Proceedings of the Institute of Radio Engineers
Volume 23, Number 3 *March, 1936*

AN EXPERIMENTAL TELEVISION RECEIVER USING A CATHODE-RAY TUBE*

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Summary—*The circuits which have proved especially suitable for receiving television broadcasts from Berlin are described. The arrangements in the high-frequency portion, conditions during rectification, the production of synchronizing impulses of constant amplitude, and a relaxation oscillator circuit producing symmetrical voltages of large amplitude, are discussed. Photographs of television pictures prove the quality obtained.*

THIS paper describes the design of a 1934 receiver developed as a result of research on high-frequency aperiodic amplifiers begun in 1925, of research on the cathode-ray tube for television begun in 1929, of practical television research begun in the author's laboratories in 1930, and of the practical experience under field strength conditions, which the public later on will have to take into account. The latter experience was gained by experiments conducted some months ago with the television transmitter in Berlin.

The transmitter in Berlin uses the modulation method of O. Schriever[1] which differs basically in many ways from arrangements found in the publications relating to the receiver in the RCA system.[2] Attention is called especially to the method of cutting off the synchronizing impulses. Other characteristic differences in the solution of the technical problems are found in the utilization of the direct-current component of the television picture, made possible by the aforementioned modulation method.

CONNECTIONS AND CONSTANTS OF THE (INTERMEDIATE FREQUENCY) PICTURE RECEIVER

Fig. 1 represents the connections in the picture portion of the intermediate-frequency receiver. At an average signal strength of about one-half millivolt per meter the receiver supplied sufficient output when small half-wave, indoor antennas were used. Less favorable receiving conditions necessitated outdoor antennas which were connected

* Decimal classification: R583×R361. Original manuscript received by the Institute, November 30, 1934; revised manuscript received by the Institute, January 8, 1935; translation received by the Institute, March 7, 1935.

[1] O. Schriever, "The latest technical devices for television broadcasting," *Fernsehen und Tonfilm*, vol. 4, p. 35, (1933).

[2] R. S. Holmes, W. L. Carson, and W. A. Tolson, "An experimental television system," PROC. I.R.E., vol. 22, pp. 1266–1285; November, (1934).

to the receiver by a transmission line. Usual circuits are used in heterodyne mixer stages.

The scanning standards used in Berlin, namely twenty-five pictures per second, 180 lines, picture aspect ratio 5:6, necessitate the uniform transmission of a frequency band of about 0.450 megacycle in order to make the vertical detail equal to the horizontal detail. As is well known, the communication band is twice as wide as the modulating-frequency band, in our case 0.9 megacycle. This is needed for perfect reproduction.

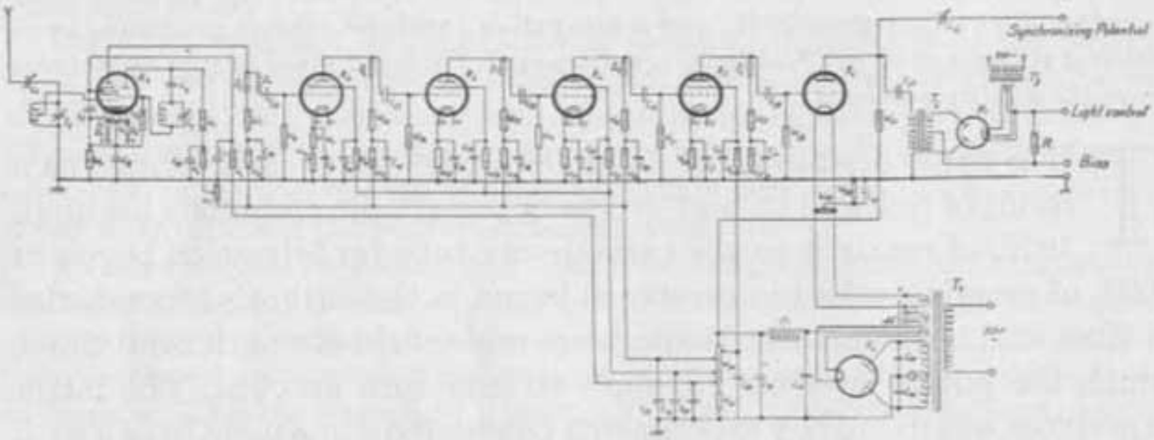

Fig. 1—Circuit of the superheterodyne television receiver (Type 1,934,135) for the 500,000-cycle frequency band of the Berlin transmitter.

