THE ELECTRICAL RECORDING OF DIAGRAMS WITH A CALIBRATED SYSTEM OF COORDINATES

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The construction of diagrams from a series of measurements demands the closest attention and takes a considerable time. Electronic engineering in recent years has enabled the construction of calculating machines which can take over some of the work of the human mind, and it also offers the possibility of constructing an apparatus which can very quickly take measurements and record their results in the form of a diagram.

Several articles have already appeared in this journal describing apparatus by means of which diagrams or graphs can be traced on the screen of a cathode-ray tube [1][2].

The tracing of such diagrams is done by periodically varying the "independent variable", measured by means of a proportional voltage, from the minimum to the maximum value. The "dependent variable" (also measured electrically) then likewise varies periodically through a certain range. After amplification these two voltages are applied to the horizontal and vertical deflection plates of a cathode-ray tube, thereby producing a curve on the screen.

In the apparatus described here, a calibrated system of coordinates in the form of a lattice is produced on the screen simultaneously with the tracing of the diagrams. This allows of an accurate numerical interpretation of the curves, which with the apparatus hitherto employed was more difficult and less accurate, owing to the lack of calibrating points.

Although this diagram-tracing apparatus can also be used for many other variables that can be measured electrically, this article will only deal with its application for recording the characteristics of electronic valves, where the quantities to be measured are already voltages or currents. This apparatus has proved to be of great value in the electronic-valve development department, where new types and modified forms of valves are frequently being examined.

Compared with the usual method of constructing a diagram point by point from meter readings, the use of the cathode-ray tube for this purpose has the advantage that a curve can be plotted very quickly. This is highly important when, in the case of static measurements, the valve is likely to be overloaded and consequently damaged.

As was the case with the apparatus previously described, a family of I_a-V_a curves is simultaneously recorded for different values of the grid voltage of the valve. For this purpose, with the apparatus referred to in footnote [1]), the grid voltage was rapidly changed in steps with the aid of a rotating commutator. Here this mechanical method of switching has been replaced by an electronic system, in view of the higher switching frequency required for the simultaneous tracing of the coordinate lattice. In place of the "impulse tube" employed by Douma and Zijlstra[2]), normal amplifying valves are used.

Principle

The main parts comprising the diagram-tracing apparatus are indicated in the block diagram of *fig. 1*. The anode of the valve T under test receives from an alternating-voltage generator G, and a direct-voltage source V_a, a periodically changing positive voltage. This voltage is also applied to the horizontal deflection plates of the cathode-ray tube K via a deflection amplifier A_H. The voltage across the resistor R in the anode circuit is applied to the vertical deflection plates of K, also via an amplifier (A_V). Thus the coordinates of the spot describing a curve on the screen due to the changing anode voltage and anode current are at any moment proportional to the instantaneous values of these two electrical quantities.

The circuit also contains direct-voltage sources V_{g2} and V_{g3}, for applying the correct voltages to the screen grid and the third grid of the valve, and a step-voltage generator V_g supplying to the control grid a series of different direct

[1]) H. van Suchtelen, Applications of cathode ray tubes IV. Philips Techn. Rev. **3**, 339-342, 1938.
A. J. Heins van der Ven, Testing output valves, Philips Techn. Rev. **5**, 61-68, 1940.

[2]) Tj. Douma and P. Zijlstra, Recording the characteristics of transmitting valves, Philips Techn. Rev. **4**, 56-60, 1939.

voltages, so that a family of I_a-V_a curves for different values of the parameter V_g are traced at short intervals.

The tracing of the set of curves is alternated by the tracing of the lines of the coordinate lattice. This is made possible by connecting at the point b_2 in the leads to the deflection amplifiers A_H and A_V electronic switches (not shown in fig. 1), which will be discussed later.

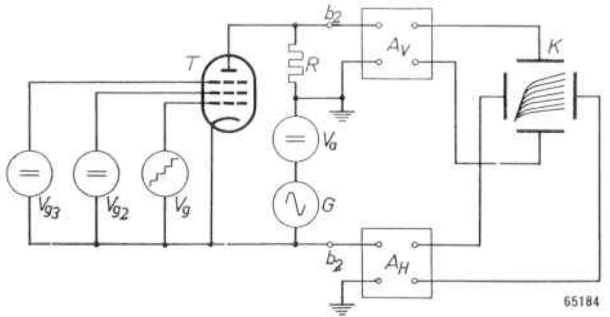

Fig. 1. Block diagram of the apparatus for measuring characteristics. T valve under test; V_a rectifier for supplying the anode direct voltage; G alternating-voltage generator for scanning the I_a-V_a-characteristic; R resistor across which a voltage is developed proportional to the anode current of the valve T; K cathode-ray tube; A_V amplifier for the vertical deflection of the beam; A_H amplifier for the horizontal deflection; V_g step-voltage generator for supplying the control-grid voltage of T; V_{g2}, V_{g3} rectifiers for the auxiliary grid voltages of T.

The tracing of the lines of the lattice is done in a similar way to the tracing of the curves, with this difference that one of the two deflection voltages is kept constant while the other varies periodically, in this case sinusoidally.

Twenty-five complete pictures (curves with lattice) are displayed per second. Each picture period is divided into four parts of 1/100 second, called quarters. In the first quarter the vertical lines of the lattice are traced, in the third quarter the horizontal lines, and in the second and fourth quarters the curves that are to be measured.

The three pairs of signals, viz. for the horizontal and vertical deflection (a) of the characteristics, (b) of the vertical lines of the lattice, and (c) of the horizontal lines, are conducted by three pairs of channels to the previously mentioned two electronic switches, which pass the pairs of signals in turn to the two deflection amplifiers of the cathode-ray tube.

