NBS REPORT

5529

TRANSLATION OF

"NEW EQUIPMENT FOR DETERMINATION OF THE STATISTICAL DISTRIBUTIONS OF IRREGULAR ELECTRICAL PHENOMENA"

by

J. Grosskopf, K.-H. Kappelhoff and G. Kopte
Fernmeldetechnisches Zentralamt
der
Deutschen Bundespost

Translation by
A. P. Barsis

NBS

U. S. DEPARTMENT OF COMMERCE
NATIONAL BUREAU OF STANDARDS
BOULDER LABORATORIES
Boulder, Colorado

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NATIONAL BUREAU OF STANDARDS REPORT

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8300-00-9083	October 20, 1957	5529

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Translator's Note: This is the translation of a paper originally published in "Nachrichtentechnische Zeitschrift", Vol. 9, No. 1, January 1956. This journal is published by Friedr. Vieweg & Sohn, Braunschweig, Germany (Federal Republic). Much of the material contained in this paper previously appeared as "Technical Report No. 5507", February 12, 1955, of the Fernmeldetechnisches Zentralamt der Deutschen Bundespost (Central Communications Laboratory of the German Federal Postal Service). Mr. Kappelhof is the author of the original report.

Translation

NEW EQUIPMENT FOR DETERMINATION OF THE STATISTICAL DISTRIBUTIONS OF IRREGULAR ELECTRICAL PHENOMENA

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Summary

New statistical counting equipment has been developed for propagation research. The operation and the construction of this equipment is described in this paper.

It is frequently desirable to determine the dependence of irregular electrical phenomena varying in time (or also in space) on their causes, which may also possess certain statistical properties. As an example consider the field strength received from a broadcast transmitter. The simplest solution consists in the use of a graphic recorder which registers the variations of the measured quantity, and in the statistical evaluation of the recordings obtained.

Consider a chart recording of the quantity x extending over a given time interval. Then it is possible to determine the amount of time in relation to the total time for which x has been found to fall within various intervals. These time ratios may be plotted on a rectilinear coordinate system versus the quantity x, and constitute the frequency distribution of x. If the percent-of-time values are summed consecutively beginning with the largest x, the cumulative frequency distribution curve is obtained. From this cumulative distribution curve it may be determined for what percentage of the total time any level has been reached or exceeded.

It has been found that most cumulative frequency distribution curves encountered in nature and technology have the form of a log-normal distribution, or may be broken up into portions having log-normal distributions. If the time probability coordinate is constructed in accordance with the error integral

$$w(\omega) = \frac{1}{\sqrt{2\pi}} \int_{\omega}^{\infty} \exp\left[-x^2/2\right] dx$$

the normal distribution curve

$$w(x) = \frac{1}{\sigma\sqrt{2\pi}} \int_{x}^{\infty} \exp\left[-(x-x_m)^2/2\sigma^2\right] dx$$

will be a straight line.* x_m is the 50% or median value (attained or exceeded for 50% of the time), and σ is the standard deviation (the difference between x_m and the value of x exceeded for 16% or 84% of the time). Median and standard deviation of the total or any partial distribution characterize the statistical properties of the measured quantity completely and uniquely.

The basic method of evaluating the recording charts utilizes measuring wheels. This method is tedious and time consuming. Various devices have been developed which permit direct determination of the distribution curve from the measured quantity, or a more rapid evaluation of the recording chart 1 - 4/. Especially for purposes of propagation research new devices have been designed and tested at this laboratory. These devices constitute developments of earlier forms, or new designs for special tasks, and their use requires only a minimum of servicing and evaluation time.

A. Automatic Recording Totalizer for Determination of the Complete Distribution Curve

1. Design and Principles of Operation.

The devices used originally by this laboratory contained ten telephone-type counters each of which were controlled by a moving-coil instrument. Besides the nuisance of noisy relays chattering about three times per second, fatigue of the relay points after longer time periods was noticed. At that time the equipment was operated continuously for eight hours daily.

* Translator's Note: In the original German manuscript the two formulas were not given correctly probably due to a misprint.