With a carrier frequency of say 1.0 megacycle (using both side bands), an aperiodic amplifier having a frequency range of about 0.5 to 1.5 megacycles is required. Such amplifiers have been available for many years. The author has already reported design calculations, as well as numerous results of measurements on these.[3] Briefly, the stage constants which have been calculated for this frequency band, normal stray capacities, and the specified type of tube are:

Type of Tube:	Telefunken RENS 1284
Plate resistor	5500 ohms
Self-inductance in anode circuit	0.3 millihenry
Voltage amplification (within frequency range mentioned)	16–18

Due to the absence of feedback, screen-grid tubes offer considerable advantages, both because of the ease of calculation of amplification as well as their satisfactory operation. However, in the tube mentioned above input and output capacities are from two to three times greater than in other multielement tubes which have been used previously.

[3] von Ardenne, "Aperiodic amplification of broadcast waves," *Jour. High-Frequency Tech.*, vol. 33, no. 5, (1929).

The inductance inserted in series with the plate resistor resonates with the stage capacity, forming an oscillating circuit which is rendered almost aperiodic by the plate resistor, and whose natural frequency is around 1.5 megacycles. The comparatively great voltage amplification per stage could be realized only by the use of this inductance in the anode circuit, despite stage capacities as great as twenty to thirty micromicrofarads. The method of using inductance in aperiodic amplifiers had previously been introduced and applied.[4] It was possible to get the necessary voltage amplification of 10^5 with relatively few stages and a relatively low plate supply current.

The apparatus could be operated either with both side bands or, preferably, with one side band. Better results were obtained with one side band and, therefore, another frequency curve was chosen, the form of which was arrived at by a design of the coupling unit whose constants differed somewhat from those given above, and by special selection and damping of the transformer supplying the intermediate-frequency rectifier. The amplification characteristic, increasing from the low-frequency end, reaches its maximum at 0.5 megacycle. Up to about 0.9 megacycle the curve falls off only slightly. The drop is more rapid above 0.9 megacycle, and is followed by a very steep drop at 1.4 megacycles. The carrier frequency is adjusted so that half of the total amount of amplification lies in the range between 0.5 and 0.9 megacycle. In the lower modulation-frequency range where both side bands are demodulated, twice the amplitude is available. This over-accentuation of the low frequencies is equalized because the amplifier has only half the amplification over this range. The result is a smooth frequency characteristic which rises slightly at higher frequencies. The frequency-response curve corresponds closely to the curve of an amplifier with choke-resistance coupling. This feature explains the great efficiency and economy of this method. The only disadvantage perhaps may be that it is necessary to employ the correct heterodyne frequency. The proper operation of the heterodyne can be simplified by means of simple markings, by using stable oscillating circuits which are only slightly affected by temperature, or, by the use of simple indicators for the carrier frequency, similar to those used with wavemeters.

The difficulties[5] accompanying the use of only one side band can be eliminated to such an extent by means of the above frequency characteristic and by a suitable choice of carrier frequency, that it is not possible to detect, by observation of the picture, that single side-band

[4] von Ardenne, "On a new device measuring field strength," *Elek. Nach.-Tech.*, vol. 7, p. 438, (1930).

[5] F. Schroeter, "The present status of television broadcasting," *Telefunkenzeitung*, no. 66. p. 15, (1934).

transmission is being used. This arrangement, single side-band operation, permits the use of modulating frequencies of 0.7 to 0.8 megacycle. This diminishes the band width required for the reception of the Berlin transmissions.

Concerning the Arrangement of the Intermediate-Frequency Rectifier

The voltage appearing at the output of the last intermediate-frequency amplifier stage is fed to the detector and to an amplitude filter which will be discussed later (Fig. 2). The type of modulation used at the Berlin transmitter makes possible the utilization of the direct-current component of the picture signal for background control. The author has made a series of comparative tests from the Berlin

