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An Electronic Drop Counter

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ABSTRACT

A new variation of the drop counter has been constructed. It functions almost completely electronically. The following advantages have been gained: By the use of modern electronics it has been possible to produce a drop counter that gives, independent of the size of the flow, an accurate measurement of the time interval between two consecutive drops. The drop counter can be coupled to an electronic recorder and by this means a true recording can be made regardless of the size of the flow. The integration time can be selected in 10 stages by means of a simple switch. This renders possible recording of both extremely low flows and flows as high as the drop technique can permit. The integration time can be chosen freely during the course of an experiment so that maximal differences between adjacent flow levels are always obtained. It will be possible to develop the instrument further in the direction of a completely electronic, linear unit, where consideration is also taken of the variations in size of the drop with different flow levels.

INTRODUCTION

There are probably few sections of the field of medico-physiological measurement technique that have so many methods as the quantitative determination of the blood flow. The explanation may be partly that each problem has demanded a special measurement technique, and the different methods have thus been devised so as to deal only with specific problems. There is no method of measurement today that can be used as a universal instrument in different types of blood flow determinations.

In studies on animals it is often suitable in short acute experiments to estimate the venous outflow from an organ in order to determine the size of the total blood flow per time unit, i.e. to cannulate the efferent vein and lead the blood to some measurement apparatus. An advantage here is that direct and accurate measurements are obtained. The choice of method depends upon what demands are placed concerning the time intervals required between each flow determination, and what flow levels are concerned. Several methods which give a more or less continuous evaluation of the blood flow have been developed (see summary by Green (6)).

With regard to low flows, an evaluation can be made with sufficient accuracy by simply counting the number of blood drops which leave the cannulated blood vessel per time unit. According to Fry & Ross (4) the volume of the drops will be independent of fairly large flow variations, provided that the viscosity is not changed to any large extent during the course of the experiment. This assumption is not absolutely correct, but the variation in drop size with the flow can be determined and by this means drop counting as a method can be made even more exact.

In the beginning the number of drops per time unit was counted visually. Later the number was recorded on a kymograph either by mechanical means or electrically, where the drop was allowed to close an electric circuit (5). These methods, however, do not give any continuous picture of the blood flow variations. Continuous flow recording was first made possible by the ordinate writer described by Fleisch (2, 3). This apparatus records automatically the time that elapses between two consecutive drops. Recording takes place when the drop closes an electric circuit. Lullies (10) described a similar time-ordinate writer, which records electrically the time interval between two consecutive impulses.

The disadvantage of these methods is that the surfaces between which the drop of fluid is to give contact often become coated as a result of electrolysis or clot formation, leading to uncertainty in the recordings.

A completely new principle was introduced with the drop counter described by Clementz & Ryberg (1). Each drop of fluid is allowed to intercept a beam of light which illuminates a phototube, thereby producing an impulse which after amplification initiates a relay which controls the recording device. The recording device consists of an ordinate writer similar in principle to that described by Fleisch (2, 3), and the recordings are made on a smoked drum. This writing device has a rather slow return to the base line, and the height of the recording is not, therefore, directly proportional to the time interval between the drops. This technique came into increasing use, however, after Hilton & Lywood (7) had described the principles of a drop chamber from which the blood is returned to the systemic circulation again. Subsequent refinements by Lindgren & Uvnäs (8) and Lindgren (9) in the construction of the drop chamber and its incorporation into the recording apparatus have further improved the technique of flow determination by drop counting.

The electromechanical drop counting devices which have been used hitherto for determining the blood flow by counting drops or measuring the interval between the drops have two main disadvantages, firstly that the recordings are made on a smoked drum, and secondly that their electromechanical components give undesirable side effects in the tracings, e.g. in the form of variable rates of return to zero level with the length of the recording. Nowadays electronic recording devices are used, and to be able to use the drop counting technique for blood flow determination a new construction of the counting unit is required, that can be connected directly to modern multi-channel writers for simultaneous recording with other variables. A new device has therefore been constructed, allowing electronic recording of the drop rate, adaptable to different types of recorders.

