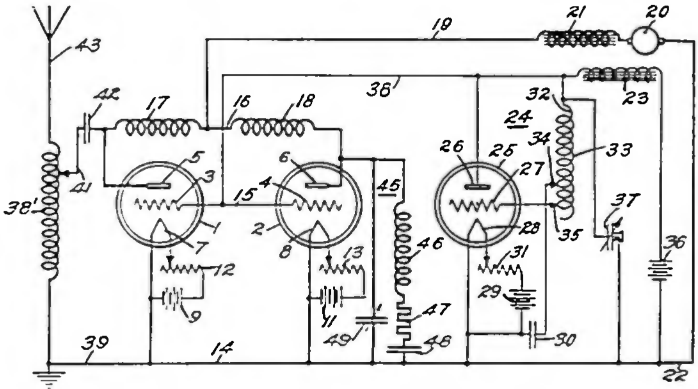
1,528,032—S. A. Staege, filed January 14, 1921, issued March 3, 1925. Assigned to Westinghouse Electric and Manufacturing Company, Pennsylvania.



Number 1,528,032—Selective Signaling System

[Selective Signaling System, in which the carrier wave frequency of a transmitting station is caused to vary thru a predetermined cycle within certain limits, while the tuning of the receiving station passes thru the same cycle of variation in frequency. This is accomplished by means of a clock mechanism at both the transmitting and receiving station by which a variable condenser is cyclically moved simultaneously. The frequency at both the transmitting and receiving station may in this manner be uniformly controlled.

1,528,047—Frank Conrad, filed March 15, 1922, issued March 3, 1925. Assigned to Westinghouse Electric and Manufacturing Company.



NUMBER 1,528,047—Radio Telephone System

RADIO TELEPHONE SYSTEM having a modulating system particularly adapted for high power operation. The modulation system employs a thermionic tube which is so associated with energy-absorbing circuits that only relatively small amounts of energy are dissipated in the modulator tube itself, the larger portion thereof being dissipated in the absorbing circuit. A pair of parallel connected valves are arranged in the transmitting circuit and modifications of the frequency of the impressed radio frequency currents cause opposite variations in the power absorbed by the respective circuits.

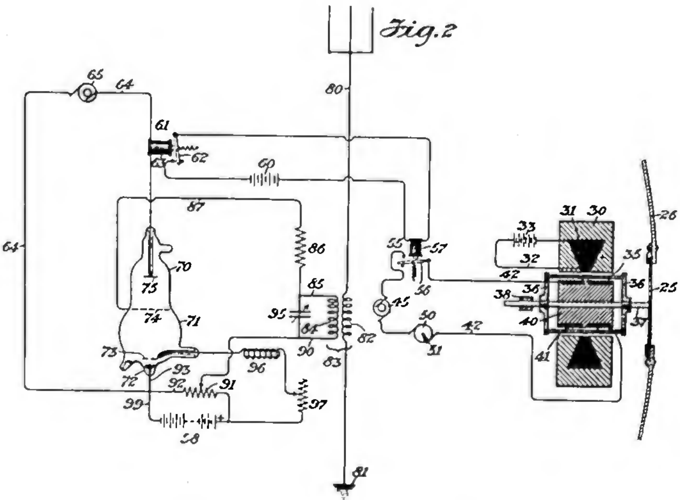
1,528,054—I. B. Harris, Wm. L. Harris, and E. B. Harris, filed March 24, 1922, issued March 3, 1925.

RECTIFIER tube having a plurality of independent cathodes anyone of which may be used in the event that another of the cathodes is destroyed. In this way the life of the rectifier bulb is increased, inasmuch as when one filament is destroyed another may be used. A form of connection for the separate cathodes is used in which a contact tap may be removed from the base of the tube to expose an auxiliary contact connected with another of the cathodes.

1,528,735—F. S. McCullough, filed June 2, 1924, issued March 3, 1925.

THERMIONIC-TUBE CONSTRUCTION, in which a radio frequency transformer is directly mounted within the tube adjacent the tube electrodes. The transformer has a pair of inductively-coupled coils which have their terminals connected thru extremely short leads with the electrodes of the tube.

1,529,065—J. H. Hammond, Jr., filed December 11, 1916, issued March 10, 1925.



Number 1,529,065—System of Radio Control

System of Radio Control of submarine vessels and other movable bodies. A combined electromagnetic wave reception system and sound wave transmission system is illustrated, whereby received radio signals are caused to actuate a submarine compression wave sound transmission system for transmitting energy under water for control of sound receiving devices on board the submarine vessel.

1,529,096—H. C. Tucker, filed October 5, 1922, issued March 10, 1925.

Electrical Control Instrument, wherein a rotatable shaft is journaled with respect to a panel by means of a sleeve which is directly supported by the panel and forms a hub thru which the rotatable shaft may be passed. The invention is shown in connection with a variable electrical condenser, altho the claims set forth in the invention are generally applicable to various rotary instruments.

1,529,455—F. K. Vreeland, filed May 3, 1920, issued March 10, 1925.