The direct-voltage components of these three signals take part in the amplification up to the output of the electronic switch, thus making it possible to compare the direct-voltage components of the three pairs of signals: when there is any inequality in the switched voltages then, upon switching over, a voltage surge occurs at the output of the switch, and this causes a discontinuity in the curve traced on the screen; where there is no such discontinuity this indicates that the switched voltages are equal.

This possibility is used for calibrating the lattice of coordinates, by comparing the direct voltage required for each line of the lattice with an accurately known, constant, direct voltage, as will be explained when describing the calibration.

Beyond the switches only the alternating-voltage components are amplified by the two deflection amplifiers, so that the centre of the picture is automatically brought into the centre of the screen of the cathode-ray tube.

As already observed, switching is done by means of two identical electronic switches, H and V, periodically passing the necessary signals to the horizontal and vertical deflection plates (see *fig. 2*). These switches each have three channels with picture-signal inputs b_1, b_2 and b_3 and three switching-signal inputs s_1, s_2 and s_3. The three channels for the picture signals are periodically opened and closed by square-wave pulses, supplied by the switching-signal generator G_1, being applied to the switching-signal inputs. The picture signals for the lattice are supplied by a step-voltage generator G_2 and an alternating-voltage generator G_3 with a fairly high frequency (7020 c/s). The form of the pulses produced by the three generators is shown in fig. 2. The switching-signal generator G_1 supplies negative pulses for opening the picture channels. In the first quarter the channels *1* are opened, the plates for the horizontal deflection receiving a step-voltage from G_2 and those for

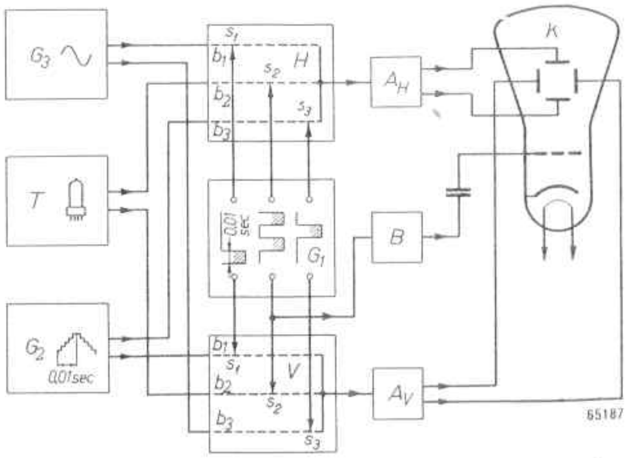

Fig. 2. Basic principle of the diagram tracer. H electronic switch for the horizontal deflection; V ditto for vertical deflection; G_1 switching-signal generator; G_2 step-voltage generator; G_3 7020 c/s generator; A_H amplifier for the horizontal deflection; A_V amplifier for the vertical deflection; B intensity control; K cathode-ray tube; T valve under test.

the vertical deflection a sinusoidal voltage from G_3. A series of vertical lines are then traced on the screen of the cathode-ray tube.

In the second and fourth quarters the channels *2* are opened and the curves are traced. In the third quarter the channels *3* are opened, the plates for the horizontal deflection receiving a sinusoidal voltage and those for the vertical deflection a step voltage, thereby tracing a series of horizontal lines on the screen.

The variation of the voltages on the two pairs of deflection plates is shown diagrammatically in *fig. 3,* where it is assumed that only one curve is being traced.

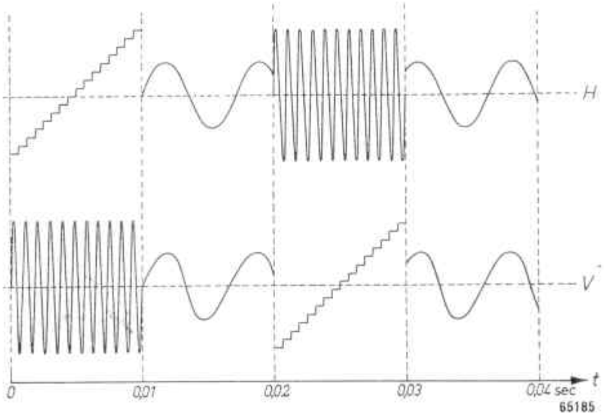

Fig. 3. Waveform of the deflection voltages when tracing one curve with a lattice of coordinates. *H* voltage on the horizontal deflection plate; *V* ditto for the vertical deflection.

As we have already seen, for the tracing of the lattice, step voltages are used. In the case where 13 lines (12 intervals) are traced the frequency in the succession of the steps is $13 \times 50 = 650$ c/s. The amplifiers have to amplify a considerable number of harmonics of this frequency with equal gain; the frequency band of the amplifiers is, of course, limited in width, so that it is advisable to keep the frequency of the steps as low as possible, thus to choose the smallest possible number of pictures per second. The lower limit of the picture frequency is determined by the persistency of