MATERIAL AND METHODS

Principles

The most important component in the construction and the part that transmits information for recording consists of an electronic integrator which is fed with a constant voltage. The integrator integrates the constant voltage according to the formula

$$V_o = -\frac{1}{R \cdot C}\int_{t_0}^{t_1} V_i dt$$

where V_o = output voltage, V_i = input voltage, R = integrator input resistance, C = integrator feedback capacitance, $t = t_1 - t_0$ = integration time, t_0 = integration start, and t_1 = integration stop.

The integrator input resistor R and the integrator feedback capacitor C are the components in the integrator circuit (Fig. 1) which together with the magnitude of the constant voltage determine that ramp function that is used for determination of the time intervals between the drops. The switch S, which has been realised in the form of a relay, connects the integrator to the constant voltage source. When the output voltage of the integrator has attained its maximal level, 10 V, a Schmitt trigger is initiated, which then delivers an output voltage to a simple form of OR-gate. This in turn activates the above-mentioned relay, which then cuts off the voltage source and discharges the integrator feedback capacitor C. If, however, the beam of light illuminating the photodiode is intercepted, the succeeding Schmitt trigger is initiated, whereby the one-shot stage reacts and transmits a short pulse to the OR gate. This then activates the relay stage to zero-set the integrator, whereby further upward movement of the voltage-time graph is interrupted before the maximal level is reached.

The integrator is thus controlled either by the immediately subsequent Schmitt trigger or by the one-shot stage of the photodiode. The Schmitt trigger has a zero-setting function only if the voltage changes on the integrator output amounts to 10 V. The one-shot of the photodetector reacts, on the other hand, if the light source has been intercepted, which then leads immediately to disengagement of the integrator and discharge of the integrator feedback capacitor.

The integrator is fed with a voltage of 1.0 V. Since C is constant but the value of R may be selected, it is

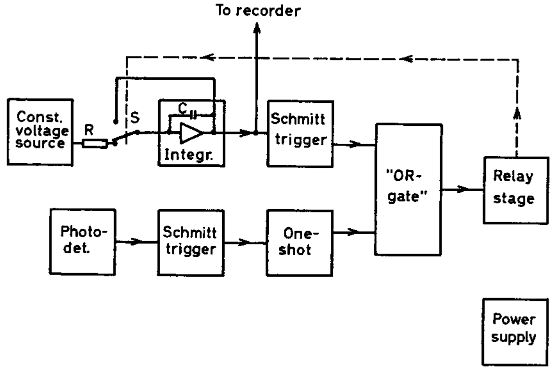

Fig. 1. Block diagram of the electronic drop counter. See text.