Counting by charging and half-hourly discharge of condensers 3/ eliminated the disadvantage mentioned above; however, the necessary workload for evaluation remained substantial. The equipment supplied only the percentages of time for each level, but not the cumulative distribution.

In order to obtain the desired statistical parameters (median value and standard deviation), half-hourly readings had to be taken, numbers added up, converted into percentages, and plotted also as functions of the receiver calibration curve. From this finally the half-hourly median and standard deviation was determined.

Another disadvantage consisted in the mechanical inertia of the moving-coil instruments. Variations in the measured voltage which were faster than 0.5 c.p.s. were not correctly reproduced at extreme amplitudes. However, in conformance to the Study Program No. 66 as set up by the CCIR London Conference of 1953, fading frequencies on the order of 10,000 c.p.s. may be important

As a consequence of these and other considerations, and various experiences the device shown schematically in Fig. 1 was developed. It registers every half-hour the distribution curve automatically when connected to a timing mechanism, and produces correct results up to fading frequencies of 10,000 c.p.s., as it is an electronic device. The initial production models have been functioning perfectly for eight months at the time this report was written. Evaluation of the daily 18-hour record is being done by a single person within approximately one-half hour using templates. This includes the determination of 36 values of medians and standard deviations each.

The principle of operation is as follows:

The AVC diode or the limiter stage of the receiver supplies a D.C. voltage proportional to the received field intensity which, after amplification in the stage V_1, controls the multivibrators in the stage V_2. If the control voltage increases from zero to 100 volts, the individual multivibrators of V_2 are triggered successively at 10 volt intervals, and activate the associated charging circuits 1 to 10. Within each charging circuit capacitors are charged by the pulse generator G_1 whenever its control tube is conducting. The voltage across these capacitors then is a measure of the amount of time during which an associated value of field intensity is attained, or exceeded. The first charging circuit is continuously active, and produces the 100% reference time.

The charges across the capacitors are read off automatically. The clock mechanism U activates the stepping switch S, which switches the vacuum tube voltmeter V_4 across the various capacitors at intervals of one second, and also discharges the capacitors after they have been scanned. The voltages read by V_4 are recorded by a D. C. recording instrument in the form of a step function (Fig. 2). The envelope of the steps constitutes the cumulative distribution curve, which is evaluated by a template marked for the 10, 50, and 90% of the time values, and for the calibration of the receiving installation in units of field strength. Fig. 3 shows the exterior view of two rack-mounted totalizers, and Fig. 4 the interior arrangement.

2. Description of Circuits.

(a) D. C. amplifier.

The input D. C. amplifier V_1 and the vacuum-tube voltmeter V_4 are compensated single-stage amplifiers designed to eliminate the influence of temperature and supply voltage variations.

(b) Multivibrators

If the grid resistance in a regular multivibrator circuit is made variable by use of a tube and can thereby be controlled, the on-off voltage differential can be made especially small. This is necessary to define a precise level when the voltage to be measured is rising and falling. Under the assumption of an exceptionally constant power supply voltage this differential may be reduced to 0.1 volt. If a standard regulated power supply is used it may be assumed that the differential may be as much as 0.5 volts for certain unfavorable conditions. The off-voltage would be the lower of the two (see Fig. 6). This amounts to a maximum of 5% for 10 volt intervals of the various multivibrator circuits. The results of the measurements should not be affected by this differential.

(c) Pulse Generators.

The capacitor voltages may not exceed a definite maximum within any measurement period, even when they are being charged continuously. The charging curve as a function of time has to be linear for all practical purposes up to this maximum. The use of D. C. for charging would necessitate charge resistors on the order of magnitude of insulating resistances in order to meet the condition of linearity. Consequently, a pulse generator is used for charging the capacitors, producing rectangular pulses at a frequency of 500 c.p.s. with 200 volt amplitude, and a pulse width of 0.5 microseconds.

(d) Charging Circuits.

If the measured voltage increases beyond the preset triggering value of the multivibrator, the grid voltage of the associated charging tube increases from -50 to +10 volts, and the capacitor C_L in the plate circuit is charged by the pulse generator (Fig. 7). With continuous charging for one-half hour the voltage across C_L increases up to 20 volts, and, within this range, it is linear with time for all practical purposes. The charging adjustment serves to correct variations within each stage.