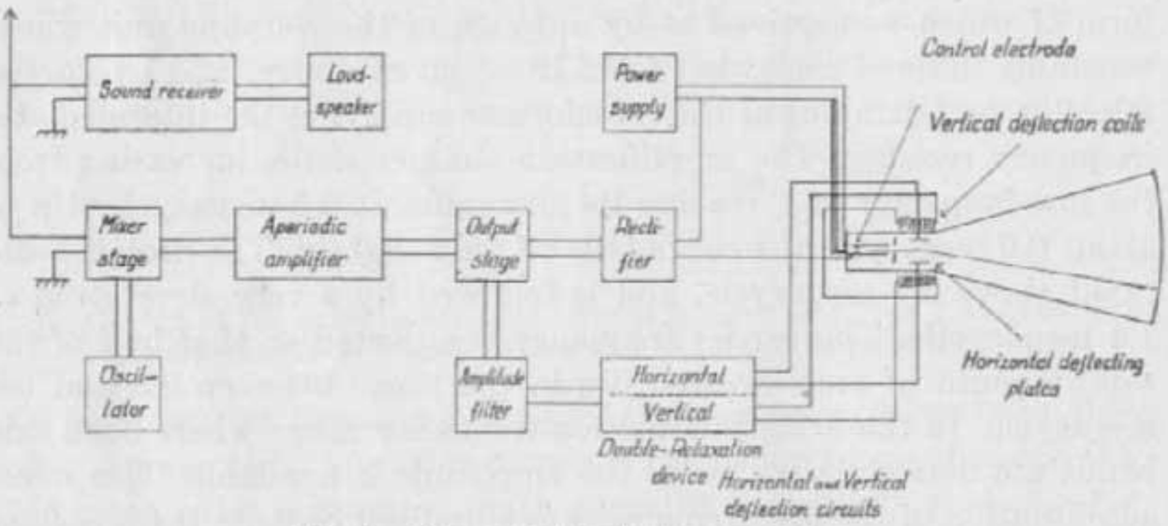

Fig. 2—Diagram of television receiver.

transmitter, in which picture reception could be carried on either with or without this direct-current component. These tests showed that, for a large percentage of pictures, the use of the direct-current component is a prerequisite for high-grade picture reproduction, particularly when reproducing pictures with dark shadows. In such tests the picture variations, when the direct-current component is omitted, are prohibitive.

The differences appear particularly great in the reception of film titles. Direct-current background control is accomplished most directly by coupling the second detector to the grid of the cathode-ray tube. The simplest way is to have rectification take place in the cathode-ray tube itself. Such rectification, however, has the disadvantage that the emission current of the cathode-ray tube is only utilized for a fraction of the time, so that comparatively dim pictures result. To prove this statement we refer to Fig. 3. In fact the operating conditions are even less satisfactory than shown in the illustration because, as required by the synchronizing level, the operating point is moved toward the more negative grid voltages. If the intermediate-frequency voltage supplied by the final stage is adapted to feed the cathode-ray tube, that is, if the peak value of the intermediate frequency reaches that grid voltage value corresponding to the greatest beam current with which sharp spot definition is obtained, then, despite this rectification in the cathode-ray tube, the greatest average picture brightness is only one third of that which is possible with other methods of operation.