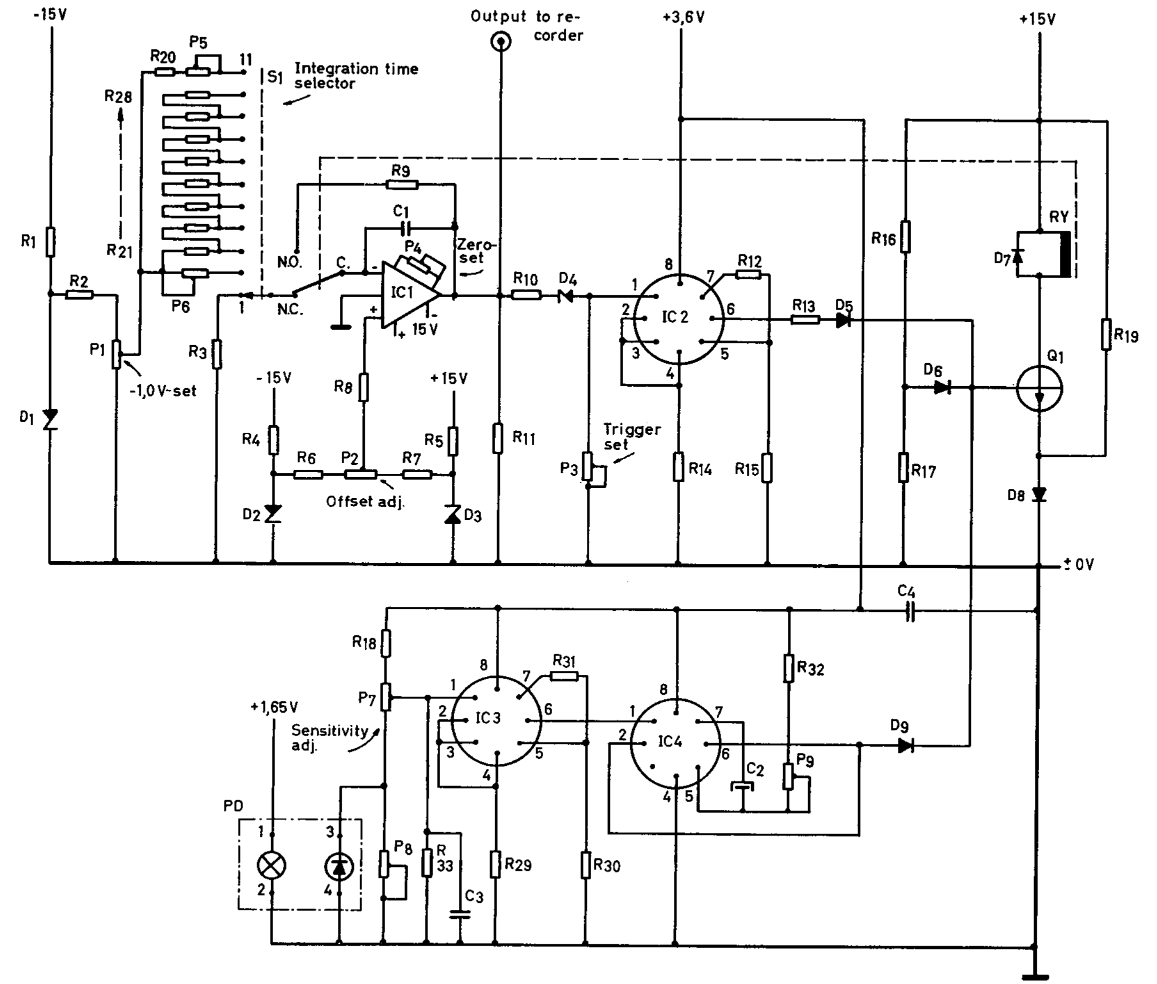

Fig. 2. Wiring diagram of the drop counter unit. See text.

possible by using different values of R to determine the time needed by the integrator to attain a certain voltage level at its output (max. 10 V). The greater the value of R, the greater t (see formula above).

Construction details

1. *Drop counter unit.* From the power supply a voltage of -15 V is fed to a Zener stabilizing circuit, consisting of a resistor $R1$ and a Zener diode $D1$, which gives a constant voltage of -5.6 V at the junction $R1$, $R2$, $D1$ (Fig. 2). This voltage is reduced to -1.0 V by a trim potentiometer $P1$ and a resistor $R2$. The integrator input resistance R consists of several resistors by means of which the value of R can be selected freely in 10 stages. When the integration time switch is in position 1 the integrator is disconnected. The resistors in the second and last stages of the switch are variable within fairly wide limits, in order to allow function within extreme flow ranges. The intermediate stage of the integration time switch is fixed at predetermined integration times which are selected between 0.5 and 12 sec. The integrator is built up of an operational amplifier IC1 furnished with an offset voltage balance potentiometer $P4$, and an offset current adjustment, consisting of a potentiometer $P2$ and two Zener diode networks which reduce the voltage from $+15$ V and -15 V to $+3.9$ V and -3.9 V, respectively. Added to these are an integration capacitor $C1$ and its discharge resistor $R9$. The relatively high maximal output voltage from the integrator which controls the following Schmitt trigger is reduced by a potential divider from 10 V to a level more suitable for the trigger, i.e. about 1.5 V; the potential divider consists of the resistor $R10$, a Zener diode $D4$ and a trim potentiometer $P3$, IC2 is a Resistor-Transistor-Logic (RTL) NOR gate, which with the aid of the resistors $R12$, $R14$ and $R15$ functions as a Schmitt trigger. $Q1$ is the transistor that controls the relay RY. This transistor, $Q1$, is activated either by the output from the above-mentioned Schmitt trigger via a resistor $R13$ and an insulating diode $D5$ or by the photo-