(e) Automatic Stepping Switch.

When switch K is closed (manually, or by the automatic timer), relay 1 is activated. It moves the contact arms I, II, and III of the stepping switch to position 1 (see Fig. 8), and cuts off the switching tube by charging the capacitor C to -70 volts, although the tube still has plate voltage applied through contact arm III of the switch. The capacitor then begins to discharge through the resistor R, and plate current starts flowing in the switching tube. It increases until relay 2 is activated, which, by means of relay 1, steps the switch to the second position; capacitor C is charged again and cuts off the tube, and the whole procedure is repeated. After all numbered positions have been passed through, the mechanism reaches the position "record", and is deactivated by opening the plate supply to the switching tube.

Simultaneously the charged capacitors are scanned successively by the vacuum tube voltmeter when the contact arm I is in positions 1 to 10; the capacitors are discharged to ground successively through contact arm II in position 2 to 11.

(f) Crossing-rate Counter.

For the purpose of many investigations it is essential to determine how many times a certain level of the measured quantity is exceeded in a positive or in a negative direction. In order to determine that crossing rate, multivibrator stave V_3 and charging stage 11 are provided, which have not been mentioned yet. Their design is similar to the other stages; except that the charging circuit is actuated only momentarily when it is triggered by the multivibrator. Thereby the voltage across the capacitor C_{L11} is proportional to the number of times the measured voltage passed through a pre-set level which may be obtained by a ten-stage voltage divider.

Fig. 9 shows the schematic diagram of the electronic totalizer with the 100%-level circuit and one of the others shown completely. All other multivibrators and charging circuits are the same as the ones shown.

3. Switching mechanism and combination of several totalizers

In order to perform the measurements fully automatically with several totalizers, a switching mechanism is required additionally which produces records from up to ten totalizers successively on one graphic instrument (Fig. 10). Every one-half hour the chart drive of the recorder is turned on by a timing device through S_1 and the polarized relay R_1. After about three seconds the second contact of S_1 is closed, which produces the same switching sequence as described under (2.c) above, using R_2, stepping switch I-V, R_3, and the switching tube. Due to the greater bias of the tube (-300 volts) the various positions of the switch are now at approximately 30 second intervals. During this time the stepping switch contained in the totalizer is actuated through the second contact of R_2 and contact arm III, and completes its individual cycle. Contact arms I and II bring the vacuum tube voltmeter outputs across the recorder. Contact arm IV finally stops the chart drive in a position given by adjustment of S_2, using the polarized relay R_1.

B. Single Level Time Totalizer.

In many applications it is more important to obtain the percentage of time for which one definite level is exceeded, rather than the entire distribution with its median and variance. As examples, the level of field intensity which assures reliable communication, or the 99% and the 1% levels are of interest. Available data on short waves also show that in some cases the half-hourly standard deviation is practically constant. In these cases it would be uneconomical to use the rather involved apparatus described in (A) above. Therefore a single level totalizer was developed, and its schematic diagram is shown in Fig. 11.

Preamplifier and multivibrator stages correspond to the ones shown in (A. 2) above. The multivibrator turns on a synchronous motor if a pre-set voltage is exceeded. This voltage may be adjusted by a 10-position switch. The synchronous motor drives a counter with 10,000 counts per hour. It starts and stops practically instantaneously when triggered by the multivibrator (using the patented start-stop mechanism of Tritschler). A second synchronous motor turns off the counting mechanism, and itself, after exactly one hour's measurement period, and actuates an alarm bell. The percentage of time during which the pre-set level has been exceeded may be read directly. If the standard deviation is known, the complete distribution of the measured quantity may be determined from the single level percentage value.

