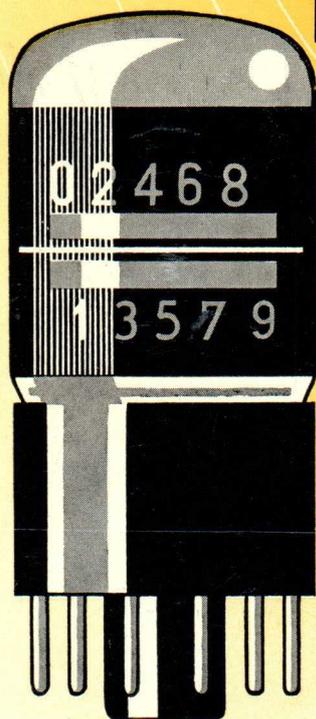
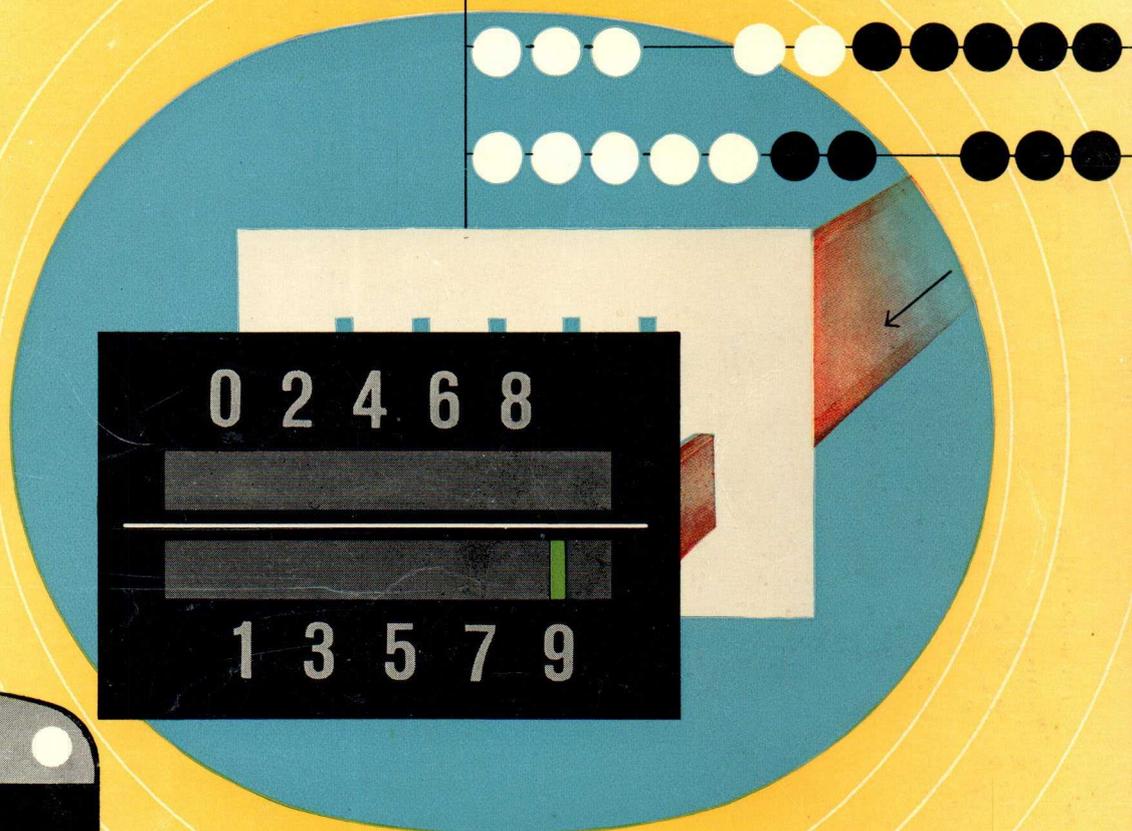


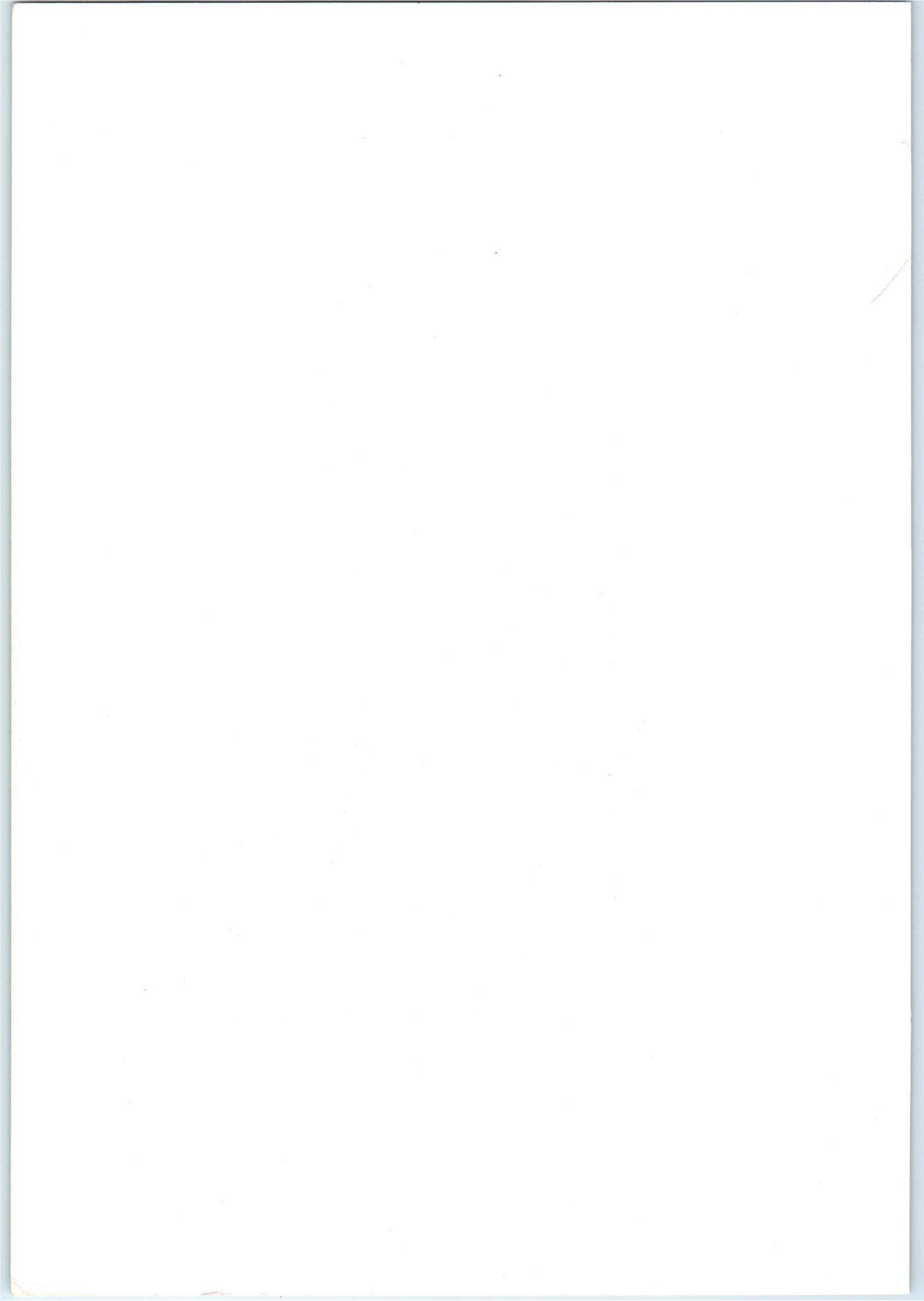
Revised edition

PHILIPS



E1T

Decade Counter Tube





The E1T Decade Counter Tube

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THE E 1 T DECADE COUNTER TUBE

INTRODUCTION

The E 1 T decade counter tube is a typical example of an electronic tube that has been specially designed for solving a particular problem, namely the counting and indicating of electric pulses, replacing in this way a considerable number of tubes with their accessory components, indication devices, etc.

The E 1 T is, in fact, a cathode-ray tube having roughly the dimensions of a radio receiving tube and operating with a supply voltage of 500 V or 400 V only. According to the number of counting pulses applied, its ribbon-shaped electron beam is shifted in a horizontal plane and passes in succession through the ten apertures of a cylindrical anode, thus impinging on the fluorescent layer with which the envelope is lined. The number of pulses can thus be read on the outside of the envelope, a rectangular luminescent spot appearing opposite one of the figures 0 to 9 indicated on the circumference of the bulb.

As the last position is passed, the beam is reset to its zero position and a counting pulse is applied simultaneously to the following tube. With several E 1 T tubes in cascade, any number can thus be directly read, the first tube counting the units, the second the decades, the third the hundreds, etc.

For counting pulses at different max counting rates, viz. 2000, 30 000 and 100 000 pulses per second, different circuits are described, together with the necessary auxiliary circuits required for counting pulses of different shapes.

By way of example, a detailed description is given of an application of the E 1 T for measuring exposure times of camera shutters.

The features of the E 1 T render this decade counter tube particularly suitable for those applications where small dimensions, high counting speeds and reliability of operation are required, such as in telecommunication, in modern computers, in radiation counter apparatus, in industrial counting devices and for indication, control and memory purposes.

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DESCRIPTION

Constructional details

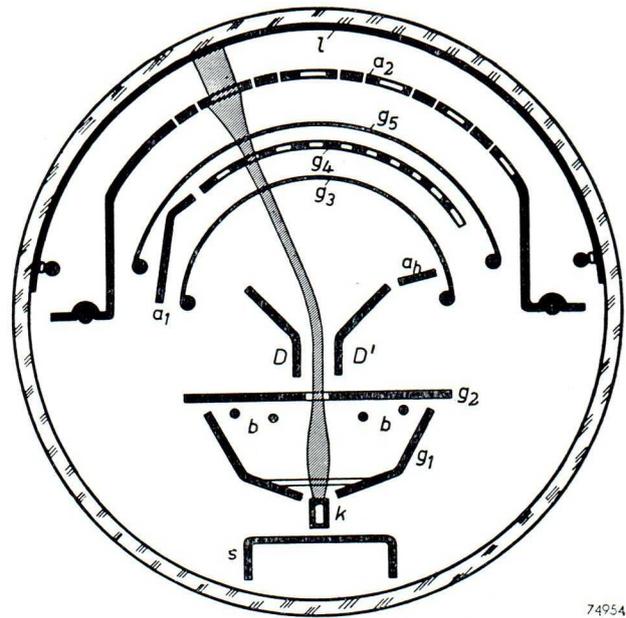
Fig. 1a shows the cross-section of the tube, and fig. 1b the diagrammatic representation. The letter references are as follows:

<i>f</i>	= heater
<i>k</i>	= cathode
<i>s</i>	= screen
<i>g</i> ₁	= control grid
<i>b</i>	= beam-forming electrodes
<i>g</i> ₂	= accelerating electrode
<i>D</i>	= left deflection electrode
<i>D'</i>	= right deflection electrode
<i>a_h</i>	= auxiliary anode
<i>g</i> ₃ , <i>g</i> ₅	= suppressor grids
<i>g</i> ₄	= slotted electrode
<i>a</i> ₁	= reset anode
<i>a</i> ₂	= anode
<i>l</i>	= conducting layer coated with fluorescent material.

The 6.3 V, 0.3 A heater *f* is mounted in a rectangular cathode *k*, the front of which is oxide-coated. The electron beam is given the required shape by the action of the control grid *g*₁, the internally connected beam-forming electrodes *b* and the accelerating electrode *g*₂.

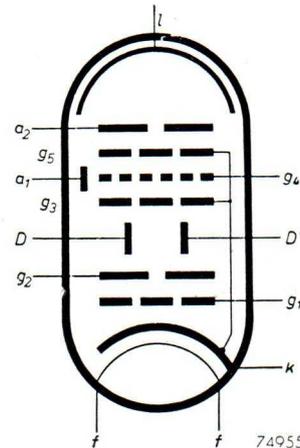
Since the deflection of the electron beam should take place in the horizontal plane only, the use of a narrow, ribbon-shaped beam of relatively great height offers substantial advantages. Space-charge effects are greatly reduced, for it will be clear that at given operating voltages the required total beam current and resolving power of the beam can be obtained at a much smaller current density with a ribbon-shaped beam than with a beam having a circular cross-section. A large current intensity is desirable because the duration required for an "electronic event" is, in general, proportional to the ratio VC/I , where V is the potential difference traversed by the electrons, I the current intensity and C the interelectrode capacitance. In order to keep this duration short, it is thus favourable that with a ribbon-shaped beam V can be kept relatively small, whereas I may assume a fairly large value. The small dimensions of the electrode system are, moreover, conducive to keeping the interelectrode capacitances small.

It has in this way proved possible to obtain a beam current of about 1 mA at a voltage of 300 V only, and to give the tube dimensions similar to



74954

a



74955

b

Fig. 1. (a) Cross section of the EIT counter tube. (b) Diagrammatic representation of the electrode system. For the letter references, see text.

those of normal receiving tubes (max. diameter 36 mm and max. height 83 mm). A further advantage of using a ribbon-shaped beam is that the electrode system need only be aligned accurately in one dimension, namely in the direction normal to the plane of the beam.

The beam, which is shifted from its initial position at the extreme right (position 0) to the left by applying positive pulses to the left deflection electrode *D*, has ten stable positions in each of which it passes through one of the ten apertures of the slotted electrode *g*₄. In these circumstances some of the electrons pass also through one of the corresponding narrow slots in the anode *a*₂ and impinge on the fluorescent material with which the

envelope is lined, so that a luminescent mark appears opposite the corresponding figure on the mask fixed on the outside of the envelope.

When the beam is deflected beyond the last stable position (marked "9"), it strikes the reset anode a_1 . The reset anode current pulse thus produced triggers a monostable (one-shot) multivibrator, by means of which the beam is reset to its zero position and a counting pulse is fed to the following EIT tube.

The suppressor grids g_3 and g_5 and the screen s , which are internally connected to the cathode, serve for suppressing any disturbing effects which might otherwise be caused by secondary emission from the slotted electrode and the anode. The auxiliary anode a_h , which is internally connected to the accelerating electrode g_2 (+300 V), serves for capturing undesired stray electrons. In order to prevent the fluorescent screen from being charged by the impinging electrons, it is applied to a conducting layer l which should be connected to the H.T. line.

Tube characteristic

When in the circuit shown in fig. 2 the anode current I_{a2} is plotted as a function of the anode and right-hand deflection electrode voltage $V_{D',a2}$, the static $I_{a2} = f(V_{D',a2})$ characteristic is obtained.

In order to explain the significance of this characteristic and the principle on which the opera-

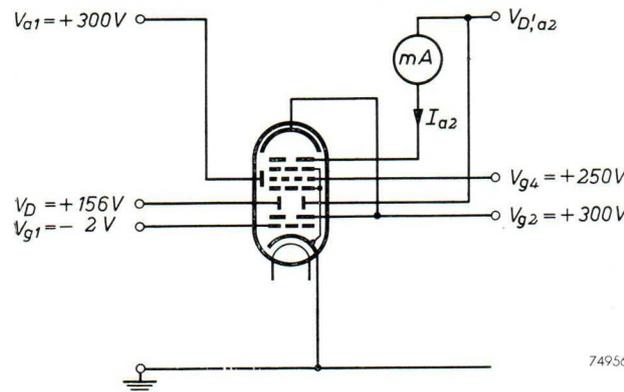


Fig. 2. Circuit for measuring the $I_{a2} = f(V_{D',a2})$ characteristic.

tion of this tube is based, the influence of the various electrodes on the electron beam will be discussed.

It will be assumed that the following voltages are applied in the circuit shown in fig. 2: slotted electrode voltage $V_{g4} = 250$ V; reset anode voltage $V_{a1} = 300$ V; left deflection electrode voltage $V_D =$

156 V; control-grid voltage $V_{g1} = -2$ V. The variable voltage $V_{D',a2}$ on the anode and right deflection electrode (these electrodes are externally interconnected) is assumed to have an initial value of 300 V. The anode current I_{a2} can be read on the milliammeter.

Provisionally it will be assumed that the slotted electrode g_4 is provided with a number of identical and equidistant, rectangular slots, as shown in fig. 3. In its initial position, the beam b will be

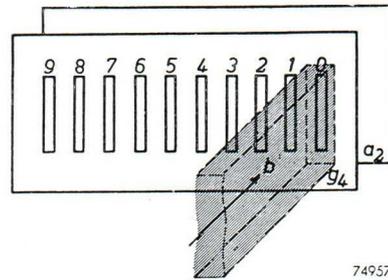


Fig. 3. Diagrammatical representation of a ribbon-shaped beam b sweeping over a slotted electrode g_4 interposed between the cathode and the anode a_2 .

focused on slot number 0, so that most electrons proceed towards the anode, and I_{a2} is at a maximum. A decrease of the right deflection electrode and anode voltage $V_{D',a2}$ will cause the electron beam to be less attracted by the right deflection electrode D' , so that it will move to the left and a steadily increasing number of electrons will be intercepted by g_4 . When the beam impinges on the centre of the area between slots number 0 and 1, the anode current I_{a2} is at a minimum, since only comparatively few electrons can now pass g_4 . A further decrease of the voltage $V_{D',a2}$ will shift the

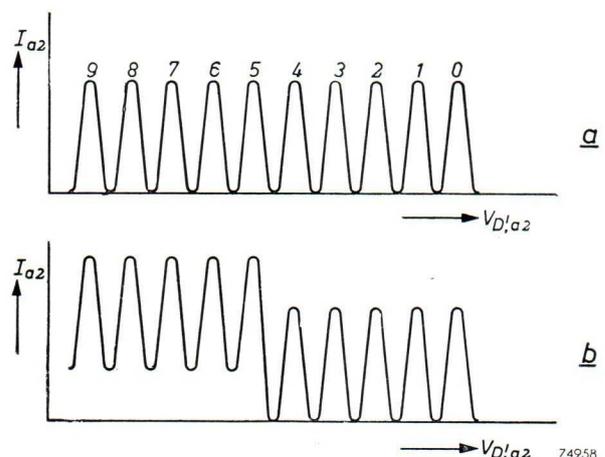


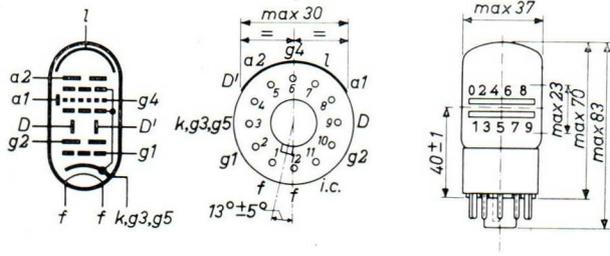
Fig. 4. (a) Hypothetical $I_{a2} = f(V_{D',a2})$ characteristic of a tube provided with a slotted electrode g_4 with identical, equidistant slots according to fig. 3. (b) As fig. 4a, but taking into account the presence of a horizontal slot at the bottom left.

beam further to the left, so that the electrons can pass slot number 1, and I_{a2} again increases.

Proceeding further on its way to the left, the action would be repeated as represented in fig. 4a. However, owing to a horizontal slot at the bottom left in g_4 , the anode current will not actually drop back to its initial minimum value once it has passed slot number 5, since some of the electrons will then

always pass through the horizontal slot, so that a curve similar to that shown in fig. 4b is obtained. To avoid trouble being experienced as a result of the asymmetrical deflection ($V_D = \text{constant}$, $V_{D'} = \text{variable}$) and the unavoidable defocusing which occurs when the beam is deflected, the slots in δ_4 are given different widths and the actual characteristic assumes a somewhat different form.