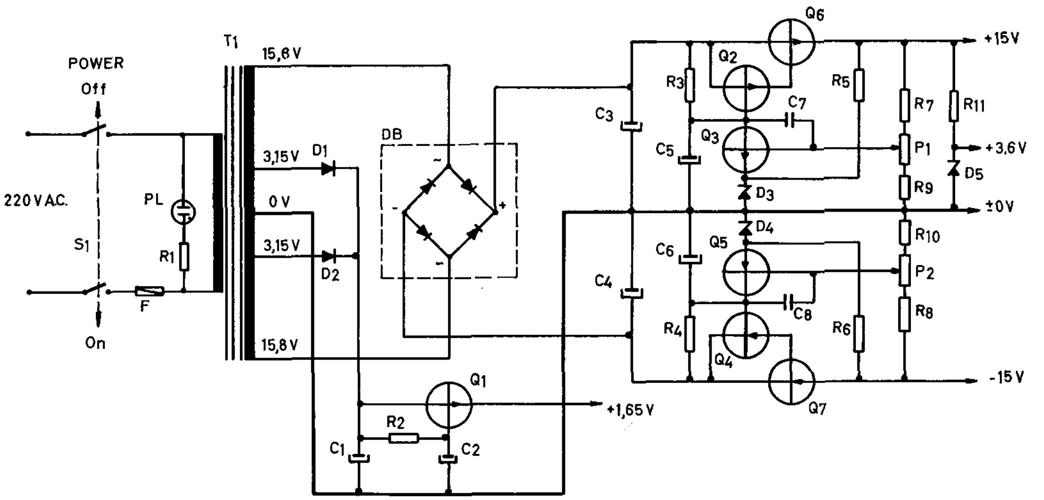

Fig. 3. Wiring diagram of the power supply. See text.

diode in the photodetector PD via the electronic circuits of the latter. The circuits contain the same type of electronic microcircuits as those of which the Schmitt trigger is constructed. The first part of this electronic coupling (IC3, *R*29, *R*30 and *R*31) comprises a Schmitt trigger of the same type as that which is controlled by the integrator as described above. This second Schmitt trigger is activated by the changes in voltage over the photodiode via a resistance network *R*18, *P*7 and *P*8 and *R*33. When a drop intercepts the beam of light, the resistance of the photodiode will increase and so also will the output voltage of the potentiometer *P*7. The Schmitt trigger (IC3, *R*29, *R*30 and *R*31) thereby reacts and delivers a voltage step to a second microcircuit IC4, which comprises here a one-shot together with a resistor *R*32, a potentiometer *P*9 and a capacitor *C*2. The one-shot stage delivers a positive pulse on being triggered. This positive pulse activates the base of the transistor *Q*1 via an insulating diode *D*9. The function of the capacitors *C*3 and *C*4 is to prevent irrelevant triggering of the above mentioned circuits. The base of the transistor *Q*1 is supplied with a bias network consisting of the resistors *R*16, *R*17 and an insulating diode *D*6. The OR gate in the block diagram (Fig. 1) mentioned previously consists of the insulating diodes *D*5 and *D*9. The transistor *Q*1 has a voltage of about 1 V at the emitter via a resistor *R*19 and a diode *D*8, so that the transistor will be properly cut off when it is not being activated by the integrator or the photodetector. A diode *D*7 constitutes a protector diode for the transistor *Q*1, preventing inductive voltage "kicks" from RY. The function of the relay, RY, is, on activation of *Q*1, to disconnect the integrator from the source of constant voltage and to discharge the integration capacitor *C*1 through *R*9.

2. *Power supply.* A quite ordinary power supply, fed from the mains (220 V a.c.) gives stabilized voltages of ± 15 V, + 3.6 V and + 1.7 V for suppling the IC circuits and for the photodetector lamp. See wiring diagram in Fig. 3.

