

A Pulse Height Analyzer with an Electron Beam Tube

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A pulse height analyzer with an electron beam tube is described. The apparatus can sort into 20 channels positive pulses with amplitudes up to 100 volts, a rise time greater than 0.1 microsecond and a duration less than 30 microseconds. With a counting rate of 17,000 counts per minute, the loss is approximately 1%. The stability of the thresholds of the channels $\sim 2\%$.

IN determining the energy spectra of elementary particles in nuclear physics, use is made of the method of measuring the heights of voltage pulses which are produced by the particles in an ionization chamber or some other detector.

If the pulses are fed into a non-linear element, for example, a diode with suitable bias, then only those pulses with amplitudes larger than this bias will pass and actuate a registering device. Changing the bias gives the curve of $n(E)$, where n is the number of pulses in a definite time whose amplitudes exceed the bias $E(V)$. After differentiating, the differential distribution is obtained, which shows how many pulses Δn are passed within the bias interval ΔE . Since the measurement of a number n has an associated root mean square error $n^{1/2}$ because of the statistical character of the emergence of the pulses, then the error of the resultant $\Delta n = n_1 - n_2$, obtained in the time 2τ is determined by the expression $(n_1 + n_2)^{1/2}$. If two diodes, whose biases are different by $\Delta E(V)$, are used at the same time, then pulses whose amplitudes are greater than $E(V) + \Delta E(V)$ will be registered by both channels. The statistical fluctuations in the rate of emergence of these pulses will effect both channels identically. Because of this it is possible to eliminate the number of pulses counted by both channels by simple subtraction. After the lapse of time τ we have $\Delta n = n_1 - n_2$ with a root mean square error $(n_1 - n_2)^{1/2}$. From these considerations we see the advantage of a differential analyzer which automatically registers the number of pulses that pass through it in a channel of width ΔE .

Any analyzer has a shaping section in which incoming pulses of different forms, rise times of the leading edge, and duration, are transformed into pulses with shapes most suitable for sorting by a given analyzer. In addition, there are the sorting elements and finally the registering devices. The

latter must register only the emergence of a pulse, i.e., they do or do not operate. Thus variation in the voltage supplied to the circuit and the resulting variation of the value of the pulse, within a fairly large range, does not effect the accuracy of the operation of the circuit. The shaping section passes all incoming pulses without exception, and therefore slow small variations of the parameters of the circuit with time will not have a great significance with respect to an accurate analysis of the pulses in the spectrum. But in contrast to what has just been said, the sorting elements of the analyzer have exacting requirements relative to stability and accuracy of operation. Here to a certain degree, a common change in the bias of all channels can be tolerated, but an arbitrary change of the width of an individual channel is completely inadmissible. Therefore, every effort is directed toward the selection of such sorting elements, that if they vary, will reduce this effect to a minimum. Various designs of analyzers differ from one another basically in their sorting elements.

The pulse analyzer described below uses an electron beam tube to sort pulses into 20 channels¹⁻⁴. With its help it is possible to determine the pulse height spectrum of pulses having a rise time of less than 5 microseconds and greater than 0.1 microsecond. However, when necessary, the upper limit can be easily extended. The duration of the pulses should not be greater than 30 microseconds. The amplitudes of the pulses can vary from 0 to +100 volts.

The incoming pulse (Fig. 1) is transformed so that the amplitude of the transformed pulse is

¹ W. E. Glenn, Jr., *Nucleonics* 4, No. 6, 50 (1949)

² W. E. Glenn, Jr., *Nucleonics* 9, No. 6, 24 (1951)

³ D. A. Watkins, *Rev. Sci. Instr.* 20, 495 (1949)

⁴ E. W. Titterton and R. S. Wilson, *J. British Inst. Radio Engr.* 13, 173 (1953)

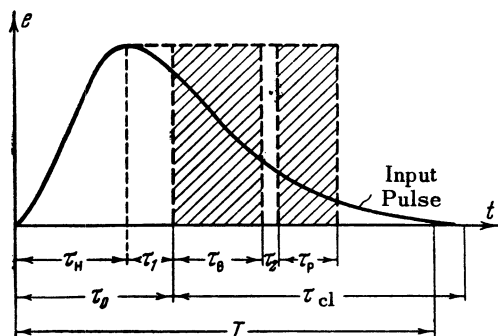


Fig. 1. The time cycle of the registration of a pulse (schematic): τ_H is the total rise time of the pulse, τ_p is the charging time of the "storage" capacitance, τ_{cl} is the time during which the input of the analyzer is clamped.

proportional to the amplitude of the incoming pulse e , and remains constant for a certain interval of time $\tau_1 + \tau_v + \tau_2$. After transformation, the pulse is applied to the deflecting plates of the electron beam tube. The electron beam, usually cut off by a negative bias, is intensified for the time τ_v by a pulse which is fed to the control grid of the electron beam tube at a time τ_0 after the start of the input pulse. In this way the beam,

whose deflection is proportional to the amplitude of the input pulse, falls on the collector plates. The charge carried by the beam for the time τ_v is collected only by that plate whose position corresponds to the given deflection of the electron beam. An amplifier is connected to each collector plate, which amplifies and lengthens the resulting pulse so that it can actuate a mechanical register. The general arrangement of the analyzer is shown in Fig. 2 and Fig. 3.

