THE DEVELOPMENT OF TUBE TRANSMITTERS BY THE TELEFUNKEN COMPANY*

By

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As a result of the development of thermionic amplifiers for transmitting and receiving purposes, radio engineering has been practically revolutionized during the years of the war. The basis of this development was the principle of reaction coupling, as it was given in its general form by the author in March, 1913, for receivers and transmitters.[1] The first researches carried out by the author were with the well-known Lieben tubes, which had oxide-covered cathodes and were filled with gas. It was possible, as early as June, 1913, to carry on two-way telephonic communication between Berlin and Nauen, a distance of 36 km. (22.5 miles). At that time, the transmitter was of small power (10 to 15 watts). The life of the tubes when loaded to this extent was short, since the gases in the tube were gradually used up or absorbed; nevertheless, for small powers and with plate voltages of 220, the transmitters of that time were very useful in practice and of great significance in connection with beat reception. At that time, the Fessenden beat reception method had only a theoretical value, since no practically useful and constant auxiliary oscillator was available. By using a heterodyne oscillator in combination with a detector in the receiving system, the author succeeded in producing a receiving arrangement which immediately displaced all other methods for the reception of continuous oscillations. This method of reception was first suggested by the author in March, 1913, was developed in common with Franklin and Round in the direc-

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[1] German patent 291,604 of April 10, 1913. The first claim of this patent covers "an electric relay provided with an incandescent cathode or ionized conducting path, which is connected to a circuit capable of oscillation, both on its input (primary) and output (secondary) sides, so that any oscillations originating in the circuit will be amplified by the relay and thereafter sustained by it."

tion of placing the tube with its reaction coupling in the receiving circuit itself, and thus permitting it to function simultaneously as a radio-frequency amplifier, as a device for the reduction of damping, as an oscillator, and also as a detector.[2]

Furthermore, the external oscillator made possible for the first time high power trans-Atlantic service between Nauen and America. At the beginning of October, 1913, the first heterodyne oscillator arrived in America. It was then used by Messrs. Pichon and van der Woude to receive signals originating from the alternator transmitter at Nauen. It was possible to receive the new high power alternators (8,000 cycles, 100 kw., with two steps of frequency doubling) on October 18, 1913, and thereafter to maintain the service. Figure 1 shows the apparatus used in Sayville for this purpose. The excellent results obtained by this new method of the producing oscillations aroused

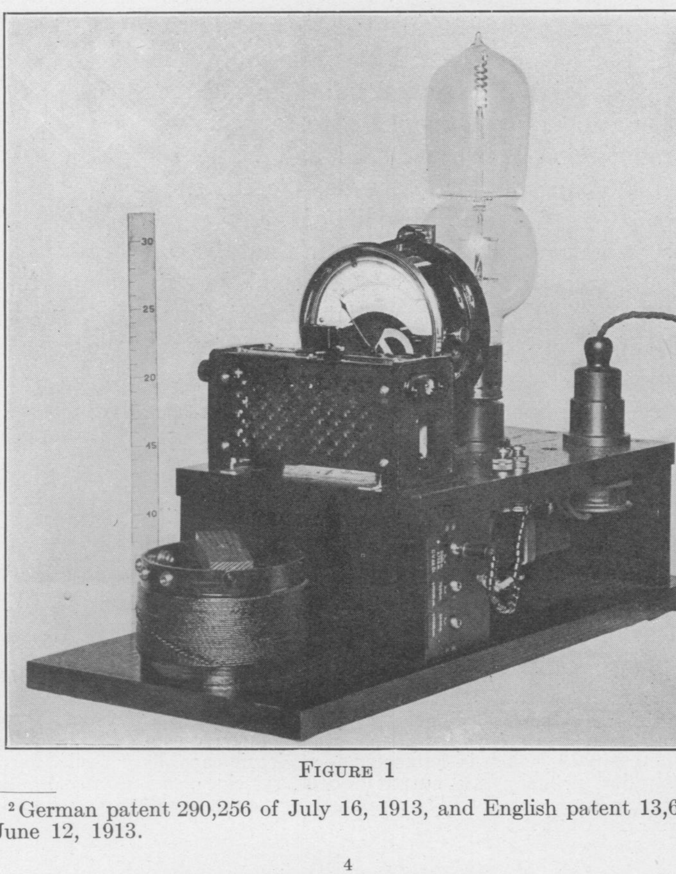

FIGURE 1

[2] German patent 290,256 of July 16, 1913, and English patent 13,636-13 of June 12, 1913.

great interest in professional circles, and led to the result that the same vigorous investigation of this subject was carried out in America as in Germany and England.

It was attempted to increase the short operating life of the Lieben tubes by using self-renewing oxide-covered cathodes, various sorts of gas content for the tubes, and automatic valves for admitting air to the device. However, the limitations of output remained. Since the middle of 1913, the Telefunken Company has also investigated high vacuum tubes as well as gas-filled tubes, and, by the beginning of 1914, had completely gone over to the use of high vacuum tubes for reception. The establishment of its own vacuum pump installation and tube factory by the Telefunken Company, under the direction of Dr. Rukop, led to the work proceeding more rapidly, and since March, 1914, it was possible to carry on vigorously the production of high vacuum transmitting tubes as well. Figure 2 shows the first high vacuum tubes for transmission, dating from the beginning of 1915. They were built with open construction. The right-

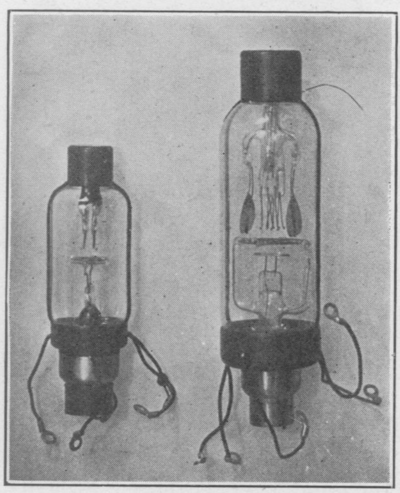

FIGURE 2

hand tube is seen to be provided with metal plates on each side of the filament in order to prevent electron streams which are produced by the magnetic field of the filament from reaching the glass walls. Figure 3 illustrates the first high vacuum tube transmitter (beginning of 1915).[3] This set was built for teleg-