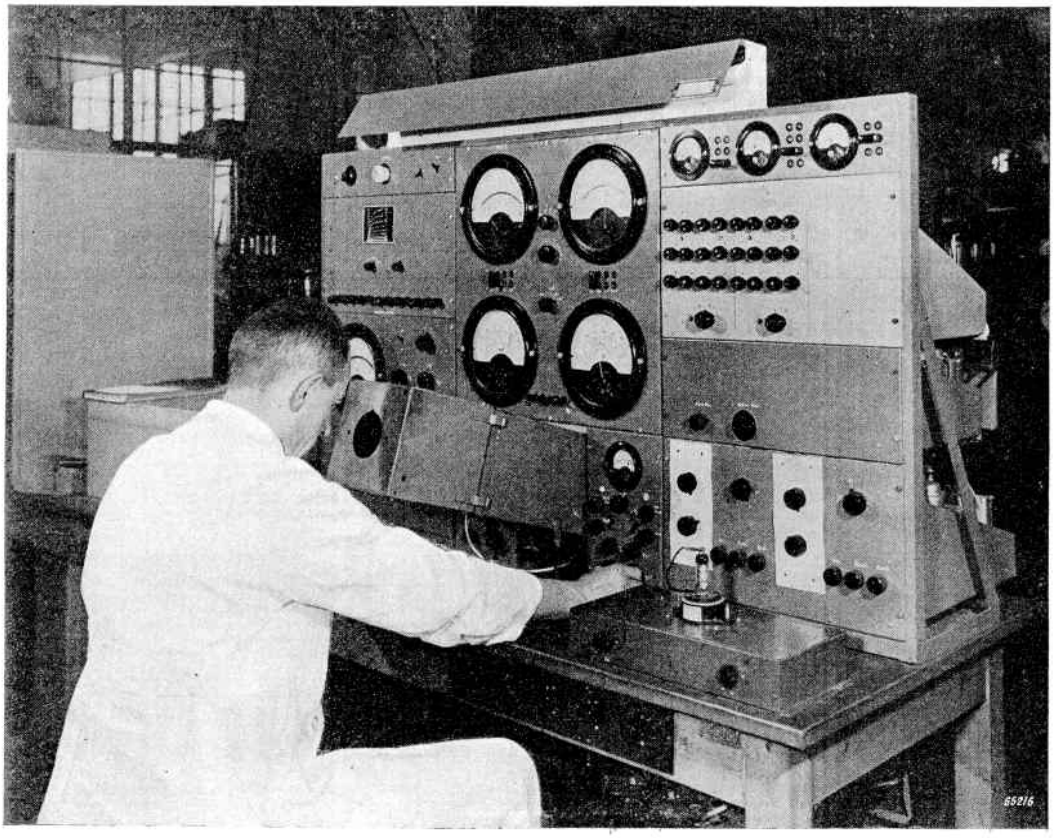

Fig. 4. Measuring and control panels of the diagram tracer. In the middle at the bottom the metal case containing the cathode-ray tube, type DW 16-2. On the bench on the right the valve under test. At the top on the middle panel the meters recording the filament current and the screen-grid voltage of the valve under test. On the right-hand panel at the top control meters for the screen-grid current, anode current and anode voltage, and underneath these the controls for adjusting the steps of the step-voltage generator for the lattice. On the left-hand panel at about the same level are the controls for adjusting the steps of the step-voltage generator supplying the grid voltage for the valve under test.

the screen and of the visual impression and also by the linearity in amplitude and phase of the amplifiers and electronic switches at low frequencies; 25 c/s has been found to be a good compromise.

In the block diagram (fig. 2) an "intensity control" B is indicated. This allows of the brightness of the lattice being varied with respect to that of the family of curves. If no special measures were taken, the curves — when there are only a few in the series — would be much brighter than the lattice and as a consequence the photographic recording of the picture on the screen would be over-exposed. To avoid this a square-wave control signal is applied via an amplifier to the grid of the cathode-ray tube, by means of which the intensity of the beam is reduced during the second and fourth quarters. This control signal has the same form as the signal that is used for opening the picture-signal channels.

The whole installation is contained in panels mounted in racks on a testing bench, a photograph of which is given in *fig. 4*. On the right of the bench is the valve under test, and in the middle of the bench, at the bottom, is the metal case containing the cathode-ray tube. The observer sitting at the bench views the screen of the tube through the opening, in front of which a camera can be placed.

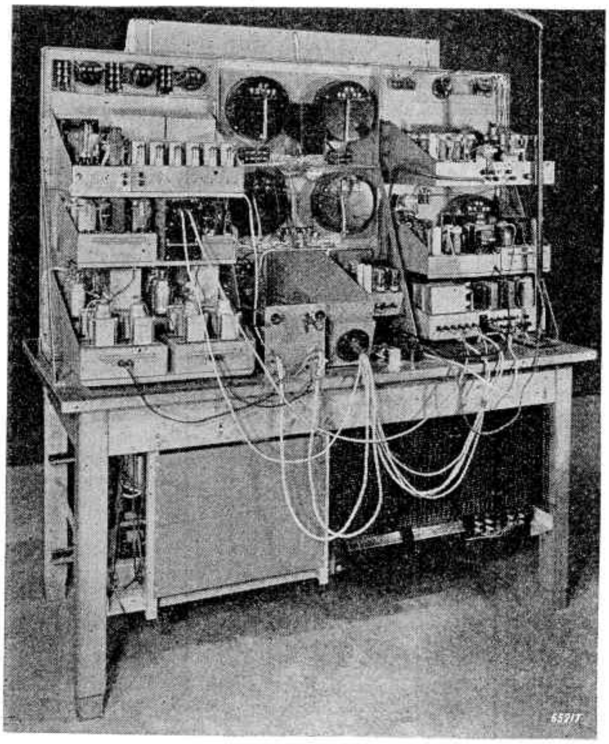

Fig. 5. Rear view of the measuring and control panels of the diagram tracer. On the right at the top the step-voltage generator for the grid voltage of the valve under test, and on the left at the top the step-voltage generator for the lattice.

Fig. 5 is a back view of the panels. Underneath the bench are the supply units and the 200 W generator for scanning the characteristic of the valve under test.

The component parts of the installation are all made as easily replaceable units, the connections between which are made with the aid of plugs and sockets. Since the whole of the apparatus contains more than 200 electronic valves, with an average life of 10,000 hours, an average of one breakdown per 50 hours has to be taken into account. Spare units are therefore provided for quick replacement.

The electronic switches

Each of the switches, as we have seen, contains three channels. In one such channel there are two valves, the switched valve T_1 and the switching valve T_2 (see *fig. 6*).