After passing through a neutralized diode discriminator, which is supplied by a battery (Fig. 4), and the input clamping circuit (T_3, T_4), the pulses are fed to a cathode follower and charge the $200 \mu\text{f}$ condenser through tube T_6 (a type 6Zh4 connected as a diode) to the amplitude of the pulse. The ungrounded side of this so-called "storage" condenser is controlled by the high resistance cathode follower T_8 (a type 6ZhZP).

This tube works with its heater at low temperature (the heater voltage is 4 volts) and has a plate current ~ 50 microamperes; its grid current is 10^{-10} amp, so that in the interval of time after charging, and until the appearance of the following pulse, the capacitance discharges an insignificant amount. It is necessary to supply the heater of this tube as well as that of diode T_6 by a battery. After this, the pulse is amplified by an inverter and push-pull

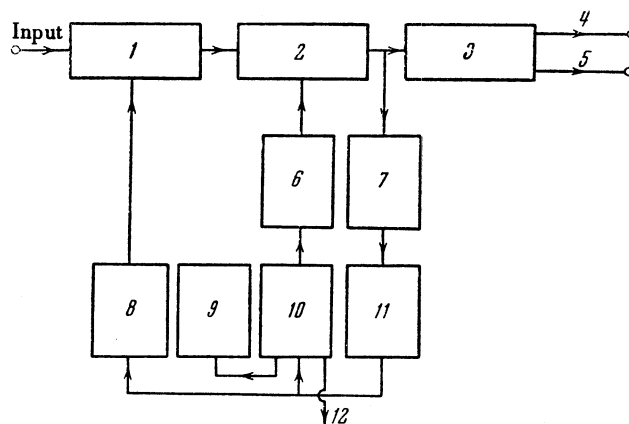


Fig. 2. Block diagram of the arrangement of the system. 1. discriminator for reducing the noise; input clamping circuit (T_3, T_4); 2. lengthening of pulses, charging "storage" capacitance; 3. push-pull amplifier; 4. and 5. deflecting pulses to Y plates of the analyzer tube; 6. delay line; 7. amplifier, trigger generator; 8. univibrator for clamping the input; 9. common pulse counter; 10. univibrator and stabilizer of the intensifying pulses; 11. delay of 2 or 6 microseconds; 12. intensifying pulse (to control grid of the analyzer tube).

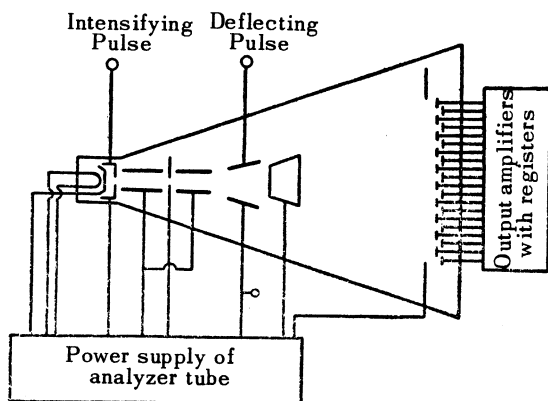


Fig. 3. Block diagram of the analyzer tube.

amplifier to a voltage of ± 140 volts, when the input pulse is 100 volts. This is sufficient to deflect the electron beam along the whole collecting system (Fig. 5). Because of the large amount of negative feedback, the amplifiers are very stable and have excellent linearity (Fig. 6). In obtaining this relationship, the input pulses used were obtained from a pulse generator and had rise times varying from 0.1 microsecond to 3 microseconds, and durations from 0.5 microsecond to 30 microseconds.

For the correct operation of a complete cycle of sorting and registering, certain auxiliary pulses are required (Fig. 1). Their generation must be started by each input pulse which passes through the shaping circuit. Since the amplification of very short pulses to a value sufficient for reliable starting of the trigger is linked with known difficulties, a lengthened pulse of duration ~ 13 microseconds from the cathode of tube T_9 , rather than the input pulse, is fed into the input of the auxiliary circuit, which consists of an amplifier and a Schmitt trigger. After a delay time τ_0 (Fig. 1) from the beginning of the input pulse, an intensifying pulse of length τ_v must be supplied to the control grid of the electron beam tube, and a pulse of length τ_{c1} must be supplied to the clamping circuit of the input. This delay is obtained from a univibrator with a cut-off time of 2 or 6 microseconds.

