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GENERAL INFORMATION

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ALFRED N. GOLDSMITH, Ph.D.

FIELD INTENSITY MEASUREMENTS IN WASHINGTON ON THE RADIO CORPORATION STATIONS AT NEW BRUNSWICK AND TUCKERTON, NEW JERSEY*

By

L. W. Austin

(Physicist, Radio Physical Laboratory, Bureau of Standards, Washington, D. C.)

(Communication from the International Union of Scientific Radio Telegraphy)

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In June, 1923, the morning signals from WII, which are more regular than those of the afternoon in summer, on account of the absence of the afternoon absorption, fell below normal on ten days, on three of which the deviation lay between 30 percent and 50 percent. In July, the morning signals were abnormal on seven days, twice being more than 30 percent low, while on July

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17th they rose for an hour or two to 85 percent above normal without apparent cause.

From August 1st to December 30th the signals were more regular. During August they varied in the morning less than 10 percent, except for slight variations on three days. In September they were also below normal on three days, one day being 40 percent low. In October they again exceeded the 10 percent variation slightly on three days. In November the three variations were all high, the greatest deviation being 24 percent. In December there was one low variation of 21 percent and one high, 63 percent.

Regular observations were begun on WGG (Tuckerton), in October. This station averages about 12 percent below WII in intensity, giving 2.7 millivolts per meter. From the tables it will be seen that the variations are of the same order as those of New Brunswick. Figure 1 shows the monthly averages of the New Brunswick (WII) observations. Figure 2 shows the daily record for WII in July, the crosses being the 10 A. M. observations and the circles those at 3 P. M. The tables give the complete daily observations for both stations.

During December there was no very cold weather in Washington, but with the cold waves of January there was a marked

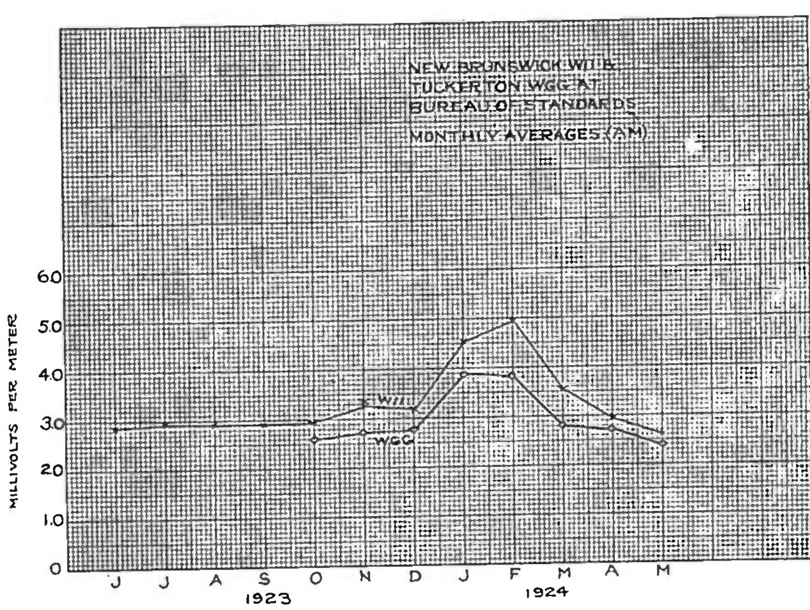


FIGURE 1

increase in the irregularities of WII and WGG and in a lesser degree of WQK. This last station was only observed occasionally.

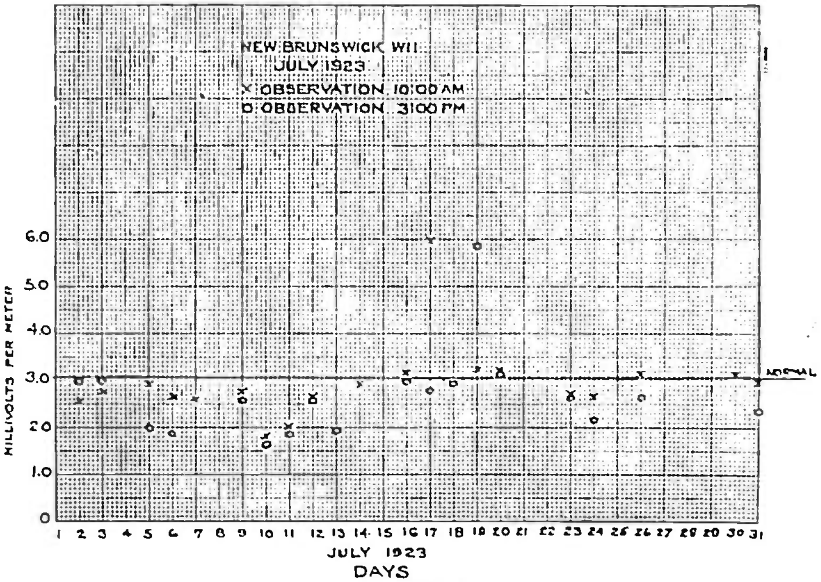


Figure 2

At the time of the passage of each of the cold waves there was an increase in signal strength, especially during the severe cold toward the end of the month. In order to show this more clearly the maximum signal of WII or WGG at the two observation times and the reciprocal of the temperature are plotted in Figure 3. The observations on the signals and the 8 o'clock A. M. temperatures are given in the January Table.

During the moderate cold of January 7th and 15th, sometimes only one of the two stations seemed to be affected and the high readings were observed for only a part of the time, but during the extreme cold of January 22d and 27th both of the stations regularly observed as well as WQK and WSO (Marion, Mass.) remained high thruout the day, and in the last case for several days. There were also at these times marked shifts in the apparent direction of the stations even in the forenoon when their bearings are usually correct. NSS (Annapolis) 53 km. away showed no increase in signal strength during these times. The end of the cold weather of January did not at once restore receiving conditions to the uniformity of the autumn and early winter, but left an instability which persisted thru the comparatively mild cold of February and a portion of March. During this time the signals from WII and WGG fluctuated frequently, going to more than twice their normal strength for a few hours and then returning to normal without any obvious relation to weather conditions.

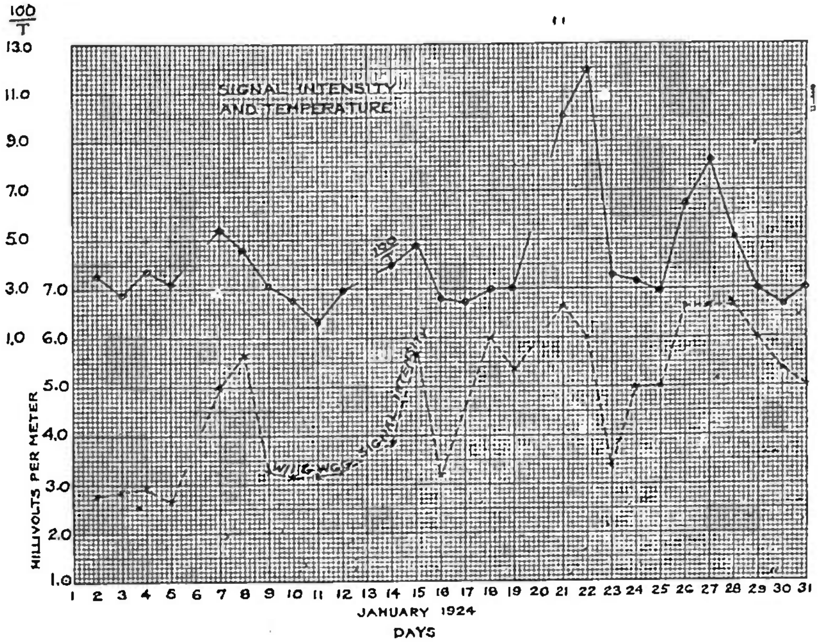


FIGURE 3

Since March 19th these large irregularities have ceased and transmission seems to have returned to a stable condition with nearly the same average signal strength as in the autumn. The observations which have been taken on Annapolis and on the Radio Corporation stations at various distances indicate that large variations in intensity do not generally occur at 50 km., that they are large at distances of 250 to 300 km. and again become less at 400 to 700 km.

The few night observations which have been taken show somewhat higher and less regular values than those taken during the day.

It is too early to give any definite explanation of the variations observed. Their cause is evidently atmospheric and the connection with the cold waves of January suggests either that the part of the atmosphere concerned in the variations lies much below the Heaviside surface (80 or 100 km.) or that weather phenomena are in some way correlated with atmospheric action at much greater heights than has been hitherto supposed.

Field Intensity of New Brunswick WII in Millivolts per Meter

Date	1923					
	June		July		August	
	A.M.	P.M.	A.M.	P.M.	A.M.	P.M.
1	2.86	....	....	....	3.13	3.13
2	....	....	2.53	2.99	3.13	2.53
3	....	3.26	2.79	2.66	2.39	....
4	2.59	2.86	....	....	3.13	....
5	....	....	2.93	1.99	....	....
6	....	....	2.66	1.86	....	1.93
7	2.86	2.79	2.59	....	3.08	....
8	1.73	1.94	....	....	....	....
9	1.46	2.66	2.79	2.59	....	....
10	....	....	1.79	1.66	....	....
11	2.39	2.46	1.99	1.86	2.99	....
12	....	2.66	2.66	2.66	....	....
13	2.66	2.19	....	1.93	2.79	2.99
14	2.53	2.66	2.93	....	....	1.99
15	2.79	1.94	....	....	2.99	2.13
16	1.93	....	3.19	2.33	....	2.33
17	....	....	6.00	2.79	2.39	1.93
18	2.53	2.16	....	2.93	2.66	....
19	2.59	3.06	3.26	5.88	....	....
20	2.93	....	3.13	3.13	3.06	3.13
21	2.66	2.33	....	....	....	1.66
22	2.59	2.86	....	....	2.99	2.86
23	2.79	....	2.66	2.66	2.53	2.86
24	....	....	2.66	2.16	....	2.79
25	2.93	2.66	....	....	2.99	....
26	3.06	2.26	3.13	2.66	....	....
27	....	2.33	....	....	3.13	2.99
28	2.99	2.66	....	....	2.99	3.13
29	2.86	2.35	....	....	3.13	2.99
30	2.66	....	3.13	....	2.99	2.86
31	....	....	2.99	2.33	....	2.46
Average	2.86	2.53	2.94	2.62	2.91	2.60

FIELD INTENSITY OF NEW BRUNSWICK WII IN MILLIVOLTS PER METER

1923

Date	Sept.		Oct.		Nov.	
	A.M.	P.M.	A.M.	P.M.	A.M.	P.M.
1	3.26	....	3.13	....	3.13	2.99
2	....	....	3.19	3.13	3.19	2.59
3	....	....	3.19	3.13	3.26	2.99
4	....	....	....	3.06	....	....
5	3.06	....	3.13	2.33	....	2.86
6	2.66	2.93	2.99	3.13	2.99	3.06
7	....	2.99	....	....	3.13	3.26
8	2.99	....	3.13	2.99	3.26	3.19
9	....	....	3.13	2.99	3.33	3.33
10	3.06	2.59	....	2.99	3.33	3.06
11	....	3.06	2.99	2.59	....	....
12	3.13	2.79	2.66	....	....	....
13	....	....	....	2.66	....	....
14	2.53	3.19	....	....	3.26	3.26
15	....	....	2.99	....	3.33	3.33
16	....	....	....	....	3.19	3.66
17	1.86	3.13	....	....	3.33	3.66
18	2.59	2.86	....	2.13	....	....
19	2.99	3.29	2.26	2.33	3.53	3.53
20	....	2.53	2.59	2.66	3.46	3.46
21	3.26	2.93	....	....	....	3.73
22	3.13	3.13	2.79	2.26	3.79	2.66
23	....	....	2.59	3.19	....	2.53
24	3.26	2.59	....	....	3.26	2.59
25	3.19	3.29	....	....	....	....
26	....	2.59	3.19	2.99	3.19	....
27	....	....	2.99	3.19	2.99	2.99
28	....	3.19	....	....	3.19	3.19
29	....	2.99	2.79	3.19	....	....
30	....	....	3.13	3.13	2.99	2.99
31	....	....	....	3.06	....	....
Average	2.91	2.96	2.94	2.84	3.26	3.13

FIELD INTENSITY OF NEW BRUNSWICK WII IN MILLIVOLTS PER METER

1923-1924

Date	Dec., 1923		Jan., 1924			Feb., 1924	
	A.M.	P.M.	A.M.	Temp. ° F. at 8 A.M.	P.M.	A.M.	P.M.
1	....	3.19	....	....	....	6.65	3.26
2	....	....	2.66	29°	2.33	5.66	5.66
3	....	....	3.06	36	2.66	....	....
4	....	....	....	27	3.13	....	6.00
5	....	3.26	....	31	3.26	5.00	3.99
6	....	3.13	....	..	....	3.66	....
7	....	3.19	5.00	19	3.13	4.33	6.33
8	5.00	3.26	....	22	3.06	6.00	5.66
9	....	....	3.25	33	....	6.33	5.66
10	....	2.33	3.13	37	3.13	....	....
11	3.13	2.13	....	63	3.19	....	6.65
12	....	2.66	3.26	35	....	5.33	4.33
13	2.99	2.99	....	..	....	3.86	3.33
14	....	2.99	3.66	26	3.06	3.73	3.66
15	2.26	2.66	....	21	....	6.33	5.00
16	....	....	3.13	40	....	5.00	5.33
17	....	2.59	4.66	41	3.33	....	....
18	2.53	....	5.66	35	6.00	....	5.00
19	....	....	5.32	33	3.26	....	6.65
20	....	3.19	....	..	....	3.66	5.33
21	....	3.13	....	10	6.65	5.00	5.00
22	....	3.19	6.00	8	4.33	....	....
23	....	....	3.26	29	3.26	....	6.00
24	3.19	....	5.00	30	5.00	....	....
25	....	....	5.00	35	....	3.19	5.00
26	3.13	3.06	5.66	16	5.00	3.19	3.19
27	....	2.99	6.65+	12	....	6.65+	6.65+
28	....	3.13	6.65+	20	4.66	5.53	6.65+
29	....	3.66	5.32	34	6.00	5.00	....
30	....	....	3.26	42	5.33	....	....
31	....	3.19	....	33	4.66	....	....
Average	3.18	3.00	4.52		4.02	4.94	5.19

FIELD INTENSITY OF NEW BRUNSWICK WII IN MILLIVOLTS PER METER

1924

Date	March		April		May	
	A.M.	P.M.	A.M.	P.M.	A.M.	P.M.
1	....	3.20	....	3.33	3.20	1.66
2	....	....	3.19	3.19	3.00	2.86
3	4.00	4.33	....	2.53	2.33	1.68
4	....	3.20	....	3.20	....	....
5	....	3.26	3.19	3.20	3.06	2.33
6	3.53	3.26	....	....	3.26	3.13
7	3.26	3.26	....	4.66	....	3.13
8	....	3.26	....	3.13	....	1.40
9	....	....	4.00	3.26	2.33	2.66
10	3.33	3.13	....	3.26	2.33	2.53
11	5.00	3.66	....	3.20	....	....
12	3.20	3.26	....	2.86	....	2.33
13	3.93	3.26	....	....	2.33	2.33
14	3.20	3.86	2.53	3.00	2.00	1.88
15	5.00	5.00	3.20	2.86	1.88	3.00
16	....	....	....	2.53	2.00	2.00
17	....	4.33	....	3.20	2.33	3.20
18	4.66	5.00	....	3.20	....	....
19	....	4.06	....	3.20	3.19	3.06
20	....	3.26	....	....	3.26	3.19
21	....	3.20	....	3.26	2.00	3.06
22	3.26	3.26	....	3.20	3.20	3.20
23	....	....	....	2.66	3.06	3.06
24	3.20	3.20	3.00	3.06	2.26	....
25	....	3.33	3.13	2.26	....	....
26	2.66	3.20	3.26	5.33	3.00	2.50
27	....	3.20	....	....	2.30	2.30
28	....	3.20	3.20	3.00	....	2.30
29	2.53	3.20	1.66	2.66	2.30	2.50
30	....	....	2.00	1.66	....	....
31	2.66	2.53	....	....	2.50	2.60
Average	3.56	3.51	2.95	3.11	2.60	2.55

Field Intensity of Tuckerton WGG in Millivolts per Meter

1923

Date	October		November		December	
	A.M.	P.M.	A.M.	P.M.	A.M.	P.M.
1	....	....	2.63	2.30	....	2.43
2	....	....	2.63	2.63	....	....
3	....	....	2.63	2.50	....	....
4	....	....	....	....	....	....
5	....	....	....	....	2.76	2.63
6	....	2.50	2.63	....	2.63	2.50
7	....	....	....	2.50	....	3.16
8	2.56	2.50	....	2.43	2.96	....
9	....	2.43	2.63	2.76	....	....
10	2.50	2.56	2.63	2.43	....	....
11	....	....	....	....	....	2.30
12	2.56	....	2.56	2.63	3.36	3.36
13	....	2.50	2.63	2.50	....	3.30
14	....	....	2.63	2.56	2.70	2.50
15	....	....	2.56	2.63	2.96	3.01
16	2.56	2.50	2.56	3.09	....	....
17	....	2.50	2.70	2.63	2.90	2.76
18	....	2.43	....	....	2.16	....
19	2.16	2.23	2.90	2.76	....	....
20	....	2.50	2.83	2.63	....	2.63
21	....	....	....	2.83	....	2.90
22	2.50	2.56	3.16	2.56	....	3.16
23	2.56	....	....	2.30	....	....
24	2.50	2.30	2.96	2.56	....	....
25	2.96	2.63	....	....	....	....
26	2.83	3.00	3.09	....	....	....
27	2.76	2.96	2.76	2.63	2.63	2.63
28	....	....	....	2.63	4.93	....
29	2.56	2.76	....	2.96	2.96	4.60
30	2.63	2.76	....	2.56	....	....
31	2.70	2.50	....	....	2.63	2.63
Average	2.60	2.56	2.72	2.60	2.77	2.79

Field Intensity of Tuckerton WGG in Millivolts per Meter

1924

Date	January		February		March	
	A.M.	P.M.	A.M.	P.M.	A.M.	P.M.
1	....	....	5.56	2.96	2.76	2.96
2	3.43	2.56	4.26	3.16	....	....
3	2.70	2.56	....	....	3.54	3.30
4	....	....	2.96	4.93	2.96	....
5	2.63	....	4.26	3.60	2.76	....
6	....	....	2.96	....	2.70	2.76
7	....	....	3.16	4.93	....	2.76
8	5.66	3.16	4.93	....	....	2.63
9	....	....	5.24	4.93	....	....
10	....	....	....	....	2.90	2.63
11	3.16	....	3.20	5.56	2.76	3.16
12	....	2.96	4.26	3.30	....	2.63
13	....	....	4.80	....	3.20	2.96
14	....	3.80	2.76	3.60	2.63	3.36
15	2.96	5.56	4.60	3.60	3.80	2.30
16	....	2.96	4.26	4.26	....	....
17	....	3.73	....	....	2.70	3.30
18	....	4.93	3.30	5.90	....	2.96
19	3.93	2.96	....	5.56	2.83	3.20
20	....	....	1.20	....	2.70	2.76
21	2.76	3.93	2.90	3.94	2.50	2.63
22	5.56	....	....	....	2.96	2.90
23	2.96	2.96	4.93	5.90	....	....
24	4.60	4.93	....	....	2.83	2.83
25	4.26	4.93	2.96	....	2.90	2.90
26	4.93	4.26	....	....	2.23	2.70
27	....	....	....	6.56	2.23	2.90
28	4.93	....	....	5.56	3.00	2.63
29	2.96	4.60	....	4.26	2.50	2.63
30	3.60	4.93	....	....	....	....
31	4.93	3.94	....	....	2.43	2.30
Average	3.88	3.88	3.82	4.58	2.81	2.84

Field Intensity of Tuckerton WGG in Millivolts per Meter

1924

Date	April		May	
	A.M.	P.M.	A.M.	P.M.
1	2.83	2.83	2.96	1.78
2	2.76	3.06	2.53	4.26
3	2.83	2.03	1.98	1.80
4	3.16	....	....	....
5	2.76	3.93	2.83	2.30
6	....	....	3.06	2.30
7	2.96	....	2.76	2.76
8	2.30	....	1.66	2.30
9	4.26	3.06	2.30	2.63
10	2.76	2.96	1.66	2.50
11	2.96	2.70	....	....
12	2.83	2.50	1.66	....
13	....	....	2.30	2.30
14	2.30	....	....	2.53
15	2.76	2.63	2.50	2.96
16	2.76	2.50	2.30	2.30
17	2.96	3.16	2.30	3.16
18	2.76	2.76	....	....
19	2.30	3.16	3.06	3.03
20	....	....	2.70	2.75
21	2.63	2.90	1.98	2.75
22	2.76	....	2.99	3.30
23	2.83	2.96	3.06	3.60
24	....	2.63	2.00	....
25	2.76	2.96	....	....
26	....	5.23	2.70	2.76
27	....	....	2.50	2.30
28	2.83	2.76	1.66	2.60
29	1.70	2.76	2.30	2.10
30	1.83	1.65	....	....
31	....	....	....	2.60
Average	2.73	2.91	2.40	2.65

TRANSMISSION DATA

	Fre-quency kc.	Approx. Antenna Current amp.	Distance from Wash-ington km.	Radia-tion height m.
New Brunswick (WII)	22.04	600	281	66.0
Tuckerton (WGG)	18.85	470	251	67.5

Bureau of Standards
Washington, D. C.

SUMMARY: The paper gives the results of field intensity measurements at the Bureau of Standards on the transatlantic radio stations at New Brunswick and Tuckerton, New Jersey. The summer measurements are somewhat weaker than those of winter and generally the afternoon signals are slightly weaker than those of the forenoon. The most interesting fact observed was the great increase in signal strength which accompanied the passage of the cold waves of January, 1924. This, if verified, will be of special interest as showing a definite connection between radio transmission and the usual weather phenomena.

THE HIGH POWER STATION AT MALABAR, JAVA*

COMPILED BY

THE EDITOR FROM PHOTOGRAPHS AND NOTES RECEIVED FROM
DR. CORNELIS J. DE GROOT

(DIRECTOR OF RADIO, DUTCH EAST INDIES, BANDOENG, JAVA)

It has been deemed desirable to present to the readers of the PROCEEDINGS OF THE INSTITUTE OF RADIO ENGINEERS, in the form of a permanent record, a description of the erection, equipment, and operation of what is to-day the highest power transmitting station in the world, and one which required for its successful construction an unusual amount of perseverance and ingenuity. Situated at Malabar, in the mountains of Java, and at a considerable distance from all cities, the problems of transportation were extreme. This point will be particularly appreciated when the construction of the gigantic arc and its massive magnetic circuits is considered below. It should also be noted that a good part of this construction was necessarily carried out either during wartime or at a period when the disorganization resulting from the war greatly handicapped the engineer-constructors.

The object of the station was to connect the principal cities of Java by direct radio communication with a correspondent station at Kootwijk, Holland, at a distance of twelve thousand kilometers (or seven thousand five hundred miles). It was desired to establish a twenty-four hour per day commercial service over this hitherto unattempted distance, and with reception in a tropical locality where atmospheric disturbances were known to be unusually heavy.

The illustrations of this compilation are arranged in a generally chronological order, thus giving a clear idea of the sequence of events during the construction and an indication of the procedure followed in the erection of large stations of this type.

The station is located at one end of a steep ravine in the mountains, in what was originally a wilderness. The mountains at each side of the ravine serve as antenna supports, as will be

*Received by the Editor, December 1, 1923.

FIGURE 1

described in further detail below. It became necessary, therefore, to build the village shown in Figure 1 in the foreground before work could be begun on the station building shown in the rear. The character of the country is also clearly depicted in this figure. A closer view of the station building in process of erection is given in Figure 2. A temporary roof is in place, and

FIGURE 2

a crane for the erection of the large arc is in place, as are the generator foundations.

Unusual precautions were taken to ensure continuity of power supply for this station. Two double 25,000-volt overhead lines carry power to the station, one from the north and the other from the south. Each of these connects both to steam-driven plants and water power plants. Thus, even in the dry season, complete reliability is obtained by dependence on the steam-driven plants. A sub-station is provided at the end of these lines, containing four transformers, each of 2,000 kilovolt-amperes, and for reducing the voltage from 25,000 to 6,000. One of these transformers is a spare. Appropriate oil switch gear is also provided in the sub-station. The layout of the horn gap arresters in this sub-station is shown in Figure 3, and the core and windings of a 2,000 kva. transformer in Figure 4. In a fireproof cellar within the transmitting station are mounted the three 250-kva. 6,000-

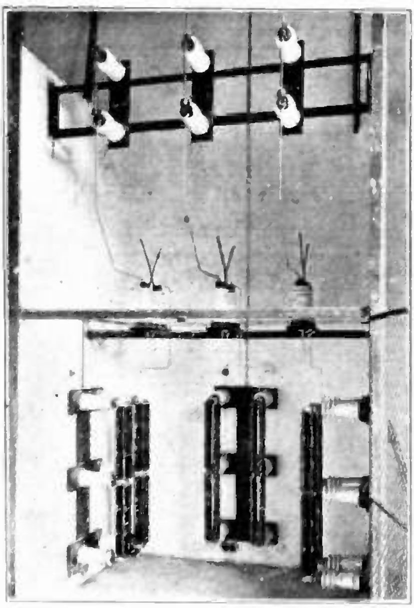


FIGURE 3—Horn Gap Arresters.

220-volt transformers shown in Figure 5, which transformers feed the motor generators in the station up to 100 kw. The large motor generators are operated directly on the 6,000-volt circuits.

There are two hydraulic power plants near the station, each of 200 kilowatts output, which act as a reserve source of power. They also form a spare source for supplying motor power to the

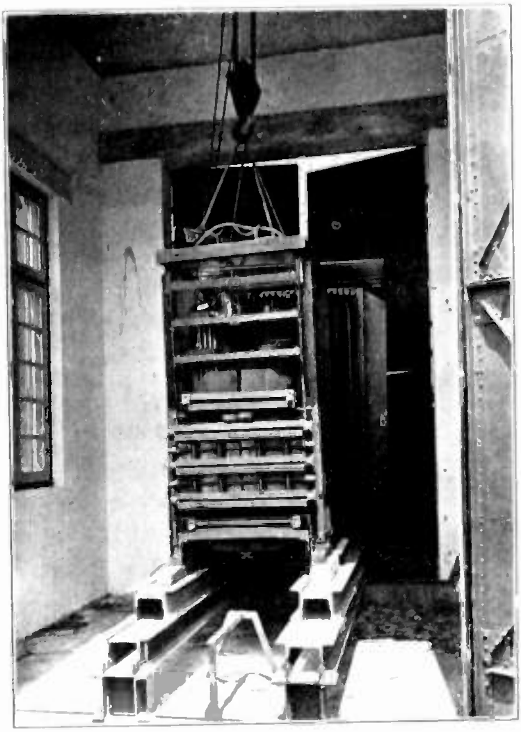


FIGURE 4—Core and Windings of 2,000 KVA Transformer

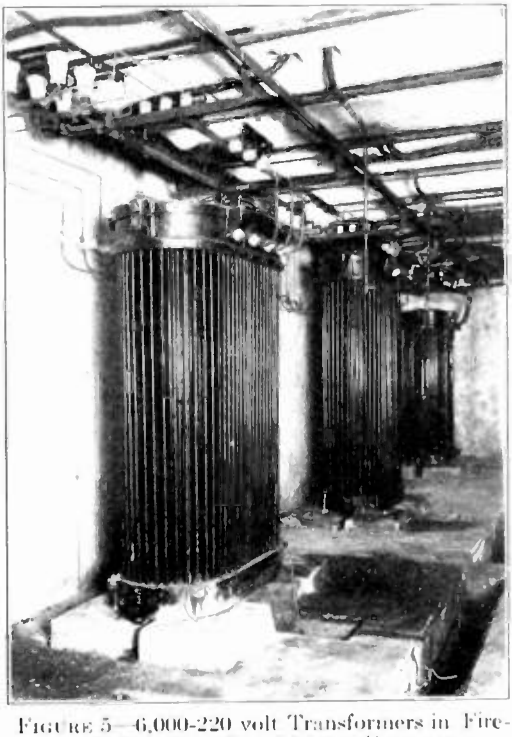


FIGURE 5—6,000-220 volt Transformers in Fire-proof Cellars for Small Motor Generators

water pumps for use in case of fire, and can supply the radio station in case the overhead lines fail or are cut. On the power available from these plants, it is possible to reach Holland at night and all of India, Cavite, or Japan by day or night. The water for these plants comes from a small river flowing down the ravine which is led into settling pools for the removal of sediment. An old wooden conduit which conducts the water from the settling ponds is illustrated in the back of Figure 6, while the

FIGURE 6

beginning of the new tunnel is shown in the left-hand front of the same figure. This same tunnel ends in an open conduit which leads into the first reservoir, and appears in Figure 7. In Figure 8 is seen the process of filling the reservoir, from which the wooden pipe shown in Figure 9 leads down to the first turbine. This wooden pipe—a war necessity—has stood up well under the pressure. It was obtained from Australia during wartime, steel pipe being unobtainable. The hydraulic plant itself is shown in Figure 10. The water wheel, at the left, was taken from a 20-year-old gold placer mine installation in Sumatra during war time. New regulators for speed control have been recently added. This wheel drives a 1,200-volt 150-kilowatt direct current generator obtained in Japan, and the only type available during the war. This generator is now connected by cable to the new radio station, where it can feed the smaller arcs. It is planned shortly to change this generator over into a 6,000-volt three-phase machine, so that the entire power supply to the radio station will be of uniform character.

After leaving the first hydraulic plant, the water flows to the second turbine shown in Figure 11. This turbine runs two

FIGURE 7—End of Tunnel with Open Conduit to First Reservoir

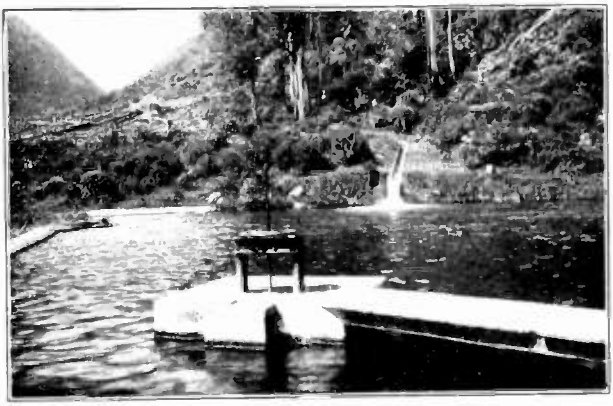


FIGURE 8—Filling Reservoir

2,000-volt three-phase alternators which are also to be replaced by a 6,000-volt three-phase alternator. The current from these alternators passes thru an overhead line to the fire pump station, which is therefore provided with an independent source of power for emergencies. This fire pump is placed near the new radio station, and from this point the power is run by

FIGURE 9

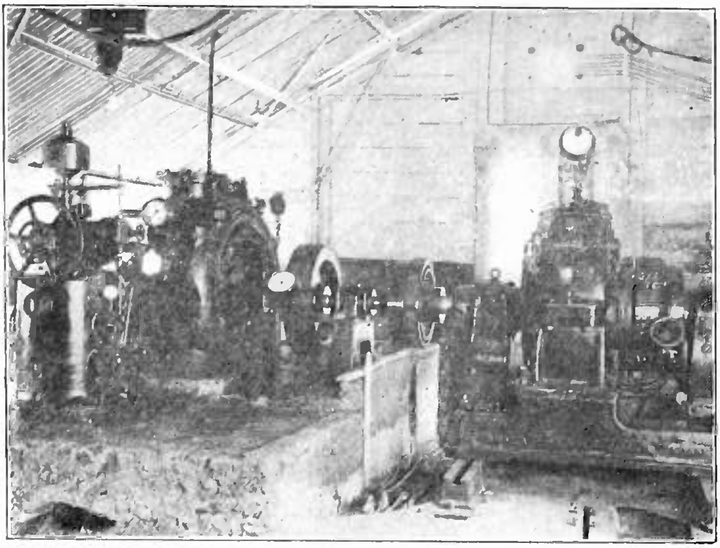


FIGURE 10

cable to the station where some motor-generators for the small arcs are fed by it. These are motor generators of 200 kw., 150 kw., and 100 kw. direct current output respectively. The first two were purchased in Japan, whereas the latter was obtained from America in wartime. In Figure 12 is illustrated a 6,000-volt 200- kilowatt generator at the radio station. Work was started on a 100-kilowatt Federal Telegraph Company arc. By 1918, this arc had reached the antipodes, and by 1919 it had reached Holland regularly at night time. Its use with Holland was discontinued in 1922 after completion of the 400 kw. Telefunken alternator.

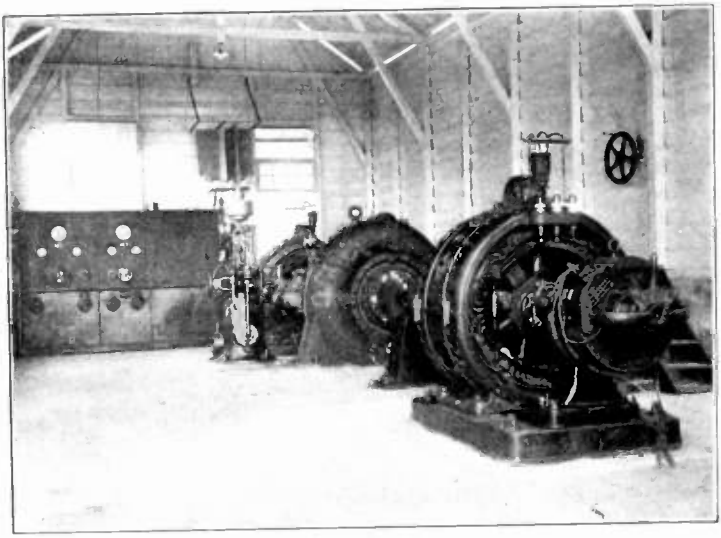


FIGURE 11

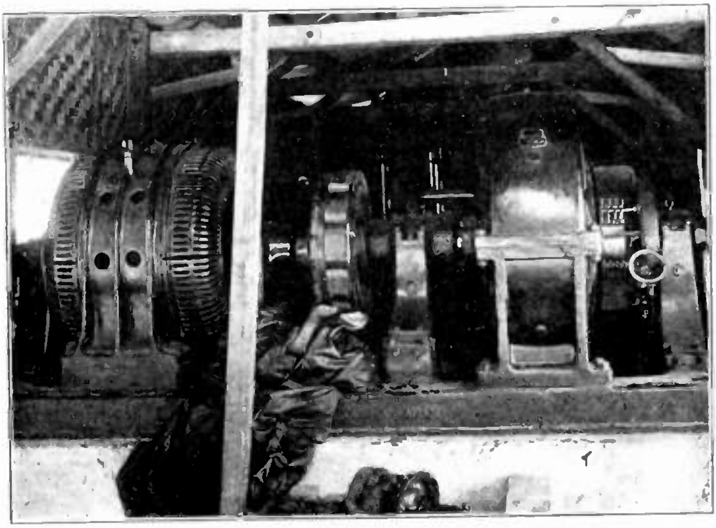


FIGURE 12—6,000-volt Motor Generator, 200 KW.

The machine room floor on which most of the preceding machines are now placed is shown in Figure 13. The switchboards to the right, for control purposes, were fabricated at the shops of the Malabar station. For supplying power to the high power arc at the new radio station, there are provided two large motor generators, shown in Figure 14. Each of these is capable of delivering 1,200 kilowatts at 3,500 volts direct current. They are

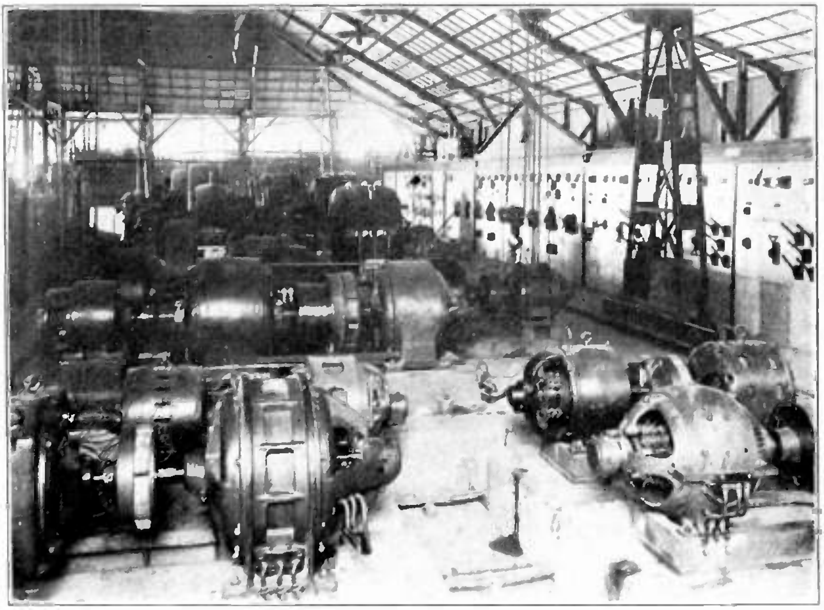


FIGURE 13

now worked in parallel every day to supply a power of 2,400 kilowatts to the arcs whereby 1,200 kilowatts are fed into the antenna. Two more of the motor-generators are to be added next year, one being a spare. It will thus become possible to supply 3,200 kilowatts to the arc, obtaining about 1,600 kilowatts in the antenna. These motor generators were supplied by the General Electric Company and operate very satisfactorily. The quick-break switches for these motor generators are mounted in the cellar, and are shown in Figure 15. These also work well and prevent flash-over on an occasional short circuit on the generators resulting from the normal operations of the arcs without any series resistance.

The lower arc core was erected, using a hydraulic jack. Its cross section is of logarithmic shape so as to produce a maximum flux. The huge magnetic circuit of the arc is built up of numerous

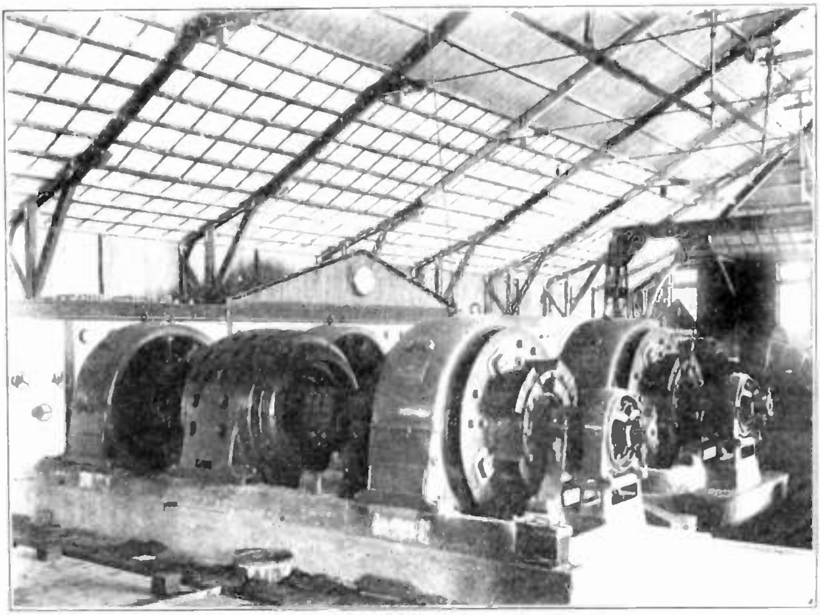


FIGURE 14

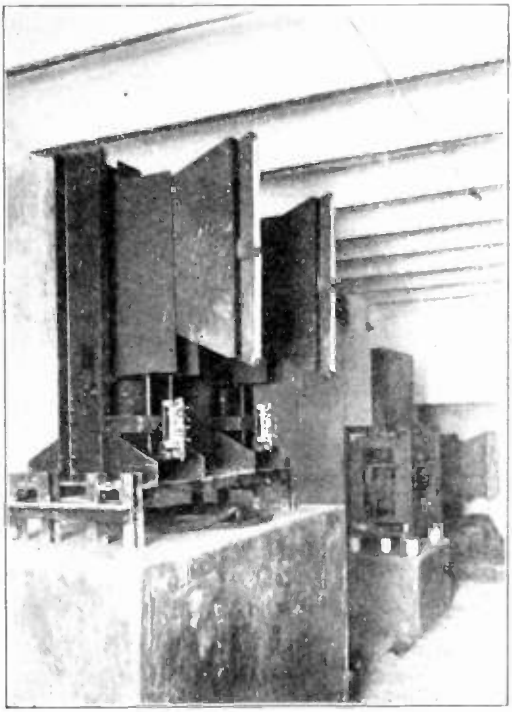


FIGURE 15—Quick Break Switches for Motor Generator

large pieces of cast iron, each weighing between 1,000 and 6,000 kilograms (2,200 and 13,200 pounds), all held together by steel plates and bolts. This construction was required because of the limitation on the size of castings which could be produced and machined in the Javanese foundries. The method of assembling the magnet core is clearly indicated in Figure 16, which represents the

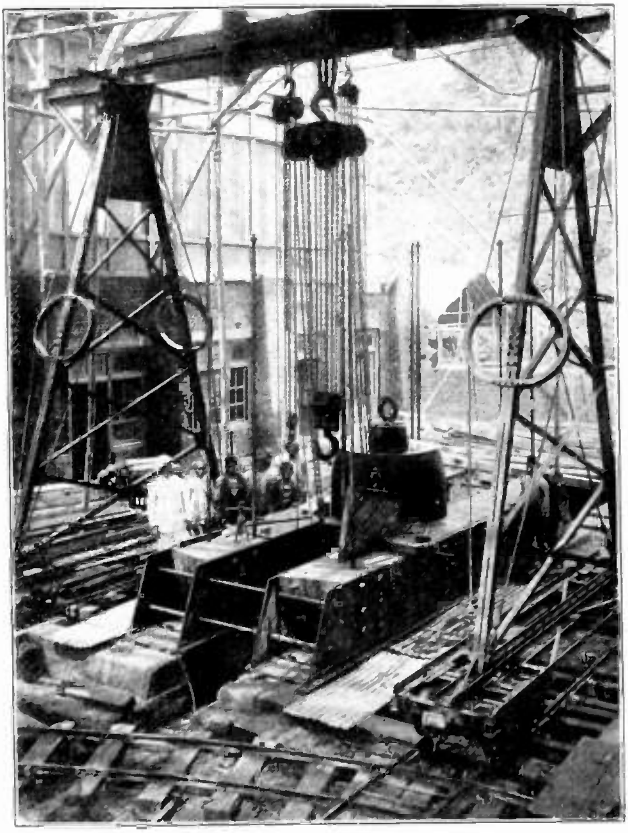


FIGURE 16—Method of Assembling Magnet Core. Lower Core Complete Except Conical Tip and Base.

lower core complete except for the conical tip and the base. The core can be moved vertically by hydraulic pressure and weighs 25,000 kilograms (nearly 28 tons). The lower magnet coil, which also acts as a choke coil in the arc supply circuit, is placed in an oil tank illustrated in Figure 17. After this tank was placed in position and portions of the vertical iron pillars forming the magnetic circuit were in place, the photograph of Figure 18 was taken, the building having progressed considerably by that time.

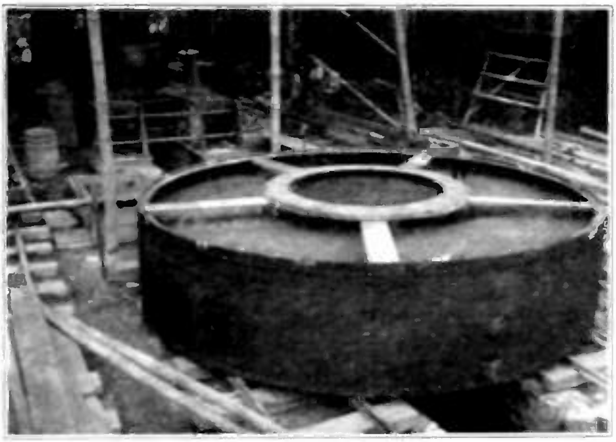


FIGURE 17.—Oil Tank for Lower Magnet Coil

FIGURE 18.—Oil Tank and Vertical Magnet Pillars in Place around Lower Coil

The construction of the lower magnet coil was a difficult task. The beginning of the winding is shown in Figure 19, and Figure 20 shows the winding nearly completed. The actual conductor was made up of nine square-cross-section copper conductors, 7 mm. by 7 mm. (0.3 by 0.3 inch), these being com-

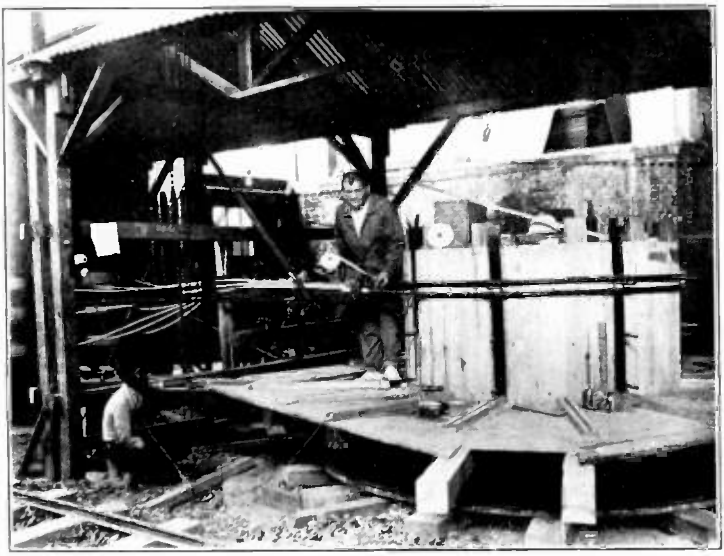


FIGURE 19—Beginning Lower Magnet Coil

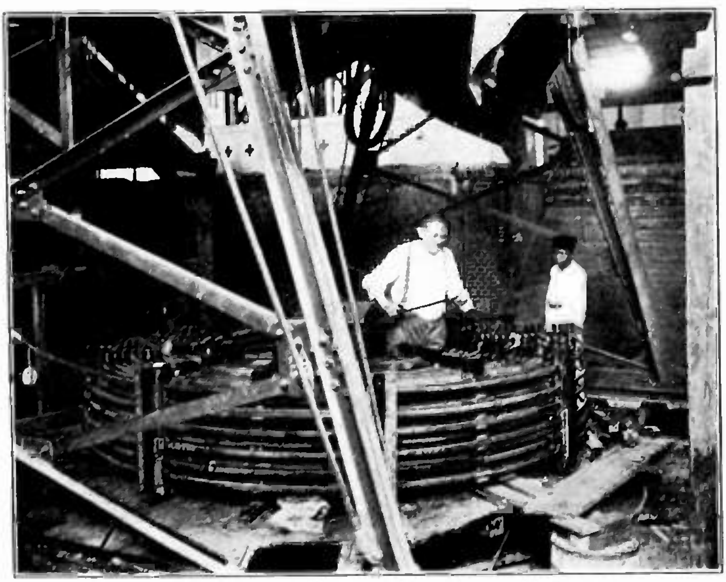


FIGURE 20—Lower Magnet Coil Nearly Completed

bined into a single conductor of 450 square mm. (1.4 square inch) cross section. It was insulated to withstand 60,000 volts from the arc. During a year of rough use, no trouble has developed in this coil. The copper in this coil weighs 10,000 kilograms (22,600 pounds). The coil is wound in seven concentric cylindrical layers for easy erection and repair.

The next group of photographs shows serially the growth of the large arc. In Figure 21, the lower coil is in place, together with the upper magnet core, and a part of the upper bridge. The four-pillar construction of the outside elements of the magnetic circuit is clearly shown in Figure 22. This type

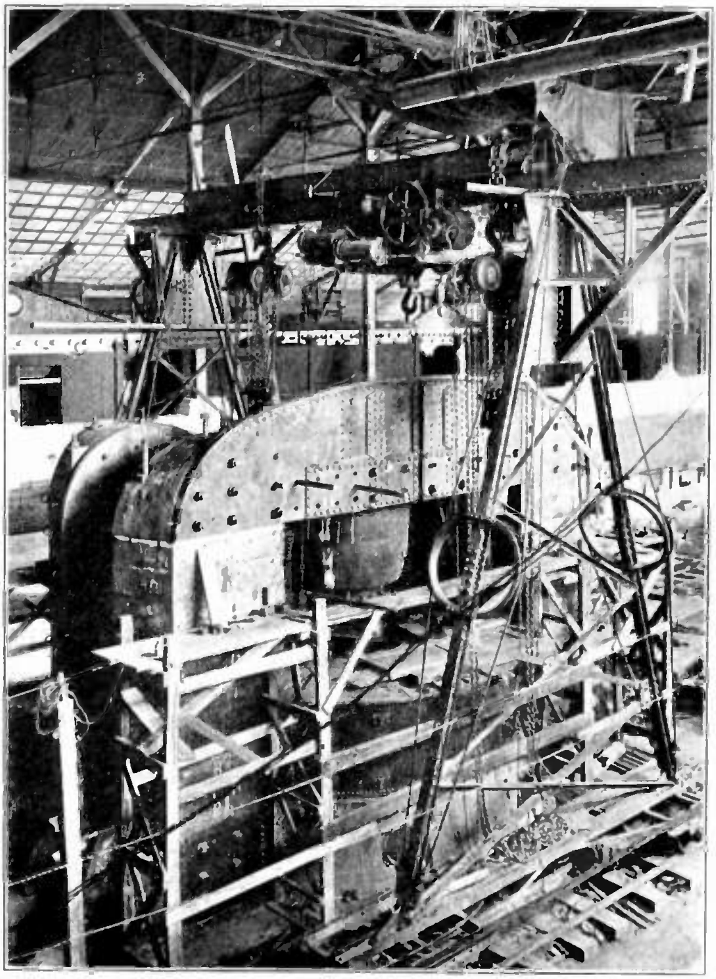


FIGURE 21—Lower Coil in Place and also Upper Magnet Core and Part of Upper Bridge

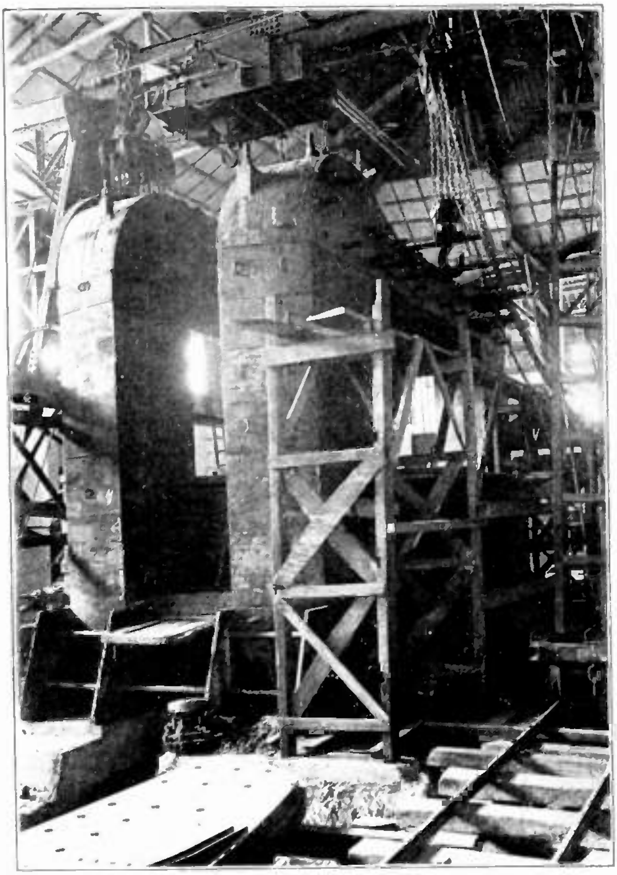


FIGURE 22

of construction was adopted to give the arc mechanical stability, and also to enable the easy insertion of the cathode and anode of the arc. The completed magnetic circuit weighed 260,000 kilograms (260 tons), and appears completed in Figure 23. The erection of the arc was taking place during the photographing of Figure 24, and it will be noted that a graceful tribute has been paid to the radio pioneers, Poulsen and Marconi, by inscribing their names in the tiling on the walls of the station. Arco, Alexanderson Wien, Latour, and Meissner have been similarly honored by inscriptions on the end walls of the station, which are illustrated later in this compilation.