[3] "London Electrician," 1914, page 702.

raphy and telephony on a single wave, and receiver and transmitter were in the same case. The circuit is shown in Figure 4. The intermediate circuit is provided by the coils L_1 and L_2 and the variable capacity C. The grid is connected across a portion of the coil L_1. The plate voltage is obtained from the coil

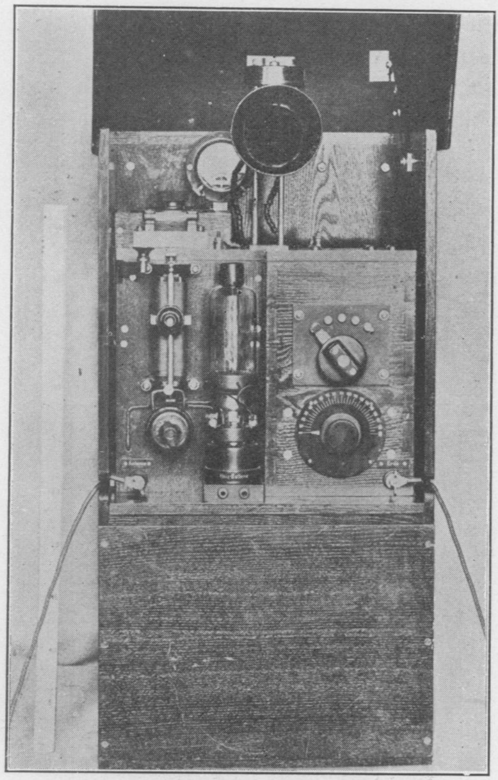

FIGURE 3

L_2. C_2 is a blocking condenser. The antenna is loosely coupled to the system thru a few turns of L_1. The plate voltage of 1,000 volts was provided by dry cells which were placed in the lower case of the transmitter. The filaments were lead by six-volt storage battery. The output of the transmitter was from 10 to 15 watts. Electrically considered, this is practically the same arrangement as the transmitter used experimentally by the Allies at the end of 1917 on the West Front.

In view of the great demands on the Telefunken Company's factories in connection with the production of receiving amplifiers, at that time, the further development of the tube transmitter was limited for a time. Because of this situation, it be-

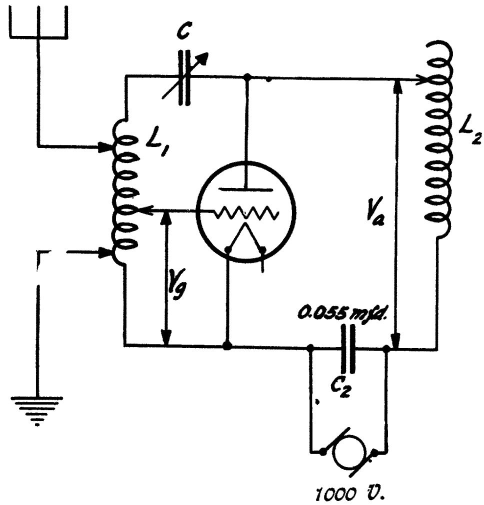

FIGURE 4

came necessary to develop high vacuum technique from the very beginning, and a whole series of physical and mechanical problems had to be solved. The work of Langmuir became known in Germany in 1915. A particular difficulty was experienced in the construction of the grid, and in securing it firmly in place. After attempts, lasting for months, to wind the grid on frames of hard glass, a satisfactory solution was found in the use of a construction due to the author wherein the grid was wound upon its own metal frames. This was so simple a matter that fine wire and narrow mesh grids, such as are necessary for tubes of high efficiency, were readily produced. Several forms of modern tube construction are shown in Figure 5. The plates are almost always made of tantalum sheet, the grids of tungsten. The usual sizes of tube deliver outputs in the antenna of 10, 75, 200, 500, 1,000, and 2,000 watts respectively. For higher powers, tubes are placed in parallel, as many as 20 being used in this fashion. Disturbing short waves, of approximately 100 meters wave length, appear quite regularly under such conditions, but are eliminated thru the use of small capacities, inductances, or resistances between the grid and filament or in the plate leads.