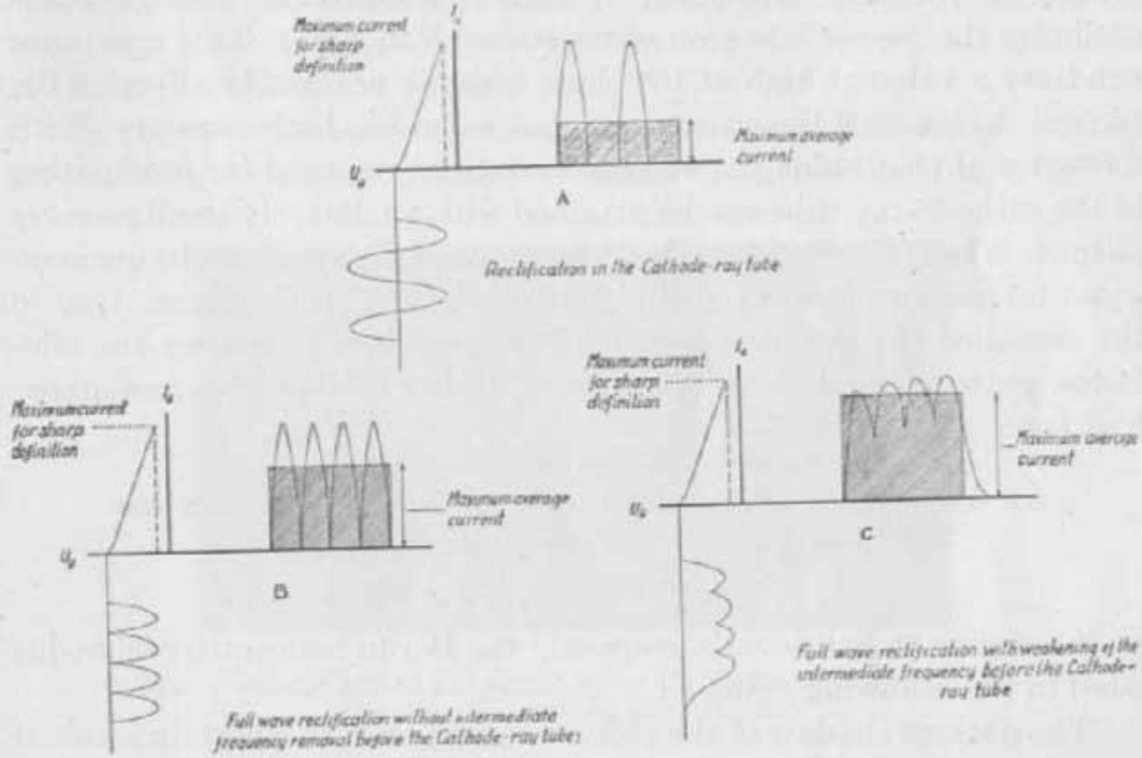

Fig. 3—Variation between intermediate frequency rectification and maximum beam current of the cathode-ray tube.

Since a reserve of brightness must be available, rectification within the cathode-ray tube is practically out of the question. More satisfactory results are obtained if a separate full-wave rectifier is placed ahead of the cathode-ray tube because then sixty to eighty per cent of the maximum emission current can be utilized. How much of the maximum beam current may be used depends upon the amount of parallel capacity which may be added across the rectifier output to remove the intermediate-frequency components from it. Experience has shown that it is not easy to get perfect results from a full-wave rectifier. At high frequencies large asymmetries are caused by small differences of stray capacities of transformer windings to ground. The alternating of brighter and darker pattern points indicates these asymmetries. Under very unsatisfactory conditions the asymmetry may become so great that one half of the wave remains unused. To avoid such difficulties it is necessary to increase the intermediate frequency greatly. At an intermediate frequency of six megacycles, it is possible to use satisfactorily a cathode-ray tube with half-wave rectification in the same way as with full-wave rectification, as shown in Fig. 3. The use of shunt capacity across the rectifier output to remove intermediate-frequency components from it tends to decrease picture detail by attenuating the higher modulation frequencies. This method then must be used with care; the trouble may be greatly diminished by the use of a high intermediate frequency. A correct compromise may be made easily by the proper selection of resistance R in Fig. 1. This resistance can have a value as high as 10^4 ohms without noticeably affecting the picture sharpness if the circuit and equipment has little capacity. With a resistor of that value the voltage variations required for modulation of the cathode-ray tube can be attained with a relatively small receiver output. When full-wave rectification was used intermediate frequencies up to 1.5 megacycles were still visible on the television screen. Due to the presence of a certain amount of intermediate frequency the television pattern acquires an appearance similar to that of a newspaper half tone.

An Amplitude Limiting Circuit of Special Design for the Separation of Extremely Constant Synchronizing Impulses

According to Schriever's proposal,[1] the Berlin transmitter is modulated in the following manner:

The darkest shadow of the picture corresponds to a certain residual antenna current, which at present is established at the transmitter at a value between twenty-five and thirty-five per cent. Picture modulation is accomplished by varying the antenna current between this value and the maximum value in accordance with the instantaneous illumination at the element of the picture being scanned. The synchronizing signals are transmitted on the other hand by cutting off the antenna current completely. This occurs at the completion of each line and at the completion of each picture. The duration of the synchronizing pulses at present is five to seven per cent of the scanning time for a line or a picture, respectively. The resulting large difference in frequency permits the separation of horizontal and vertical synchronizing impulses by means of frequency separating circuits.

This procedure, which has shown good results in practice, has the advantage that only a fraction of the transmitter output (at present about one tenth) is used for synchronizing, that is, is lost as far as the transmission of the picture signal is concerned. In addition the cathode-ray tube beam is cut off at the end of each line and at the end of each picture, due to the pulses, so the return traces of the electron beam remain invisible. This blanking-out effect is necessary, not only for the return of the electron beam to the top of the scan after each complete frame, but also for the return of the beam at the completion of scanning each line, because otherwise the attainable contrast interval will be limited in accordance with the ratio of the speed scanning—speed retrace. Moreover, when intermediate-frequency reception is used, the spot intensity also varies periodically during the retrace. If, therefore, this trace is not blanked out, very disturbing streaks will be visible in the dark portions of the picture.