For input pulses with a rise time of less than 1 microsecond, a delay of 2 microseconds is chosen, and for slower rising pulses a delay of 6 microseconds is chosen. Special care is given in obtaining the intensifying pulse, since its stability with time, and likewise stability in amplitude, determines, to a certain degree, the stability of the

operation of the analyzer. A pulse of length 7 microseconds generated by a univibrator with cathode coupling, after inversion, is fed by direct coupling to the grid of the stabilizing tube T_{30} . The value of the pulse at its plate is determined by the current flowing and the value of the plate load resistor (Fig. 7 and Fig. 8). Because of the necessity of connecting the circuit to the electron beam tube by a cable of approximately 1 m in length, another cathode follower T_{31} is included. The pulse from the plate of tube T_{29} is also fed, after differentiating, through a line with a delay of 0.8 microsecond (time τ_2 in Fig. 1), and a cathode follower, to tube T_7 , which discharges the "storage" condenser (Fig. 9). The pulse for the input clamping is produced by a univibrator in tube $T_{25/26}$ and has a length ~ 25 microseconds (Fig. 10). Thus, a pulse applied to the input of the analyzer at a time τ_0 after the first pulse will not cause a change in the amplitude of the latter. The probability of the admission of a second pulse within the time τ_0 after first pulse is very small and is, with a counting rate ~ 200 pulses per second and $\tau_0 = 2$ microseconds, $\sim 0.04\%$, and with $\tau_0 = 6$ microseconds, correspondingly, $\sim 0.12\%$. The univibrator generating the intensifying pulse also starts a common counter which is connected to the 20-fold scalers.

The electron beam tube is constructed from parts of an oscilloscope tube of domestic manufacture, type 13-L037, from which the part with the fluorescent screen is cut. The electron gun, together with the deflecting plates, is removed.

A new electron gun of the same type was constructed with the aid of a glass sleeve, since it was found that repeated activation of the oxide coated cathode formerly used did not give satisfactory results. The part of the sleeve which was cut away from the fluorescent screen was polished, and the cylinder was placed on a metallic base. The vacuum seal between the cylinder and the base was made with the aid of "pitseina". The collecting system is built up on this base. For shielding, the tube is surrounded by two iron sheaths. The collecting system consists of 21 collector plates of dimension 4×5 mm each. The collector plates are arranged in two rows, an upper and a lower. The effective widths of the lower collectors is determined by the distance between the upper collectors, because the lower collectors are a little wider than the upper ones. The deviation of the geometric widths of the individual collectors does not exceed 1%. The relationship between the position of the beam and the deflecting