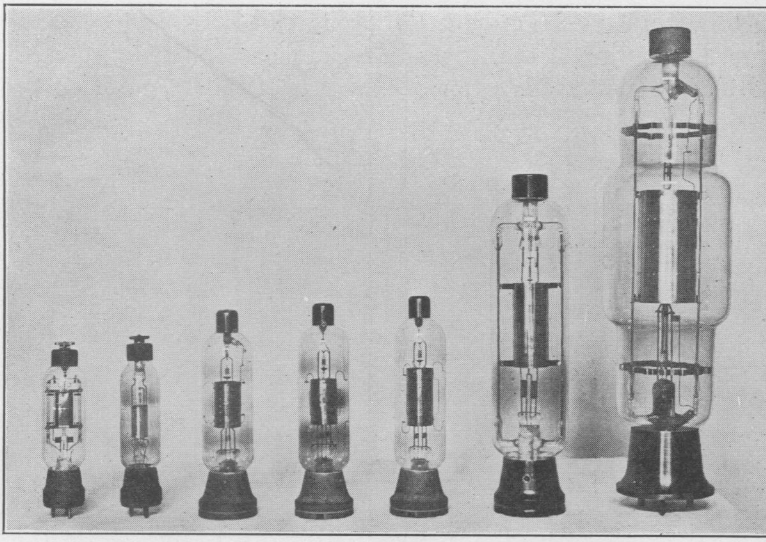

FIGURE 5

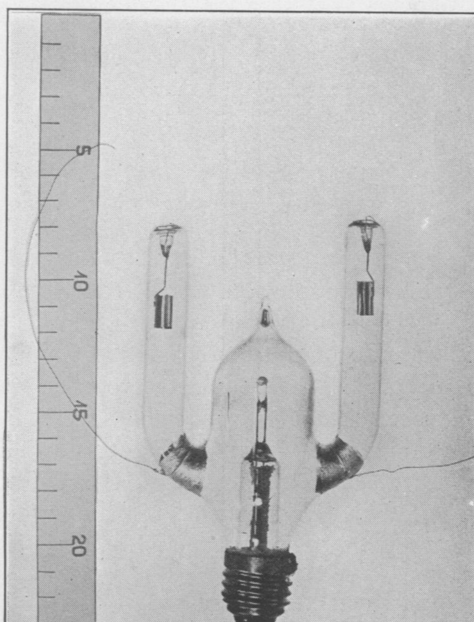

FIGURE 6

As sources of power for the plate circuit the following are available:

—for voltages up to 500, small direct current converters (dynamotors) with a single armature, operated from a 12-volt storage battery.
—from 1,000 to 2,000 volts, direct current generators.
—up to 3,000 volts, 50-cycle or 500-cycle alternating current, converted into direct current by an oxide cathode argon-filled rectifier produced by the Haagener Storage Battery Manufacturing Company.
—for voltages above 3,000, kenotrons or mercury arc rectifiers

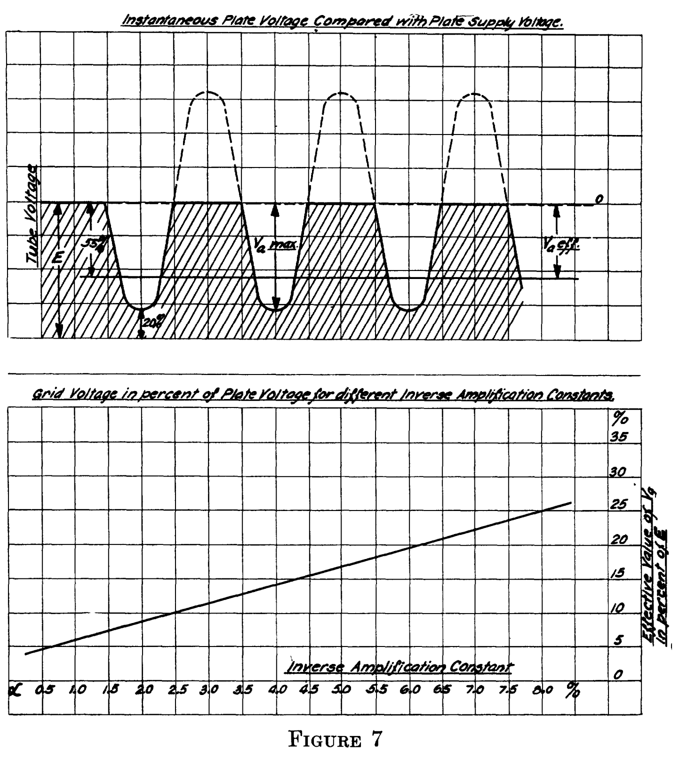

FIGURE 7

The bases of the design of transmitters are always the simple relations which exist between the radio frequency voltages impressed on the plate and grid and the direct current supply voltage The effective alternating plate voltage is 45 to 60 percent of the direct current supply voltage (as shown in Figure 7, part 1), the grid voltage from 4 to 20 percent. Figure 7, part 2, shows the relation between the grid voltage and the inverse amplification constant.[4] If the output of any particular tube is known (for

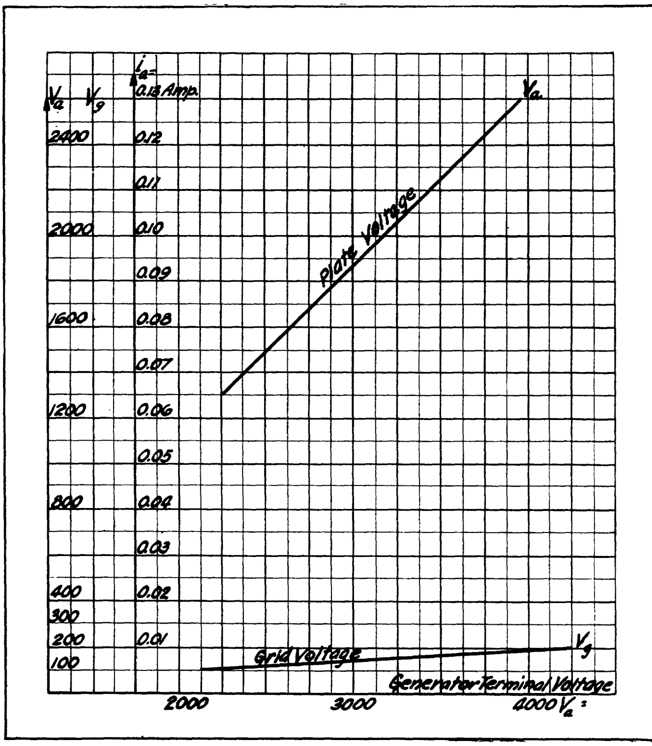

FIGURE 8

example, Figures 8 and 9 show the working curves of a 500-watt tube), and also the resistance of the oscillation circuit, then there can immediately be obtained for a transmitter with any chosen supply voltage and wave length, the values of the inductance or capacity which must be connected to the grid and plate. The condition which must be satisfied is that the above plate and grid voltages using inductive coupling must be equal to

$$2 \pi n L I$$

or using capacitive coupling

$$\frac{1}{2 \pi n C} I$$

[4] (The term "Durchgriff" has been translated as "inverse amplification constant" since it is the reciprocal of the amplification constant, as defined by van der Bijl (PROCEEDINGS OF THE INSTITUTE OF RADIO ENGINEERS, 1919, page 106) and Carson (PROCEEDINGS OF THE INSTITUTE OF RADIO ENGINEERS, 1919, page 188).—EDITOR.)