Electrical Oscillator for securing purity of wave form in an oscillating circuit having inductance and capacity reactances which are large with respect to the other impedances of the system with which it is associated. The specific means for securing this result includes a step-up coupling of the system including the power circuit to the oscillating circuit.

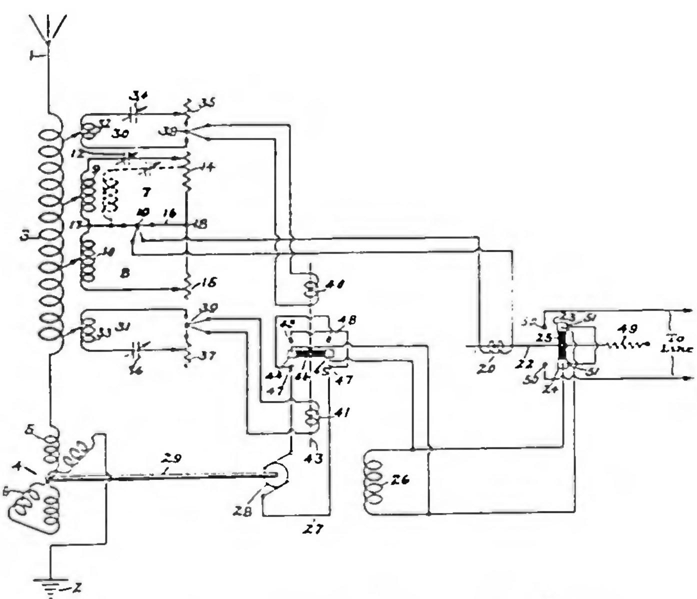
1,529,597—I. Langmuir, filed August 11, 1921, issued March 10' 1925. Assigned to General Electric Company, New York.

ELECTRON-EMITTING DEVICE AND METHOD OF PREPARATION of electron-emitting cathodes of the thoriated type, containing an amount of carbon sufficient to render the cathode less sensitive to the deleterious effect of gases than a cathode body unprovided with carbon. The specification describes a cathode which contains less than 3 percent by weight of carbon.

1,529,626—E. Y. Robinson, filed March 21, 1924, issued March 10, 1925.

VACUUM ELECTRIC TUBE for high powered operation, where the plate is sealed to the glass envelope and closes the lower portion of the envelope for the circulation of a cooling fluid around the depending metallic portion. The patent describes a method of removing gases and vapors from the metallic portion of the tube which consists in heating the metallic portion while protecting the zone at which the metallic portion is sealed to the glass envelope.

1,530,169—W. F. Grimes, filed June 7, 1923, issued March 10, 1925.



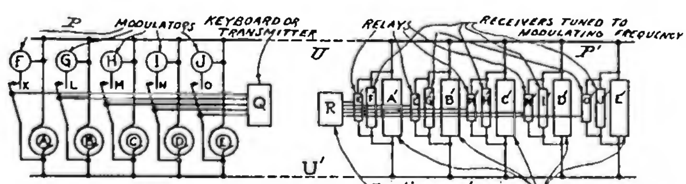
NUMBER 1,530,169—Radio Signaling System

Radio Signaling System, in which the signaling frequency of a transmitting station may be maintained constant. The antenna circuit of the transmitter is coupled with a pair of balanced circuits which at normal frequency remain in balanced condition. In the event that the frequency of the transmitter shifts, the control circuits become operative to adjust the antenna circuit to the normal frequency.

1,530,498—B. W. Kendall, filed November 20, 1917, issued March 24, 1925. Assigned to Western Electric Company, Incorporated, New York.

Synthesis of Compound Tones by Vacuum Tube Oscillators, by which various tones over the musical scale may be produced by electron tube circuits. A complex wave is generated which includes a plurality of different frequencies components which may be selected to produce desired oscillations of particular frequencies. The different frequencies may be utilized for the reproduction of audio notes of desired pitch and timbre.

1,530,660—W. F. Friedman, filed July 26, 1922, issued March 24, 1925.



Number 1,530,660—Printing Telegraph System

Printing Telegraph System for effecting simultaneous transmission and reception of a plurality of code signal impulses representing the individual elements of the message characters that are to be transmitted. The object of the invention is to reduce the time necessary for the transmission of printed messages by telegraph. A set of generators of radio frequency oscillations at different radio frequencies are provided. A single modulation frequency is employed for telegraphically modulating the oscillations. A set of make and break keys are arranged to control the modulating or non-modulating of the oscillations. The keys are operated simultaneously and permutatively to correspond to the permutations of a plural unit signaling code representing message characters. At the receiving station sets of receiving instruments are arranged to isolate the respective oscillations, detect the same, and control relay circuits which are operated permutatively to actuate a printing mechanism reproducing the transmitted messages.

1,530,666—J. H. Hammond, Jr., filed October 31, 1917, issued March 24, 1925.

MULTIPLEX SYSTEM FOR THE TRANSMISSION OF RADIANT ENERGY over the same antenna system. The transmitting circuit is supplied with energy from a single source of oscillations which is modulated by independent keying circuits, each of which may be interrupted at a rate within audibility. In this manner different tone frequencies may be produced for different signaling channels over the same antenna system.