RESULTS OF FUNCTION TEST

In order to illustrate the changes of voltage in the photodiode of the photodetector when a drop intercepts the light beam, and the way in which this voltage change blocks the integrator, a two-channel storage oscilloscope was connected, with one channel to the photodetector (points 3 and 4, Fig. 2) and the other channel between earth and the output to the recorder. The storage oscilloscope then showed the pattern of the voltage changes in the time during the passage of the drop through the beam, and the voltage at the output of the integrator. It is desirable that the system is made selective such that, for example, small splashing drops are not recorded. For this reason the voltage level at which the Schmitt trigger of the photodetector reacts has been adjusted by means of trim potentiometers *P*7 and *P*8 so that a fairly high voltage difference on the photodiode has to be attained before the subsequent Schmitt trigger will react. It is evident from Fig. 4 that the voltage change over the photodiode must amount to about 0.4 V before triggering of the relay stage will occur. The voltage change over the photodiode which is produced by interception of the light beam by a falling drop has a time extent which is more or less independent of the size of the flow. This is evident from Figs. 4 and 5, which illustrate

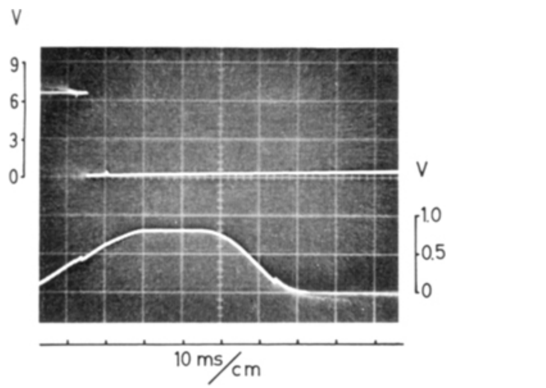

Fig. 4. Oscilloscopic recording of the output voltage of the integrator (upper tracing) and of the change in voltage in the photodiode produced by interception of the light beam in the photodetector by a falling drop (lower tracing). The figure shows the voltage change with time produced by the drop and the point at which triggering of the relay stage takes place (about 0.4 V). Flow 5 ml/min.

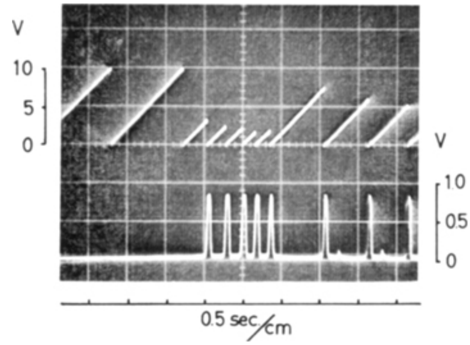

Fig. 6. The same type of oscilloscopic recordings as in Figs. 4 and 5. The figure illustrates varying output voltages from the integrator caused by varying drop rates. In the upper tracing a maximal output voltage is first seen, followed by varying levels. The lower tracing illustrates the voltage changes produced by the drops. After the 6th and 7th drop recordings in the lower tracing there is a spike which is due to a small partial drop. Owing to the fact that the trigger point lies at a higher level, this small drop was not included in the recording.

these voltage changes at flows of 5 ml/min and 30 ml/min, respectively. The maximal time difference between these flow sizes is 10 msec. This is probably associated with the variations in size of the drops at different flows. It can be stated, however, that the most important parts of the voltage changes, viz. the upstrokes of the pulses, are completely identical, i.e. that part of the curve where the triggering takes place is quite independent of drop size and flow level. It is also evident from these figures that the reset time for the integrator is short in relation to the integration time.

The drop counter has been constructed such that the integration time to the maximal output voltage can be regulated in 10 stages. The time of return from the maximal level is very short in relation to the integration time, and has an order of magnitude of a few microseconds. Owing to shortcomings in the recording device, however, the return time may be somewhat prolonged, but always to a practically constant value regardless of the size of the flow. On regaining the zero level from any output level, the integrator should start again immediately. In order to test that this does in fact occur, the same connection was made as described above with the same storage oscilloscope. Fig. 6 shows first a maximal output level, then

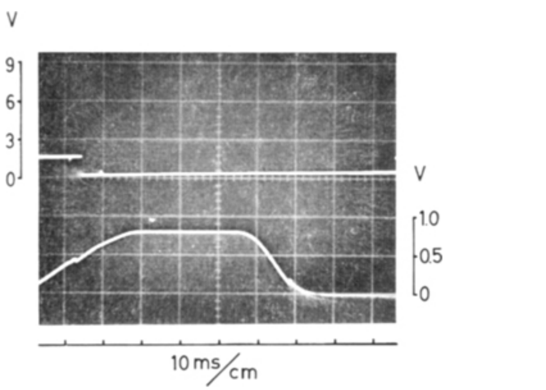

Fig. 5. Similar recording to that in Fig. 4. Flow 30 ml/min.