TECHNICAL DATA



- f* = heater
- k* = cathode
- g*₁ = control grid
- g*₂ = accelerating electrode
- D* = left deflection electrode
- D'* = right deflection electrode
- g*₃, *g*₅ = suppressor grids
- g*₄ = slotted electrode
- a*₁ = reset anode
- a*₂ = anode
- l* = conducting layer
- i.c.* = internally connected

TUBE OUTLINE AND ELECTRODE CONNECTIONS OF THE E 1 T COUNTER TUBE

Heater data

Supply

Heater voltage	
Heater current	

Indirect by A.C. or D.C.;
series or parallel supply

V_f	=	6.3 V ± 10%
I_f	=	0.3 A

Operating characteristics

Supply voltage	
Cathode current	
Cathode resistor	
Control-grid voltage	
Accelerating-electrode voltage	
Left deflection electrode voltage	
Slotted-electrode resistor	
Conducting-layer voltage	
Anode resistor	
Reset-anode resistor	
Accelerating-electrode current	

V_b	=	300 V *)
I_k	=	0.95 mA
R_k	=	15 kΩ ± 1%
V_{g1}	=	11.9 V *) ± 0.15 V
V_{g2}	=	300 V *)
V_D	=	156 V *) ± 1.5 V
R_{g4}	=	47 kΩ ± 5%
VL	=	300 V *)
R_{a2}	=	1 MΩ ± 1%
R_{a1}	=	39 kΩ ± 10%
I_{g2}	=	0.1 mA

Capacitances

Anode capacitance	
Left deflection electrode capacitance	
Right deflection electrode capacitance	
Reset-anode capacitance	
Control-grid capacitance	
Slotted-electrode capacitance	

C_{a2}	=	10.5 pF
C_D	=	3.5 pF
$C_{D'}$	=	3.8 pF
C_{a1}	=	4.9 pF
C_{g1}	=	6.8 pF
C_{g4}	=	7.7 pF

*) All voltages are quoted with respect to the chassis. Provided the ratios of the supply voltages are strictly maintained by using a suitably designed voltage divider consisting of 1% precision resistors, there is no need to stabilize the supply unit, voltage fluctuations of ± 10% then being permissible. It should be borne in mind, however, that during life a change may occur as a result of lack of stability of the resistors.
 $V_b = \text{max } 400 \text{ volt.}$

Sensitivity to magnetic fields

Care should be taken to prevent magnetic fields from upsetting the operation of the counter tube, the electron beam being sensitive to the influence of external fields. The flux density of these fields should not exceed 2×10^{-4} Wb/m² (= 2 gauss) in any direction.

Ambient illumination

In order to obtain a clear reading, the ambient illumination should range from 40 lux to 400 lux, to be measured by means of a luxmeter, set up vertically. At too low a value of the ambient illumination, it may become difficult to read the figures

on the masks of the counter tubes, and some inconvenience may occasionally be experienced by the two neighbouring spots showing some fluorescence. When, on the other hand, the ambient illumination exceeds 400 lux, it may become difficult to discern the luminescent spot.

Mounting position

Any, except with the tube horizontal and the fluorescent screen downward.

Socket

Duodecal socket type 5912/20.

GENERAL CONSIDERATIONS ON THE APPLICATION

Stability of the beam

The operation of the tube will be explained on the basis of the circuit shown in fig. 5, in which a load resistor R_{a_2} of $1\text{ M}\Omega$ is included in the common anode and right deflection electrode lead. The load line of this resistor has been drawn in the actual tube characteristic plotted in fig. 6a, which is valid for the voltages stated at the beginning of the preceding section, the H.T. supply voltage being 300 V.

It will be assumed that the beam is in the position corresponding to point *a* of fig. 6a, and the voltage on the left deflection electrode *D* is increased so slowly that the influence of the capacitance *C* shown in fig. 5 can be disregarded. This capacitance represents the sum of C_{a_2} (capacitance of the anode with respect to all other electrodes), $C_{D'}$ (capacitance of the right deflection electrode with respect to all other electrodes) and the unavoidable wiring and stray capacitances. The electron beam will then tend to move to the left, but this results in the beam being intercepted to a greater extent by the slotted electrode g_4 , so that the anode current decreases, and the anode voltage (and thus also the voltage on the right deflection electrode *D'*) increases by

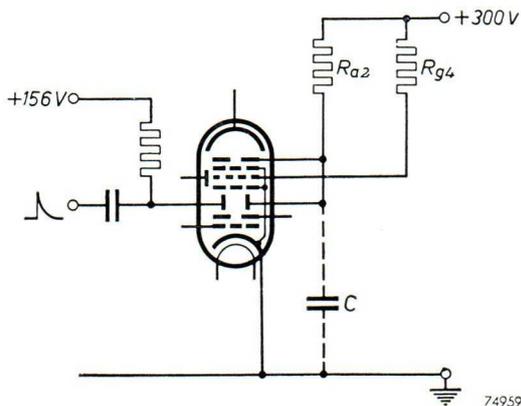


Fig. 5. Circuit for explaining the operation of the E1T counter tube, positive voltage pulses being applied to the left deflection electrode. *C* represents the sum of the capacitance of the anode and of the right deflection electrode with respect to all other electrodes and the wiring and stray capacitances.

practically the same amount as the voltage on the left deflection electrode *D*. The beam therefore remains at practically the same position, any gradual variation of the voltage applied to *D* being counteracted by a corresponding variation of the voltage on *D'* due to the stabilizing of R_{a_2} . This phenomenon may thus be regarded as a form of

negative feedback, the feedback factor being very high.

As a result of a gradual increase of V_D by, say, 14 V, the characteristic will no longer be as depicted in fig. 6a (where $V_D = 156\text{ V}$), but will be shifted in its entirety with respect to the system of coordinates, as shown in fig. 6b (where $V_D = 156 + 14 = 170\text{ V}$). In fact, the position of the electron beam depends in the first instance on the voltage difference between V_D and V_{D',a_2} , all other voltages remaining constant.

The situation is fundamentally different when, instead of gradually varying the voltage applied to *D*, a positive pulse with a steep front is fed to this electrode, for now the capacitance *C* comes into play. Due to this capacitance by-passing the load resistor R_{a_2} , a positive pulse with a sufficiently steep front fed to *D* will no longer be accompanied by a corresponding decrease of the voltage across R_{a_2} . In fact, this voltage, and hence also the voltage on *D'*, cannot closely follow the sudden variation of the voltage applied to *D* and is maintained substantially constant*) for a short interval (depending on the value of *C*). The beam is therefore displaced towards the left, over a distance corresponding to the amplitude of the pulse.

In order to shift the beam from one stable point of operation to the next, the shape of the pulse must be of the general form indicated in fig. 7. The amplitude of this pulse should be approximately equal to the voltage difference between two stable working points of the characteristic of fig. 6a, that is between the points *a*, *c*, *e*, etc. situated at the intersection of the load line with those parts of the characteristic which have a positive slope. The slope of the leading edge should be at least $20 \times 10^6\text{ V/sec}$, that of the trailing edge should not exceed $1.2 \times 10^6\text{ V/sec}$. Taking the average amplitude of the pulse to be 13.6 V, the time of rise should therefore have a maximum value of $0.7\ \mu\text{sec}$, and the time of fall a minimum value of $11\ \mu\text{sec}$.

The delay with which V_{D',a_2} follows V_D due to the presence of the capacitance *C* is large compared

*) This "stabilizing" effect of *C* on the voltage across R_{a_2} should not be confused with the stabilizing effect that R_{a_2} has on the position of the beam. Advantage is taken of the latter effect — which is suppressed during the steep front of the pulse by the presence of *C* — for maintaining the beam at the correct position after it has been displaced.

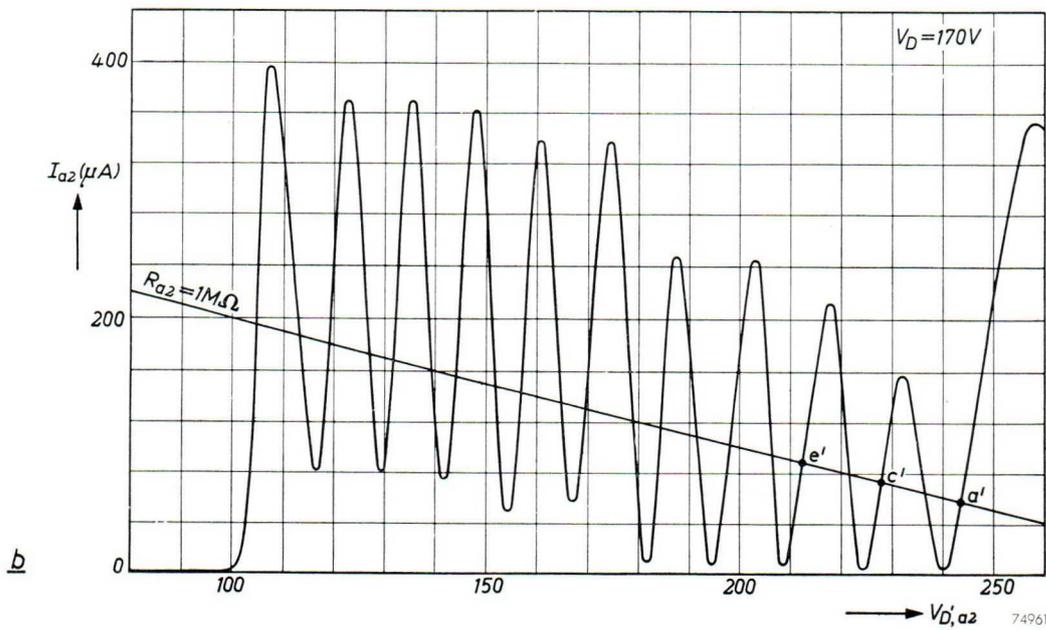
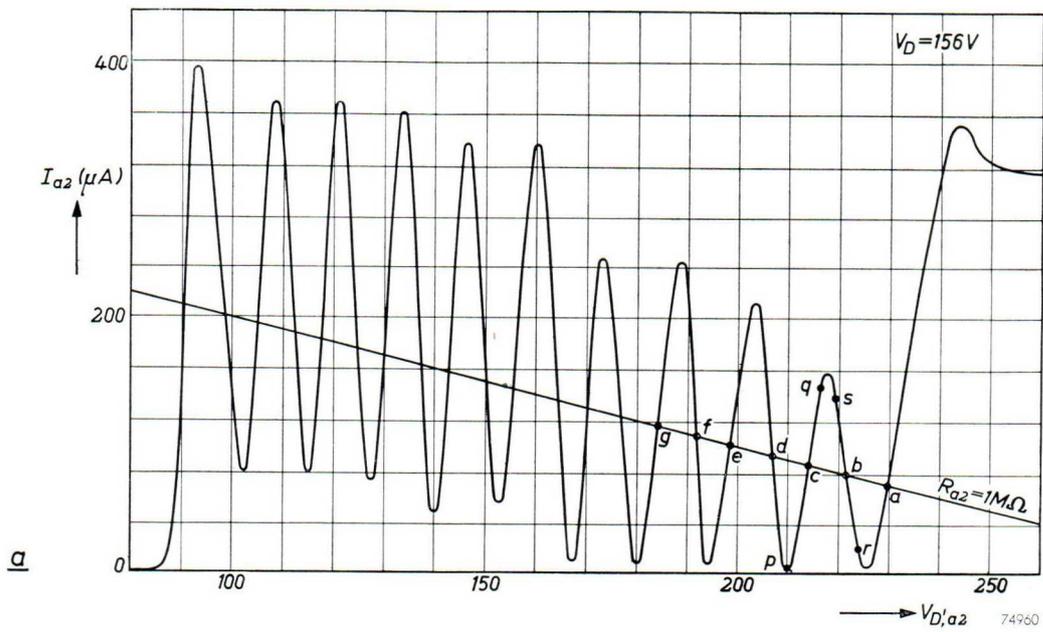


Fig. 6. $I_{a2} = f(V_{D',a2})$ characteristic for a left deflection electrode voltage $V_D = 156 V$ (a) and for $V_D = 170 V$ (b).

with the time of rise of this pulse, and small compared with the time of fall. The voltage across R_{a_2} therefore remains substantially constant during the build-up of the pulse to its maximum value.

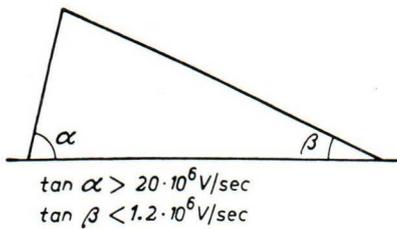


Fig. 7. Required form of the positive pulses to be applied to the left deflection electrode. The slope of the leading edge should be at least 20×10^6 V/sec, that of the trailing edge should not exceed 1.2×10^6 V/sec. The amplitude of the pulse 1.2 should be 13.6 V, $\pm 15\%$.

It is of interest to investigate this mechanism by means of the tube characteristics, fig. 6. It will be assumed that the beam is in its initial position 0, corresponding to point a of the characteristic, fig. 6a, V_{D',a_2} being about 230 V and V_D being 156 V. When V_D is suddenly increased by a pulse with an amplitude of 14 V to 170 V, V_{D',a_2} has no time to follow this variation, as explained above. The voltage V_{D',a_2} thus remains substantially constant at about 230 V, whereas V_D temporarily assumes a value of 170 V. The beam will thus be shifted to a position corresponding approximately to point c' in fig. 6b, the characteristic having been rapidly displaced to the right to such an extent that the metastable working point, maintained by the presence of C , is again situated on a part of the characteristic having a positive slope.

The beam has thus reached the new stable position 1. The decay of the pulse is so slow that the decrease of V_{D',a_2} can easily keep pace, notwithstanding the presence of C , and thus drops to about $230 - 14 = 216$ V, corresponding to point c in fig. 6a.

Once this voltage has been reached, the tube is ready to receive another pulse by which the beam will be shifted to position 2, corresponding to points e' and e respectively in figs 6b and 6a.

It has been assumed so far that the pulse amplitude was such that point q was reached. When this amplitude is smaller, so that the peak of the pulse corresponds to point r in fig. 6, for example, the following situation will arise.

When point r has been reached, the current flowing through R_{a_2} , which is determined by the voltage drop across this resistor, exceeds the current

actually flowing through the tube, so that the charge of the capacitance C will increase. Consequently, the voltage drop across R_{a_2} will gradually decrease and V_{D',a_2} will rise. A pulse with an amplitude smaller than the voltage difference between the points a and b will therefore result in the beam returning to point a .

Theoretically, a voltage pulse which shifts the beam to a position corresponding to point s would suffice to displace the beam to point c , but due to the limited front slope and the trailing edge of the pulse, its amplitude should be slightly higher to ensure reliable operation. On the other hand, the amplitude of the pulse should not exceed the voltage difference corresponding to the distance between the points a and d , as can be readily understood. It is clear that point b , and thus also the points d, f , etc., are unstable, since any small voltage fluctuations will return the beam to the nearest stable points a, c or e , etc.

It should be recognized that any tendency of the anode voltage to vary, due to such causes as supply voltage fluctuations, noise, etc., will be counteracted by a corresponding variation of the anode current, so that the position of the beam will not be influenced, once a stable point has been reached. If the supply voltage decreases, so that the beam would be shifted, for example, from the position corresponding to point c towards point p , the anode current will decrease, since point c is situated on a part of the characteristic having a positive slope. For the same reason, the anode current will increase with increasing supply voltage. Since the fluctuations are usually relatively slow and of small amplitude, the capacitance C will have little effect and the current variation will be followed closely by a variation of the voltage drop across R_{a_2} , so that the beam remains at the position corresponding to point c .

Interstage coupling

It has already been explained that there are ten stable points of operation. When suitable positive-going pulses are fed to the left deflection electrode D of the first counter tube, its beam will move from the right to the left in nine steps, starting from position 0. After nine pulses have been counted, the beam will finally arrive at the last stable position. The next pulse will shift the beam to the reset anode a_1 , from which it must be returned to the zero position, so that the counting action can continue. It is mainly the time required for this oper-

ation that determines the counting rate of the complete circuit.

In the circuit to be described here, an interstage coupling consisting of a monostable (one shot) multivibrator is used for rapidly resetting the beam to its zero position. This multivibrator is triggered by the sudden drop of the reset anode voltage caused by the electron beam impinging on this electrode.

A negative-going, trapezoidal, pulse is thus generated by the multivibrator, and this resets the beam of the preceding counter tube to its zero position. Simultaneously, a positive-going pulse is produced by which the beam of the next tube is advanced one position.

The beam of the preceding counter tube is reset by applying the negative-going pulse thus produced to the control grid g_1 , so that the tube is temporarily cut off. It will be clear that this will result in the voltage on the anode and thus also on the right-hand deflection electrode rising to its maximum value. The anode voltage will, however, not rise suddenly but exponentially, due to the presence of the capacitance C , and the duration of the pulse cutting off the tube should obviously be so long that at the instant when this pulse ceases, the anode voltage has risen to at least the value corresponding to the zero position of the beam.

If the duration of the pulse cutting off the tube is insufficient, the beam may be reset to any position, so that a safety margin within the minimum duration should be observed. Too long a pulse, on the other hand, increases the reset time.

The minimum reset time t , which determines the maximum pulse frequency and thus the counting rate, is calculated as follows. When the beam is in position 9, the anode voltage is at the lowest value $V_{a_2 \min}$, and this should rise to a value $V_{a_2 \text{init}}$, slightly exceeding the value of V_{a_2} at position 0 of the beam. This gives:

$$V_b - V_{a_2 \text{init}} = (V_b - V_{a_2 \min}) \cdot \exp. - \frac{t}{R_{a_2 \max} C_{\max}},$$

where V_b denotes the H.T. line voltage (300 V) and C_{\max} is the maximum capacitance (16.5 pF) by-passing R_{a_2} *).

*) This capacitance should be reduced to the minimum by keeping the wiring as short as possible and minimizing the stray capacitances, especially the capacitances with respect to a_2 and D' . The anode load resistor (R_{a_2} in fig. 5) should be soldered directly to the socket contacts a_2 and D' .

It is recommended to use a duodecal socket 5912/20. When a different type of socket is used, care should be taken that the capacitance of contact 5 (or 4) of the unmounted tube socket to all other contacts connected together does not exceed 1.3 pF.

Setting $V_{a_2 \text{init}} = 240$ V and $V_{a_2 \min} = 95$ V, which are the extreme values that may occur in practice, and taking $R_{a_2 \max}$ to be 1.02 M Ω **), this expression gives $t = 20.7$ μ sec, so that a maximum counting rate of 30 000 pulses per second can easily be achieved, allowance being made for spread in the tube characteristics, etc.

The mechanism of operation will be explained by means of the circuit given in fig. 8. There is only one stable position of the multivibrator, with the left triode section (T_1) conducting, and the right section (T_2) biased beyond cut-off. When a negative-going triggering pulse is fed to the grid of T_1 , its anode current will decrease and the voltage at point A will rise, taking along the grid potential of T_2 . Tube T_2 then becomes conducting, and the cathode potential V_k suddenly assumes a high value, which now definitely cuts off T_1 . The charge of C_8 is subsequently increased, so that the grid potential of T_2 decreases exponentially. Since T_2 is in fact connected as a cathode follower, its cathode follows the grid potential very closely, as a result of which V_k also decreases exponentially. As V_k continues to decrease, the cut-off value of T_1 (the anode voltage of which is fairly high) will rapidly be reached, so that this tube again becomes conducting.

The voltage at point A then decreases, and this voltage drop is communicated to the grid of T_2 , cutting off this tube. The capacitor C_8 then starts to discharge, the stable position of the circuit thus being reached again.

In the circuit shown in fig. 8, the values of the electrode potentials have been indicated for the stable position. The negative potential at the grid of T_2 is seen to be $45 - 20 = 25$ V, which is ample for cutting off T_2 at an anode voltage of $300 - 45 = 255$ V.

The anode load R_{12} of T_1 is 39 k Ω . This value is in fact too high to permit a pulse with a sufficiently steep leading edge to be taken from the cathode resistor for feeding to the next counter tube. A lower value of R_{12} would, however, result in a greater drain on the H.T. line. This difficulty has been overcome by shunting the main part of the cathode resistor by the capacitor C_6 , so that only the resistor R_{15} of 1 k Ω is operative for abrupt

** The rated value of this load resistor is 1 M Ω . Since in the actual circuit a 1 M Ω resistor is used, connected in series with a 10 k Ω resistor required for checking purposes, the permissible tolerance of the 1 M Ω resistor must be $\pm 1\%$, to obtain the quoted value of 1.02 M Ω for $R_{a_2 \max}$.