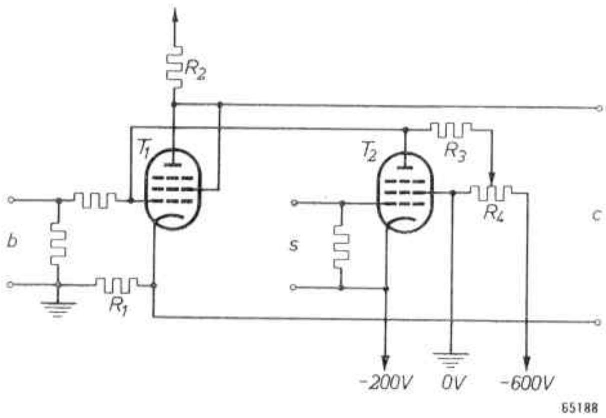

Fig. 6. Principle of the electronic switch circuit. T_1 switched valve, T_2 switching valve, b signal input, s switching-signal input, c signal output connected to the deflection amplifier.

For electronic switching a pentode is usually employed, and a positive pulse is applied to the second grid during the period that the valve has to transmit the switched signal. However, in the event of interferences arising in the switching pulses, this will affect the amplification factor of the switched valve and, therefore, the signal transmitted.

With the method employed for this apparatus the valve T_2 is cut off during the interval that the switched valve T_1 is conducting. The control grid of T_1 then receives via the resistor R_3 and the potentiometer R_4 a negative bias from a stabilized supply unit of —600 V.

During the interval that the valve T_2 is open, T_1 is cut off. The grid of T_1, which is connected to the anode of T_2, then has a voltage only slightly higher than the cathode voltage of T_2, which is at a potential of —200 V with respect to earth. Fluctuations in the switching impulse at s, although strongly influencing the negative control-grid voltage of T_1, are not transmitted, because T_1 is cut off.

The correct working voltage for T_1 can be adjusted with the potentiometer R_4. The three parallel-connected valves T_1, one of which is always open and two cut off, have common cathode and anode resistors R_1 and R_2, so that the signals entering the three channels at b leave the switch through the common output c.

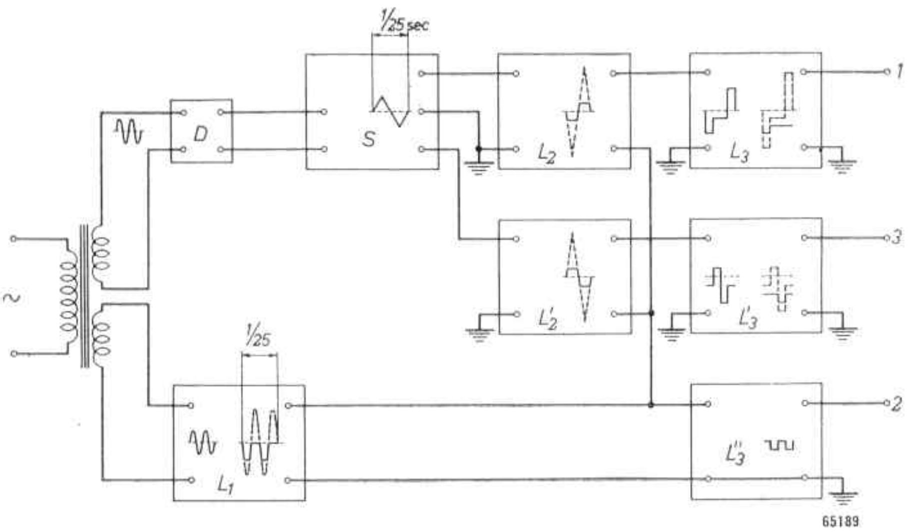

Fig. 7. Block diagram of the switching-signal generator. L limiters. D frequency divider. S triangular-pulse generator. Wave forms in broken lines: without limiting; fully drawn: with limiting. The output terminals *1*, *2* and *3* are connected to the switching-signal inputs s_1, s_2 and s_3 of the electronic switches.

The resistors R_1 and R_2 are of equal value, and so the output terminals receive equally large alternating voltages of opposite polarity with respect to earth. These voltages are applied via blocking capacitors to the input of the push-pull amplifier for the beam deflection of the cathode-ray tube. Apart from the fact that the two voltages in anti-phase thus obtained are suitable for feeding the push-pull amplifiers, the cathode resistance gives a heavy negative feedback highly stabilizing the gain of the valves T_1. This is necessary because in this part of the circuit the signals that are to be compared are transmitted by different valves and any variations of the gain of this stage would upset the accuracy of the calibration.

Switching-signal generator

As already mentioned when dealing with the principle of the system, the switching-signal generator supplies three different signals consisting of negative voltage pulses lasting 1/100 second. In order to avoid hum trouble these signals are synchronized with the mains frequency (50 c/s): any hum interference arising in some way or other in the amplifier would lead to distortion of the picture on the screen of the cathode-ray tube. The signals being synchronized, any interference will only manifest itself in a slight curving of the lattice lines, which is not troublesome; if the signals were not synchronized the interferences would be manifest in a wave travelling right along the lines, which would immediately be noticed, and a photograph would show thick lines unfavourably affecting the accuracy of the measurements.

The switching signals are generated in different stages, which will be explained with the aid of *fig. 7*.

A sinusoidal alternating voltage of 50 c/s is applied to a limiter L_1, and to a frequency divider D. The latter passes every 1/25th of a second a pulse to a circuit S generating a triangular voltage with a frequency of 25 c/s. This triangular voltage is applied, in anti-phase, to two limiters L_2 and L_2', which clip pieces out of the triangular voltages and thus produce square-wave pulses of the form shown in fig. 7. To these pulses are added the signals coming from the limiter L_1. When the differences between the maximum and the minimum output voltages of L_1 and L_2 (or L_2') are equal then L_3 and L_3' receive pulses of the form drawn in fig. 7. From these signals, which have a repetition frequency of 25 c/s, the limiters L_3 and L_3' clip out negative square-wave pulses with a duration of 1/100 second.