The process of winding the upper magnet coil is shown in Figure 25. This coil is independently excited in order to regulate the field to a value most suitable for the wave length at which operation is being maintained. Figure 26 gives a close-up view

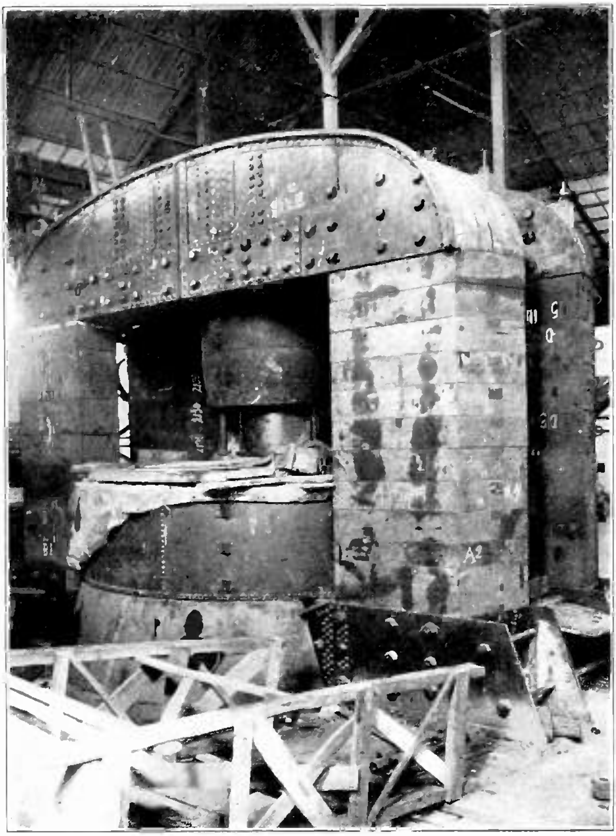


FIGURE 23—Magnetic Circuit

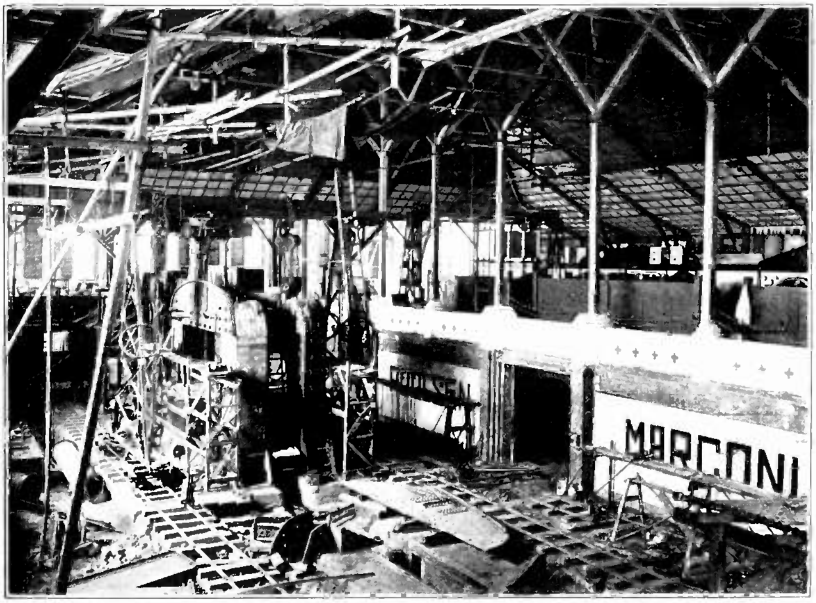


FIGURE 24—Erection of Arc.

of this upper coil in place together with the interior of the oil tank containing the lower coil. The shape of the conical wrought-iron tip of the lower pole is to be noted. The upper pole tip is of the same shape. By this time, the construction of the arc was

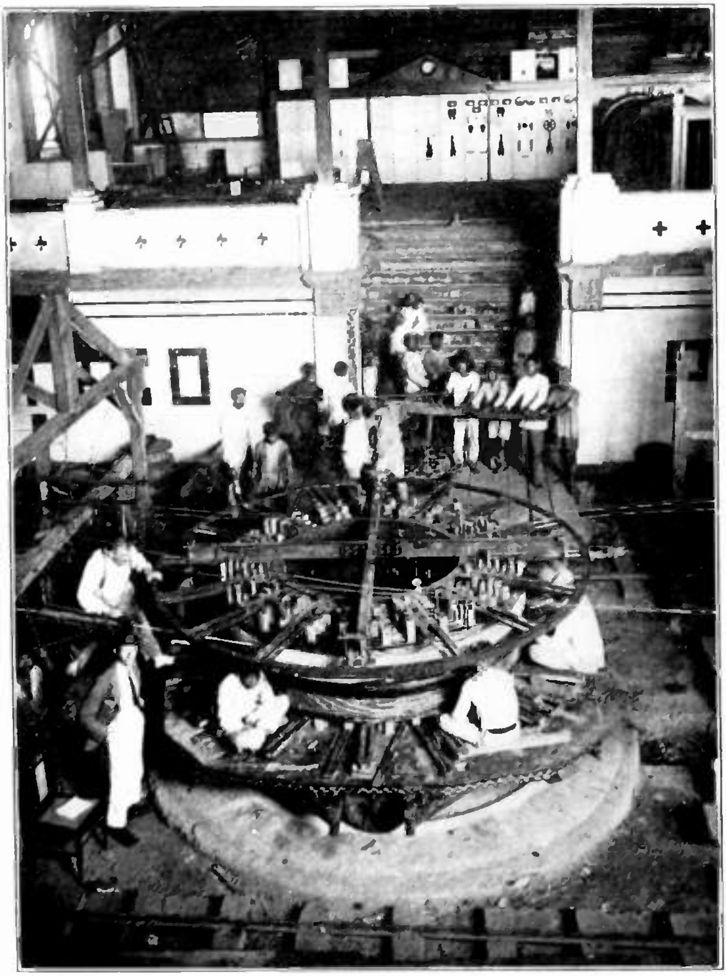


FIGURE 25—Winding of Upper Magnet Coil

proceeding rapidly, and the process of inserting the brass arc chamber (weighing 5,000 kilograms or 11,000 pounds) is illustrated in Figure 27, wherein also appear the magnetic circuits of two auxiliary arcs for military work, each of 200 kilowatts input power. After the arc chamber was in place, the safety valve was fitted into its side as shown in Figure 28. Not long thereafter it was possible to open the station officially, and Figure

29 shows the memorable occasion on which the first service messages were sent direct by day to the Queen of Holland from the Governor-General of the Dutch East Indies.

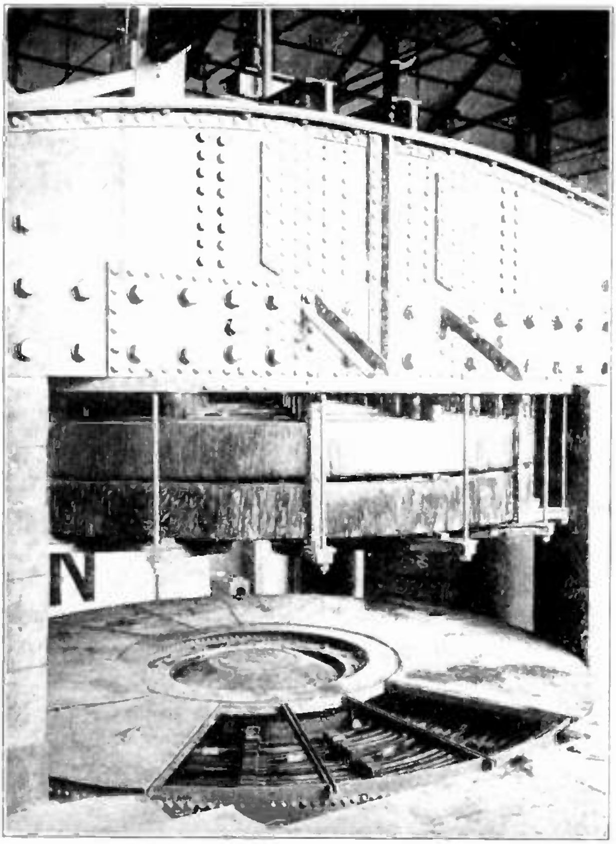


FIGURE 26—Upper Coil in Place, also Interior of Lower Drum

Some of the station auxiliaries merit attention. Cooling water for the circulation system of the arcs and for the fire pumps is run thru filters, and then reaches the arcs. After leaving the arcs, it passes to a cooling pond in the front of the station, whence it is pumped back to the upper reservoir. The cooling at the pond is carried out from horizontal spray pipes. The pipe to the upper reservoir and the tunnel from the reservoir are illustrated in Figure 30. The station is also provided with a plant for producing pure hydrogen for the arcs (to ensure continuous operation without cleaning) and tanks for storing hydrogen and oxygen in sufficient quantities. The cooling reservoir and pumps, while under construction, appear in Figure 31.

The control of the large radio frequency output of the station presented some problems. A remotely controlled switch had to be provided for selecting whichever one of the arcs was to be connected to the antenna. It is shown in Figure 32. The insulators are of hard rubber, made in the rubber factory at Bandoeng during wartime, and corona helmets are provided over

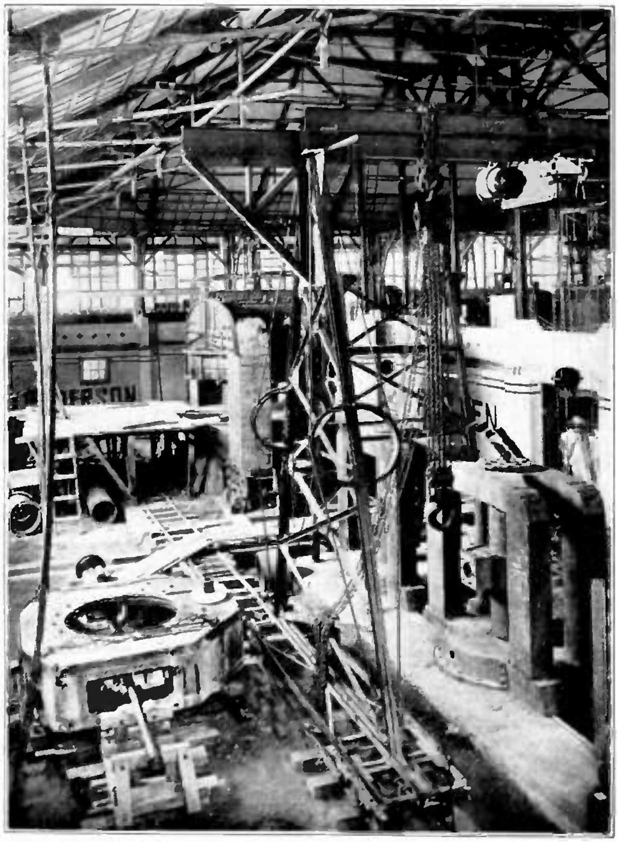


FIGURE 27—Brass Arc Chamber, on Way to Mounting Platform

the switch contacts. The arrangements for the tuning of the station are indicated in Figure 33, which is a photograph of the equipment in process of construction. The loading coil at the right is of copper tubing silver-plated. Two of these coils placed in the main antenna enable covering the wave length range from 7,000 to 20,000 meters. A number of taps connected to a selector switch (remotely controlled) enable tuning to within 1,000 meters by this method. A switch is also provided between the two antenna loading coils to prevent dead-end losses. The selector switch in question was under construction at the time this photograph was taken. It consists of a long vertical shaft with a rotating switch arm, with motor drive thru a worm wheel at its lower end. It is mounted on insulators designed to withstand 150,000 volts. For fine tuning of the set, the Rendahl variometer at the left is provided. By its use it is possible to alter the wave length of the station by as much as 1,000 meters

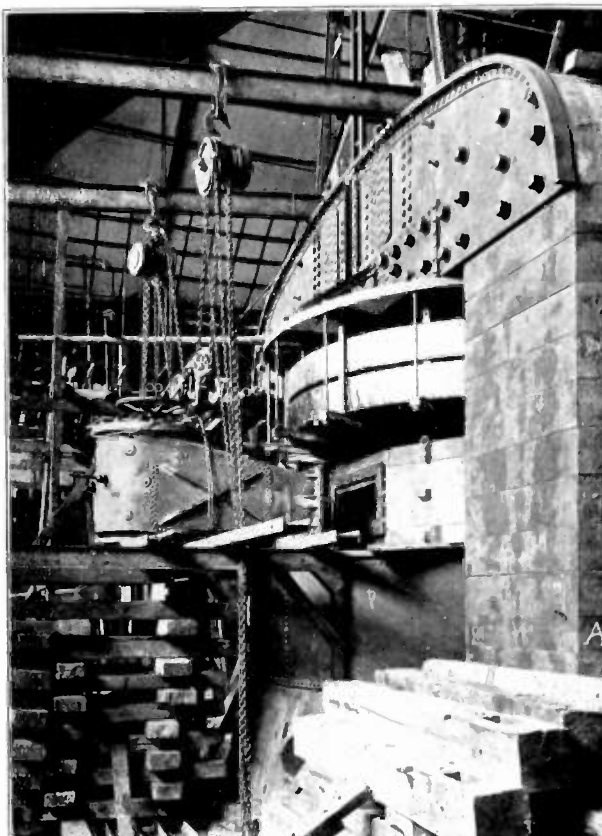


FIGURE 28—Arc Chamber and Safety Valve Being Fitted

while the arc is in operation, which is of importance for a station intended for the special services required in this case. Each arc is provided with its own direct-reading wave meter built by the Lorenz Company. The operator of the station can remotely control the tuning variometer, thereby avoiding even small variations in the wave length of the stations during transmission. In Figure 34 is shown a front view of a portion of the station building. The antennas are led out thru a hole in the front of the building, since all forms of porcelain tubes failed in the foggy climate of Java. The down-leads of the antennas are clearly visible in the figures as well as the strings of disc insulators.

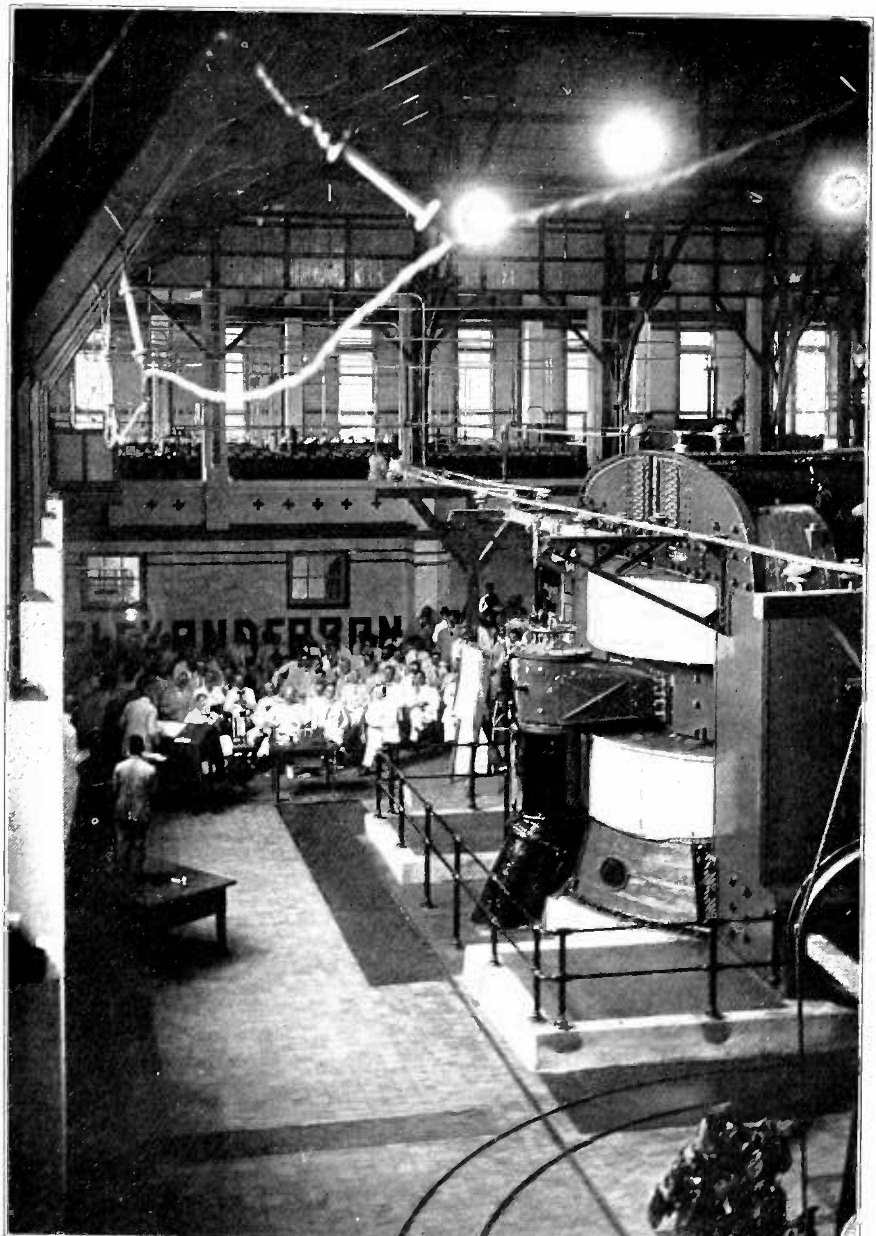


FIGURE 29—Sending First Service Message from Java to Holland

FIGURE 30—Upper Reservoir

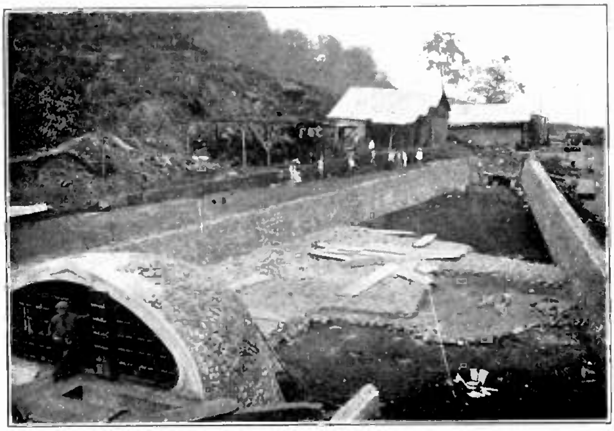


FIGURE 31—Cooling Reservoir Under Construction, and Pumps

These have since been replaced by porcelain insulators. The four towers at the two ends of the building are not purely ornamental. They serve to support the lower ends of the four antennas which it is planned to use for four simultaneous transmissions in the future. The present antenna is supported by five hawsers fixed to the local mountain tops and crossing the ravine. To keep the tension in the antenna constant, the wires thereof are passed over pulleys in the building tower tops and then counterbalanced by weights. At every one of the cross-ravine hawsers, the antenna wires run over large aluminum pulleys on ball bearings, which pulleys are fastened to the lower ends of the corona shields, ending the strings of insulators. The aerial is worked at an effective voltage of 125,000 and shows traces of corona. As it is intended to raise the voltage to 150,000 for full power, a special aerial wire having a ¾-inch hemp core

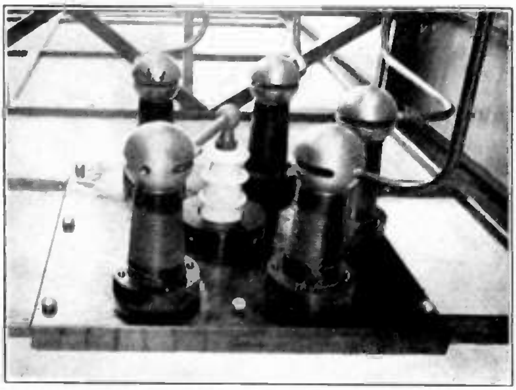


Figure 32

will be used in the future. In Figure 34, the Governor-General is shown just leaving the station on its opening day. The cooling pond and the pump appear at the left of the figure.

In addition to the arc installations constructed, erected, and owned by the Radio Department of the Government Telegraph Service, the Telefunken Company was allowed to erect at their own risk in an annex a 400-aerial-kilowatt radio frequency alternator.

The Telefunken Company's installation is shown in Figures 35, 36, and 37. The station is installed on one of the large elevated galleries and is practically a duplicate of those at Nauen, Germany and Kootwijk, Holland. It is still owned by the Telefunken Company. It operates very reliably, though only at manual speed when radiating full power, but is not powerful enough to meet the contractual obligation of providing 24-hour per day commercial service to Holland. It is, in fact, only trustworthy at night, and even then fails absolutely on many nights in the bad season. Because of obligations incurred by the Dutch Government in wartime, it will be purchased. It is an excellent mercantile transmitter for less distant work, such as service to Japan, Saigon, Australia, and Cavite in the Philippines. It serves in this way to collect messages for re-transmission to Europe and can serve during part of the year as a spare transmitter to Europe.

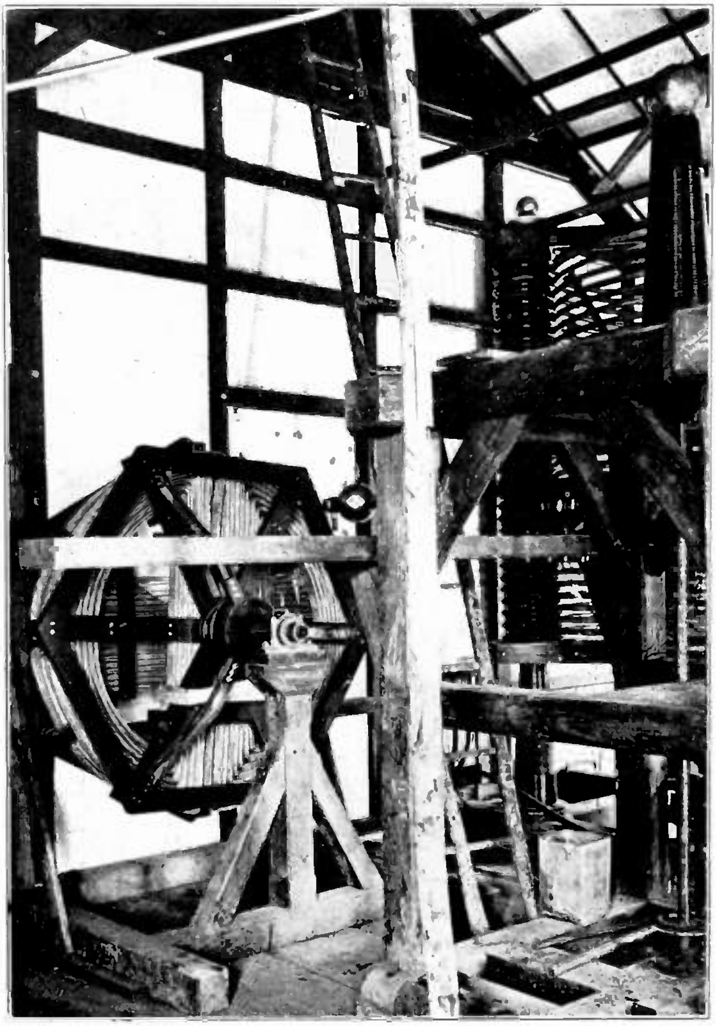


FIGURE 33—High Power Tuning Equipment

FIGURE 34

In Figure 37, the control relays of the Telefunken alternator set are shown in the front. There is also available a magnetic amplifier for key control of the transmitter which, however, does not function properly at high speeds since the antenna power decreases markedly as the speed increases. In the background of this figure are seen the frequency doublers and triplers. The four fixed wave lengths of this set are 7,500, 10,000, 15,000, and 20,000 meters. The first two often provide excellent service to Holland in the night time. The 15,000-meter wave is best in the daytime, but does not give reliable communication on the available power of this transmitter. The 20,000-meter wave can never be copied, either day or night. The results found by experiment are not in accord with the Austin-Cohen transmission formula, since the best wave length for daytime working over a 12,000-kilometer

FIGURE 35

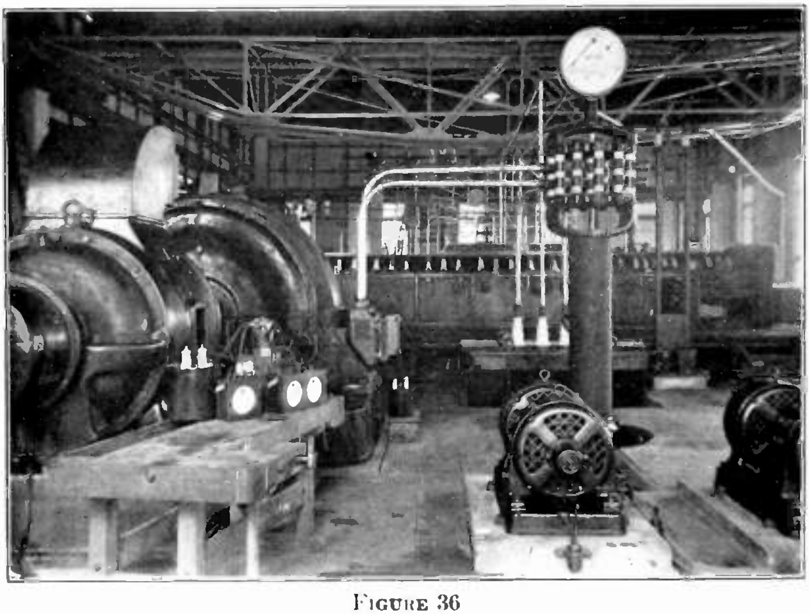


FIGURE 36

stretch (7,500 miles), from Java to Holland is found to be about 16.000 meters both for the arc and for the alternator, which is several times smaller than the value given by the formula. During complete darkness, the best results are obtained on wave lengths of between 7,500 and 9,000 meters even with a much smaller output. All-year operation requires about 120,000 meter-

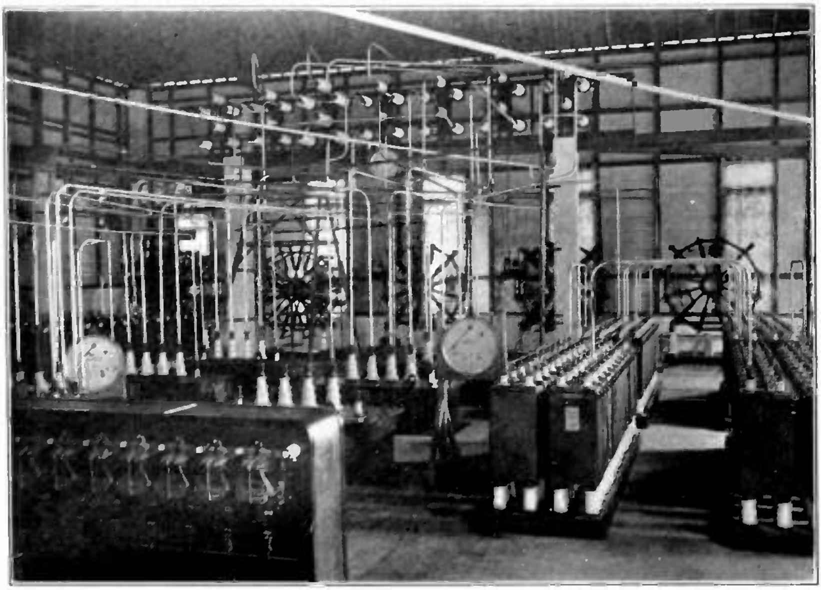


FIGURE 37

amperes on the shorter wave. In full daylight, 250,000 meter-amperes are required on the 15,000-meter wave. During the hours when the transmission path is partly illuminated, the full output of 300,000 meter-amperes is rather below the necessary output for commercial communication. During a recent twenty-four hour test working to Holland, and with the arc furnishing about 200,000 meter-amperes on the 15,600-meter wave at hand speed, communication could be maintained for nineteen hours for plain language text and for eighteen hours with code text. It was possible to deduce from these results that, using the full 300,000-meter-ampere output of the station, twenty to twenty-one hours' daily communication could be dependably secured, which would enable handling more traffic than is now available between Java and Europe. However, it is necessary to await improvements in reception before thoroly satisfactory 24-hour per day communication with Holland can be obtained during the entire year. Of course, the weak 50,000 meter-ampere alternator transmitter, working at a long wave length in Holland, gives very poor service in Java thru the strong local static, and is of use chiefly during the night time. This naturally hampers the service from Java to Holland to a considerable extent.

The station being in an isolated location, a repair shop has been provided at the transmitting station. The receiving station is located at Tjangking, and is illustrated in Figure 38. The taller structure in the background is the receiving station, the coil antenna being mounted in the upper story. The lower stories

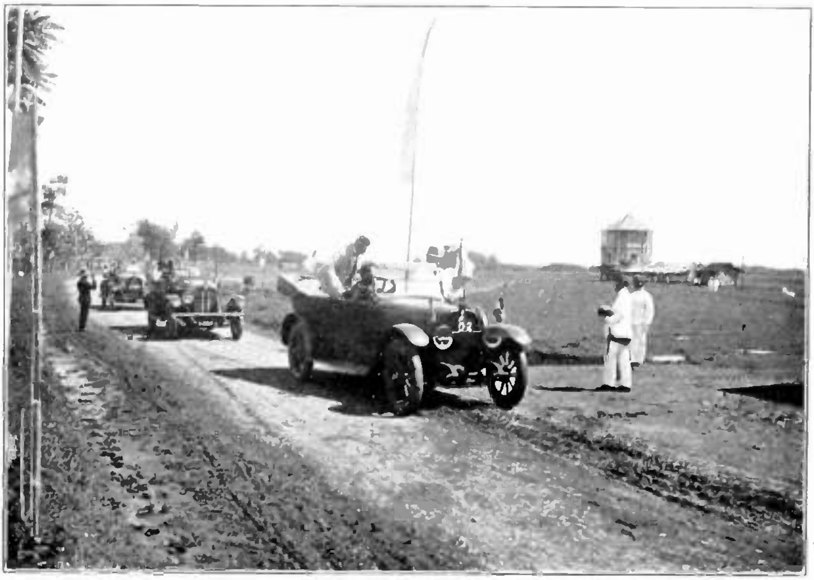


FIGURE 38—Receiving Station, Tjangking

are apparatus rooms completely enclosed by sheet iron. Receivers are provided for four simultaneous services. Either coil antennas, long horizontal wires, or buried wires are used for reception. When the loops are employed, there is no interference whatever from the Malabar station working at a slight wave length separation from the incoming signal, even tho this very powerful transmitter is only 9.5 kilometers (5.9 miles) away, thus demonstrating the purity of the wave of both transmitters. The other structure shown is an exchange or central from which wire lines branch out to the large towns of Java, to the Malabar transmitters, and to the various receivers. This central will be transferred to Bandoeng at a later date. Its present situation has, however, some advantages since no town in Java is a large business center in comparison with large European and American cities. Therefore, except for the comfort of the staff, there is no great advantage in having the central located in a large town. Siemens high speed transmitters are used on the circuits leading from the central station to the chief towns of Java. The Malabar transmitters are worked by Wheatstone equipment, even when operated at hand speed, to ensure accuracy and also enable the tape to be inspected before transmission, and to be stored against possible later claims for errors in transmission.

The arc has been operated recently at higher speeds—up to sixty words per minute—reception in Holland being accomplished on a special receiver patented by the Dutch East Indian Government. The transmission is based on an entirely new principle, the keying for compenastion wave being done by a very small pneumatic relay which alters the frequency by only one-half of one part in a thousand in changing from the working to the spacing wave (at hand speed), and from one to one-and-a-half parts per thousand for high speed transmission. Such slight frequency changes are almost unnoticeable in the case of aural reception and are insufficient for copying on all other known forms of recorders, especially at the longer wave lengths. The high degree of frequency constancy obtained at the Malabar arc station is evident from this method of reception. This method of transmission removes the objection to the compensation wave system of keying, enables the use of light and quick-acting control mechanism (which is of great advantage in very high power stations), and even without the use of a code (which limits the operating speed) provides practically absolute secrecy against amateur reception. A portion of a test tape made in Holland on the Malabar reception is shown in Figure 39. This illustrates hand speed and higher speeds up to 45 words per minute.

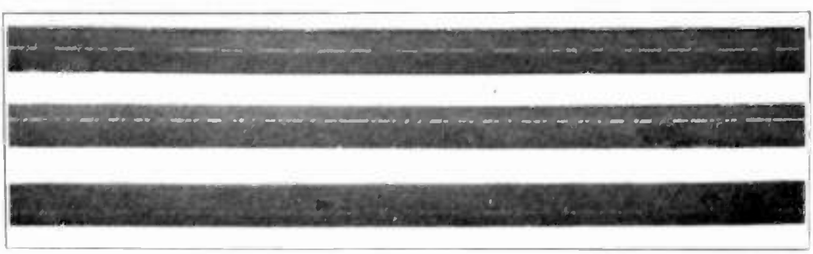


FIGURE 39

The Malabar transmitter PKX operates on the 15,600-meter wave using the arc transmitter or alternator every day except Sunday from 23.40 to 10.40 with brief interruptions when local traffic is being handled. Operation is also carried on using the arc on the 13,400-meter wave from 12.40 to 18.40; and from 18.40 to 23.40 the arc or alternator is used mostly on the 7,700-meter wave (altho at times the 13,400- or 15,600-meter wave is used during this schedule). All the above are Greenwich Mean Time. Station PKX can be copied almost continuously at the Radio Corporation of America and Naval stations on the Pacific Coast of the United States. It has been copied during a six-hour stretch at its antipodes—Curaçao—during the previously mentioned 24-hour tests. Communications relative to the reception of this station at remote points, if addressed to the Editor of the PROCEEDINGS OF THE INSTITUTE OF RADIO ENGINEERS, will be promptly forwarded to the administration of the station, who, it is known, will be glad to obtain either graphic records or data on ear reception of this station.

SUMMARY: The construction of the Malabar, Java station of the Dutch East Indian Administration for direct communication with Holland is described. The antenna structure, high power and low power arcs, the alternator transmitter, and the receiving arrangement are considered.

SHORT-WAVE RADIO BROADCASTING*

By

Frank Conrad

(Westinghouse Electric and Manufacturing Company, East Pittsburgh, Pennsylvania)

During the year of 1920 the author, for a hobby, maintained a radio transmission schedule with Mr. J. C. Ramsey, of Boston, with the power then available, that is, about 100 watts in the antenna; communication was very uncertain during the summer months and, in fact, had to be abandoned during the particularly unfavorable periods owing to the reduction of the received signal and the increased interference from strays. The radio frequency employed in these transmissions was about 1,200 kilocycles (250 meters). Being aware of the reduction of atmospheric strays on the higher ranges of frequency then in use, and from some experiments in listening to harmonics from other transmitting stations, the author was convinced that there were greater possibilities of improvement in reliability of transmission by increasing the frequency than by decreasing it, as was the general tendency at that time. Accordingly, a series of tests were run between Mr. Ramsey's station (1XA) in Boston and the author's station (8XK) in Pittsburgh. The cooperation of the station of the Massachusetts Institute of Technology (IXM), and that of Mr. R. D. Decker (1RD), of Boston also was enlisted in the tests. These tests were made during the spring of 1921 and consisted of a series of transmissions from each of the Boston stations at various wave lengths and of measurements at Pittsburgh of the audibility of received signals.

The curves in Figure 1 show the ratio of signal strength from the different stations at the various wave lengths operated on. The transmitters were adjusted to give a maximum output at each wave length, with a constant input to the oscillating tubes. Owing to the great variability of the strength of night signals and the small numbers of observarions taken, the results served as only crude approximations, but they indicated some gain of sig-

* Received by the Editor, April 14, 1924. Presented before The Institute of Radio Engineers, New York, April 16, 1924.

nal strength as the frequency was increased, which, coupled with the great reduction in interference from strays on the higher frequencies, would increase the reliability of transmission with a given antenna power.

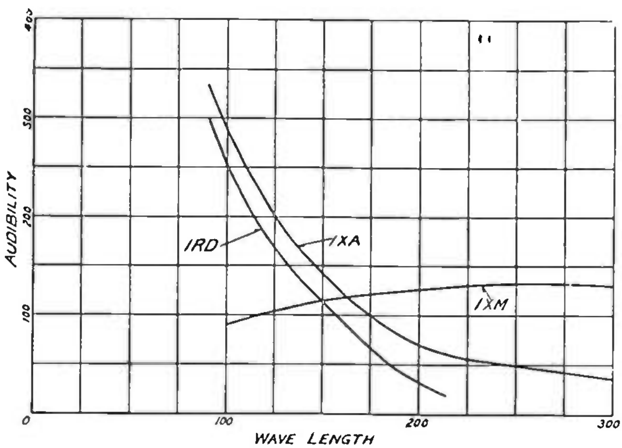


FIGURE 1

To permit of further observations, the equipment at 1XA and at 8XK was remodeled to better adapt it to the higher frequencies. The circuit finally used is seen in Figure 2, which, for the sake of clearness, shows the radio frequency oscillating circuits only. The equipment consists of a coupled circuit in which the local oscillating circuit is coupled to the antenna circuit thru the coupling condenser (*C*). With this arrangement it is unnecessary to extend the antenna down-lead into the building containing the radio equipment, and as the current in the coupling wire is small, because it represents the energy component only, a comparatively small conductor can be used. This small current minimizes losses due to radio frequency fields. The operation of this transmitting scheme was so satisfactory that it was adopted for the several broadcasting stations operated by the Westinghouse Company. The entire system has been described in a previous paper by Mr. D. G. Little.

As no coupling coils are required, the antenna can be operated at its fundamental without the introduction of loading condensers or inductances. The fundamental of the antenna at 8XK was approximately 2,700 kc. (110 meters), at which frequency it was operated. The fundamental of the much smaller antenna used at 1XA was approximately 5,000 kc. (60 meters), and transmissions were carried on from this station on frequencies ranging up to this value. The transmission tests during the following year between these two stations indicated much greater reliability of communication than during previous operation on 1,200 kc. (250 meters). In fact, with the same power which had previously been employed, there were seldom any conditions under which night transmission by straight continuous wave telegraph could not be carried out.

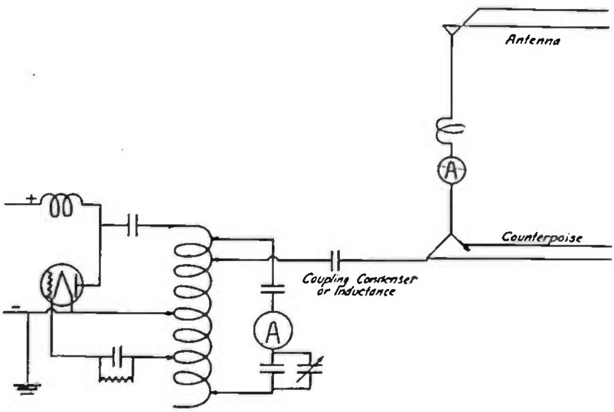


FIGURE 2

As it was evident that the greatest use of these high frequencies would be over the longer distances where communication becomes difficult with the ordinary broadcasting frequencies, it was decided to build a transmitter with sufficient power reliably to cover the range then somewhat uncertainly covered by the broadcasting stations of the usual power; that is, about 500 watts. This transmitter was then built as an adjunct to the transmitting equipment of KDKA, at Pittsburgh, thereby permitting of more continuous observation by transmitting the program of KDKA simultaneously on its regular broadcasting wave and on one of a higher frequency.

The general scheme of the transmitter is the same as that just described. The antenna shown in Figure 3 consisted merely of a vertical pole mounted on the flat roof of one of the factory buildings; the pole being directly connected to the building structure. In order to eliminate high resistance joints in this pole, a number of continuous copper strips were fastened to its surface and at the foot of the pole these strips were carried out over the roof, forming an extended ground. Measurements showed that nearly all the current was confined to the copper strips, altho a small percentage was conducted down thru the iron pole to the building frame. The degree of coupling between the antenna and the local oscillating circuit is determined by the point of connection of the leads on the pole or coil and on the impedance of the coupling condenser.

FIGURE 3

In the operation of this transmitter, difficulty was experienced in maintaining a fixed frequency. When operating, the wave would vary thru a range of frequencies of as much as 1,000 cycles, so that it was very difficult to carry on telegraphic reception by the heterodyne method or to receive telephone signals on a sharply tuned set. This variation of frequency was apparently due in part to changes taking place in the various circuits of the building, which acted as an extended ground. Any alteration of circuits in the interior of the building was found to have a slight effect on the resonant frequency of the antenna.

To overcome this difficulty, the vertical-pole antenna was replaced by the conventional form of inverted "L" with insulated counterpoise, the counperpoise being placed about 12 feet (3.7 m.) above the building. This arrangement was found to overcome the abrupt frequency shifts, but there remained the general irregular fluctuations of this frequency due to various causes, such as the vibration of connecting wires or the variation of plate supply voltage. To overcome the effects of vibration, the inductances were wound from strap on heavy frames, and all connecting conductors were made from copper tubing rigidly supported on insulators. The small remaining vibration due to machinery in the building was eliminated by suspending the whole transmitting structure from a set of springs. To improve the regularity of the supply voltage, power was supplied to the transmitter thru separate lines run direct to a special generator in the powerhouse. The effect of these precautions was greatly to improve the constancy of frequency.

For telegraphic communication it was found preferable to signal by key modulation or the so-called spacing wave rather then by totally interrupting the antenna power; the use of the spacing wave eliminating key clicks in receiving sets tuned to broadcasting waves. The spacing wave was about 500 cycles removed from the signal wave, this shift being brought about by shunting a small capacity across one turn of the primary tuning inductance. The amount of energy in this additional shunt circuit was so small that it could be controlled by a relay similar to the ordinary telegraph relay. In the final form of relay, no contacts were used, the change in capacity shunted across one of the turns being brought about by the movement of a metal plate attached to the relay arm, and it was found that a plate about two inches (5.08 cm.) in diameter moving thru a distance of one-eighth inch (3 mm.) was sufficient to control a transmitter delivering 1 kilowatt to the antenna.

This transmitter was equipped with four 250-watt air-cooled oscillators and five modulators of similar type, the modulator tubes being disconnected when the set was operated for telegraphy. The four oscillators delivered approximately 800 watts to the antenna circuit.

The first transmission experiments were carried on between

Pittsburgh and Cleveland, attempts being made at Cleveland to pick up the high-frequency signals and relay them thru a small broadcasting set installed there. On the night of October 27, 1922, KDKA's program was first relayed in Cleveland from 8:00 to 10:00 P.M. Cleveland is only about 110 miles (176 km.) from Pittsburgh by air line, but lies in one of those peculiar radio areas where reception of signals from Pittsburgh is comparatively difficult. It was found that the signals received at Cleveland from this high-frequency transmitter were very much louder than those received from the regular broadcasting transmitter, having about the same power output. It also was found that the signals were nearly as loud during the daylight hours as at night. However, the following peculiarity was noted: When operating at 3,300 kilocycles (91 meters), the signals were somewhat louder at night, but when operating at 3,750 kilocycles (80 meters), the signals were louder during the daylight hours than during the night. Interworks communication was carried on for a short time with the messages being transmitted by telephone on a wave length of 80 meters during the daylight hours, but changed to 90 meters when darkness came on.

At first serious difficulty was experienced in obtaining good quality from telephonic transmission, the signals received being very much distorted. This distortion was found to be caused in part by frequency changes caused by variations of average plate current by modulation, and to a peculiar effect of high-speed fading, which at times became so marked as to give an audible noise in the receiving station even tho a perfectly continuous unmodulated wave was being radiated from the transmitter. The distortion due to changes of oscillating constants in the transmitter caused by modulation was reduced by careful adjustment of the set. However, the distortion due to causes existing in the intervening space could not be entirely overcome, but it was minimized by the employment of a comparatively strong signal; a hand adjustment was employed to compensate somewhat for the changes due to slow fading.

During 1922 some development work was made on a special type of transmitter for operation on 3,000 kilocycles by F. W. Dunmore of the Bureau of Standards. Transmission experiments with this equipment at Washington and the set at 8XK indicated a daylight signal strength which was only slightly less than that of the night signal.

Reports received from various sections of the country on comparative signal strength of the two waves from KDKA, indicated the possibilities of establishing a broadcasting system which would cover the entire country with a comparatively high degree of reliability. To carry out this scheme, it was thought advisable to install a transmitter about midway between the Pacific Coast and Pittsburgh to act as a repeater station. Hastings, Nebraska, was selected as the location for this station, its distance from Pittsburgh not exceeding that which our tests indicated could be covered with fair reliability.

Analysis indicated that an antenna input of possibly 10 kilowatts would be required for reasonable reliability. Accordingly, two complete new transmitters were built; one being installed at East Pittsburgh and one at Hastings. The tubes used in these sets are water-cooled 10-kilowatt capacity, but to allow an ample margin two tubes are operated in parallel as oscillators and two as modulators. The plate voltage is eight thousand volts. As might be expected, this increase in power brought with it a train of miscellaneous difficulties one of them being the construction of a condenser which could handle the large kilovolt-amperage required. Mica condensers of conventional design which had been used on the previous sets were found to be very unsatisfactory for the higher power, owing to their greatly reduced kilovolt-amperage capacity at these higher frequencies. A type of oil condenser was developed which, altho simple and comparatively inexpensive, gave very satisfactory results. This condenser is shown assembled in Figure 5 and in partially disassembled condition in Figure 6.

The type of inductance used which is shown in Figure 7 consists of a helix of thin copper ribbon wound on Pyrex glass blocks supported on a rigid frame of vacuum-impregnated wood. The assembled transmitter units comprising rectifiers, modulator, and oscillator are shown in Figure 8. The scheme of connection is shown in Figure 9 and the arrangement of the antenna in Figure 10.

The transmitter at East Pittsburgh was designed to operate only within the frequency range of 3,000 to 3,600 kc., but the set at Hastings was designed to operate at a frequency within this range or at a lower one, within the regular broadcasting range. This arrangement permitted operation under a scheme in which the short wave signals being transmitted from KDKA could be received in Hastings, and from there re-transmitted on the regular broadcasting wave (800 kc.). With the power available the signals from this station would, during the favorable season of the year, be received over the entire United States with a good signal—stray ratio.

It was possible also to re-transmit from Hastings on a high frequency wave which was necessarily spaced sufficiently from the incoming wave of station KDKA to prevent feed-back troubles in the receiving equipment used at Hastings. Advantage then could be taken of the better transmission efficiency of the high frequency wave when it was desired to reach the Pacific Coast with a signal capable of again being relayed.

FIGURE 5

The receiving atation used at Hastings developed some troubles which, altho not entirely unforseen, yet were of considerably greater magnitude than had been expected.

Hastings is a small city, the population being less than fifteen thousand, and contained no feature which would ordinarily be expected to set-up interfering strays. When the high frequency receiving equipment was installed in the central part of town, it was found that a fairly complete log could be obtained of the operation of nearly every X-ray, violet ray, and massage machine, as well as the number of street lights and elevator motors that were being operated. This, of course, does not imply that satisfactory audible signals could not be received, but it did indicate that for repeating purposes a considerably higher signal-stray ratio was required.

The signal distortion which was noted in preliminary experiments at Cleveland was experienced, as might be expected, to a more marked degree at Hastings, but was subject to great irregularity of intensity; some nights the received signals being practically undistorted while on other nights speech would be unintelligible. The greatest factor in bringing about this distortion was apparently the peculiar high-speed fading and fluttering of signals. From observations of fading, phenomena as related to ordinary broadcast waves, it is known that the phase of the fading cycle is not constant over the whole area within which a signal can be received; but, in fact, may show a considerable change at receiving stations located within a few wave lengths of each other.