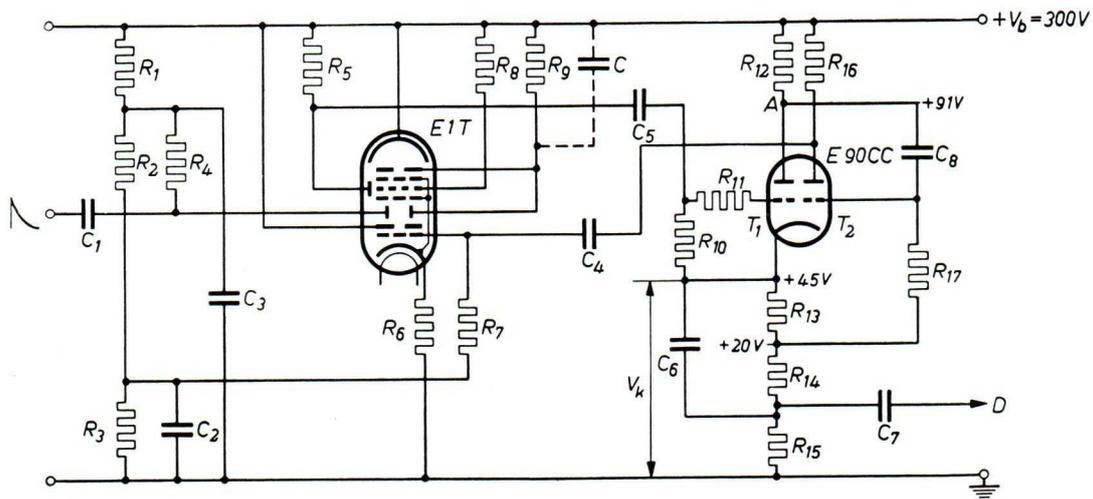


Fig. 8. Circuit diagram of an interstage circuit preceded by an E1T tube. The interstage circuit is equipped with a E90CC double triode, acting as a monostable multivibrator.

Component values

$R_1 = 68 \text{ k}\Omega \pm 1 \%$	$R_{10} = 0.56 \text{ M}\Omega \pm 10 \%$	$C_1 = 680 \mu\text{F} \pm 5 \%$
$R_2 = 68 \text{ k}\Omega \pm 1 \%$	$R_{11} = 5.6 \text{ k}\Omega \pm 10 \%$	$C_2 = 0.39 \mu\text{F} \pm 20 \%$
$R_3 = 5.6 \text{ k}\Omega \pm 1 \%$	$R_{12} = 39 \text{ k}\Omega \pm 2 \%$	$C_3 = 0.15 \mu\text{F} \pm 20 \%$
$R_4 = 15 \text{ k}\Omega \pm 2 \%$	$R_{13} = 4.7 \text{ k}\Omega \pm 2 \%$	$C_4 = 0.0068 \mu\text{F} \pm 10 \%$
$R_5 = 39 \text{ k}\Omega \pm 10 \%$	$R_{14} = 2.7 \text{ k}\Omega \pm 2 \%$	$C_5 = 220 \text{ pF} \pm 10 \%$
$R_6 = 15 \text{ k}\Omega \pm 1 \%$	$R_{15} = 1 \text{ k}\Omega \pm 1 \%$	$C_6 = 68 \text{ pF} \pm 2 \%$
$R_7 = 0.33 \text{ M}\Omega \pm 10 \%$	$R_{16} = 3.3 \text{ k}\Omega \pm 2 \%$	$C_7 = 680 \text{ pF} \pm 5 \%$
$R_8 = 47 \text{ k}\Omega \pm 5 \%$	$R_{17} = 0.15 \text{ M}\Omega \pm 2 \%$	$C_8 = 68 \text{ pF} \pm 2 \%$
$R_9 = 1 \text{ M}\Omega \pm 1 \%$		

changes. The large value of the cathode resistor, combined with the fairly large value of R_{12} , renders the circuit extremely stable, resulting in a pulse amplitude and duration of high constancy, and insensitivity to spread in the tube characteristics.

Fig. 9a shows the negative-going pulse at the anode of T_2 , for resetting the beam of the preceding counter tube, while fig. 9b shows the positive-going pulse at the cathode resistor of the multivibrator for operating the next counter tube.

The minimum amplitude of the negative-going pulse is 27 V, which ensures complete suppression of the beam; its duration of 27 μsec is ample for

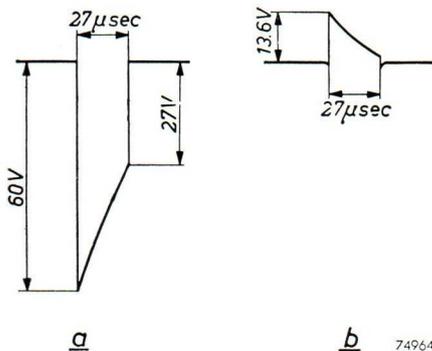


Fig. 9. Negative-going pulse (a) and positive-going pulse (b) derived from the multivibrator shown in fig. 8.

resetting the beam to the zero position without unduly increasing the reset time.

The cathode resistor has been so tapped that the positive-going pulse assumes the correct value to be fed to the left deflection electrode of the next counter tube. Because of the unilateral deviation of V_k from its stable value, there is no need for adding a clipping diode.

To ensure reliable operation of the circuit, it is of particular importance that the amplitude of the positive-going counting pulse fed to the next counter tube and the duration of the negative-going pulse required for resetting the beam of the preceding counter tube remain well within the limits to be observed. Experiments have shown that, at extreme spread in the tube characteristics, a variation of all resistors and capacitances of 2% in an unfavourable sense results in the amplitude of the pulses changing by 8% and in their duration changing by 7.5%.

At an average value of 13.6 V, the amplitude of the positive-going pulse may thus vary between 12.5 V and 14.7 V, which is well within the limits of 11.5 V and 15.6 V given by the characteristics of the tube.

As calculated previously, the duration of the

pulse for resetting the beam of the preceding counter tube should be at least $20.7 \mu\text{sec}$. To remain on the safe side, the required minimum value will be taken to be $23 \mu\text{sec}$. Taking the same safety margin for the pulse duration as that for the pulse amplitude, this gives for the average value of the duration $(13.6/11.5) \cdot 23 = 27.2 \mu\text{sec}$, and for the maximum value $(15.6/11.5) \cdot 23 = 31 \mu\text{sec}$. Allowing for another $23 \mu\text{sec}$ for stabilizing purposes, the maximum duration of the pulse which may occur under unfavourable conditions thus becomes $31 + 2.3 = 33.3 \mu\text{sec}$, giving a pulse repetition frequency of $10^6/33.3 = 3 \times 10^4$ pulses per second.

Input circuit

The first counter tube must be preceded by a pulse shaper (see fig. 10). A monostable multivibrator similar to that used in the interstage circuit may be employed for this purpose, the only difference being the somewhat lower values of the coupling capacitor between T_1 and T_2 and of the grid leak of T_2 . Reliable operation at the highest counting rate of 3×10^4 pulses per second is thus ensured. The resulting reduction of the pulse duration is of no consequence, since no negative-going pulse for resetting the beam of a preceding counter tube is needed in this case.

The pulse shaper must, moreover, be preceded by a differentiating network, because — particularly at

low counting rates — the duration of the counting pulses applied to the input might otherwise exceed the duration of the pulse produced by the multivibrator. In that case, the trailing edge of the differentiated positive pulse would trigger the input shaper again, and this might result in more than one count being produced per pulse applied to the input. (The duration of the pulses derived from the reset anode of a preceding counter tube is only a fraction of a microsecond, so that this difficulty is not experienced in the interstage circuits.)

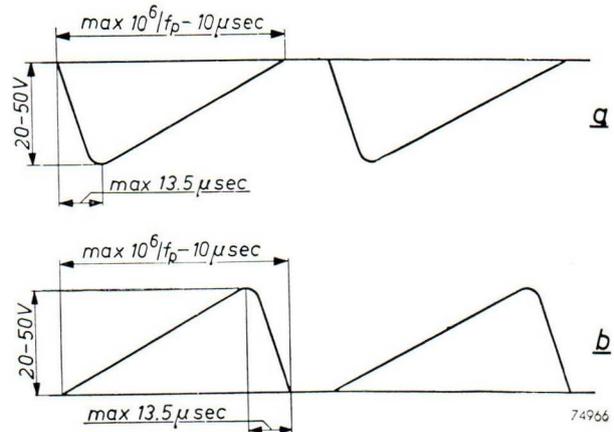


Fig. 11. Examples of a negative-going pulse (a) and a positive-going pulse (b) to be fed to the input pulse shaper shown in fig. 10.

For triggering the multivibrator of the input circuit, the counting pulses, which are to be fed to the differentiating network, may be either negative-going with a leading edge duration not exceeding $13.5 \mu\text{sec}$, or positive-going with a trailing edge duration not exceeding this value. The total duration of the pulse must be equal to one cycle of the pulse repetition frequency f_p less at least $10 \mu\text{sec}$. At the highest frequency of 3×10^4 pulses per second, this duration may therefore not exceed $33.3 - 10 = 23.3 \mu\text{sec}$.

The amplitude of the counting pulses may range from 20 V to 50 V . Two examples of suitable counting pulses to be fed to the pulse shaper are schematically represented in figs 11a and b.

The purpose of the germanium diode OA 55 shunted across the resistor R_1 of the differentiating network is to prevent positive pulses, caused by the trailing edge of a negative-going or the leading edge of a positive-going counting pulse, from being fed to the grid of T_1 , thus producing faulty counts.

If the waveform of the signals to be counted is either sinusoidal, negative-going with a leading edge duration not exceeding $13.5 \mu\text{sec}$, or positive-going

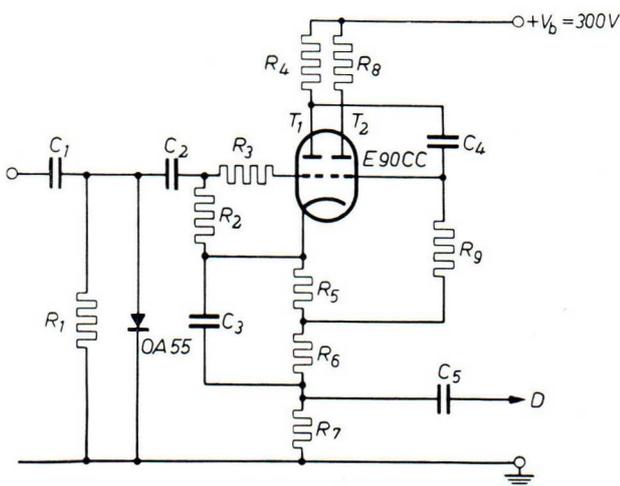


Fig. 10. Input pulse shaper for the first E1T tube.

Component values

$R_1 = 39 \text{ k}\Omega \pm 10 \%$	$R_8 = 3.3 \text{ k}\Omega \pm 2 \%$
$R_2 = 0.56 \text{ M}\Omega \pm 10 \%$	$R_9 = 0.1 \text{ M}\Omega \pm 1 \%$
$R_3 = 5.6 \text{ k}\Omega \pm 10 \%$	$C_1 = 470 \text{ pF} \pm 10 \%$
$R_4 = 39 \text{ k}\Omega \pm 2 \%$	$C_2 = 0.0068 \mu\text{F} \pm 10 \%$
$R_5 = 4.7 \text{ k}\Omega \pm 2 \%$	$C_3 = 82 \text{ pF} \pm 2 \%$
$R_6 = 2.7 \text{ k}\Omega \pm 2 \%$	$C_4 = 39 \text{ pF} \pm 5 \%$
$R_7 = 1 \text{ k}\Omega \pm 1 \%$	$C_5 = 0.0068 \mu\text{F} \pm 10 \%$

with a trailing edge not exceeding $13.5 \mu\text{sec}$, the first counter tube should be preceded by an auxiliary pulse shaper. Figure 12 shows the circuit then to be used. With this circuit, sinusoidal voltages down to 10 c/s can be counted, provided the signal voltage is at least $15 V_{\text{rms}}$. The input voltage is applied to the terminal marked V_i .

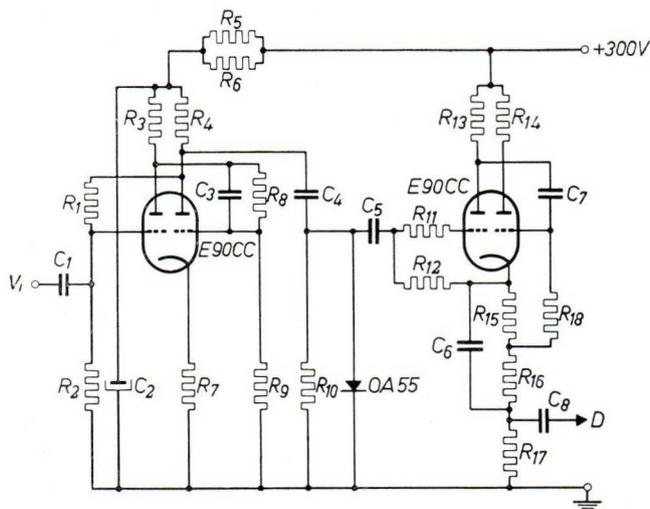


Fig. 12. Input pulse shaper with auxiliary pulse shaper. For values of components, see fig. 27, page 28.

If sinusoidal signals have to be counted with a frequency less than 10 c/s, the input signal should have a higher amplitude, and a clipper should be provided to render the waveform more suitable for triggering the auxiliary pulse shaper, i.e. to provide a signal whose positive and negative-going flanks have a sufficiently steep slope. Another pos-

sibility consists in increasing the value of the capacitor C_1 .

Pulses produced by mechanical means, for example by closing a switch or operating a telephone dial across which a direct voltage is applied, are likely to produce faulty counts. This is due to the fact that the decade counter might react on short interruptions during the time that the switch should actually be closed; such interruptions are apt to be produced by rebounding of spring contacts. It will in this case be necessary to connect filter circuits between the switch and the auxiliary pulse shaper.

Fig. 13 gives an example of a suitable filter network. The mechanical switch S , across which a voltage of approximately 40 V is applied by means of the voltage divider R_1R_2 , is followed by two RC filters. The output signal at terminal B should be fed to the input terminal of the auxiliary pulse shaper shown in fig. 12.

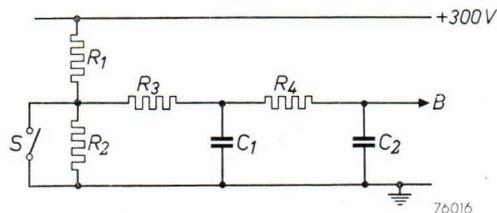


Fig. 13. Filter circuit for avoiding faulty counts which may be produced by rebounding of the spring contacts of mechanical switches.

$R_1 = 68 \text{ k}\Omega, 2 \text{ W}$	$R_4 = 3.9 \text{ k}\Omega, \frac{1}{4} \text{ W}$
$R_2 = 10 \text{ k}\Omega, \frac{1}{4} \text{ W}$	$C_1 = 0.47 \mu\text{F}, \frac{1}{4} \text{ W}$
$R_3 = 390 \Omega, \frac{1}{4} \text{ W}$	$C_2 = 0.47 \mu\text{F}, \frac{1}{4} \text{ W}$

COMPLETE CIRCUIT OF A MULTI-DECADE COUNTER

WITH A COUNTING OF 30.000 PULSES PER SECOND

The circuit diagram of a complete decade counter will be explained by means of fig. 14, which shows the input pulse shaper, the first and second counter stages and the supply unit. The subsequent counter stages have been omitted in the circuit diagram, these being identical to the second counter stage.

The supply unit and the voltage divider consisting of the resistors R_{41} , R_{42} and R_{43} have been designed for feeding up to 7 counter stages, the highest number to be registered then being 9 999 999. If a larger number of counter stages is required, it is merely sufficient to change the supply unit and voltage divider accordingly.

There is no need to stabilize the supply unit, since mains voltage fluctuations will result in all voltages taken from the voltage divider to vary simultaneously by the same relative amount, and this has no noticeable effect on the performance of the counter tubes. Experiments have shown that reliable operation is still obtained at mains voltages ranging from 140 V to 270 V (nominal value 220 V). It is true that prolonged operation under these conditions may be harmful to the useful life of the tubes, but in practice such extreme fluctuations will hardly ever occur. Care must, however, be taken that the specified tolerances of $\pm 1\%$ of the resistors R_{41} , R_{42} and R_{43} of the voltage divider are strictly observed. The use of wire-wound resistors is highly recommended for this purpose.

The input circuit comprises a pulse shaper equipped with a E 90 CC double triode.

The counter stages, marked by the broken lines in fig. 14, are equipped with an E 1 T counter tube and a double triode E 90 CC. The counter tubes are connected as outlined in the preceding sections. Effective D.C. feedback is applied by using cathode resistors R_{12} , R_{27} (cf. fig. 8); the cathode current is thus kept constant within narrow limits, which ensures reproducible sensitivity of the counter tubes.

During the intervals between the negative-going pulses fed to the control grid g_1 of the counter tubes for resetting the beam, the potential of this electrode depends on the counting frequency. In the first counter stage, where the highest counting rate occurs, this would be objectionable, so that a

germanium diode OA 55 is shunted across the resistor R_{14} , thus maintaining the direct voltage level of g_1 at a constant value. Apart from this diode, all counter stages are identical.

In order to ensure that reliable operation at the counting rate of 30 000 pulses per second is obtained under the most unfavourable conditions, the rated values of the components of the counter stages should be as specified in the caption of fig. 14).*) When the counting rate is lower, such as for example in the second and subsequent stages, normal $\pm 10\%$ components may, however, be used in the multivibrator circuits, provided the rated values of the coupling capacitor C_{14} and the grid leak R_{39} are slightly increased, namely to 82 pF and 0.18 M Ω instead of 68 pF and 0.15 M Ω respectively. It is then necessary to adjust the amplitude of the positive-going pulse (V_p in fig. 14) with a diode voltmeter (slide-back peak meter for positive peaks) to $13.6 \text{ V} \pm 2\%$ by connecting an additional correction resistor in series with or parallel to the 1 k Ω cathode resistor R_{38} . Since normal $\pm 10\%$ resistors may show considerable drift during life, it may be necessary to readjust the setting of the correction resistor from time to time. It should be noted that it remains essential to use $\pm 1\%$ precision resistors in the cathode and anode circuits of the counter tubes.

The press-button switch S in fig. 14 serves for resetting all tubes to zero by applying a negative voltage exceeding 10 V temporarily to their control grids. This voltage is obtained by means of the germanium diode OA 55 in the supply unit.¹⁾

An oscilloscope may be connected to the points p in fig. 14 for checking each individual stage for reliable operation. Some marginal test may be made for example by raising and lowering the supply voltage around its average value. The oscillograms should be as depicted in figs 16a and b, with ten distinctive steps.

*) To cope with the variations to which the components may be subject due to ageing or temperature effects, a safety margin has been observed, but it should be noted that even after prolonged use and under working conditions, the deviations should never exceed twice the tolerances specified in the caption of fig. 12.

¹⁾ See note ¹⁾ page 47.