C. Chart Analyzer for Determination of the Complete Distribution Curve.

Frequently it is not possible to determine quantities varying in space by use of the time totalizers described above. As an example, determination of field strength distributions over streets within a city is only possible by the use of a graphic recorder driven through a suitable coupling arrangement from the axle of the car used for making the measurements. This is due to the varying speed of the car. In order to evaluate chart records of this type, a scanning device was developed which is shown schematically on Fig. 12. The chart is moved under a laterally movable pointer by the use of a synchronous motor and a gear-box producing continuously variable speeds. The pointer is connected to a contact arm which controls the cut-off of the charging tubes in accordance with its position. If the pointer is made to follow the curve on the chart while the chart is run through the instrument at a constant speed, the capacitor charges at the end of the run are a measure of the distribution curve just as in (A) above. The constant chart speed is selected in accordance with the appearance of the record to be evaluated. Short and abrupt variations require a slow speed, while longer and more gradual changes may be followed at a faster rate. In accordance with the speed selected, and the length of the record to be evaluated, the sensitivity of the vacuum-tube voltmeter may be adjusted by use of a table. Thereby the capacitor charge of the first level will always produce full deflection, and the other levels may be read directly in per cent for 100 scale divisions. The exterior appearance of the device is shown on Fig. 13.

D. Two-level Evaluation Device.

For point-to-point microwave and U.H.F. relays the received field strength is normally reasonably constant. Slow variations of small amplitude are immaterial as far as the use of the link is concerned, and thus not interesting. However, unusual weather conditions, surface-based inversions, or the formation of ducts may produce sudden increases or fades of the received field strength values 5/, which have to be investigated for operational purposes, or in the interest of propagation research. Use of the devices described above would be uneconomical. Instead, the field received at the various receiving stations is recorded graphically in the normal way, and the recording charts are then evaluated by use of the "two-level evaluation device."

The appearance of this device is similar to the one discussed in (C) above. It is shown on Fig. 14. The recording chart is guided below two adjustable pointers, and the chart speed may be controlled by a foot pedal over a considerable range while the evaluation is in progress. Evaluation is done by the use of three mechanical counters. One is permanently coupled to the chart drive, and supplies the 100% value. The two others are turned on and off by two push buttons located to the right and to the left of the recording chart.

As an example the pointers may be adjusted so that the left one corresponds to a minimum measuring value, and the right one indicates short-time values greater than a pre-set high level. During the process of analysis the left button is pushed when the curve to be evaluated passes to the left of the left-hand pointer, and the right button is pushed when the curve passes to the right of the right-hand pointer. From the counters the percentage values of time are obtained (after dividing by the 100% value) for which the pre-set levels were exceeded. The foot-pedal operated speed control enables the operator to obtain very precise on and off switching of the counters when the critical levels are reached, whereas at other times the chart may be advanced quite rapidly.

Similarly, setting of both pointers close together enables the evaluator to investigate any small portion of the distribution curve, which may be of special interest. As an example, point-to-point communications require that value of field strength which is exceeded for 99% of the time; in the study of interference fields the 1% of-the-time level is of interest. The pointers may be set above and below a rough estimate of the desired value, and the desired level percentage is determined easily by interpolation or extrapolation of the measured values.

The devices were assembled and built in the shops of the Central Communications Laboratory. The authors wish to acknowledge especially the efforts and first-class workmanship of Messrs. Eichhoff and Lubrich.

Concluding Summary

This paper first discusses the normal probability distribution and its parameters median and standard deviation, and then describes four devices designed for statistical evaluation of radio wave propagation measurements. These devices consist of a time totalizer which produces a distribution curve automatically every half hour, a single level time totalizer for less demanding applications, and corresponding to each of the two devices, a chart analyzer for determination of percentage values at one or two levels. By the use of the device most suitable to a given evaluation task, the otherwise substantial workload connected with the analysis may be reduced to a minimum.