The limiter L_3'' finally reverses the square-wave pulses supplied by L_1, so that in the second and fourth quarters negative pulses are obtained for opening the electronic switches transmitting the signals from the valve under test.

Step-voltage generator

When square-wave pulses of equal frequency but mutually shifted in phase are applied to the control grids of a number of amplifying valves with common anode resistor, then at that resistor an alternating step voltage is obtained. In *fig. 8* this is illustrated schematically for the case where there are six steps. The fundamental frequency of the square-wave pulse, synchronized with the mains, is 50 c/s, whilst each step lasts 1/100 sec. Only the ascending step voltage is used, the descending voltage being suppressed by the electronic switch.

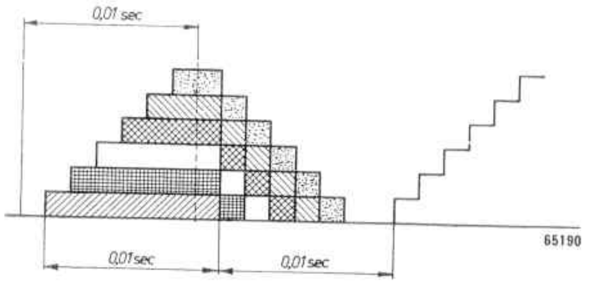

Fig. 8. The building up of a step voltage from six equal, square-wave signals, mutually shifted in phase.

The phase shifts between the successive square-wave pulses have been made equal, so that the steps of the voltages are equal in width. Thus the lines on the screen are all traced during equal intervals of time and have equal brightness.

The mutually shifted square-wave pulses are obtained, again with the aid of limiters, from sinusoidal voltages shifted in phase and generated in circuits as represented in *fig. 9* [3]). Twelve of these circuits, with a common transformer, supply twelve sinusoidal alternating voltages E_f, mutually shifted in phase. These voltages are applied to the grids of twelve valves T_1. (See *fig. 10*, where the circuits of two of these valves are drawn.) The alternating voltages E_f are much greater than the grid base of these valves (pentodes EF 40). During the greater part of the negative half of the grid voltage T_1 is cut-off; when the grid voltage is positive the valve is saturated and as a result the anode current assumes the form of a square wave. The square-wave pulses at the anode resistors R_1 are transmitted via the capacitors C_1 to the grids of twelve valves T_2 (also EF 40 pentodes) with common anode resistor R_2, amplified and then added together in R_2. The screen grid voltages of the valves T_2 can be individually adjusted between + 100 and — 10 V with respect to the cathode, for each valve separately by means of the potentiometers R_3. In this way it is possible to change the anode currents and thereby the heights of the steps, and thus the distances between the lines of the lattice. For the anode currents to be

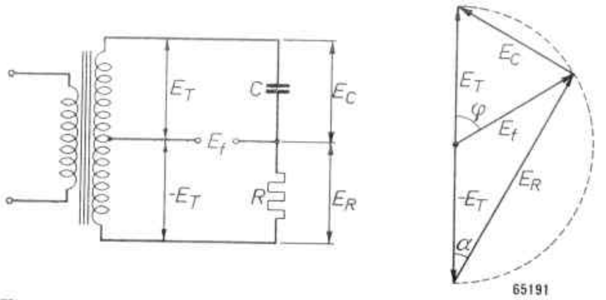

Fig. 9. Network for obtaining alternating voltages E of constant amplitude, and shifted in phase, with the corresponding vector diagram. Between the centre tap of the secondary of a mains-fed transformer and the common point of the capacitor C and the resistor R, an alternating voltage E_f is developed which, with respect to the transformer voltage E_T, is shifted over a phase angle determined by the choice of R and C. Since the vector E_C is in quadrature with E_R the extremity of the vector E_f lies on a semicircle with radius E_T, so that for all the twelve phase-shifting networks the amplitude of E_f is always equal to that of E_T. (The impedance of the transformer winding is assumed to be low.)

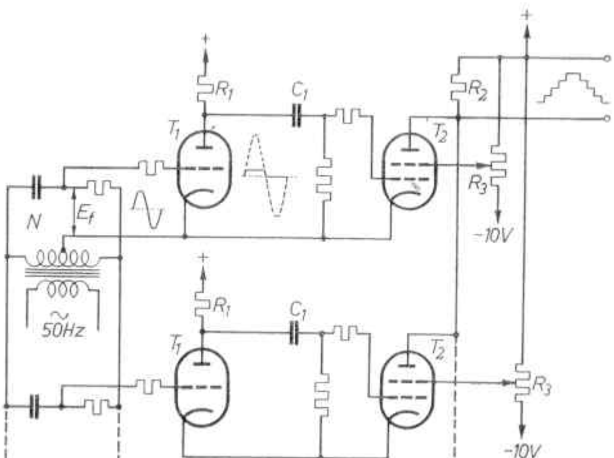

Fig. 10. Circuit of the step-voltage generator. N Network for obtaining sinusoidal voltages mutually shifted in phase; T_1 amplifying valves converting these sinusoidal signals into square-wave pulses; T_2 valves connected in parallel, with common anode resistor R_2, adding up the square-wave pulses shifted in phase, thus forming a step voltage.

3) The working is described, i.a., in Philips Techn. Rev. **12**, 91, 1950 (No. 3).

reduced to zero it was found necessary to give the screen grid a negative potential with respect to the cathode.