In order to illustrate present procedure, an oscillograph of the intermediate-frequency voltage provided by a receiver tuned to the

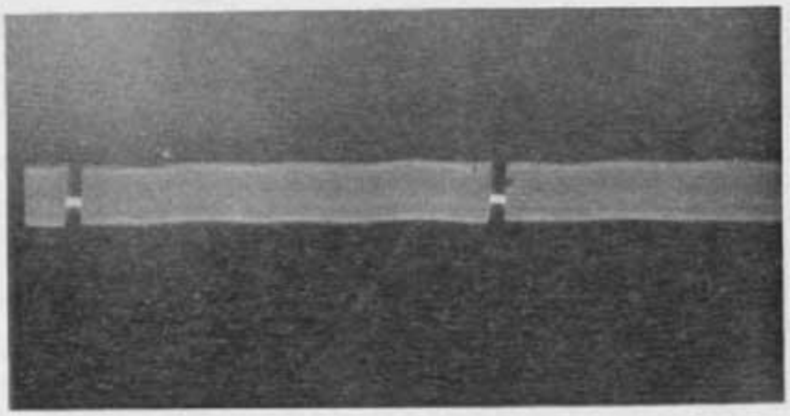

Fig. 4—Oscillogram of carrier wave of Berlin television transmitter. No picture modulation.

Berlin transmitter is shown in Fig. 4. This was made under conditions of no picture modulation, and shows that even under the comparatively good receiving conditions at the author's laboratory in Lichterfelde, interference voltages may amount to as much as one eighth to one fifth of the intermediate-frequency output during absence of picture modulation.

One of the chief difficulties in television consists in obtaining exactly similar synchronizing impulses which are not only entirely free of picture signal content but also are affected least by the mean disturbance voltage from the receiver. Even very slight variations, particularly in the intensity of the synchronizing impulse, suffice to cause a considerable displacement of lines or a change in picture size (height of the picture). The result is a lack of sharpness in the picture and unpleasant picture flicker. Changes in synchronizing impulse intensity naturally have more effect the greater the synchronizing power. The problem of securing steady synchronizing impulses from the mixture of voltages at the intermediate-frequency output was solved by the insertion of a tube having the characteristic curve shown in Fig. 6. The operating point of the grid of this tube is made strongly negative (in Fig. 5, for example −5 volts), thereby preventing the disturbing voltages during transmission of synchronizing impulses from reaching the value at which plate current of this amplitude filter begins to flow. As soon as the synchronizing impulse is over (assuming correct division of the receiver output voltage) a current always flows in this tube, the mean value of which is about equal to half the maximum value of the tube characteristic. This current does not depend on the respective modulation values during the picture modulation interval (i.e., on the picture content) because the characteristic after reaching its upper break drops again. For the type of tube in Fig. 5 and the voltage

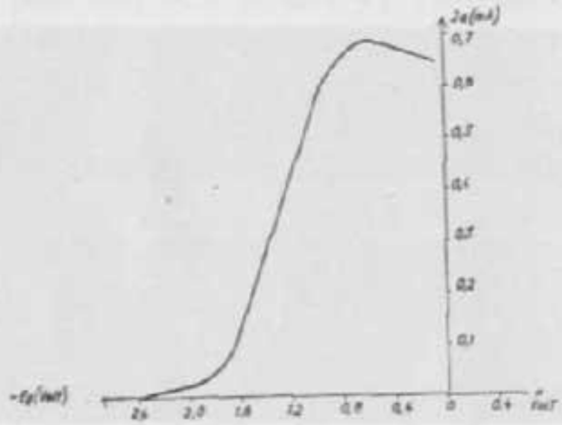

Fig. 5—Characteristic curve of amplitude filter using screen-grid tube.

selected, the drop in the characteristic after reaching its upper break is attained by the familiar current distribution effect (retarded field arrangement). The proper selection of the auxiliary grid voltage makes it easy to bring the drop to a value which gives practically ideal independence from the degree of modulation of the transmitter prevailing during the picture modulation interval. In the final analysis this process is based on the selection and utilization of a very small modulation interval at the transmitter, for example, an interval of from twenty to twenty-five per cent of the total modulation interval so as to allow always the same current. The regularity of the resultant synchronizing impulses is so absolute that extremely stable synchronization is afforded, even without the use of additional frequency selecting stages. The pictures have remained flawless and stable over periods of several hours.

Properties of the High Vacuum Television Tube Used

High vacuum tubes of the Leybold and von Ardenne Oszillographen-Gesellschaft, Köln-Bayental, were used in the arrangement described. A detailed account of the history of these tubes has been reported[6] recently and the author will give only brief data.

The electron-optical arrangement of this type of tube operates with double electrostatic concentration according to George,[7] of a similar type to that employed in practically all modern television tubes. In the ordinary design this type of tube has only two deflecting plates which are charged by the horizontal deflection potential in accordance with the author's publication mentioned in this paragraph. Symmetry, with reference to the anode, is maintained by the use of push-pull output tubes to drive the horizontal deflecting plates.[8] The low-frequency vertical deflection is accomplished by means of deflecting coils fed with current from a relaxation oscillator. These deflection arrangements permit the maintenance of spot sharpness to the extreme edges of the screen. These conditions prevail, not only for wide deflection angles but also at high beam currents and small beam sections.