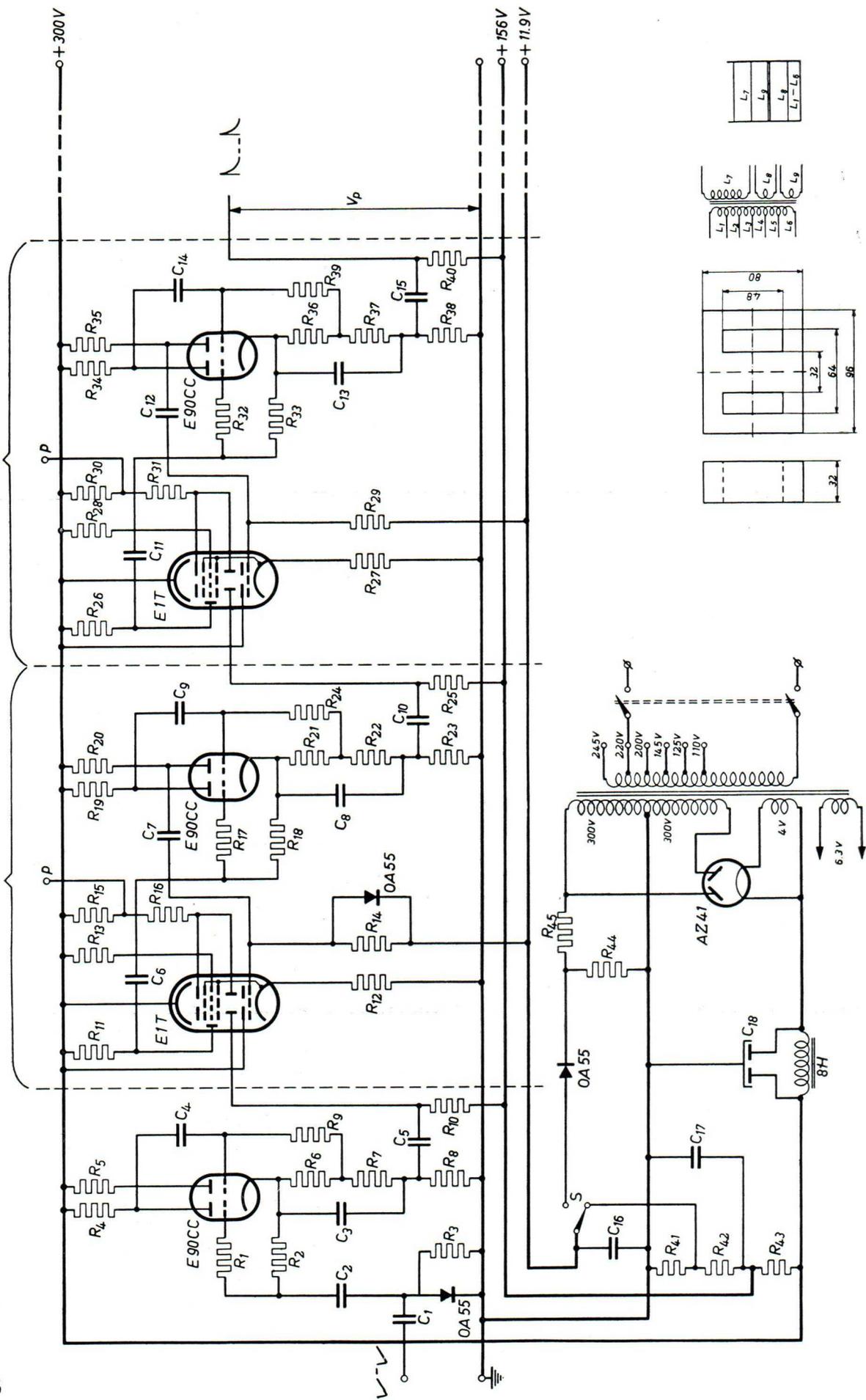


Fig. 14.

Fig. 14. Complete circuit of a decade counter. Only the first two counter stages have been drawn, the subsequent stages being identical to the second counter stage. The supply unit and voltage divider have been designed for feeding up to seven stages.

Component values

R_1	=	5.6 k Ω	\pm 10%	1/2 W
R_2	=	0.56 M Ω	\pm 10%	1/2 W
R_3	=	39 k Ω	\pm 5%	1/2 W
R_4	=	39 k Ω	\pm 2%	2 W
R_5	=	3.3 k Ω	\pm 2%	1/2 W
R_6	=	4.7 k Ω	\pm 2%	1 W
R_7	=	2.7 k Ω	\pm 2%	1/4 W
R_8	=	1 k Ω	\pm 1%	1/8 W
R_9	=	0.1 M Ω	\pm 1%	1/4 W
R_{10}	=	15 k Ω	\pm 2%	1/8 W
$R_{11} = R_{26}$	=	39 k Ω	\pm 10%	1/2 W
$R_{12} = R_{27}$	=	15 k Ω	\pm 1%	1/8 W
$R_{13} = R_{28}$	=	47 k Ω	\pm 5%	1/2 W
$R_{14} = R_{29}$	=	0.33 M Ω	\pm 10%	1/2 W
$R_{15} = R_{30}$	=	10 k Ω	\pm 10%	1/2 W
$R_{16} = R_{31}$	=	1 M Ω	\pm 1%	1/2 W
$R_{17} = R_{32}$	=	5.6 k Ω	\pm 10%	1/2 W
$R_{18} = R_{33}$	=	0.56 M Ω	\pm 10%	1/2 W
$R_{19} = R_{34}$	=	39 k Ω	\pm 2%	2 W
$R_{20} = R_{35}$	=	3.3 k Ω	\pm 2%	1/8 W
$R_{21} = R_{36}$	=	4.7 k Ω	\pm 2%	1/4 W
$R_{22} = R_{37}$	=	2.7 k Ω	\pm 2%	1/8 W
$R_{23} = R_{38}$	=	1 k Ω	\pm 1%	1/8 W
$R_{24} = R_{39}$	=	0.15 M Ω	\pm 2%	1/8 W
$R_{25} = R_{40}$	=	15 k Ω	\pm 2%	1/8 W
R_{41}	=	5.6 k Ω	\pm 1%	1/8 W
R_{42}	=	68 k Ω	\pm 1%	1 W
R_{43}	=	68 k Ω	\pm 1%	1 W
R_{44}	=	15 k Ω	\pm 10%	1 W
R_{45}	=	0.33 M Ω	\pm 10%	1 W

C_1	=	470 pF	\pm 10%
C_2	=	0.0068 μ F	\pm 10%
C_3	=	82 pF	\pm 2%
C_4	=	39 pF	\pm 5%
C_5	=	0.0068 μ F	\pm 10%
$C_6 = C_{31}$	=	220 pF	\pm 10%
$C_7 = C_{12}$	=	0.0068 μ F	\pm 10%
$C_8 = C_{13}$	=	68 pF	\pm 2%
$C_9 = C_{14}$	=	68 pF	\pm 2%
$C_{10} = C_{15}$	=	680 pF	\pm 5%
C_{16}	=	0.39 μ F	\pm 20%
C_{17}	=	0.15 μ F	\pm 20%
C_{18}	=	$2 \times 59 \mu$ F, 400 V	

Transformer data:

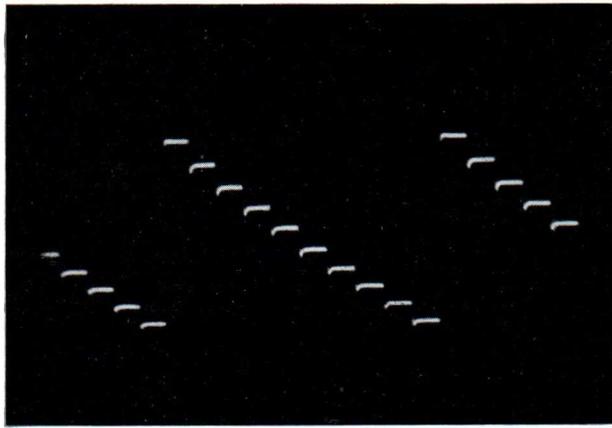
Winding number	Number of turns	Wire diameter	Voltage	Current
L_1	470	0.50 mm	110 V	0.52 A
L_2	64	0.50 mm	15 V	0.45 A
L_3	86	0.45 mm	20 V	0.39 A
L_4	234	0.40 mm	55 V	0.29 A
L_5	86	0.35 mm	20 V	0.26 A
L_6	108	0.35 mm	25 V	0.23 A
L_7	2×1420	0.25 mm	2×300 V	0.07 A
L_8	30	2.0 mm	6.3 V	5.0 A
L_9	19	1.0 mm	4.0 V	1.1 A

The counter stages may be built as small, interchangeable units as shown in fig. 15. These can be plugged into a chassis containing the input pulse shaper and supply unit. It is also possible to combine the stages into a compact counter apparatus similar to that shown in fig. 17.

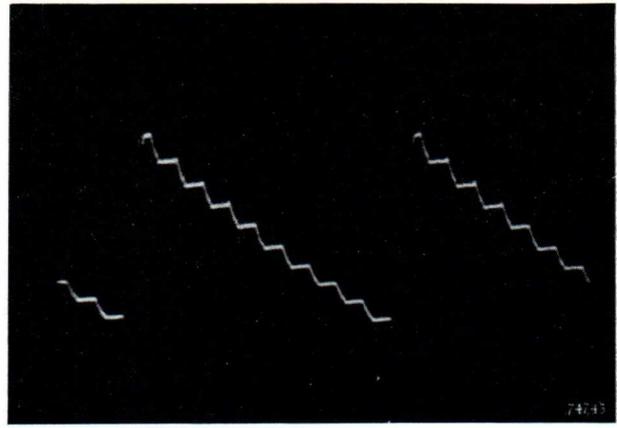
As for clear reading the ambient illumination should range from 40 lux to 400 lux, as indicated in the data, it is of advantage to mount the E 1 T tubes at some distance behind the front panel of the apparatus, thereby providing a light screen bringing the ambient illumination on the fluorescent coating to the desired value in a well lighted room.



Fig. 15. Interchangeable counter unit comprising an E 1 T counter tube and an E 90 CC double triode.



a



b

Fig. 16. Examples of oscillograms of the voltage at point p of the first counter stage (fig. 12): (a) at 3000 and (b) at 30 000 counts per second.

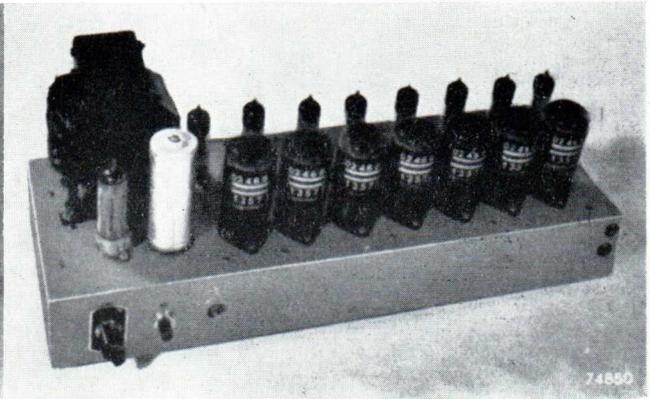
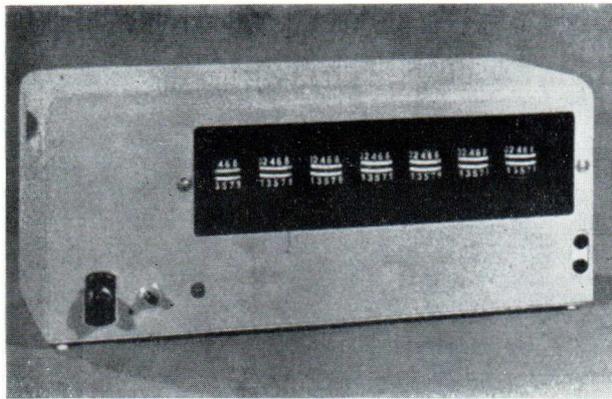


Fig. 17. Complete decade counter containing seven counter stages. The first counter tube at the left registers the millions, the second the hundred thousands, and so on. The press-button at the left serves for resetting all counter tubes simultaneously to zero. Cabinet dimensions: width 43 cm, height 17.5 cm, depth 15.5 cm. Weight: 7.5 kg. Power consumption: 77 watts.

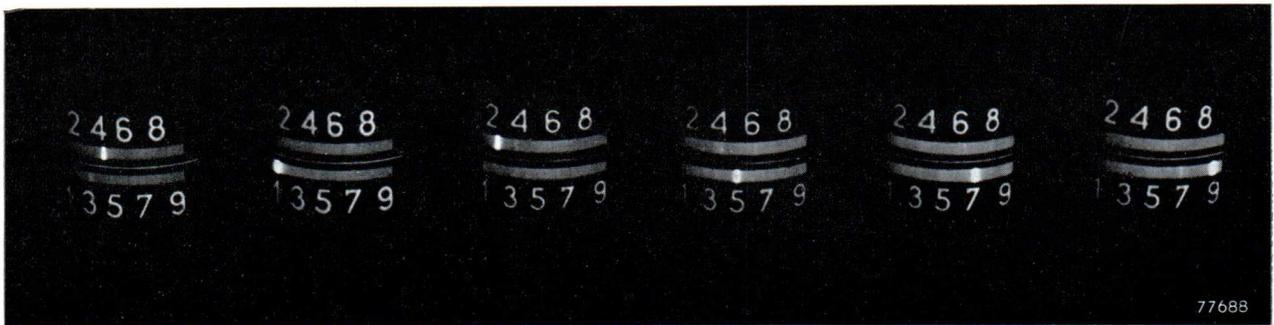


Fig. 18. Decade counter showing the number 412579.

A MULTI-DECADE PREDETERMINED COUNTER

In industry, particularly in mass production, it is often necessary to divide a continuous flow of products into specified quantities. When the counting rate is relatively low, mechanical means may give satisfactory results, but at high counting rates an electronic counter will provide the obvious solution.

A description is given of a fully automatic four-decade counter device which will count any predetermined number up to 10 000. Its construction is very similar to that of the multi-decade counter described, the main difference being the addition of three double diodes and one double triode. The number of counts registered can be read directly from the four E I T decade counter tubes with which the device is equipped. After the desired cycle of counts has been completed, the counter is automatically reset to its starting position and a pulse is produced which operates a relay by means of an additional output stage. The maximum counting rate is 12 500 counts per second, whilst the minimum duration of a complete cycle of counts is 1/3000 sec.

PRINCIPLE OF OPERATION

The explanation of the principle of operation of the predetermined counter will be based on the description of the multi-decade counter described above.

It will first be supposed that all counter tubes indicate zero in the four-decade counter the block diagram of which is given in fig. 19. After 9 counts have been applied to the input, the decade which counts the units will indicate number 9. The following count will reset this decade to zero and a pulse is fed to the following decade, counting the tens, which will thus be advanced one position, i.e. to the figure 1. In this way, all decades may be brought to position 9. The 10 000th count will return all decades to zero. The resulting sudden voltage variation at the cathode of the counter tube in the last decade (which counts the thousands) is used for indicating that the cycle of 10 000 counts has been completed.

It will be clear that this principle can be used only for cycles of 10^n counts, where n indicates the number of decades. This will serve little purpose, since as a rule a signal should be produced after a number of pulses differing from 10^n has

been applied. This can be achieved by presetting the counter to a number which is the complementary of the number that should be counted. When, for example, the signal should be produced after 7236 counts, the counter must be preset to $10\ 000 - 7236 = 2764$. After 7235 counts have been registered, all decades then indicate the figure 9 and the next count will reset all decades to zero, the pulse produced by the last decade indicating that the cycle of counts has been completed.

However, when all decades are returned to zero, the desired cycle of counts will be registered only once. Provision must therefore be made that the counter is returned to the initially selected, preset number, each time this cycle is completed. This may be achieved in the following way.

As previously explained, an E I T decade counter tube is a small cathode-ray tube in which the electron beam may occupy any of ten discrete, stable positions. Each position corresponds to a definite voltage difference $V_D - V_{D',a2}$ between the left deflection electrode voltage on the one hand and the voltage applied to the right deflection electrode (and anode) on the other hand.

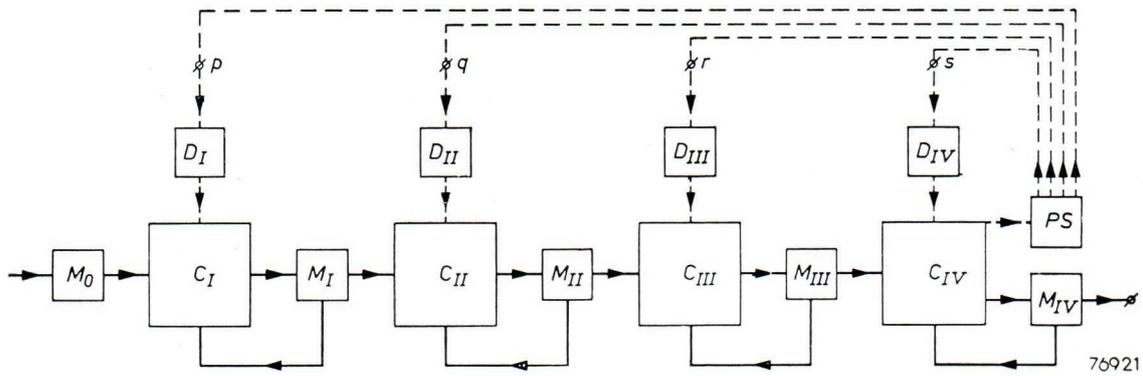


Fig. 19. Block diagram of a four-decade counter. C_I to C_{IV} — counter stages, M_0 — input stage, M_I to M_{IV} — inter-stage pulse shapers. By adding the pre-setting stage PS and the four diodes D_I to D_{IV} , the circuit can be converted into that of a predetermined counter.

By connecting the right deflection electrode and anode via the switch S to a variable voltage source as shown in fig. 20, the EIT tube can thus be adjusted to any desired figure, a fixed voltage of 156 V being applied to the left deflection electrode. When switch S is closed, the right deflection electrode and anode assume the same potential as the positive terminal of the voltage source. The lower the voltage V_{D',a_2} thus applied to the right

beam had been shifted to the preset position by applying a corresponding number of positive-going pulses to its left deflection electrode.

In practice, the somewhat different circuit shown in fig. 21 is used. The right deflection electrode and anode of the counter tube are connected to the anode of an additional diode (level catcher), the cathode of which is connected to the slider of the potentiometer P_1 .

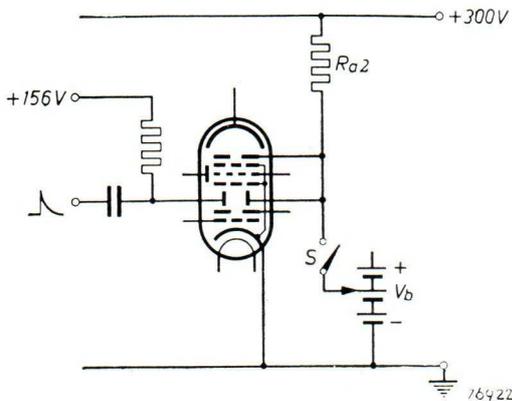


Fig. 20. Basic circuit for adjusting a counter tube to an arbitrary figure.

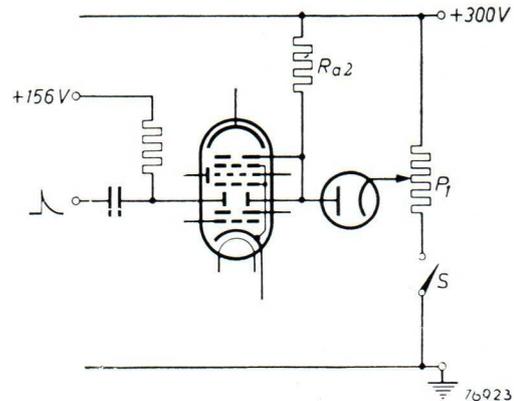


Fig. 21. Circuit similar to that shown in fig. 20, incorporating a diode acting as a level catcher.

deflection electrode and anode with respect to the voltage V_D applied to the left deflection electrode, the further will the beam be deflected to the left and the higher will be the number indicated. When switch S is subsequently re-opened, the beam will travel towards its nearest stable position, due to the stabilizing effect of the resistor R_{a2} , and V_{D',a_2} will assume a value which is almost equal to that of the voltage temporarily applied. The counter tube will then work normally as if its

When switch S is open, the diode and potentiometer have no effect on the position of the beam, since the cathode potential of the diode is higher than its anode potential. Upon closing switch S , the cathode voltage of the diode is, however, reduced, and when it drops below the voltage at the right deflection electrode and anode of the counter tube, current starts to flow from $+V_b$ towards $-V_b$ via R_{a2} , the diode and part of P_1 . Since the internal resistance of the diode is very much smaller than

the resistance of R_{a2} , the right deflection electrode and anode voltage of the counter tube will drop almost to the potential at the slider of the potentiometer. The lower the position of this slider, the greater will be the resulting deflection of the beam towards the left, which corresponds to a higher number being indicated by the counter tube.