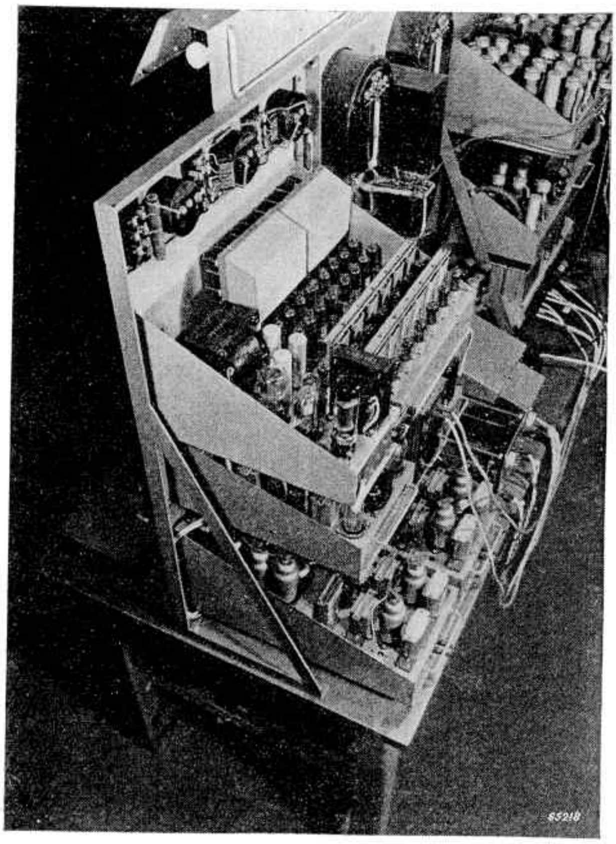

Fig. 11. Double step-voltage generator for tracing the lattice lines. Immediately behind the panel are the two sets of 12 valves of the two second stages. On the right, in two rows of six, the valves of the common first stage.

Fig. 11 is a photograph of the step-voltage generator for tracing the lattice. The circuits are duplicated so as to allow the intervals between the horizontal and the vertical lines to be adjusted independently of each other. The valves of the first stage (T_1 in fig. 10) are common to both systems, but those of the second stage are separated. For adjusting the intervals there are two sets of 12 controls, seen in fig. 4 on the right-hand panel at the top. The two controls underneath these are for adjusting the amplitudes of the two step-voltage generators, this being done without altering the proportions of the steps.

The construction of the step-voltage generator supplying the grid voltages for the valve under test (V_g in fig. 1) is similar to that of the generator supplying the signals for tracing the lattice lines. The controls for this generator are seen in fig. 4 on the left-hand panel.

Deflection amplifiers

These are designed as normal A.C. push-pull amplifiers that have to reproduce frequencies, undistorted in amplitude and phase, in a range from 25 c/s (the picture frequency) up to about 50,000 c/s (the frequency of the higher harmonics of the step-voltage generators). The valve capacitances, and stray capacitances in the output circuit, form the limiting factors, but these are compensated by means of capacitors. The usual method of reducing the influence of stray capacitances, by employing small anode resistances, could not be used here for the following reason. The output voltages required for the deflection plates of the cathode-ray tube have to be high (about 300 volts), so that if small anode resistors were used the output valves would have to deliver high powers which would be needlessly dissipated in the resistors.

By means of a compensating circuit such as used by Carpentier [4]) it has been possible to use anode resistors of a high value (100,000 ohms) and amplifying valves (type CF 50) which are capable of supplying high alternating voltages with only a small amount of distortion. The gain is constant between 10 and 15,000 c/s within $\pm$ 2% (between 10 and 60,000 c/s it is constant within $\pm$ 20%); the phase shift is less than $\pm$ 2° between 10 and 15,000 c/s.

With a push-pull amplifier the compensation can easily be obtained by coupling the grids of the amplifying valves in one of the stages, via a small capacitance C_c, to the anodes of the corresponding valves of the other phase, as is done in neutralization. The only difference is that in the case of normal neutralization only the anode-to-grid capacitance is rendered harmless, whereas here an additional voltage 90° in advance of the signal is applied to the grid via the capacitor C_c. Thus the anode current is increased by the charging current of the anode capacitance.

For a flat frequency characteristic the capacitance C_c of the compensating capacitor has to bear a certain relationship to the grid capacitance plus the stray capacitance (sum C_0), such that the condition $C_0/C_c = R_g S$ is satisfied; here R_g represents the equivalent resistance of the anode resistance of the valve in the preceding amplifying stage and the grid-leak resistance of the valve in the last stage connected in parallel, whilst S is the mutual conductance of the latter valve.

[4]) E. E. Carpentier, A cathode-ray oscillograph with two push-pull amplifiers, Philips Techn. Rev. **9**, 202-210, 1947.

In our case $R_g = 25{,}000$ ohms, $S = 5$ mA/V, $C_0 = 300$ pF, so that C_c has to be given a value of about 3 pF.

The compensating capacitances have been obtained with the aid of trimmers in series with a fixed capacitor of 3.3 pF.

With this system it has to be borne in mind that both the valve capacitances and stray capacitances, as well as the compensating capacitances additionally load the output stage, which at high frequencies involves an increase of the A.C. output current. It is therefore advisable to keep the stray capacitances as small as possible by careful assembly.

Supply units

For the proper functioning of the diagram tracer, direct-current sources of highly constant voltages are essential. Not only must the voltage be independent of the mains voltage and frequency, but it also has to be free of ripple and hum. Furthermore, the sources have to be variable within a wide range and have a small internal impedance.

The supply units used are in principle similar to those described in this journal in 1941 [5]). There the mains-independent voltage was obtained by balancing the output voltage against the reference voltage from a dry-cell battery; the potential difference between the two voltages influences the resistance of a regulating valve incorporated in the current circuit in such a way that the output voltage remains practically constant. In the apparatus used here the dry-cell batteries are replaced by separate voltage sources kept constant with neon voltage-reference tubes. For the functioning of the regulating valve a pentode is used instead of a triode. Since a high degree of stabilization requires a high amplification factor in the regulating valve, with a pentode a better regulation is obtained, whilst at the same time the hum ripple is suppressed to less than 1 mV. (For details see the article quoted in footnote [5]).) With this construction of the supply units a variation of 5% in the mains voltage causes a variation of only 0.01% in the output voltage.