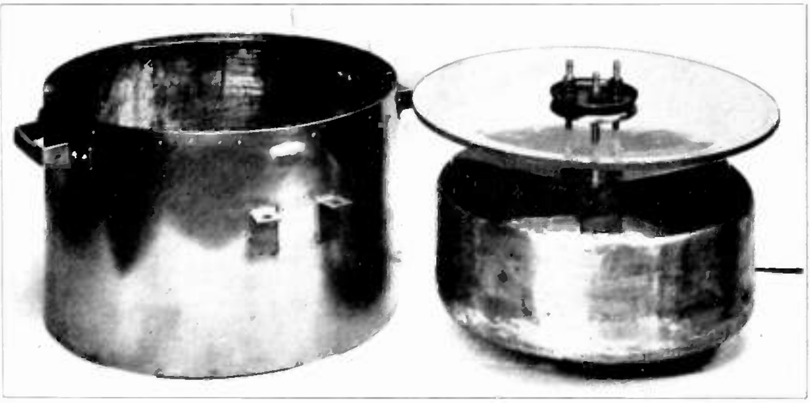


FIGURE 6

To take advantage of a possible overlapping of the fading cycle, two receiving stations were installed, the distance between these stations being about three miles (4.8 km.). As they were not on a line intersecting the transmitting station, the actual difference in distance to Pittsburgh was about two miles (3.2 km.). This arrangement incidentally solved the local stray problem as the receiving stations were installed in the outlying farm districts beyond the disturbing radius of the town's activities. The receiving equipment, a diagram of which is shown in Figure 11, consists of a conventional coupled circuit tuner, detector and two stages of audio amplification. The inductance and capacity elements, which are connected in parallel with the primary tuning element, constituted wave traps which served to eliminate interference from the local transmitter. To provide ample output and to minimize distortion, two tubes are used in the second audio stage. These are connected in push-pull fashion. The output transformer of the amplifier is wound to the proper step-down ratio to suit it to the connecting lines between the receiving and transmitting station. At the transmitting station the incoming lines from the two receiving stations may be paralleled and connected to the input terminals of an additional amplifier which steps up the received voltage to the value necessary for control of the modulator tubes.

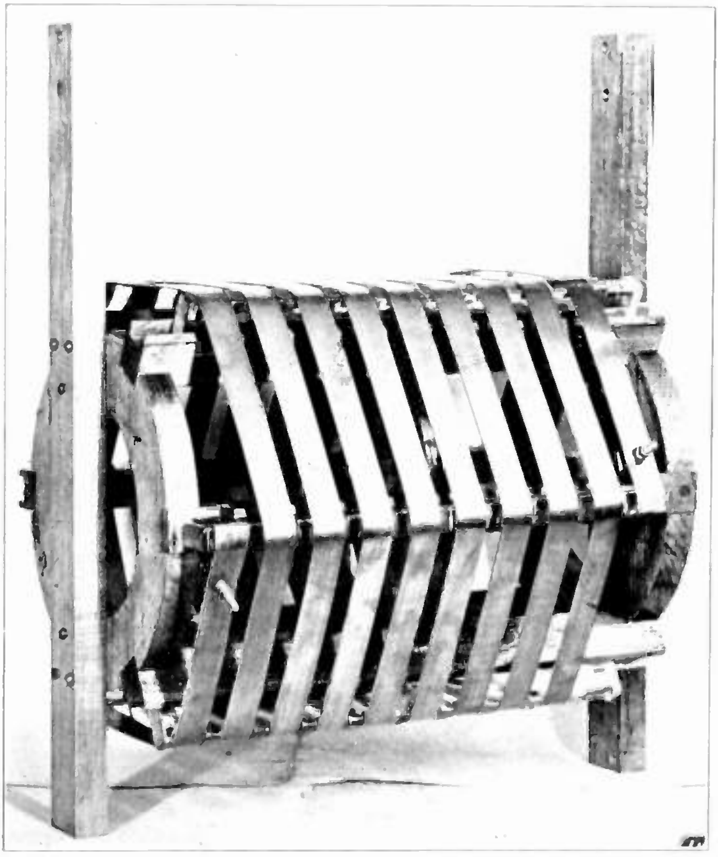
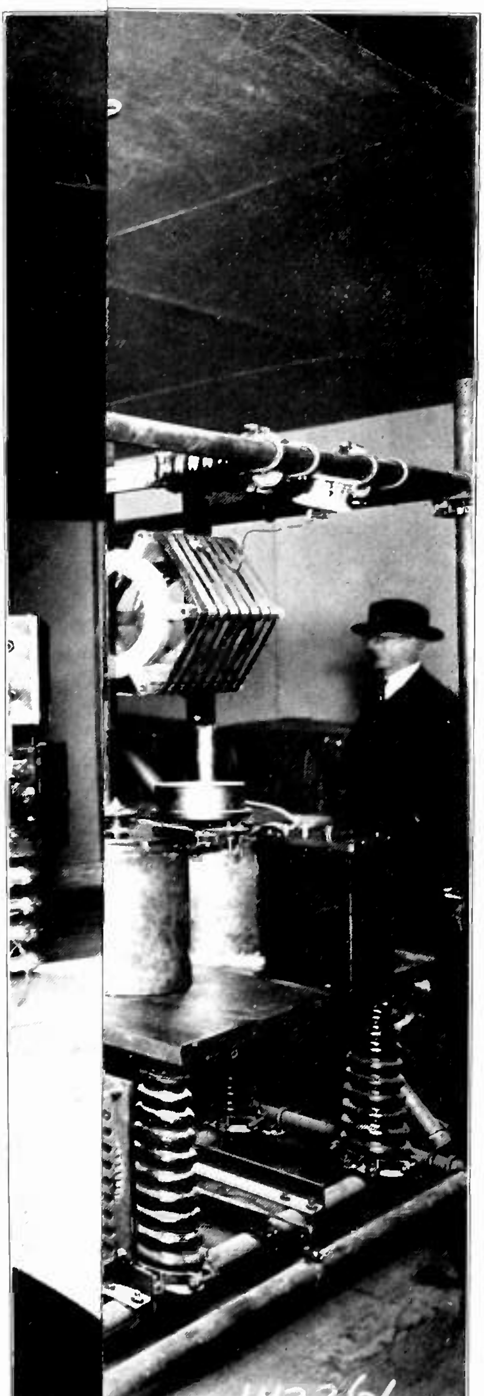


FIGURE 7

To provide for remote control of the receivers, a connection is made to the center of the line transformer windings whereby direct current may be sent over two lines in parallel in connection with a ground return. This serves to operate a relay at the receiving station for controlling the receiving tube filament circuit; the receiver having been previously tuned to the incoming signal wave.



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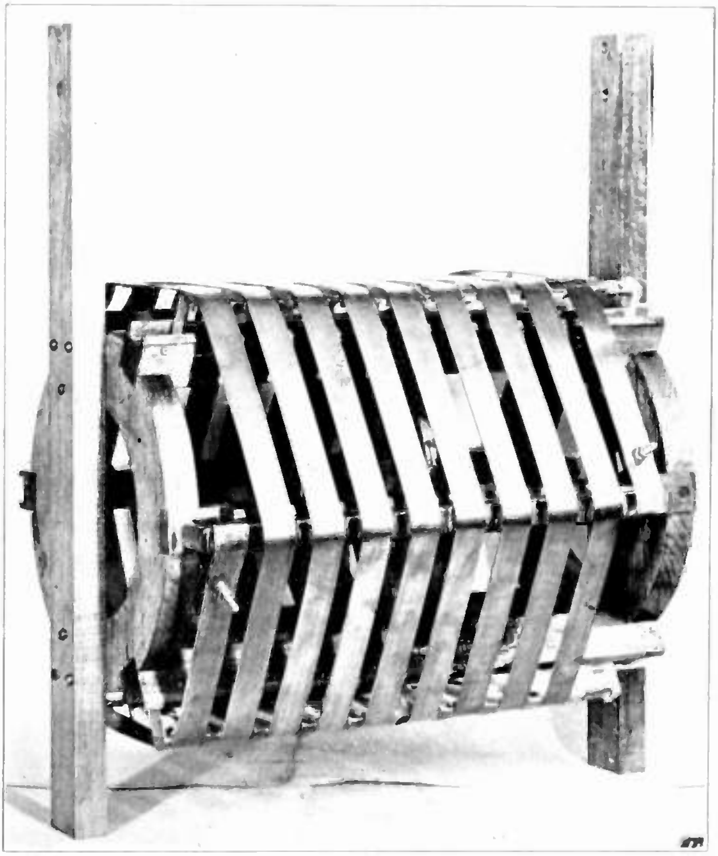

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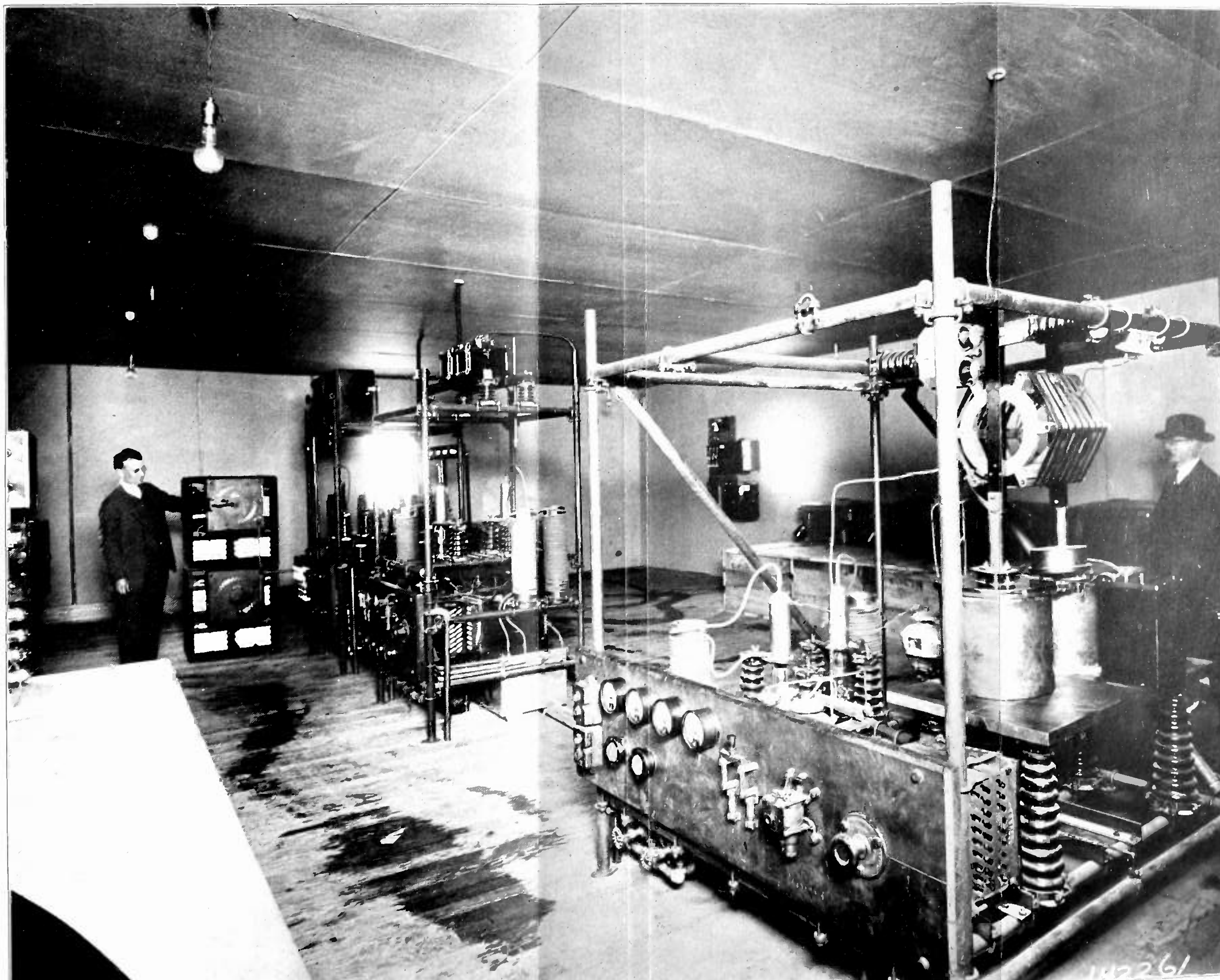

Figure 8

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The use of multiple receiving stations at certain times were found to reduce materially the signal distortion. At other times, however, it seemed to have no effect, so that the arrangement, altho effecting an improvement, could not be considered a solution. It is hoped, however, that investigation of the best separating distances between the receiving stations may produce further improvement.

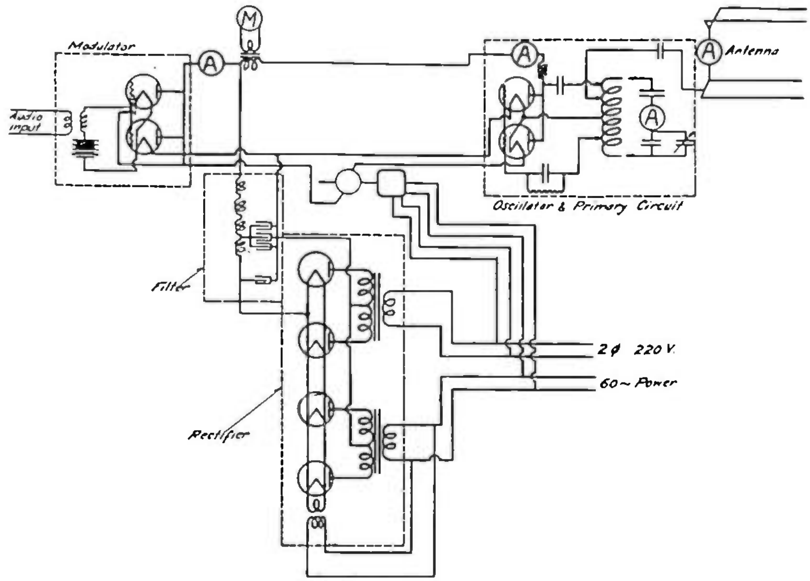

FIGURE 9

From experiments, which have been carried out, the most promising possibilities of undistorted transmission appeared to be in the selection of the particular frequency which will give the minimum fading distortion; this frequency value possibly varying from day to day.

The general trend will be toward a higher frequency, the limitation in this direction being those incident to the building of transmitting equipment of the capacity required.

Experiments which have been carried on heretofore on what might be termed ultra-high frequencies, were at comparatively low powers. The low power units, however, except in certain particulars such as directivity, would not compete in transmitting ranges with even the smaller conventional wave broadcast equipments.

The upper frequency limit of the sets now installed at Pittsburgh and Hastings is about 3,800 kc. (79 meters), the principal

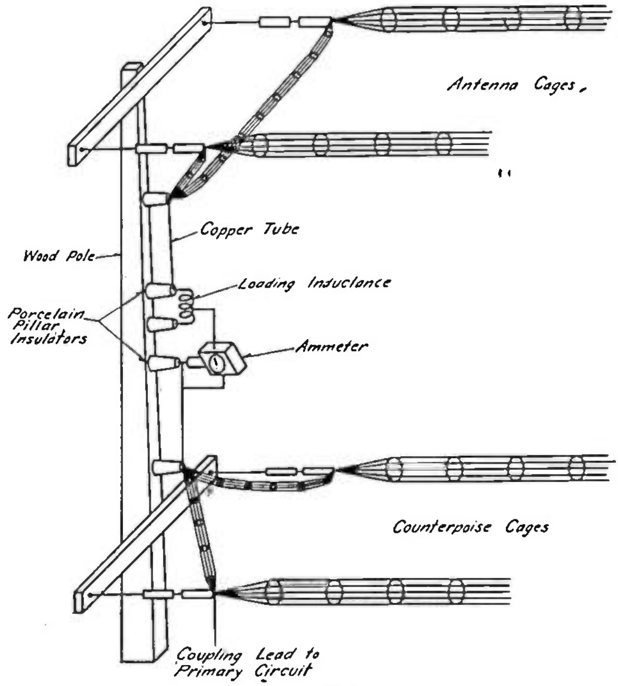

FIGURE 10

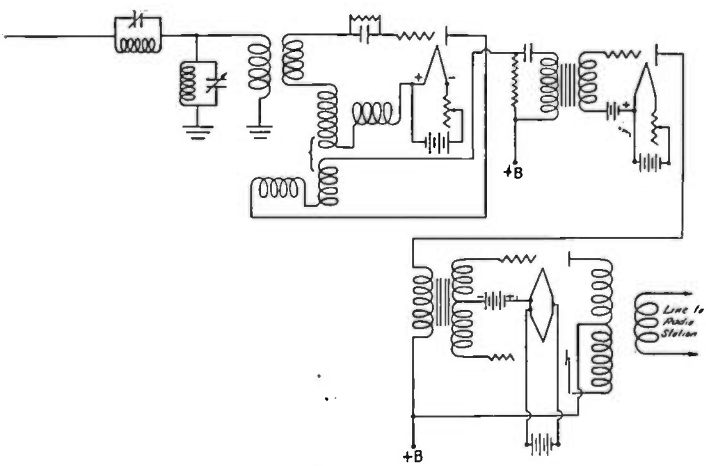

FIGURE 11

limitation being the current-carrying capacity of the grid lead-in connections and the heating of glass parts due to radio frequency electrostatic fields. This limitation will be appreciated when it is known that the grid charging current at about thirty-eight hundred kc. is approximately ten amperes.

New tubes are now in the course of construction which should permit an increase of frequency to possibly 6,000 kc., at which value when under full power, the set, like the traditional "one-horse shay" probably will reach a general break-down limit.

So far, no accurate measurements of absolute signal strength have been made, but there has been taken a rough survey of the country, to determine the signal strength at various locations. A number of small receiving sets consisting of a tuning element detector and one stage of audio amplification were sent to various parts of the United States, England, and Canada. These sets were used with the same general type of antenna. The antenna used had a total length of 15 ft. (4.6 m.) and was usually strung indoors. With this receiving equipment, telephone transmission was intelligible in nearly every location with audibilities ten times and upwards.

The reduction of signal strength with the increase of distance from the transmitter differs widely from that which might be expected. Within a few miles of the transmitter the signal strength from the high frequency transmitter is about one percent of that from the regular broadcasting wave transmitter. There are areas a few hundred miles distant where this approximate ratio is reversed.

As we approach the limits of range of the regular broadcasting transmitter, we are all familiar with the phenomena of good reception on some nights and no detectable signals on other nights. At these distances the signals from the high frequency set are markedly uniform, reception in general being possible on the receiving set just described. Reports received from the sets installed in England indicate that the intelligibility of received signals is determined in a great measure by the degree of distortion due to fading, rather than by actual signal strength.

It seems almost a flight of fancy to state that signals from East Pittsburgh are picked up in England on the two-tube dry cell detector used with an antenna from 10 to 15 feet (3 to 4.6 m.) long and the whole inside of a building, but it is a fact.

The areas of intense signal strength brought out unlooked-for defects in the selectivity of receivers adapted to receive the usual broadcast wave. At first, when we started operating the high frequency transmitter at KDKA, comments came in on the broadness of the KDKA wave and each step of power increase of the high frequency transmitter would open up new areas where the general comments would be "The KDKA wave was all over the scale." This phenomena applied to all types of tuners. The apparent lack of selectivity of the tuner was due to the fact that sufficient signal voltage was being induced in the antenna to give a response of the detector independent of any building-up due to resonance. This condition was illustrated by several experimental transmissions sent out from Hastings. This station transmits two local musical concerts each week on the regular broadcasting wave. The transmitting frequency of several of these concerts was shifted to the high-frequency wave; that is, in place of being transmitted on the regular wave of 880 kilocycles, they were transmitted on a wave of approximately 3,000 kilocycles. A great number of letters were received from listeners, indicating a quite general reception of these high-frequency transmissions, altho the receivers were in most cases the usual type of broadcasting receivers, having a frequency limit of about 1,500 kilocycles. However, the almost universal comment was that the reception was particularly good as regards signal strength but that the station could not be tuned out, it being equally loud on all parts of the tuning scale. Some of the letters received from as far as 1,000 miles (1,600 km.) away indicate reception on receivers of the simple crystal detector type.

The simplest method of eliminating interference from these high frequencies is the use of a wave trap, or resonant circuit, tuned to the high-frequency wave and connected from antenna to ground terminals of the receiver. This trap, if made with a comparatively low value capacity unit, will have an inappreciable effect on signals of ordinary frequencies.

The results obtained so far indicate that, altho there is considerable further development required, the use of these higher frequencies will be a decided forward step in extending the range of broadcasting stations. For comparatively short distances there seems no particular advantages to be gained over the normal waves other than the possibility of increasing the number of communication channels. However, it is in the possibility of greatly extending the broadcasting radius that the greatest promise lies, the first application being the broadcasting of items of international interest and importance. Several transmission schedules have been carried out thru the East Pittsburgh-Hastings transmitters which indicate these possibilities.

On November 22, 1923, a talk given at Pittsburgh by Mr. E. H. Sniffin was received at a meeting of the National Electric Light Association being held at Salt Lake City, the transmission circuit being from KDKA to KFKX (Hastings, Nebraska), on 3,000 kilocycles; from there re-transmitted at 1,050 kilocycles.

at which frequency it was received at Salt Lake City. This event possibly marks the first regularly scheduled long distance relay transmission.

Tests were also being carried on between an experimental receiving station located at the Metropolitan-Vickers Electrical Company's Works in Manchester, England, on the high-frequency waves transmitted from KDKA. So successful were preliminary tests that it was decided to institute a special service for English listeners. Arrangements for the event occurred near the close of the year 1923, so it was decided to hold the actual broadcasting of the first English program from KDKA until the New Year. Accordingly, New Year's Eve, Mr. H. P. Davis, Vice-President of the Westinghouse Company, broadcast a New Year's greeting from the "Pittsburgh Post" Studio. This greeting was transmitted at 7:00 P. M., Eastern Standard Time, which, because of the difference in time, was 12 o'clock in Great Britain. This message was received on the short-wave receiver, was transmitted from station 2ZY of the Metropolitan-Vickers Company and was simultaneously transmitted from the other seven stations of the British Broadcasting Company. This was the first pre-arranged regular broadcasting sent to England for re-broadcasting, from KDKA.

All of you, probably, are familiar with the transmission of the dinner held by the Massachusetts Institute of Technology Alumni at New York City on March 7. By several relay stages the speeches and music at this dinner were received over the greater part of the English-speaking world. At this time the signals were transmitted from the Waldorf-Astoria Hotel, where the dinner was held, to the Radio Corporation's station (WJZ) at New York and the General Electric Company's station (WGY) at Schenectady by direct wire connection. At Schenectady the signals were transmitted by radio on their regular broadcasting wave, as well as on the high-frequency wave of approximately 2,900 kilocycles. Both these waves were received at Pittsburgh and re-transmitted by KDKA on 920 kilocycles and on 3,000 kilocycles. At Hastings the 3,000-kilocycle wave was received and re-transmitted at 1,050 kilocycles. At Oakland, California, both the 1,050 kilocycle wave from Hastings and the 3,000-kilocycle wave from East Pittsburgh could be received. This latter wave was received with the greatest signal intensity and was therefore used in re-transmitting on their regular broadcasting wave of 900 kilocycles. In addition to this, the 3,000-kilocycle wave from East Pittsburgh was received in England

and re-transmitted thru several of the British Broadcasting Company's stations. The success of this undertaking serves to show the possibilities of this high-frequency relaying system.

SUMMARY: A brief history of short wave broadcasting as carried on under the direction of the author is given, together with the difficulties encountered and the results obtained. The transmitter and receiver employed experimentally for repeating KDKA's programs from KDPM at Cleveland are described. The high power short wave transmitter at 8 XS (Pittsburgh) is described particularly in regard to the radio frequency condensers and inductances required. A description of the receiver and transmitter at the Hastings, Nebraska, repeating station KFKX is given.

DISCUSSION

Greenleaf W. Pickard (by letter):* Mr. Conrad's timely paper is one of deep significance to radio engineers. For a quarter century the higher transmission frequencies have remained in innocuous desuetude, while the infra-red of the radio spectrum has been investigated and utilized. But now that the ultra-violet had been harnessed, we may expect a rapid extension of our knowledge in this direction, and the certain addition of many useful frequency channels.

From the time that KDKA at Pittsburgh began its high frequency broadcasting I have been an interested observer, and for some time past a recorder as well. When WGY at Schenectady began a similar transmission, I was able to make reception comparisons at my laboratory at Newton Centre, Massachusetts, from transmitters at nearly equal frequencies at distances of 760 and 225 kilometers (475 and 145 miles), respectively. And altho a fair picture of broadcast transmission at 3,000 kilocycles (100 m.) would require a far more extensive investigation than mine, I feel that certain of my results may be of interest.

Thru the courtesy of the Westinghouse Company, KDKA radiated for me at its two frequencies, 920 and 3,000 kilocycles (326 and 94 m.), thru dawn and sunrise of January 15th and 16th, 1924, and in Figure 1 is shown the record of these two transmissions.

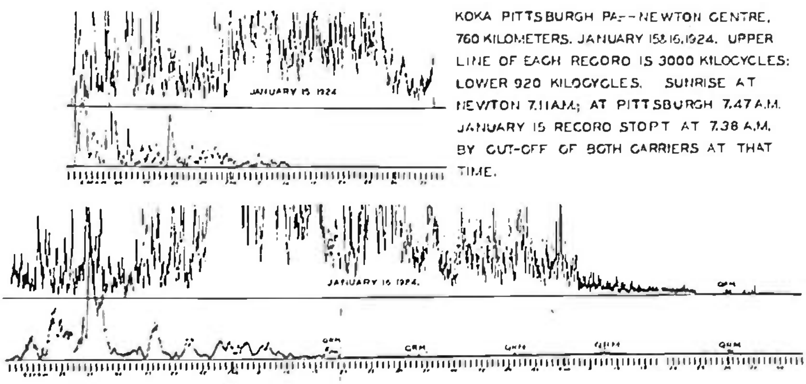

FIGURE 1

On these two mornings sunrise at Newton was at approximately 7.11 A. M., and the records show that this was an epoch time for the 920-kilocycle field, which then sank to its normal

*Received by the Editor, May 6, 1924.

low daytime intensity. But the 3,000-kilocycle field continued without material change thru sunrise at both Newton and, thirty-six minutes later, sunrise at Pittsburgh. At 8.03 A. M. the high frequency field fell off markedly, and finally at 8.24 A. M. it reached its normal low daytime intensity, an hour and thirteen minutes after the 920-kilocycle field.

Thru the day both the 920- and 3,000-kilocycle fields are too near the disturbance level for satisfactory recording. But two or three hours before sunset at Newton the 3,000-kilocycle field begins to rise, and good reception can usually be obtained at this frequency for nearly two hours before the 920-kilocycle field has risen sufficiently above the noise background for reception. So far as Newton Centre is concerned, KDKA's high frequency radiation has therefore added at least three hours of possible reception to the day.

WGY at Schenectady, now radiating at 790 and 2,800 kilocycles (380 and 107 m.), and at less than one-third the distance of KDKA from Newton, is well above the noise background at any hour of the day or night at its higher frequency. But the 2,800-kilocycle field shows severe and rapid fading, both by night and by day. Figure 2 fairly represents the normal daytime fluctuation of this station at its higher frequency. The normal 790-kilocycle transmission from this station, as I have shown in a recent paper,[1] shows practically no daytime fading in Newton.

WGY MARCH 20&16,1924. MORNING AND AFTERNOON AT 2800 KILOCYCLES.

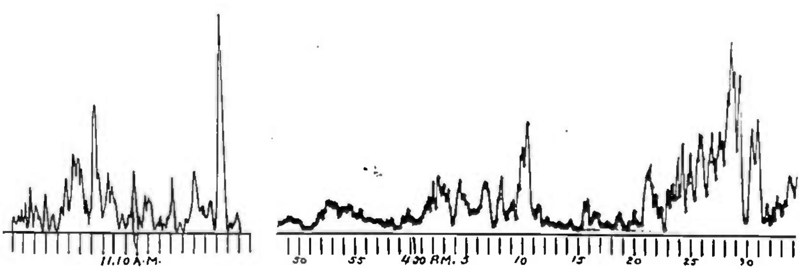

Figure 2

Another interesting effect of high frequency transmission is its penetration of steel frame buildings. The other evening, in

[1] "Short Period Variations in Radio Reception," Proceedings of The Institute of Radio Engineers, volume 12, number 2, 1924, Figure 7.

my room on the fifteenth floor of the Commodore Hotel in New York, I was able to receive KDKA at 3,000 kilocycles with excellent intensity on a small indoor antenna, whereas, with approximately the same amplification, there was no trace of the 920-kilocycle wave; an indoor field difference of certainly a hundred-fold. A similar difference was also observed with WGY.

Night-time reception of KDKA at Newton at 3,000 kilocycles is frequently marred by a severe and curious impairment of quality, usually accompanied by a rushing or roaring sound. Similarly, in receiving WGY either by night or day at 2,800 kilocycles, there is an even more pronounced and frequent distortion. By using a string galvanometer for recording, I have discovered that the distortion is caused by an ultra-rapid fading, the fluctuation frequently being at audio frequencies. In Figure 3 is shown one of these records.

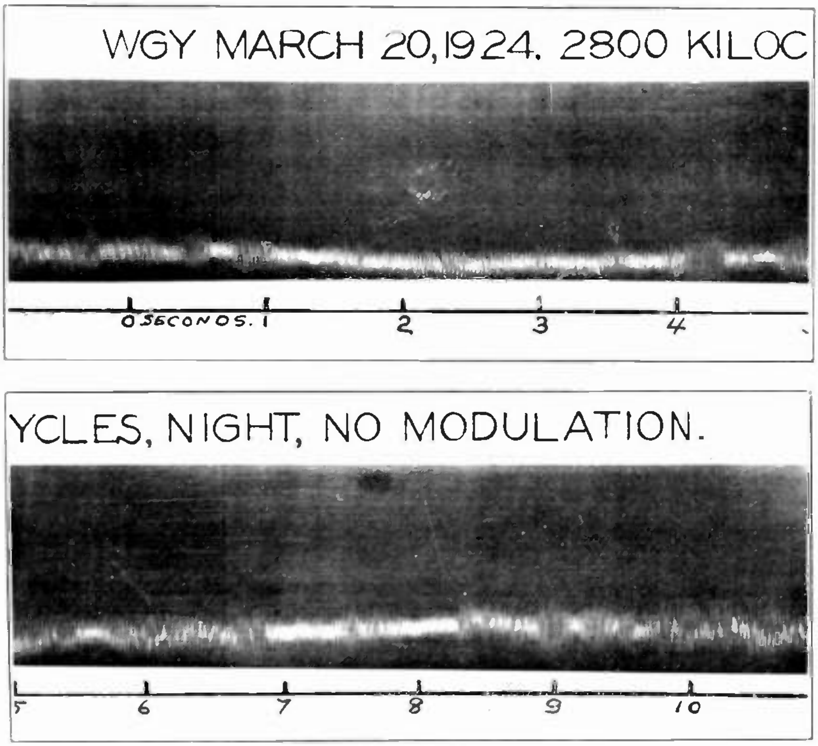

FIGURE 3

This record was made at a time when the station was not modulating, and shows a number of bursts of high frequency fading. Altho a careful examination of the record shows that these bursts are not exactly musical notes, but rather oscillograms of noise, frequencies of at least seventy cycles are not uncommon.

It is only necessary to listen in for an evening with fair amplification to observe that the frequency band from 3,000 to at least 6,000 kilocycles is far from a silent one. Altho the static and general noise background is usually several times less than in the normal broadcasting range, this region is harmonically haunted by many transmitters, including a number of broadcasters. At Newton I can usually hear WHN, New York, on its fourth harmonic at about 3,300 kilocycles; WFI, Philadelphia, on its fifth at 3,800, and even KYW, Chicago, on its eighth at 4,480, not to speak of the myriad amateur continuous wave harmonics. So far the high frequency band has been largely spared the wail of the mishandled regenerative receiver, that chorus of the damned which so sorely afflicts the normal broadcasting band. But now that the newspapers are publishing detailed descriptions of single circuit regenerators for 3,000-kilocycle reception, this happy state will soon vanish. Perhaps the only way any frequency channel can be swept free of this pest is to fill it with transmission of such a character that a very complicated reception system is needed for its unscrambling.

However, harmonic radiation from broadcasting stations is not entirely a waste product; I have found it distinctly useful. It is, for example, a most excellent thing with which to study high frequency reception at many other frequencies and distances than those of KDKA and WGY. In Figure 4 the upper record is from WEAN, Providence, Rhode Island, 60 kilometers (38 miles) distant, on its second octave at 4,400 kilocycles. This harmonic is very weak in Newton by day, but at night WEAN's field at this frequency is quite strong. The second record is from WBZ, Springfield, Mass., 118 kilometers (74 miles), also on its second octave at 3,560 kilocycles.

In the third record, shown for comparison, is WBZ at its fundamental of 890 kilocycles (337 m.), this record being made on the same evening and only a few minutes after the second record. It is interesting to note that reception from WBZ on the harmonic is generally far worse in quality than on the fundamental, as the high frequency is severely afflicted with ultra-rapid fading.

Altho based on very meagre data, my present feeling is that transmission in the neighborhood of 3,000 kilocycles is somewhat limited in its applications. It certainly does not carry speech or

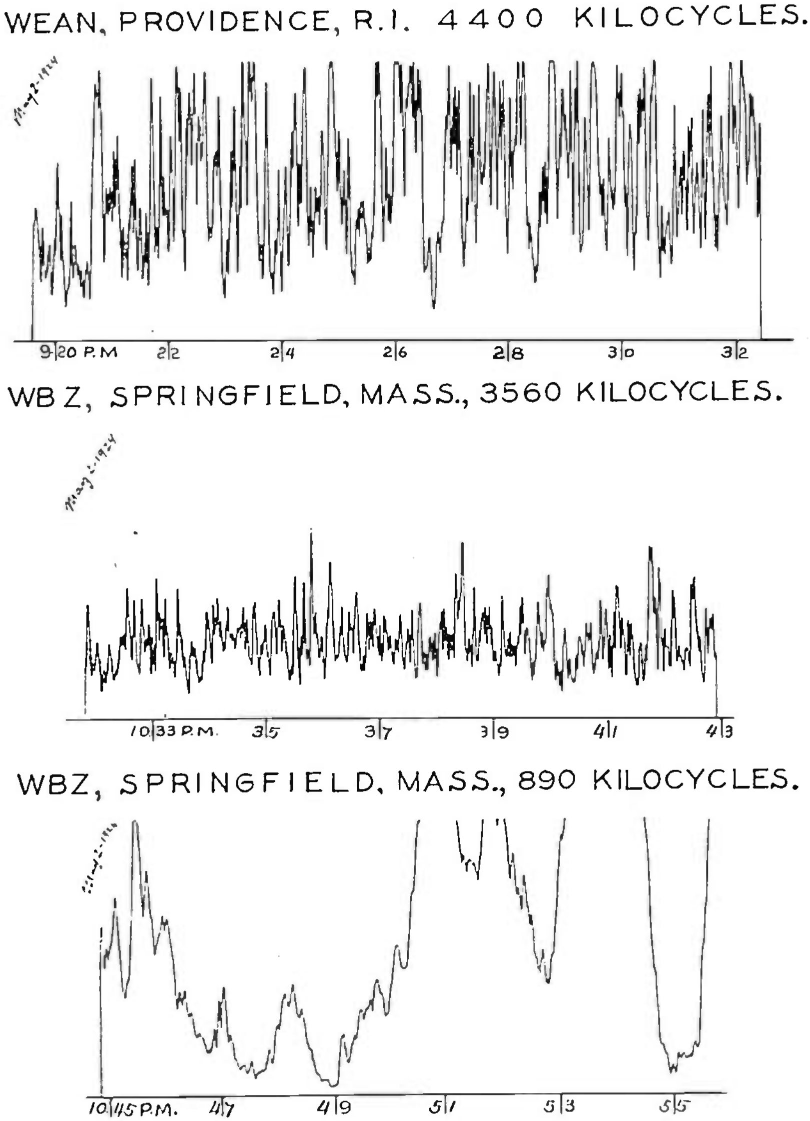

FIGURE 4

music well from Schenectady to Newton, a distance of 225 kilometers, and altho from Pittsburgh to Newton, a distance of 760 kilometers, the quality of the transmission is much better, it is still inferior to the normal 920-kilocycle radiation. Judging simply from my hotel experience, it may be an excellent means of reaching the city cliff-dweller in his cage of steel. Overland, for distances of over two or three hundred kilometers, its principal usefulness is for night transmission, as the sun finally kills its field. Over salt water my observations of this frequency are limited to trans-Atlantic reception, and here, also, daylight is fatal. Simultaneous records made at slightly separated receiving points have shown such marked differences that some form of distributed pick-up is strongly indicated as a means of reducing distortion.

An extended investigation of transmission at frequencies materially higher than 3,000 kilocycles is now very much in order. Among other things, it would be interesting to compare the fading for a beam with that for distributed radiation; if our hypothesis have any real footing there should be a marked difference.

BROADCAST TRANSMITTING STATIONS OF THE RADIO CORPORATION OF AMERICA*

By

Julius Weinberger

(Research Engineer, Technical and Test Department, Radio Corporation of America, New York)

The purpose of this paper is to describe the general arrangement, apparatus and operation of the radio broadcasting stations, with their associated wire line facilities, established by the Radio Corporation of America in the cities of New York and Washington, D. C., and placed in operation during the spring and summer of 1923.

The New York City station is known as "Broadcast Central," and transmits on two wave lengths or channels simultaneously, these being at present 455 and 405 meters (660 and 740 kilocycles). Its call letters are WJZ and WJY, respectively. The Washington station has a single channel only, with the call letters WRC, and transmits at present on 469 meters (640 kilocycles) wave length. All channels deliver approximately 500 watts to the antenna, at the carrier frequency. In all cases complete duplicate units of equipment are provided, with the exception of the antenna, and these can be thrown into action, in most cases, by means of relays, should failure occur in any part of the working equipment. This precaution has proven of great value in practice, in maintaining the uninterrupted service demanded of broadcasting stations located in large cities.

In addition to its own studio, each station has wire line facilities for the transmission of events occurring at outside points (for example, concert halls or theatres), these lines being connected to the radio transmitter thru appropriate means. Wire connections have also been established, linking the New York and Washington stations, as well as station WGY of the General Electric Company at Schenectady, New York, so that programs originating at any one of these stations may be transmitted from another, or simultaneously from all three.

*Received by the Editor, May 13, 1924. Presented before The Institute of Radio Engineers, New York, June 4, 1924.

Broadcast Central
General

As mentioned above, this station was designed to transmit on two channels simultaneously. Originally the intention was to utilize one channel exclusively for classical music, instructional lectures, and serious types of entertainment generally, while the other channel was to be used for popular music, athletic events and lighter forms of entertainment; so that the listener might choose the particular kind of amusement which pleased him best. This plan has been adhered to, so far as possible.

In considering the location of the station, it was felt from the first that this should be conveniently accessible for artists, and should be such that short wire lines could be run directly to theatres and other places of amusement from which entertainment material might be obtainable.

The site finally chosen was the Aeolian Building in West 42nd Street, between Fifth and Sixth Avenues, New York City (Figure 1). This building is practically the musical center of New York, housing Aeolian Hall (where many concerts are given thruout the year), and the offices of the representatives of many of the foremost musicians and musical organizations. It is also near the center of the theatrical district, which makes it easily accessible for artists; and sufficiently far out of the highly attenuating tall building zone of lower Manhattan Island so that the signal intensity from the transmitting station was expected to be good in the residential sections of New York.

The Aeolian Company arranged to lease space to us on the sixth floor of their building for studios, control room, and offices, while the transmission apparatus was placed in a specially built house on the roof (about 200 feet (61.5 meters) above street level), where two self-supporting steel towers were also erected for the antennas.

The general arrangement of the station is shown in Figure 2 while a more detailed view of the arrangement on the studio floor is given by Figure 3.

On the sixth floor are located the studios for each channel, with suitable reception and coat rooms for artists. Here also are offices for the Program Division, and for the operating staff, which offices are not shown in the figure. Between the two studios, a room called the "Control Room" is placed (described in detail later on), from which the technical operation of the station is governed.

The furnishings and color scheme of the studios and their reception rooms were chosen with reference to the two-channel operation previously referred to. Thus the rooms of the "classical" channel, WJZ, were finished in dignified and somewhat restrained fashion, while those of the popular or "jazz" channel, WJY, were decorated in bright colors with suitable hangings. Photographs showing the interior of these studios are given in Figures 4 and 5, respectively. On the end wall of the WJZ studio a mural painting was placed (the work of Mr. Leon Soderston), depicting the many types of broadcast listeners. This

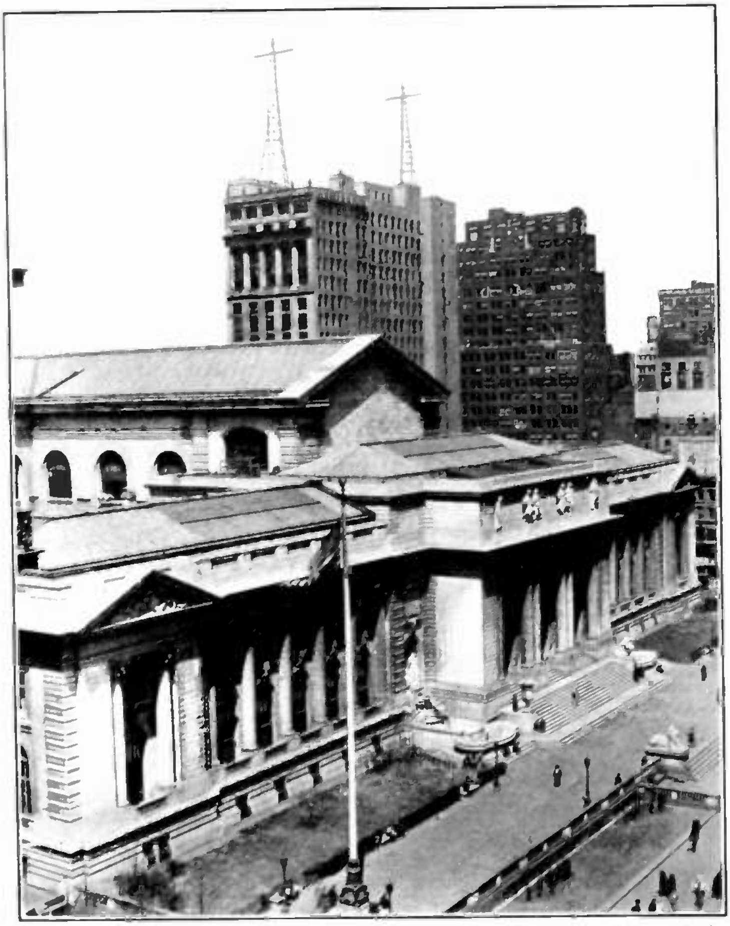

FIGURE 1—Site of Broadcast Central (Aeolian Building) New York

is faced directly by artists, when broadcasting, and by its appeal to the imagination helps to give them the feeling of a vast listening audience.

The studio ceiling and walls are covered by an acoustical treatment[1] consisting of one inch (2.5 cm.) thick, special acoustical hair felt next to the wall, with a layer of muslin stretched over the hair felt and spaced from it by half an inch (1.25 cm.) of air space. The muslin is painted with a special paint which transmits sound, so that the felt may absorb it. When the treatment is finished the impression of a solid wall is given the casual observer. This acoustical treatment is carried down the walls to a point about 3 feet (0.92 meter) from the floor line, and from this height to the floor a solid material, such as gypsum wall board, is used. This is done in order to avoid the damage which might be caused to the stretched muslin covering, were it used, by careless persons.

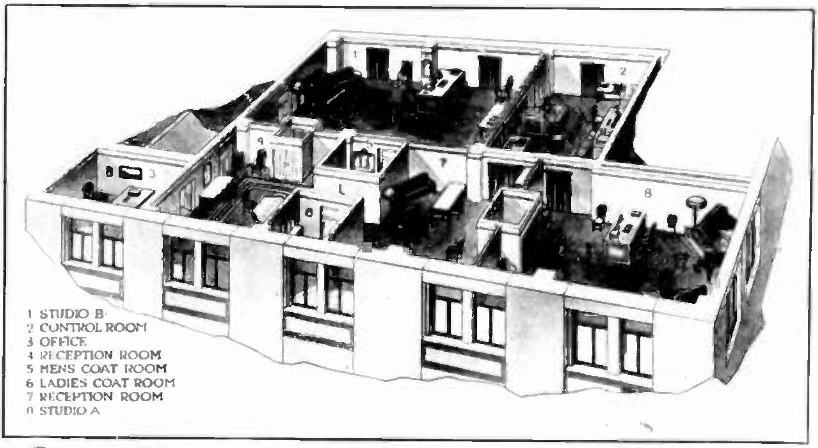

FIGURE 3—Arrangement of Rooms on the Sixth Floor, Aeolian Building

The studio floors are covered with thick carpet and the furniture is heavily cushioned. All of these acoustical measures are employed in order to reduce the "reverberation time"[2] of the studios to a minimum. This is a customary procedure in broadcasting studios and is frequently the source of question on the part of musicians as well as scientists.

W. C. Sabine found that good musical taste demanded a reverberation time of 1.1 second at 512 cycles for a room in which

[1] Installed by the Johns-Manville Company, New York City.

[2] See "Collected Papers on Acoustics," by Wallace Clement Sabine, Harvard University Press, Cambridge, Massachusetts. The reverberation time of a room is defined as follows: Assume a sound source to produce a sound intensity (energy), at a given point in a room, of 1,000,000 times the energy which would be just audible; if this source be stopped, the reverberation time is the time taken for the sound energy at that point to fall to a just audible value.

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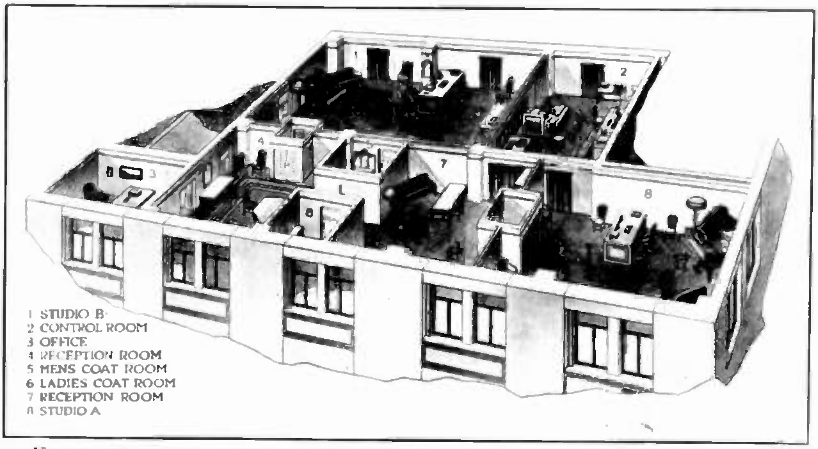

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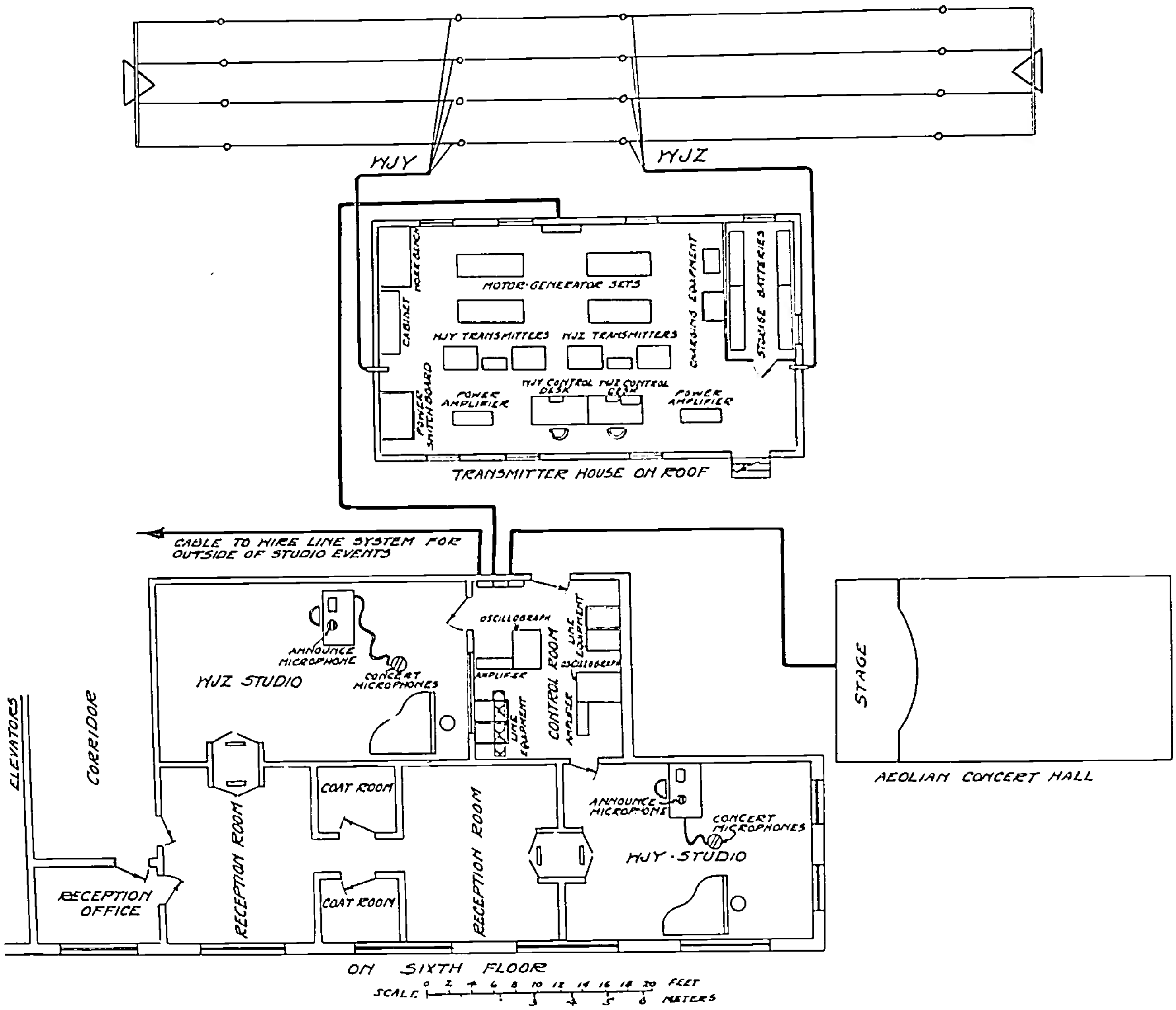

FIGURE 2—Broadcast Central: General Arrangement, in Aeolian Building

The studio ceiling and walls are covered by an acoustical

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piano music was to be given, in order to give the correct "ring" to the piano tones. However, were the studios designed for this value, objectionable resonance phenomena would be found, when using microphones to convert the sound to electrical energy.