regardless of whether the grid and plate have voltage applied to them directly or thru an oscillating circuit. If high efficiency is required, it is desirable to couple the plate circuit more closely to the oscillation circuit and the grid circuit more loosely. In

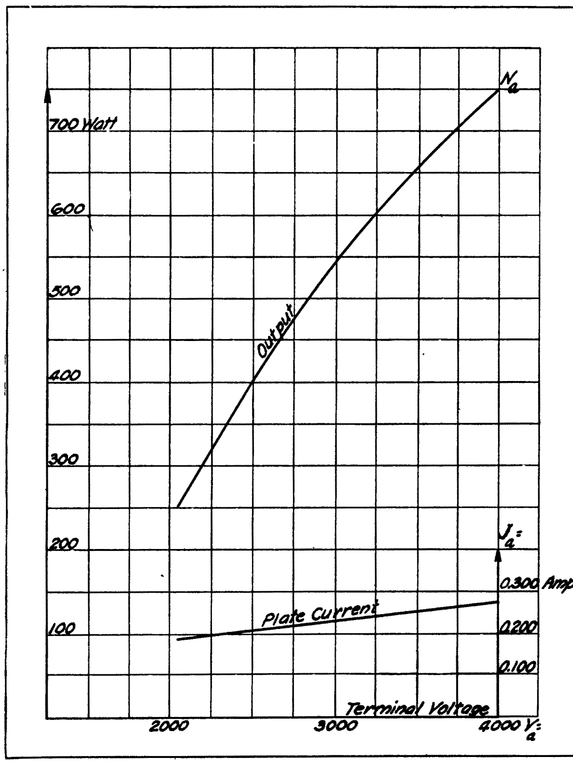

FIGURE 9

order to draw still greater output from the tube, there are produced in the plate circuits currents of special wave form (Rukop) or else an auxiliary voltage of triple frequency is impressed on the grid (Meissner). The losses are then greatly reduced, since during the operation of the tube the time during which the highest voltages are applied to the tube is reduced, and, furthermore, because at the time when the highest voltages are applied to the tube, the passage of current thru it is prevented. Under such conditions there will be produced powerful overtones or harmonic oscillations of higher frequency. When using transmitters directly coupled to the antenna circuit, such harmonic currents are avoided by the use of absorbing circuits or of an intermediate circuit, or by the control of a power tube amplifier by a small tube oscillator (German patent 298,484, Meissner).

Several forms of a modern transmitter will be described below. In the first transmitters, an inductance in the grid circuit was generally used either with or without grid circuit tuning, and more or less closely coupled to the plate circuit, either inductively or capacitively. In the latter transmitters, using more stable tubes, practically only direct coupling between the grid and plate circuits was employed. Figures 10 and 11 show a small type of transmitter, with an output of 20 watts, for use in the trenches. In order to meet the difficult military requirements for such a transmitter, it was designed for a continuous wave length range of from 300 meters up to almost 2,000 meters. The oscillating

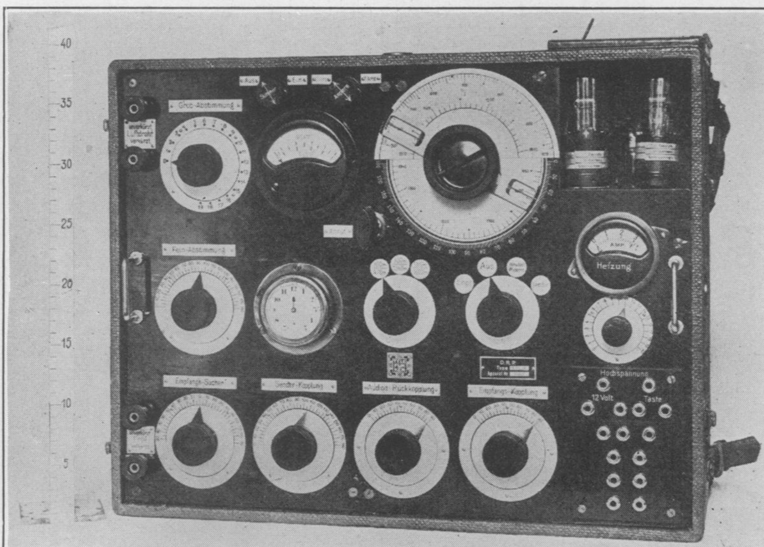

FIGURE 10

tube receiver is contained in the same case. The transmitter can be used with any desired antenna. These requirements could be met only thru providing the transmitter with an intermediate circuit.

An aircraft transmitter and receiver are illustrated in Figure 12 and shown with the cover removed in Figure 13. In this case as well, a long range of wave lengths from 300 to 750 meters is

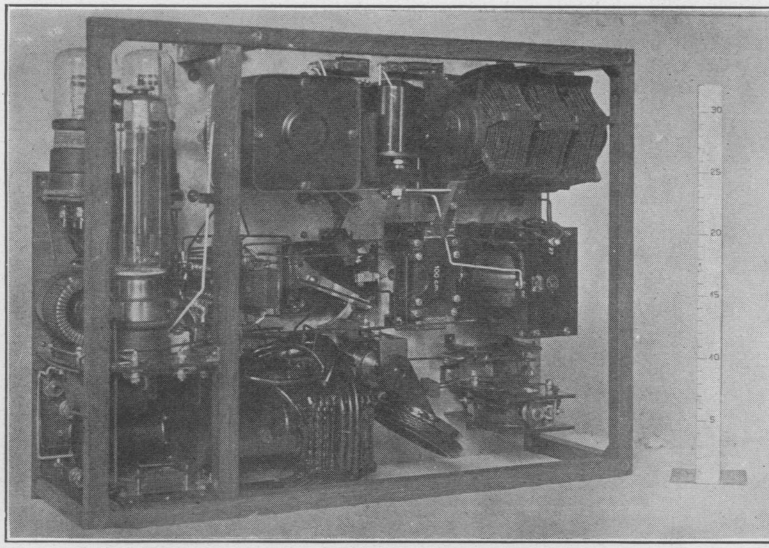

FIGURE 11

provided. The transmitter is set to a definite wave length while on the ground, and the antenna is tuned in flight. The operator then has no further opportunity to alter the circuits. For radio telephony, the microphone transmitter is generally inserted into the antenna.