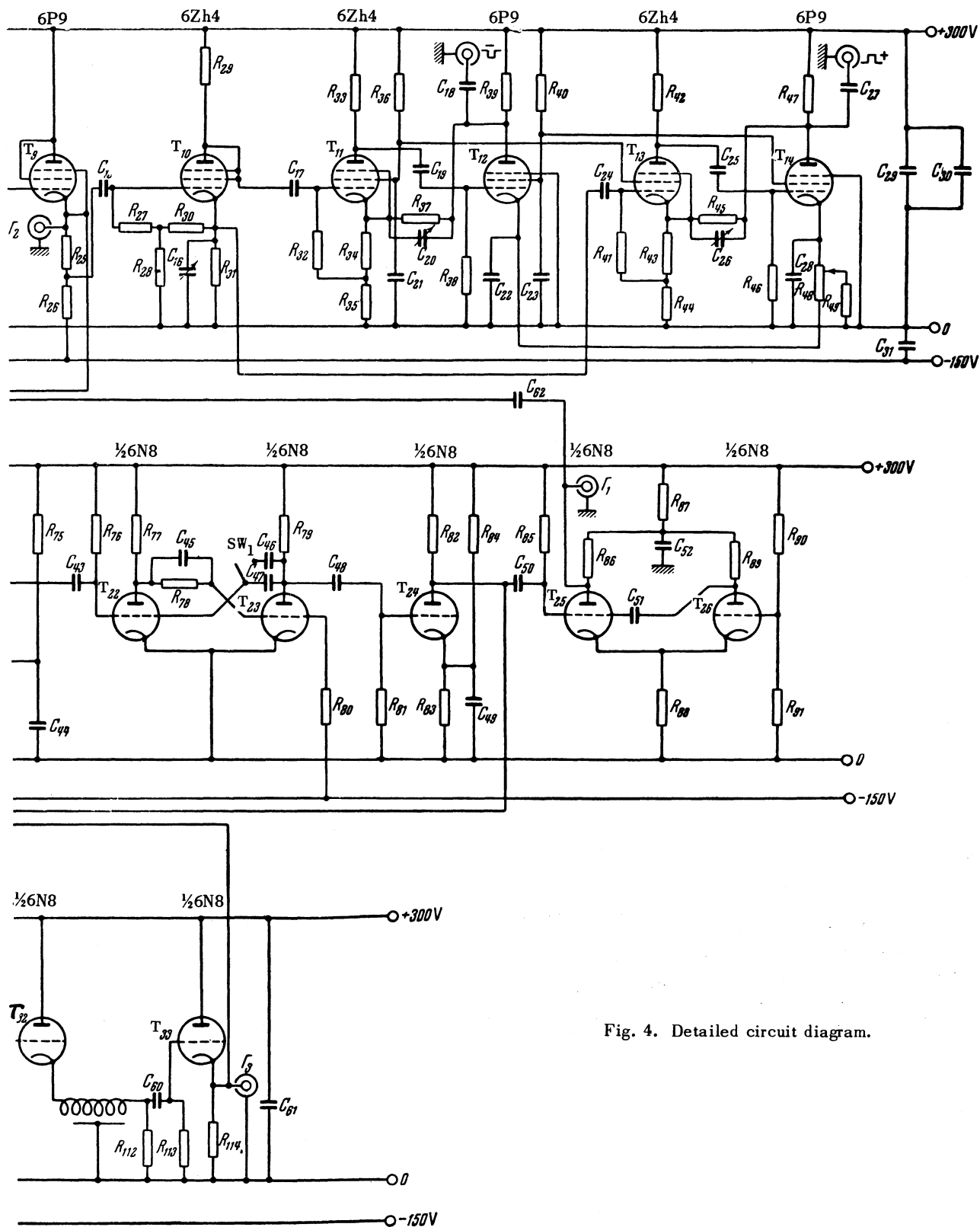
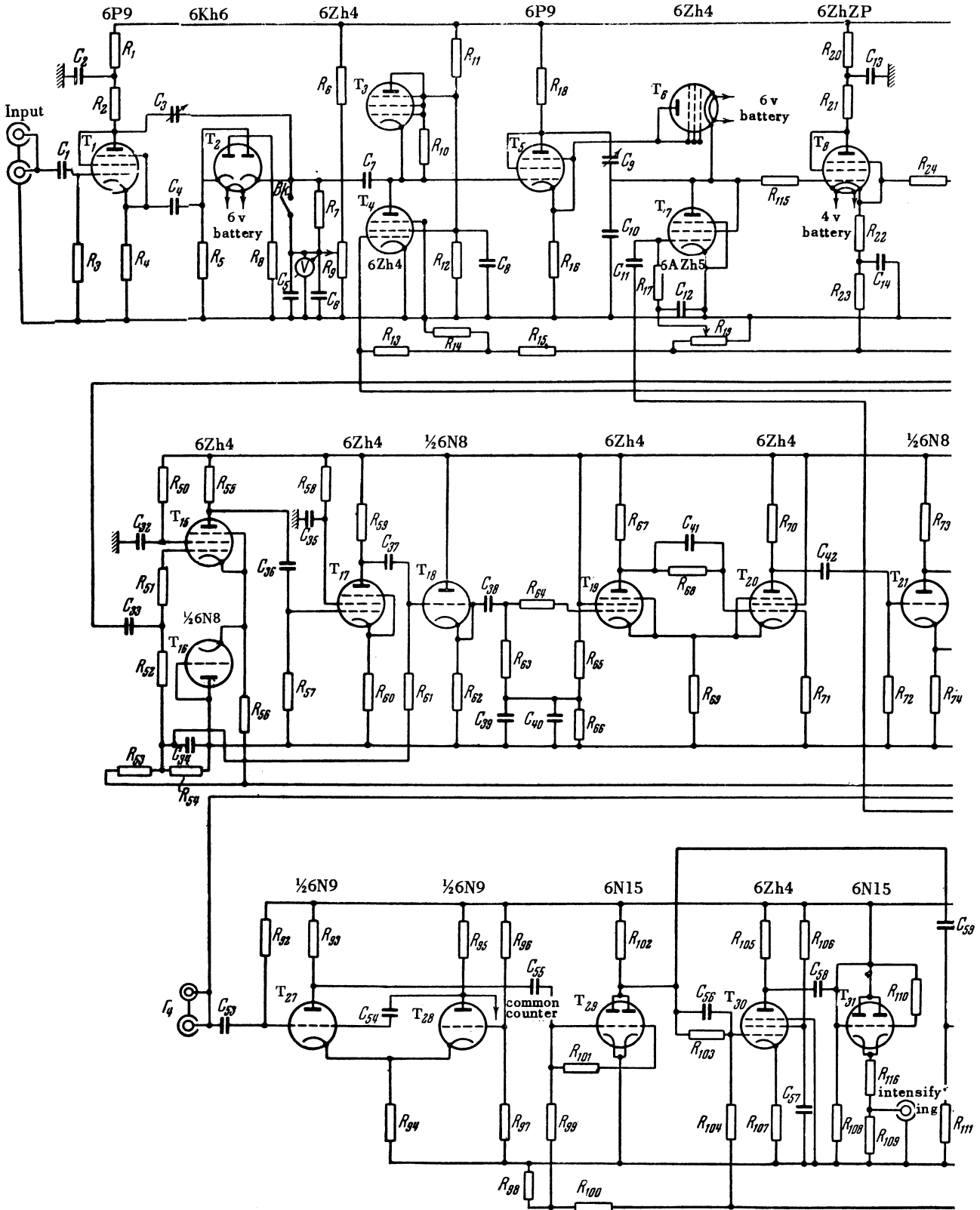