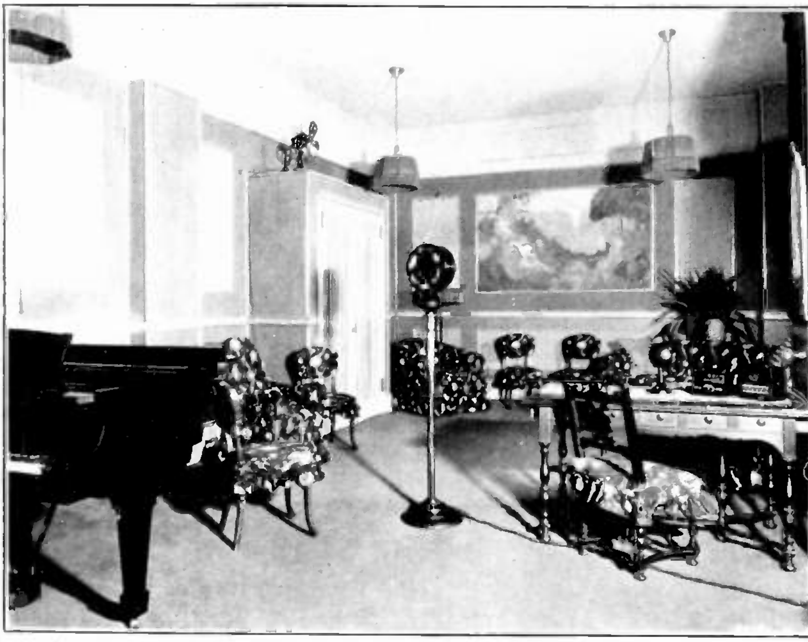

FIGURE 4—Studio of Station WJZ, Broadcast Central, New York

A possible explanation of this may be the following: When sound energy leaves a source, it spreads out in an air wave, the energy of which is partly contained in pressure variation and partly in the velocity of motion of the air particles. The wave energy is thus lodged in two components, in a similar manner to that of an electromagnetic wave, in which the energy is contained in an electric and a magnetic field. When the sound wave strikes an obstruction, such as the walls of a room, energy is partly transmitted, partly absorbed, and partly reflected, the proportion of each varying with the material and composition of the obstruction; so that at a given point in the room the resultant intensity at various frequencies due to sound coming directly from the source added to sound due to all reflections from obstructions, has one set of values for the pressure components and another set of values for the velocity components. Now, the human ear probably responds to both energy components in some measure, while all the microphone devices we have (with the exception of the thermophone) respond largely to the pressure component. Thus, when we place a microphone at a point within a room, we obtain a response indicating only the pressure fluctuations at that point, while with the ear both pressure and velocity fluctuations would be indicated. Thus if a very large pressure with small velocity existed at one frequency and a small pressure with large velocity at another frequency, the microphone would give a widely different response at the two frequencies, being operated mainly by pressure; while the ear, drawing its energy from both components, would give a fairly equal response.

FIGURE 5—Studio of Station WJY, Broadcast Central, New York

The usual solution of this difficulty is therefore to make the studios highly damped, so that there is as little reflection as possible from the walls. Then interference and resonance phenomena occur in a more limited measure, the microphone being arranged so as to be operated by the direct sound coming from the source. The calculated reverberation time of the WJZ studio is 0.4 second (at 512 cycles), as compared with the 1.1 second value considered correct for ear listening. It is likely, however, that as we learn how to make converters of sound to electrical energy which simulate the ear more closely in their response to the two energy components of sound waves, that the damping of studios will be reduced to a value more in accord with that for ear listening.

Returning now to the layout of Figure 2, it will be noted that the control room is connected by means of cables to the wire lines for transferring material picked up outside the studios, to the transmitter house on the roof, and to the Aeolian Concert Hall (Figure 6). Between the control room and the WJZ studio a long narrow window is placed, and a door opening into the WJY studio, thru which the control operators may observe the performance going on in the studios. The control and supervisory apparatus is located near these observation points.

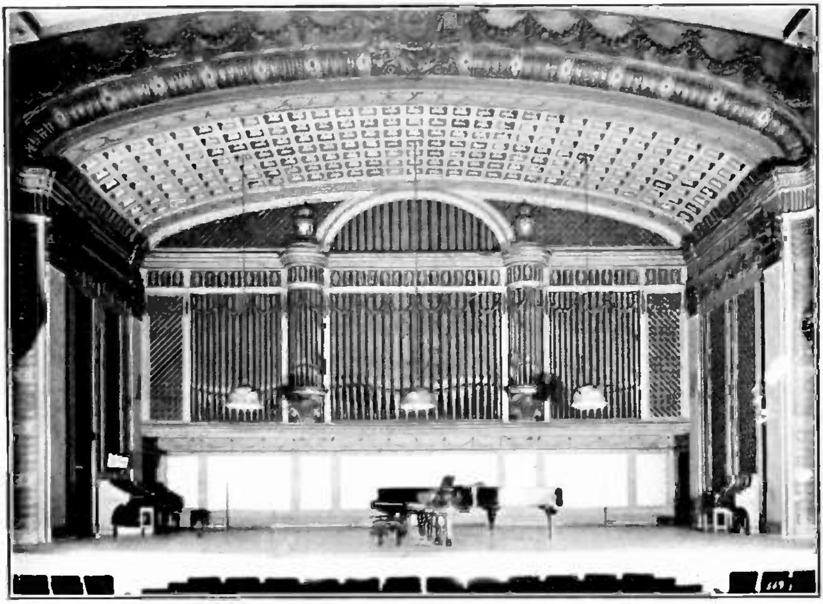

FIGURE 6—Stage of Aeolian Hall

A ventilating system is provided for blowing fresh air (heated in winter) into the studios and control room. An interesting point in connection with this is that by merely lining the ducts with hair felt 1 inch (2.5 cm.) thick, all noise from the ventilating motor is reduced to inaudibility in the rooms, and sounds emanating from one studio do not pass into the other, or into the control room, via the ventilating ducts.

On the roof, four transmitters (a working transmitter and a spare transmitter for each channel) and duplicate batteries for each channel are provided. The exterior of the transmitter house is shown in Figure 14 and the interior in Figures 15 and 16, while a view of the antenna towers[3] and the antennas is given in Figure 7.

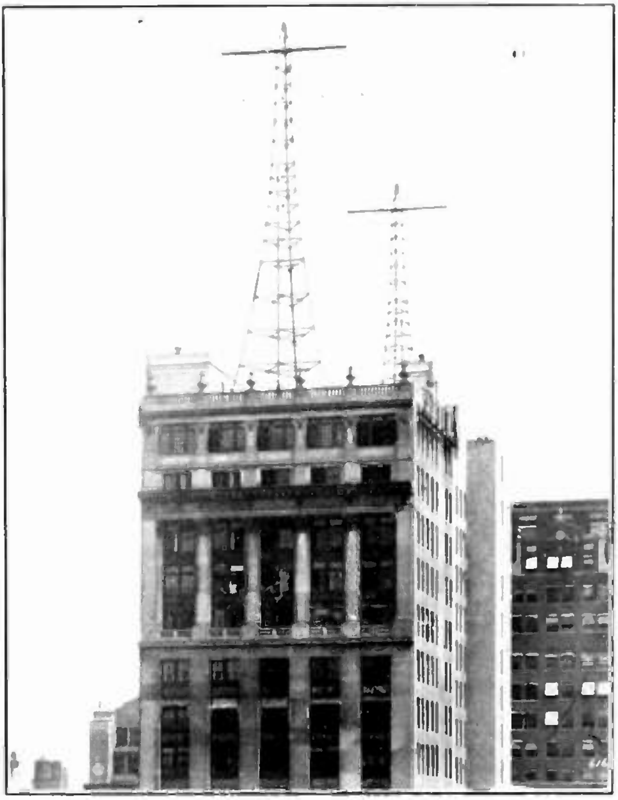

FIGURE 7—Antenna Towers at Broadcast Central

STATION APPARATUS

The apparatus used in broadcasting may be divided into:

(a) Station apparatus, more or less fixed in place, used in connection with broadcasting from the local studios, or in connection with wire line transfer of material to be broadcast from points outside the studios.

(b) Portable apparatus, such as microphones and amplifiers, for picking up material outside the studios, and arranged to convert sound energy to electrical energy of suitable value for wire transmission to the station, there to be broadcast thru the station

[3] For the details of mechanical design of these towers as well as those of the Washington Station, see: Albert W. Buel: "The Development of a Standard Design for Self-Supporting Radio Towers," PROCEEDINGS OF THE INSTITUTE OF RADIO ENGINEERS, volume 12, page 58, 1924.

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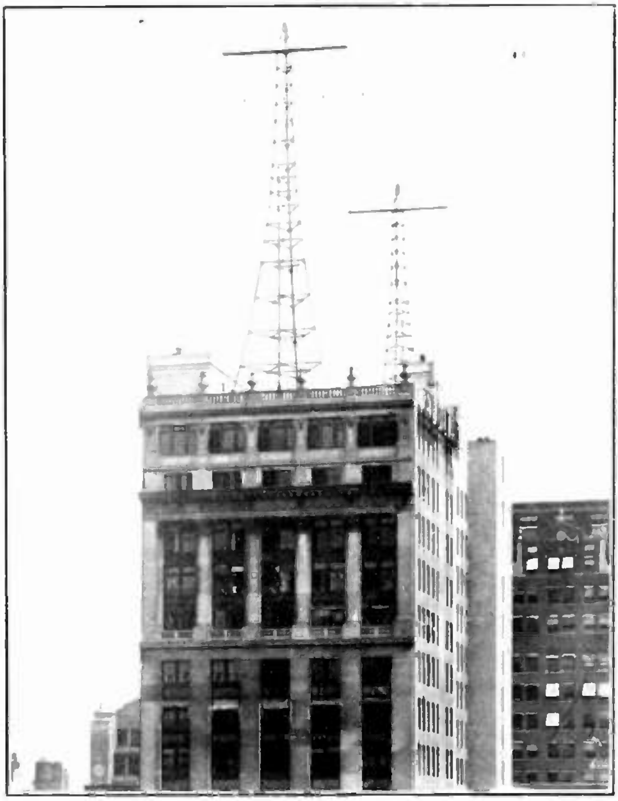

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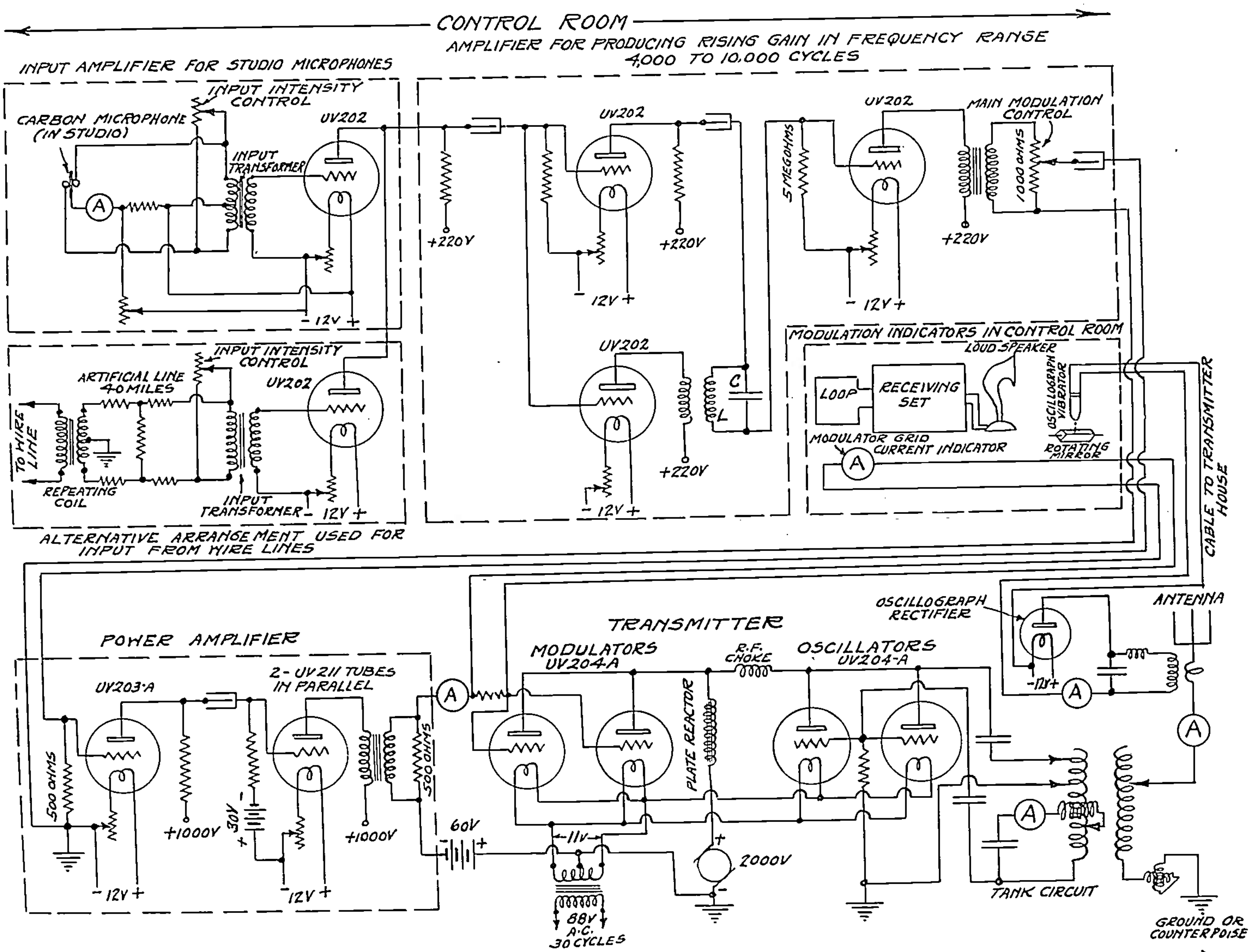

FIGURE 8—Schematic Diagram of One Channel

apparatus. The portable apparatus will be described in a subsequent section.

A schematic wiring diagram of the station apparatus involved in broadcasting on one channel is shown in Figure 8[4]. Starting at the upper left hand corner of the figure, we have single stage amplifiers which are arranged for inputs from a studio microphone or wire line (in case of broadcasting from points outside the studio). The microphone is connected directly to the input transformer, while in the case of wire lines a 40-mile resistance artificial line is connected between the line and input transformer to lower the input energy to a level of the same order of magnitude as that obtained from a microphone. The voltage produced by a microphone across the terminals of the input transformer is about two millivolts, while at the end of a line, a signal of about two-tenths of a volt is usually available.

The first stage is resistance coupled to the input side of a special amplifier designed to give uniform amplification over the frequency band from 100 to 4,000 cycles. From 4,000 to 10,000 cycles it is arranged to produce gradually increasing amplification. The reason for doing this is that all present loud speakers, head telephones, and many audio frequency transformers (as used in receiving sets) give a decreasing output in this range, and a rising frequency characteristic at the transmitting station will tend to compensate for this. As a result, such sounds as the consonant "s," the characteristic frequency of which is of the order of 10,000 cycles, are reproduced very clearly on the average receiving set, while music is also given greater clearness because of the better reproduction of harmonics.

The method of obtaining a flat curve for part of the range of this amplifier, and a rising curve for another part, will be evident from the figure. The output of the microphone amplifier is fed to the grids of two tubes, in parallel. The upper tube has a resistance in its plate circuit and the lower one a resonance transformer composed of air-core coils and a condenser with its resonance peak at 10,000 cycles. The voltage delivered by the upper (resistance) coupled tube is uniform with respect to frequency, while that of the lower tube is a resonance curve having a maximum at 10,000 cycles. The voltages delivered by these two tubes are added in series and applied to the grid of a third tube, the magnitudes being so chosen that the sum of the two gives a

[4]The station apparatus at Radio Corporation stations was originally built by the General Electric Company, and was modified in a number of details after some operating experience therewith. The description in this paper refers to the modified apparatus.

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frequency characteristic of the type mentioned above. The third tube serves as an output tube, and its output is stepped down in order to feed the input side of the power amplifier in the transmitter house thru a cable which is about 600 feet (185 meters) long. On the low voltage side of the output transformer is placed the main modulation control, a 1,000-ohm potentiometer, by means of which the voltage supplied to the power amplifier may be regulated. The transmitter house end of the cable is terminated by a 500-ohm resistance, from which the grid of the first power amplifier tube is fed. It may appear uneconomical not to place a step-up transformer at this point, but it is preferable to avoid transformers whenever sufficient amplification is already available, since each transformer cuts off transmission of low and high frequencies to some extent.

The power amplifier has two stages, the first being resistance coupled and the second transformer coupled to the grids of the modulator tubes. A step-down transformer with 500 ohms across the secondary is used so that with positive potentials applied to the modulator grids no distortion will occur, due to the grid current drawn. The customary "constant current" modulation system is used. The oscillators work into a local circuit (called the "tank circuit") which is inductively coupled to the antenna. Variometers are provided for wave length control in both local and antenna circuit. The antenna power, unmodulated, is normally 500 watts, antenna current about 7 amperes, on 455 meters and 6 amperes on 405 meters.

Supervision of the modulated antenna current is obtained in the control room by several methods (oscillographic observation of a small portion of rectified antenna energy, modulator grid current, and receiving set with loud speaker), the connections of which are evident from the diagram, and which will be discussed in more detail later on.

All units are supplied in duplicate, on each channel, but on the schematic diagram the various relays, jacks, plugs and switches for transferring from a working unit to a spare unit have been omitted, for clearness.

All filaments of vacuum tubes, except those in the transmitting set, are supplied from common 12-volt storage batteries in the transmitter house. The plate voltages of all tubes are supplied from the 2,000-volt motor-generator sets of the transmitters, the low plate voltages for the amplifiers being obtained from potentiometers fed thru resistance-capacity filters by one of the 1,000-volt commutators of these generators. The necessity of maintaining high voltage storage batteries for amplifier plate supply is thus eliminated, the supply from the generators being quite free from ripple after filtering.

For the sake of those readers who wish more details concerning the constants of the vacuum tubes used, reference is made to previous papers published in these PROCEEDINGS.[5,6]

We will next consider some of the apparatus units in greater detail.

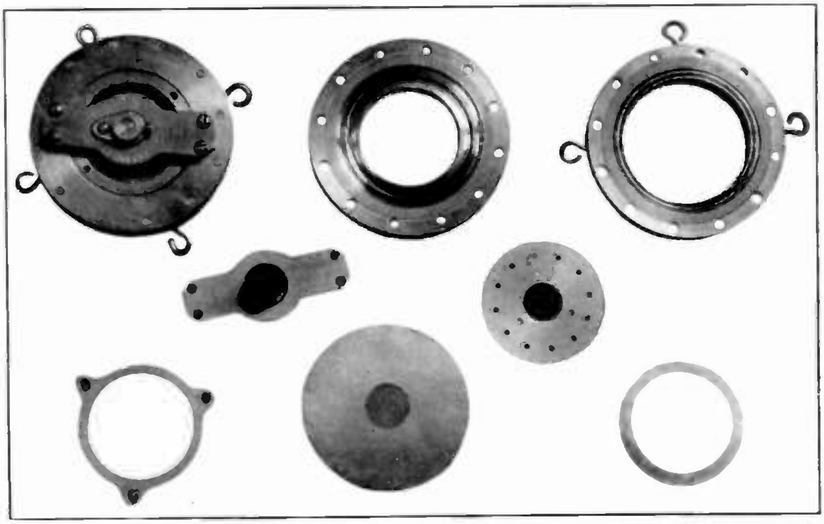


FIGURE 9—Double Button Carbon Microphone Assembled and Disassembled

STUDIO APPARATUS

The microphones used are modelled after the double button carbon type originated by the Western Electric Company.[7] This transmitter contains a stretched diaphragm of duralumin, about 0.0015 to 0.002 inch (0.0038 to 0.005 cm.) thick, spaced 0.001 or 0.002 inch from a metal surface, on one side, so as to secure high air damping;[8] carbon containing chambers are placed one on each side of the diaphragm, and current supplied to the microphone

[5] W. R. G. Baker: "Commercial Radio Tube Transmitters." PROCEEDINGS OF THE INSTITUTE OF RADIO ENGINEERS, volume 11, page 601, 1923 (particularly the tables on pages 653 and 654).

[6] J. C. Warner: "Recent Developments in High Vacuum Receiving Tubes —Radiotrons Model UV-199 and Model UV-201-A," PROCEEDINGS OF THE INSTITUTE OF RADIO ENGINEERS, volume 11, page 587, 1923.

[7] I. W. Green and J. P. Maxfield: "Public Address Systems" (Section entitled "Transmitters"), "Journal of the American Institute of Electrical Engineers," April, 1923.

[8] I. B. Crandall: "The Air Damped Vibrating System," "Physical Review" 2nd Series, volume XI, page 449, 1918.

as shown in the schematic diagram of Figure 8. Normally the maximum permissible current thru each button is 20 milliamperes, and with this each button has an internal resistance of about 100 ohms; thus the transmitter forms a generator (as applied to the input transformer) having an internal resistance of about 200 ohms. The voltage produced across a 200-ohm load is about 5 millivolts for one dyne per sq. cm of sound pressure in air.

The diaphragm characteristics are such (due to its high natural frequency and great damping), that practically uniform output is secured, for equal incident sound pressures over the frequency range from 30 to 7,000 cycles. Higher frequencies up to 10,000 cycles are usually reproduced well with fresh carbon, and when the transmitter current is first switched on, but after some running, the reproduction of these frequencies falls off. However, for nearly all work, these transmitters are quite as satisfactory in their reproduction as a condenser transmitter, and are simple, require much less amplification than the condenser transmitter, are conveniently portable, and may have as long leads as desired attached to them (which can be done only in a limited degree with the condenser transmitter). Figure 9 is a photograph of one of these microphones.

In the studio, two microphones are hung on spring suspensions in the stand shown in Figure 10, for picking up studio concerts, one microphone being in operation and the other a spare capable of being switched in from the control room to replace the working microphone.

For announcing, a single microphone only is usually found sufficient, altho provision was originally made to have a spare for this purpose also. This is suspended in a small support of convenient height.

A control box (Figure 11) is also placed on the announcer's table. This contains a switching key, by means of which the announcer may connect his own microphone, or the studio microphone to the microphone amplifier in the control room, or cut off both. This key operates relays in the control room which switch on filament current to the single stage amplifier connected to the particular microphone which is operating. A small signal lamp, mounted above the switching key, remains lit automatically while current flows in the antenna, so that the announcer is thus informed, should the antenna power go off at any time. The signal current is supplied to this lamp by means of a special relay in the transmitting set, connected in series with the oscillator grid leak, so that it is operated by the direct current flowing thru the leak.

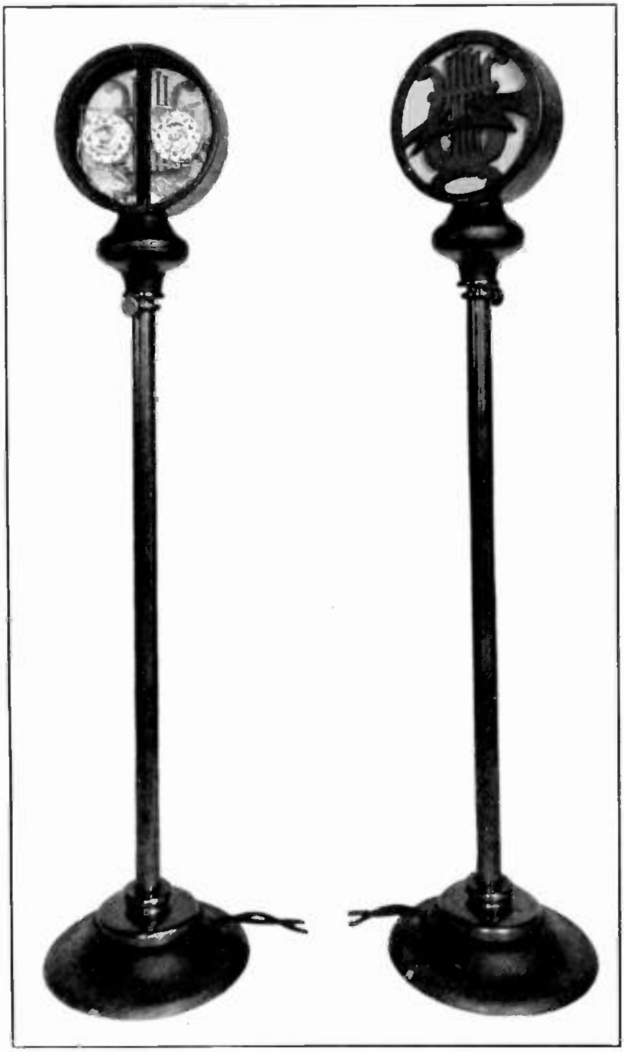


FIGURE 10—Studio Microphone Stand, Open and Closed

CONTROL ROOM APPARATUS

The apparatus here is the following:

1. A single stage amplifier rack, shown in Figures 12 and 13. This contains, in the upper row, two amplifiers suitable for microphone input and one for input from telephone lines, and in the second row, duplicates of these. Any amplifier may be connected

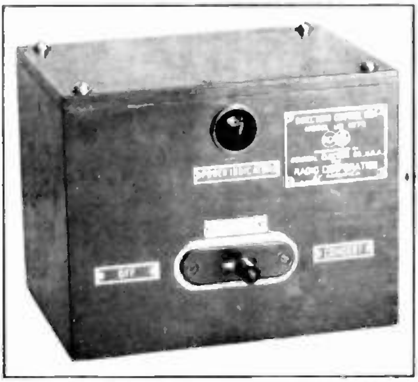


FIGURE 11—Announcer's Control Box

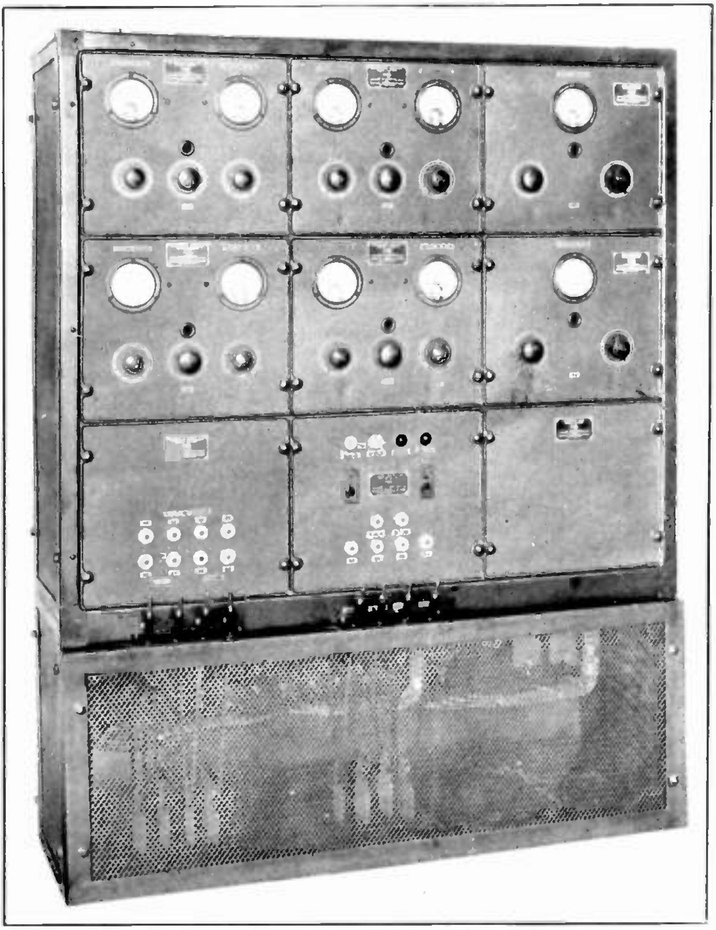


FIGURE 12—Control Room Amplifier Rack, Front

to any microphone by means of the jacks and plugs shown in the lower row of panels. Here also are jacks for listening to the output in the plate circuit of whichever single stage amplifier happens to be in operation, and also for listening to the radio output (conducted thereto from the monitoring receiving set). Signaling lamps are also provided, one to indicate when either concert or announce microphone is in operation in the studio, one to indicate the presence of antenna power, and two for signaling between control room and transmitter house, if desired. Each single stage amplifier is equipped with filament voltage control and voltmeter, microphone rheostat, ammeter (in microphone amplifiers), and an input intensity control. The latter is a small carbon plate compression type of rheostat, which is quite noiseless in operation, permitting a shunt resistance of from about 50 ohms upward to be placed across the input transformer. All tubes are the UV-202 type, rated at 5 watts as oscillators, having tungsten filaments.

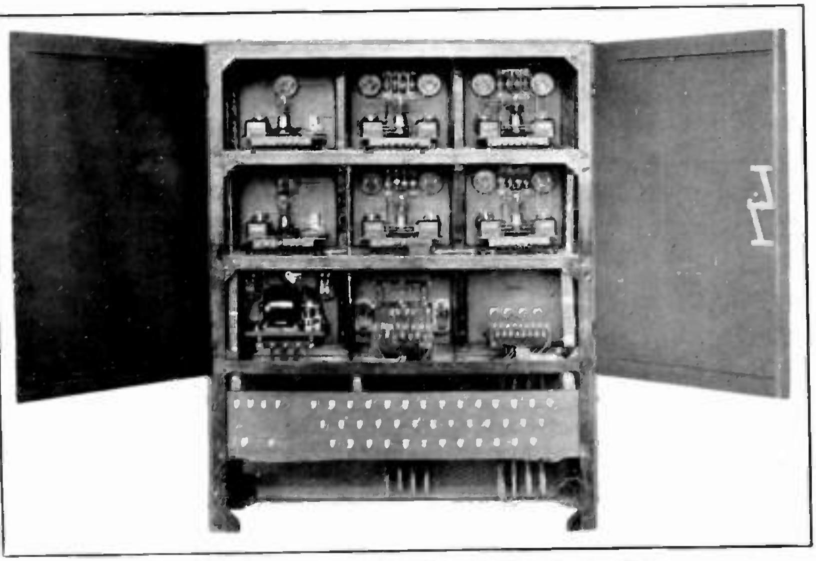


FIGURE 13—Control Room Amplifier Rack, Rear

This amplifier rack also contains relays by means of which the filament circuits of the amplifiers which the control operator has selected for the announcing or concert microphones are closed when the key in the announcer's control box is operated.

2. A special amplifier for producing a rising gain in the frequency range from 4,000 to 10,000 cycles; this is mounted above the microphone amplifier, as shown in Figure 14, duplicate equip-

ments being provided. Its wiring was indicated in the schematic diagram of Figure 8, and its operation has already been described. In the operation of the station it is usually referred to as the "S amplifier" because of the marked improvement it produces in the reproduction of this usually difficult consonant.

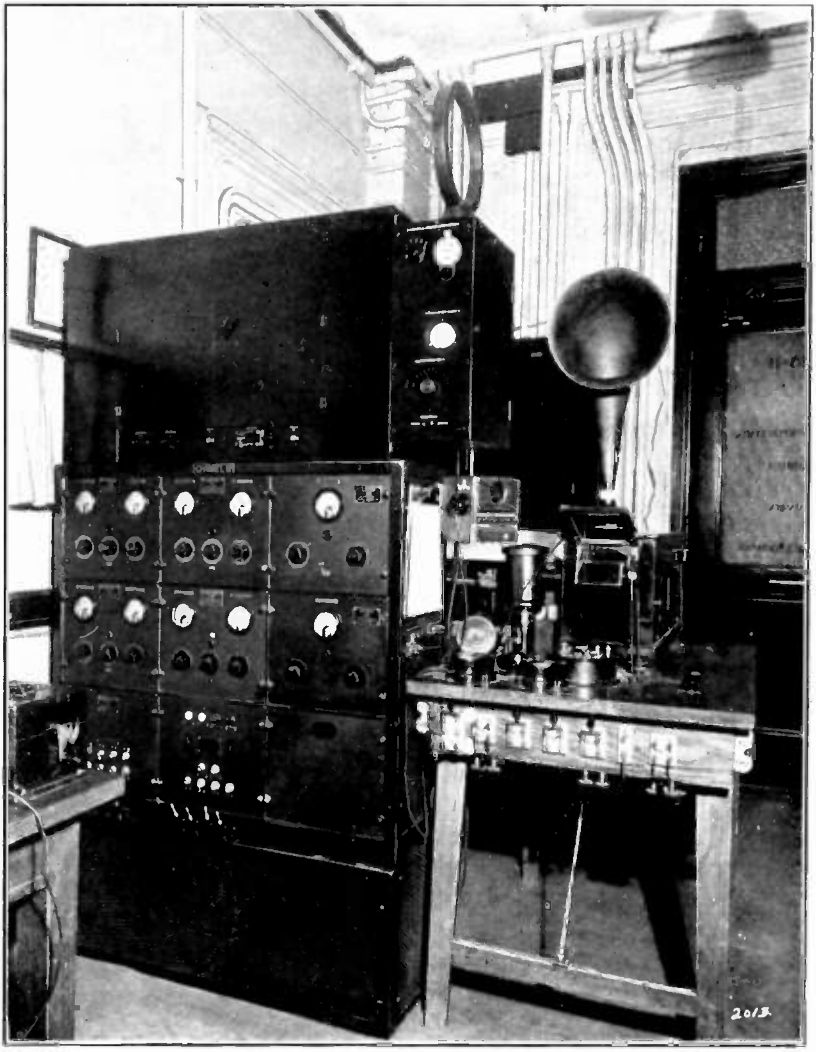


FIGURE 14—Control Room Amplifier, "S Amplifier," Modulation Control and Supervisory Equipment

3. A monitoring receiver consisting of a small loop, tuning condenser, detector, and two stage audio frequency amplifier. This receiver has approximately the same audio frequency repro-

duction characteristics as the average good present-day receiver, so that what the control operator hears has the same quality as would be heard by the average listener. The receiver is in the box to the right of the "high audio frequency" amplifier, in Figure 14. In the same box are placed the main modulation control, and a galvanometer which indicates the grid current taken by the modulator tubes in the transmitting set. The latter is used for supervisory purposes.

4. A General Electric Company oscillograph, one vibrator of which is fed from rectified antenna current. (See diagram, Figure 8). This appears below the monitoring receiver. Lines are marked on the ground glass screen to indicate full antenna current and fractions thereof, up to double and down to zero. These lines and the vibrator spot are reflected in rotating mirror, and the control operator thus has a visual picture of the modulated antenna current.

The subject of supervising will be treated further in a subsequent section.

The connections between control room and transmitter house, for amplifier power supply, audio frequency, rectified modulated radio frequency, and signaling, are all lead-covered cable in iron conduit; this method of connection is quite adequate for keeping radio frequency out of the audio frequency lines. The conduits are run thru the hall to the rear elevator shaft of the building and then up thru this to the roof, a total distance of some 600 feet (185 meters).

The control room also contains all equipment for wire line transfer of incoming or outgoing material for broadcasting; this will be described in another section.

Transmitter House

An external view of this is shown in Figure 15. It is a building 37 feet (11.4 m.) long by 20 feet (6.2 m.) wide by 12 feet (3.7 m.) high, inside.

Internal views are shown in Figures 16 and 17. Figure 16 shows a view of the following: at the extreme front, left, the power amplifier of one channel, beyond this the operating tables, and beyond this, a power amplifier of the second channel; beyond this last, the power switchboard for the direct current supply to the motor-generator sets. At the right side of the picture are four transmitters, with their motor generator sets behind them. The high panels are the transmitting sets, and between each pair of transmitters is a panel containing the filters and potentiometers for plate power supply to the various station amplifiers, derived from the transmitting motor generator sets. At the distant end of the room can be seen the oscillograph rectifier and coupling to the antenna.

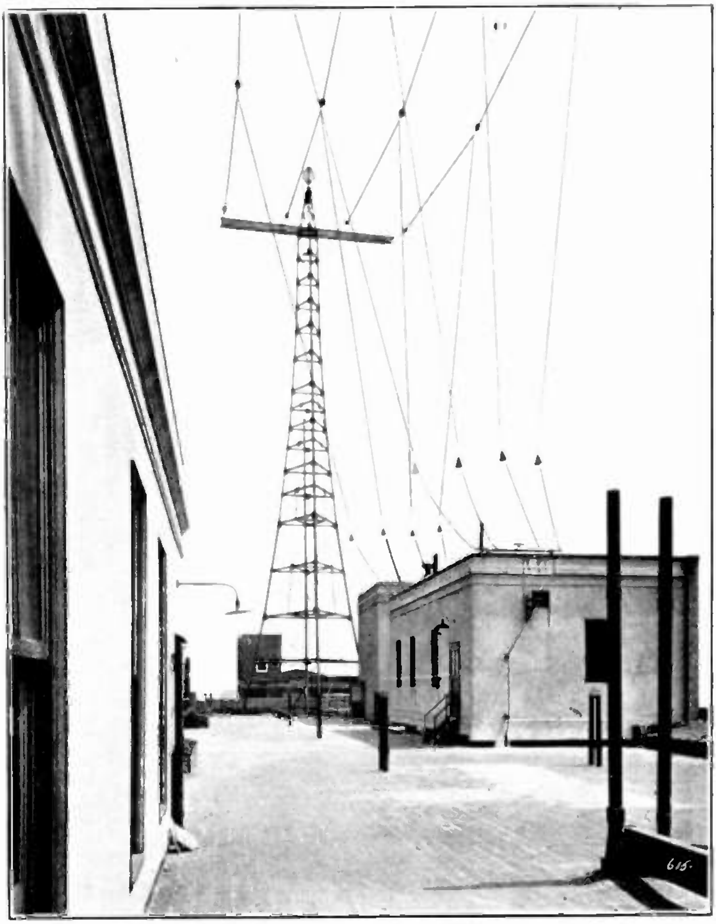


FIGURE 15—Transmitter House, Broadcast Central, Exterior

Figure 17 shows a rear view of the transmitting sets and motor generators. One motor generator set is associated with each transmitter, and bears on a common bedplate the driving motor, a combination 110-volt exciter and 30-cycle volt alternating current generator for the filament power of the transmitters, and a 2,000-volt direct current generator for plate power. The last-named has two commutators, 1,000 volts each, and from one of these plate power for the amplifiers is taken to the filter panel.

FIGURE 16—Transmitter House, Broadcast Central, Interior

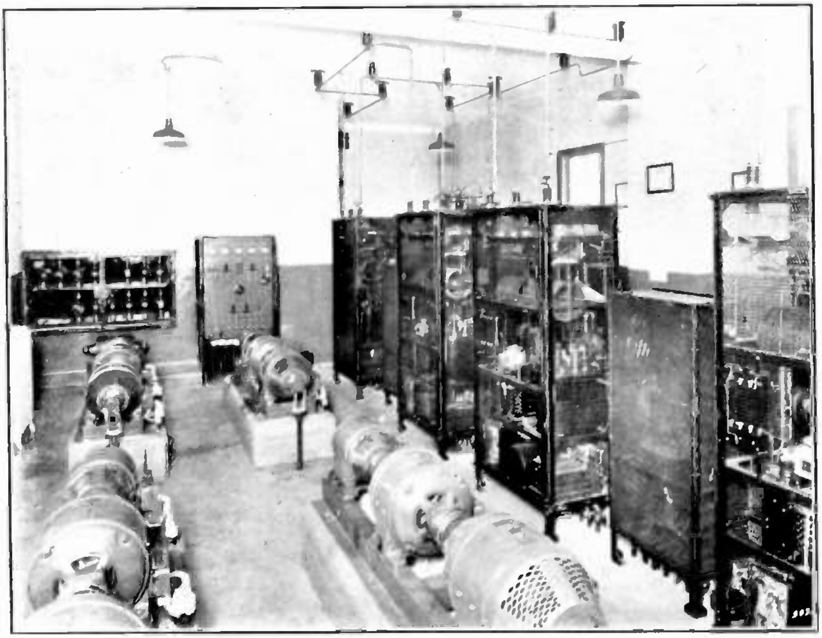


FIGURE 17—Transmitter House, Broadcast Central, Interior

At the end wall are the storage battery charging panel and charging motor-generator, as well as a rack for holding transmitting tubes.

The interconnection of the various units will be evident from the schematic wiring diagram of Figure 8.

A closer view of a power amplifier rack is given by Figures 18 and 19. Here three stages of amplification are provided, of which normally only two stages are used. The number of stages

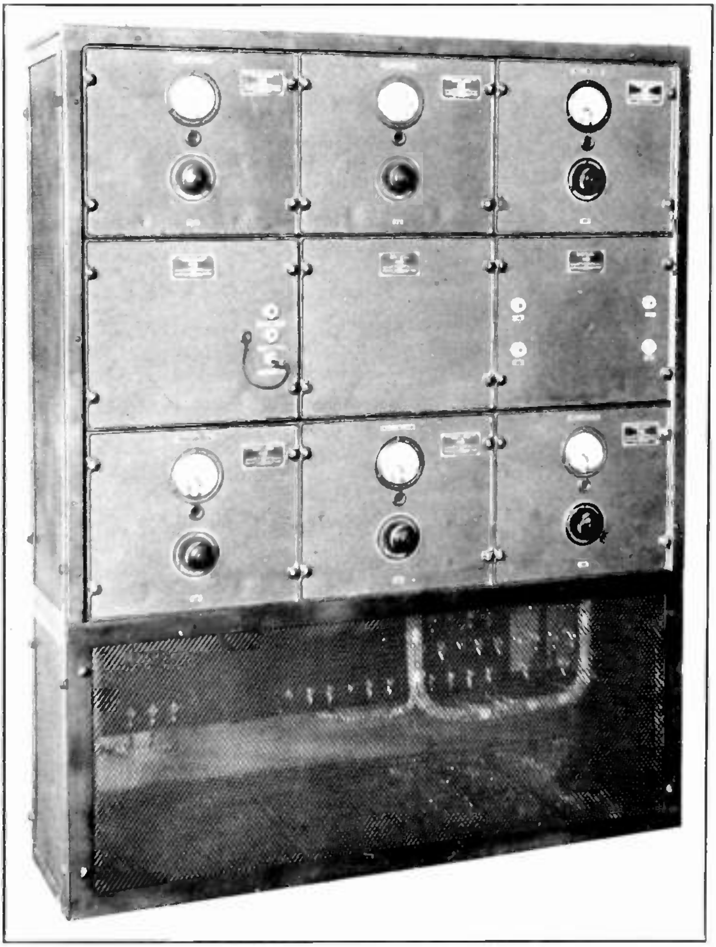


FIGURE 18—Power Amplifier, Front

desired can be connected by the plug and jacks on the left hand center panel. All tubes are of the UV-203-A type, except the last, which are UV-211, rated at 50 watts when used as oscillators, and having thoriated tungsten filaments. The amplifier stages are placed in the upper and lower rows of panels (working and spare units), the center row containing relays by means of which either amplifier can be cut in, these relays being controlled by change-over switches in the control box on the operator's table. Filament voltmeters and voltage control are the only controls provided here. On the right-hand panel in the center row (Figure 18) are listening jacks for checking the amplification in each stage. Each jack is shunted by a 500-ohm resistance, and this is placed in series with a fairly high resistance (of the order of hundreds of thousands of ohms) in parallel with the grid leaks of the respective amplifier tubes. The series resistances are adjusted to give equal loudness at each listening jack.

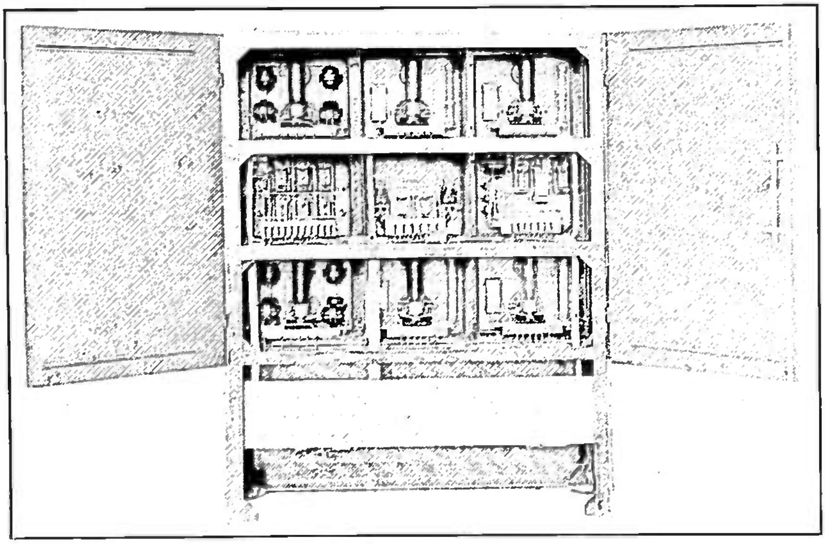


FIGURE 19—Power Amplifier, Rear

The connection from the output of the power amplifier to modulator grids is made by wire shielded by means of grounded copper tubing run overhead. These are the leads coming from insulators, on top of the power amplifiers in Figure 16. Shielding was found essential in order to prevent radio frequency currents from the antenna leads being induced in this circuit and causing the modulator tubes to overheat because of the high voltages impressed on the grids; in addition to the shielding, a small condenser (0.005 microfarad) is placed between modulator grids and filaments, in the transmitting set.

One of the transmitter panels is shown in Figures 20 and 21.

The schematic circuit of these is indicated in Figure 8, and it will be noted that two oscillator and two modulator tubes are employed. Each tube is of the UV-204-A type, rated at 250 watts as an oscillator, and having thoriated tungsten filaments. On the

FIGURE 20—Transmitter Panel, Front

front panel are, respectively, tank circuit and antenna ammeters, plate supply voltmeter, controls for filament and plate voltages, voltage regulator (to maintain constant filament voltage if motor-generator speed varies), an overload relay (which shuts down the motor generator set if plate current becomes excessive thru poor circuit adjustments or tube failure), and the relay which lights the antenna power signal lamps in the control room and studio. The rear view of the transmitter (Figure 21) shows at the bottom, left, a multiple contact automatic switch (operated by push button from the operator's control box), which connects the antenna and performs various other functions to put the set in operation, and an automatic motor starter; beside these is the filament power transformer, and at the right the smoothing con-

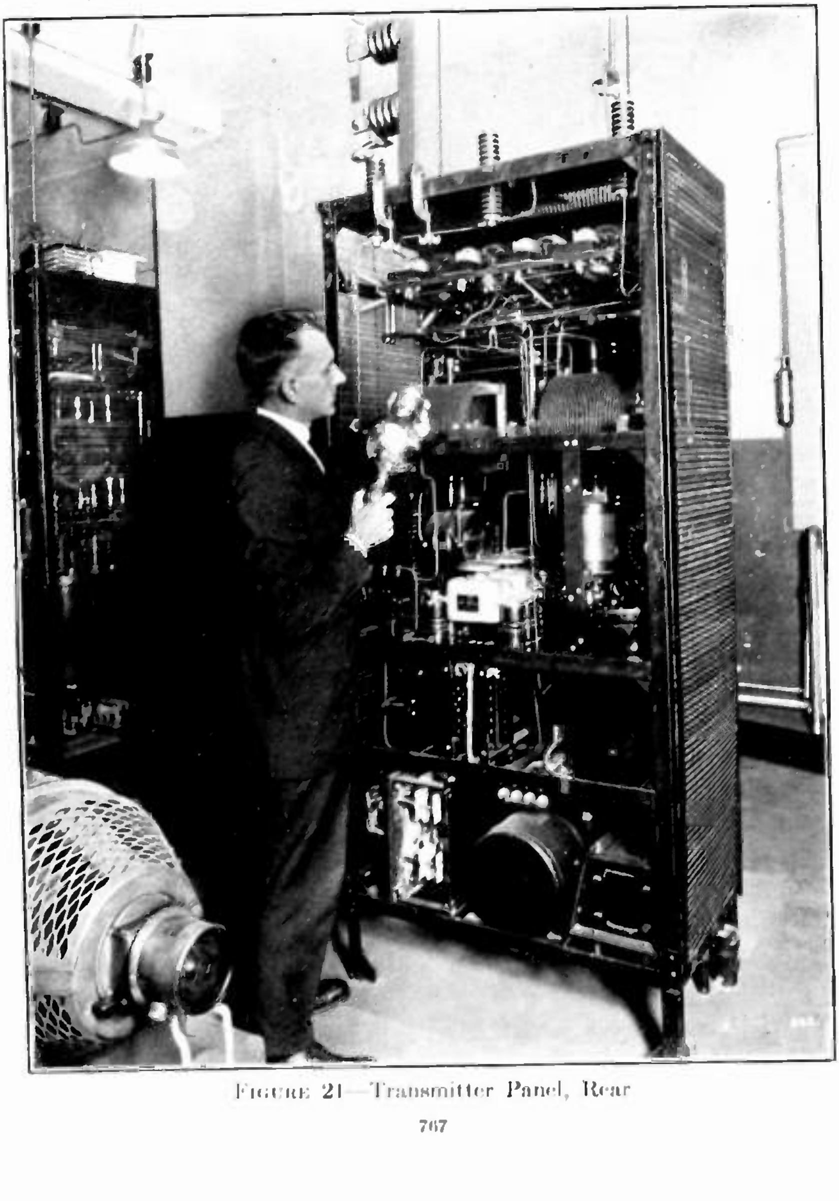


Figure 21—Transmitter Panel, Rear

densers for the plate power supply. Above these condensers is the plate reactor, to the left of it are various condensers used in the oscillating circuit. Immediately above these are the tank circuit and antenna tuning coils, of edgewise wound flat copper strip, and at the top of the set are the transmitting tubes in a spring-suspended cradle.