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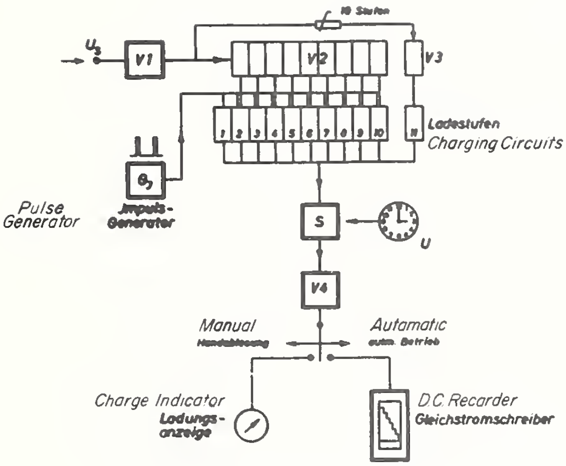


Fig. I SCHEMATIC DIAGRAM

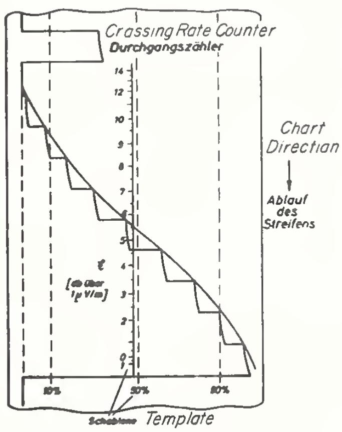


Fig 2 RECORDING CHART WITH STEP FUNCTION

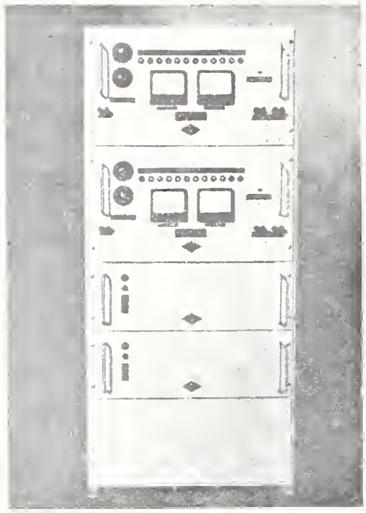


Fig. 3 EXTERIOR OF TWO RACK-MOUNTED TOTALIZERS

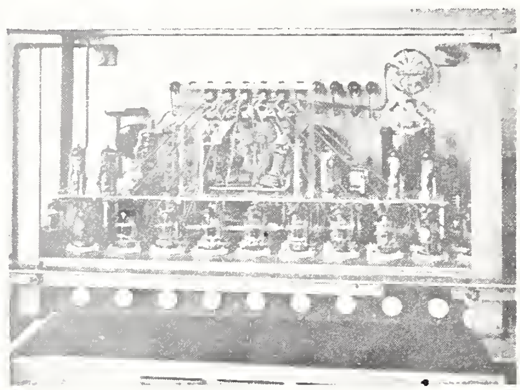
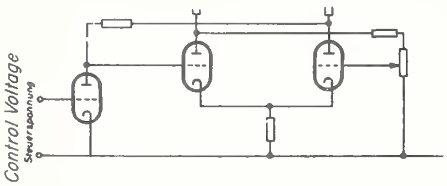