Fig. 4. Detailed circuit diagram.



Resistances *

R_1	1	1**	R_{30}	50	0.25**	R_{59}	10	2**
R_2	1	1	R_{31}	5.1	2	R_{60}	150 Ω	1
R_3	100	0.25	R_{32}	800	0.25	R_{61}	510	0.25
R_4	10	2	R_{33}	15	4	R_{62}	20	2
R_5	1 M Ω	0.25	R_{34}	120 Ω	0.25	R_{63}	1 M Ω	0.25
R_6	60	4	R_{35}	5	10	R_{64}	4,5	0.25
R_7	15	0.25	R_{36}	15	2	R_{65}	120	2
R_8	51	0.5	R_{37}	20	2	R_{66}	56	2
R_9	4.5 wire wound potentiometer		R_{38}	510	0.25	R_{67}	4	2
R_{10}	1 M Ω	0.25	R_{39}	5	10	R_{68}	100	1
R_{11}	41	4	R_{40}	10	10	R_{69}	10	2
R_{12}	2.2	1	R_{41}	800	0.25	R_{70}	10	2
R_{13}	100	0.25	R_{42}	15	4	R_{71}	60	1
R_{14}	36.5	0.25	R_{43}	120 Ω	0.25	R_{72}	50	0.25
R_{15}	100	0.25	R_{44}	5	10	R_{73}	20	2
R_{16}	10	2	R_{45}	20	2	R_{74}	10	1
R_{17}	100	0.25	R_{46}	510	0.25	R_{75}	150	2
R_{18}	2.2	2	R_{47}	5	10	R_{76}	300	1
R_{19}	100	type VK 0.5	R_{48}	10 Ω	wire wound	R_{77}	20	2
R_{20}	510	0.25	R_{49}	34 Ω	2	R_{78}	240	0.25
R_{21}	200	0.25	R_{50}	60	0.5	R_{79}	20	2
R_{22}	3 M Ω	1	R_{51}	50 Ω	0.25	R_{80}	200	0.25
R_{23}	510	0.25	R_{52}	510	0.25	R_{81}	10	0.25
R_{24}	50 Ω	0.25	R_{53}	100	0.5	R_{82}	20	2
R_{25}	8	2	R_{54}	8.25	0.5	R_{83}	10	1
R_{26}	20	2	R_{55}	10	2	R_{84}	10	2
R_{27}	510	0.25	R_{56}	30	2	R_{85}	800	1
R_{28}	1 M Ω	0.25	R_{57}	200	0.25	R_{96}	4	2
R_{29}	5.1	2	R_{58}	60	0.5	R_{87}	20	2

* If not specifically shown, resistances are given in kilohms.