A very simple 20-watt transmitter for use on two wave lengths is shown in Figure 14. It is arranged for two-way opera-

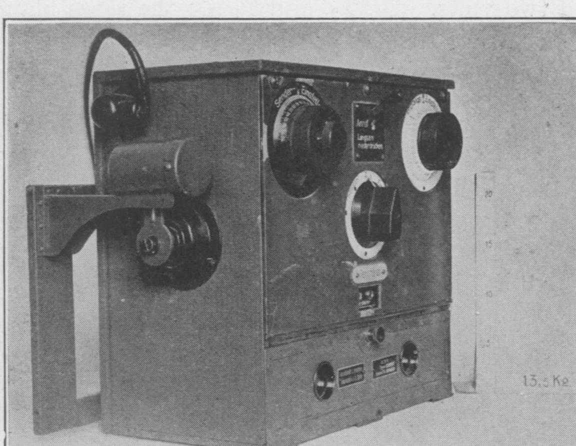

FIGURE 12

tion. The right hand case contains the tuning circuits necessary for this purpose, together with the tube detector and three-step amplifier. This set is intended for radio telephony between fishing boats. The speech voltages in this set are introduced into the grid circuit in series with the radio frequency voltages.

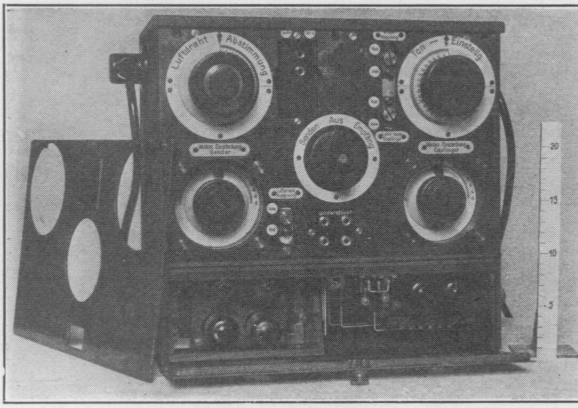

FIGURE 13

Figure 15 shows the schematic circuit of a one-kilowatt tube transmitter. Both filament and plate voltages are obtained from the same 500-cycle alternator of 1.5 kw. output. The transmitter is provided with two 500-watt tubes, requiring four amperes and six volts for the filaments; while the alternating current is rectified by an oxide cathode rectifier using five amperes and two volts. T_1, T_2, and T_3 are the three filament cur-

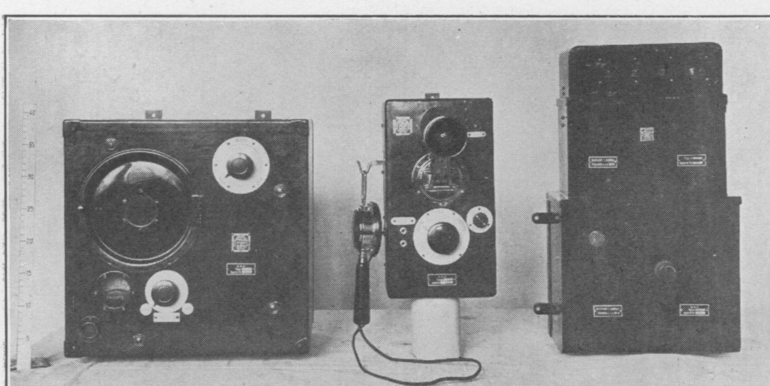

FIGURE 14

rent transformers. To avoid changes in filament current while operating, due either to variations in the speed of rotation of the alternator, or due to fluctuations of the load in the plate circuit when transmitting, a compensation transformer, T_v, is provided.