Fig. 4 INTERIOR VIEW

Fig. 5 MULTIVIBRATOR STAGE



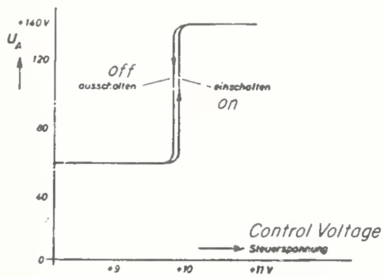


Fig. 6 MULTIVIBRATOR CHARACTERISTICS

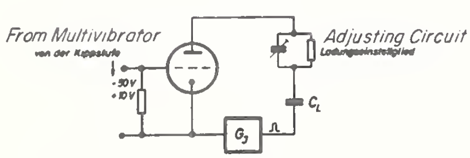


Fig. 7 CHARGING STAGE

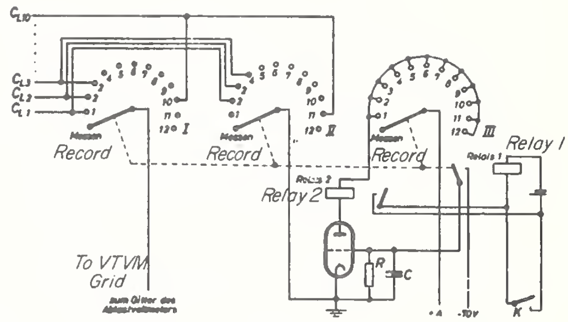


Fig. 8 AUTOMATIC STEPPING SWITCH

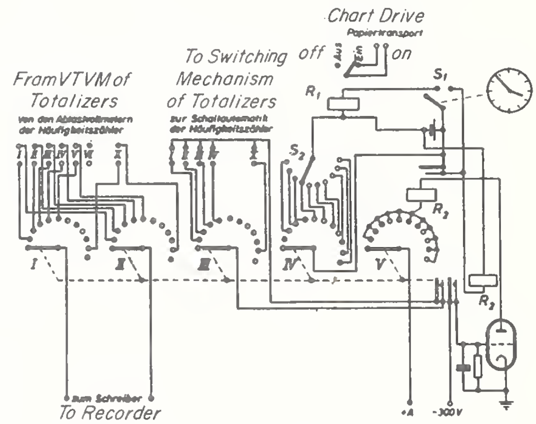


Fig. 10 SWITCHING MECHANISM FOR SIMULTANEOUS OPERATION OF SEVERAL TOTALIZERS

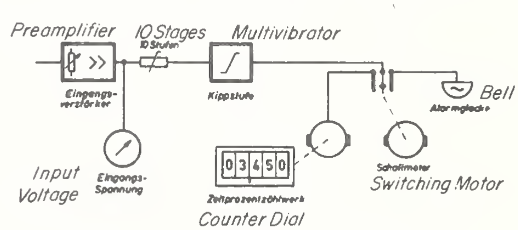