Furthermore, by reducing the distance between the electron gun and the fluorescent screen by the length which is required by a pair of plates, a corresponding increase in the sharpness of the spot results as a corresponding decrease in the over-all length of the tube as compared with a double electrostatic deflection type of tube. Finally, through the use of magnetic deflection in the vertical direction it is possible to adjust precisely the size of the picture from the outside of the tube. Thus, all the advantages of magnetic deflection are available without the disadvantage of requiring a large amount of electrical energy for deflection at the higher frequencies.

Fig. 6 is an enlargement of a section of a television picture on the fluorescent screen. No lack of illumination control is noticeable with this type of tube. A size of 18×22 centimeters is used. At an anode voltage of 4000 volts pictures of these sizes were so brightly illuminated that the bright parts of the picture reached and exceeded the brightness at which a strong flicker occurred when twenty-five pictures per second were shown. The screen has a white-black tone, which imparts a very pleasant quality to the picture.

The relaxation device described in the following paragraph was used to produce perfect scanning on the screen.

[6] von Ardenne, "On the construction of Braun tubes with a high vacuum for television and measuring purposes," *Jour. High-Frequency Tech.*, vol. 44, no. 5, (1934).

[7] R. H. George: "A new type of hot cathode oscillograph and its application to the automatic recording of lightning and switching signals," *Jour. A.I.E.E.*, vol. 48, p. 534, (1929).

[8] The same solution is also to be found on page 1282 of reference 2, "An Experimental Television System," which was published at the same time as the author's book.

Circuit of the Push-Pull Thyratron Relaxation Device

The following method has proved itself to be a simple one for the production of relaxation oscillations which are sufficiently linear for television use.

Fig. 6—Magnified section of received picture.

The voltage difference between the ignition and extinguishing points of a grid-controlled gaseous discharge tube is adjusted to a value that is small compared with the charging voltage source. The ignition value is chosen so that breakdown occurs at the level of about one half of the charging source voltage. Under such operating conditions a sufficiently linear rise in current for television purposes is obtained,

even when the capacity which is in parallel with the thyratron is charged through a resistance. This is because the portion of the curve used is only a very small part of the central portion of the usual charging curve, and thus it is sufficiently linear. The resulting relaxation voltage is usually either too small (even if the anode supply of the cathode-ray tube is used as a charging voltage) or, if it is large enough, requires such heavy discharges that the life of a gaseous discharge tube is critically shortened. Also, the relaxation voltage is not symmetrical with respect to ground. For this reason the method of connection shown in Fig. 7 was selected, in which the relaxation voltage is amplified in a supplementary amplifier stage. In this diagram, tubes with a large voltage amplification factor are used, as well as plate resistors which are large compared with the internal resistance of the tube. The operating characteristic of a stage designed in this manner is so linear over a wide range (depending on the magnitude of the anode voltage used) that up to seventy or eighty per cent of the voltage at the plate supply may be linearly controlled. Even with one stage this percentage is as great or greater than may be obtained by charging the relaxation condenser through a tube which gives a constant load current (such as tubes using saturation or suitably connected dual grid tubes) without subsequent amplification. The output voltage is effectively doubled when the push-pull circuit is used. This circuit has the added advantage of providing deflection potentials symmetrical with respect to ground which are required when operating high vacuum tubes. Using such circuits and a plate voltage of 1000, sufficiently undistorted relaxation voltages of magnitudes up to 1500 volts have been produced.

The antiphase voltage required for controlling the grid of the symmetric stage is tapped off of the plate resistor of the main stage, as shown in Fig. 7. Formerly the plate resistor was used as a voltage divider to supply the correct grid potential. Now, the actual voltage division takes place in the grid circuit of the symmetric stage. This arrangement has the advantage of dividing the hum voltage as well as the signal voltage, so that less smoothing is necessary.

In Fig. 7 resistances are provided in the discharge circuit of the relaxation tubes which not only act as protective resistances for the gaseous discharge tubes, but also have, in conjunction with the output stage,[9] the important function of accelerating the recurrence of the relaxation oscillations. It was possible with these resistances to accelerate the relaxation recurrence to as much as one third of the original value.

[9] The same trick is also referred to in the paper mentioned in reference 2 Proc. I.R.E., vol. 22, November, (1934).