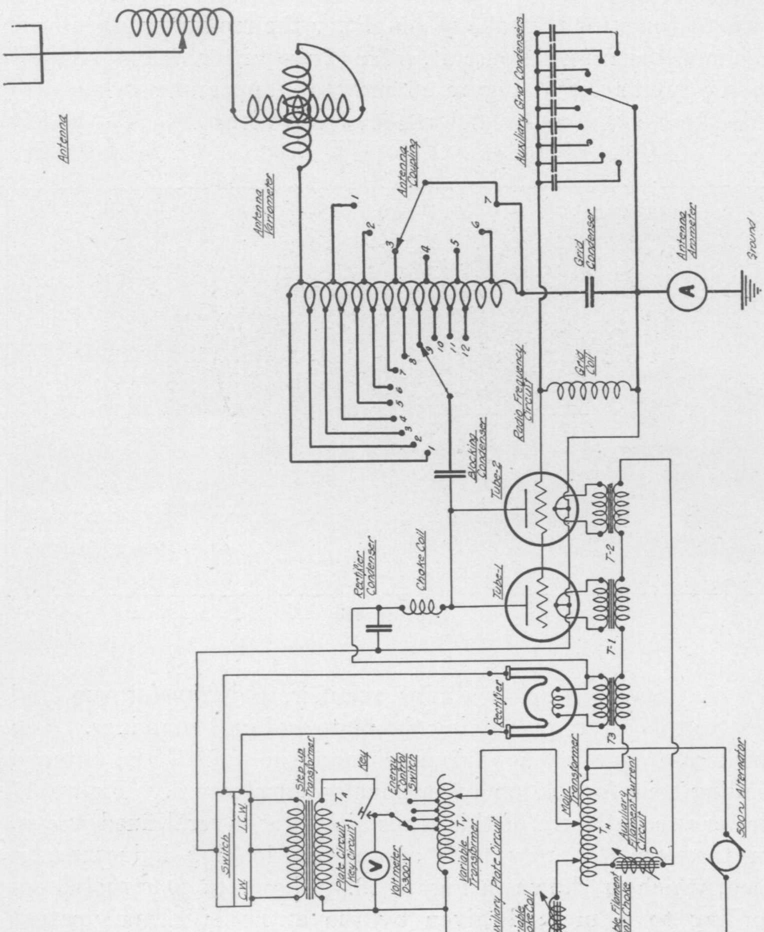

FIGURE 15

This is an open core auto-transformer, with several taps for different outputs, which is connected to the high-voltage plate current transformer T_a. The compensation for load is accomplished by T_h. When the key is depressed, the main current induces an extra voltage in T_h which, with correct adjustment of the choke coil D, compensates for the effect of the drop in voltage of the machine, resulting from the increase in load when the key circuit is closed. Thus the filament current remains unchanged. Energy passes from the high-voltage side of the transformer T_a to the rectifier and the tubes thru a switch arranged for transmission either with or without a musical tone. For transmission without tone, for the sake of simplicity the rectifier condenser is disconnected from the circuit. This transmitter was much used on the submarines. Figure 16 shows its appearance when provided to cover a continuous range of wave lengths. To the left

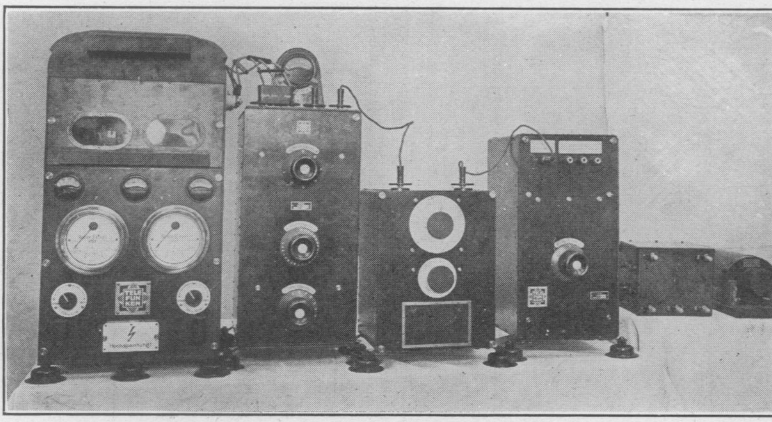

FIGURE 16

is a container holding the bulbs, rectifier, and transformers, and next to this a case containing the plate and grid couplings. The third case contains a variometer and the fourth the antenna loading coils for use on exceptionally long waves. Figure 17 shows a recent form of this transmitter for several fixed waves. In these sets, a new type of antenna loading inductance is used, which is shown in Figure 18. These are constructed according to a method given by the author (German patent 309,203), involving the use of multi-layer coils so arranged that between all cross sections there is the same separation of several millimeters. This design leads to the smallest possible damping where large inductances are required of fairly small volume. One-kilowatt transmitters are now used in several of the larger German cities in connection with the postal service network and especially for press service. When these transmitters are used for radio telephony, a tube is inserted