For the supply of the deflection amplifiers, however, the hum level is still too high. To reduce this further, a very large smoothing capacitance would be required. With the aid of a so-called reactance valve [6]) this can be achieved with a comparatively small capacitor. With suitably chosen elements the valve is equivalent to a capacitance of RS times the capacitance in the grid circuit, where R is the value of a resistor connected in series with this capacitance in the grid circuit and S is the effective mutual conductance of the reactance valve. By using a pentode, a factor $RS = 1800$ was reached.

For the anode supply of the valve under test, in addition to a direct-voltage source V_a (fig. 1) an alternating-voltage generator G is also required for the periodical variation of the anode voltage. The generator consists of an R-C generator followed by a push-pull power amplifier with an output of 200 W, this being necessary for measuring output valves. The frequency can be varied between 700 and 1800 c/s, and is asynchronous with the mains frequency, so that the transitions from one curve to the next (at the change of the grid voltage taking place synchronously with the mains frequency) are distributed over the screen of the cathode-ray tube, leaving no visible connecting lines between them.

The R-C generator consists of a two-stage amplifier fed back by a network of resistances and capacitances. The circuit starts to oscillate at the frequency at which the input voltage of the network is in phase with the output voltage [7]).

The sine-wave voltage generated in this way is applied to an amplifier the output stage of which is formed by a push-pull amplifier with 2 × 2 valves, type EL 34, connected in parallel. At an output of 200 W the maximum amplitude is about 220 volts. The maximum variation obtainable in the anode voltage is therefore $2{\cdot}220\sqrt{2} = 620$ V. As indicated in the block diagram of fig. 1,

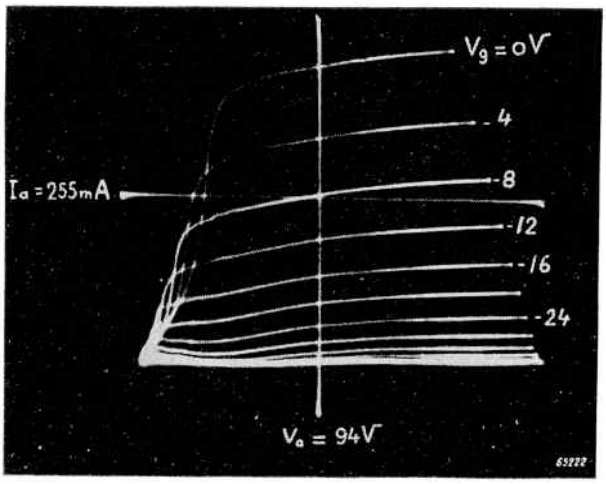

Fig. 12. Electronic crosshair on the I_a-V_a characteristics of a television pentode PL 81.

[5]) H. J. Lindenhovius and H. Rinia, A direct-current supply apparatus with stabilised voltage, Philips Techn. Rev. **6**, 54-61, 1941.

[6]) See, e.g., Philips Techn. Rev. **8**, 47, 1946.

[7]) See, e.g., J. J. Zaalberg van Zelst, Stabilised amplifiers, Philips Techn. Rev. **9**, 24-32, 1947.

in series with this generator is a direct voltage source. The two voltages can be adjusted individually, so that any anode-voltage range can be examined.

Calibration of the lattice

For calibrating the lattice the valve under test (T in fig. 1) is disconnected, and the resistor R in fig. 1, shunted across the input b_2 of the electronic switch V (fig. 2), is connected to a variable current source fitted with a milliammeter.

The voltage divider, connected to the input b_2 of the electronic switch H (fig. 2), is connected to an adjustable direct-voltage source with a voltmeter. Instead of a set of curves being traced a fluorescent spot is seen on the screen of the cathode-ray tube. With this spot, the coordinates of which are exactly known, the lattice is calibrated in the following way.

First the current and voltage sources are switched off. The spot then indicates on the screen the position of the origin of the system of coordinates. The origin of the lattice has to coincide with this point, any adjustments needed being made with the potentiometers R_4 (fig. 6) of the electronic switches.

The current and voltage of the calibrating point are then adjusted to the values corresponding to the first horizontal and vertical lattice lines to be traced. The point where these lines intersect has to coincide with the calibrating point, adjustments being made with the potentiometers R_3 (fig. 10). In this way all the lattice lines are adjusted in succession.

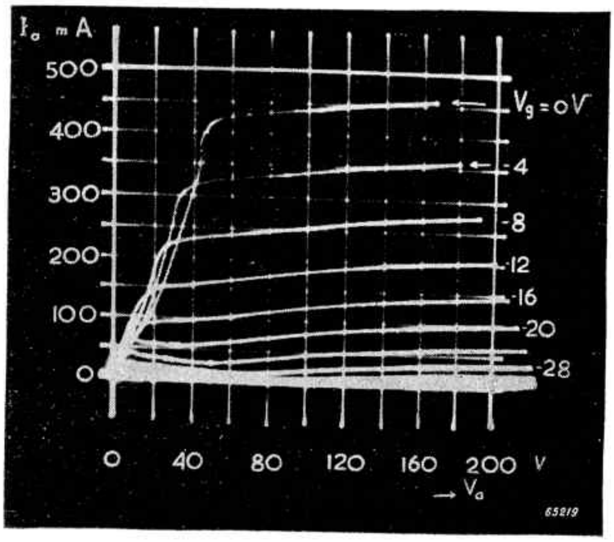

Fig. 13. I_a-V_a characteristics of a television pentode PL 81 (line-output pentode). Screen-grid voltage 180 V.