1,530,684—J. O. Mauborgne and Guy Hill, filed June 29, 1921, issued March 24, 1925.

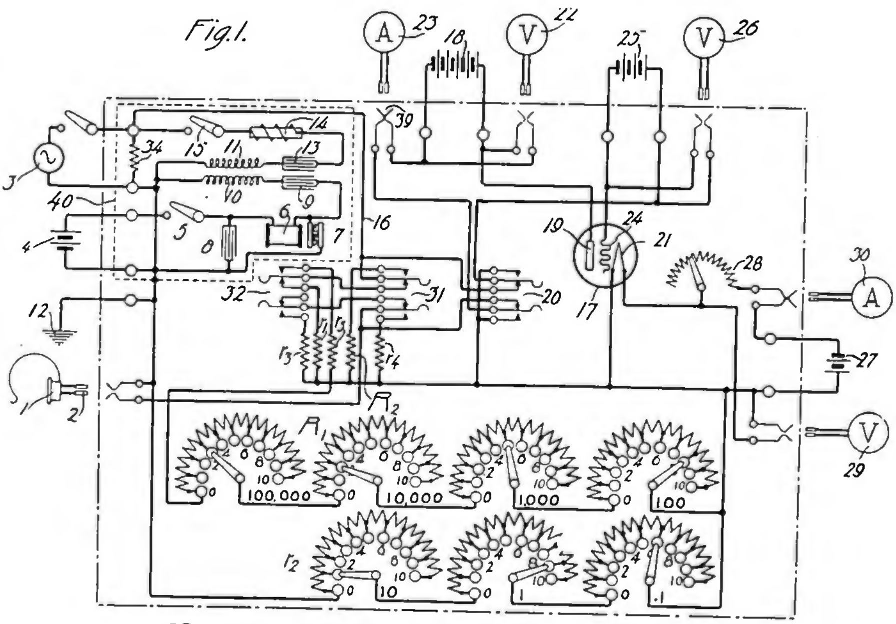
ANTENNA SYSTEM, consisting of a flat spiral resonance wave coil. The wave coil is constructed of a fixed distributing inductance and capacity of such values that the spiral is capable of having developed thereon a number of standing waves corresponding to a wide range of frequencies. A point may be selected in the coil for operation of the wave coil at the particular frequency desired and connections taken to a radio transmitter or receiver.

1,530,687—C. Murray, filed August 7, 1923, issued March 24, 1925.

DOUBLE-FILAMENT VACUUM TUBE, in which the filaments project inwardly into the tube from opposite directions. Contacts are provided at opposite ends of the tube for the separate filament terminals. When one filament is destroyed the other may be utilized.

1,530,988—H. W. Everitt, filed November 6, 1920, issued March 24, 1925. Assigned to Western Electric Company, Incorporated, New York.

TESTING VACUUM TUBES and measuring the operational constants of electron discharge tubes. The constants which it is desired to measure are one or more of the following: amplification factor μ, which is the ratio of the amplified current from the output circuit of the tube to the potential applied to the input: cathode-anode, impedance, R_p, that is, the internal output circuit impedance of the tube; and the mutual conductance $\frac{\mu}{R_p}$. By the present invention the constants of the tube can be read directly from dials which operate the different parts of the testing apparatus. An adjustable balancing resistance is provided connected in circuit with the electron tube tested. The resistance is calibrated in terms of the impedance of the space discharge path between two of the electrodes of the tube. When proper readings are obtained on meters in the tube circuits the tube constants may be determined from the dial settings.



NUMBER 1,530,988—TESTING VACUUM TUBES

1,531,029—F. M. Ryan, filed August 24, 1921, issued March 24, 1925. Assigned to Western Electric Company.

RADIO TRANSMISSION SYSTEM arranged to co-operate with a carrier-wave receiving system which has a closed energy receiving circuit or loop connected to the receiving apparatus with a circuit interposed between the receiving apparatus and the loop which has inductive reactance at desired frequencies functioning to exclude energy of undesired frequency from the receiving circuit. In this manner the transmission system may be operated in close proximity to the receiving system without interference therebetween.

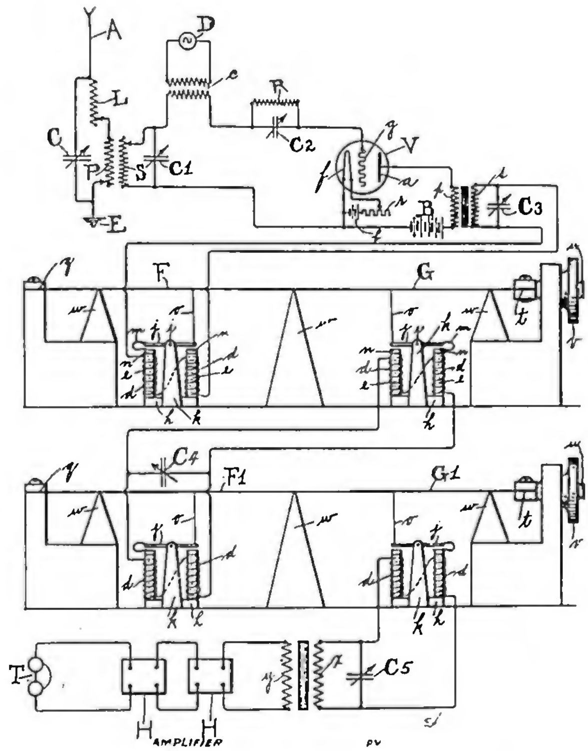
1,531,278—G. H. Clark, filed February 16, 1921, issued March 31, 1925. Assigned to Radio Corporation of America.