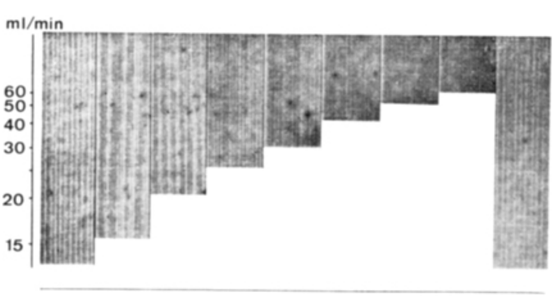

Fig. 7. Example of recordings of different, carefully calibrated flows. The same setting on the integrator is used (setting no. 3). Paper speed 2 cm/min.

follows a sequence in which the photodetector has interrupted the function of the integrator at varying time intervals. This also illustrates clearly the rapidity in return from the different output levels and the fact that the integrator starts again immediately and with no delay.

The drop counter described is used together with a UV recorder (Visicorder, Honeywell), where the output voltage of the integrator controls one of the galvanometers of the writer. Fig. 7 shows a flow recording in which varying, carefully determined flows have been used at the same setting of the integration time on the drop counter (the same R). By simply measuring the size of the recordings a picture of the flow level is obtained. The speed of the recorder determines the resolution between the individual drop recordings. In this case the paper speed was 2 cm/min. It can be seen in Fig. 7 that the resolution between different flow levels for each setting of the integration time decreases with increasing flows. By choosing a suitable integration time in each individual case, optimal differentiation between different large flows can always be achieved.

DISCUSSION

The basic aim was to construct an inexpensive modernized electronic counterpart to earlier time-ordinate writers, adaptable to electronic writers, using easily available components. The constructed pulse generator (drop counter) delivers pulses to the writer in the form of a voltage increasing linearly with time from 0 to a maximum of 10 V. When the maximal value is reached a zero position is assumed instantaneously and a new pulse starts immediately. If a blood drop intercepts the light beam in the photodetector the upward movement of the recording is interrupted and a zero position is assumed, after which a new recording is started immediately. The size of the blood drop varies with the size of the flow, but it is evident from the function test described above that the change in voltage that takes place in the photodiode when the light source is intercepted by a falling drop has a time extent that is more or less independent of the size of the flow (Figs. 4 and 5). The voltage change that has to take place in the photodiode to trigger the relay stage can be selected, and by this means it has been possible to make the system selective, so that, for example, small splashing drops or parts of drops separated from the whole cannot be recorded as a whole drop. The pulse generator gives output voltages that are directly proportional to the interval between each blood drop. In order to produce a direct proportionality between the amplitude of the emitted pulse and the time interval between the blood drops it is necessary that a new pulse should be emitted immediately after the foregoing pulse has either attained the maximal output value (10 V) or has been interrupted by activation from the photodetector. That this does in fact take place is clearly evident from the function test described above (Fig. 6). With a constant number of output pulses per time unit, the resolution between different adjacent flow levels will diminish with increasing flows. By the fact that the number of output pulses per time unit can be regulated in 10 stages, which in principle means a change of the flow scale, a suitable "scale" can always be chosen at each measurement in order to achieve maximal differentiation between different adjacent flow levels.

Owing to the use of modern electronic components in this construction it will be possible to develop the instrument further and produce a linear unit. It will also be possible to produce a construction that also takes into consideration the variation in size of the blood drops with different flow levels.