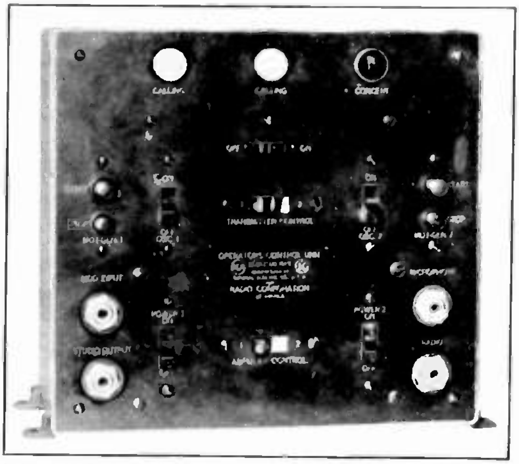


FIGURE 22—Transmitter Operator's Control Box, Front

On the operator's table is placed a control box, for each channel, which is shown in Figures 22 and 23. In this, viewed from the front, are placed the following controls for relays in the various units: near the bottom, filament power switches and change-over switch for either power amplifier, and at the sides, monitoring jacks for the input and output of the power amplifier and the radio output. In the middle at the sides are placed push-button switches for starting either motor-generator set, for throwing on plate and filament power, and for connecting either transmitting set to the antenna. At the top of the box are signaling lamps to the control room, and a lamp indicating that the announce or concert studio microphone is in operation. Thus in a very short time any distortion or trouble can be located by means of the monitoring jacks as arising in some particular section of the equipment, and a spare substituted for it.

A receiving set is also located on the operating table, and here a continuous watch is maintained so that the station may cease operation at once in case of marine distress signals; this is legally required of all coastal radio stations. The same receiver is utilized for the reception of time signals on a wave length of 2,500 meters

(120 kc.), from Arlington (distance 220 miles) (350 kilometers), and these are re-transmitted on the 455-meter (660 kc.) wave by connecting the output of the receiver's audio frequency amplifier to the input of the transmitting power amplifier thru a suitable transformer. No difficulty is experienced in receiving on wave lengths of 600 meters (500 kc.) and above, due to interference by the local transmitters; the receiving antenna is run away as far as possible from the transmitting antennas, a coupled trap is connected across the antenna and ground posts of the receiver, this trap being tuned to the wave lengths to be received, and all equipment is housed in a metal case.

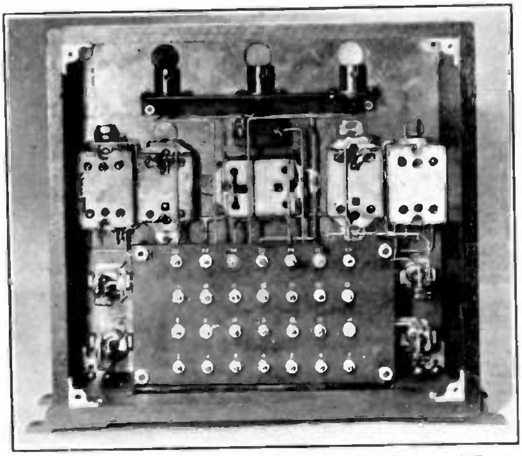


FIGURE 23—Transmitter Operator's Control Box, Rear

Figure 24 shows in somewhat better detail the following: at the bottom, one of the oscillograph rectifiers (containing a 50-watt, UV-203-A tube with grid and plate connected in parallel so as to function as a rectifier); above this, the coupling arrangement of the rectifier to the antenna, consisting of a single turn of the antenna lead placed within a helix; above this, a trap circuit necessitated by duplex operation, of which more will be said in a subsequent section; and finally, the antenna leading-out insulator.

The antenna system is shown in Figure 25, each channel being connected to an inverted "L."

SUPERVISION DURING OPERATION

In the description of control room apparatus the following were mentioned as being furnished for supervisory purposes to the control operator:

(a) A receiving set, containing a vacuum tube detector, and two stage audio frequency amplifier, with a loud speaker, to represent the average listener's receiver.

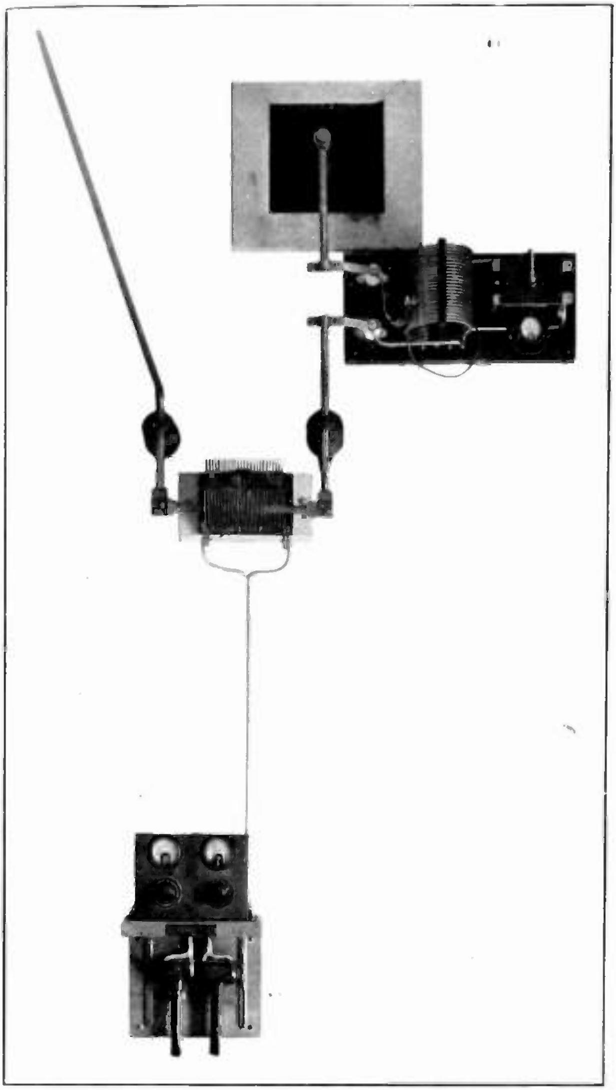


FIGURE 24—Oscillograph Rectifier with Antenna Coupling Arrangement, and Wave Trap

(b) An oscillograph, to one vibrator of which a small amount of rectified antenna current is brought, the fluctuations of the vibrator spot being made visible in a rotating mirror.

(c) A galvanometer which indicates the direct current drawn by the grid circuit of the modulator tubes, when positive voltages are impressed.

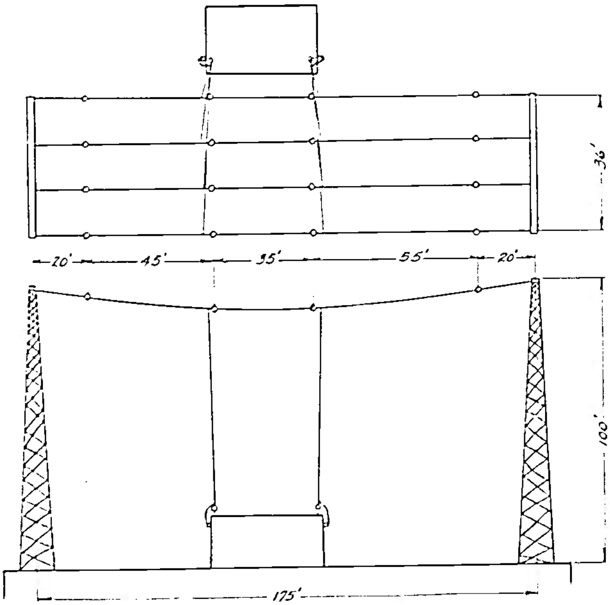


Figure 25—Broadcast Central, Antennas for Two-Channel Transmission

The control operator is concerned first, with maintaining as high a percentage of modulation (that is, ratio of side bands to carrier wave) as possible, without distortion; and, second, with the determination of the proper placing of artists in the studio, so that correct balance is obtained between soloists and accompanists, or between the various instruments of an orchestra. The receiving set is used to determine the general character of the performance, the presence of distortion, or to indicate any sudden interruption. The oscillograph indicates the percentage of modulation, while the modulator grid current galvanometer is an indicator which warns the operator that the maximum permissible percentage of distortion-free modulation is being obtained. The manner in which the last-named instrument is used is as follows: observation of the shape of the modulated wave in the oscillograph mirror will indicate that, in general, it is very irregular, having occasioned high "peaks" and many smaller irregular undulations; and it is essential to regulate the degree of modulation so that these peaks will not exceed a permissible maximum. Now, in the oscillograph, these peaks occur very rapidly, and are intermixed with all the other irregular fluctuations, so that for continual observation the eye would soon tire of judging the percentage modulation this way. However, it is really not necessary for the control operator to know the actual percentage at all times; all he is concerned with is that the modulation shall not *exceed* a certain maximum. This is conveniently done by the use of the modulator grid current indicator. Normally, with modulation less than about 30 percent (a fluctuation of antenna current from 30 percent below maximum to 30 percent above), no positive audio frequency voltages are impressed on the modulator grids, hence no grid current flows, and the galvanometer remains at zero. Whenever the modulation peaks exceed this value, a rapid "kick" of the galvanometer will be seen at each of the occasional peaks; thus this instrument is really a peak-reading ammeter. The presence and magnitude of these occasional deflections warn the control operator that modulation in excess of 30 percent is being obtained; normally a modulation of about 40 percent is allowed, corresponding to a certain deflection of the galvanometer. A greater degree than this would result in the generation of double frequency harmonics of appreciable magnitude, in receiving sets using square-law rectifying detectors, when sinusoidally modulating the transmitting set at a given audio frequency.[9] Thus the control operator need only watch to see that the occasional kicks of the galvanometer pointer do not exceed a certain value; most of the time the pointer will remain at zero.

This sort of observation method is considerably better for control purposes than one which involves the watching of a continually flickering object or wave, altho observation of the oscillograph is useful in making more exact observations of the character of the modulating wave and as a check against the galvanometer.

Audio Frequency Characteristics of Station Apparatus

In a broadcasting system it is necessary to transmit a range of frequencies, from the source of sound to the ear of the auditor, which up to the present we have taken as lying between 30 and 10,000 cycles. The frequencies which occur in music, in fundamental tones, range from 16 cycles for the largest organ pipes up to about 4,000 cycles for the highest instrument tones; how-

[9] R. V. L. Hartley: "Relations of Carrier and Side Bands in Radio Transmission." Proceedings of The Institute of Radio Engineers, volume 11, page 34, 1923.

ever, harmonics which characterize the different instruments, or the singing voice, require the effective transmission of frequencies up to at least 10,000 cycles, in order to secure the clear, "keen" quality appreciated by musicians. Another aspect of these transmission requirements is that we find, experimentally, with a transmission range extending as high as 10,000 cycles, that each instrument or group of instruments in an orchestra seems to stand out clearly when reproduced in a good receiver, while limitation of the upper frequency transmission to 3,000 cycles, for example, causes the musical rendition to become "muddy" or blurred. The latter effect probably occurs because with a combination of instruments very rapid transients or changes in the sound wave shape may occur, taking place in a time much shorter than that corresponding to the fundamental frequencies being played; but a transmission system which will transmit frequencies up to 10,000 cycles will also transmit sudden fluctuations in wave shape taking place in a ten-thousandth of a second.

In the case of speech, the transmission of such consonants as "S" requires effective transmission of a frequency of the order of 10,000 cycles; similarly, to secure natural voice quality, particularly of male voices, it is necessary to transmit effectively frequencies down to perhaps 30 cycles.

The foregoing statements are mainly the result of qualitative observations on apparatus of which the frequency range of transmission was known, when listening with ordinary telephone receivers (as the broadcast listener does). We have not had any opportunity to determine in detail what the permissible change may be in the ratio of amplitudes of one frequency to another, as it exists in the initial sound, compared to what it may become by the time it reaches the listener, before the listener is aware of distortion.

The extent to which we have been able to meet the foregoing transmission requirements, in the station apparatus, is shown in Figure 26, and the method of taking the observations in Figure 27. This curve represents the amplitude of the alternating voltage applied by the modulators to the plates of the oscillator tubes (to which the modulation will be proportional), when a constant sinusoidal voltage of variable frequency is impressed in place of the microphone (a resistance of 200 ohms being placed in series with the voltage source to represent the internal resistance of the microphone). The microphone itself may be considered as sensibly such a source. The reason for the rising gain

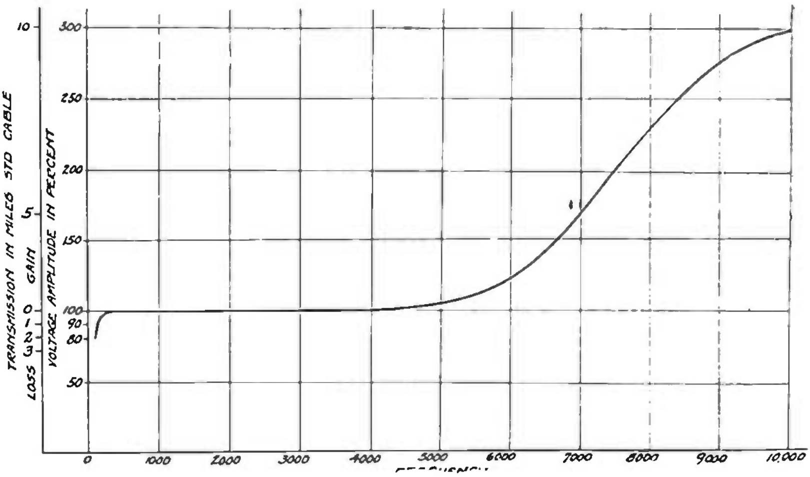


FIGURE 26—Performance Curve of Station Apparatus

at the high frequency end of the range has been mentioned previously.

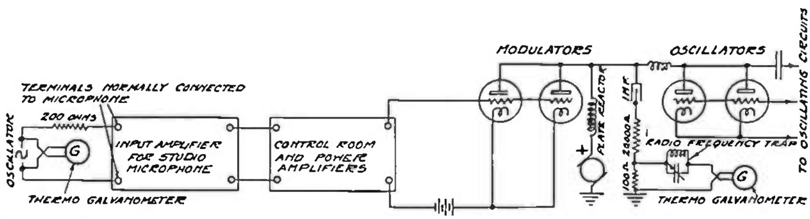


FIGURE 27—Method of Measuring Audio Frequency Modulation Characteristics of a Radio-Telephone Transmitter

Two-Channel Transmission

The operation of two channels simultaneously, at Broadcast Central, was attended at the start with difficulties due to "cross-talk" between the two channels. This cross-talk was due to modulated radio frequency currents induced from the transmitting apparatus or antenna of one channel in circuits connected with the other channel; these currents were rectified by vacuum tubes or other apparatus capable of rectifying action, became audio frequency currents, then passed thru the audio frequency amplifiers to the modulators, and modulated the transmitting set. Thus the audio frequencies modulating each channel might be heard on the wave length of the other channel.

No pure audio frequency cross-talk between the two channels was experienced, since audio frequency circuits where cross-talk might have been set up were only the connections between transmitter house and control room, and here each channel was run in lead-covered cable, in separate iron conduits.

Radio frequency induction was found in the following circuits, and eliminated in each case by the measures indicated:

1. In studios and control room, the microphone leads to the amplifiers required very careful shielding, copper sleeving over the flexible microphone conductors being sufficient. The shielding was continuous from the amplifier terminals to the microphones; in a first installation, the wiring had been run from control room to studio, thru lead-covered cable between terminal boards located in these rooms, in standard electrical fashion, and in each terminal box a few feet of unshielded cable had been left. These few feet were quite sufficient to give rise to serious cross-talk.

2. The control room amplifiers themselves, being in steel cases, picked up no appreciable amount of radio frequency. However, there was always a considerable amount of radio frequency which came in on the outside wire lines, when these were connected to the amplifiers. This was prevented from reaching the first amplifier tubes by the use of audio frequency input transformers having a copper shield between primary and secondary windings. In some cases cross-talk was found even after this was done; this was traced to the rectifying action of some of the carbon block compression rheostats, which were shunted across the primary windings of all input transformers, for modulation control purposes, in the original installation. This control method was superseded later on by the arrangement shown in Figure [illegible].

3. In the transmitter house, the proximity of the two antennas caused a current of 1 to 2 amperes from each channel to flow in the down-lead of the other channel. This current eventually caused radio frequency voltages to be induced in the grid circuits of the modulator tubes, large enough to give serious cross-talk. The difficulty was remedied by inserting coupled trap circuits in each antenna lead, as shown in Figure 28. Each trap was tuned to the wave length of the opposing channel, and the coupling was adjusted to build up as high an effective resistance as possible at the wave length of the opposing channel, with still no appreciable loss of energy at the wave length of its own channel. The method of adjustment was simply to note the current in the antenna lead of each channel with the other channel running alone, and adjust so that the cross-talk current was made as small as possible, without affecting the desired antenna current; all circuits were left com-

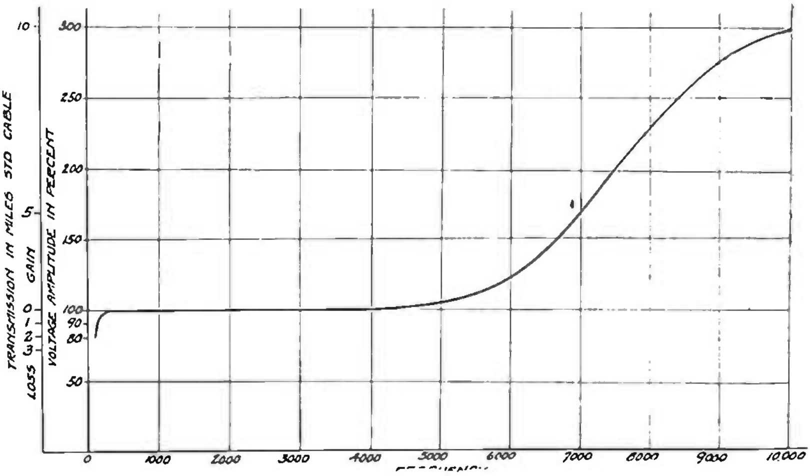
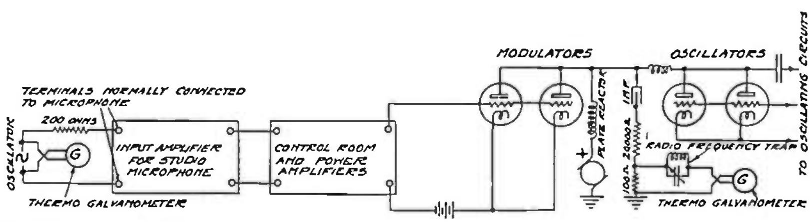


FIGURE 26—Performance Curve of Station Apparatus

at the high frequency end of the range has been mentioned previously.



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No pure audio frequency cross-talk between the two channels was experienced, since audio frequency circuits where cross-talk might have been set up were only the connections between transmitter house and control room, and here each channel was run in lead-covered cable, in separate iron conduits.

Radio frequency induction was found in the following circuits, and eliminated in each case by the measures indicated:

(1) In studios and control room, the microphone leads to the amplifiers required very careful shielding, copper sleeving over the flexible microphone conductors being sufficient. The shielding was continuous from the amplifier terminals to the microphones; in a first installation, the wiring had been run from control room to studio, thru lead-covered cable between terminal boards located in these rooms, in standard electrical fashion, and in each terminal box a few feet of unshielded cable had been left. These few feet were quite sufficient to give rise to serious cross-talk.

(2) The control room amplifiers themselves, being in steel cases, picked up no appreciable amount of radio frequency. However, there was always a considerable amount of radio frequency which came in on the outside wire lines, when these were connected to the amplifiers. This was prevented from reaching the first amplifier tubes by the use of audio frequency input transformers having a copper shield between primary and secondary windings. In some cases cross-talk was found even after this was done; this was traced to the rectifying action of some of the carbon block compression rheostats, which were shunted across the primary windings of all input transformers, for modulation control purposes, in the original installation. This control method was superseded later on by the arrangement shown in Figure 8.

(3) In the transmitter house, the proximity of the two antennas caused a current of 1 to 2 amperes from each channel to flow in the down-lead of the other channel. This current eventually caused radio frequency voltages to be induced in the grid circuit of the modulator tubes, large enough to give serious cross-talk. The difficulty was remedied by inserting coupled trap circuits in each antenna lead, as shown in Figure 28. Each trap was tuned to the wave length of the opposing channel, and the coupling tap adjusted to display as high an effective resistance as possible at the wave length of the opposing channel, with still no appreciable loss of energy at the wave length of its own channel. The method of adjustment was simply to note the current in the antenna lead with each channel running alone, and adjust so that the cross-talk current was made as small as possible, without affecting the desired antenna current; all circuits were left com-

plete thruout, as for two channel operation, and oscillations started by applying plate voltage.

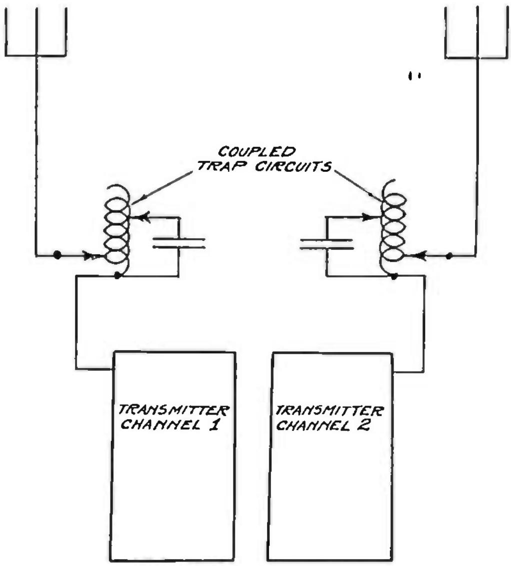

FIGURE 28—Trap Circuits for Reduction of Cross Talk Between Channels

(4) When using portable amplifiers on work outside the studio within a distance of about a mile from the station, or of other radio stations, and in certain locations, considerable radio frequency was found present in the wire lines to the station. These lines are often overhead twisted pairs, which act as a very good antenna. The radio frequency current flowing in these lines would cause voltages to be induced in the apparatus of the portable amplifiers (which was partly unshielded); this eventually resulted in audio frequency cross-talk due to rectification in the amplifier vacuum tubes. The difficulty was remedied by inserting a trap circuit, consisting of a variable condenser in parallel with an inductance, in series with each side of the line, and tuning each trap to the interfering signal. The radio frequency current flowing in the line wires was thus greatly reduced and the cross-talk correspondingly lessened. Future models of portable amplifiers will be thoroly shielded to avoid this difficulty.

Studio Operation

In the organization of these stations the control operator is responsible for the general supervision and maintenance of the technical standard of the performance. He normally remains in the control room, but it is his duty to advise or correct the studio announcer in his placing of performers with respect to the microphone. For this purpose a "Dictograph" interphone system is provided, by means of which the control operator may signal or talk to the announcer; a lamp signal is used for attracting attention, or a buzzer signal may be used instead by throwing a switching key. The microphone used in this type of interphone is exceedingly sensitive, so that the announcer may talk to the control room in a very soft tone, during a performance, without disturbing the artist. The same interphone system connects to all other parts of the station.

Figure 29 shows some of the typical methods of placing performers with respect to the microphone. These are the result of experience in the WJZ studio and would probably not hold very strictly for other rooms. With all new performers, a trial placing is made according to experience, for the first number; this can be altered during the number, if necessary, by moving the microphone stand, or after the first number by suitable alteration of positions of performers. The announcer is usually familiar with the placing required for various types of performance and normally arranges the performers without any specific instructions from the control operator. The latter observes the effect of the announcer's placing, controls the degree of modulation, and makes an estimate, if possible, of the volume range the performers are capable of. Judging from this, he instructs the announcer to make such changes in placing as he deems necessary, so as to prevent blasting of the microphones or to secure a better "balance" (ratio of volume of soloist to accompaniment or ratio of volume of various instruments in an ensemble).

It may appear that less work would have to be done with regard to proper placing of the performers if the microphone were not used relatively close up, being placed instead, for example, at the opposite end of the studio. In the latter case, the relative distance of the microphone from each of several performers would be nearly the same and there would apparently be less of a problem so far as proper "balance" is concerned. However, it has been found that this cannot be done for a number of reasons. [illegible] the farther away the microphone is from the performers, the greater is the proportion of sound which reaches it by reflection from the room walls, compared with that reaching it direct from the source of sound. The reflected sound are generally distorted, since they not only are reflected in a variable fashion with respect to frequency, but interference phenomena occur between reflected sounds coming from various reflection points. Thus, it is found that the sounds as heard from a microphone located, say 20 feet (6 meters) from the source are more distorted than those heard when the microphone is placed relatively close.

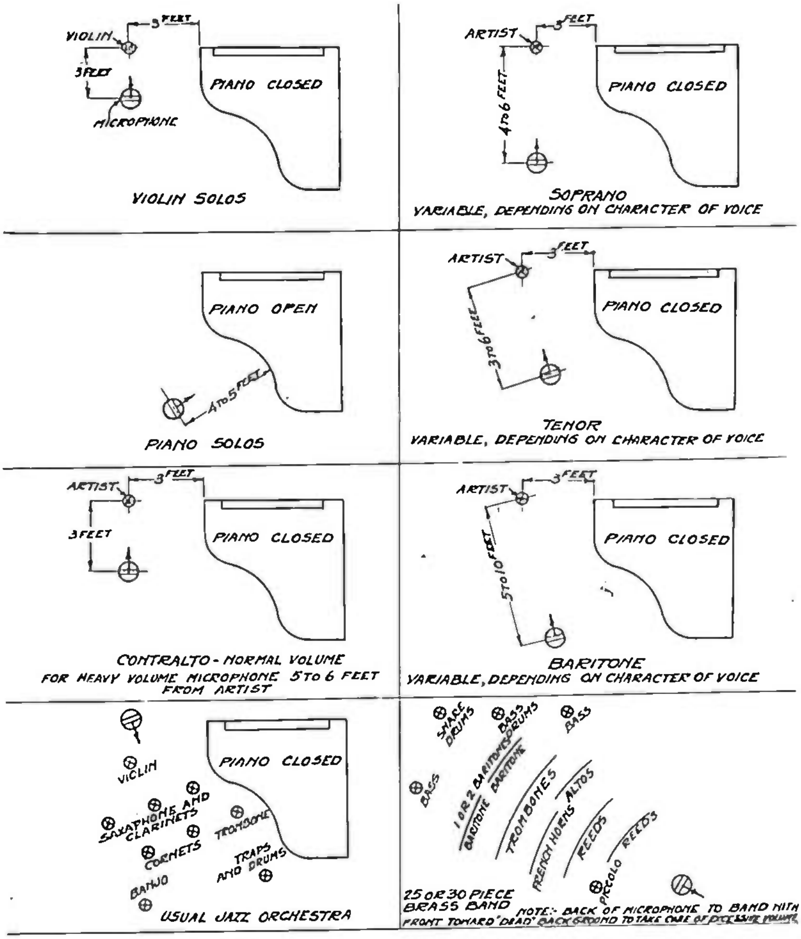

FIGURE 29—Placing of Microphone in Studio

Second, the sounds reaching the microphone must be strong enough to give an output far exceeding the hiss due to the use of carbon, and this again necessitates fairly close placing with all performers except orchestras or large choruses.

Third, there is a certain advantage is giving the performers an object, such as the microphone stand, at which to direct their remarks, or music. A difficulty which all broadcasting stations experience is the lack of an audience to which the artists are accustomed. Usually this is helped by trying to have the radio listeners send in telegrams or make telephone calls during the performance, which are transmitted to the artist. We have tried to improve this situation further by placing a large mural painting on the wall of the studio, which is faced directly by the artist when broadcasting. In this, the painter has tried to depict some of the types of people who, the performer may imagine, are listening to him, and the vast spaces over which his voice or music may be traveling out to reach them. This is shown in the studio photograph, Figure 4.

One point that may be of interest is the variety of entertainment that is broadcast; Table I gives a list of typical program material transmitted from the studios at Broadcast Central during the first year of operation. (This table, as well as Table II, was very kindly supplied by Mr. Charles B. Popenoe, Program Director.)

TABLE I

STUDIO EVENTS
BROADCAST CENTRAL
May 15, 1923, to May 1, 1924

CLASSIFICATION	Number of Events
Alto Solos	3
Bands	48
Baritones	163
Bass Solos	32
Cellists	12
Concerts	157
Contraltos	104
Duets (Vocal and Instrumental)	12
Harpists	14
Miscellaneous Events: Celebrations, Music Lecture Recitals, Whistlers, Saxophones, Harmonicas, Languages, etc.	159

(*Table I—Continued*)

Classification	Number of Events
Orchestras (including Dance Orchestras)	113
Piano	401
Poetry—Readings	100
Popular Songs	215
Quartettes	57
Songs (Sacred and Folk)	45
Sopranos	505
Stories (Bedtime)	294
String Music (Miscellaneous)	25
Talks	1336
Tenors	159
Trios	23
Violinists	186
Vocal Concerts	47
U. S. Army Bands	12
U. S. Navy Bands	12
U. S. Marine Band	1
Total	4235

Broadcasting From Points Outside the Studios

At Broadcast Central approximately 100 events per month are broadcast which emanate from points outside of the station, such as hotels, theatres, concert halls, and so on.

Table II shows the range and variety of subject matter that was handled from such points during the first year of operation of Broadcast Central. Special portable microphone and amplifier equipment has been developed for this work, in order to convert the sounds produced to electric currents of suitable character and intensity for transmission over a pair of wires to the broadcasting station, there to be radiated. A special wire line system has been erected in New York City for this service, a similar system is being installed in Washington, District of Columbia, and connections to station WGY of the General Electric Company, at Schenectady, New York (distant about 160 miles (256 km.)), as well as to station WRC at Washington, District of Columbia (distant about 220 miles (350 km.)) are also being provided; so that events at New York, Schenectady, Washington, or other cities enroute, may be broadcast simultaneously from these three stations if desired.

TABLE II

Events Outside of Station
Broadcast Central
May 15, 1923, to May 1, 1924

Classification	Total
Aeolian Hall Recitals	19
Banquets	70
Baseball Games	6
Boxing Bouts	8
Concerts (Vocal and Instrumental)	82
Church Services	100
Football Games	7
Band Concerts	16
Miscellaneous Events	69
N. Y. Board of Education Lectures	16
N. Y. University Lectures	44
Opera	3
Orchestra (Hotel and Dance)	348
Organ Recitals	116
Polo Games	3
Symphony Orchestra Concerts	23
Theatres (Plays and Musical Plays)	34
Town Hall Events (Addresses and Concerts)	14
Total	978

Wire Line System in New York City: The system in use has been installed by the Western Union Telegraph Company, in co-operation with the Radio Corporation of America, and consists partly of new facilities exclusively provided for this service and partly of existing facilities which are leased as required from time to time. The system is based to a considerable extent on the use of the elevated railways which traverse Manhattan Island (the principal borough of New York City) lengthwise, to carry trunk line cables. These cables have outlet terminal boxes and switchboards at important points, so that overhead twisted pair connections can be made from the trunk lines to points from which broadcasting is to be done. The system thus obtained is very flexible, makes it possible to lay trunk cables exclusively for this work at moderate expense, and also provides connections at a reasonable cost, since the work of running weatherproof twisted pair over the housetops, from the trunk cable terminal boxes to a desired point, can usually be done by one lineman in a few hours. Fortunately, also, the theatrical and hotel district, in which the great majority of events originate, is fairly restricted in area, and thus the trunk cables need not be very extensive. Connections to points in New York not reached by the regular broadcasting trunk cables are made via other facilities at the main terminal office of the Western Union Telegraph Company, situated at 24 Walker Street, by means of special pairs connecting to Broadcast Central. At this same office connections are also made to Schenectady, and to certain points outside of New York City.

The trunk lines so far installed on Manhattan Island are shown in Figure 30. These follow the elevated railways on Third, Sixth, and Ninth Avenues, with cross-connecting links. The trunk cables are terminated at small switchboards installed at the elevated railway stations, at certain points, so that connections of trunks may be made up as desired, and also so that a minimum length of "dead end" trunk cable is left connected in parallel to a working circuit. Terminal boxes at which overhead pairs may be bridged across any trunk line are installed about every 600 feet (200 meters) along the cables; in the less important districts they are placed only where it is likely that connections may be wanted.

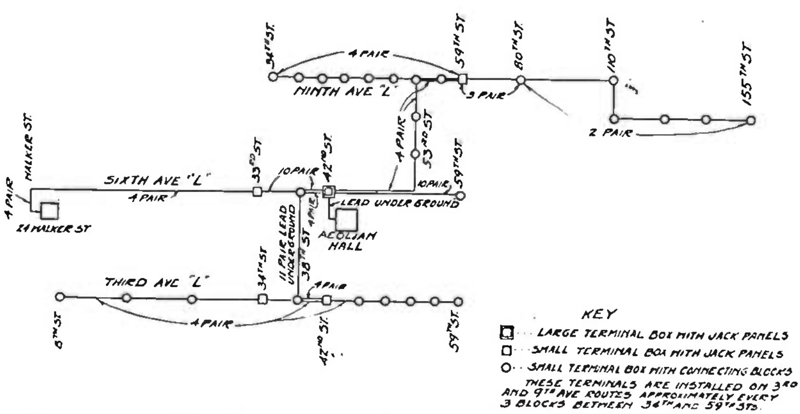

FIGURE 30—Wire Line System, Broadcast Central, New York City

An interesting point in connection with this elevated railway plant is its absolute freedom from induction, due to the motors of passing trains (the railways use 600 volts, direct current), tho the cable is only about five feet from the power rail. It was originally feared that lead-covered cable would be required, but the experience of the Western Union Company had been that lead-covered cable soon crystallized under the continuous vibration to which it is subjected on these railway trestles; hence a rubber-covered cable made up of rubber insulated pairs was recommended. However, the first installation of the rubber-covered cable soon proved that our fears of induction had been groundless, and it has accordingly been used thruout. The runs are sufficiently short so that the somewhat worse telephonic transmission qualities of rubber insulated wire as compared with the customary paper insulation do not matter to any appreciable extent.

Long Distance Wire Lines: Connections to points outside of New York City are obtained either via special facilities installed for the purpose by the Western Union Telegraph Company, or by the Postal Telegraph Company, or by lease of existing facilities. Figure 31 shows the long lines so far specially installed or in process of installation. Existing facilities available for broadcasting use are not shown. The Postal Telegraph Company is making connections between the New York and Washington stations, which enable events to be broadcast from these cities or also others en route, as indicated in the figure; while the Western Union Telegraph Company has furnished the connections to Schenectady.

The apparatus used in connection with simultaneous broadcasting thru the medium of this wire system will be described later on.

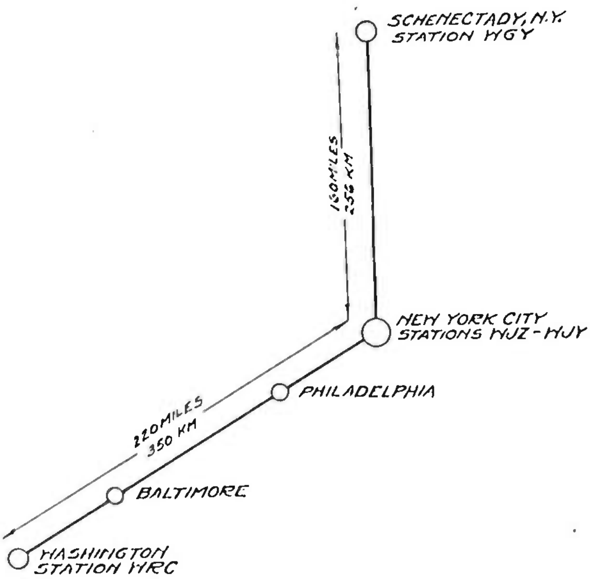

Figure 31—Long Distance Wire Lines for Broadcasting

Portable Apparatus

In broadcasting from points outside of the station various types of portable amplifiers and battery boxes, microphones, microphone stands or housings, and an accessories kit for wire and tools are required.

Amplifiers: A standard set of equipment for the more usual types of work comprises the portable battery box and amplifier shown in the photograph, Figure 32, and its wiring diagram in Figure 33. The box at the left contains a 6-volt, 20-ampere

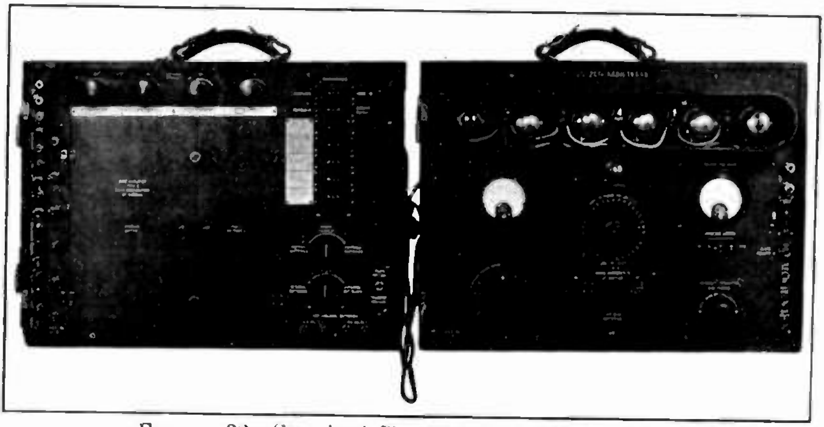

Figure 32—Standard Type of Portable Amplifier

hour battey for filament and microphone current, and five 20-volt "intermediate size" batteries forming a 100-volt battery for the plate voltage; here also (at the left) are mounted binding posts for connecting a total of five carbon double button microphones (called "concert" microphones), if desired, an announcing microphone, or the output terminals of a previous amplifier for example, for a condenser transmitter or line. At the right side are keys for switching from the announcing to the carbon concert microphones, or to the "condenser transmitter amplifier" or for connecting the carbon microphones in parallel. Cords and multiple contact plugs are provided for making connections from battery box to amplifier box. Switches are provided for connecting either the batteries contained within the box, or external ones in an emergency, to the amplifier. At the top of the battery box are four rheostat knobs which are used individually to regulate the microphone current of concert microphones numbered 1, 2, 3, and 4. These rheostats are a carbon compression type and permit the microphone current to be regulated smoothly

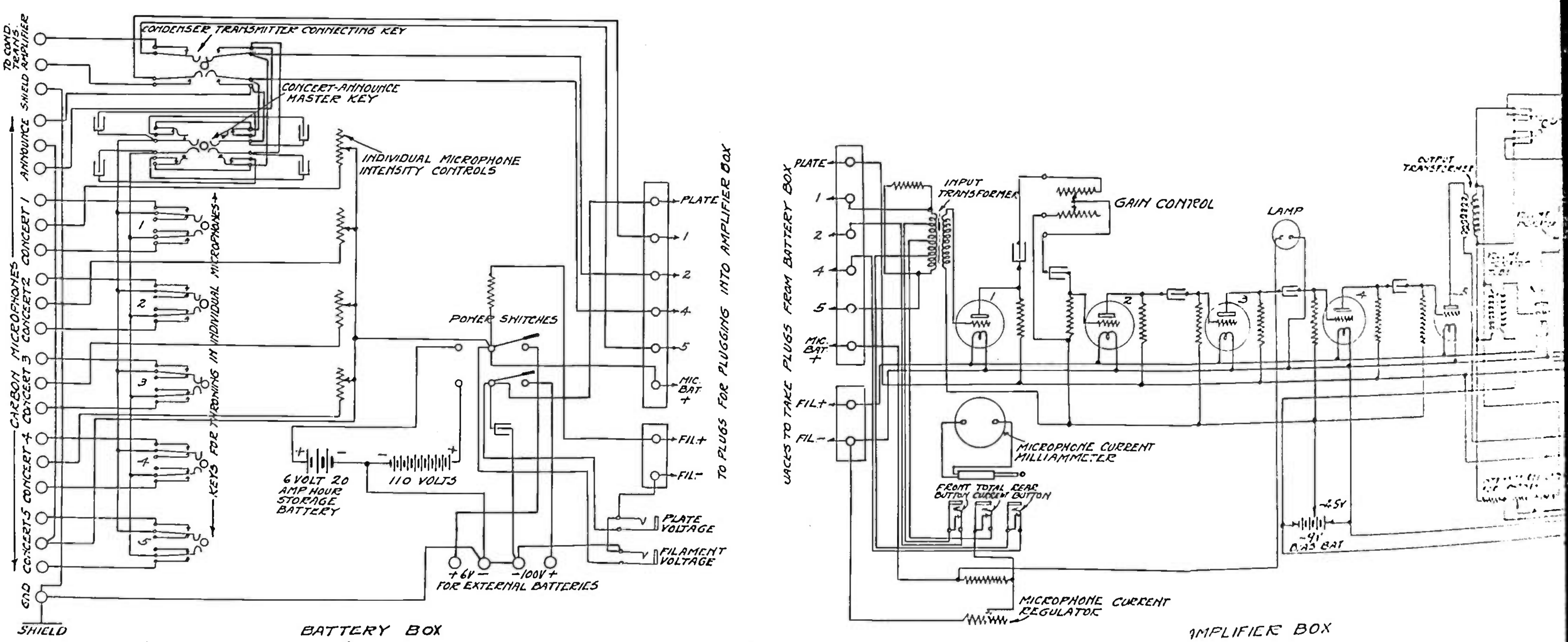

FIGURE 33—Wiring Diagram, Standard Portable Amplifier

Portable Apparatus

In broadcasting from points outside of the station various types of portable amplifiers and battery boxes, microphones, microphone stands or housings, and an accessories kit for wire and tools are required.

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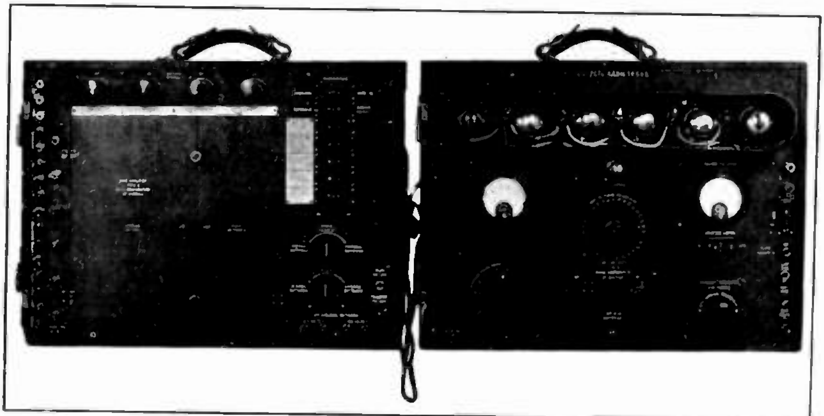

Figure 32—Standard Type of Portable Amplifier

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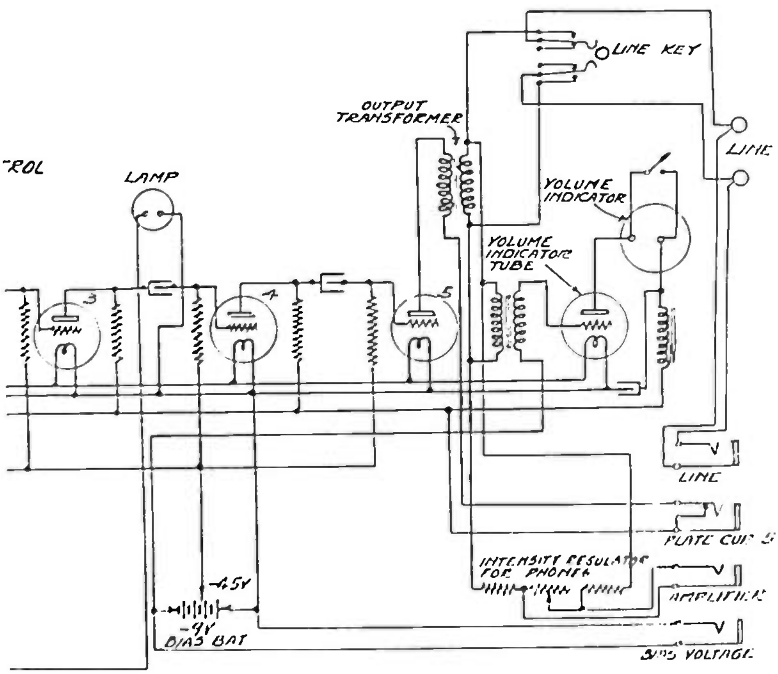

AMPLIFIER BOX

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and without noticeable noise, from a few milliamperes up to the rated current of 40 milliamperes. In this way, microphones placed, for example, on a stage and in the orchestra pit may be thrown in parallel, the volume contributed by each microphone (which is proportional to the microphone current) regulated individually, and a suitable balance of the voices from the stage with the orchestra accompaniment thus obtained. This feature is especially useful in broadcasting musical comedies or grand opera.

The right hand or amplifier box contains six tubes, along the top. Five of these are amplifier tubes, the sixth serves as a "volume indicator" (vacuum tube voltmeter indicating the voltage impressed on the telephone line). In the center of the panel is a "Gain Control," by means of which the amplification can be controlled by 20-percent steps from maximum to practically zero. This is merely a potentiometer between the plate circuit of the first tube and grid circuit of the second tube, as will be apparent from the wiring diagram. To either side of the gain control are meters for the microphone current and volume indication. Below the microphone current ammeter is a stepwise rheostat for roughly controlling microphone current, and below the gain control a compartment for housing a 9-volt battery for the volume indicator grid bias tapped at 4.5 volts for amplifier grid bias. At the right-hand end of the box are line binding posts, line switching key, and jacks for measuring various battery voltages, or currents, and for listening either directly across the line or in a special circuit fitted so as to permit the operator to regulate the intensity of the signal to suit himself, without affecting the outgoing signal intensity. A small automobile lamp, run off the 6-volt filament battery, and mounted above the gain control, has proved quite an essential feature, since it is frequently necessary to handle the amplifier in dark places (theatres).

Covers with padlocks are provided for both boxes, each box weighs about 35 pounds (16 kg.), and the two boxes with accessories kit can easily be transported by two men.

The maximum voltage amplification obtainable by this amplifier, from a 250-ohm input circuit (equivalent to a microphone) to a 250-ohm output circuit, is about 3,400 times (a gain of nearly 75 miles, in telephone terminology). However, we have never found it necessary to use this much, the usual practice being to work the amplifier at a step corresponding to a voltage amplification of about 200 times (49 miles). With this the announcer's speech (talking a distance of about 1 foot (30 cm.) from the microphone) or other material being broadcast, with normal microphone placing (see Figure 41 showing typical placings for outside work) is brought to normal telephone level before being impressed on the line. (A line voltage of the order of 0.25 to 0.5 volt is usually employed.)

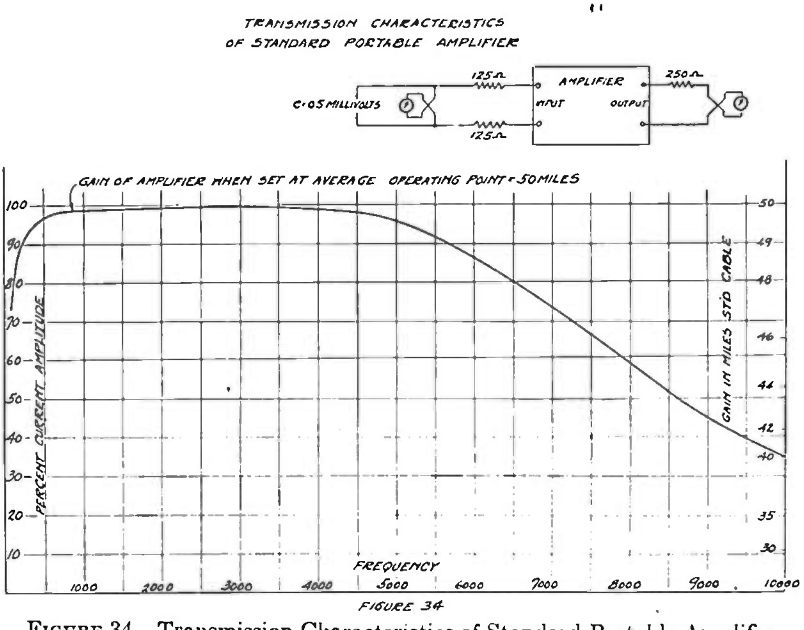

FIGURE 34—Transmission Characteristics of Standard Portable Amplifier

A frequency characteristic of one of these portable amplifiers is shown in Figure 34, with 250-ohm input and output circuits (resistance). The wide frequency range is obtained by the use of resistance amplification with the coupling elements calculated to transmit low frequencies with good efficiency, and carefully designed input and output transformers having high inductance windings with very low leakage.

A special type of portable amplifier for use in crowded places is shown in Figure 35. This is used at athletic contests, boxing matches, outdoor concerts or other events where only one or two seats can be had for the broadcasting staff. The operator can place this instrument between his knees (it is about 8 inches (20 cm.) square, at the base) and operate it readily, when seated in a chair among the audience, with the announcer in the seat next to him. If necessary, one man can both operate and announce. The amplifier apparatus is placed back of the sloping panel, and filament, bias, and plate batteries in the lower part of the box.