CONTROLLER for OSCILLATION GENERATORS of the arc type in which the striking of the arc may be controlled by an operator at the transmitting station. The hydrogen gas supply to the arc is mechanically controlled before the arc is struck. A mechanical and electrical circuit arrangement is shown whereby the liquid which supplies the hydrogen gas in the arc chamber is first supplied to the chamber before the arc is struck.

1,531,633—H. J. Vennes, filed December 22, 1920, issued March 31, 1925. Assigned to Western Electric Company.

Oscillation Generator having a circuit for production of currents of more than one frequency which are independent of one another. A plurality of tuned circuits are provided which are coupled with the oscillating current path. The tuned circuits may have the periodicity of any one of them adjusted, while the periodicities of any of the others of the tuned circuits may be maintained constant.

1,531,801—D. G. McCaa, filed May 2, 1922, issued March 31, 1925.



Number 1,531,801—Signaling System

Signaling System designed to eliminate the effects of static, strays, and electrical atmospheric disturbances. The invention is based on the principle that the telegraph signaling currents have a characteristic note of tone whereas stray currents differ substantially from the audio frequency note of the signal. A mechanical vibratory system is provided at the receiving station which may be set into operation by the periodic signal resisting current. The vibration of the mechanical system will independently generate the signaling energy which is finally observed free and clear of the effects of static disturbances.

1,531,805—R. C. Mathes, filed July 10, 1920, issued March 31, 1925. Assigned to Western Electric Company.

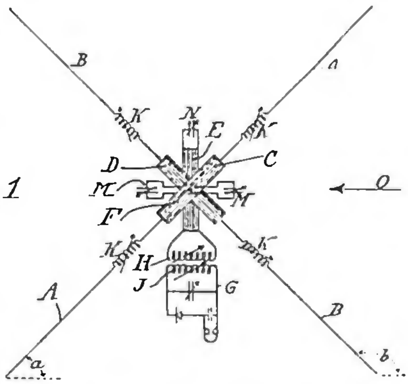
OSCILLATION GENERATOR having a regenerative feedback circuit which is not subject to the reaction of impedance of the output circuit. The object of the circuit arrangement is to produce a purer final wave form or more constant frequency than is produced in the usual electron tube oscillatory circuit. The tube of the present invention has a plurality of space discharge paths of different impedances and energy is supplied thru one path to control the regenerative operation of the circuit while load current is supplied thru the other path.

1,532,336—W. H. Nottage and T. D. Parkin. Filed December 18, 1920, issued April 7, 1925. Assigned to Radio Corporation of America.

RADIO TELEGRAPH CALLING DEVICE, in which a balance wheel is provided at a receiving station which has a natural oscillation equal to the interval between successive transmitted impulses so that tho the relay may be unaffected by ordinary signals, yet when a train of impulses at predetermined intervals is incident upon the receiver the oscillations of the relay are increased by the impulses sufficiently to enable it to actuate a bell or other signal or operate an electric corcuit for the control of apparatus.

1,532,356—R. A. Weagant, filed February 7, 1919, issued April 7, 1925. Assigned to Radio Corporation of America.

RADIO SIGNALING SYSTEM for minimizing the effects of static interference in radio reception. An antenna system is provided by which signaling energy and static energy may be received simultaneously from different directions with respect to the horizontal plane. The currents due to the static energy are balanced out in the receiving circuit while the currents due to the signaling energy are retained and amplified.

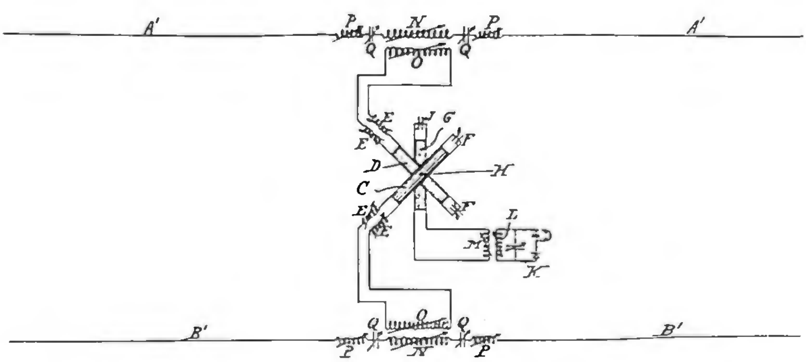


NUMBER 1,532,356—Radio Signaling System

1,532,364—O. A. Berman, filed October 2, 1922, issued April 7, 1925.