When switch S is re-opened, the beam will travel towards its nearest stable position, V_{D',a_2} assuming a voltage that differs little from that which was present at the slider of P_1 when switch S was closed. Since the cathode voltage of the diode now rapidly rises to $+V_b$, this tube becomes non-conducting and the counter tube again operates normally, starting from the preset position.

the beam of tube III from position 7 to position 8. After 7235 counting pulses have been applied, the beams of all tubes will thus occupy position 9 and the 7236th pulse will have the following effects:

- (1) All tubes are reset to position zero.
- (2) As a result of the pulse produced at the cathode of the last counter tube IV , when it is reset to zero, switch S is temporarily closed. All tubes are thus advanced to their preset positions.
- (3) Switch S is subsequently re-opened after a short interval, so that the original condition is restored, the counter being ready to count the following cycle.

Instead of operating switch S mechanically, a presetting stage incorporating an electronic tube is

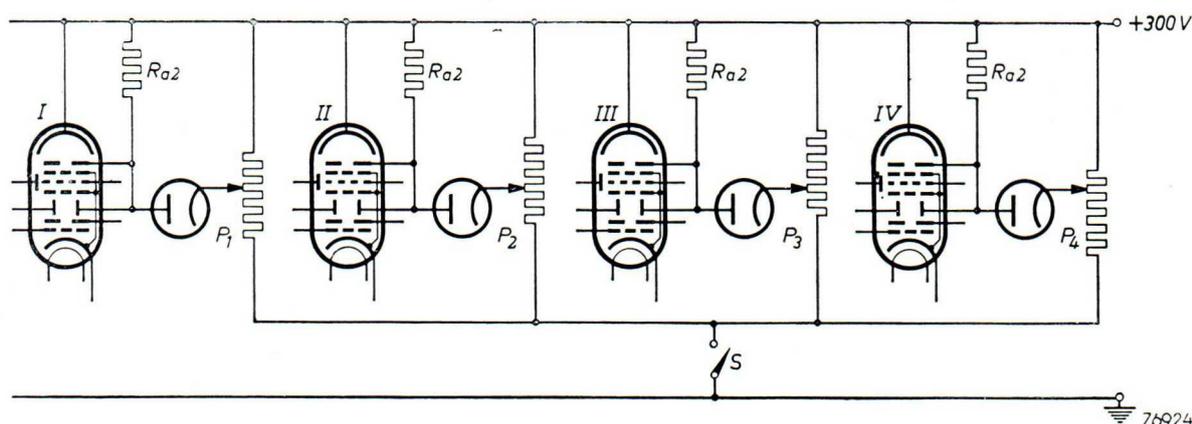


Fig. 22. Basic circuit of a four-decade predetermined counter. In order to obtain a cycle of 7236 counts (i.e. the complement of $10\,000 - 7236 = 2764$), the potentiometers $P_1 - P_4$ must be so adjusted that the counter tubes $I - IV$ are preset to figures 4, 6, 7 and 2 respectively.

The operation of a multi-decade predetermined counter will be explained by means of the basic circuit shown in fig. 22. It will again be assumed that a cycle of 7236 should be counted. The counter tubes must then be preset to the number $10\,000 - 7236 = 2764$. For this purpose, switch S is temporarily closed and the beams of the tubes I , II , III and IV are adjusted to the positions 4, 6, 7 and 2 respectively, by means of the potentiometer P_1 , P_2 , P_3 and P_4 . Switch S is then re-opened.

After 5 counting pulses have been applied to tube I , its beam will have advanced from its original position 4 to position 9. The next pulse resets the beam of this tube to position zero, as a result of which a pulse is fed to tube II , advancing its beam from position 6 to position 7. After 35 pulses have been applied, the beams of tubes I and II will both occupy position 9, and the next pulse will reset these tubes to position zero and advance

used, thus rendering the presetting after completion of a cycle of counts fully automatic. This presetting stage, which has also been drawn in the block diagram shown in fig. 19, will be dealt with later.

THE COUNTER STAGES

The counter stages differ slightly from those of the decade counter described previously, the following changes being necessary (see fig. 23).

Additional diodes, consisting of one electrode system of the double diodes EAA 91, are connected with their anodes to the right deflection electrode and anode of the counter tubes. The cathodes of the diodes are connected to the sliders of the potentiometers forming part of the presetting stage. It should be recognized that in view of the high value of the anode resistor, it is not permissible to use germanium diodes, their back resistance being too low.

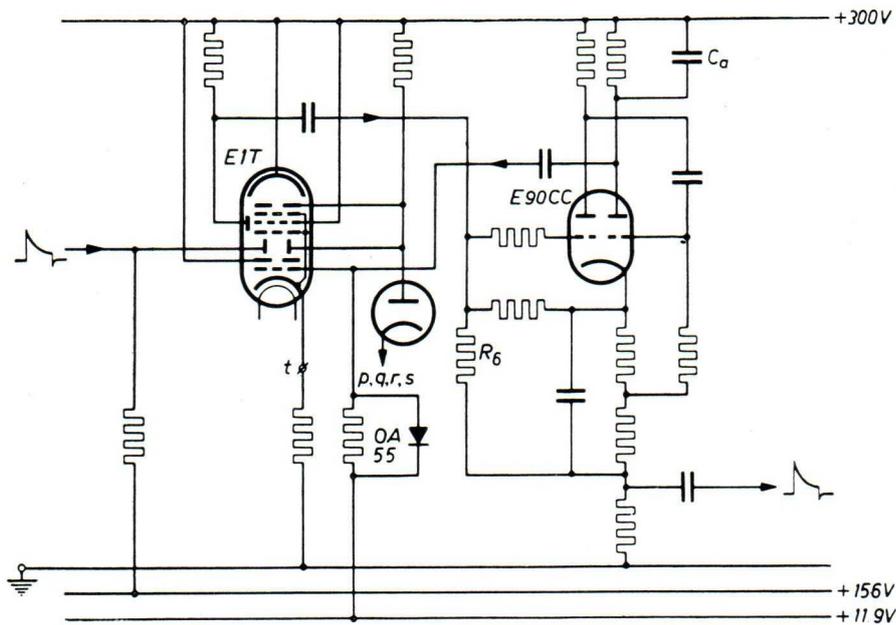


Fig. 23. Circuit of one decade of the predetermined counter. The last decade differs from the preceding decades by the slightly increased value of the capacitor between the two triode sections of the E 90 CC (180 pF instead of 100 pF), whilst, moreover, the pulse required for operating the presetting stage is taken from the cathode of the counter tube (point t).

Some further changes are required to avoid the risk of difficulties being experienced when the counter tubes are preset to figure 9. This will become clear when it is realized that for presetting a counter tube to lower figures, the slider of the potentiometer can easily be correctly adjusted by setting it midway between the positions at which the beam is preset to the adjacent figures, but when a tube should be preset to 9, the knob of the potentiometer will occasionally be turned too far*). In that case, the electron beam of the counter tube may be stabilized at a position at which it passes not only through the last aperture of the slotted electrode g_4 (see fig. 1a), but also through the slit between this electrode and the reset anode a_1 , impinging partly on this anode. The next counter pulse will then still advance the beam further to the left, so that it impinges in its entirety on the reset anode, but the negative pulse thus produced at the reset anode will not have the required amplitude and duration for completely triggering the monostable multivibrator which forms the following interstage circuit. This multivibrator will then operate merely as an amplifier, feeding the ampli-

*) This cannot be prevented by connecting a fixed resistor in series with the potentiometers, because in that case it would no longer be possible to cope with the unavoidable spread between individual counter tubes and it might therefore become impossible to preset the tubes beyond figure 8.

fied negative-going pulse back to the control grid g_1 of the counter tube. As soon as the beam current is thus suppressed, the negative-going pulse at the reset anode will then cease, and so will the pulse at the control grid for suppressing the beam. The tube will thus remain at the preset position (9).

For this reason, the anode resistor of 3.3 k Ω of the right-hand triode of the interstage circuit is shunted by a capacitor C_a of 270 pF. The suppression of the electron beam of the counter tube is thus delayed and the beam will continue its way towards the reset anode, giving the interstage multivibrator time to be completely triggered.

When the electron beam impinges partly on the reset anode at position 9, the amplitude of the pulse produced at the reset anode when the beam is further advanced will be approximately 3 V instead of 4 V. To ensure that the following interstage multivibrator is nevertheless triggered, its sensitivity is slightly increased applying a negative grid bias of 2.3 V to the grid of the left-hand triode by joining R_b .

The resistor of 47 k Ω originally connected between the slotted electrode g_4 and the +300 V line gives rise to some negative feedback during the resetting of the beam, which may lead to difficulties in the modified circuit. This electrode is therefore connected directly to the +300 V line.

As a result of this resistor being omitted, the amplitude of the counting pulses applied to the left deflection electrode must be slightly increased, the required limits being from 12.7 V to 16.9 V (average value 14.7 V) instead of from 11.5 V to 15.6 V (average value 13.6 V). The required increase of the pulse amplitude is obtained by shunting part of the cathode resistor of the input pulse shaper by a capacitor of 100 pF instead of by one of 82 pF. (In the interstage circuits there is no need to increase the corresponding capacitance; the pulse amplitude is already sufficiently increased by the capacitor of 270 pF which by-passes the anode resistor of the right-hand triode).

At high counting rates, it is necessary to use a germanium diode OA 55 *) in all counter stages, to maintain the direct voltage level of the control grid g_1 at a constant value. This is due to the fact that the counting rate of the second and subsequent decades may become fairly high when the preceding stages have been preset to a high number.

Due to the diode connected to the anode of the counter tube, the maximum capacitance at the anode is increased from 16.5 pF to 22.5 pF, which gives a minimum reset time t_{\min} of 29.1 μsec instead of 20.7 μsec . It should however be recognized that a tube may have been preset to position 9, so that its beam impinges partly on the reset anode; when this tube is reset, the duration of the pulse produced by the corresponding interstage circuit will then be up to 7 μsec shorter than normally. Taking moreover into account the possible spread in the circuit components, the first three decades must be so designed that under the most unfavourable conditions their reset times have a duration of $t_{\max} = 48.5 \mu\text{sec}$.

It will be clear that the time available for presetting the beams should always exceed the maximum duration of the reset time t_{\max} . This is necessary because the beams may otherwise not be returned to the desired preset positions, but to a lower figure. Since the time available for presetting the beams depends on the time during which the beam of the last counter tube is suppressed when it is reset to zero, the multivibrator following this tube should be so designed that its pulse duration is at least 49 μsec . Considering again that the counter tube may have been preset to position 9, so that part of its beam impinges on its reset anode, and taking into account the maximum spread that may occur

*) In general, all germanium diodes should be mounted in such a way that adequate cooling is provided.

in the circuit components, the maximum duration of the pulse produced by this multivibrator and serving for suppressing the electron beam of the last counter tube is 76 μsec . Since the presetting tube is so connected that 4 μsec are required for restoring the original condition at which this tube is cut off, there should be an interval of $76 + 4 = 80 \mu\text{sec}$ between the counting pulses. The maximum counting rate is therefore $\frac{10^6}{80} = 12\,500$ counts per second.

To obtain the longer pulse duration, the triode sections of the first three interstage multivibrators should be coupled by means of capacitors of 100 pF instead of 68 pF. The coupling capacitor in the multivibrator following the last counter tube should be 180 pF.

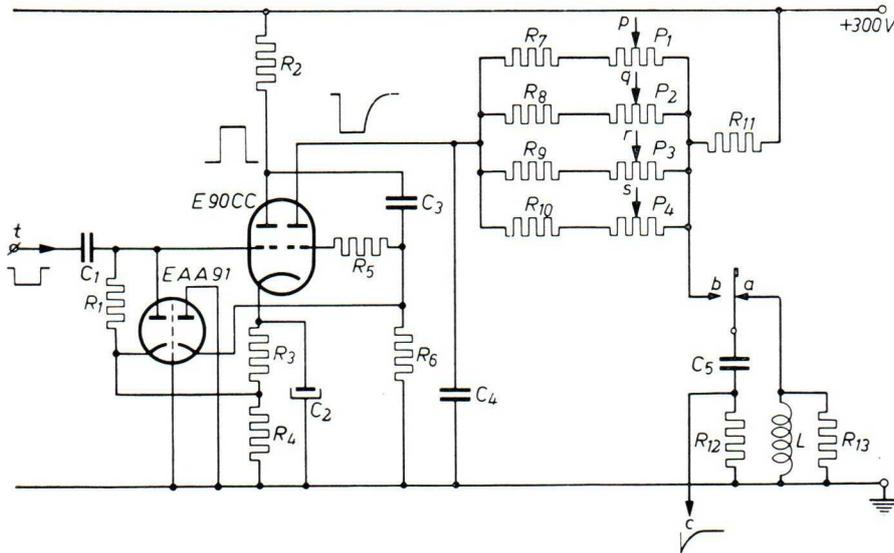
THE PRESETTING STAGE

As previously mentioned, an electronic tube is used instead of the switch marked S in fig. 22. This tube is normally biased to such an extent that it is completely cut off, but when the last counter tube is reset to zero, it is made conducting for a short interval, which corresponds to the switch being temporarily closed. This is achieved in the following way:

When the electron beam of a counter tube impinges in its entirety on the reset anode, the following multivibrator stage is triggered and produces a negative-going pulse which is applied to the control grid g_1 of this counter tube. The electron beam is thereby suppressed, and the cathode current suddenly drops to zero until the multivibrator returns to its original condition.

The negative-going square-wave voltage pulse thus produced at the cathode of the last counter tube when the cycle of counts is completed, is amplified and reversed by the left section of the E 90 CC double triode shown in fig. 24, and subsequently applied to the grid of the right-hand triode section. The latter acts as the switch for presetting the counter tubes to the selected figures. For this purpose, the four potentiometers $P_1 - P_4$ of 50 k Ω (cf. fig. 22) connected in parallel are incorporated in the anode circuit of this triode.

The square-wave voltage pulse applied to the left triode section has a duration ranging from 49 μsec to 76 μsec , according to whether the last counter tube has been preset to position 9 with part of the beam impinging on the reset anode or to a lower position.



Component values

R_1	=	0.56 M Ω ,	\pm 10%,	1/2 W
R_2	=	18 k Ω ,	\pm 2%,	1/2 W
R_3	=	1.5 k Ω ,	\pm 2%,	1/2 W
R_4	=	3.9 k Ω ,	\pm 2%,	1/2 W
R_5	=	33 k Ω ,	\pm 10%,	1/2 W
R_6	=	1 M Ω ,	\pm 10%,	1/2 W
R_7	=	100 Ω ,	\pm 10%,	1/2 W
R_8	=	100 Ω ,	\pm 10%,	1/2 W
R_9	=	100 Ω ,	\pm 10%,	1/2 W
R_{10}	=	100 Ω ,	\pm 10%,	1/2 W
R_{11}	=	3.9 k Ω ,	\pm 2%,	1/2 W
R_{12}	=	100 Ω ,	\pm 10%,	1/2 W
R_{13}	=	680 Ω ,	\pm 10%,	1/2 W
P_1	=	50 k Ω ,	wire wound,	2%
P_2	=	50 k Ω ,	wire wound,	2%
P_3	=	50 k Ω ,	wire wound,	2%
P_4	=	50 k Ω ,	wire wound,	2%
C_1	=	470 pF,	\pm 10%	
C_2	=	25 μ F,	25 V	
C_3	=	560 pF,	\pm 10%	
C_4	=	180 pF,	\pm 10%	
C_5	=	0.47 μ F,	\pm 10%	
L	=	1 mH		

Fig. 24. Circuit of the presetting stage. Point *t* (input) is connected to the cathode of the last counter tube. The sliders of potentiometers P_1 — P_4 are connected to the cathode of the corresponding diodes incorporated in the individual decades. By pressing the push-button switch at the right, all counter tubes are advanced to position 9; when the switch is subsequently released, so that it returns to position *a*, the negative-going pulse produced at point *c* is applied to the input stage, so that all tubes are reset to their predetermined positions.

When the beam of the last counter tube is reset to zero, the voltage pulse produced at the cathode has an amplitude of about 15 V, so that the left triode section is completely cut off and the grid of the right-hand section is driven positive; as a result, its anode potential suddenly drops from its initial value of 300 V to 95 V. The latter value is sufficiently low for the beams to be returned to position 9 when the sliders of the corresponding potentiometers occupy their lowest positions. (The voltage drop across the 100 Ω resistors R_7 — R_{10} , which serve only for preventing undesired interaction of the potentiometer settings as a result of the self-inductance of the wire-wound potentiometers, is negligible.) Due to the presence of the 3.9 k Ω resistor R_{11} , the highest potential available at the potentiometers, when the right-hand section of the E 90 CC is conducting, amounts to 240 V. This is ample for presetting the counter tubes to position 0.

The anode capacitance of the right-hand triode sections is increased by the capacitor C_4 , thus reducing the slope of the trailing edge of the negative-going pulse. If this capacitor were omitted, an inadmissibly large proportion of the high-voltage pulse produced when this triode section is cut off would be transmitted to the right deflection electrode of the counter tubes via the anode-to-cathode capacitance of the additional diodes connected to points *p* to *s*.

The double diode EAA 91 has been provided

to restore the rest level of both grids at high repetition frequencies of the cycle of counts, thus ensuring that the anode potential of the right-hand triode section is always exactly 95 V during the interval it is conducting.

The presetting switch at the right has been provided for static control. This should be a push-button switch and make reliable contact either with point *a* or *b*, without rebounding or undue arcing being produced; moreover, there should be no possibility whatsoever of contact being made simultaneously with both *a* and *b*, since this would result in resistor R_{11} being seriously overloaded.

When the switch is pressed, establishing contact with point *b*, capacitor C_5 will be suddenly charged. This results in the potential at the potentiometers dropping to such an extent that the beams of all counter tubes are advanced to figure 9, irrespective of the positions occupied by the sliders of the potentiometers. *) When the switch is subsequently released, contact with point *a* is re-established, so that C_5 discharges through the choke L shunted by the damping resistor R_{13} . The negative-going pulse thus produced at point *c* is fed to the input stage, which is thus triggered. As a result, all counter tubes are successively reset to zero, the fourth decade brings the presetting stage into operation,

*) If any of the counter tubes is not advanced to position 9 this is an indication that the switch makes poor contact.

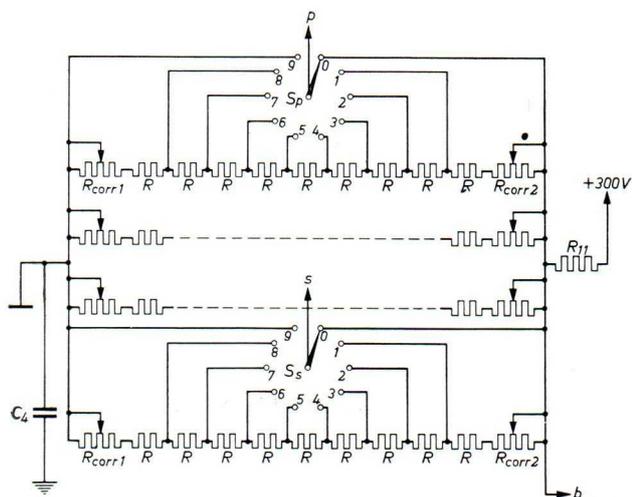


Fig. 25. Circuit for replacing the four wire-wound potentiometers $P_1—P_4$ and the resistors $R_1—R_{10}$ shown in fig. 6 by fixed resistors R ($4.7\text{ k}\Omega \pm 2\%$, $\frac{1}{4}\text{ W}$) and four ten-way switches $S_p—S_s$. The variable resistors R_{corr} need be readjusted only when the tubes are replaced. They may be of the carbon type and should have a value of $10\text{ k}\Omega$. Only two of the four branches have been completely drawn.
All resistors of this circuit should be mounted such that adequate cooling is provided; this may be done by drilling holes in the chassis above these resistors.

and the electron beams are thereby advanced to their preset positions.

In an alternative circuit, the potentiometers $P_1…P_4$, which must be wire-wound, are replaced by fixed carbon resistors R and four ten-way switches $S_p…S_s$, as shown in fig. 25. In this way, the counter can be preset to any number at a moment's notice without risk of inaccurate adjustment. The variable resistors R_{corr} , which may be of the carbon type, need be readjusted only when the corresponding counter tube is replaced. (In the circuit shown in fig. 24, it may be necessary to change the calibrated dials of the potentiometers when the counter tubes are replaced.)