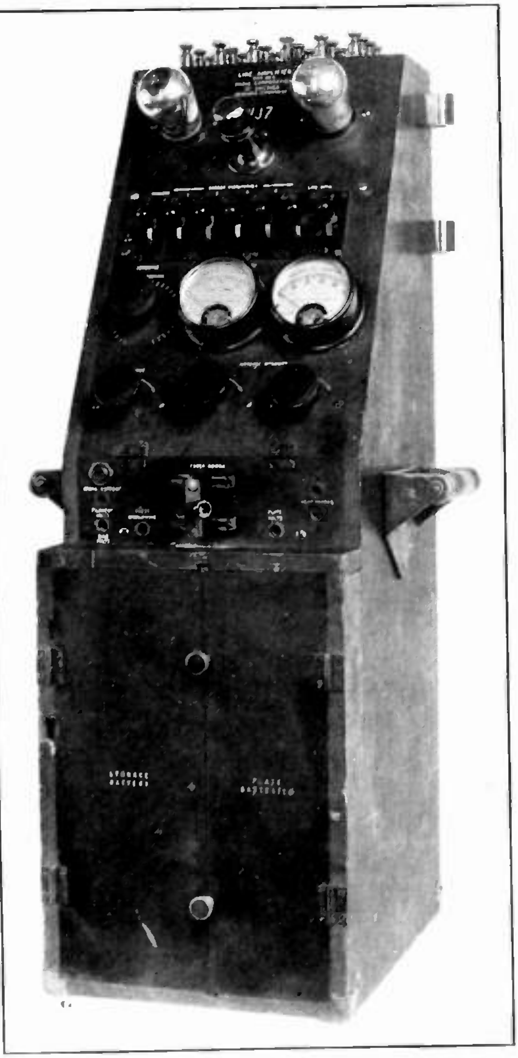

FIGURE 35—Special Type Portable Amplifier

The binding posts on the top are for announcing and other microphones and lines. There are posts for four "concert" or field microphones, one announcing microphone, and two telephone lines (one for the material to be broadcast and one for intercommunication). On the sloping panel are mounted, at the top, two vacuum tubes (the first one being a special high amplification constant tube, reactance-coupled to the second which is an output tube). Since the amplifier is used only for close talking or relatively loud sounds, less amplification is provided than in the standard amplifier; the total voltage amplification from a 250-ohm source to a 250-ohm output circuit is about 230 times (50 miles). Below the tubes are keys for the various microphones and a double key for interchanging broadcasting and intercommunication lines, so that if the broadcasting line should become noisy or fail the other line can be used instead. Below the keys are a gain control of the total amplification and ammeters showing the tube plate current and microphone current; the plate current ammeter is useful as an indicator of the presence of distortion, due to working of the output tube in excess of its linear amplication range, by the extent to which it flickers during speech.

The plate current is normally 7 milliamperes for both tubes and a flicker of a fraction of a milliampere is permissible. At the lower end of the sloping panel are three carbon compression rheostats for individually controlling the current of the announcing microphone and two of the field microphones. On the small vertical panel are a power switch, jacks for measuring the battery voltages, for connecting in an inter-communicating breast type telephone transmitter and for the operator's head telephones. One of the pair of telephones is connected across the inter-communicating line, the other to the broadcasting line, so that the operator can monitor on one line but still hear a call on the other.

In the practical operation of this equipment at an athletic contest, the field microphones are placed to pick up bands, cheering, announcements by field umpires, and so on. The individual volume controls and paralleling switches enable the operator to bring in these sounds as background to the announcing or after an announcement to gradually "fade in" or "fade out" the cheering or band music, thus giving a more artistic performance than merely the more or less dry announcing.

Another special amplifier is shown in Figures 36 and 37, and its wiring in Figure 38, for use with condenser transmitters.[10] Here it is necessary to shield the amplifier acoustically and electrically, because of the greater amplification necessary with condenser transmitters. The principal difficulties are acoustical, due to shocks or powerful low frequencies (such as the low tones of the organ), causing the tube elements to vibrate. Three tubes of the UV-201-A type are employed, the output of the amplifier being fed thru a step-down transformer to suitable input terminals on the standard portable amplifier previously described. Each

[10] References in connection with the condenser transmitter: E. C. Wente, "Physical Review," 2d series, volume 10, page 39, 1917; and volume 19, page 498, 1922.

I. B. Crandall, "Physical Review," 2d Series, volume 11, page 449, 1918.

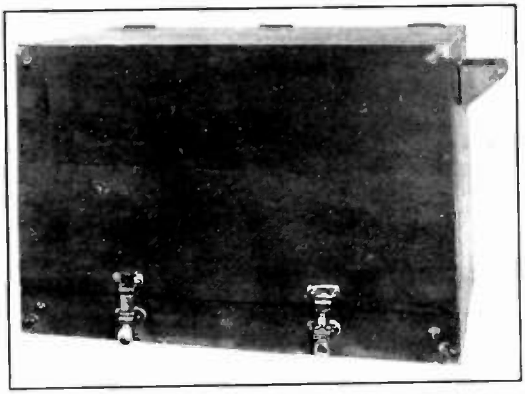

FIGURE 36—Condenser Transmitter Amplifier, Exterior

socket is mounted on soft rubber, and the three tubes enclosed in a metal case for electrical shielding. This case is hung on springs inside of a large wooden felt-lined box, for preventing the access of acoustic or mechanical vibrations. The condenser transmitter is used only where it is necessary to locate the pick-up device at a distance from the source, and where the sound is

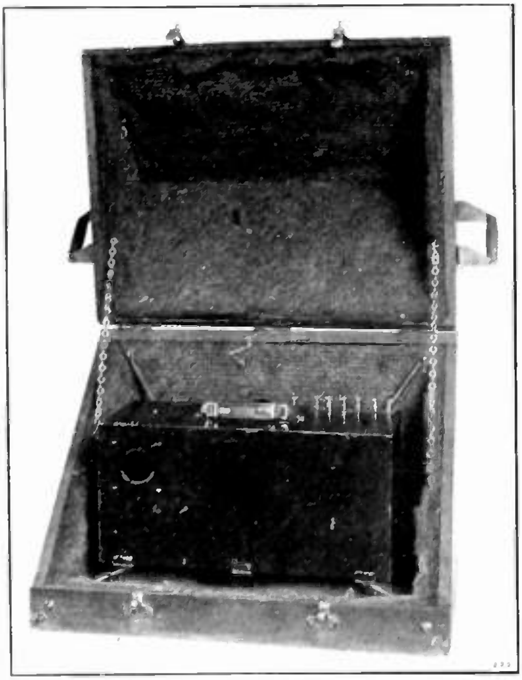

FIGURE 37—Condenser Transmitter Amplifier, Interior

relatively weak, so that the hiss of the carbon transmitter would be noticeable to an undesirable extent. Such occasions arise at times in broadcasting large organs, or symphony orchestras, where it is desirable for good balance to have the microphone out some distance, because of the widespread area occupied by these sources. For general use, however, the condenser transmitter is undesirable because of the fact that long leads cannot be run to it from the amplifier, and the extra amplifier with batteries are an inconvenient extra burden.

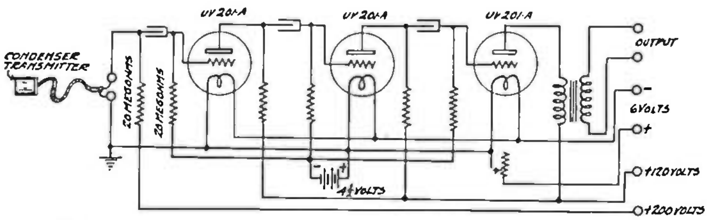

FIGURE 38—Condenser Transmitter Amplifier, Wiring Diagram

MICROPHONES AND MICROPHONE HOUSINGS: The microphones used on outside work are of the same double button carbon type as previously described (Figure 8), except that a modification is made in the diaphragm characteristics of these for certain kinds of work. In the microphones previously described, a diaphragm is used which is stretched so as to have a natural frequency of about 7,000 cycles, and heavily damped by means of an air damping chamber back of the diaphragm. Normally the spacing between the back of the damping chamber and diaphragm is about 0.001 inch (0.025 mm.). Under these conditions a certain ratio exists between the voltage generated by the microphone for a given sound pressure and the hiss due to the carbon, called the output-hiss ratio. For stage work it is sometimes desirable to use microphones having a greater output-hiss ratio than the normal, to pick up speech or music where the actors may be 15 to 20 feet (5 to 7 meters) from the microphone. This may be secured by making the microphones with a lower natural frequency (less tension on the diaphragm) and somewhat lower damping (greater air space). This sacrifices high frequencies somewhat, but not seriously. For other purposes a microphone going to the opposite extreme, namely, a lower output-hiss ratio is desirable. This is the case where the microphone is used on very loud sounds, which might cause the normal type to blast. Such a contingency occurs when the microphone is used in announcing from boxing matches. Here the noise from the crowd is at times terrific, and the announcer must shout into the transmitter at the top of his voice to have his speech go over the noise. For this purpose the microphone can be made with heavier diaphragms, such as steel, so that the force impressed on the carbon is less for a given sound pressure than in the normal microphone.

These microphones are enclosed in various types of housings, except that where it is desired to render the microphone as inconspicuous as possible, it is hung without a housing. In the design of housings it is always necessary to be sure that the enclosure will not have a natural frequency in the audible range, otherwise distortion will result. It seems that most of the sounds we have to deal with, as they strike a microphone in its housing, contain a great many steep wave fronts, which shock-excite anything having a natural tendency to vibrate into oscillations at its natural frequency and damping. Hence resonance in a housing or in the microphone makes itself heard as a more or less continuous "ringing" along with the sounds desired. The best form of housing is one which has a minimum amount of solid wall, and in which the enclosing surfaces are perforated or covered with gauze as far as possible. In all cases the microphone is hung on springs or rubber bands.

A number of typical housings are shown in Figure 39. The smallest is used for general pick-up purposes, on the stage, for orchestras, public addresses, and so on. The next in size is for announcing, and is therefore made so as to be held in the hand. Then there is a support of adjustable height, for use with small orchestras, where it may be necessary to have the microphone from three to five feet (1 to 1.5 meters) above the floor. In Figure 40 a special housing of attractive appearance, designed[11] especially for use in broadcasting speeches from banquets, is shown (front and rear views). This housing, when standing on the table, brings the microphone to about the height of the speaker's chest; this gives a much better frequency response than having the microphone on the table, as it is found in the latter case that high frequencies are principally absent (perhaps due to greater absorption by the table coverings) and the speech sounds thick or muffled.

Operation Outside of Station

An event outside of the station is supervised from the con-

[11] The original model was designed by Mr. Edwin Field Sanford, Jr., a well-known sculptor of New York City.

trol room in much the same way as a studio performance. The "outside crew," usually consisting of two men for a normal event, will report at the place from which the broadcasting is to be done, several hours in advance, set up their apparatus, run the microphone wiring, and test the line to the station which has been previously installed by a lineman. They can then test their choice of microphone placing, if suitable sounds are available (for example, in the case of a hotel orchestra), by listening to the output of the portable amplifier, and assure themselves that proper balance and correct output-hiss ratio are present. About

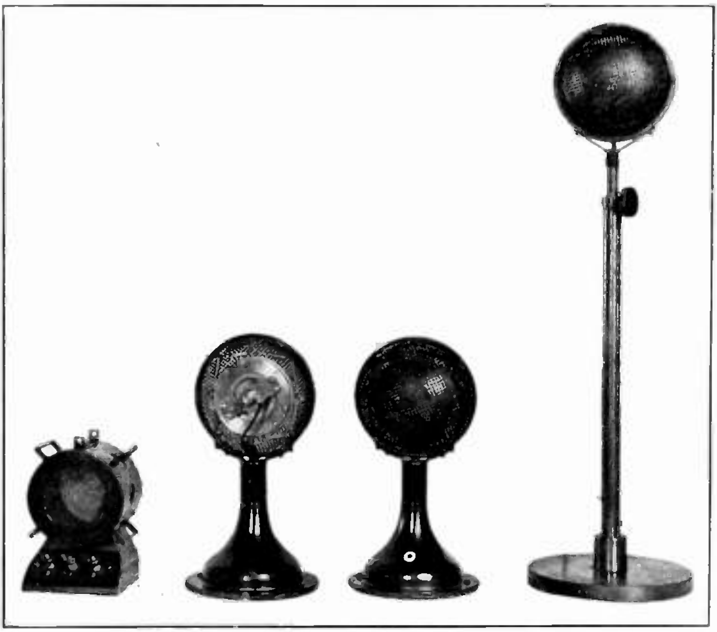

FIGURE 39—Typical Microphone Stands

five minutes before the event is due, they stand by with headphones across the broadcasting line and have their announcer and performers ready. The control operator then calls them and informs them approximately of the time he will be ready for them, the distant operators using the announcing microphone and amplifier to reply. At the moment the studio performance is completed the control man says "On the air" and switches the line to the input of the control room line amplifier. In the reverse case, where a transfer is to be made from the outside performance, a pair of telephone receivers is provided for the announcer in the studio by means of which he can listen to the material going out of the station; as soon as the distant announcer has announced the end of his program, the control operator switches the studio to the amplifier and at the same time the studio announcer takes up the program.

FIGURE 40—Special Microphone Stand, Designed by E. F. Sanford, Jr.

In the case of theatrical performances, one or more rehearsals are held before the broadcasting. This is done at actual performances, on previous matinees or evenings, with half a dozen microphones placed at strategic locations, on the stage and in the house, connected to the switches on a standard portable amplifier. The operator who is to handle the event finally chooses two microphone locations (usually one in or above the footlights and one in the orchestra), which will best pick up the performance, switching from one to the other if required, to take orchestra only, or sounds coming from the stage only. The switching is done by working the individual microphone volume controls, bringing up one while reducing the other, so that the listener is not aware of the change, as he would be from the click of a key.

Similar trial placings are made wherever the event is of a new character or likely to be difficult. However, the majority of the work cannot be carried out this way, as often the event only happens once (as in the case of athletic events) and set-ups must be made from previous experience with various contingencies anticipated if possible. This work outside the studio often calls for considerable resourcefulness and quick thinking on the part of the operating staff, if the performance is to go smoothly.

A number of microphone placings have become fairly well standardized, and serve as a guide when trials are not possible. Some of these are shown in Figure 41.

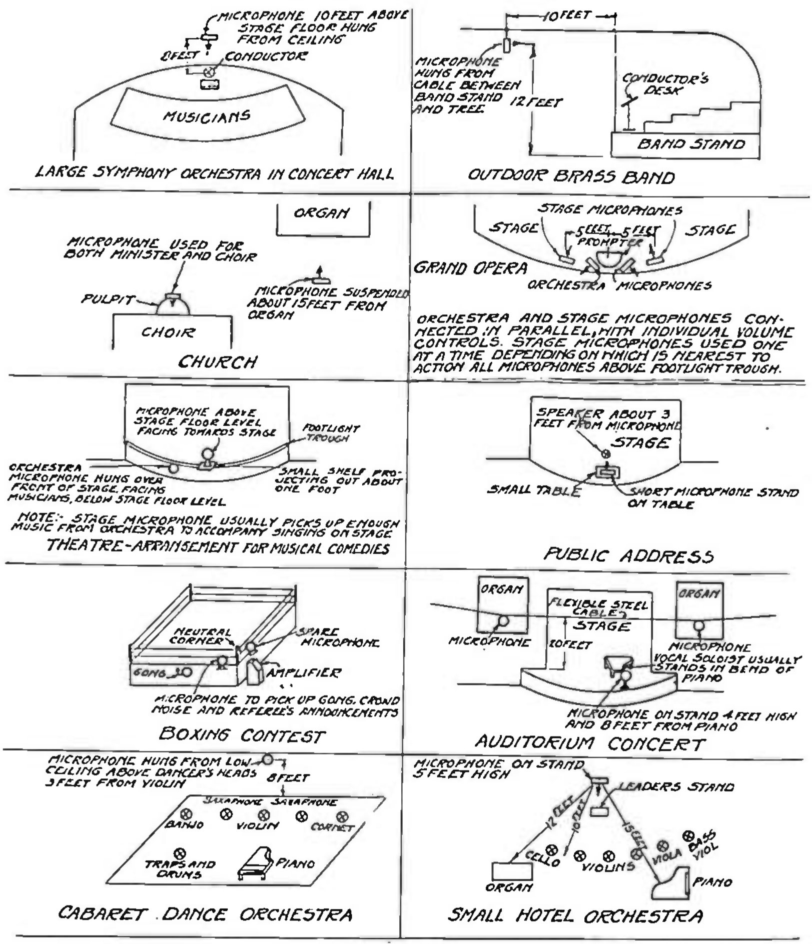

FIGURE 41—Microphone Placing in Outside-of-Studio Events

In places outside of the station there is usually no means of controlling the reverberation time of the auditorium or the distribution of the sound. The general rule is to have the microphone fairly close up, and the distances indicated on the figure have been found to give quite good balance of orchestras, without the reverberation that would be heard at greater distances (for example, on the balcony rail in a theatre). It will be noted that for grand opera two microphones are used for the orchestra, one to take each of the two halves; while for the average orchestra a single microphone placed near the first violins usually picks up enough from the remaining instruments to give a sufficiently satisfactory balance. At any rate, until a pick-up device is invented that can be placed at a distance without showing excessive reverberation, relatively close placing with a multiplicity of microphones, paralleled when necessary, is likely to continue. With this close placing, apparently small differences in position will sometimes show surprisingly large differences in the character of the sound picked up. For example, a microphone placed in the footlights on a stage does not appear to get nearly as good a range of frequencies from speech on the stage as one placed *above* the footlight level and on a small shelf projecting out over the orchestra pit. Thus a certain amount of preliminary exploration is very desirable, particularly where abrupt changes in the contour of the house occur or where reflection or absorption of the sound waves is likely to take place.

One point in connection with work outside the station concerns the control of modulation. Where the sound volume to be transmitted is more or less uniform, as in the case of speech, the outside operator keeps his gain control set so that an approximately constant level of intensity is sent into the line, as indicated by the volume indicator, and the control operator at the station controls the percentage modulation as usual. However, with such work as grand opera, where the volume is constantly changing, the best method of control is to have the control room operator make an initial modulation setting corresponding to a certain level (on the announcer's speech, for example), and then have the operator at the theatre listen to the performance as it leaves the station's antenna, by means of a small portable receiving set, adjusting the gain on his portable amplifier so as to keep proper output or to avoid over-modulating the radio transmitter. Thus a guide to the average volume is obtained by the volume indicator, and to over-modulation by the sound of the performance as heard in the receiving set. After a very short time the operator soon learns to adjust the gain control so as to keep pace with the slow changes in volume, and to set his gain so as to avoid overmodulation on the occasional loud bursts. Of course, it is practically essential that an operator for this sort of work should have a good musical sense, and it is desirable that he be familiar with the operas to be broadcast.

Simultaneous Broadcasting and Special Wire Line Apparatus

In Figure 31 certain wire lines have been shown for linking the New York, Schenectady, and Washington stations for simultaneous broadcasting. To carry out this work necessitates the use of special apparatus, fitted to take energy from a line or from station equipment and transmit it out over a number of circuits simultaneously, without interaction between circuits, and without the possibility of an accident on one circuit affecting the others. At the same time it is desirable to arrange for the use of greater than ordinary telephone energy levels, if desired, so as to permit of a greater ratio of signal to disturbances (cross-talk or noise) on the line, and also to arrange for correction of line characteristics. All of this obviously involves the use of special vacuum tube amplifiers, and certain units of apparatus have been standardized on which can be arranged and connected (directly or via a switchboard) to meet various requirements. A number of such units are arranged on racks at each broadcasting station.

In Figure 42 (a) is shown a set-up for simultaneous broadcasting from a station or line to three outgoing lines. The apparatus is divided into units as shown, the input terminals of the preliminary amplifier and the output terminals of the multiple repeaters being connected to jacks on a telephone and telegraph switchboard, at which the various lines are terminated on jacks also, so that various connections can be made with plugs and cords.

When used from a station to lines, the preliminary amplifier is connected to the output from the main modulation control; hence, after a preliminary setting of volumes at the distant stations, the modulation at all stations is controlled simultaneously from the initiating station. A volume indicator is provided for use in making preliminary adjustments, but the normal functioning of the multiple amplifiers during operation is supervised by observing that the plate current ammeters of all the repeaters flicker in unison. A plate voltage of 500, and UV-202 tubes (normally rated at 5 watts as oscillators) are used, and with these a maximum of 5 volts (root-mean-square), audio frequency, may be impressed on the outgoing lines, should it be required.

With incoming signals, a repeating coil and line corrector (often termed "attenuation equalizer" in telephone practice) can be connected to any line, and the output of the corrector to the input of one of the line amplifiers in the control room amplifier rack, via the telephone switchboard.

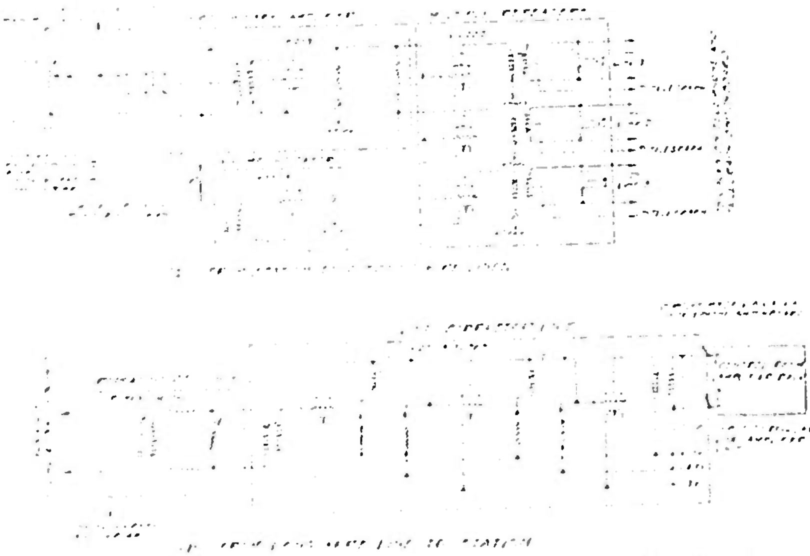

Figure [illegible]. Circuit Arrangement Used in Simultaneous Broadcasting

This is shown in Figure 12 also. The function of a line corrector is to amplify various frequencies in inverse proportion to their loss on the line, so that the combined frequency transmission of line plus corrector is as nearly uniform over as wide a range as possible. In the particular corrector shown each tube and its associated circuit has a rising frequency amplification characteristic which, when combined with the falling frequency transmission characteristic of the line, gives uniform over-all transmission for the desired frequency range. The required characteristic for any particular line is obtained by suitably proportioning the inductance and resistance in the plate circuit of the tube. Similar arrangements can be made to correct transmission over various types of circuits, such as underground cable, open wire lines, and so on, with a corrector supplied to go with each circuit which is regularly used. The three-tube corrector shown can also be used in sections, or other sections added, for greater or lesser lengths of the type of wire circuit which it is required to correct.

Communication between the various stations, while broadcasting is going on, is handled by means of telegraph over the same lines, the two wires of a pair being used in parallel against ground in accordance with standard practice.

Broadcasting Station at Washington, D. C.

This station, having the call letters WRC, is located at 14th Street and Park Road, N. W., the quarters being leased in an office building. The choice of location was necessitated by the fact that in the main hotel and theatre district of Washington it was not permitted to place antenna towers on the roofs of existing buildings, because of maximum building height restrictions. The site chosen is approximately 2 miles (3.2 km.) from this district, but connections to the principal possible sources of broadcasting are being made by means of underground cable installed by the Postal Telegraph Company.

The building in which the station is situated and the antenna towers are shown in Figure 43. The antenna towers are 100 feet (31 meters) high and the antenna is a "T" with flat top 160 feet (49 meters) long. Since this building is quite low, it was possible to place the studio, control and transmitter rooms on the same floor (about 20 feet (6.2 meters) below the roof), the antenna lead-in being run down the side of the building in the form of stiff copper tubing spaced away from the wall. The arrangement is less expensive in installation and operating cost than in the case of the New York station, where it was not possible to secure space on the upper floors of the building (close to the roof).

The arrangement of rooms (Figure 44) is similar to that in New York except that the transmitting sets and control apparatus are placed in the same room, so that one operator can handle all of this apparatus. Views of the operating and motor-generator rooms are shown in Figures 45, 46, and 47, and the studio in Figure 48. The equipment in general is the same as that in the New York station, and the acoustic treatment of the studio the same. A point that may be of some interest is the mounting of the motor-generator sets, to prevent vibration and noise from reaching the control room or other parts of the building; these are placed in a room having felt-lined walls and ceiling, each motor-generator set on a steel bed plate placed on a three-inch (7.6 cm.) cork mat; the cork is a few inches larger all around than the bed plate, and along each of its sides a piece of angle iron is placed, one side of the angle being secured to the floor and the other projecting several inches above the top of the bed plate.

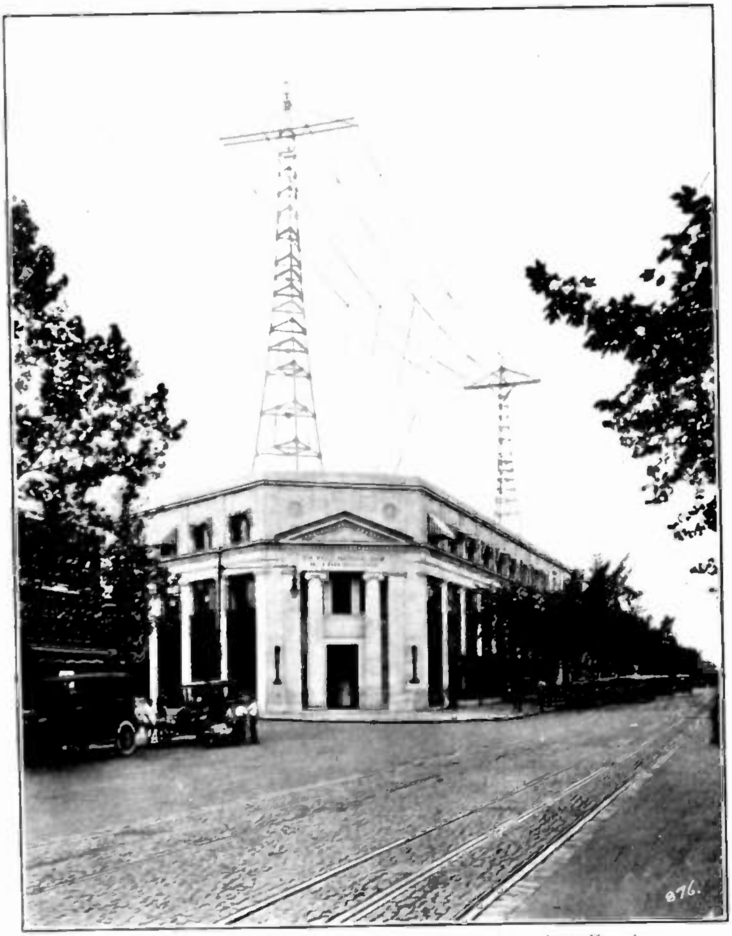

FIGURE 43—Site of Washington Broadcasting Station

Between this vertical side and the motor-generator base a cork strip is placed; thus the machine rests on cork, and is prevented from moving sidewise by the angle irons and cork strips. No holding down bolts are used on the machine base. Hence all vibration from the machine must travel thru cork, and the felt-lined room greatly reduces the noise generated within the room or transmitted thru the walls. The arrangement is quite successful, the noise of the machines being so low as to be negligible in the control room next door.

The wire line system in Washington is not nearly so extensive as in New York, since Washington is a smaller city and there are a lesser number of points outside the studio from which events of broadcasting interest can be obtained. To reach these, a

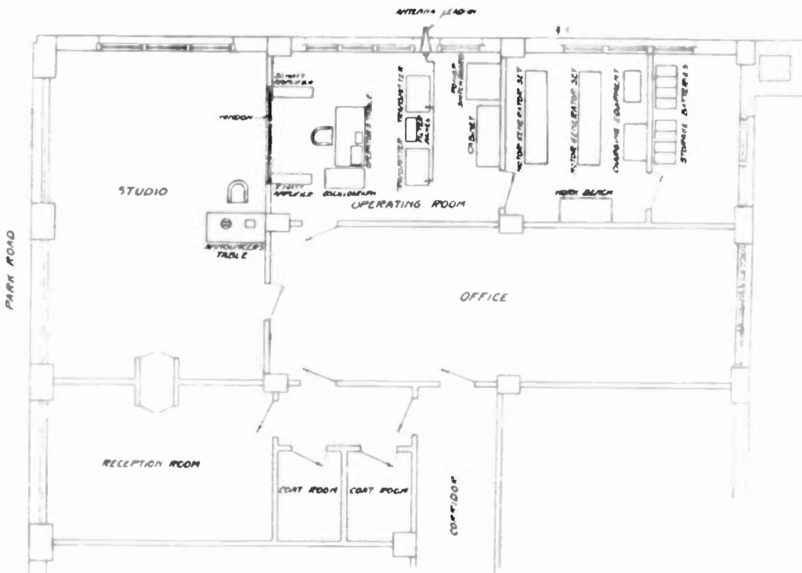

FIGURE 44—Plan of Rooms, Washington Station

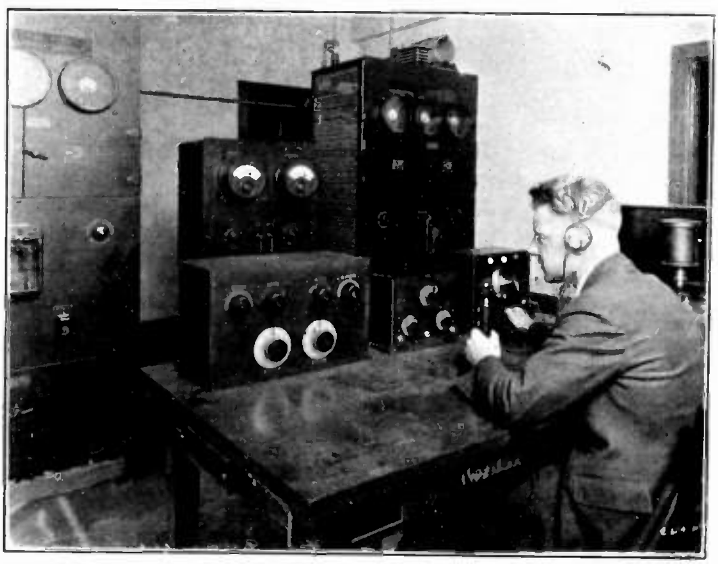

FIGURE 45—Washington Broadcasting Station Operating Room, Showing Control Desk, Duplicate Transmitters, and Filter Panel

special 5-pair underground cable two miles (3.2 km.) long connects the station with the main terminal office of the Postal Telegraph Company, in the center of the hotel and theatre dis-

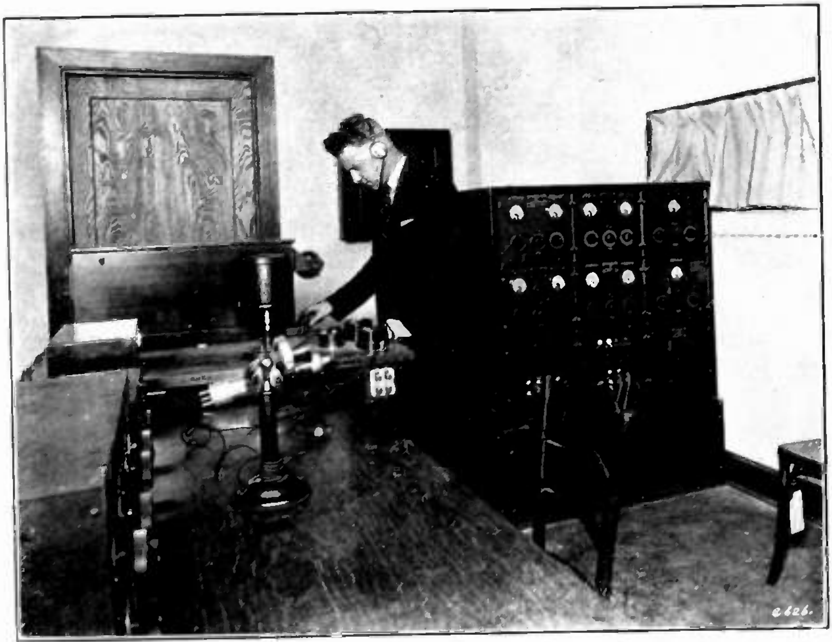

FIGURE 46—Washington Broadcasting Station Operating Room, Showing Control Room Amplifier Rack and Oscillograph

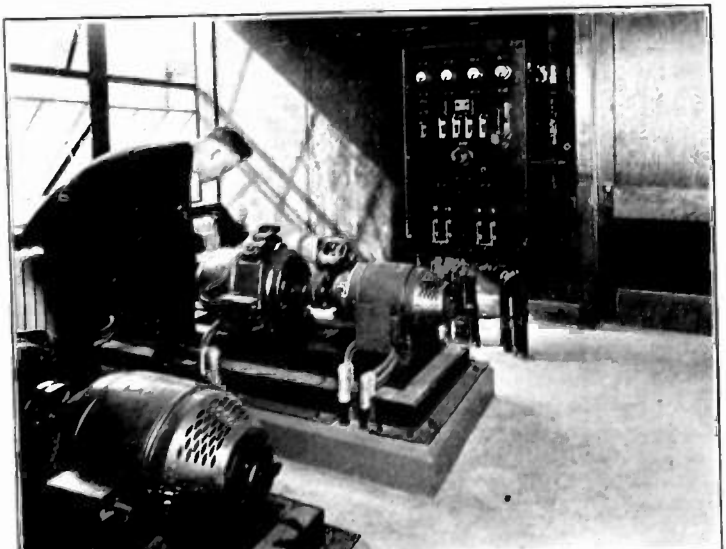

FIGURE 47—Washington Broadcasting Station, Motor Generator Room

trict. Here connections are made as required, to various existing underground cables of this company in order to reach desired points. All of these cables consist of twisted pairs, and therefore are suitable for telephone use. One of the pairs in the cable to the station is permanently connected to the long distance line to New York, at the terminal office. The equipment used on the wires and the portable equipment is the same as previously described.

FIGURE 48—Washington Broadcasting Station, Studio

ACKNOWLEDGMENTS

In a project of this sort the responsibility for various portions of the work is naturally divided, and I wish gratefully to acknowledge the co-operation of the following gentlemen, all of the Radio Corporation of America, who were concerned in it:

Mr. J. H. Shannon, of the Design Division, Engineering Department, was in charge of the preparation of the detailed designs and specifications for the construction work.

Mr. S. C. Miller, of the Technical and Test Department, was responsible for the mechanical design of all of the portable equipment described in the paper, as well as certain station equipment. He also assisted in the experimental work and made all the drawings of this paper.

Mr. Jesse Marsten, of the Technical and Test Department, was responsible for carrying out a good deal of the experimental work, alone or assisted by Mr. Miller.

Mr. Walter L. Tesch, now Engineer-in-Charge of the Washington Station, rendered valuable help in the initial testing and putting into service of the New York station.

Mr. Carl Dreher, now Engineer-in-Charge of the New York station, co-operated in all experimental work in a most friendly fashion, and furnished most of the data relative to operating experience given in the paper.

Mr. Raymond F. Guy, in charge of field (outside) operation at the New York station, has given valuable criticisms and suggestions concerning apparatus for this type of work, and also furnished data relative to experience gained therein.

Finally, the interest, encouragement, suggestions, and criticisms of Dr. Alfred N. Goldsmith, Chief Broadcast Engineer, have been of great value thruout the work.

SUMMARY: The general arrangements of the broadcast transmitting stations established by the Radio Corporation of America in New York and Washngton, D. C. (U. S. A.), are described. The station and portable apparatus, with wiring diagrams and frequency characteristics, are shown. Each station has an associated local wire line network, for broadcasting from points outside the studio, and long distance lines inter-connect the studios at New York, Washington, and Schenectady, N. Y., for simultaneous broadcasting. Equipment for this purpose is described. Various points in connection with practical operation in studio or outside broadcasting, such as supervision, microphone placing, and modulation control are dealt with. Experiences in two-channel transmission, at New York, are discussed.

AN INTERNATIONAL COMPARISON OF RADIO WAVE-LENGTH STANDARDS BY MEANS OF PIEZO-ELECTRIC RESONATORS[1]

By

W. G. Cady

(Wesleyan University, Middletown, Connecticut)

While traveling last year in Italy, France, and England, the writer took advantage of the opportunity to make some wave-length comparisons between his piezo-electric resonators and the standard wave-meters or other high-frequency standards in those countries.[2] Six resonators were used of wave-lengths in the neighborhood of 200, 400, 1,300, 3,300, 10,300, and 20,800 meters. Four of these had been compared with the wave-meter at the Bureau of Standards in Washington in December, 1922, and all were sent to Washington for re-comparison at the close of the trip.

Observations were made in Italy at the Istituto Centrale di Radiotelegrafia ed Elletroteenica del Genio Militare in Rome, and in the Istituto Elletroteenico e Radiotelegrafico della Regia Marina at the Naval Academy in Livorno; in France, at the Etablissement Central du Materiel de la Radio-télégraphique Militaire in Paris; and in England at the National Physical Laboratory in Teddington, and the research laboratory of the Royal Aircraft Establishment at Farnborough.[3]

The dimensions of the resonators are as follows:[4]

G1, quartz rod 1.76×1.13×0.63 mm.
G2, quartz rod 3.60×1.40×0.51 mm.
G3, quartz rod 12.02×2.16×1.08 mm.
G4, quartz rod 30.3×2.64×1.23 mm.

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[1] Communication from the International Union of Radiotelegraphy. Received by the Editor, June 3, 1924.

[2] For theory and description of the piezo-electric resonator, see Proceedings of The Institute of Radio Engineers, volume 10, page 83, April, 1922. A few corrections are given in the number for August, 1922, title page.

[3] I take this opportunity of expressing my thanks to Dr. G. Vanni, Director of the Institute in Rome, Dr. G. Vallauri, of the Italian Naval Academy, General Ferrié and Messrs. R. Jouaust and R. Mesny of the French Ministry of War, Mr. D. Dye of the National Physical Laboratory, and Major Le Fry of the Air Ministry in England, for the courtesies which they extended to me in their laboratories.

[4] For photographs of resonators, see Figures 7 and 9 in the paper in the Proceedings referred to above.

These four rods were mounted together in a bakelite casing 8.9×1.7×1.6 cm.

F23, steel rod 90.5×9.75×3.16 mm., to the opposite sides of which were cemented quartz plates 8.9×8.95×1.13 mm.

F24, steel rod 180×9.23×3.14 mm., with quartz plates 13.4×9.0×1.18 mm.

Methods of Comparison

Four different methods of comparison were employed, the choice in each case depending upon the laboratory facilities available for the various wave-lengths.

Method A—The resonator is connected in parallel with the capacity of the wave-meter, the circuit of which must also contain an indicating instrument—for example, hot-wire meter or thermo-element of low resistance[5]. A tube generating circuit with fine frequency-regulation is loosely coupled to the wave-meter, and the two circuits are brought into resonance at approximately the natural frequency of the resonator. The generator frequency is then slowly varied one way or the other until a sudden and very sharply defined minimum in the wave-meter current indicates that the resonator frequency has been very exactly reached. Leaving the generator oscillating at this point, we remove the resonator and adjust the wave-meter to resonance with the generator as precisely as possible. In place of the wave-meter, an auxiliary tuned circuit containing resonator and indicating instrument may of course be used. The wave-meter itself is then compared by any desired method with the generator, after the latter has been adjusted to resonator frequency.

Method B—This is similar to Method A, save that the tuned secondary circuit, which may or may not be the wave-meter, contains a detector and telephone receiver in addition to the resonator. When the generator capacity is varied, resonance with the resonator is indicated by a click in the receiver, which usually comes at slightly different points on increasing and decreasing frequency. The mean of these is taken as the correct setting of the generator.

Method C—A telephone method, similar to Method B, but having in the generator circuit a small capacity and key in parallel with the tuning condenser. When the generator is adjusted to resonator frequency, the key is closed, causing the frequency to change abruptly by a small amount. A brief beat note is heard

[5] Proceedings of The Institute of Radio Engineers, previous citation, Figure 3.

in the secondary circuit, caused by interference between this new frequency and the frequency due to the vibration of the resonator. When this note is of maximum loudness we know that the generator, before the key was pressed, was adjusted very precisely to resonator frequency.

METHOD D—This method makes use of the frequency-stabilizing property of the resonator.[6] The latter is connected in parallel with the tuning condenser of the generator, which must be of low power. The frequency is varied until the characteristic click in a receiver in the generator circuit, or in a tuned receiving circuit loosely coupled to it, is almost but not quite reached. If the secondary receiving circuit is regenerative, a beat note is heard, the pitch of which becomes practically constant when the stabilizing frequency of the resonator is reached. The generator frequency may then be compared with that of the wave-meter. For comparisons of highest precision, the difference between the stabilizing frequency and the natural vibration-frequency of the resonator must be taken into account. This difference is never over a tenth of a percent, and was disregarded in the present work.

Using Methods A or C, comparisons may be made which are accurate to within one part or less in 10,000. With Methods B and D, the order of accuracy is one part in 1,000. As to the constancy of the piezo-electric standards themselves, the following may be said: A variation in the distance between the brass electrodes, between which the crystal resonator lies, has a slight effect upon the natural frequency of vibration, as does also a shift in the position of the crystal when the air gap on each side is considerable. With the standards mentioned in this paper, such variations can hardly have amounted to more than one part in 1,000. Improvements in construction have been effected since these comparisons were made, which greatly reduce the possibility of chance variations in frequency.

Measurements of temperature coefficient indicate that an increase in temperature of 1° C. lowers the natural frequency of quartz resonators by one part in 200,000, and of steel resonators by one part in 10,000, approximately.

OBSERVATIONS

The comparisons made at the several laboratories will now be considered in detail.

[6] PROCEEDINGS OF THE INSTITUTE OF RADIO ENGINEERS, previous citation, page 112.

In Tables I to V, the symbol *p* stands for what we may term the "precision of comparison." It is an approximate estimate, expressed in percent, indicating the precision with which the wave-meter is probably tuned to the resonator. It is based on consideration of degree of coupling found necessary, accuracy with which the auxiliary generator set is tuned to the resonator, and precision of comparison between auxiliary generator set and wave-meter (or multi-vibrator). Except in Tables IV and V, *p* does *not* include the errors in wave-meter calibration. In most cases, the sharpness of tuning between generator and resonator was much greater than that between wave-meter and generator.

April 13-24, 1923. RADIOTELEGRAPHIC INSTITUTE, ROME.—Resonators G1, G2, G3, and G4 were compared with Wave-meter Number 6, Signals Experimental Establishment, Woolwich. A calibration of this instrument in terms of a Marconi standard, carried out some months later, indicated that all readings should be increased by two percent. This correction has been applied in the last column of Table I.

TABLE I

Re-sonator	Method	*p*	Wave-lengths in Meters		
			Observed	Mean	Corrected Mean
G1	B	0.5%	192	192	195.8
G2	B	0.5	388	388	395.7
G3	A	0.15	1250	1252	1277
G3	A		1255		
G3	B		1250		
G4	C	0.2	3190	3192	3256
G4	C		3195		

April 26-28, 1923. NAVAL ACADEMY, LIVORNO.—All resonators except G1 were compared with a standard Marconi wave-meter, Number 15,700. A later calibration of this wave-meter showed that all values of wave-length should be increased by 0.35 percent. The values so corrected are still probably somewhat too small, since in the resonator comparisons a thermo-element was in the wave-meter circuit. The calibration of the wave-meter consisted in a careful determination of its capacities and inductances, and took no account of the thermo-element.

Unfortunately, a wave-meter which Dr. Vallauri had calibrated by means of a high-frequency alternator whose speed was controlled stroboscopically by a standard tuning fork, was not available for these comparisons. Observed and corrected values are recorded in Table II.

TABLE II

Resonator	Method	p	Wave-lengths in Meters	
			Observed	Corrected
G2	D	0.2%	385	386.4
G3	A	0.1	1222	1226
G3	D[8]	0.2	1240	1244
G4	C	0.15	3243	3254
F23	C	0.1	10278	10314
F24	C	0.1	20619	20691

June 15-18, 1923. Military Radiotelegraphic Laboratory, Paris.—Comparisons were made with Wave-meter Number 7, Modele Radiotélégraphique Militaire, System H. Armagnat, made by Précision Electrique, Paris. The circuits employed were those described by M. Mesny for the measurement of resistances at high frequency.[9] Extremely loose coupling was used thruout. Immediately upon the conclusion of the resonator comparisons, the wave-meter was compared with a standard tuning fork by Abraham's multi-vibrator method. The slight corrections obtained in this manner are included in the wave-length values in Table III.

TABLE III

Resonator	Method	p	Wave-length, Meters	
G1	D	0.05%	197.2	Note on Table III: The two observations on G4 were separated by an interval of several days. In the absence of an explanation of the large discrepancy between them, the mean value, 3,264 m. has been chosen.
G2	A	0.02	394	
G2	D	0.06	394	
G3	A	0.05	1272	
G4	A	0.05	3260	
G4	A	0.1	3268	
F23	A	0.01	10,355	
F24	A	0.01	20,760	

[8] Thermo-element out, hence this value considered best.

July 1-3, 1923. NATIONAL PHYSICAL LABORATORY, TEDDINGTON.—The writer was so fortunate as to be able to compare the resonators directly with the standard multi-vibrator, the fundamental frequency of which was determined by a tuning fork of 999.94 cycles per second. Method A was used thruout, an auxiliary generator set being carefully tuned to a thermo-electric circuit containing the resonator. The coupling was kept extremely loose—an important precaution when great accuracy is sought.

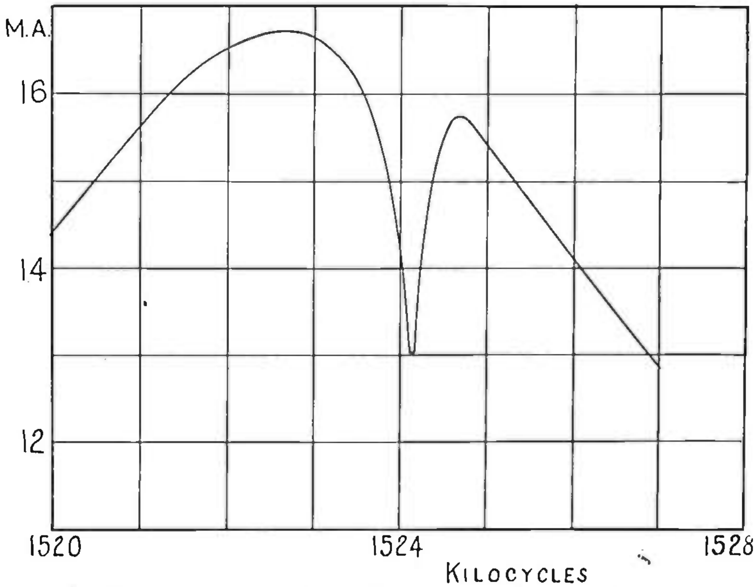

FIGURE 1—Resonance Curve for Quartz Resonator G1, which has a Frequency over 1,500 Kilocycles. The Resonance Point is at the Bottom of the "Crevasse"

The precision with which the generator could be adjusted to the resonator frequency is shown by the curve in Figure 1. Ordinates represent milliamperes in the thermo-electric circuit, and abscissas the impressed frequency. In the absence of the resonator, the curve would be an ordinary resonance curve, without the sharply-pointed "crevasse." When the resonator is in circuit, the curve suddenly develops a small and very sharp crevasse as the generator frequency is increased. The bottom of the crevasse is extremely sharp. It comes at the same setting of the generator condenser, whether the peak of the curve of electrical resonance occurs at this frequency or not, but

[9] Mesny, "L'Onde Electrique," volume 1, page 164, 1922.

the effect is of course more pronounced the closer together the frequencies lie—that is, the better the electrical tuning of the thermo-electric circuit. In Figure 1 the electrical resonance comes at a slightly lower frequency than the mechanical resonance of the resonator. The figure also shows strikingly how much sharper the mechanical resonance was than the electrical resonance, in spite of the fact that the electric circuit was well designed and of low resistance. It should be noted that the fragment of quartz crystal producing this effect weighed only 3.3 milligrams.

Settings could be made to within 0.05 mmf. This corresponds to a precision of one part in 20,000, that is, of one centimeter in a 200-meter wave. Of course this has only to do with the precision in making settings. To measure the absolute frequency with this precision is another question. The multi-vibrator principle seems to be the only one at present making possible the measurement of absolute frequencies with this degree of accuracy.

A similar degree of precision (a few parts in 100,000), was attained with the other resonators. In each case, after the auxiliary generator circuit had been tuned to the frequency of the resonator, its frequency was determined by interpolation between selected harmonics of the standard multi-vibrator.

The fundamental frequency of the multi-vibrator was controlled, as has been stated, by a tuning fork of approximately 1,000 vibrations per second. The auxiliary generator set was brought alternately into synchronism with the quartz resonator, by the method outlined above, and with one of the multi-vibrator harmonics. In this way the effect of any drift in the frequency of the generator was eliminated.

The following information concerning the method of calibrating the generator set has been kindly furnished by Mr. Dye, of the National Physical Laboratory:

"The calibration of the generator set is carried out by adjustment of an open scale standard air condenser forming a small part of the total capacity of the generator oscillatory circuit.

"When the selector condenser of the multi-vibrator selector is set so as to select the desired harmonic having a frequency near that under measurement, a beat tone is heard in the amplifier receiving the two frequencies. By adjustment of the generator frequency this beat tone can be reduced to zero frequency, when the generator frequency becomes synchronous with that of the selected harmonic.

"Fiducial points are thus obtained at frequencies of, for example, 30, 31, 32 . . . kilocycles per second. It will be seen that in this region of frequency these points differ in frequency by three percent, which, tho not large, does throw considerable resposibility on the accuracy and uniformity of the scale of the standard condenser when an accuracy of one or two parts in ten thousand is required. It is fortunate, however, that a number of subsidiary synchronizations can be obtained at frequencies intermediate between the main harmonics. For example, when the generator is set at frequencies close to 30.250, 30.333, 30.500, 30.667 and 30.800 kilocycles per second, slow beats may also be heard and can be reduced to zero rate by very precise adjustment of the source.

"The explanation of these beats is, of course, that in the multi-vibrator selector circuit currents at the frequencies of the neighboring harmonics 29 and 31 are present. When the generator is set at, say, 30.333, the difference tone 333.3 cycles per second between its frequency and the 30th harmonic of the multi-vibrator is heard, and also the difference tone 666.7 cycles per second between the generator and the 31st harmonic. The second harmonic of the difference tone 333.3 cycles per second then interferes with the 666.7 cycles per second difference tone and gives the slow beat by which the final setting is actually made.

"The setting on the generator condenser is extremely precise for these sub-harmonics and the resulting accuracy is therefore very great."