MANUFACTURE OF CONDENSERS, in which the condenser elements are constructed of conductive plates which may be moved positively towards or from an adjacent dielectric plate in an axial direction. A movable plate is mounted upon a screw-threading member which is adjusted in screw threads which pass thru an adjacent dielectric plate which separates the movable plate from the conductive plate.

1,532,367—R. A. Weagant, filed February 7, 1919, issued April 7, 1925. Assigned to Radio Corporation of America.



NUMBER 1,532,367—Method and Apparatus for Radio Signaling

METHOD AND APPARATUS FOR RADIO SIGNALING for reducing the effect of static disturbances. An antenna system comprising pairs of collectors is provided in which static energy may be successively received while signaling energy is simultaneously received from substantially the same general direction. The relative differences of phase between the resulting currents is utilized to select the desired current.

1,532,388—H. M. Dowsett, filed August 16, 1921, issued April 7, 1925. Assigned to Radio Corporation of America.

RADIO TELEGRAPH APPARATUS FOR AIRPLANES, consisting of an antenna system for aircraft where the bracing wires are located within the frame of the aircfaft and connected together and used as part of the radio signaling system.

1,532,523—F. Weinberg, filed August 11, 1923, issued April 7, 1925.

DETECTOR of the crystal type in which a pair of crystals are provided in vertical alignment with means for resiliently placing one crystal in contact with another. A threaded sleeve is provided upon the end of which is secured a crystal holder for maintaining the movable crystal in contact with the fixed crystal.

1,532,533—James E. Harris, filed December 16, 1919, issued April 7, 1925. Assigned to Western Electric Company, Incorporated, New York.

COLLOIDAL SUSPENSION for coating composition for filaments used in electron discharge tubes. The colloidal composition consists of particles of salt of an alkaline earth metal in solution. This colloidal solution is coated upon the cathode forming a thermionically active coating.

1,532,846—C. H. Thordarson, filed March 31, 1920, issued April 7, 1925.

ELECTRICAL CONDENSER designed for high tension operation, in which the conducting elements are formed of tube-like structures having side members for contact with the dielectric elements which are interposed between the tube-like conducting plates. The plates are so spaced that a cooling medium may be circulated therebetween.

1,532,964—C. Valguarnera, filed August 9, 1924, issued April 7, 1925.

MEANS FOR RADIO SIGNALING SHIPS DURING A FOG as a supplement to acoustic and luminous fog signals. The ships are equipped with special transmitting and receiving apparatus having limited range, each tuned to each other on a predetermined wave length. Signals are transmitted automatically and actuate the receiving station which is adjusted to receive the particular signals transmitted. As soon as the signals are picked up audibly a radio direction finder may be connected to the receiving set for accurately determining the position of the transmitting station.

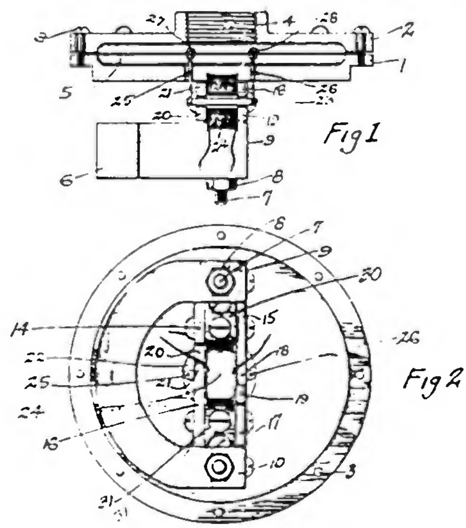
1,533,070—T. E. Arundel, filed May 26, 1924, issued April 7, 1925. Assigned one-fourth to Guy D. Shipherd and one-fourth to William H. Metcalfe, both of Omaha, Nebraska.

DETECTOR construction designed to maintain its adjustment permanently. The detector comprises a pair of electrodes which are secured within an insulated block and arranged to be adjusted exteriorly of the block and maintained in adjusted contact position for effecting rectification in an electrical circuit.

1,533,223—L. W. Chubb, filed June 30, 1921, issued April 14, 1925. Assigned to Westinghouse Electric and Manufacturing Company.

SYSTEM OF CONTROL for radio telegraph transmission wherein the signaling energy may be properly utilized between the signaling periods. A double antenna system is provided in which the antenna circuits may be employed as an absorbing circuit or as a radiating circuit and by varying the phase of the currents in the antenna circuits they may relatively add or subtract in their effects. By utilizing the phase control method the use of large absorbing circuits usually employed at an arc-signaling station is eliminated.