** In watts.

Capacitances ***

R_{88}	2	1**	C_1	0.1	C_{32}	10
R_{89}	20	2	C_2	10	C_{33}	5000 $\mu\mu\text{F}$
R_{90}	300	1	C_3	5—30 $\mu\mu\text{F}$	C_{34}	1
R_{91}	15	1	C_4	0.03	C_{35}	10
R_{92}	390	0.5	C_5	0.015	C_{36}	5000 $\mu\mu\text{F}$
R_{93}	3	1	C_6	20	C_{37}	5000 $\mu\mu\text{F}$
R_{94}	2.2	2	C_7	200 $\mu\mu\text{F}$	C_{38}	1000 $\mu\mu\text{F}$
R_{95}	20	2	C_8	40	C_{39}	10
R_{96}	300	1	C_9	5—20 $\mu\mu\text{F}$	C_{40}	0.02
R_{97}	15	0.25	C_{10}	200 $\mu\mu\text{F}$	C_{41}	32 $\mu\mu\text{F}$
R_{98}	43	0.5	C_{11}	0.01	C_{42}	50 $\mu\mu\text{F}$
R_{99}	200	0.25	C_{12}	0.5	C_{43}	50 $\mu\mu\text{F}$
R_{100}	300	1	C_{13}	2	C_{44}	5000 $\mu\mu\text{F}$
R_{101}	100	0.25	C_{14}	2	C_{45}	32 $\mu\mu\text{F}$
R_{102}	3	2	C_{15}	0.01	C_{46}	30 $\mu\mu\text{F}$
R_{103}	100	2	C_{16}	7—45 $\mu\mu\text{F}$	C_{47}	25 $\mu\mu\text{F}$
R_{104}	53	1	C_{17}	0.01	C_{48}	50 $\mu\mu\text{F}$
R_{105}	4	2	C_{18}	0.01	C_{49}	5000 $\mu\mu\text{F}$
R_{106}	30	1	C_{19}	0.01	C_{50}	50 $\mu\mu\text{F}$
R_{107}	150 Ω	0.5	C_{20}	1—5 $\mu\mu\text{F}$	C_{51}	200 $\mu\mu\text{F}$
R_{108}	100	0.25	C_{21}	0.1	C_{52}	10
R_{109}	2	1	C_{22}	20	C_{53}	50 $\mu\mu\text{F}$
R_{110}	100 Ω	0.25	C_{23}	0.1	C_{54}	100 $\mu\mu\text{F}$
R_{111}	50	0.25	C_{24}	0.01	C_{55}	5000 $\mu\mu\text{F}$
R_{112}	3	2	C_{25}	0.01	C_{56}	10 $\mu\mu\text{F}$
R_{113}	1 M Ω	0.25	C_{26}	1—5 $\mu\mu\text{F}$	C_{57}	10
R_{114}	20	2	C_{27}	0.01	C_{58}	0.02
R_{115}	50 Ω	0.25	C_{28}	20	C_{59}	20 $\mu\mu\text{F}$
R_{116}	2	1	C_{29}	20	C_{60}	1000 $\mu\mu\text{F}$
			C_{30}	0.25	C_{61}	20
			C_{31}	0.1	C_{62}	0.1

*** If not specifically shown, capacitances given in μF .

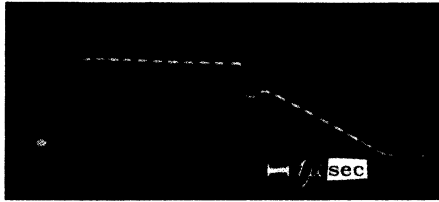


Fig. 5. Lengthened pulse of positive polarity, supplied to one deflecting plate of the electron beam tube.

voltages is linear over the whole length of the system. The collectors are surrounded by a frame-plate which simultaneously serves several purposes. It is coated with a fluorescent material which forms a convenient means of observing the focusing of the beam and its path upon deflection. On the axis of symmetry two lines are drawn which serve for checking the path of the beam along the collectors. A voltage of -750 volts with respect to ground is applied to the frame, i.e., with respect to the potential of the collectors. Secondary electrons knocked out by the beam from the aquadag coating of the collectors pass in this way into a strong retarding field and fall back to the collectors. Use of the secondary electron emission to amplify the collector current seems very doubtful to us because of the difficulty of securing its stability, even with special treatment of the collector material. Finally, the frame does not permit the beam to fall on the insulator which serves as the holder of the collectors; i.e., in the present case, on the plate of the surrounding glass.

The experimental electron beam tube is evacuated by a mercury diffusion pump, through a liquid-air trap, during the time of operation. The tube works satisfactorily with a vacuum of the order of 10^{-6} mm of mercury. The electron current in the beam was 10 microamperes with an accelerating voltage of 2000 volts and a bias on the control grid of 65 volts.