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LIST OF COMPONENTS

TIMER

Resistors 0.5 W

*R*1	470 ohm
*R*2	680 ohm
*R*3	10 k
*R*4	470 ohm
*R*5	470 ohm
*R*6	100 k
*R*7	100 k
*R*8	10 M
*R*9	22 ohm
*R*10	820 ohm
*R*11	5.6 k
*R*12	1 k
*R*13	1 k
*R*14	56 ohm
*R*15	1.2 k
*R*16	47 k
*R*17	1 k
*R*18	1 k
*R*19	2.2 k
*R*20	1.5 M
*R*21	810 k (*R*21 through *R*28 are especially selected to give desired integration time)
*R*22	660 k
*R*23	1.2 M
*R*24	450 k
*R*25	450 k
*R*26	680 k
*R*27	520 k
*R*28	500 k
*R*29	56 ohm
*R*30	1.2 k
*R*31	1 k
*R*32	2.7 k
*R*33	5.6 k
*P*1	500 ohm, trimpot
*P*2	50 k, trimpot
*P*3	1 k, trimpot
*P*4	50 k, trimpot
*P*5	1 M, trimpot
*P*6	1 M, trimpot
*P*7	10 k, trimpot
*P*8	10 k, trimpot
*P*9	50 k, trimpot

Capacitors

*C*1	0.1 μF, polystyrol, high grade
*C*2	1 μF, polystyrol
*C*3	10 nF, polystyrol
*C*4	20 nF, polystyrol

Semiconductors

*D*1	Zener diode, 5.6 V, 0.4 W, LVA 56
*D*2	Zener diode, 3.9 V, 0.4 W, 1N748
*D*3	Zener diode, 3.9 V, 0.4 W, 1N748
*D*4	Zener diode, 6.8 V, 0.4 W, LVA 68
*D*5	Silicon diode, BAY 72
*D*6	Silicon diode, BAY 72
*D*7	Silicon diode, 10D2, International Rectifier
*D*8	Silicon diode, 10D2, International Rectifier
*D*9	Silicon diode, BAY 72
IC1	Operational amplifier, SQ 10A, Nexus
IC2	RTL NOR gate, μL 914, Fairchild
IC3	RTL NOR gate, μL 914, Fairchild
IC4	RTL NOR gate, μL 914, Fairchild
*Q*1	Silicon transistor, MPS 6554, Motorola

Switches etc.

*S*1	Rotary switch, single pole, eleven way
RY	Hg-wetted reed-relay, Clare type HGS2M-50009
PD	Photo detector, Philips type AP 8603-185

POWER SUPPLY

Resistors 0.5 W

*R*1	300 k
*R*2	1.5 k
*R*3	10 k
*R*4	10 k
*R*5	2.2 k

*R*6	2.2 k
*R*7	1 k
*R*8	1 k
*R*9	330 ohm
*R*10	330 ohm
*R*11	330 ohm
*P*1	500 ohm trimpot
*P*2	500 ohm trimpot

Capacitors

*C*1	6 000 μF, 6 V, electrolytic
*C*2	1 000 μF, 6 V, electrolytic
*C*3	2 500 μF, 25 V, electrolytic
*C*4	2 500 μF, 25 V, electrolytic
*C*5	100 μF, 25 V, electrolytic
*C*6	100 μF, 25 V, electrolytic
*C*7	10 nF, 50 V, ceramic
*C*8	10 nF, 50 V, ceramic

Semiconductors

*D*B	Full wave, diode bridge, Varo type VS 247
*D*1	Silicon diode, 1N1487
*D*2	Silicon diode, 1N1487
*D*3	Zener diode, 5.1 V, 0.4 W
*D*4	Zener diode, 5.1 V, 0.4 W
*D*5	Zener diode, 3.6 V, 0.4 W
*Q*1	Silicon transistor, 2N5036
*Q*2	Silicon transistor, 2N3704
*Q*3	Silicon transistor, 2N3704
*Q*4	Silicon transistor, 2N3703
*Q*5	Silicon transistor, 2N3703
*Q*6	Silicon transistor, 2N3053
*Q*7	Silicon transistor, 2N4037

Switches etc.

*S*1	Power switch, double pole, single throw
*T*1	Mains transformer, 220 V primary, 4×6.3 V and 2×3.15 V, 0.5 A secondary
PL	Neon indicator lamp
F	Fuse, 0.5 A, slow blow