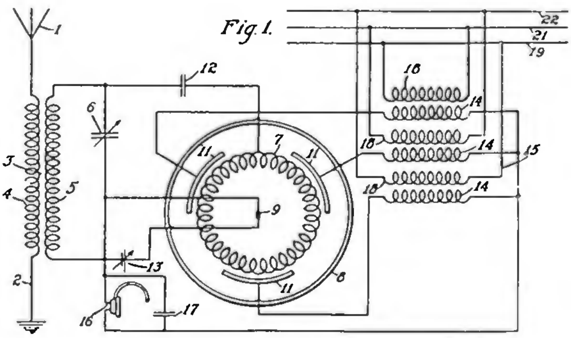
1,533,372—C. E. Brigham, filed June 14, 1924; issued April 14, 1925. Assigned to C. Brandes, Incorporated.



NUMBER 1,533,372—Loud Speaker

LOUD SPEAKER for radio reproduction, in which the maximum energy from the electromagnetic fluctuations is derived by means of a freely floating armature disposed in the magnetic field. The armature is arranged within the electromagnetic field and is actuated by the variations in the magnetic flux in such manner that all the vibrations are effectively employed for the reproduction of signals.

1, 533,278—J. Slepian, filed November 20, 1920, issued April 14, 1925. Assigned to Westinghouse Electric and Manufacturing Company.



NUMBER 1,533,278—Plate Circuit Excitation

PLATE CIRCUIT EXCITATION for an electron tube system, in which multiphase alternating current is used for exciting the plate filament circuit. A polyphase source of electromotive force is included in the plate filament circuit to produce a flow of current therein similar to that produced by the direct current electromotive force method of plate excitation. A rotating electrostatic field is thus produced within a closed vessel, which field may be controlled for further controlling energy in the output circuit of the electron tube.

1,533,334—H. O. Russell and C. L. Paulus, filed April 18, 1922 issued April 14, 1925.

CONDENSER of the fixed type in which a stack of mica sheets having metallic coatings thereon are positioned adjacent each other; the mica sheets each have a coating of material subject to the action of electrolysis, such as lead oxide. On the surface of the lead oxide coating an electrically deposited plate of copper is formed. The mica sheets may then be stacked one adjacent the other to build up the condenser and the plates maintained under pressure in the stack.

1,533,502—J. L. Jenks, Jr., filed February 11, 1922, issued April 14, 1925.

Method of and Means for Adjusting Rotary Spark Gaps of Radio Apparatus by controlling the phase of the current supplied to the driving motor and thereby regulating the discharge according to the spark gap. The supply circuit is adjusted by means of variable reactance for controlling the phase of the energy to the motor. By a change in reactance sufficient lag may be introduced to obtain a consequent lag in the spark gap.

1,533,611—W. R. Respess, filed December 22, 1923, issued April 14, 1925. Assigned to New Jersey Research Company.

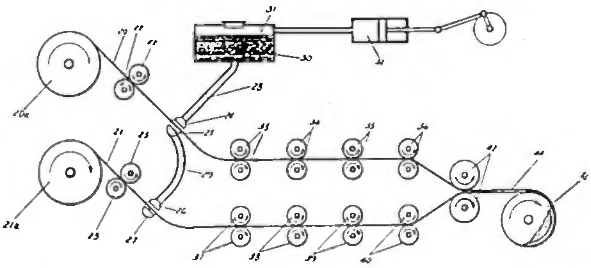
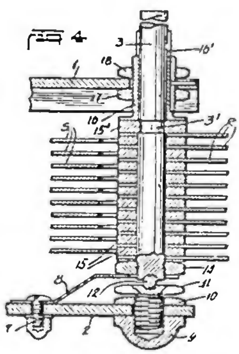


FIG 6

Number 1,533,611—Electrical Condenser and Method of Manufacturing the Same

Electrical Condenser and Method of Manufacturing the Same, where the metallic armatures are coated with rubber in solution which, when dry, forms an insulating filament directly upon the conducting plate, permitting condensers to be built up by stacking the conducting plates one upon another.

1,534,160—S. Cohen, filed February 17, 1925, issued April 21, 1925.



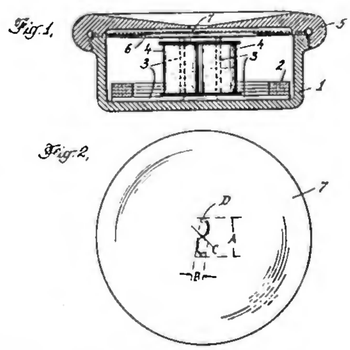
Number 1,534,160—Condenser

Condenser, in which the rotor plates are mounted on a ball-bearing member with the rotatable shaft journaled in a spring chuck secured in one of the end plates forming the condenser frame. The condenser is designed for high electrical efficiency and high dielectric characteristics. The frame of the condenser and the rotor plates is of the same electrical potential.

1,534,213—G. Hill, filed February 3, 1923, issued April 21, 1925.

VARIABLE CONDENSER, in which the stator plates are cut from circular sheet material having a peripheral rim which extends around the plate in a complete circular form with a cut-out portion in the plate. The movable plates are arranged on a shaft and may be inter-leaved between the stator plates passing through the open portion of the stator plates. The stator plates are supported at different points around the edge thereof.

1,534,373—H. Fischer, filed October 25, 1922, issued April 21, 1925. Assigned to C. Brandes, Incorporated, New York.