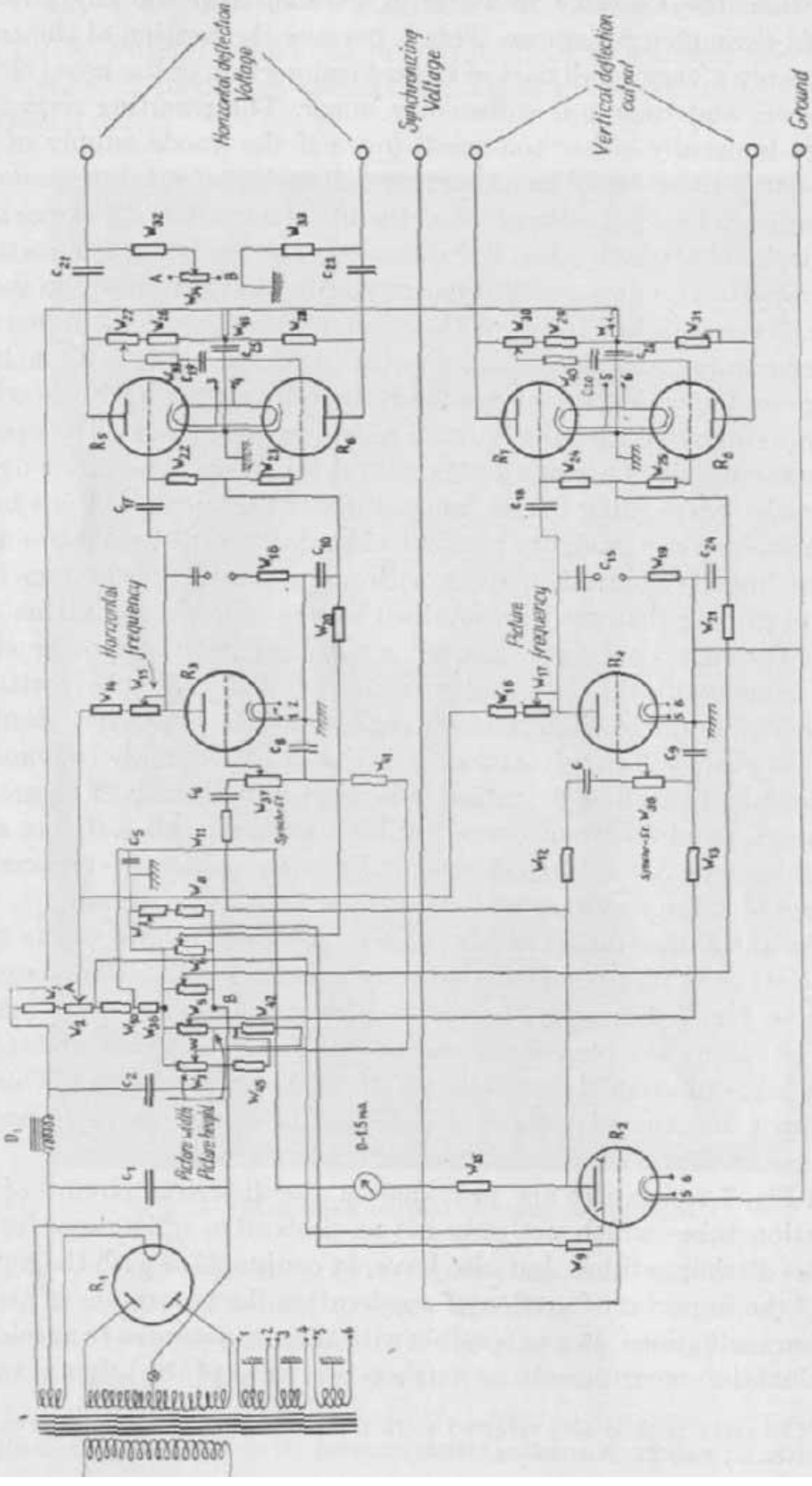

Fig. 7—Push-pull deflecting circuit. (Type 1933/34.)

On the left-hand side of Fig. 7 is shown the amplitude filter described in a preceding paragraph. The coupling of the synchronizing grids of the two discharge tubes to the amplitude filter is accomplished with condensers of different sizes. These condensers are so chosen that frequency components of the horizontal and vertical synchronizing impulses are transmitted without undue loss.