An amplifying channel is connected to each of the collectors (Fig. 11) which actuates a mechanical register. The collector is connected to the input of a cathode follower by means of a cable which has a double shield for reducing the effective input capacitance. To shield the collector completely from large signals in the following univibrator, and to prevent coupling from one operating channel to a neighboring one, the second half of the tube is used as an amplifier with a grounded grid. A potentiometer is used in its

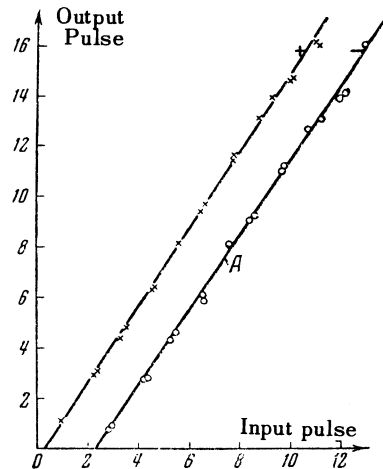


Fig. 6. Linearity of the assembled system (10 divisions = 100 volts). The input pulse is 4 microseconds, the delay is 2 microseconds, the intensifying pulse is 7 microseconds. The line A corresponds to negative pulses and is displaced to the right by 2 divisions for display purposes.



Fig. 7. Intensifying pulse.

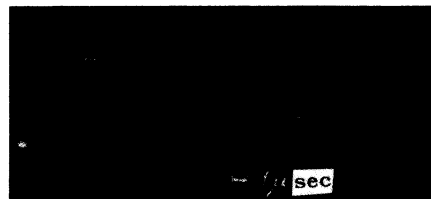


Fig. 8. That section, during which time the intensifying pulse is supplied to the control grid of the electron beam tube, is cut out on the lengthened pulse.

plate circuit, and serves to vary the threshold of operation of the channel. The following univibrator generates a pulse of duration ~ 10 microseconds, which starts a second univibrator. A pulse of 3 microseconds duration is taken from the latter univibrator and fed to the grid of the last

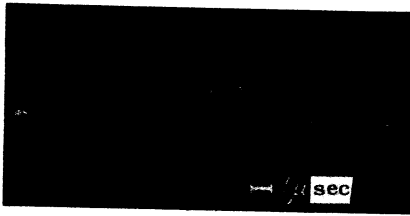


Fig. 9. The pulse which makes tube T₁₇ conduct and discharge the "storage" capacitance.

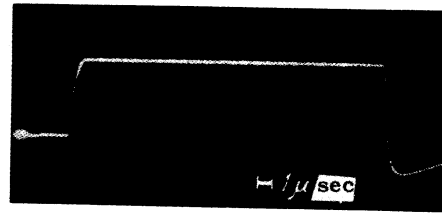


Fig. 10. The pulse which clamps the input.

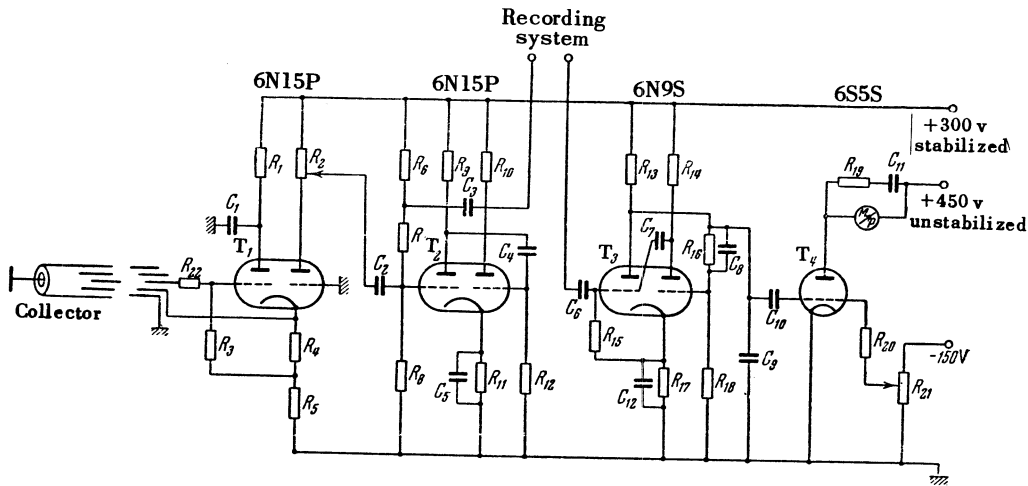


Fig. 11. Diagram of a collector channel

Resistances (in kilohms)				Capacitances (in μf)					
R ₁	30	1*	R ₁₂	50	0.25*	C ₁	5000	C ₇	1000
R ₂	500	potent. type VK 0,5	R ₁₃	39	1	C ₂	5000	C ₈	32
R ₃	100	0.5	R ₁₄	39	1	C ₃	50	C ₉	100
R ₄	1	1	R ₁₅	1 MΩ	0.25	C ₄	50	C ₁₀	0.25 μF
R ₅	1	1	R ₁₆	510	0.5	C ₅	100	C ₁₁	0.05 μF
R ₆	2,5 MΩ	0.5	R ₁₇	39	1	C ₆	100	C ₁₂	0.01 μF
R ₇	510	0.5	R ₁₈	200	0.25				
R ₈	100	0.5	R ₁₉	2.2	1				
R ₉	30	1	R ₂₀	200	0.25				
R ₁₀	15	1	R ₂₁	1 MΩ	potent type VK 0,5				
R ₁₁	7	0.5	R ₂₂	300 Ω	0,25				