THE OUTPUT STAGE

The trapezoidal voltage pulse produced at the lower tap of the cathode resistor of the last pulse shaper when a cycle of counts has been completed, can be applied to an output stage specially designed for the purpose in view. The circuit of a universal output stage, which operates an electromagnetic relay, is given in fig. 26. This circuit offers the advantage that the time during which the relay is energized can be adjusted from 20 milliseconds to 2 seconds.

Similarly to the interstage circuits, this output stage consists of a monostable multivibrator and is

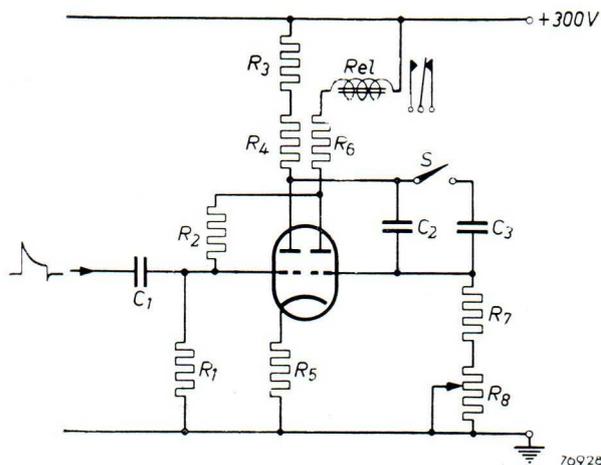


Fig. 26. Circuit of an output stage. The time during which the relay *Rel* remains energized when a pulse is fed to the input depends on the values of R_8 and the coupling capacitance between the two triode sections of the E 90 CC.

Component values

R_1	=	$0.1\text{ M}\Omega$,	$\pm 2\%$,	$\frac{1}{2}\text{ W}$
R_2	=	$1\text{ M}\Omega$,	$\pm 2\%$,	1 W
R_3	=	$15\text{ k}\Omega$,	$\pm 5\%$,	$\frac{1}{2}\text{ W}$
R_4	=	$47\text{ k}\Omega$,	$\pm 5\%$,	1 W
R_5	=	$10\text{ k}\Omega$,	$\pm 2\%$,	$\frac{1}{2}\text{ W}$
R_6	=	$6.8\text{ k}\Omega$,	$\pm 5\%$,	$\frac{1}{2}\text{ W}$
R_7	=	$0.33\text{ M}\Omega$,	$\pm 10\%$,	$\frac{1}{2}\text{ W}$
R_8	=	$2.6\text{ M}\Omega$,	carbon	
C_1	=	22 pF ,	$\pm 10\%$	
C_2	=	$0.056\text{ }\mu\text{F}$,	$\pm 10\%$	
C_3	=	$0.47\text{ }\mu\text{F}$,	$\pm 10\%$	
<i>Rel</i>	=	$\left\{ \begin{array}{l} \text{resistance: } 3\text{ k}\Omega \\ \text{attracting current: } 8.5\text{ mA} \\ \text{releasing current: } 3.5\text{ mA} \end{array} \right.$		

fed by the common supply unit. The multivibrator is triggered by the negative-going flank of the differentiated pulse applied to the left triode section. The time during which the relay remains energized can be adjusted by means of the variable resistor R_8 or by connecting the additional capacitor C_3 by means of switch S across the coupling capacitor C_2 . The maximum repetition frequency of this output stage is 20 cycles of counts per second, which is ample for most practical purposes. When it is required to take full advantage of the maximum repetition frequency of the predetermined counter (3000 c/s), an output circuit equipped with a thyratron instead of an electromagnetic relay may be used.

THE COMPLETE CIRCUIT

Fig. 27 shows the complete circuit of the predetermined counter with output stage, built according to the principles outlined above. It is, moreover, preceded by an additional input pulse shaper ensuring reliable operation even when the input

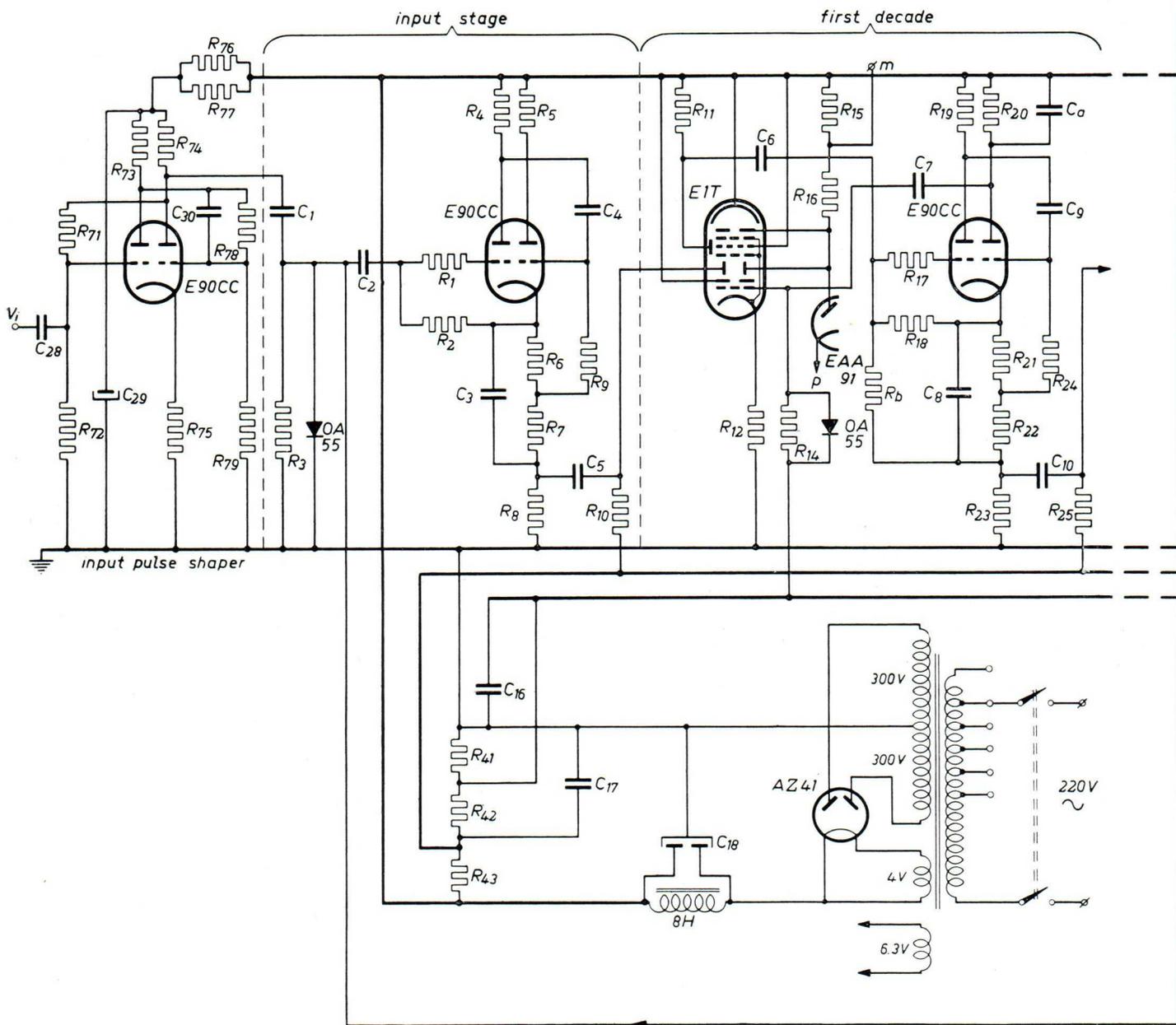
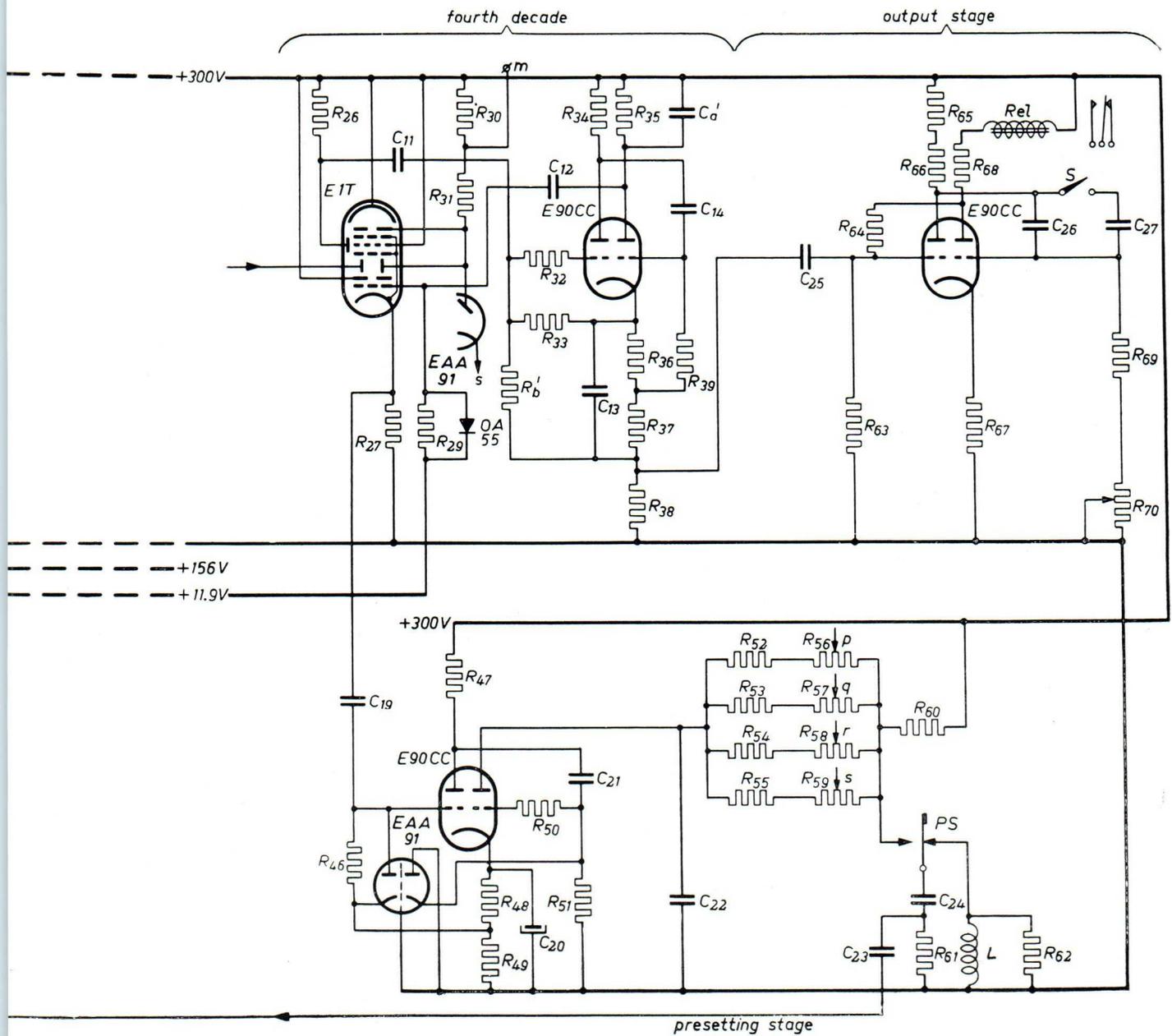


Fig. 27. Complete circuit of the predetermined counter with additional input pulse shaper and

R_1	=	5.6 k Ω ,	$\pm 10\%$,	$\frac{1}{2}$ W
R_2	=	0.56 M Ω ,	$\pm 10\%$,	$\frac{1}{2}$ W
R_3	=	56 k Ω ,	$\pm 10\%$,	$\frac{1}{2}$ W
R_4	=	39 k Ω ,	$\pm 2\%$,	2 W
R_5	=	3.3 k Ω ,	$\pm 2\%$,	$\frac{1}{2}$ W
R_6	=	4.7 k Ω ,	$\pm 2\%$,	1 W
R_7	=	2.7 k Ω ,	$\pm 2\%$,	$\frac{1}{4}$ W
R_8	=	1 k Ω ,	$\pm 1\%$,	$\frac{1}{8}$ W
R_9	=	0.1 M Ω ,	$\pm 1\%$,	$\frac{1}{4}$ W
R_{10}	=	15 k Ω ,	$\pm 2\%$,	$\frac{1}{8}$ W
$R_{11} = R_{26}$	=	39 k Ω ,	$\pm 5\%$,	$\frac{1}{2}$ W
$R_{12} = R_{27}$	=	15 k Ω ,	$\pm 1\%$,	$\frac{1}{8}$ W
$R_{14} = R_{29}$	=	0.33 M Ω ,	$\pm 10\%$,	$\frac{1}{2}$ W
$R_{15} = R_{30}$	=	10 k Ω ,	$\pm 10\%$,	$\frac{1}{2}$ W

$R_{16} = R_{31}$	=	1 M Ω ,	$\pm 1\%$,	$\frac{1}{2}$ W
$R_b = R_b'$	=	8.2 M Ω ,	$\pm 2\%$,	$\frac{1}{4}$ W
$R_{17} = R_{32}$	=	5.6 k Ω ,	$\pm 10\%$,	$\frac{1}{2}$ W
$R_{18} = R_{33}$	=	0.56 M Ω ,	$\pm 5\%$,	$\frac{1}{2}$ W
R_{19}	=	39 k Ω ,	$\pm 2\%$,	2 W
R_{20}	=	3.3 k Ω ,	$\pm 2\%$,	$\frac{1}{8}$ W
R_{21}	=	4.7 k Ω ,	$\pm 2\%$,	$\frac{1}{4}$ W
$R_{22} = R_{37}$	=	2.7 k Ω ,	$\pm 2\%$,	$\frac{1}{4}$ W
$R_{23} = R_{38}$	=	1 k Ω ,	$\pm 1\%$,	$\frac{1}{8}$ W
$R_{24} = R_{39}$	=	0.15 M Ω ,	$\pm 2\%$,	$\frac{1}{8}$ W
R_{25}	=	15 k Ω ,	$\pm 2\%$,	$\frac{1}{8}$ W
R_{41}	=	5.6 k Ω ,	$\pm 1\%$,	$\frac{1}{8}$ W
R_{42}	=	68 k Ω ,	$\pm 1\%$,	1 W
R_{43}	=	68 k Ω ,	$\pm 1\%$,	1 W

R_{46}	=	0.56 M Ω ,	$\pm 10\%$,	$\frac{1}{2}$ W
R_{47}	=	18 k Ω ,	$\pm 2\%$,	$\frac{1}{2}$ W
R_{48}	=	1.5 k Ω ,	$\pm 2\%$,	$\frac{1}{2}$ W
R_{49}	=	3.9 k Ω ,	$\pm 2\%$,	$\frac{1}{2}$ W
R_{50}	=	33 k Ω ,	$\pm 10\%$,	$\frac{1}{2}$ W
R_{51}	=	1 M Ω ,	$\pm 10\%$,	$\frac{1}{2}$ W
$R_{52} - R_{55}$	=	100 Ω ,	$\pm 10\%$,	$\frac{1}{2}$ W
$R_{56} - R_{59}$	=	50 k Ω ,	$\pm 2\%$,	wire-wound
R_{60}	=	3.9 k Ω ,	$\pm 2\%$,	$\frac{1}{2}$ W
R_{61}	=	100 Ω ,	$\pm 10\%$,	$\frac{1}{2}$ W
R_{62}	=	680 Ω ,	$\pm 10\%$,	$\frac{1}{2}$ W
R_{63}	=	0.1 M Ω ,	$\pm 2\%$,	$\frac{1}{2}$ W
R_{64}	=	1 M Ω ,	$\pm 2\%$,	1 W
R_{65}	=	15 k Ω ,	$\pm 5\%$,	$\frac{1}{2}$ W



output stage; the second and third decades, which are identical to the first decade, have been left out.

values

R_{66}	=	47 k Ω , \pm 5%, 1 W	C_1	=	220 pF, \pm 10%	C_{18}	=	$2 \times 50 \mu\text{F}$, 450 V
R_{67}	=	10 k Ω , \pm 2%, $\frac{1}{2}$ W	C_2	=	220 pF, \pm 10%	C_{19}	=	470 pF, \pm 10%
R_{68}	=	6.8 k Ω , \pm 5%, $\frac{1}{2}$ W	C_3	=	100 pF, \pm 2%	C_{20}	=	25 μF , 25 V
R_{69}	=	0.33 M Ω , \pm 10%, $\frac{1}{2}$ W	C_4	=	39 pF, \pm 2%	C_{21}	=	560 pF, \pm 10%
R_{70}	=	2.6 M Ω , carbon	C_5	=	0.0068 μF , \pm 10%	C_{22}	=	180 pF, \pm 10%
R_{71}	=	56 k Ω , \pm 2%, $\frac{1}{2}$ W	$C_6 = C_{11}$	=	220 pF, \pm 10%	C_{23}	=	15 pF, \pm 10%
R_{72}	=	56 k Ω , \pm 2%, $\frac{1}{2}$ W	$C_7 = C_{12}$	=	0.0068 μF , \pm 10%	C_{24}	=	0.47 μF , \pm 20%
R_{73}	=	8.2 k Ω , \pm 2%, $\frac{1}{2}$ W	$C_8 = C_{13}$	=	68 pF, \pm 2%	C_{25}	=	22 pF, \pm 10%
R_{74}	=	8.2 k Ω , \pm 2%, $\frac{1}{2}$ W	$C_a = C_a'$	=	270 pF, \pm 10%	C_{26}	=	0.056 μF , \pm 10%
R_{75}	=	12 k Ω , \pm 2%, $\frac{1}{2}$ W	C_9	=	100 pF, \pm 2%	C_{27}	=	0.47 μF , \pm 20%
R_{76}	=	56 k Ω , \pm 2%, 1 W	C_{10}	=	680 pF, \pm 5%	C_{28}	=	1 μF , \pm 20%
R_{77}	=	56 k Ω , \pm 2%, 1 W	C_{14}	=	180 pF, \pm 2%	C_{29}	=	25 μF , 300 V
R_{78}	=	56 k Ω , \pm 2%, $\frac{1}{2}$ W	C_{16}	=	0.39 μF , \pm 20%	C_{30}	=	100 pF, \pm 10%
R_{79}	=	56 k Ω , \pm 2%, $\frac{1}{2}$ W	C_{17}	=	0.15 μF , \pm 20%	L	=	1 mH

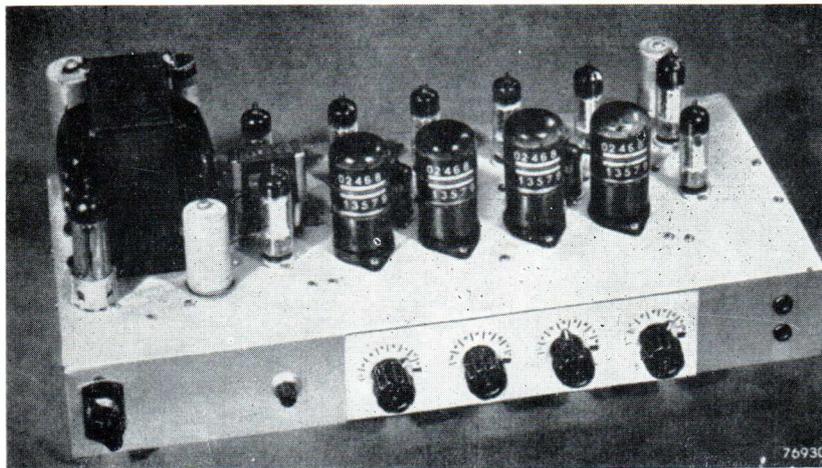


Fig. 28. Front view of the predetermined counter without hood. Length of the chassis 42 cm, height 6 cm, depth 20 cm.

signals do not comply with the specifications given. Sinusoidal voltages down to 10 c/s may thus be applied to the input, provided their amplitude ranges from 15 V to about 50 V. If there is a risk of random pulses being produced by rebounding of the spring contacts of mechanical switches, the additional input shaper should, moreover, be preceded by a low-pass filter.