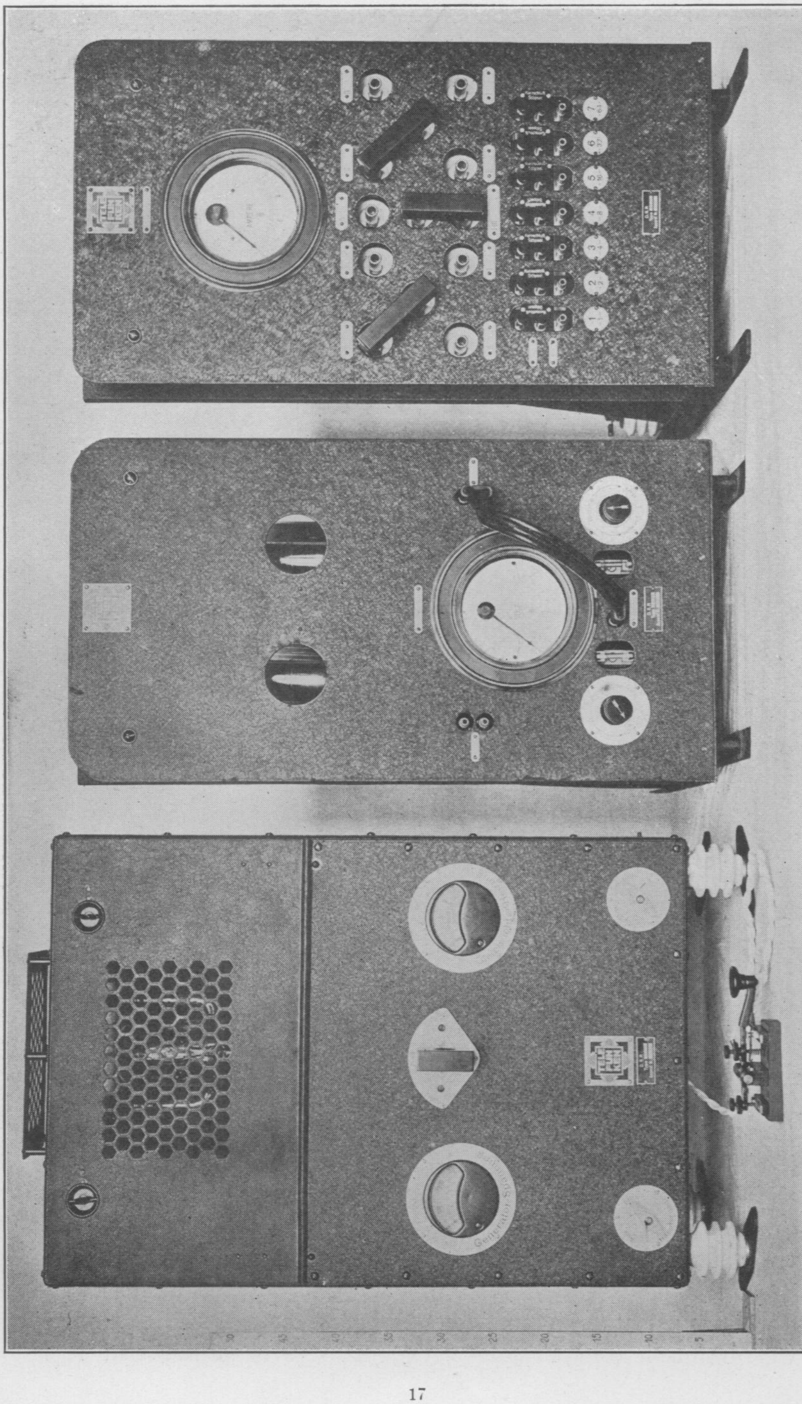

FIGURE 17

into the plate lead so that the entire plate current passes thru it. By impressing the amplified speech voltages on the grid of this control tube, the plate current of the main tube is suitably varied.

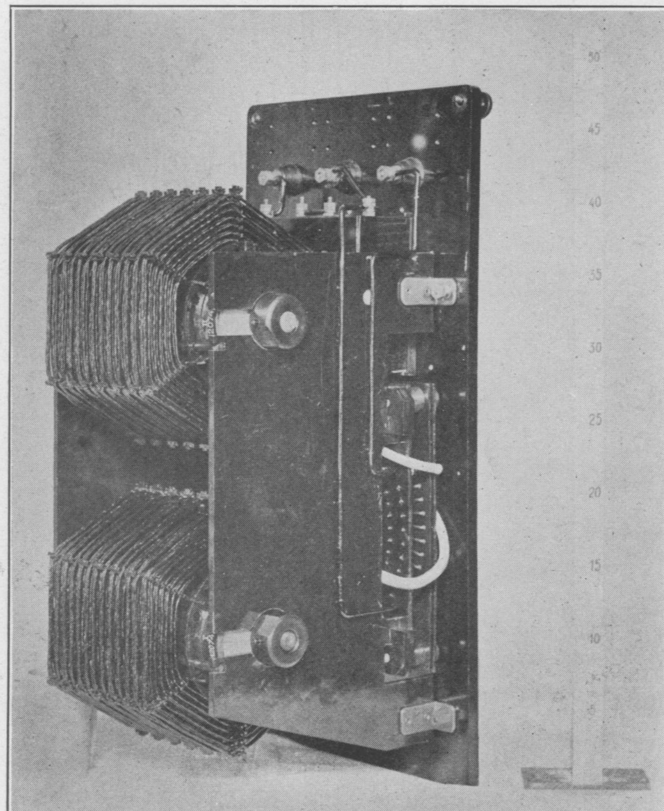

FIGURE 18

A tube transmitter using 20 bulbs in parallel is shown in Figure 19; and another transmitter with 8 tubes, each delivering 1.5 kw. and placed in parallel, is illustrated in Figure 20. In these larger tube transmitters, both telegraphy and telephony are carried out by the master control system; that is, a small tube transmitter of approximately 1 kw. output is used to impress the necessary voltages on the grids of the larger tubes. Such transmitters have been used for some time in Königswusterhausen and Prague with entire satisfaction, and it is expected shortly to carry on the transmission of press material for all of Germany by means of such a set.

The apparatus developed for radio telephony has found a large field of usefulness for multiplex telephony along conductors ("guided radio"). Even during the war experiments were carried

FIGURE 19

out by the Telefunken Company in telephony along wires by using radio frequency currents, and also, in cases of need, for telephoning over broken conductors. While the researches carried on at that time did not lead to finished apparatus, they furnished the basis for the later development of this process and for its use on a larger scale immediately after the end of the war for the improvement of the German Post Office telephone network. At the present time, a considerable number of channels of communication using radio frequency multiplex telegraphy are in existence in Germany for distances up to more than 600 km. (375 miles). Some of these have been in use with excellent results for over a year. In general, two radio frequency communications are carried on over each wire. The wave length range employed is between 5,000 and 20,000 meters. Speech modulation is obtained thru direct control of the plate voltage or thru separately excited generator tubes. In order to operate with the least possible intermediate amplification and the simplest circuits, fairly considerable power is employed (from four to eight watts), resulting in currents in the conductor of 0.1 ampere. The protection of the receiver from the transmitter is accomplished thru a suitable choice of the radio frequency resistance of the circuits or thru Wheatstone bridge circuits. Figure 21 gives a view of the radio frequency room of the Berlin central or ex-