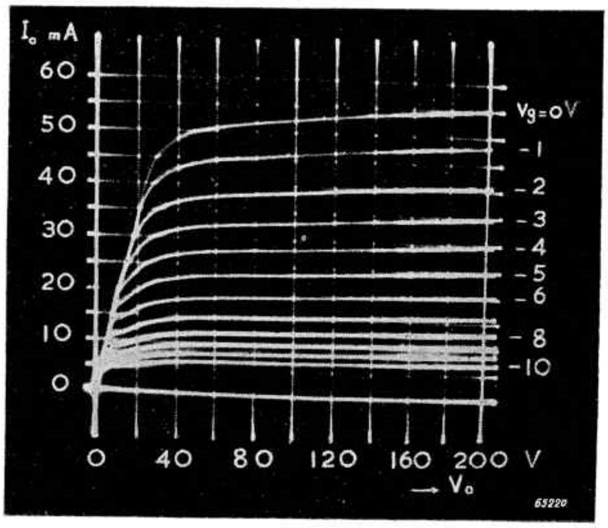

Fig. 14. I_a-V_a characteristics of the pentode part of a triode-pentode ECL 80. Screen-grid voltage 170 V.

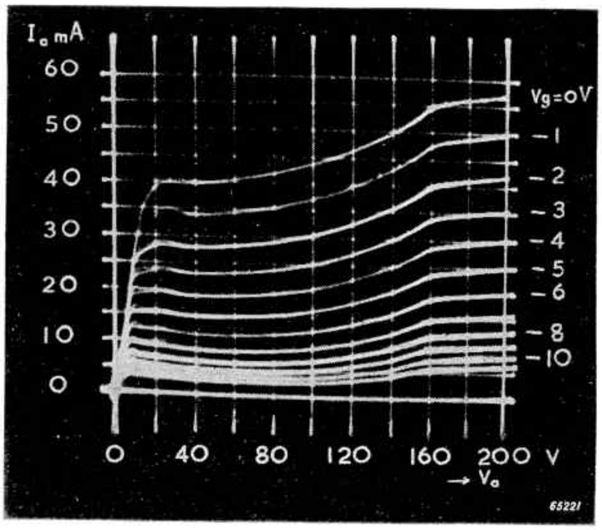

Fig. 15. As in fig. 14, but with the third grid and anode interconnected.

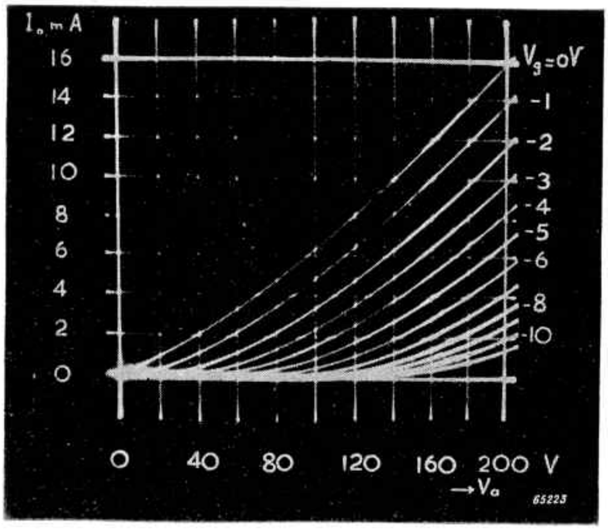

Fig. 16. I_a-V_a characteristic of the triode part of an ECL 80.

Usually the lattice will be so adjusted that the distance between two successive lines corresponds to equal potential differences at the terminal b_2.

As a rule it will be found that the voltage steps at the output of the step-voltage generator are not exactly equal, owing to the curvature of the characteristic of the operative valve of the electronic switch. Neither will the lattice lines on the screen of the cathode-ray tube then be equi-distant, because the deflection of the cathode-ray tube will not be exactly linear with the voltage on the deflection plates. However, owing to the method of calibrating described, no errors arise from these two discrepancies.

Electronic crosshair

To determine the coordinates of an interesting point, as for instance a bend or maximum in a characteristic, without interpolation between two lattice lines, the apparatus is provided with an "electronic crosshair" which can be moved across the screen. For this purpose the step-voltage generator can be replaced by variable direct-voltage sources the voltages of which can be measured with two moving-coil meters. Instead of the lattice there then appear on the screen of the cathode-ray tube two coordinate lines the values of which are known from the readings of the moving-coil meters. These meters are mounted on the panel immediately above the cathode-ray tube (fig. 4).

This method of determining the coordinates with the aid of the crosshair is less exact than the lattice method, because errors may arise from the inequality of the operative valves of the electronic switches. The crosshair method is nevertheless useful when it is desired to determine the coordinates of a point visually, for the errors due to the cause mentioned are less than those resulting from interpolation by eye between two lattice lines. Moreover, when greater accuracy is desired, there is a possibility of calibrating the coordinates of the intersecting lines, after adjustment, with the method applied for the lattice.

Fig. 12 is a photographic recording of the screen picture with electronic crosshair. *Figures 13, 14, 15* and *16* are photographs of the lattices and characteristic curves of television receiving valves, reproduced here to give an idea of the quality of the diagrams.

Summary. An apparatus is described with which a series of curves, e.g. the I_a-V_a characteristics of an electronic valve, and a calibrated lattice of coordinates can be traced simultaneously on the screen of a cathode-ray tube. In cycles of 1/25th of a sec the spot traces in succession the vertical lines of the lattice, the family of curves being examined, the horizontal lines of the lattice and once more the family of curves. The pairs of signals for tracing these three pictures are applied to the cathode-ray tube by means of two electronic switches. The lattice is calibrated by replacing the electrical quantities to be measured by two known direct voltages which are adjusted so that the spot coincides with a chosen point on the lattice. In this way the influence of non-linearities in the apparatus is eliminated. The diagrams produced can be measured with an accuracy of 1% on photographic recordings. The coordinates of any point can be exactly determined with the aid of an "electronic crosshair", which can be moved across the screen of the cathode-ray tube by the adjustment of two direct voltages.