The supply unit differs slightly from that of the multi-decade counter, which is attributed to the

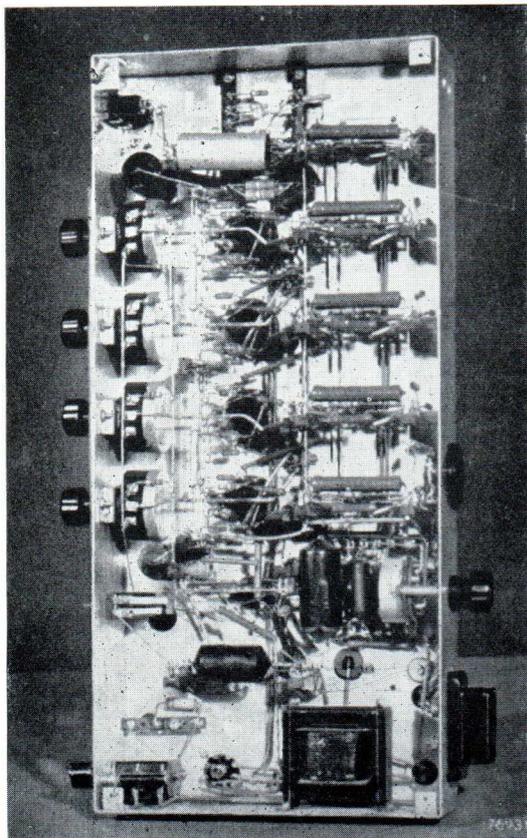


Fig. 29. The chassis depicted in fig. 28, seen from below.

Fig. 28 shows the front view of the complete predetermined counter containing the additional input pulse shaper and the output stage mentioned above. At the front can be seen the four control knobs with calibrated dials for presetting the counter to the required number. At the right of the counter tubes is the E 90 CC double triode of the additional input pulse shaper, and at the left that of the presetting stage. The relay is mounted behind the mains transformer to the left. The additional controls for adjusting the time during which the relay remains energized are mounted at the rear of the chassis next to a female plug to which the relay contacts are connected.

Fig. 29 shows the chassis seen from below. The four wire-wound potentiometers for presetting the counter tubes can be clearly seen. The wiring towards these potentiometers should be kept clear of the other wiring, in order to avoid random pulses being induced capacitively into other leads. The double diodes EAA 91 are mounted close to the corresponding counter, to keep the wiring as short as possible and away from the chassis, undue increase of the stray capacitance at the right deflection electrode and anode thus being avoided. In order to prevent interaction between the two diode systems of the EAA 91, the internal screen of this tube should be connected to the +300 V line.

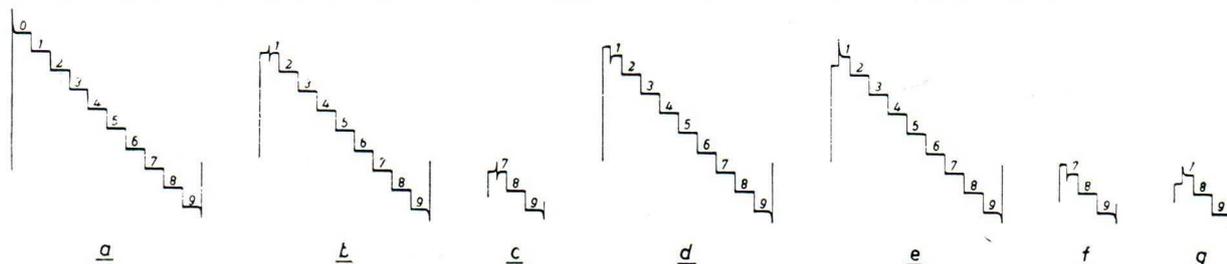
ADJUSTMENT AND CALIBRATION

Presetting by means of potentiometers

The optimum settings of the potentiometers corresponding to the figures from 0 to 9 differ slightly for each decade and can be determined in the following way. A pulse generator having a frequency of up to 3000 c/s is connected to the input

terminals. First the potentiometer that presets the "unit" decade is calibrated, the other potentiometers being turned as far as possible in a clockwise direction*). The transitional points at which the beam is preset to a next figure are sharply defined. The optimum positions are obviously those midway between these points. After this potentiometer has been calibrated, its knob is set to position 0, and the potentiometer by means of which

Due to the spread in the characteristics of the counter tubes, the voltage at the anode and right deflection plate may range from 215 V to 240 V at position 0, and from 95 V to 115 V at position 9. When a counter tube is replaced, it is therefore necessary to check the calibration of the corresponding potentiometer. As a rule, there is no need to draw a new dial, it being sufficient to rotate the calibrated dial over a small angle.



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Fig. 30. Oscillograms of a decade incorporating a ten-way switch for the presetting. *a*—switch at position 0; *b*—switch at position 1, R_{corr2} accurately adjusted; *c*—switch at position 7, R_{corr1} accurately adjusted; *d*—switch at position 1, R_{corr2} too low; *e*—switch at position 1, R_{corr2} too high; *f*—switch at position 7, R_{corr1} too high; *g*—switch at position 7, R_{corr1} too low.

the tens are preset is calibrated in a similar way; the knobs for presetting the hundreds and thousands should remain turned entirely to the right. The frequency of the pulse generator may now be increased to 12 500 c/s, which facilitates in particular the calibration of the potentiometers for presetting the hundreds and the thousands.**). For calibrating the potentiometer that presets the hundreds, the knobs for presetting the units and tens should occupy position 0, and the knob for presetting the thousands should remain at its extreme right-hand position. Accurate calibration of the potentiometer for presetting the thousands — which is carried out with the other knobs still set to position 0 — takes a little more time. This is due to the fact that transitional points can no longer be clearly distinguished because the rate at which the electron beam travels over the fluorescent screen becomes fairly low, even at the maximum frequency of 12 500 c/s.

*) It is assumed that the potentiometers are connected so that, during the resetting, the highest potential (corresponding to position 0) is obtained at the slider when the knob is turned entirely in an anti-clockwise direction.

***) It should be recognized that, when the knob of the potentiometer which presets the "units" decade is adjusted beyond the position corresponding to figure 5 and the other potentiometers are turned as far as possible in a clockwise direction, it is no longer the maximum counting frequency (12 500 counts per second), but the maximum frequency of the cycle of counts (3000 c/s) that limits the counting rate.

Presetting by means of ten-way switches

When ten-way switches and fixed resistors are used (see fig. 25), the adjustment of the variable resistors R_{corr} is preferably carried out with the aid of an oscilloscope connected to terminal *m* of the corresponding decade (see fig. 27). Adjustment should be carried out in the same sequence as described in the preceding section for predetermined counters incorporating potentiometers.

When the switch is set at position 0, the oscillogram displayed will be as shown in fig. 30*a*, consisting of ten distinct steps. When the variable resistors R_{corr2} and R_{corr1} are correctly adjusted, the oscillograms will be as shown in fig. 30*b* and *c* at positions 1 and 7 respectively. If the value of R_{corr2} , which serves for correction of the lower positions, is too low, the oscillogram will be similar to that shown in fig. 30*d* at position 1; if it is too high, an oscillogram similar to that shown in fig. 30*e* is obtained. After R_{corr2} has been accurately adjusted, the switch is set to a higher figure, and the adjustment of R_{corr1} is checked. If its value is too high, the oscillogram will be similar to that shown in fig. 30*f* at position 7; if it is too low, the oscillogram will be as shown in fig. 30*g*.

A DECADE COUNTER STAGE WITH A COUNTING RATE OF 100 000 PULSES PER SECOND

FUNDAMENTAL PROBLEMS

As explained above, the counting operation of the EIT decade counter tube may be regarded as consisting of two phases, namely the stepping operations from position 0 to 9 and the fly-back of the beam from position 9 to 0. The two principal problems which arise when the EIT is required to operate at a counting rate of 100 000 pulses per second are:

- (1) The fly-back time during which the voltage $V_{D',a2}$ at the right-hand deflection electrode and the anode of the EIT should increase by about 140 V may not exceed 10 μsec .
- (2) Each stepping operation must be completed within 10 μsec .

The fly-back operation

The fly-back operation consists of:

- (a) Initiating the fly-back, for example by means of a pulse derived from the reset anode.
- (b) Raising the voltage $V_{D',a2}$ from the level at position 9 to that which corresponds to position 0.
- (c) Settling of all voltages in the circuit to such quiescent values that the counter tube is ready for the next stepping operation.

In the circuit for a decade counter with a counting rate of up to 30 000 pulses per second, the fly-back is obtained by applying a negative pulse to the control grid of the counter tube, so that its beam is blanked; with a load resistance of 1 M Ω and a total anode by-pass capacitance of 16.5 pF, the fly-back time is approximately 27 μsec . Since for a counting rate of up to 100 000 pulses per second the total fly-back time must be less than 10 μsec , additional measures must therefore be provided to raise the anode voltage fast enough. This may be achieved by connecting the anode of the counter tube to the cathode of a separate tube which should

be non-conducting during the stepping operation from 0 to 9, whereas it should be conducting during the fly-back, so that the anode of the counter tube is raised at the required speed. It should be recognized that, because of the connection of the EIT anode to the additional circuitry, the total anode by-pass capacitance is increased from 16.5 pF to about 23 pF.

The stepping operation

It should be borne in mind that for the stepping operation the input pulses which are needed for proper counting should have a special shape. In the decade counter for counting rates up to 30 000 pulses per second, the triangular positive-going pulses applied to the left-hand deflection electrode should have an amplitude of 13.6 V \pm 15%. The duration of the leading edge should, in general, not exceed 0.7 μsec , and the trailing edge — provided its slope is constant — should have a duration of at least 11 μsec . These specifications are, however, only valid when the total anode by-pass capacitance of the counter tube is 16.5 pF.

The minimum permissible duration of the trailing edge of these pulses is highly dependent on the characteristics of the counter tube. This will be explained by means of the graph shown in fig. 31, which represents a part of the $I_{a2} = f(V_{D',a2})$ characteristic of the EIT counter tube and the load line for $R_{a2} = 1 \text{ M}\Omega$ (see fig. 6).

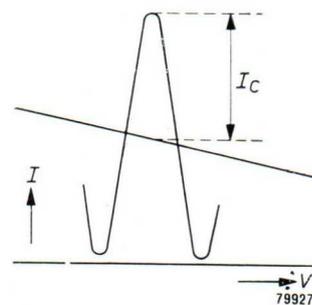


Fig. 31. Part of the $I_{a2} = f(V_{D',a2})$ characteristic of the EIT counter tube with the load line for $R_{a2} = 1 \text{ M}\Omega$.

It will be assumed that a positive-going pulse with a very steep front and an amplitude of about 14 V is applied to the left-hand deflection electrode. As a result, the beam will suddenly be shifted to the next higher position; the voltage $V_{D',a2}$ at the anode and right-hand deflection electrode will, however, not suddenly decrease, due to the presence of the anode by-pass capacitance of the E I T.

In order to ensure that the beam remains in its new position, the speed at which the amplitude of the counting pulse decreases should never exceed that at which the anode voltage can decrease. The latter speed is determined by the maximum available current with which the anode by-pass capacitance can be discharged. This current (denoted by I_C in fig. 31) is the difference between the maximum tube current which flows in a peak of the characteristic and the current flowing through the load resistor at the existing instantaneous anode voltage.

It will be assumed that I_C remains substantially constant when the beam is shifted from one position to the next, so that $V_{D',a2}$ decreases linearly during a stepping operation if the slope of the trailing edge of the counting pulse is also constant. The time t required by $V_{D',a2}$ to decrease by an amount V when the by-pass capacitance C is discharged with the constant current I_C , is then given by:

$$t = \frac{C \cdot V}{I_C}.$$

Since the minimum permissible duration of the trailing edge of the counting pulses is equal to the time t , this expression shows that this duration is proportional to the anode by-pass capacitance of the E I T and inversely proportional to the value of the maximum available current I_C .

In fact, the critical point is not the minimum duration of t , but the maximum value of the slope of the trailing edge of the pulse, a given minimum permissible duration of the trailing edge corresponding to a certain amplitude of the counting pulse. This duration depends linearly on the amplitude of the counting pulse. This has been verified by plotting the minimum permissible duration of the trailing edge of the pulse at which the tube still counts properly against the amplitude of the applied pulse for an average tube (see fig. 32). The graph thus obtained shows that this relation is indeed linear within the extreme values of the permissible pulse amplitude (11.5 V to 15.6 V (indicated by the dashed lines).

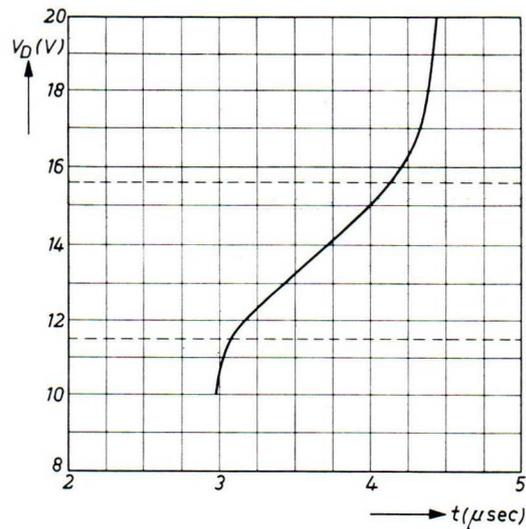


Fig. 32. Minimum duration t_{\min} of the trailing edge of the pulses plotted against the amplitude V_D of the applied pulses for an average tube.

The anode voltage difference between two adjacent stable positions of the beam is approximately 14 V. The total anode by-pass capacitance in the circuit for counting up to 100 000 pulses per second is about 23 pF. The smallest positive peak in the characteristic is that which is situated between the points corresponding to the positions 0 and 1. For an average tube, this peak exceeds the load line by approximately $70 \mu\text{A}$, which gives a minimum permissible duration of the trailing edge of the counting pulses of $4.6 \mu\text{sec}$. This peak may, however, be considerably lower in some standard production tubes, but provided it is at least about $35 \mu\text{A}$, the condition that each stepping operation must be completed within $10 \mu\text{sec}$ can still be complied with.

For this purpose, an input pulse shaper, preceded by a squarer, has been designed, which converts the applied signal voltage into pulses with the correct amplitude, a very steep leading edge and a linear trailing edge, the total duration being just under $10 \mu\text{sec}$.

SQUARER AND INPUT PULSE SHAPER

Fig. 33 shows the circuit diagram of the squarer followed by the input pulse shaper. The squarer

In the quiescent condition, the left-hand section of the E 92 CC is conducting, the right-hand section

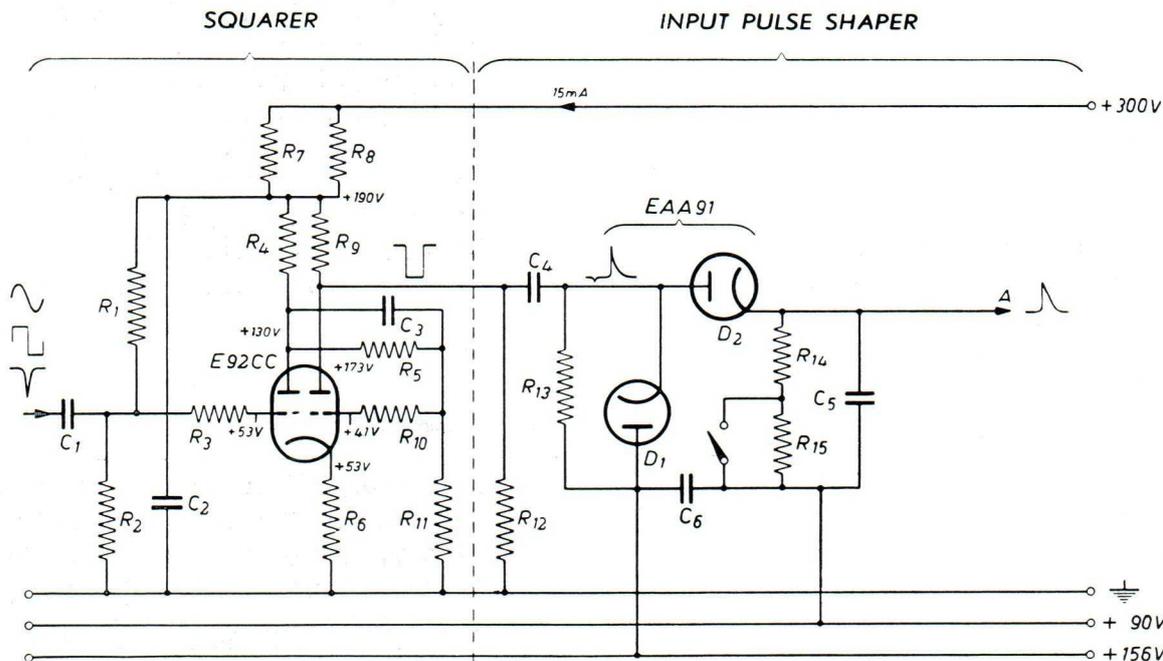


Fig. 33. Circuit diagram of the squarer followed by the input pulse shaper. The voltages and the current indicated are those which occur in the quiescent state. Instead of the E 92 CC, an E 90 CC double triode may be used.

Component values

$R_1 = 82 \text{ k}\Omega \pm 1\%, \frac{1}{2} \text{ W}$	$R_{11} = 18 \text{ k}\Omega \pm 1\%, \frac{1}{2} \text{ W}$
$R_2 = 33 \text{ k}\Omega \pm 1\%, \frac{1}{4} \text{ W}$	$R_{12} = 56 \text{ k}\Omega \pm 2\%, 1 \text{ W}$
$R_3 = 1 \text{ k}\Omega \pm 10\%, \frac{1}{4} \text{ W}$	$R_{13} = 47 \text{ k}\Omega \pm 2\%, \frac{1}{4} \text{ W}$
$R_4 = 5.6 \text{ k}\Omega \pm 1\%, 1 \text{ W}$	$R_{14} = 0.68 \text{ M}\Omega \pm 1\%, \frac{1}{4} \text{ W}$
$R_5 = 39 \text{ k}\Omega \pm 1\%, 1 \text{ W}$	$R_{15} = 0.15 \text{ M}\Omega \pm 2\%, \frac{1}{4} \text{ W}$
$R_6 = 6.8 \text{ k}\Omega \pm 1\%, 1 \text{ W}$	$C_1 = 2 \mu\text{F} \pm 10\%, \text{ paper}$
$R_7 = 15 \text{ k}\Omega \pm 2\%, 2 \text{ W}^*)$	$C_2 = 0.1 \mu\text{F} \pm 10\%$
$R_8 = 15 \text{ k}\Omega \pm 2\%, 2 \text{ W}^*)$	$C_3 = 22 \text{ pF} \pm 10\%$
$R_9 = 5.6 \text{ k}\Omega \pm 1\%, 1 \text{ W}$	$C_4 = 47 \text{ pF} \pm 2\%$
$R_{10} = 1 \text{ k}\Omega \pm 10\%, \frac{1}{4} \text{ W}$	$C_5 = 39 \text{ pF} \pm 2\%$

$C_6 = 0.01 \mu\text{F} \pm 10\%$

has been so designed that input signals of an arbitrary waveform may be applied; it is equipped with an E 92 CC¹⁾ double triode which acts as a monostable (one-shot) multivibrator. The pulse shaper contains two diodes. The input pulse shaper should supply pulses with the correct amplitude and shape, independent of the pulse repetition frequency and of the waveform of the signal applied to the squarer. Moreover, the pulses produced should not be affected by differences in the characteristics of the tubes. The operation of the squarer may be explained as follows.

*) The parallel-connected resistors R_7 and R_8 may be replaced by a single wire-wound $\pm 5\%$, 3 W resistor of 7.5 k Ω .
¹⁾ Instead of an E 92 CC, it is possible to use an E 90 CC double triode in the squarer without the necessity of changing the component value.

then being cut off. When a negative-going pulse is applied to the input terminals, the conditions of the two sections are reversed, the left-hand section then being cut off and the right-hand section becoming conducting. As a result, the anode voltage of the latter section drops from 173 V to 130 V. The multivibrator returns to its original state at some point of the positive-going flank of the applied signal. The anode voltage of the right-hand triode section is thereby again raised from 130 V to 173 V.

In order to ensure that the supply voltage of the squarer at the lower end of the dropping resistors R_7 R_8 is independent of the pulse repetition frequency, the currents of the triode sections of the multivibrator are made to be identical in the conducting state.