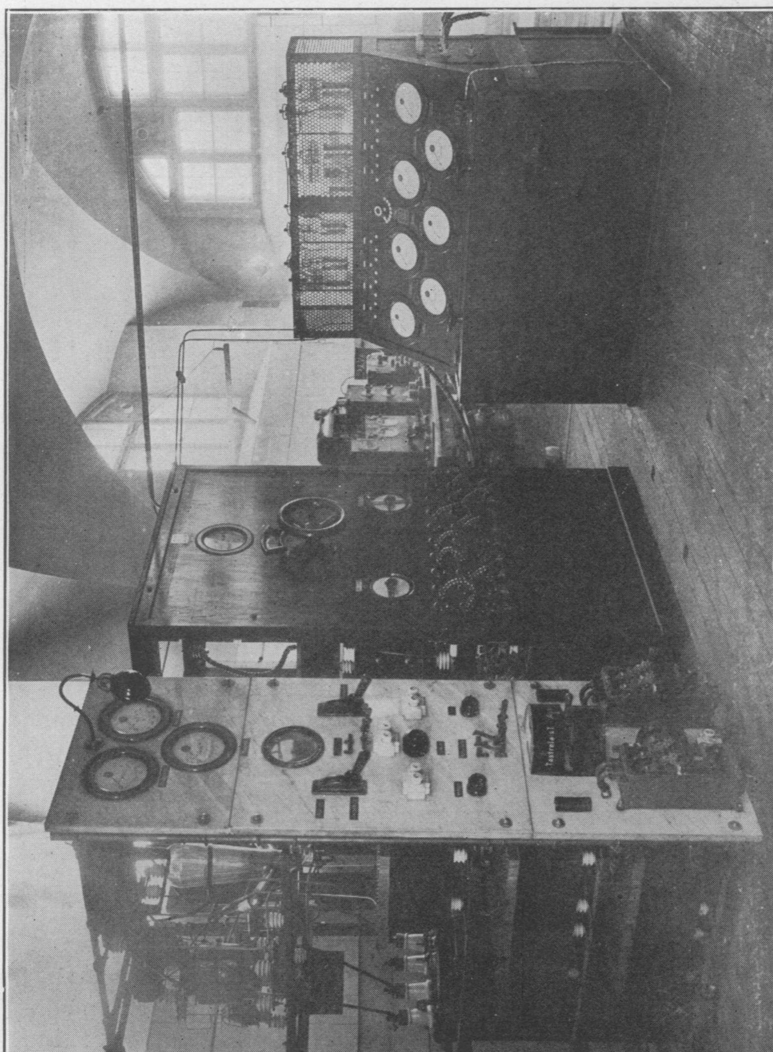

FIGURE 20

change. To the right can be seen the transmitters, and to the left the receivers, while in the middle are shown the circuits necessary for connecting the receivers and transmitters properly to the nearby central equipment. Figure 22 shows a small set for multiplex telephony. Multiplex high speed telegraphy

FIGURE 21

on a single wire (quadruplex-duplex) has been established between Frankfort and Berlin, permitting perfect transmission of 4,000 words per minute. For this purpose there are generally used shorter waves than for telephony (below 8,000 meters). The Siemens high speed telegraph equipment (printing telegraph) working at 600 to 1,000 letters per minute, which is here used, is an ideal solution, and is also equally applicable to high speed radio service.

Figure 23 shows a transmitter for telephoning along high voltage lines, such as is now frequently used to connect the large power plants with their sub-stations. Such transmitters are provided with a simple modulation system with direct application of the speech voltages to the grid. In view of the low damping of high voltage lines and the short distances generally covered by such sets (usually less than 200 km. or 125 miles), these transmitters work at wave lengths below 2,000

FIGURE 22

meters. The apparatus is built in very rugged form, is provided with two 10-watt tubes, and is arranged to work thru the line even if the line switches are open. A call signal device is provided with this set. Transfer of the radio frequency energy to the line is thru either one or two wires stretched parallel to the high voltage line for a distance of about 100 meters (300 feet). Recently these sets have generally been connected to the line directly thru small capacities or else the leading-in insulators are arranged to serve as such transfer capacities.

SUMMARY: The development of gas-containing and high vacuum transmitting tubes in Germany is described. The main forms of tube transmitters are illustrated and their circuits given. The application of such transmitters to multiplex telephony or telegraphy along high voltage lines is described.

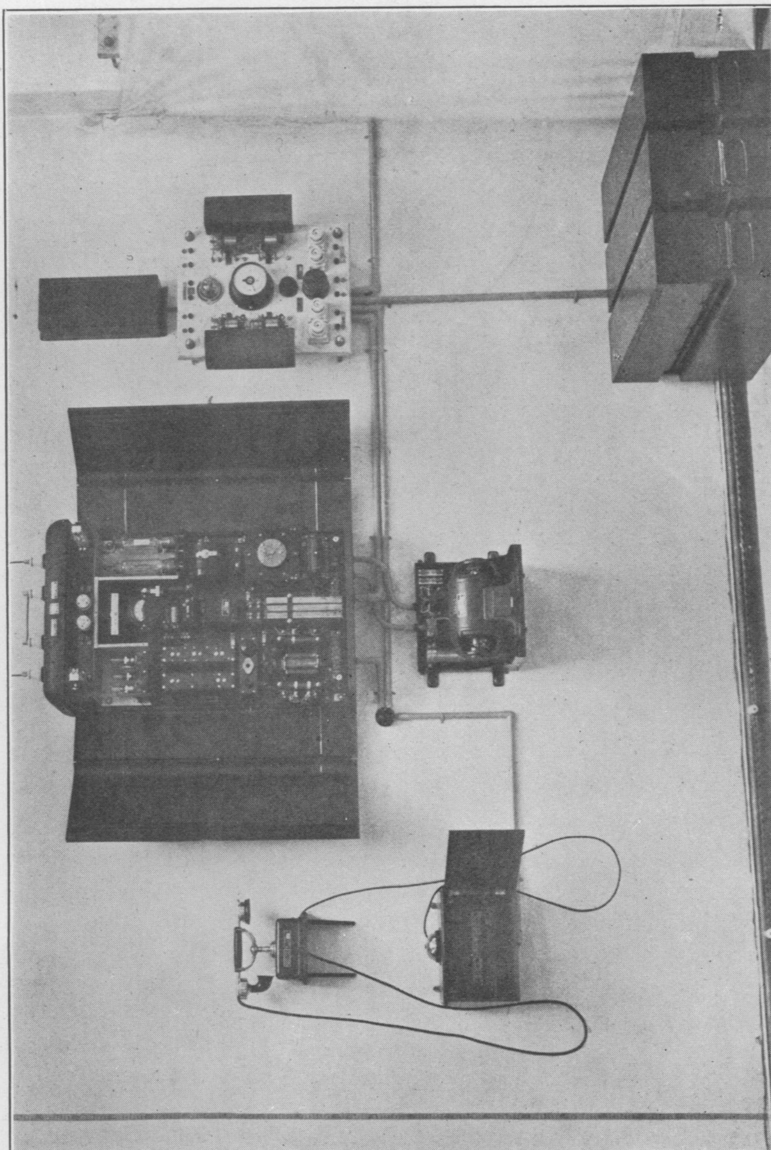

FIGURE 23