* in watts

tube, in the plate circuit of which is a mechanical register of type S3 - 1M. The plate of this tube is connected to an unstabilized power supply. When necessary, a scale of 16 scaler can be connected between the two univibrators. In the present system ten such circuits have been provided.

If we consider the discrimination of the system, i.e., the electron beam tube, together with the

included amplifiers and univibrators in the collector channel, we obtain at the boundary of some collector plate

$$e_d = e_1 + \frac{e_2}{K_1} = e_1 + \frac{e_3}{K_1 K_2},$$

$$[\Delta e_d]_{\max} = \Delta e_1 + \frac{e_3}{K_1 K_2} \left[\frac{\Delta e_3}{e_3} + \frac{\Delta K_1}{K_1} + \frac{\Delta K_2}{K_2} \right],$$

where e_D is the overall threshold of the discriminator, e_1 is the threshold of boundary of the collector plate, for the tube considered, e_2 is the threshold of operation of the collector channel, e_3 is the threshold of operation of the univibrator in the collector channel, K_1 is the amplification coefficient of the tube from the deflecting plate to the collector and K_2 is the amplification coefficient of the input amplifier of the collector channel.

For the given instrument we have

$$K_1 \approx \Delta e_{\text{coll}} / \Delta e_{\text{plate}} = n i_0 \tau_v / C = 3$$

Here n is the number of incoming beam diameters passed over by the beam at the plane of the collectors when the deflecting voltage equals 1 volt, i_0 is the current in the beam, τ_v is the duration of the intensifying pulse and C is the input capacity of the collector channel, $K_2 \sim 25$ and e_3 is of the order of several volts. From this it follows that a variation of e_3 , K_1 and K_2 will not cause much variation of the threshold, and that the greatest attention must be given to the stability of operation of the tube. It is necessary to note that the power supplied to all circuits except the counters is produced by electronically stabilized sources. After adjusting the voltage stabilizers to the operating voltages, the stability of the output voltage in time $\sim 10^{-2}\%$. With unfavorable conditions:

$$\Delta e_3 / e_3 = \Delta K_1 / K_1 = \Delta K_2 / K_2 = 0.1,$$

$$\Delta E_0 / E_0 = 0.01$$

(where E_0 is the voltage accelerating the electrons in the tube) the stability of the thresholds of the channels is of the order 1 - 2%. The condition is verified by an experiment with the analyzer. If, after 1½ hours of warming up by all of the instruments, pulses with amplitudes within the limit of a given channel are supplied from a stabilized pulse generator, then in the course of 6 hours the departure of the beam and change of the operation of the analyzer cannot be observed. With the aid of the potentiometers installed in the plate circuits of the second tubes of the collector channels, it is possible to obtain overlapping of the electrical widths of the channels or to have a gap between them. The pulses within this gap will not be counted. The width of the gap can be set equal to 2% of the width of the channel. Since the time cycle of the registrations of one pulse ~ 35 microseconds, the loss of pulses equals 1% when the counting rate is 285 impulses per second, =17,000 impulses per minute. If it is necessary, the time can be decreased to ~ 15 microseconds.

Translated by F. P. Dickey
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The dependence of the isotherms ρ_{eff}/ρ on the angular velocity is shown in the Figure. The values of ρ_n/ρ are taken from the review of Lifshitz² (Fig. 210, p. 404).

Experimental investigation of the dependence of $\rho_{\text{eff}}(\Omega)$ provides, it seems to us, a definite possibility of finding the stratification of He II predicted by Landau and Lifshitz. In this case, in order that the meniscus effect does not distort the

results, it is necessary that the liquid fill the vessel completely.

¹ L. D. Landau and E. M. Lifshitz, Dokl. Akad. Nauk SSSR 100, 669 (1955)

² E. M. Lifshitz, *Superfluidity (Theory)*. (Appendix to the monograph of V. Keesom, *Helium*, 1949)

Translated by R. T. Beyer
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ERRATUM

Khartman, Leont'eva, Siniavskii and Vasil'ev, Soviet Phys. 1, 537-545 (1955). The two halves of the circuit diagram have been transposed. The half that appears on page 541 should be at the left; the half on page 540 should be at the right.