For example, consider the case where one is obtaining a beat between the 4th harmonic of the 200 beat tone corresponding to one main multi-vibrator harmonic, and the 800 beat tone corresponding to the next multi-vibrator harmonic, that is, a generator frequency of 30,200. If now the generator frequency is altered to 30,201, the 200 beat tone becomes 201 and the 4th harmonic of 201 is 804; also the 800 beat tone becomes 799, the beats between these are 5 per second for a change of one cycle per second in the source. These subsidiary harmonic beats are very valuable for interpolating purposes, and remove nearly all the responsibility from the frequency-adjusting condenser in the generator circuit."

For the resonators of highest frequency, a harmonic of a harmonic was employed in calibrating the generator set. That is, by the use of the selector circuit of the multi-vibrator, one particular harmonic of the 1,000-cycle fundamental was amplified, and a group of its harmonics used for the calibration. Thus in the case of the resonator G1, of over 1,500-kilocycles frequency, it was necessary to extend the range to the 76th harmonic of a fundamental of 20,000 per second, this latter being in turn the 20th harmonic of the tuning-fork frequency. Synchronism was obtained between the generator and sub-harmonics of frequencies 1,523, 1,524, 1,524.5, 1,525, and 1,526 kilocycles, as well as the main harmonics (76th and 77th), 1,520 and 1,540 kilocycles, respectively.

The results obtained at the National Physical Laboratory are given in Table VI. The precision of comparison in each case is estimated to be a few parts in 100,000.

July 20, 1923. ROYAL AIRCRAFT ESTABLISHMENT, FARNBOROUGH.—Resonator G4 was compared with the standard wave-meter by methods A and D, and a mean value of 3,275 meters found for the wave-length, the order of precision being 0.1 percent.

At the BUREAU OF STANDARDS in Washington the frequencies of Resonators F23, F24, and G3 were measured in December, 1922, and in September, 1923, the frequencies of all six were measured. Method A was used, and the auxiliary generator set was compared with the standard wave-meter. The precision was estimated at the Bureau of Standards to lie between 0.1 and 0.2 percent, probably nearer to 0.1 percent, and this figure includes the precision of the wave-meter itself. As the writer did not make the comparisons in person, he is unable to estimate the probable precision of the piezo-electric comparisons by themselves, p, as distinguished from the probable accuracy as the wavemeter, hence the value of p in Table IV includes the estimated wave-meter accuracy.

TABLE IV

Date	Resonator	Wave-length in Meters	p
December, 1922	G3	1,271	0.1%
December, 1922	F23	10,390	0.1
December, 1922	F24	20,800	0.1
September, 1923	G1	196.5	0.1
September, 1923	G2	393.1	0.1
September, 1923	G3	1,270	0.1
September, 1923	G4	3,277	0.1
September, 1923	F23	10,400	0.1
September, 1923	F24	20,790	0.1

In Table VI, the mean values from Table IV are reproduced, converted into kilocycles.

The Bureau of Standards wavemeter is calibrated for the lower frequencies in terms of a standard tuning fork, for the higher frequencies by means of stationary waves on parallel wires. Over the range where the frequencies overlap, the values check to within 0.1 percent.

In January, 1923, Professor G. W. Pierce kindly measured the frequencies of resonators G1, G2, G3, and G4, by comparison with the multi-vibrator in the CRUFT LABORATORY at Harvard University. In October, 1923, these observations were repeated, and data were also obtained for F23. Method D was employed. Following are the values obtained, a slight correction for frequency of standard tuning fork having been applied:

TABLE V

Date	Resonator	Wave-length in Meters	p
January, 1923	G1	196.7	0.1%
January, 1923	G2	393.6	0.1
January, 1923	G3	1,273	0.1
January, 1923	G4	3,272	0.1
October, 1923	G1	196.5	0.1
October, 1923	G2	392.9	0.1
October, 1923	G3	1,271	0.1
October, 1923	G4	3,266	0.1
October, 1923	F23	10,363	0.1

Mean values from this table are given in the general summary in Table VI, converted into kilocycles. The same remarks concerning the precision of comparison p apply to Table V as to Table IV.

SUMMARY AND CONCLUSION

The entire series of comparisons is now summarized in Table VI, wave-lengths being converted into kilocycles. The velocity of electromagnetic waves is assumed to be 3×10^{10} centimeters per second.

In computing the "weighted means," only those values based ultimately upon the frequency of a standard tuning fork (or, at the Bureau of Standards, upon waves on parallel wires) are considered. Inasmuch as the comparisons at Teddington were made directly with the multi-vibrator, weight 3 is attached to these values. In Paris, one day elapsed between the comparison of the wave-meter with the resonators and that with the multi-vibrator, hence weight 2 is assigned in this case. Values obtained at the Bureau of Standards and the Cruft Laboratory receive each weight 1.

TABLE VI

Station	G1	G2	G3	G4	F23	F24	Weight
Rome	1,532	758.2	234.9	92.14	......	......	....
Livorno	....	776.4	241.2	92.19	29.09	14.49	....
Paris	1,521	761.4	235.8	91.91	28.972	14.451	2
Teddington	1,524.1	761.82	235.90	91.480	28.960	14.421	3
Farnborough	....	....	....	91.60	......	......	....
Bureau Stand	1,526	762.7	236.1	91.55	28.835	14.420	1
Cruft Lab	1,526	762.9	235.9	91.78	28.948	......	1
Weighted means	1,523.8	761.99	235.90	91.656	28.944	14.431	....
Probable error of weighted means in percent	0.032	0.018	0.009	0.051	0.040	0.027	

The weighted means are shown at the bottom of Table VI, as well as the probable error of each, computed in the usual way from the values used in deriving the weighted means. This "probable error" should be regarded only as a means for judging the closeness of agreement between the observed values at the different stations. Owing to the fact that in some cases different methods of comparison were employed at different stations, and also owing to possible changes in the natural frequencies of the resonators resulting from transportation and so on, the values should not be taken too confidently as an exact measure of the agreement between the wave-length standards in the countries visited. Nevertheless, the writer ventures the belief that they may not be entirely valueless in this respect.

The deviations of the values obtained at each station from the weighted mean are given in Table VII.

Considering only Paris, Teddington, Bureau of Standards, and Cruft Laboratory, we find the greatest single deviation to be 0.38 percent, while the average of all deviations in Table VII for these four stations is 0.11 percent. This is of the same order of magnitude as the estimated "precision of comparison," and it indicates that the wave-length standards in the four laboratories named are in agreement, on the average, to within one part in a thousand.

TABLE VII

DEVIATION, IN PERCENT, FROM WEIGHTED MEANS

Station	G1	G2	G3	G4	F23	F24
Rome	+0.54	−0.50	−0.43	+0.52	....	....
Livorno	....	+1.5	+2.2	+0.58	+0.50	+0.41
Paris	−0.18	−0.08	−0.038	+0.27	+0.097	+0.14
Teddington	+0.02	−0.022	+0.000	−0.192	+0.055	−0.07
Farnborough	....	....	....	−0.061	....	....
Bureau Stand.	+0.14	+0.09	+0.08	−0.12	−0.38	−0.076
Cruft Lab	+0.14	+0.12	0.00	+0.14	−0.01	....

If the available time and facilities had been such that all comparisons could have been made by the most precise method (Method A), more importance could be attached to the values of these deviations.

In constancy and sharpness of tuning, as well as in simplicity, the piezo-electric standards are already superior to any type of wave-meter in use at present, except the multi-vibrator. Further refinements in mounting and in methods of comparison will be described in a later paper. In cases where a precision of one or two parts in a thousand is sufficient, comparisons with the resonators can be made very easily and quickly, without other auxiliary apparatus than a detector and telephone receiver.

Wesleyan University, Middletown, Connecticut,
June 2, 1924.

SUMMARY: Piezo-electric wave length standards of the quartz or quartz-steel types previously described by the author have been compared with standard wave meters or multi-vibrators in the United States, Italy, France, and England. Six standards were used, of frequencies ranging from 14 to 1,500 kilocycles. The methods of comparison are described, and data obtained at the various laboratories presented. The tabulated results show that the average deviation from the weighted means, for all comparisons, is about 0.1 percent. It is shown that by the simplest methods of comparison a precision of 0.1 percent is attained, while in a comparison with the multi-vibrator, by more elaborate means, the precision is a few parts in 100,000.

CORRECTION FACTOR FOR THE PARALLEL WIRE SYSTEM USED IN ABSOLUTE RADIO FREQUENCY STANDARDIZATION*

By

August Hund

(Electrical Engineer, Bureau of Standards, Washington, D. C.)

A pair of parallel wires was used in the early days of radio by Hertz, Lecher, Lodge, and others for demonstrating stationary electromagnetic waves. With the development of radio-frequency generating sets producing sinusoidal currents, this experiment became simpler, so that voltage nodes and the corresponding current antinodes can now be located with ordinary thermo-electric instruments with a high degree of precision.

It is the purpose of this paper to give the formulas and the corrections needed when the parallel wire system is used for primary frequency standardization.[1] In the parallel wire system[2] used by the Bureau of Standards the basis of frequency standardization involves the direct measurement of the wave lengths of very short[3] waves (1 to 20 meters in length) on a pair of parallel wires as indicated in Figure 1. The wave length λ is found by moving a shunted thermo-galvanometer G, which is suspended between the two wires, along the wires until it shows a maximum current. This galvanometer arrangement has a very low effective resistance. The point of maximum current is marked on the wire as position I-I and the galvanometer moved still further along the wires until a second current maximum II-II is indicated. The distance I-II between these points of successive current maxima is one-half wave length. If the paral-

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[1] The complete theory is given by the author in a Bureau of Standards Scientific Paper now in press.

[2] A detailed description of the arrangement and the apparatus was given by J. W. Dunmore and F. H. Engel in the Proceedings of The Institute of Radio Engineers, page 467, October, 1923.

[3] For standardizing lower frequencies, a local generating set producing currents of lower frequencies is loosely coupled to the detector and the settings of the frequency meter are compared to the frequency of the short waves by means of the harmonics of the low frequency source.

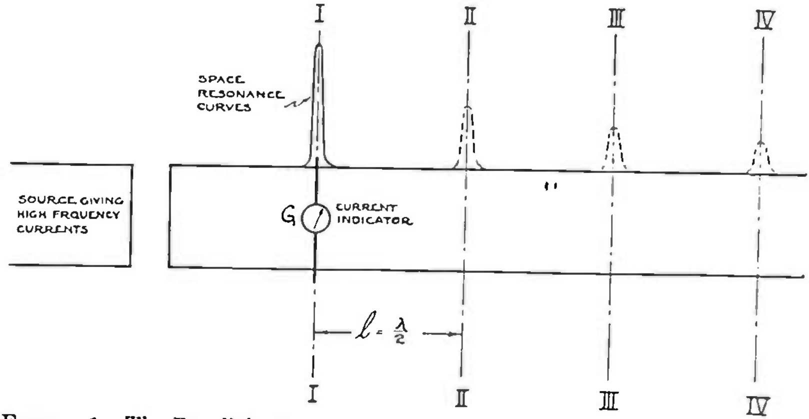

FIGURE 1—The Parallel Wire System of the Bureau of Standards Indicating the Space Resonance Curves as Determined with the Ammeter Bridge

lel wires are sufficiently long a number of such points, as III-III, IV-IV, and so on, may be found. The actual determinations are made with the positions I-I and II-II only since the distance $l = \frac{\lambda}{2}$ can be measured most accurately and the value obtained can be shown to be most reliable. Using a small condenser across the input terminals shifts the two maximum settings closer to the input end without changing the distance between them. The frequency f may be calculated from the formula.

$$f = \frac{v}{2l}$$

where v is the velocity of propagation along the parallel wires. The theory shows that the wave length λ set up on the parallel wire system is just $2l$, that is, twice the distance between two consecutive maximum settings except for a second order small quantity, but the velocity v with which the wave is propagated in the direction of the parallel wires is not the velocity of light ($v_o = 2.9982 \times 10^{10}$ cm./sec.) but a smaller velocity

$$v = v_o(1 - \Delta)$$

This velocity divided by the true wave length λ must be equal to the frequency f.

The frequency f in kilocycles per second is therefore calculated from the formula

$$f = \frac{v_o}{2l}(1 - \Delta)$$

where v_o is the velocity of light. Therefore,

$$f = \frac{1.4991 \times 10^5}{l}(1 - \Delta) \qquad (1)$$

where the distance l between two consecutive maximum settings is expressed in meters. Figure 2 gives a plot for the small quantity Δ for different values of l. This curve is calculated for a parallel wire system using copper wire, 0.145 cm. diameter (number 15 American Wire Gauge) with a spacing of 4.2 cm. between centers.

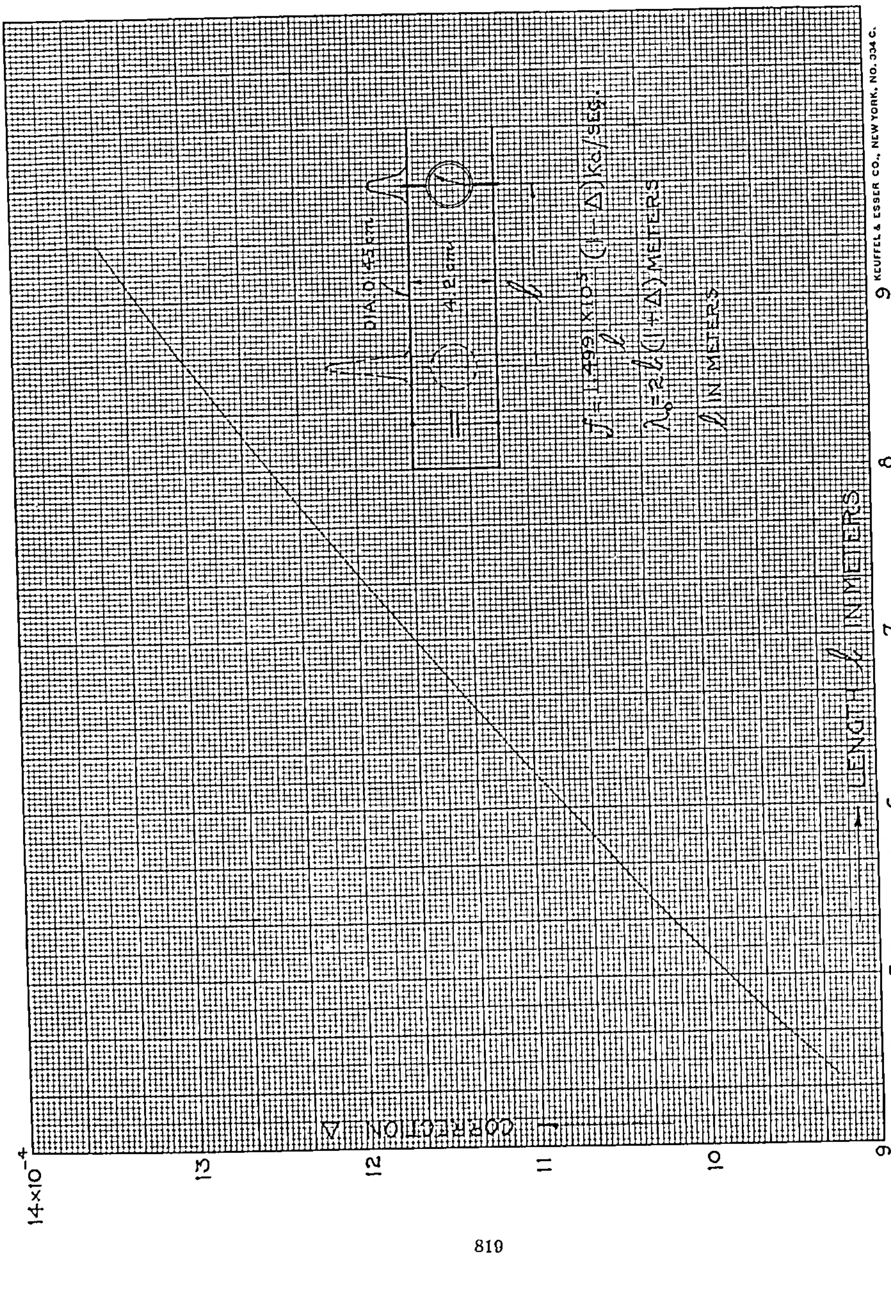

FIGURE 2—Curve Giving the Correction Factor Δ for Different Values of l and Fixed Dimensions of the Parallel Wire System

The calculation is based on the expression [4].

$$\Delta = \frac{\sqrt{r_0}}{8\, l n\, B \sqrt{\omega}\left[1-\left(\frac{d}{a}\right)^2\right]} \qquad (2)$$

where

$$B = \frac{1+\sqrt{1-\left(\frac{d}{a}\right)^2}}{\frac{d}{a}}$$

which for normal spacings between the centers of the wires which are as a rule large compared with the diameter d of the wire gives practically $B = \frac{2a}{d}$

a = distance between the centers of the wires.

d = diameter of the wire.

r_0 = the direct current resistance per centimeter length of the double line expressed in electromagnetic c. g. s. units (10^9 e. m. u. = 1 ohm).

$\omega = 2\pi f$.

f = frequency in cycles per second.

Formula (2) is applied as follows: Using for example the parallel wire system of the Bureau of Standards for a frequency $f = 2 \times 10^7$ cycles per second, a diameter $d = 0.145$ cm., and a spacing $a = 4.2$ cm., $\frac{d}{a} = 0.0345$; $\left(\frac{d}{a}\right)^2 = 0.00119$ which is in this particular case negligible compared with unity. Hence

$$B = \frac{2a}{d} = 57.92.$$

Assuming the resistivity of copper equal to 1,600 c. g. s. units, we find for one centimeter length of the parallel wire system

$$\sqrt{r_0} = \sqrt{\frac{2 \times 1600}{\frac{\pi}{2} \times 0.145^2}} = 440 \text{ electromagnetic c.g.s. units}$$

and $\Delta = 0.00121$, which shows that the frequency would be about 1/10 of a percent too high if the correction term Δ were neglected in equation (1). The result has been substantiated by experiment; frequencies calculated with formula (1) agreed with results

[4] This formula utilizes among other quantities an unpublished high frequency formula for the inductance of the parallel wire system which is due to Dr. Chester Snow of the Bureau of Standards.

obtained by an entirely different method of frequency standardization using Lissajous figures and a standard tuning fork.[5]

Department of Commerce,
Washington, D. C.

SUMMARY: The above paper describes briefly calculations required in the parallel wire system used by the Bureau of Standards for radio frequency standardization. Formulas involving a correction term are given by means of which the standard frequency can be calculated from the distance between two consecutive maximum settings along the parallel wire system. A numerical example is added. showing the magnitude of the correction term.

[5] This method is described in a Bureau of Standards Scientific Paper now in press.

ON THE RADIATION RESISTANCE OF A SIMPLE VERTICAL ANTENNA AT WAVE LENGTHS BELOW THE FUNDAMENTAL*

By

STUART BALLANTINE

(JOHN TYNDALL SCHOLAR IN PHYSICS, HARVARD UNIVERSITY, CAMBRIDGE MASSACHUSETTS)

The calculation of the radiation resistance of a simple vertical antenna erected over a perfectly conducting plane earth has been discussed by several investigators, including Abraham[1] and Pierce.[2] Abraham regards the wire as equivalent to an ellipsoid of revolution the major axis of which is very much longer than its minor axis, and rigorously investigates the oscillation of charge by applying Maxwell's equations to it in suitable curvilinear coordinates; he thus derives values for the damping due to radiation at certain definite wave lengths corresponding to the fundamental and the several harmonics. Pierce has extended the calculation to wave lengths above the fundamental by making the assumption that the variation of the current amplitude along the antenna remains sinusoidal when an inductance is included at the base; he is then able to calculate the radiated power by integration. The value of the resistance at the fundamental (36.57 ohms) obtained by Pierce is in agreement with that rigorously derived by Abraham, but it should be noted that this does not imply that the assumed current distribution is correct for wave lengths other than the fundamental; there are, in fact, good reasons to suspect that the current distribution is not of such simple sinusoidal type, but, because of the non-uniformity of the inductance and capacity per unit length, would be given by more complicated functions, such as Bessel's I_m and K_m functions. Stone and Roos discussed this twenty years ago and the subject has lately been revived by Press in these PROCEEDINGS and in the London "Electrician." I do not propose to examine this point

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[1] M. Abraham: "Ann. der Phys.," 66, page 435 (1898); "Math. Ann.," 55, page 81, (1899); "Phys. Zeit.," 2, page 329, (1901).

[2] G. W. Pierce: "Proc. Amer. Acad.," 52, page 192, (1916), or "Electric Oscillation and Electric Waves," page 435 (New York, 1920).

critically in the present short paper, but merely to extend the calculations of radiation resistance to wave lengths below the fundamental, making use of Pierce's assumption of sinusoidal current distribution. In view of the uncertainty of this assumption the extension may appear to be of little final value; nevertheless the results are by no means trivial, since they permit the examination of certain important questions, which, if we wait for a really rigorous theory, will probably remain unsolved. One such question, which I propose to discuss in a separate paper, is that relating to the best transmitting wave length for a vertical antenna. It turns out that this wave length, for highly conducting earth, lies below the fundamental, hence the importance of these calculations. Aside from this it is well to have them on permanent record in the hope that experimental data may be available for comparison later.

METHOD OF CALCULATION

The method here used is the classical one derived from the electron theory, which furnishes an easy means of finding the electric and magnetic forces by integration when the distribution and motion of the charges is known. Pierce's doublet method is equivalent to this, but somewhat less elegant mathematically. The intregation extends over the known distribution of current in the antenna wire and the current which spreads out radially over the surface of the earth. Since the earth is assumed to be perfectly conducting, this surface current may be represented by an image of the antenna extending below the earth. The integration is then simplified and extends over the antenna and its image.

For convenience the set of spherical coordinates shown in Figure 1 will be employed. We shall also use Gaussian units,

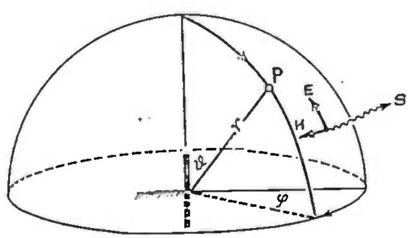

FIGURE 1—Spherical Coördinates

in which all electrical quantities (electric force (E), current density (i), resistance (R), etc.), are measured in electrostatic c. g. s. units, and the magnetic quantity (magnetic force (H)) in electromagnetic units. The electric and magnetic forces at any point due to the current are found by first calculating the scalar and vector electromagnetic potentials ϕ and A by integration, and then deriving E and H by differentiation, as follows:

$$E = -Grad\,\phi - \frac{1}{c}\frac{\partial A}{\partial t}; \tag{1}$$

$$H = Curl\,A; \tag{2}$$

where

$$\phi = \iiint \frac{\rho\left(t \pm \frac{r}{c}\right)}{r}\,d\,v, \tag{3}$$

$$A = \iiint \frac{i\left(t \pm \frac{r}{c}\right)}{c\,r}\,d\,v. \tag{4}$$

E and H being found, the flow of energy, which we shall suppose to be represented by the Poynting-vector,[3] S, can be found; thus:

$$S = \frac{c}{4\pi}[E \times H.] \tag{5}$$

Since the earth is assumed to be perfectly conducting and there are no sinks of power in the field, the total power escaping from the antenna is found by integrating the normal component of the Poynting-vector over any surface inclosing it, it being a matter of indifference what surface is taken. For convenience we take the surface to be a hemisphere with center at the antenna base. The time-average of the total power is next found, and from this the resistance equivalent to radiation is derived by dividing it by the average current square. The essential steps of this process are given below; to save space all trifling algebraic details are omitted.

1. Assumed Current Distribution

The current amplitude is assumed to be sinusoidal as a function of position along the antenna wire (see Figure 2), and the instantaneous current is sinusoidal in time. Denoting the current amplitude at the base by I_o and the current amplitude at the "current-loop" by I, the instantaneous current at a point distant x from the earth is given by:

[3] It will be noted that the Poynting-vector gives precisely the same representation of the energy flow as Macdonald's energy-vector (Compare: "Electric Waves," page 72, Cambridge, 1902), because we are dealing with a periodic source and Macdonald's extra term, $\frac{d}{d\,t}[H \times A]$ vanishes when integrated over a complete period.

$$i = I \sin\frac{2\pi(l-x)}{\lambda} \sin \omega t,$$

$$= I_o \frac{\sin\frac{2\pi(l-x)}{\lambda}}{\sin\frac{2\pi l}{\lambda}} \sin \omega t. \qquad (6)$$

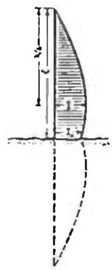

FIGURE 2—Assumed Sinusoidal Variation of Current Amplitude Below the Fundamental

It will be convenient to use the abbreviation: $a = \frac{2\pi l}{\lambda}$, or since we will take the fundamental wave length, λ_o, to be equal to the length of the wire multiplied by 4, $a = \frac{\pi}{2}\frac{\lambda_o}{\lambda}$, λ being the operating wave length.

2. Calculation of the Vector Potential

The vector potential may be either of the accelerated or retarded variety and is obtained by integrating the current over the antenna and its image. Using the retarded potential:

$$A = \frac{I}{c}\int_o^l \sin\frac{2\pi(l-x)}{\lambda} \sin \omega\left(t - \frac{r'}{c}\right)\frac{dx}{r'} + \int Image. \qquad (7)$$

A is given in a point of the surface of the sphere for which r is constant. The distance from the integration element to this point is represented by r'. Now we will assume that the radius of this sphere is large compared with the length of the antenna. This permits us to neglect the effect of the variation of r' on the amplitude, but we can never neglect its effect on the phase, no matter how large r may be. We have approximately:

$$r' = r - x \cos \theta$$

The effect of the image is got by reversing the sign of $\cos \theta$. Performing the integration, we get:

$$A = -\frac{I\lambda}{\pi r c} \sin \omega\left(t - \frac{r}{c}\right)\frac{[\cos a - \cos(a \cos \theta)]}{\sin^2 \theta}, \qquad (8)$$

which gives the retarded vector potential at a point the co-ordinates of which are r and θ.

3. Calculation of the Electric and Magnetic Field Intensities

It is unnecessary to calculate the scalar potential because we shall only require the electric force at a large distance from the antenna and in the self-conjugate field which exists at this distance, E and H are equal and orthogonal to each other and to the direction of propagation. Hence a calculation of H thru:

$$H = Curl\, A$$

suffices also for E. For the important components we have:

$$E_\theta = H_\phi = Curl_\phi\, A = sin\, \theta \frac{\partial A}{\partial r} + \frac{cos\, \theta}{r} \frac{\partial A}{\partial \theta}, \tag{9}$$

Performing the indicated operation and ignoring terms in r^{-2}:

$$E_\theta = H_\phi = \frac{2\,I}{c\,r} cos\, \omega \left(t - \frac{r}{c}\right) \frac{cos\, a - cos(a\, cos\, \theta)}{sin\, \theta}. \tag{10}$$

E is entirely longitudinal and H is latitudinal.

4. Calculation of the Power Radiated

Since E and H arenormal to each other and to the spherical surface of integration, the Poynting-vector is entirely normal to the surface so we have simply to integrate the absolute value:

$$S = \frac{c}{4\,\pi} H_\phi^2, \tag{11}$$

over the hemisphere. The surface element is $d\,s = 2\,\pi\, r^2\, sin\, \theta\, d\,\theta$, hence:

$$\text{Total power} = \frac{2\,I^2}{c} cos^2\, \omega\left(t - \frac{r}{c}\right) \int_0^{\frac{\pi}{2}} \frac{[cos\, a - cos(a\, cos\, \theta)]^2}{sin\, \theta} d\,\theta. \tag{12}$$

This integral apparently cannot be evaluated in simple functions. Pierce's method leads naturally to the same integral, which he attacks boldly, expending the integrand in series and integrating term by term. With the range of values of a with which Pierce was concerned (wave lengths *above* the fundamental) the convergent series so obtained can be computed with moderate patience and a calculating machine, but for wave lengths below the fundamental the argument becomes so large that the labor of calculation has appeared to me prohibitive. It is possible to develop the integral by successive partial integrations in an asymptotic series in inverse powers of a, and this is useful for large a, but there is still a region immediately below the fundamental where a is too small for accurate work. A lazy man thus finds himself between a convergent Scylla and a divergent Charybdis.

The simplest functions in terms of which the integral could be expressed seemed to be the following, the notation $S_1(x)$ and $S_2(x)$ being my own:

$$S_1(x) = \int_0^x \frac{1-\cos z \, . \, dz}{z} = \frac{x^2}{2 \, . \, 2\,!} - \frac{x^4}{4 \, . \, 4\,!} + \frac{x^6}{6 \, . \, 6\,!} - \frac{x^8}{8 \, . \, 8\,!} + \quad (13)$$

$$S_2(x) = \int_0^x \frac{\sin z \, dz}{z} = x - \frac{x^3}{3 \, . \, 3\,!} + \frac{x^5}{5 \, . \, 5\,!} - \frac{x^7}{7 \, . \, 7\,!} + \quad (14)$$

Being convinced, from the simplicity of these functions, that thay had important mathematical properties, and should be fundamental, I made a search of the literature and was gratified to find that 4-place tables of the Sine-integral, $Si(x)$ and the Cosine-integral, $Ci(x)$ were available[4] in terms of which S_1 and S_2 could be expressed as follows:

$$S_1(x) = \log x + \gamma - Ci(x) \quad (15)$$

$$S_2(x) = Si(x); \quad (16)$$

where γ is Euler's constant $=0.5772$. Thus the laborious computation of the series (13) and (14) is avoided.

The integral for the power is expressed in terms of S_1 and S_2 as follows, after the time average has been taken:

$$\overline{\text{Total power}} = \frac{I^2}{c}\left[\cos^2 a \, S_1(2a) - \frac{1}{4}\cos 2a \, S_1(4a) - \frac{1}{2}\sin 2a\left(S_2(2a) - \frac{1}{2}S_2(4a)\right)\right]. \quad (17)$$

5. Expression for the Radiation Resistance

The radiation resistance is defined as the average power radiated per second divided by the average current square at the point of the antenna at which the power is introduced. If the resistance is calculated at the base we have to divide by $I_o^2/2$, I_o being the base current. Below the fundamental the current-loop (point at which the amplitude is maximum) moves up from the earth and at $\lambda_o = 2\lambda$ is situated half-way up the antenna. The resistance referred to this point is also of interest, as well as the usual base resistance; we shall represent it by R (loop), the

[4] Jahnke and Emde: "Funktionentafeln," page 19 (Teubner's reprint, Leipzig, 1923), or J. L. Glaisher: "Phil. Trans.," London, 160, page 368, (1870).

base resistance being denoted by R_o. The complete expressions for the radiation resistance referred to these points follow:

$$R_o = \frac{2}{c \sin^2 a}\left[\cos^2 a\, S_1(2a) - \frac{1}{4}\cos 2a\, S_1(4a) - \frac{1}{2}\sin 2a\left(S_2(2a) - \frac{1}{2}S_2(4a)\right)\right]$$

. . . . electrostatic c. g. s. units,

$$= \frac{60}{\sin^2 a}\text{ [same bracketted expression] ohms} \qquad (18)$$

$$R(loop) = 60 \text{ [same bracketted expression] ohms} \qquad (19)$$

Formulas (18) *and* (19) *give the radiation resistance of a vertical single wire antenna over perfect earth for a sinusoidal current distribution, R_o being the resistance referred to the base, and R (loop) being the resistance referred to the point of the antenna at which the current-loop is situated in the case of wave lengths below the fundamental.* $a = \frac{\pi \lambda_o}{2\lambda}$, *where λ_o = fundamental wave length and λ = the operating wave length.*

Computations, Tables, and Curves

For values of a up to about 4, the values of Si and Ci can be taken from the 4-place tables of Jahnke and Emde, a being chosen so that $4a$ is an integer (to avoid interpolation). Between $x=16$ and $x=20$, however, there is an important gap in the tables, corresponding to wave lengths between one-half and one-third the fundamental. This gap is filled in by computations from the following asymptotic series, the terms of which have a sufficiently rapid descent to make the remainder ignorable after one or two terms.

$$S_2(x) \backsim \frac{\pi}{2} - \frac{\cos x}{x}\left(1! - \frac{2!}{x^2} + \frac{4!}{x^4} - \ldots\right) - \frac{\sin x}{x}\left(\frac{1!}{x} - \frac{3!}{x^3} + \ldots\ldots\right), \qquad (20)$$

$$S_1(x) \backsim \log x + .5772 - \frac{\sin x}{x}\left(1! - \frac{2!}{x^2} + \frac{4!}{x^4} - \ldots\right) + \frac{\cos x}{x}\left(\frac{1!}{x} - \frac{3!}{x^3} + \ldots\right) \qquad (21)$$

With these formulas and tables, the computation easily proceeds, giving the results tabulated in Table I.

TABLE I

Radiation resistance in ohms of a vertical antenna over perfectly conducting earth, the current distribution being assumed sinusoidal.

λ/λ_o	a	R_o (*base*)	R (*loop*)	λ/λ_o	a	R_o (*base*)	R (*loop*)
1.40	1.122	15.08		0.524	3.0	5270.	104.54
1.20	1.310	22.10		0.507	3.1	58200.	101.1
1.15	1.368	24.75		0.492	3.2	27900.	97.20
1.05	1.497	31.64		0.448	3.5	650.	80.0
1.00	1.570	36.54	36.54	0.418	3.75	191.	62.52
0.98	1.6	40.0	38.61	0.392	4.00	88.0	50.40
0.872	1.8	55.5	52.80	0.369	4.25	55.8	44.66
0.785	2.0	83.0	68.82	0.349	4.5	46.0	44.16
0.700	2.25	143.5	86.57	0.342	4.6	46.8	46.42
0.654	2.4	210.	95.45	0.314	5.0	79.5	73.01
0.571	2.75	730.	106.0				

For easy reference the results are also shown graphically in Figure 3, the dotted curve representing the resistance at the base, the full line curve representing the resistance at the current-loop.

I have carried thru the computations a short distance above the fundamental in order to make connections with Pierce's computations, and find a very satisfactory numerical agreement.

For wave lengths substantially above the fundamental, formula (18) is not convenient, since the resistance becomes increasingly small and is given by the difference between two functions of approaching equality. In this case a simplification is possible, as pointed out by Cutting[5], which follows from the fact that the current distribution approaches linearity as a decreases, and for small λ_o/λ we have very approximately:

$$R_o = 2.5\,\pi^2\left(\frac{\lambda_o}{\lambda}\right)^2 = 40\pi^2\left(\frac{l}{\lambda}\right)^2 \text{ ohms.} \qquad (22)$$

Returning to the curves, at first sight it seems odd that the maximum of resistance (loop resistance) should occur somewhat short of the half-wave length, at $\lambda/\lambda_o = 0.56$ rather than at 0.50; similarly that the minimum should fall short of the 1/3 position. This led me to check the formula and computations very carefully, but no error was revealed. Upon more mature consideration, there seems to be no reason why the curve should not be of this form.

The calculations are carried to a wave length one-third the fundamental. It might seem desirable to extend these calculations to the inverted "L" type of antenna, thus supplementing

[5] Fulton Cutting: PROCEEDINGS OF THE INSTITUTE OF RADIO ENGINEERS, 10, page 129, (1922).

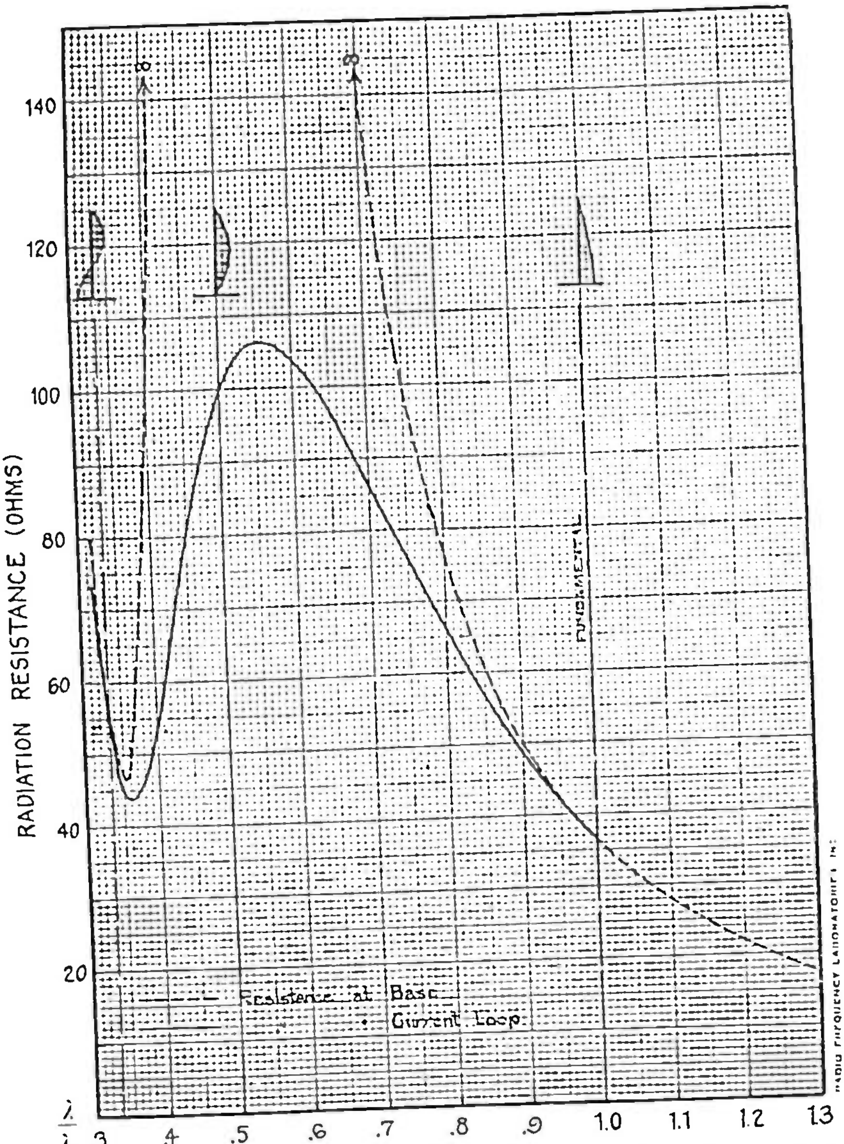

FIGURE 3—Radiation Resistance of Simple Vertical Antenna Over Perfect Earth for Wave Lengths Below the Fundamental

Pierce's study of the resistance of this type of antenna at wave lengths above the fundamental. But in view of the labor involved and the lack of faith which must be entertained for the fundamental assumptions—perfect earth and sinusoidal current distribution—I have not considered this to be worth while.

(Note, added July 15, 1924:- Professor G. W. Pierce, commenting upon this paper, informs me that some calculations of the radiation resistance of a vertical antenna below the fundamental wave length were made in 1919 by Dr. Yu Ching Wen, a former pupil of his. This work exists in the form of a thesis entitled "Theoretical Treatment of the Radiation Resistance of Antennas," in the Library of Harvard University, and has not been published. Mr. Robert F. Field, of Cambridge, has kindly consulted this thesis for me and sends the following values for the resistance at the antenna base calculated by Wen:

λ/λ_0..........	1.00	0.94	0.90	0.82	0.80	0.76	0.70	0.66	0.64
R..........	36.6	43.7	50.3	71	78	96	162	212	236

These calculations go down to 0.64 λ_0 and agree satisfactorily with my values (dotted curve, Figure 3).)

Cambridge, Massachusetts,
November 8, 1923.

SUMMARY: In this paper, the radiation resistance of a filamentary vertical antenna erected over perfectly conducting plane earth is calculated for wave lengths down to 0.3 of the fundamental. Pierce's assumption of sinusoidal variation of the current amplitude along the antenna forms the basis of an application of the methods of the electron theory, whereby the e.m. potentials are found by integration and the field and Poynting vectors subsequently derived by differentiation. An improved method of computation, using the sine- and cosine-integrals, is introduced. The numerical results are tabulated and exhibited graphically.

ON THE OPTIMUM TRANSMITTING WAVE LENGTH FOR A VERTICAL ANTENNA OVER PERFECT EARTH*

By

STUART BALLANTINE

(JOHN TYNDALL SCHOLAR IN PHYSICS, HARVARD UNIVERSITY, CAMBRIDGE MASSACHUSETTS)

The question as to the best operating wave length for a transmitting antenna is of considerable theoretical and practical interest, and one which does not appear to have received much published discussion. The mathematical difficulties of the theoretical study are very formidable if the actual conditions of the practice are imposed and an effort made to take into account all kinds of antenna forms and grounding methods, and the variations of earth conductivity and susceptibility. But certain simple cases can be advantageously treated mathematically, leaving the more complicated and large scale engineering projects to be tested by model experiments, the model being constructed in accordance with the principles of dimensional similarity. In a forthcoming series of papers I propose to publish the results of theoretical and experimental work on this subject, and in this preliminary article shall consider the simplest possible case, namely, that of a simple vertical antenna over a perfectly conducting plane earth.

We shall start out with the additional assumption that there are no dielectric or other losses present, so that the antenna resistance will be entirely due to radiation. In a companion paper entitled "The Radiation Resistance of a Simple Vertical Antenna at Wave Lengths Below the Fundamental," published in these PROCEEDINGS, I have discussed the radiation from such an antenna in these circumstances, and calculated the radiation resistance for wave lengths down to 0.3 of the fundamental. The formulas and results of this investigation form the basis of the present inquiry.

For terrestrial point-to-point communication the function of a transmitting antenna is to produce an electric force at a receiving station located on the horizon, therefore the best operating

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wave length is that for which the electric force on the horizon is greatest for a given power input into the antenna. There is a considerable confusion of ideas on this point due to an excessive use of the conception of radiation resistance, the temptation being to regard the point at which the radiation resistance is highest as the best wave length. But since the object is to heat the wires of the receiving station, and not the universe, it is easy to see that the best wave length is that which will cause the antenna to radiate most of its energy at a low angle and along the earth's surface. Unless communication with aircraft is desired, or the efficiency of the Heaviside layer is more definitely established, there seems to be no point in radiating the antenna's energy up into the air.

2. DISTRIBUTION OF THE RADIANT ENERGY—The energy beam diverges from the power source at the base of the antenna, or if the power is not applied at the base, from the point of its application. There is no divergence from the antenna wires themselves, the energy being merely reflected by them. No detailed inquiry of the distribution of energy at points near the antenna will be made; the zone of chief interest is the so-called "wave zone" which exists at some distance from the antenna and in which the wave is self-conjugate, the electric and magnetic forces being equal. The intensity of the energy beam, or the rate of flow of the energy in the wave, is generally and conveniently represented by the Poynting vector, the magnitude of which is:

$$S = \frac{c}{4\pi} E\,H, \tag{1}$$

where c is the light-velocity, E the electric force, H the magnetic force (both in Gaussian units). The direction of this vector is at any instant at right angles to both E and H, so that at a reasonably large distance from the antenna, where E and H lie in the surface of a sphere surrounding it, S is normal to the surface and therefore directed away from the antenna. Also E and H being equal in the wave-zone, S can be simply written as:

$$S = \frac{c}{4\pi} E^2 = \frac{c}{4\pi} H^2 \tag{2}$$

In the paper just cited will be found formulas for calculating E at various angles, θ, from the pole, for different wave lengths. From these S can be calculated and plotted as a function of the polar angle in the form of a *distribution diagram*. Such a diagram will be of interest in showing how much energy is radiated in the various angular directions for different current distributions in the transmitting antenna, the current distribution being governed by the wave length and the height of the antenna wire. Several diagrams of this sort will be given later.

3. CALCULATION OF THE OPTIMUM TRANSMITTING WAVE LENGTH—As previously remarked the signal-producing value of the antenna's radiation is represented by the electric field intensity E on the horizon. On the horizon, θ of formula (10) of the previous paper is $\pi/2$ so that the amplitude of E is given by:

$$E=\frac{2I}{cr}\left[1-\cos\left(\frac{\pi\lambda_o}{2\lambda}\right)\right], \quad (3)$$

where I is the current at the current-loop of the antenna, λ is the operating wave length and λ_o is the fundamental wave length. Since the antenna resistance is entirely radiational, R_r:

$$I^2 R_r = \text{antenna power} = P, \quad (4)$$

R_r being the radiation resistance at the current-loop, and

$$I=\sqrt{\frac{P}{R_r}}, \quad (5)$$

What we are interested in making a maximum is the ratio $E/\sqrt{P}$, which is given by substituting (5) in (3):

$$\frac{E}{\sqrt{P}}=const. \frac{1-\cos\left(\frac{\pi\lambda_o}{2\lambda}\right)}{\sqrt{R_r}} \quad (6)$$

The data for R_r as a function of $a=\frac{\pi\lambda_o}{2\lambda}$ is given in the companion paper (previous citation) for a vertical antenna over perfect earth. Using these results, the expression (6) has been calculated and plotted in Figure 1; the full-line curve represents $E/\sqrt{P}$, the dotted-line curve the radiation resistance (loop). The best operating wave length for this idealized antenna is thus seen to be closely equal to 0.39 of the fundamental. A comparison with the R_r curve convinces us that no deductions of any value can be drawn from the variation of radiation resistance alone.

4. DISTRIBUTION DIAGRAMS—In Figures 2 and 3 are plotted the diagrams showing the distribution of radiant energy at various altitudes for several important wave lengths. In all cases the input power to the antenna is the same. These are polar graphs and the strength of the radiation (Poynting vector) is given as the distance from the antenna base to the curve for a particular

value of the polar angle, θ. In all cases it will be noticed that the usual "dead spot" occurs directly over the antenna.

In the first diagram, Figure 2a, for wave lengths very much greater than the fundamental, altho the main tendency is for the energy to flow along the earth, a considerable amount is radiated at high angles; the 45° radiation, for example, is about half as intense as that along the earth. As the wave length is decreased to the fundamental and beyond, more and more of the energy is radiated along the earth, and less gets up into the air.

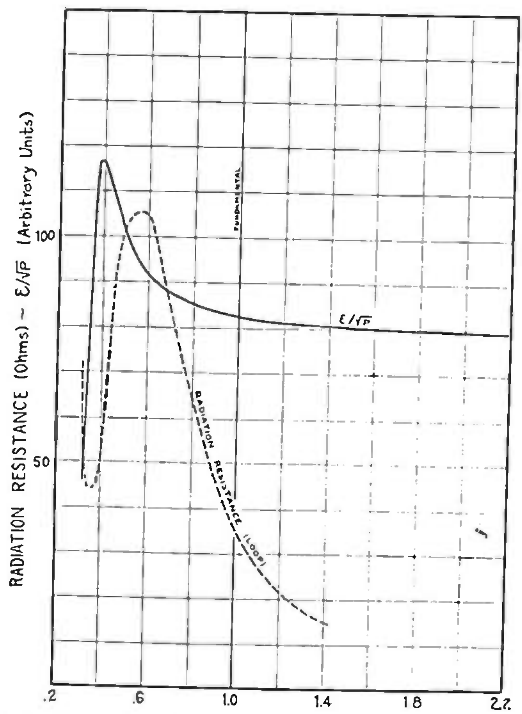


FIGURE 1—Vertical Antenna Over Perfect Earth; Variation of Electric Force on the Horizon for Given Power Input as a Function of the Ratio: Operating Wave Length λ/Fundamental Wave Length λ_o. Best Transmitting Wave Length = $0.39\,\lambda_o$.

When the operating wave length is decreased below the half-fundamental wave length, the wave breaks up into two parts, and a secondary wave, complete in itself and unguided by the earth, appears at high angles. These waves are separated by a conical surface, $\theta = const.$, in which the electric and magnetic forces are zero. There are then two points of maximum radiation. This

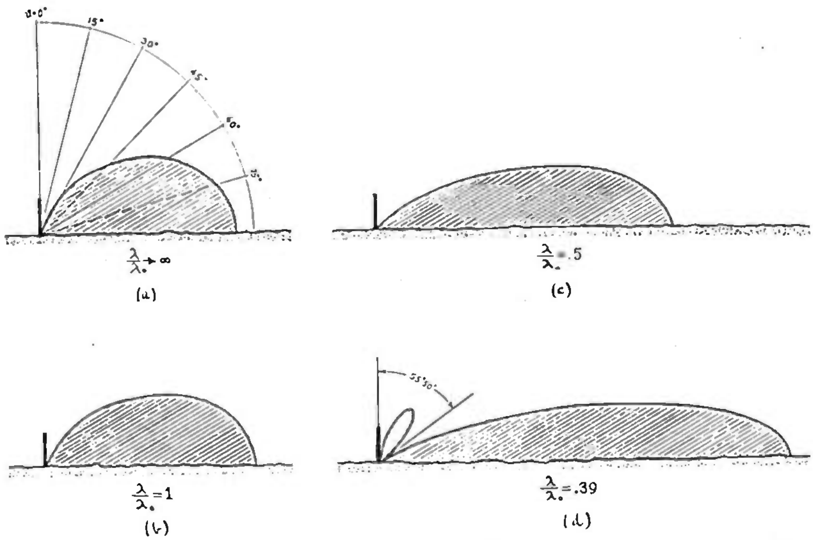


FIGURE 2—Vertical Antenna Over Perfect Earth; Diagrams Representing Intensity of the Radiation (Poynting Vector) at Various Angles of Altitude for Various Wave Lengths

is illustrated in Figure 2 (d), which represents the case $\lambda/\lambda_0 = 0.39$, which as was shown in a previous paragraph is the best operating wave length. Here the radiation along the earth in the direction of the distant receiving station is very intense, and relatively little energy is wasted in high angle radiation. The maximum of the secondary wave occurs at $\theta = 35°$, and $\theta = 55°50'$ is the conical surface of zero radiation. As the wave length is shortened below this point, the primary radiation decreases very rapidly, until at $\lambda/\lambda_0 = 1/4$ the separating cone becomes the earth surface and the primary wave has been completely supplanted by the secondary wave. This case is shown in Figure 3, and is of special interest.