Fig. 11 SINGLE STAGE TOTALIZER

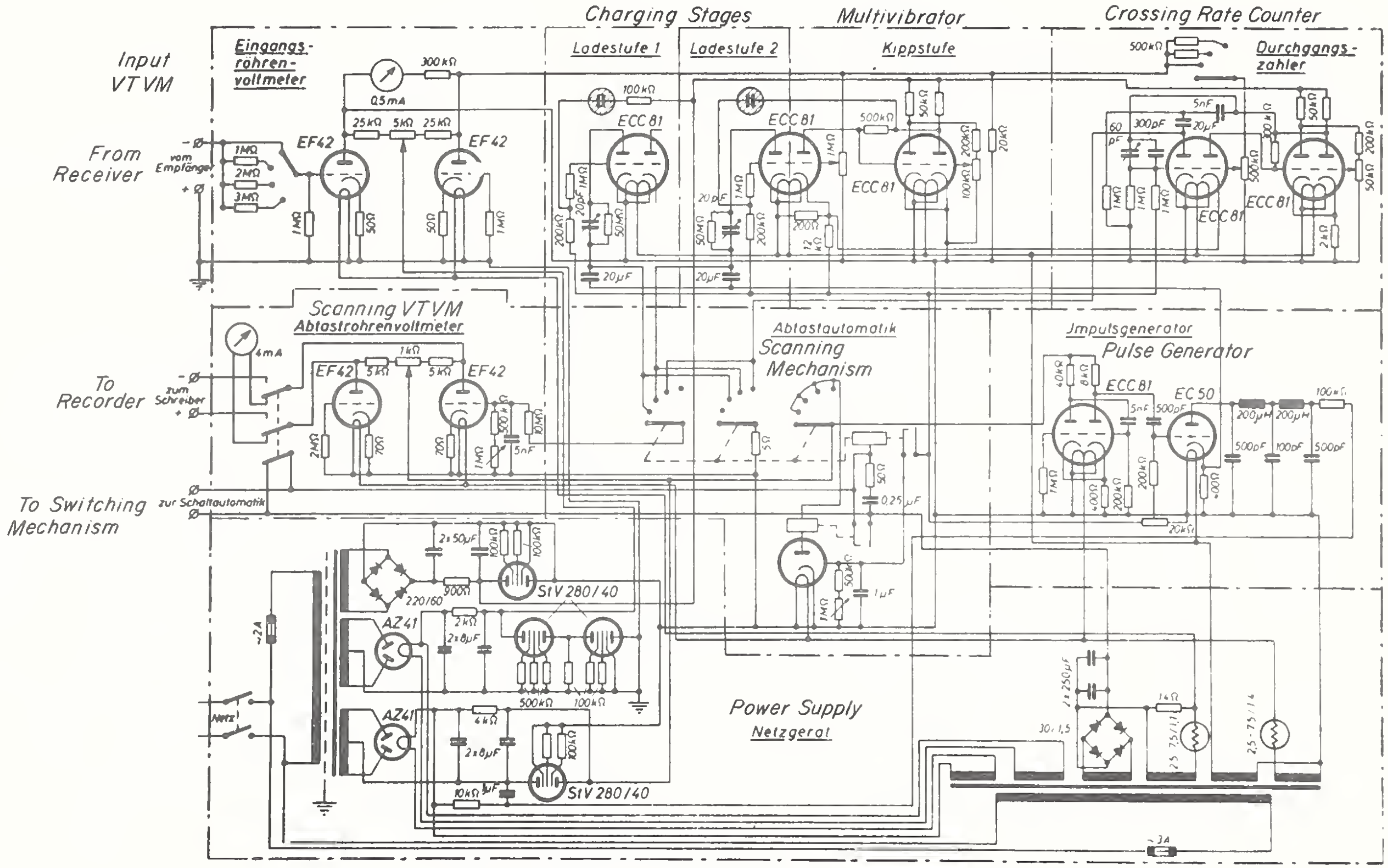


Fig. 9 COMPLETE TOTALIZER CIRCUIT DIAGRAM

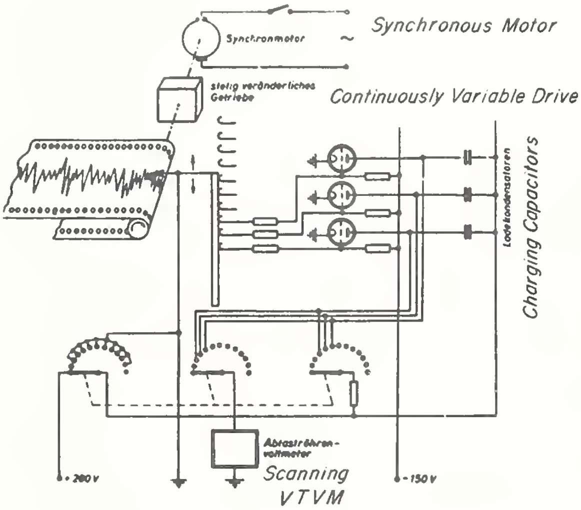


Fig. 12 BASIC CIRCUIT OF ANALYZER

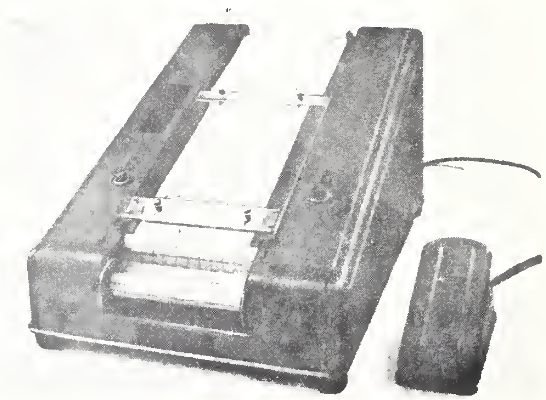


Fig. 14 TWO-LEVEL EVALUATING DEVICE

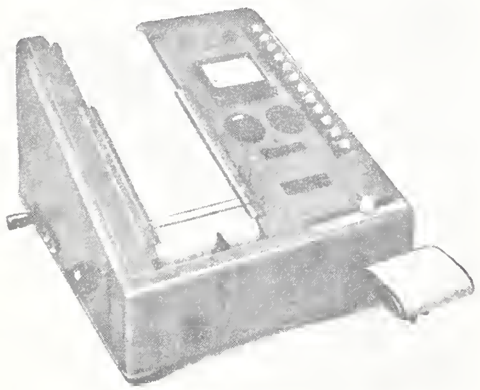


Fig. 13 EXTERIOR VIEW OF ANALYZER

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