A number of decoupling devices are provided in this wiring diagram in order to prevent coupling between the two relaxation parts, as well as to prevent reactions of the relaxation potential amplifier on the re-

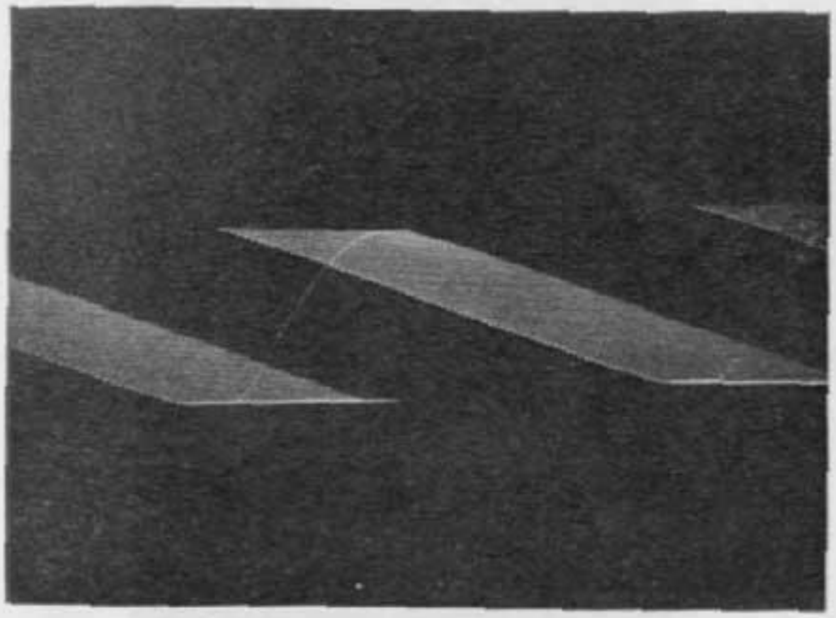

Fig. 8—Oscillogram showing quality of scanning pattern. Vertical deflection frequency 25 cycles; horizontal deflection frequency 2500 cycles; high vacuum tube with anode voltage 4000; lens f. 2. 8.

laxation generator. Extensive elimination of such disturbances, as well as a high degree of attenuation of the hum voltage, are necessary for stable synchronization by the impulses of the transmitter. Fig. 8 is an oscillogram of a television pattern, taken with a rotating camera. The relaxation apparatus, described above, and a Leybold high vacuum tube were used. The reader can see the constant high intensity of the light spot, the satisfactory linear course of the electrostatic horizontal deflection, as well as of the magnetic vertical deflection and even the vertical return line which occurs in the oscillogram in less than 1/2000 of a second. The return time obtained with magentic deflection was sufficiently short, since the vertical synchronizing impulses last longer than 1/1000 of a second.

Practical Experience in Reception from the Berlin Television Transmitter

With the arrangement[10] described in this paper the Berlin transmitter was regularly received in Lichterfelde for extended periods. A very sharp 180-line picture, almost free from faults, was received. Its

Fig. 9—Unretouched snapshot of 180-line picture received from Berlin transmitter.

Fig. 10—Showing reception of a film title.

quality was hardly noticeably below that of the picture at the monitor at the transmitter. When using the above-mentioned type of tube, picture brightness was great enough to permit photographing the received pictures with an exposure time of a fraction of a second. Sharp pictures, therefore, could be produced in spite of the constant motion of the films from which they were transmitted.

[10] A number of patents were applied for on these ideas. They will be exploited for television purposes by the C. Lorenz Company, Berlin-Tempelholf. Above investigations were supported by the C. Lorenz Company.

Some unretouched characteristic photographs are shown in Figs. 9, 10, and 11. They were taken when double side-band transmission was still in use. Single side-band operation gives pictures of greater sharpness. Such pictures are shown in a recently published book[11] by the author.

The immediate impression at the television receiver is that of a sharp picture, much more satisfactory than these photographs, because

Fig. 11—Another received picture.

Fig. 12—Showing the effect of purposely inserted interference from a sparking commutator.

of the motion of the film and the constant transition to new screen pattern elements. Synchronization was unusually stable, both horizontally and vertically, so that the pictures remained perfectly framed for several hours. The picture in Fig. 12 proves how little the synchronization is subject to disturbances. This picture was taken during an artificially created disturbance, the peak potentials of which amounted to fifty per cent of the voltage obtained from the dark value of the

[11] von Ardenne, "Television Reception," Berlin, January, (1935), Weidmannsche Buchhandlung.

transmitted signal. Good synchronization was maintained despite this extraordinarily unfavorable condition. The disturbance in the pictures, which causes a slight variation in the length of the scanning lines, was not any more noticeable (that is subjectively) than the disturbance of the picture content which is due to light modulation. In other words, a condition has been arrived at where the synchronization is no more subjected to disturbances than the light control circuit of the cathode-ray tube. Disturbances to the latter source, of course, are unavoidable. The use of a separate circuit for synchronization would not appreciably improve the picture quality.