5. SPECIAL TRANSMITTING ARRANGEMENT FOR TESTING UPPER-ATMOSPHERIC REFLECTION—In most of the experimental work that has been done to establish or disprove the theory of the Heaviside-layer and upper-atmospheric reflection, ordinary transmitting arrangements have been employed. At the receiving point it is therefore necessary to provide an elaborate system of loops to separate the direct ray along the earth from the ray reaching the receiver by reflection from the upper atmosphere. The ingenious experimental arrangements described by Eckersley ("Radio Review") are of this nature. Several years ago it occurred to me that the experiment would be very conveniently

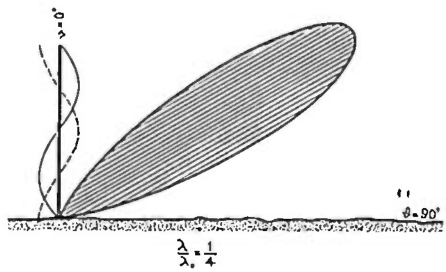


FIGURE 3—Distribution Diagram for the Case: Height = Wave Length, in which the Radiation Along the Earth is Zero. Same Scale and Power Input as Figure 2

simplified if the transmitted wave could be entirely directed up into the air, thus eliminating the direct ray along the earth. The transmitting arrangement for high angle radiation could consist of a vertical antenna erected preferably over sea water and excited at a wave length one-quarter of its fundamental. At this wave length the voltage and current distribution would be approximately that shown in Figure 3, so that the radiation resistance being high (at the base) the antenna would naturally be excited by "voltage excitation," that is, it would be connected in parallel with an anti-resonant $L\,C$ circuit. The distribution of energy about such a radiator is shown in Figure 3. The radiation centers about an altitude of $\theta = 57°$, and if the conductivity at the base be sufficiently good there will be no disturbing direct ray along the earth. The possibility would then be that any radiation reaching a distant receiving station would be due to reflection and refraction in the upper-atmospheric layers. The experiment would preferably be conducted entirely over sea-water on account of its superior conductivity, because, as I shall show in another paper, one of the effects of imperfect earth is to bring down to the earth energy originally sent up into the air. The elimination of the direct ray would permit an easy study of the polarization and other characteristics of the reflected ray. As to the practical aspects, the height of the antenna would have to be equal to the wave length so that a comparatively short wave length will be imposed.[1] This in itself will not be disadvantage-

[1] The necessity for an antenna length actually equal to the wave length can be obviated without changing the required current distribution by decreasing the velocity of the wave along the wire by artificially loading with inductance coils, or by constructing a helical antenna of not too large diameter. Two inductance coils, situated ¼ and ¾ of the distance from the earth to the end of the antenna, respectively, and kept approximately equal in value, will suffice to produce the required double current-loop distribution in a short antenna. Oscillating in this mode the antenna can be looked upon as consist-

ous, provided proper audions are used for receiving, and with shorter waves, smaller reflecting masses can be detected. A wave length of 50 meters is feasible and demands an antenna height of 154 feet (50 m.).[1] Being forced to abandon this work on account of failing health, I have included this description of the plan in the hope that it might interest other investigators; it offers a very promising method of attacking this fascinating puzzle.

November 8, 1923.

SUMMARY: This paper considers the idealized problem of the transmission from a perfect vertical antenna over perfectly conducting plane earth. The distribution of current amplitude along the antenna is assumed to be sinusoidal. The antenna resistance is entirely radiational and has been calculated in a companion paper. The amount of energy radiated in various altitudinal directions is calculated, and distribution diagrams are given illustrating special cases. The conditions for the greatest economy of radiated energy are formulated for the case of a terrestrially located receiving station, the optimum wave length being determined as 0.39 of the fundamental. A transmitting arrangement of special interest for Heaviside-layer experiments is also described.

ing of two Hertzian antennas in series, each with its inductance load in the middle. One Hertzian antenna is positive, the other negative; the radiation effects cancel along the equatorial plans and on account of the phase change do not completely cancel at other angles. The radiation from the artificially loaded antenna will be less, of course, than from the natural antenna of Figure 3.

ELECTRICAL CONSTANTS OF DIELECTRICS FOR RADIO FREQUENCY CURRENTS*

By

R. V. GUTHRIE, JR.

(STATE UNIVERSITY OF IOWA, IOWA CITY)

I. INTRODUCTION

The electrical constants of dielectrics are the dielectric constant K and the power factor ψ, where ψ is the power factor of a condenser using the given material as a dielectric. Determinations of power factors for a few materials have been made by MacLeod,[1] Bryan[2] and others. Tables of dielectric constants are to be found in engineering handbooks, "Smithsonian Physical Tables," and elsewhere, but these were made for the most part using currents of zero frequency. Therefore it seems of interest to determine the dielectric constants and power factors of a number of insulating materials over a range of radio frequencies.

The method employed was the obvious one and consisted of measurements of the capacity and resistance of a carefully made parallel-plate condenser with air and the material in turn between the plates. From these measurements the dielectric constant and the power factor were calculated.

Consider the arrangement in Figure 1 consisting of a condenser C' and a resistance r'' in series. The impedance of the combination from A to B is given by

$$Z_{AB}=\frac{1}{j\,\omega\,C'}+r'' \tag{1}$$

where $j=\sqrt{1}$, and $\omega=2\pi$ times the frequency, all quantities being expressed in electrostatic units. From a consideration of Figure 1, it is seen that $E_{r''}$ across the resistance is in phase with the current I, and the $E_{C'}$ across the condenser is 90° behind I. From Figure 2 we see that the resulting emf. is less than 90° out of phase with the current by the phase difference ψ, the

*Received by the Editor, June 10, 1924.

[1] MacLeod, "Phys. Rev.," volume 21, January, 1923, page 53.

[2] Bryan, "Phys. Rev.," volume 22, October, 1923, page 399.

power factor being given by $\sin \psi$, but for small angles the sine is the same as the tangent, then

$$\text{Power factor} = \tan \psi = r'' \omega C' \qquad (2)$$

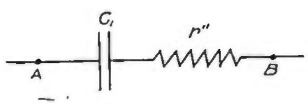


FIGURE 1

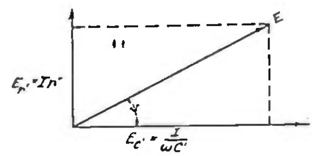


FIGURE 2

If, however, C' be measured by substitution against a standard condenser, not the real capacity but the apparent or effective capacity will be obtained. The equivalent of Figure 1 may be represented as in Figure 3 by a pure capacity C with a resistance r' in parallel. Here the impedance is given by

$$Z_{AB} = \frac{1}{j \omega C + \frac{1}{r'}} \qquad (3)$$

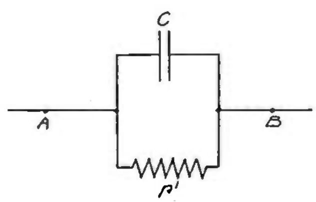


FIGURE 3

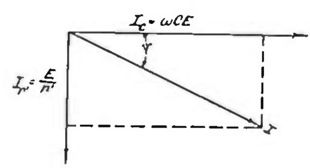


FIGURE 4

It may be seen that the current thru r' is 90° out of phase with that thru C. The resultant current leads the impressed emf. by an angle which is less than 90° by the phase difference ψ. The power factor is again the sine of ψ, which for small angles is the same as the tangent of ψ, so that

$$\text{Power factor} = \tan \psi = \frac{1}{r' \omega C} \qquad (4)$$

The source of power losses in a condenser may be represented by a series resistance as in Figure 1, or by a parallel resistance as in Figure 3, the power factors for small angles being the same as the phase differences as given by equation (2) or (4) in which, for small angles, the tangents may be taken as the angles. Before the application of these formulas it is necessary

[3] "Circular of Bureau of Standards," Number 74, "Radio Instruments and Measurements," page 180.

to determine the appropriate values of the capacity, resistance, and ω.

By including AB in a suitable measuring circuit to be described, r'' may be determined by resistance variation,[3] and C' by substitution against a standard condenser, for any value of ω. To obtain a relation between the measurable quantities C' and r'', and the quantities C and r' we combine equations (1) and (3), separate the real parts from the imaginary ones in both members of the equation, equate reals to reals and imaginaries to imaginaries, and solve the two resulting equations simultaneously. We obtain

$$C = \frac{C'(r'-r'')}{r'} \tag{5}$$

$$r' = \frac{1}{C'^2 r''^2 \omega} + r'' \tag{6}$$

Since C' and ω are known from measurements, r' and C are determined by equations (5) and (6), therefore we have the quantities r', r'', C', C, and ω all measurable or calculable.

II. Method and Apparatus

The schematic diagram of apparatus used is shown in Figure 5, the portions to the right of the dotted line being the coil of a thermionic tube oscillator for the generation of continuous waves, and that to the left of the line being the measuring circuit. The measuring circuit consisted of a coil L_2, the terminals of which dropped into the mercury cups a and b, thus allowing rapid change to coils of any desired inductance; also a capacity C_1 or C_2 depending on which way the mercury switch $c\,d\,e$ was thrown. There was included in this circuit a thermocouple T which actuated the galvanometer G, and two mercury cups f and g, between which standard resistance links r of various values might be connected. C_1 is a standard quartz-insulated condenser, which was assumed to be perfect and was carefully calibrated.

A photograph of condenser C_2 is shown in Figure 6. It had two plates m and n, 7.3 cm. in diameter, m being insulated from the other parts by the quartz rod q. The similar plate n was capable of vertical motion by a screw s. The dielectric to be studied was placed between these plates, thus forming a condenser having a solid dielectric. The position of n at any time could be determined by the dial d and the vernier v.

The insulating material was placed between the plates of C_2, which was connected into the circuit by joining c and d by a heavy copper link between the cups. The condenser C_2 could

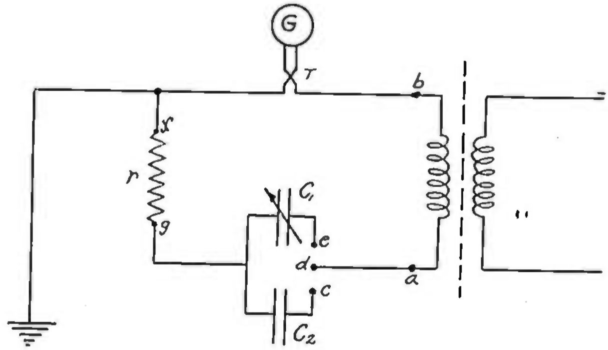


FIGURE 5

then be represented as in Figure 1. Resonance was effected in the L_2 C_2 circuit by varying the frequency of the input, all measurements being made at resonance. The resistance of the circuit L_2 C_2 was then determined by resistance variation.

When a link of negligible resistance was connected between g and f, suppose a beam of light reflected from a small mirror on the coil of the galvanometer G, read a deflection d_1 on a scale not shown in the diagram. When the link is replaced by a standard resistance of R_1 ohms, the deflection would decrease to some value d_2, then the resistance R_x of the circuit is given by

$$R_x = \frac{R_1}{\sqrt{\frac{d_1}{d_2}} - 1} \qquad (7)$$

Without changing the frequency of the input, the standard C_1 was substituted for C_2 by changing the connection $d\,c$ to $d\,e$, adjustments to resonance being made with C_1. If we represent the circuit resistance as R_x', then $R_x' - R_x$ is the equivalent series resistance of the condenser C_2 with the solid dielectric and is r'' of equation (6). The capacity as read from the dial of C_1 is the pure capacity of C_1, but is the effective capacity of C_2 corresponding to C' of equation (6).

The wave length λ was determined by use of a Kolster decremeter calibrated by the Bureau of Standards. From the relation $\omega = 2\pi f = (2\pi \times 3 \times 10^8)/\lambda$, ω was determined.

Having now measured r'' and C', r' may be obtained from equation (6), then C is given by equation (5). After all quantities have been reduced to electrostatic units, the power factor is given either by equation (2) or (4), both giving the same result.

Knowing the pure capacity of the two-plate condenser with the dielectric, and also its capacity without the dielectric, the quotient of the former by the latter is, by definition, the dielectric constant. C has been calculated from equation (5), and the capacity without the dielectric must be obtained by substitution against the standard.

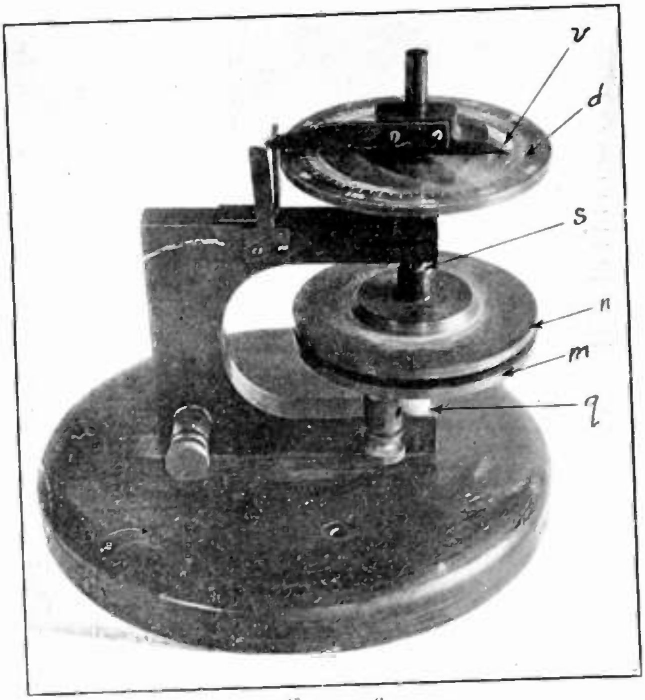


FIGURE 6

III. RESULTS

The constants of the materials investigated are given in the table. The first six were tested over a band of frequencies ranging from 600,000 to 1,700,000 cycles per second. It was found that the error introduced by assuming $C = C'$ was never more than 0.25 percent, which was much below the error of observation. The constants given are accurate to within about 2 percent. The dielectric constants were found to be nearly constant within the frequency limits mentioned, and the power factors changed gradually but according to no apparent rule.

If $C = C'$, then it is not necessary to use either equation (5) or (6). The dielectric constant is determined by using C' instead of C, and the power factor is determined by use of equation (2). Moreover, in applying (2), C' may be expressed in microfarads if r'' is expressed in ohms, thus eliminating the necessity

TABLE OF CONSTANTS FOR FREQUENCY OF 10^6 CYCLES PER SECOND

Number	Material	Dielectric Constant	Power Factor
1	Hard Rubber	2.53	0.007
2	Celluloid	4.10	0.042
3	Formica	3.83	0.050
4	Mica	2.94	0.0004
5	Sulphur	3.03	0.006
6G	Glass	5.65	0.008
7	Petrite	5.34	>0.100
8	Bakelite Dilecto Gr. 20	3.86	0.057
9	Bakelite Dilecto Gr. 20	3.86	0.059
10	Hard Rubber	2.60	0.012
11	Vulcanized Hard Rubber	2.92	0.007
12	Hard Fibre (gray)	6.05	0.070
13	Hard Fibre (black)	5.26	0.052
14	Bakelite Dilecto	3.91	0.059
15	Formica (grade M)	3.60	0.051
16	Radion (black)	3.22	0.017
17	Hard Rubber (2 XX)	2.66	0.011
18	Hard Rubber (40)	2.57	0.011
19	Hard Rubber (35 R)	2.79	0.008
20	Hard Rubber (7A)	2.56	0.014
21	Red Fibre	4.35	0.054
22	Bakelite	3.87	0.037
23	Leatheroid	4.27	0.048
25	Mahogany	4.43	0.051
26	Celeron	4.12	0.049
27	Celeron	4.40	0.065
28	Celeron	3.73	0.057
29	Celeron	3.93	0.057
30	Fibroc	3.99	0.041
31	Bakelite No. 1	3.83	0.039
32	Bakelite No. 2	3.73	0.039
33	Bakelite No. 3	3.81	0.042
34	Bakelite No. 4	3.88	0.043
35	Bakelite No. 5	3.84	0.044
36	Bakelite No. 6	3.76	0.045
37	Vulcabeston No. 120	3.42	0.037
38	Vulcabeston No. 701	3.71	0.046
39	Vulcabeston No. 501	3.95	0.050

of reduction to and from electrostatic units. This very materially lessens the labor of measurements and is the method followed in the determinations of the constants of the materials from number 6 to the close of the table.

For all materials in the table, the given constants are for currents of a frequency of 1,000,000 cycles per second, which corresponds to a wave length of 300 meters.

Measurements of the variation of resistance of coils with diameter of coil, pitch of winding, and size of wire, are in progress, and a report is expected to be submitted in the near future.

In conclusion the writer wishes to express his thanks to Dr. E. O. Hulburt for suggesting the problem and rendering frequent assistance during the experiment.

State University of Iowa.

SUMMARY: The source of power losses in a condenser may be considered as a resistance in series or in parallel with the condenser. If the resistance is considered as in series, the capacity must be considered as the effective capacity, and the power factor is given by a simple formula. If the resistance is considered as in parallel, the capacity must be considered as a pure capacity, and knowing the pure capacity with the given dielectric, and with air in turn between the plates of the condenser, the quotient of the former by the latter is the dielectric constant. The dielectric constants of several solid dielectrics were found to be approximately constant over the band of frequencies investigated, and the power factors changed according to no apparent law. A table of electrical constants for a number of materials and for a frequency of 1,000,000 cycles per second is given.

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

ISSUED AUGUST 26, 1924–OCTOBER 28, 1924

BY

JOHN B. BRADY

(PATENT LAWYER, OURAY BUILDING, WASHINGTON, D. C.)

1,499,979—C. M. Gray, filed August 15, 1921, issued July 1, 1924.

TUNING DEVICE FOR RADIO RECEIVING CIRCUITS, in which a fixed coil is provided with a second coil arranged in inductive relation to the fixed coil and mounted for rotary movement. A third coil is rotatively mounted in inductive relation to the aforementioned coils and has relatively few turns as compared with the second coil. The third coil is connected in series with the second coil and all coils are arranged for connection in the circuits of the system to be tuned.

1,506,046—W. H. Bullock, filed January 23, 1923, issued August 26, 1924. Assignor of 49 percent to Frederic W. Proctor, of New York.

RADIO RECEIVING SYSTEM, in which a plurality of signals transmitted on different wave lengths may be received by using the same antenna system without interference of one receiving circuit with respect to the other. An energy-absorbing circuit is employed in each of the receiving branches which prevents the flow of current in one direction for preventing the grid of one electron tube connected in circuit therewith from acquiring a static negative charge. The resistance of the absorbing circuit is too high to permit radio frequency oscillations, thereby preventing reaction of one circuit upon another while freely passing the desired signal frequency.

1,506,358—Otto Von Bronk, filed September 3, 1921, issued August 26, 1924. Assigned to Gesellschaft für drahtlose Telegraphie m. b. H. Hallesche, of Berlin, Germany.

SENDING ARRANGEMENT FOR RADIO TELEGRAPHY, in which the desired phase relations of the transmitted energy is regulated

* Received by the Editor, November 17, 1924.

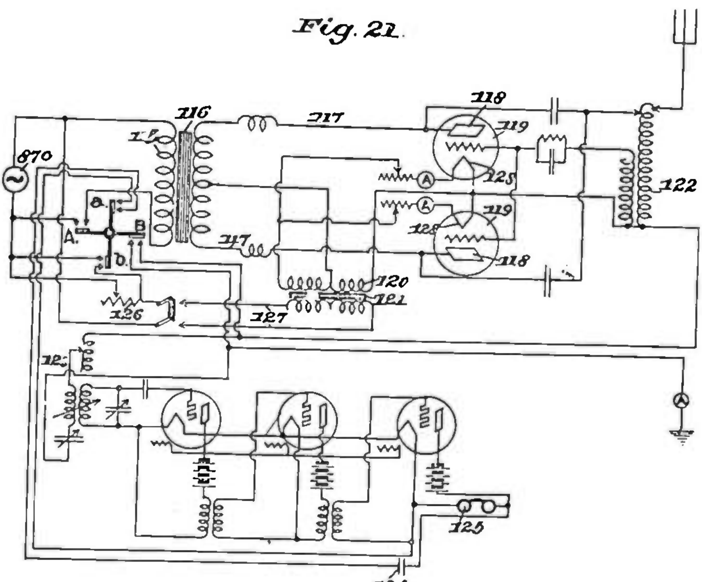
by arranging a plurality of separated radiators in positions to radiate currents of low intensity having a frequency difference equal to the frequency to be transmitted. These currents are received at each of the radiators and are employed to control the radiation from the radiators in proper phase relation.

1,506,468—W. C. White, filed October 28, 1920, issued August 26, 1924. Assigned to General Electric Company, of New York.

ELECTRON DISCHARGE DEVICE of the "soft" tube variety designed to be fully as sensitive as the best gas detectors formerly constructed, and as regular and reliable in its operation as the vacuum detector. The detector embodying the invention contains certain gases immune to the "clean-up effect," particularly the gases of the "rare" or noble gas group, such as argon, helium, neon, and even nitrogen.

1,506,580—H. E. Hallborg and H. R. Miller, filed October 25, 1920, issued August 26, 1924.

Fig. 21.



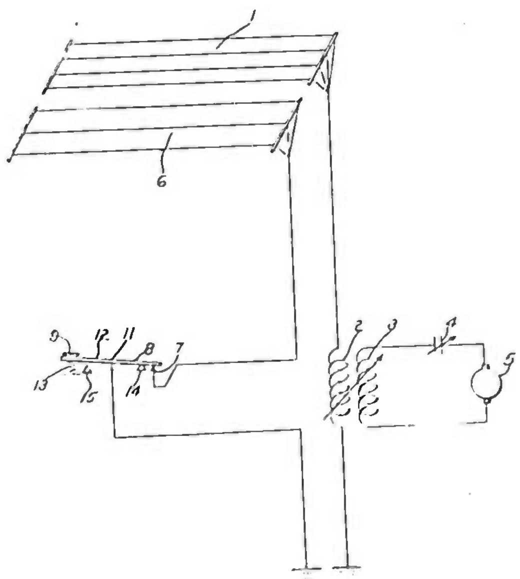
NUMBER 1,506,580—Quick Acting Amplifying Break Key for Radio Telegraphy

QUICK ACTING AMPLIFYING BREAK KEY FOR RADIO TELEGRAPHY for placing the receiver in condition for operation between the transmission periods. A quick acting break key is provided for controlling the connection of a shunting condenser across the telephone receivers in the electron tube receiving system intermediate the times that the antenna is radiating the transmission signals. The shunting condenser prevents objectionable noise in the telephone system by reason of the radiating energy.

1,506,486—A. W. Hull, filed March 1, 1920, issued August 26, 1924. Assigned to General Electric Company, of New York.

ELECTRIC OSCILLATOR, including an evacuated vessel with the electrodes arranged in such manner that the device will efficiently operate as an oscillator without making the grid positive. The cathode and anode are placed close to each other and control electrode or grid is so placed as to exercise a weak electrostatic control on one side of the cathode opposite the anode. The potential of the control member varies between the potential of the cathode and a potential which is negative with respect to the cathode.

1,506,736—L. Dorfman, filed August 3, 1921, issued September 2, 1924. Assigned to Westinghouse Electric and Manufacturing Company, of Pennsylvania.



NUMBER 1,506,736—Signaling System

SIGNALING SYSTEM having an antenna system consisting of two sections. A source of undamped radio frequency energy is connected to one of the antenna sections and a signaling key provided in a circuit connecting the other antenna section. The antennas are electrostatically coupled and the frequency of the source of radio energy is such that its antenna is resonant when the signaling key is open. In this way radiation may occur to represent the signal characters while the energy is absorbed by one of the antenna sections between the signal characters.

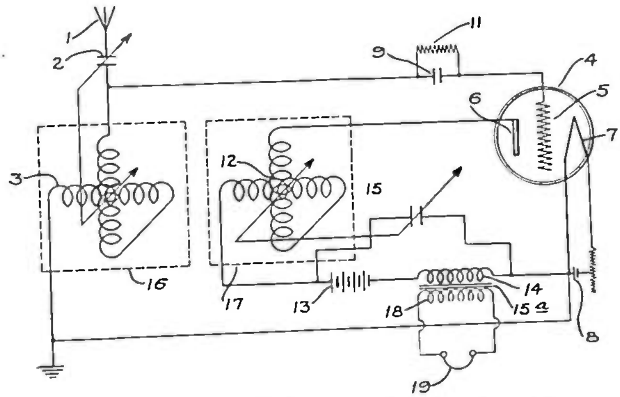
1,506,742—C. Le G. Fortescue, filed June 25, 1921, issued September 2, 1924. Assigned to Westinghouse Electric and Manufacturing Company, of Pennsylvania.

MODULATING SYSTEM for radio transmitting systems in which the load on the generator is maintained substantially constant in either the up position or the down position of the telegraph key. A tuned antenna circuit having an inductance coil therein is provided, and located in inductive relation to the inductance coil is a controller primary inductance coil. A balancing inductance coil is connected in parallel with the controller primary coil thru contacts controlled by a telegraph key. A source of radio-frequency current is connected to the middle points of the controller primary and balancing inductance coils, and the key controls the flow of current thru said coils. Means may also be provided for maintaining the load on the radio-frequency source substantially constant. By reason of the coupling of the antenna inductance coil to the controller primary inductance coil, when the key is in the up position, no effective power is delivered through the transformer coupling, and the frequency of oscillation of the antenna circuit is greatly reduced, as compared with the operating frequency. This takes place by reason of the fact that, in the down position of the key, when the transformer is delivering power to the antenna, the primary coil of the transformer coupling is, in effect, short-circuited by the radio-frequency source.

1,506,781—J. E. Shrader, filed August 18, 1921, issued September 2, 1924. Assigned to Westinghouse Electric and Manufacturing Company, of Pennsylvania.

VARIABLE LEAKY CONDENSER, comprising a plurality of conductors and dielectric material treated with a conducting material interposed between the conductors. The distance between the conductors is made variable by a pressure varying screw bearing upon one of the conductors whereby the distance between the conductors is varied at the same time that the resistance may be increased or decreased. The spacing member may be of resilient corrugated material adapted to be flattened under variable pressure. The dielectric material may be impregnated with India ink, forming a partial conductor. In this way a grid leak and grid condenser may be embodied in the same instrument.

1,506,799—P. E. Wiggin, filed July 9, 1921, issued September 2, 1924. Assigned to Westinghouse Electric and Manufacturing Company, of Pennsylvania.



NUMBER 1,506,799—Radio Tuning System

RADIO TUNING SYSTEM for operation with an oscillatory or regenerative system including an electron tube. The input circuit of the tube is tuned by controlling the impedance of the circuit. The output circuit of the tube is tuned by simultaneously varying the impedance and the capacity of a variable by-pass condenser in the said circuit. The circuit is described with particular application to a radio receiver for the reception of broadcast signals.

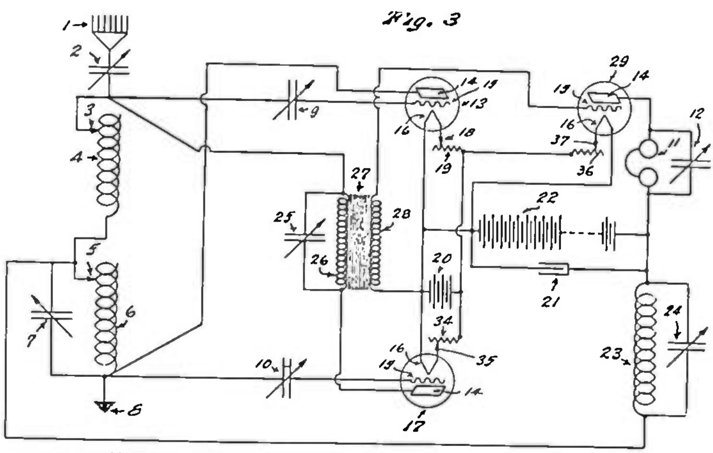
1,507,016—L. De Forest, filed September 23, 1915, issued September 2, 1924. Assignor to De Forest Radio Telephone and Telegraph Company, of New York.

RADIO SIGNALING SYSTEM, employing an electron tube circuit arranged to function as an oscillator with an inductive coupling between the oscillation circuit and an antenna system. The oscillating system is employed as a generator of energy at a radio transmission system.

1,507,017—L. De Forest, filed March 20, 1914, issued September 2, 1924. Assigned to De Forest Radio Telephone and Telegraph Company, of New York.

Radio Telephone and Telegraph System, in which an electron tube circuit is employed, connected as an oscillator for generating oscillators at a transmitting station. The claims of this patent recite the tube structure and electrodes therein with circuits connecting the electrodes associated to react upon each other. The diagrams in the patent show the tube functioning as an oscillator at the radio transmitter.

1,507,689—F. G. Simpson, filed November 4, 1922, issued September 9, 1924.



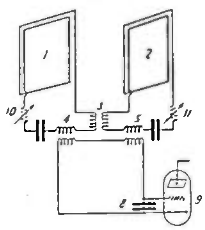
Number 1,507,689—Radio Telegraph and Telephone Receiving System

Radio Telegraph and Telephone Receiving System, employing a local generator at the receiving station. A pair of valves are connected in the receiving circuit and arranged to permit the generator to supply uni-directional current impulses to the oscillator antenna circuit. The circuit including said generator is adjusted to be resonant at substantially twice the frequency of the oscillatory antenna circuit.

1,507,725—J. Bethenod et al, filed August 19, 1921, issued September 9, 1924.

Doubly Tuned Radio Receiver, including one circuit tuned to a frequency greater than the signal frequency, and a second circuit tuned to a frequency lower than the signal frequency. The circuits are so arranged that the current therein may be opposed to prevent the response of the system to sudden discharges, such as static, but to permit the system to operate on the receipt of signals.

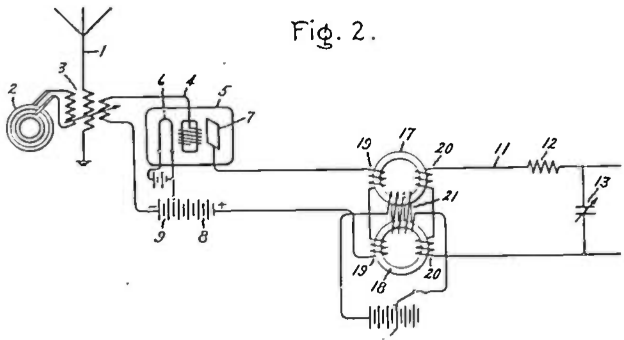
Fig. 2



NUMBER 1,507,725—Doubly Tuned Radio Receiver

1,508,151—E. F. W. Alexanderson, filed April 19, 1916, issued September 9, 1924. Assigned to General Electric Company, of New York.

Fig. 2.



NUMBER 1,508,151—Radio Signaling System

RADIO SIGNALING SYSTEM, for the reception of signals without disturbances from static effects. The patentee points out that in order to receive signals thru strays, a circuit must be provided to discriminate between these two sources of energy, by comparing the character of the energy over relatively long periods. A circuit is shown for prolonging the time during which the signal can act with accumulative effect on the receiving circuit considerably beyond the time during which disturbances can act. In order to prolong the time during which the signals and the disturbances may be compared, a tuned circuit of lower than radio frequency, but above audibility, is provided. The desired lowered frequency is obtained by means of interference beats between the incoming signals and the local source to produce a current of radio frequency having amplitude pulsations of much lower frequency, but above audibility. This current is used to produce an alternating current having a frequency corresponding to the frequency of the amplitude pulsations. A resonant circuit is provided for accumulating the energy of this alternating current and a detector is operated by the energy thus accumulated.

1,508,356—W. C. White, filed February 18, 1920, issued September 9, 1924. Assigned to General Electric Company, of New York.

ELECTRON DISCHARGE DEVICE, in which the elements are arranged within an evacuated vessel in such manner that the controlling electrode is located about the cathode and within electron receiving relation therewith. The anode is enclosed by the cathode. The anode may consist of a rod extension within the cathode while the control electrode may comprise a small cup enclosing the other electrodes.

1,508, 615—E. C. Rowley, filed December 27, 1922, issued September 16, 1924.

CRYSTAL DETECTOR FOR RADIO APPARATUS, in which a multipoint contact element is provided, consisting of a conducting disk, a clamping disk and securing means for locking the disks together, in order to hold a plurality of cat whiskers between the disks. The plurality of cat whiskers are placed in contact with the surface of a sensitive crystal element.

1,508,893—F. G. Mitchell, filed June 24, 1922, issued September 16, 1924.

CRYSTAL DETECTOR FOR RADIO RECEPTION, in which a pair of plates supported by a base is arranged with serrated edges between which a sensitive crystal is gripped, thereby providing a rectifying system.

1,509,139—D. Grimes, filed April 21, 1922, issued September 23, 1924. Assigned to American Telephone and Telegraph Company, New York.

RADIO RECEIVING APPARATUS, in which the filaments of the electron tube amplifier are heated from an alternating current of relatively low frequency. A coupling is provided between the filament circuit of the tubes and the source of alternating current, including a condenser offering small impedance to radio frequencies and large impedance to other frequencies and a shunt associated with the coupling and arranged to be anti-resonant to radio frequency, but resonant to lower frequency.

1,510,341 J. A. Proctor, filed June 1, 1921, issued September 30, 1924. Assignor to Wireless Specialty Apparatus Company, Boston.

ELECTRICAL APPARATUS, forming a quick break-in system, for placing receiving apparatus at a radio station in condition of operation intermediate the transmitting periods. The apparatus consists of a switch, the contacts of which are operated within a vacuum. The contacts are positively opened during the transmitting intervals disconnecting the receiver from the antenna.

1,510,624 A. J. Kloneck, filed March 31, 1920, issued October 7, 1924.

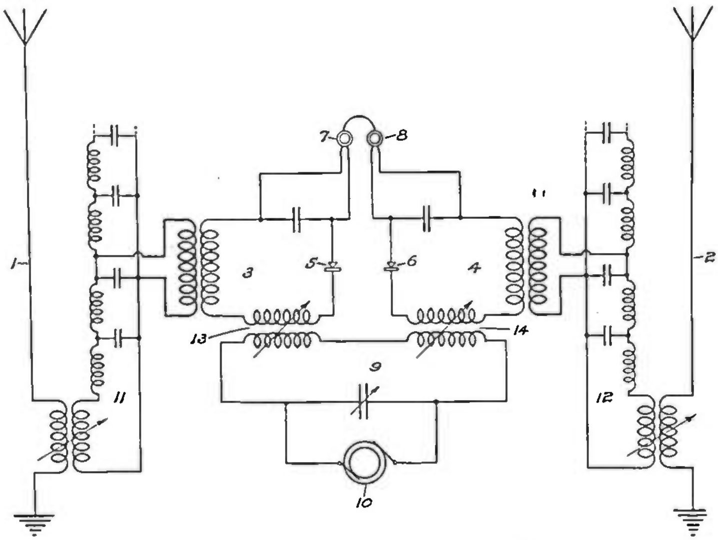
ELECTRICAL POWER TRANSMISSION BY RADIATION, for the purposes of driving machinery at distant points from one or more central power stations. The patent describes a system for transmitting and receiving light and motor power, comprising a plurality of independently operating generating dynamos arranged at remote points from one another and adapted for cooperatively radiating electrical energy of one character and of a frequency below 200 cycles. Independent radiating circuits are provided for the separate dynamos and each of the radiating circuits are tuned to a corresponding frequency.

1,510,741 E. G. Danielson, filed October 30, 1919, issued October 7, 1924. Assigned to Gray and Danielson Manufacturing Company, San Francisco.

ROTARY SPARK GAP APPARATUS for a radio transmitter, wherein the rotor is driven by a rotatable shaft passing thru a rotary electrode drum. The stationary supporting drum is provided with insulators projecting therein, which support stationary electrodes with pairs thereof, interconnected by arc-shaped members upon which the stationary electrodes may be relatively adjusted with respect to the rotary electrodes.

1,510,792 E. Merritt, filed July 1, 1921, issued October 7, 1924.

METHOD OF AND MEANS FOR DETERMINING PHASE DIFFERENCE, whereby the direction of the waves may be determined. The fundamental principle involved is the determination of phase difference between trains of waves or vibrations, by means of the phase difference between the beats that are produced when such wave trains or vibrations are combined, in the process of heterodyning, with another wave train or vibration of a different frequency.



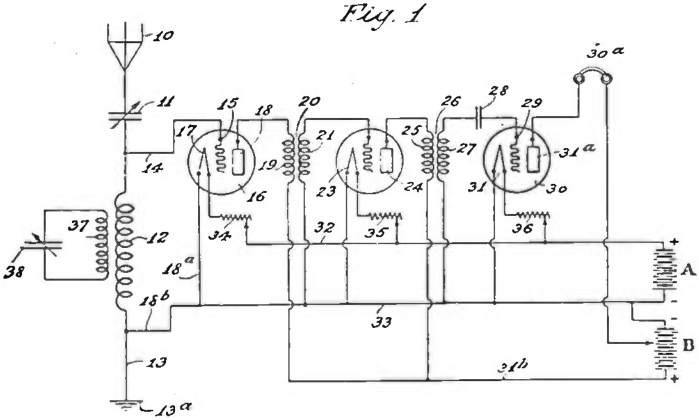
NUMBER 1,510,792—Method of and Means for Determining Phase Difference

1,510,799—J. H. Rogers, filed July 12, 1923, issued October 7, 1924.

LOOP AERIAL, in which all of the turns of the loop lie substantially in the surface of a polygonal tore. The loop is constructed on a frame having arms at each end, on which a circular disk-like member is provided. The circular members are apertured to receive the turns of the loop in such position that all of the turns are disposed symmetrically with respect to the others.

1,510,945—E. B. Lewis, filed August 8, 1922, issued October 7, 1924.

Fig. 1



NUMBER 1,510,945—Radio Receiving System

Radio Receiving System, in which undesired locally generated "feed back" currents occurring in the electron tube circuits are suppressed and thus prevented from building up to an injurious degree. An absorbing device for the undesired oscillations fed back into the grid circuit from the associated tube circuits is provided. The device comprises an inductance coil in the grid circuit, including an outer stationary ring in series therewith. The stationary outer ring has an inner-closed ring mounted on an axis in the plane of the outer ring and adapted to be rotated on its axis, whereby the energy of said oscillations will be selectively absorbed by induction and dissipated as heat.

Re. 15,924—E. A. Sperry, filed March 12, 1920, issued October 7, 1924. Assignor to Sperry Gyroscope Company, Brooklyn, New York.

Radio Repeater System for automatically transmitting the readings of an indicating member by radio to a distant point. The invention is described as applied in automatically transmitting by radio to an aircraft or other distant point the readings of a compass, fire control instrument, or other indicator on board a ship, whereby the ship's heading or the bearing of a target observed from the ship may be constantly communicated to such distant point. Such a system has especial uses in the aerial ordnance control for heavy guns where the target is only visible from airplanes, which signal to the ships or other firing station the bearings of the target. The ship's compass is used to control the radio transmitter and at the receiver an indicator is actuated to reproduce the compass reading.

1,511,935—E. A. Bayles, et al, filed July 20, 1921, issued October 14, 1924.

Electrical Condenser, in which a liquid impregnating dielectric is used and the condenser units are formed of laminae of paper and metal. The dielectric is wound around a layer of corrugated material which spaces the condenser sections apart. By reason of the separation of the condenser units by the corrugated material a high degree of insulation against breakdown is obtained.

1,512,398—R. C. Browne, filed October 14, 1922, issued October 21, 1924.

Air Condenser, having a plurality of movable vanes and a locking member associated with one of the vanes adapted to co-operate with a desired number of the other movable vanes to control their operation in unison. The condenser may be varied over small ranges of capacity by moving one of the vanes independently of the others and then moving all of the vanes or a portion thereof simultaneously.

1,512,824—H. M. De Bellescize, filed August 29, 1921, issued October 21, 1924.

RADIO TELEGRAPH AND TELEPHONE RECEIVER, which is substantially protected against static and strays by a differential circuit, including two opposing resonators. The incoming signaling energy is impressed upon a detector and then upon a pair of circuits, tuned to slightly different tone frequencies. The circuits are connected in opposition and deliver energy to a telephone receiver circuit, connected with both of the opposition circuits in such manner that persistent signals may actuate the responsive device while strays may be canceled.

1,512,960—J. Weinberger, filed October 11, 1921, issued October 28, 1924.

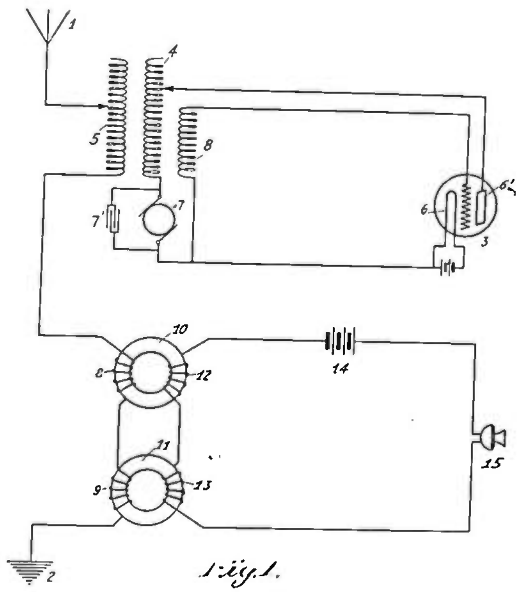
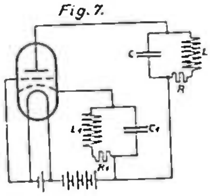


Fig. 1.

NUMBER 1,512,960—Radio Signaling System

RADIO SIGNALING SYSTEM, employing a modulation circuit for controlling the amplitude of radio-frequency signaling energy by means of an arrangement in which the variation of an audio-frequency magnetization circuit having an iron core, co-operates with a radio-frequency winding on the core to greatly vary the effective resistance of the latter. The change in the resistance of the radio frequency winding is due to the change of the iron losses of the core when the direct current magnetization is varied.

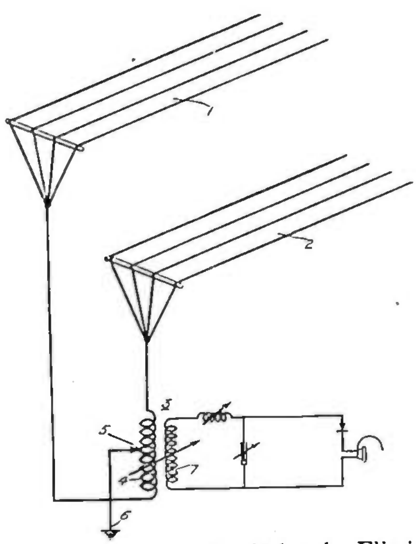
1,513,010—H. Rukop, filed May 3, 1922, issued October 28, 1924.



Number 1,513,010—Arrangement for Producing Electrical Oscillations

Arrangement for Producing Electrical Oscillations, wherein an electron tube, provided with a special positive electrode is employed, connected in an oscillatory circuit. The tube contains a cathode, a space-charging positive electrode, a grid and an anode arranged in the order named. A circuit connects the space-charging electrode and the anode with the cathode. A grid circuit and an anode circuit is provided, the positive space-charging electrode operating to influence the negative characteristic of the tube to maintain the circuits in oscillation.

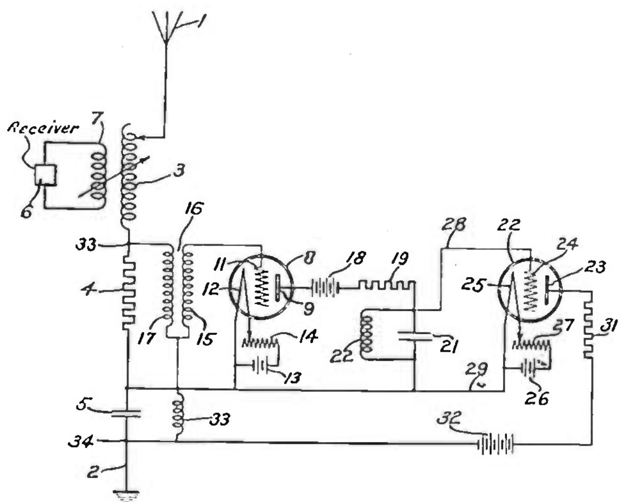
1,513,223—F. Conrad, filed October 17, 1918, issued October 28, 1924.



Number 1,513,223—Receiving Circuit for the Elimination of Static Disturbances

Receiving Circuit for the Elimination of Static Disturbances, employing two antennas associated with the receiving apparatus in such manner that substantially equal charges imparted thereto by static influences cancel each other within the receiving apparatus, thus being rendered imperceptible to the operator. The antennas are supported at different heights so that the signal impulses will be stronger in one antenna than in the other. The unequal amounts of energy imparted to the antenna by incoming signal impulses fail to cancel each other and thus a residual effect is imparted in the receiving apparatus which may be amplified if desirable, in order to render it more clearly perceptible to the operator.

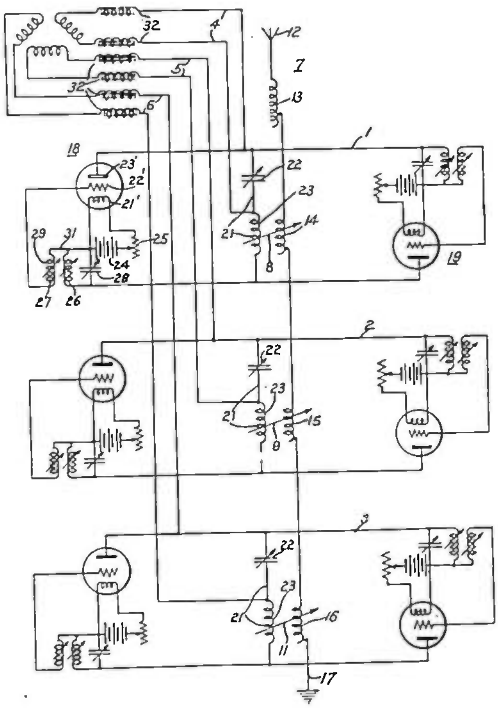
1,513,286—J. Slepian, filed November 16, 1921, issued October 28, 1924.



Number 1,513,286—Static Elimination System

Static Elimination System for radio receiving apparatus, wherein a resistor having such a value as effectively to damp the receiving system is connected in the antenna circuit. A non-resonant circuit is associated with the resistor, in such manner that the voltage drop therein may be substantially neutralized for current of predetermined frequency only whereby the system is screened against static.

1,513,324—S. M. Kintner, filed October 25, 1921, issued October 28, 1924. Assignor to Westinghouse Electric and Manufacturing Company.



NUMBER 1,513,324—Polyphase Plate Circuit Excitation System

POLYPHASE PLATE CIRCUIT EXCITATION SYSTEM for electron tubes connected to form an oscillation generator. A circuit arrangement is shown for the connection of a plurality of tubes, wherein the plates are energized from three phase alternating currents of commercial frequency. The invention describes a transmission system, wherein commercial three phase alternating current is placed directly upon the plates of the several tubes which supply oscillations to a common circuit associated with the radiation system.

1,513,326—W. C. Lamphier, filed February 9, 1923, issued October 28, 1924.

RADIO DETECTOR, consisting of two contact devices, one of which is a steel-wool sensitive contact member and the other graphite. The steel-wool is mounted in the usual detector cup and the graphite is adjusted in contact therewith to obtain the desired rectifying characteristic.

1,513,561—F. Schroter, filed October 5, 1920, issued October 28, 1924. Assignor to Gesellschaft für drahtlose Telegraphie m. b. H. Berlin, Germany.

Gas Relay, comprising an evacuated vessel containing an anode, a grid and a cathode, which consists of an alkaline metal together with an inert mixture of a gaseous medium in the tube.

1,513,707—J. H. Hammond, Jr., original filed August 5, 1919, issued October 28, 1924.

Fig. 1

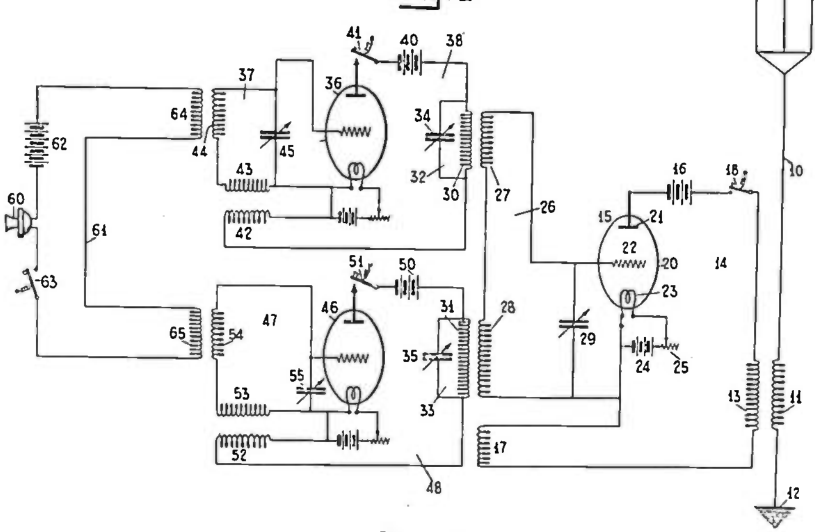
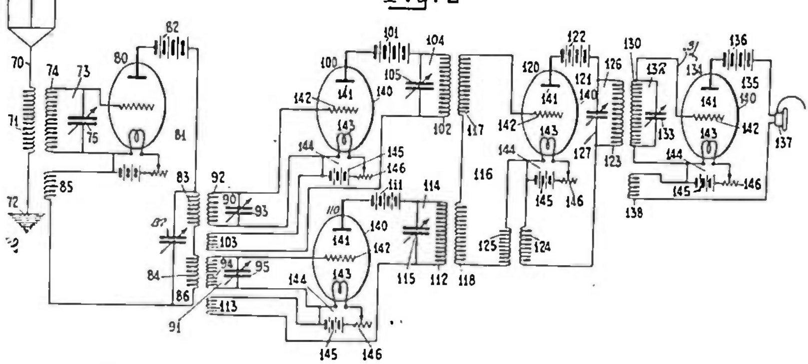


Fig. 2



Number 1,513,707—Transmission and Receiving System

Transmission and Receiving System for secret communication by radio, wherein the transmitted signals consist of a series of impulses having impressed thereon a plurality of series of periodic modifications of different frequencies which are received and combined at the receiving station to produce an intelligible signal.