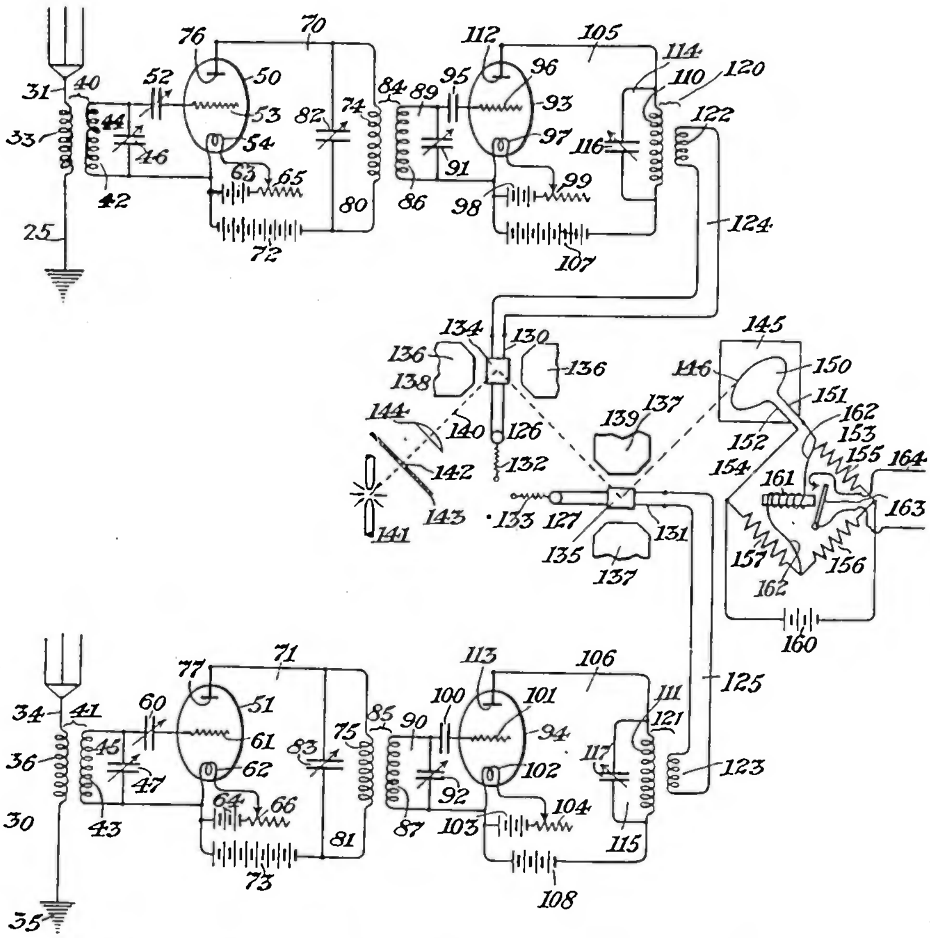


NUMBER 1,534,373—Diaphragm for Telephone Receivers

DIAPHRAGM FOR TELEPHONE RECEIVERS, consisting of a pair of super-imposed members forming an air chamber therebetween in which one of the members has an F-shaped slot therein. The object of the invention is to provide a diaphragm structure which will faithfully reproduce all of the tones of the musical scale. The patent covers an electromagnetic sound-reproducing mechanism having a base made up of a plurality of stamped metal parts. The invention is particularly adapted for quantity production of electromagnetic sound reproducers.

1,534,704—J. H. Hammond, Jr., filed September 9, 1918, issued April 21, 1925.

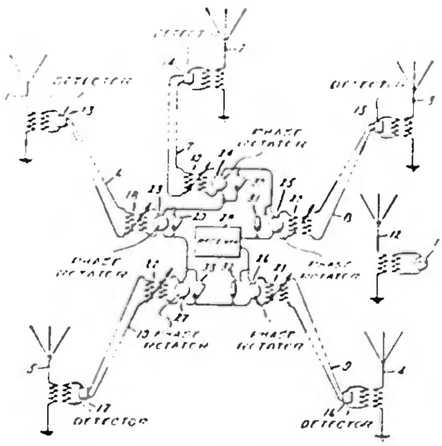
RECEIVING SYSTEM FOR RADIANT ENERGY, having separate circuits in which two series of impulses of radiant energy having a predetermined phase difference may be utilized to control the operation of selenium cells at a receiver which in turn control circuits at the receiving station to selectivively actuate the receiving mechanism.



NUMBER 1,534,704—Receiving System for Radiant Energy

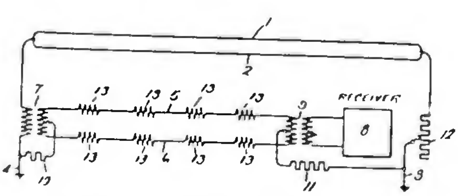
1,534,719—E. W. Kellogg, filed April 21, 1921, issued April 21, 1925. Assigned to General Electric Company.

RADIO RECEIVING SYSTEM, in which a plurality of widely separated receiving antennas are connected by transmission lines to a central receiving station. A radio frequency wave is radiated at a frequency differing from that of the signal waves to be received by an amount sufficient to produce audible beats with the signaling waves. At each receiving station the signaling wave is detected and the resultant audio frequency current is sent to the central receiving station where the signals may be received with the most favorable stray ratio. The multiple reception method insures the more accurate copying of the signals despite stray interferences.



NUMBER 1,534,719—Radio Receiving System

1,534,720—E. W. Kellogg and C. W. Rice, filed May 18, 1921, issued April 21, 1925. Assigned to General Electric Company, New York.



NUMBER 1,534,720—Radio Receiving System

RADIO RECEIVING SYSTEM employing a uni-directional horizontal receiving antenna for the reception of desired signals free of interference from disturbing waves coming from another direction. A long horizontal receiving antenna is provided with a transmission line running parallel with the antenna for conveying signaling currents from a selected point in the antenna to a distant receiving station.

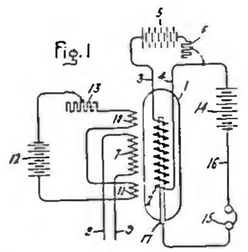
1,534,769—R. Brownlie, filed January 19, 1924, issued April 21, 1925.

OSCILLATION DETECTOR of the crystal type wherein the crystal is supported within a holder and a contact member arranged to be contacted thereagainst and moved by rotative movement to a desired point with respect to the surface of the crystal.

1,535,016—O. Scheller and R. Herzog, filed August 31, 1921, issued April 21, 1925. Assigned to C. Lorenz Aktiengesellschaft, of Lorenzweg, Berlin-Tempelhof, Germany.

KEY CONNECTION FOR RADIO TRANSMISSION OF MESSAGES, for maintaining a steady load on a transmitting System. A circuit is provided at the transmitter where a choke coil may be brought into shunt relation to the antenna generator circuit when the transmitting key is closed, while a condenser is connected in parallel with the generator circuit when the key is open for alternately radiating and suppressing the signal energy.

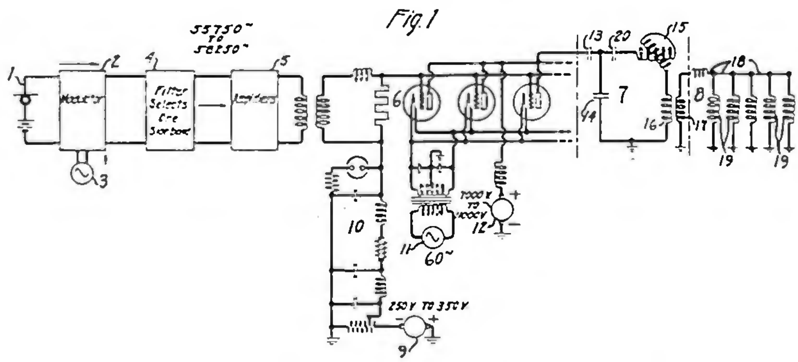
1,535,082—E. F. W. Alexanderson, filed September 28, 1920; issued April 21, 1925. Assigned to General Electric Company.



NUMBER 1,535,082—Electron Discharge Device

ELECTRON DISCHARGE DEVICE, in which an elongated anode is disposed within an evacuated envelope with a filamentary cathode symmetrically spaced around the anode. A magnetic field is generated substantially parallel to the axis of the cathode. By controlling the magnetic field the electron emission from the cathode is controlled to effect variation between the anode and cathode circuit.

1,535,130—A. A. Oswald, filed March 20, 1924, issued April 28, 1925. Assigned to Western Electric Company, New York.



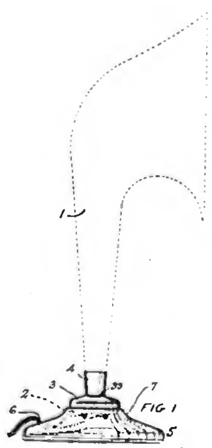
NUMBER 1,535,130—High Power Radio Telephony

High Power Radio Telephony for long distance communication where a band of frequencies of the order of 2,000 cycles is employed. The antenna which is utilized has a resonance charccteristically materially narrower than 2,000 cycles with a substantially uniform effectiveness over the entire frequency range of the band.

1,535,189—R. E. Thompson, filed March 7, 1919, issued April 28, 1925. Assigned to Wireless Improvement Company, of Jersey City, a corporation of New York.

Radio Communication Apparatus, in which a single control is employed for tuning the apparatus. The variable inductance and condenser are mechanically adjustable thru the same interconnecting linkage to permit variation of the wave length of the circuit over a wide range by a single operation.

1,535,734—D. H. Moss, filed February 9, 1924, issued April 28, 1925. Assigned to C. Brandes, Incorporated, New York.



Number 1,535,734—Support for "Table Talkers" and Method of Making the Same

Support for "Table Talkers" and Method of Making the Same. The patent shows a method of construction for an electromagnetic sound reproducer. The construction of the base and means for mounting the acoustic reproducer therein is described in connection with the process of manufacture by which the instruments can be produced on a quantity-production scale inexpensively.