The input pulse shaper operates as follows: Due to the presence of the diode D_1 , no negative-going pulse appears at the anode of the diode D_2 when the anode voltage of the right-hand triode section of the squarer decreases. As a result, the anode voltage of D_2 remains practically constant at a value of 156 V during this part of the operation. This is of importance when the squarer is triggered with a negative-going pulse the duration of which is in the order of magnitude of the time constant $R_{13} C_4$. If the diode D_1 were omitted, the anode voltage of D_2 would still be well below 156 V by the time that the squarer has returned to its original state, and the amplitude of the output voltage produced at point A would be too small.

When, on the other hand, the anode voltage of the right-hand triode section of the squarer is positive-going, the diode D_1 becomes non-conducting, whereas the diode D_2 becomes conducting. The total by-pass capacitance at point A (including C_5) is then charged via D_2 , as a result of which the voltage at the left-hand deflection electrode of the first E I T counter tube, which is connected to this point, is raised to a value of approximately 170 V.

By suitable choice of the time constant $R_{13} C_4$, the anode voltage of D_2 , after having reached its peak value, can be made to decrease faster than the cathode voltage of this diode, so that D_2 now becomes non-conducting. The total by-pass capacitance at point A then starts to discharge via $R_{14} + R_{15}$, so that the voltage at this point tends to a value of 90 V. However, as soon as the voltage at point A has dropped to 156 V, the diodes D_1 and D_2 become conducting once again, the voltage at the left-hand deflection electrode of the E I T thus remaining at a potential of 156 V. This results in the trailing edge of the positive-going pulses produced at point A being substantially linear, as can be seen from the oscillograms shown in figs 34 and 35 displaying the voltage produced at point A at pulse repetition frequencies of 50 kc/s and 100 kc/s respectively.

The output pulses at point A have an amplitude of approximately 14 V, the duration of the leading edge and the top is approximately 1 μ sec, and that of the trailing edge is approximately 8 μ sec, thus giving a total pulse duration of approximately 9 μ sec. It should be noted that both the amplitude and the duration of these pulses are highly dependent on the value of the total capacitance at point A , including that of the left-hand deflection electrode of the first E I T with respect to earth. It is there-

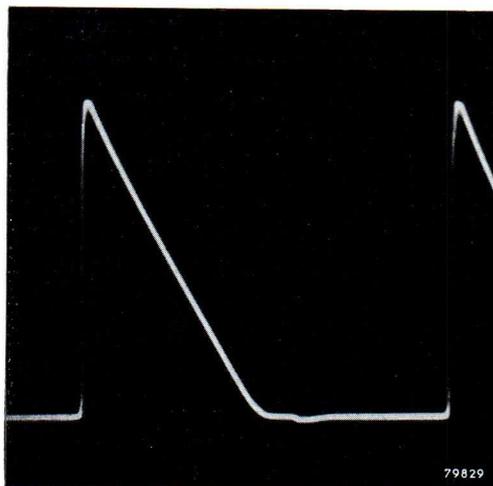


Fig. 34. Oscillogram displaying the voltage at point A at a pulse repetition frequency of 50 kc/s.

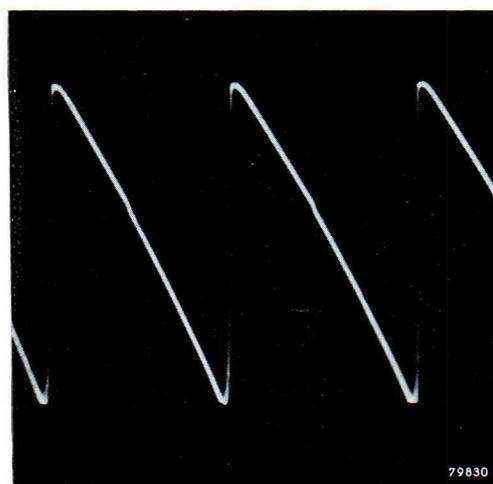


Fig. 35. Oscillogram displaying the voltage at point A at a pulse repetition frequency of 100 kc/s.

fore essential that the variations in the total by-pass capacitance at this point are minimized by keeping the stray capacitance at this point as small as possible. Similarly, the stray capacitance in the multivibrator circuit should be reduced to a minimum.

The squarer can be triggered either with a sinusoidal voltage, with a square-wave voltage or with negative-going pulses, provided the amplitude of the input signal exceeds approximately 15 V. If regularly spaced negative-going pulses are applied to the input terminals, the pulse repetition frequency may range from zero to 100 kc/s. The negative-going pulses should have a duration of at least 2 μ sec. It is true that the squarer will be triggered

when pulses of a shorter duration are applied, but in that case the amplitude of the output pulses at point *A* will slightly decrease. This is due to the fact that, when the squarer is triggered by the leading edge of the negative-going input pulse, the voltage at the cathode of diode D_1 drops slightly below the 156 V level due to the internal resistance of this diode not being infinitely small. It takes about 2 μ sec for the voltage at this point to return to the 156 V level. If the squarer is reversed within 2 μ sec to its original state by the trailing edge of the input pulse, the amplitude of the resulting positive pulse at the cathode of diode D_1 will therefore not reach its correct value.

Similarly, the amplitude of the output pulses at point *A* will decrease when a sinusoidal voltage of very low frequency is applied, the switching time of the squarer being affected thereby. It was found that the circuit operates satisfactorily with a sinusoidal input voltage with a frequency ranging from 20 c/s up to 100 kc/s. If the circuit is to be operated with a sinusoidal voltage of a few cycles per second only, it may be advisable to increase the value of the input capacitor C_1 or the amplitude of the applied signal.

The shape of the pulses produced at point *A* may be checked by means of an oscilloscope preceded by a cathode follower, provided the input by-pass capacitance of the latter is equal to the by-pass capacitance of the left-hand deflection electrode of the first decade counter tube. Point *A* should then be connected to the grid of the cathode follower tube instead of to the left-hand deflection electrode. Provision should be made that the cathode follower does not draw any grid current. If the pulse shape is observed directly at the left-hand deflection electrode of the counter tube when the tube is in operation, it will be noticed that the pulse duration is smaller when the beam is shifted from, say, position 8 to 9 than when it is shifted from position 0 to 1. This is due to the fact that in the higher positions the beam is in the neighbourhood of the left-hand deflection electrode, and the latter then draws some current because the beam is not ideally focused. The resulting finite internal tube resistance between the deflection electrode and cathode partly shunts the high differentiating resistance $R_{14} + R_{15}$, which results in a decrease of the duration of the trailing edge of the pulse. This is, however, of little consequence, because the current which is available for discharging the anode by-pass capacitance of the coun-

ter tube is larger in the higher positions than in the lower ones. (This is clearly shown by the $I_a = f(V_{D',a2})$ characteristics of the counter tube given in fig. 6; the peaks above the load line are much larger at the higher positions than at the lower positions.)

FLY-BACK CIRCUIT

The fly-back circuit is required to ensure a fast fly-back of the beam when it has to be reset from position 9 to 0. Moreover, this circuit should produce an output pulse of appropriate shape to operate the following counter stage.

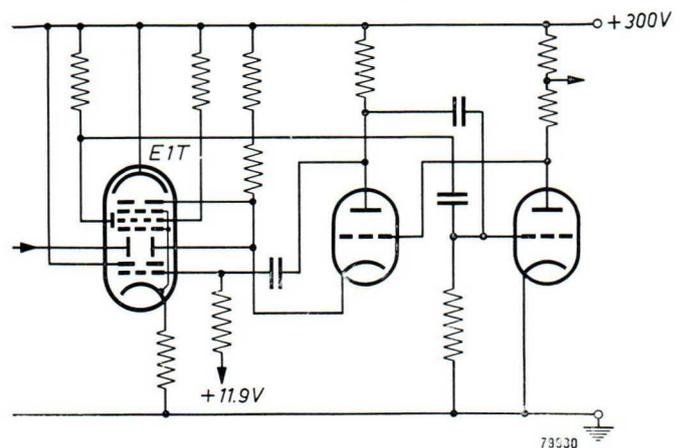


Fig. 36. Decade counter tube followed by a fly-back circuit formed by a monostable multivibrator.

The simplest system consists in using a monostable multivibrator circuit for this purpose. Fig. 36 gives an example of such a circuit. When the beam of the counter tube hits the reset anode, a negative pulse is passed on to the grid of the right-hand triode, which is normally conducting. The anode voltage of this tube then rises, and so does the anode voltage of the counter tube, the left-hand triode now acting as a cathode follower. The negative-going voltage pulse at the anode of the left-hand triode is used both for blanking the beam of the counter tube and for keeping the right-hand triode cut off until the grid voltage of the latter again passes the cut-off point. If this additional beam blanking were not used, there would be a risk that with some counter tubes the rising anode voltage of the E1T would be caught in position 1, thus making the fly-back incomplete.

The disadvantages of such multivibrator circuits are:

- (a) The high heater-to-cathode voltage of the left-hand triode.
- (b) The high grid-to-cathode voltage of the left-hand triode when the anode voltage of the E I T counter tube is high.

- (e) The poor shape of the output pulse derived from the anode circuit of the right-hand triode. It is difficult to obtain a pulse with a sufficiently steep leading edge.

In view of these disadvantages, a more elaborate fly-back circuit has been designed in which a diode

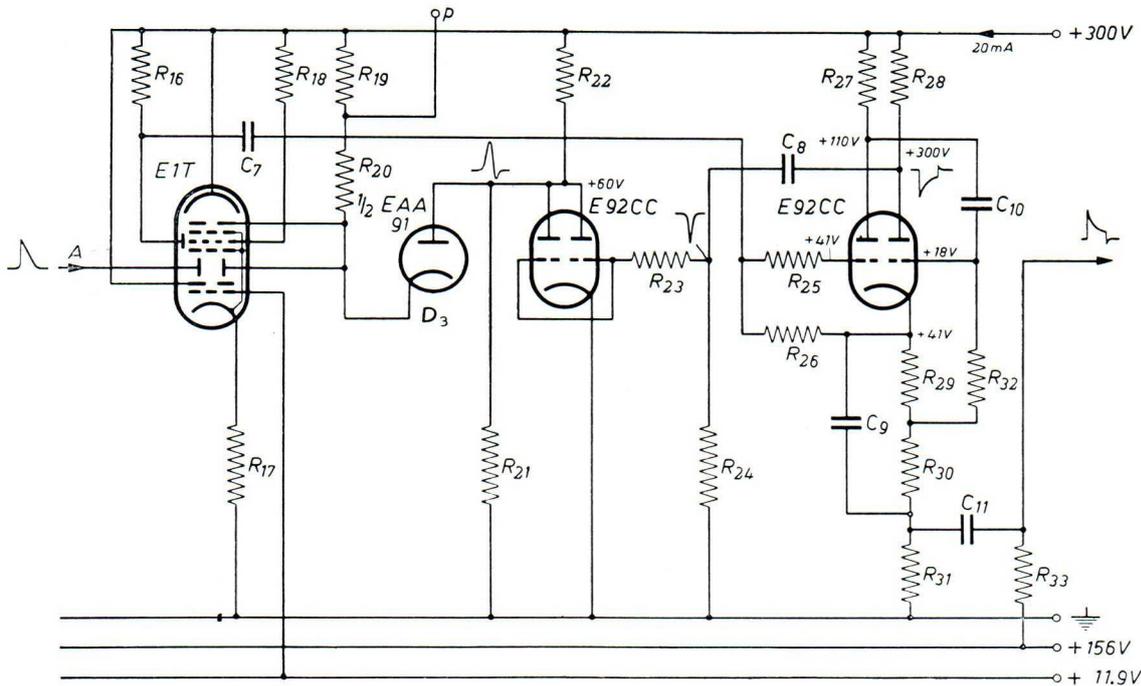


Fig. 37. Recommended fly-back circuit. The voltage and the current indicated are those which occur in the quiescent state. There is no objection to replacing the double triodes E 92 CC by double triodes E 90 CC, provided a few minor changes are made in the fly-back circuit and the interstage shaper shown above. These changes are:

- (a) The resistor R_{21} should be omitted.
- (b) The value of C_9 should be increased from 56 pF to 68 pF.
- (c) The value of C_{11} should be reduced from 0.0068 μ F to 680 pF ($\pm 5\%$).

Component values

$R_{16} = 39 \text{ k}\Omega \pm 10\%, \frac{1}{2} \text{ W}$	$R_{25} = 5.6 \text{ k}\Omega \pm 10\%, \frac{1}{4} \text{ W}$	$C_7 = 220 \text{ pF} \pm 10\%$
$R_{17} = 15 \text{ k}\Omega \pm 1\%, \frac{1}{4} \text{ W}$	$R_{26} = 0.56 \text{ M}\Omega \pm 10\%, \frac{1}{4} \text{ W}$	$C_8 = 220 \text{ pF} \pm 2\%$
$R_{18} = 47 \text{ k}\Omega \pm 5\%, \frac{1}{2} \text{ W}$	$R_{27} = 39 \text{ k}\Omega \pm 2\%, 2 \text{ W}$	$C_9 = 56 \text{ pF} \pm 2\%$
$R_{19} = 10 \text{ k}\Omega \pm 10\%, \frac{1}{4} \text{ W}$	$R_{28} = 3.3 \text{ k}\Omega \pm 2\%, \frac{1}{2} \text{ W}$	$C_{10} = 68 \text{ pF} \pm 2\%$
$R_{20} = 1 \text{ M}\Omega \pm 1\%, \frac{1}{2} \text{ W}$	$R_{29} = 4.7 \text{ k}\Omega \pm 2\%, 1 \text{ W}$	$C_{11} = 0.0068 \text{ }\mu\text{F} \pm 10\%$
$R_{21} = 0.47 \text{ M}\Omega \pm 5\%, \frac{1}{2} \text{ W}$	$R_{30} = 2.7 \text{ k}\Omega \pm 2\%, \frac{1}{2} \text{ W}$	
$R_{22} = 18 \text{ k}\Omega \pm 5\%, 5 \text{ W}^*)$	$R_{31} = 1 \text{ k}\Omega \pm 1\%, \frac{1}{4} \text{ W}$	
$R_{23} = 1 \text{ k}\Omega \pm 10\%, \frac{1}{4} \text{ W}$	$R_{32} = 0.15 \text{ M}\Omega \pm 2\%, \frac{1}{4} \text{ W}$	
$R_{24} = 6.8 \text{ k}\Omega \pm 2\%, \frac{1}{4} \text{ W}$	$R_{33} = 15 \text{ k}\Omega \pm 2\%, \frac{1}{4} \text{ W}$	

*) Wire-wound.

- (c) The effect of the residual cathode current of the left-hand triode when this tube is cut off. This current has the same effect as a resistor shunted across the 1 M Ω $\pm 1\%$ load resistor of the E I T, and even a current of, for example, 10 μ A would be inadmissible.
- (d) The effect of the leakage current between heater and cathode of the left-hand triode. This current also has the effect of partly shunting the load resistor of the E I T.

(for example one section of an EAA 91) and an E 92 CC double triode are used. Fig. 37 shows the circuit diagram of the first E I T counter tube followed by this fly-back circuit and the interstage shaper, which is identical to that used in the decade counter for counting rates up to 30 000 pulses per second, apart from the fact that an E 92 CC is used instead of the E 90 CC double triode. The negative-going pulse which is produced at the anode of the right-hand triode section of this interstage pulse

shaper is, however, not used for blanking the beam of the preceding counter tube, but differentiated and applied to the grids of the two parallel-connected sections of the additional double triode of the fly-back circuit. During the fly-back, this tube is thus temporarily cut off. Its anode voltage then suddenly increases, and so does the anode voltage of the preceding E I T as soon as the diode D_3 becomes conducting.

The oscillogram given in fig. 38 displays the anode voltage of the double triode in the fly-back circuit as a function of time at a pulse repetition frequency of 100 kc/s at the input of the decade counter. Due to the cathode-to-anode capacitance of the diode D_3 , there is a tendency of the E I T anode voltage to be lowered just after having reached the zero position level. This is caused by the fact that, when the additional double triode becomes conducting again, part of the negative-going voltage excursion at its anode is transmitted to the anode of the E I T via the capacitive voltage divider formed by the capacitance of D_3 and the total anode by-pass capacitance of the E I T.

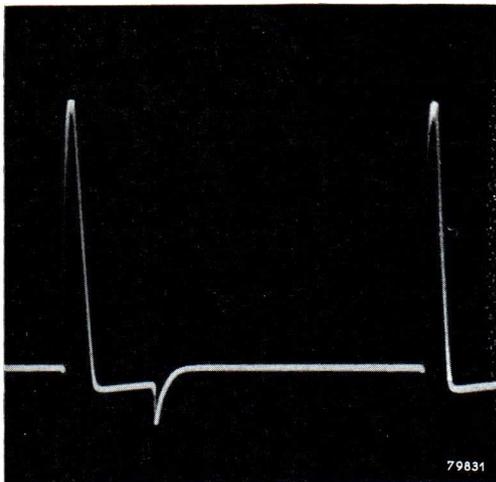


Fig. 38. Oscillogram displaying the anode voltage of the double triode in the fly-back circuit at a pulse repetition frequency of 100 kc/s.

The E I T anode voltage should therefore be raised sufficiently high during the fly-back, but if it is raised too high, it will take too long for this anode voltage to drop back to the correct level at the zero position, and counting of 100 000 pulses per second would become impossible. The rate at which the E I T anode voltage can decrease to the correct value is determined by the height of the $I_{a2} = f(V_{D',a2})$ characteristic of the counter tube above the load line beyond the stable position zero.

This height is indicative for the maximum available current with which the total by-pass capacitance at the anode of the E I T can be discharged.

The highest level to which the E I T anode voltage is actually raised in this circuit is determined by the duration and the amplitude of the differentiated pulse applied to the grids of the double triode of the fly-back circuit, by the cut-off voltage of this tube and, finally, by the total by-pass capacitance in the anode circuit of this tube and of the E I T. The stray capacitances at these points should therefore be kept as small as possible. A good compromise is obtained by connecting the anode of the double triode of the fly-back circuit via the 0.47 M Ω resistor R_{21} to earth (see fig. 37).

Figs 39 and 40 show the oscillograms of the E I T

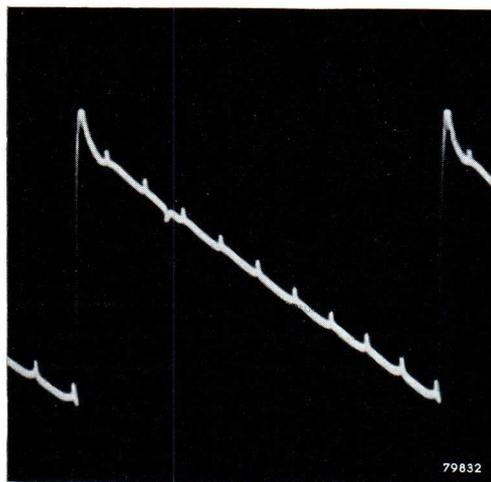


Fig. 39. Oscillogram of the E I T anode voltage at a pulse repetition frequency of 100 kc/s.

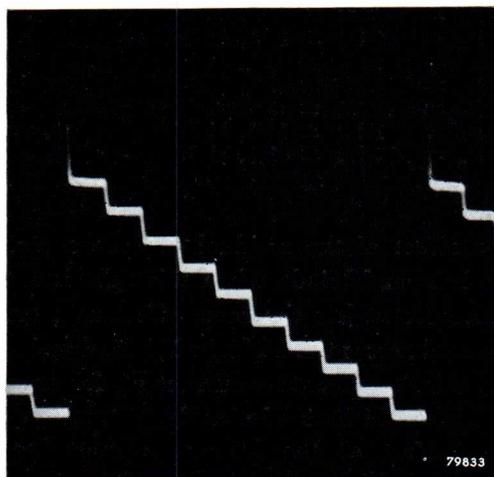


Fig. 40. Oscillogram of the E I T anode voltage at a pulse repetition frequency of 10 kc/s.

anode voltage at pulse repetition frequencies of 100 kc/s and 10 kc/s respectively.

The leakage current between the heater and cathode of the diode D_3 is as a rule smaller than $1 \mu\text{A}$, which is not objectionable. To keep the maximum voltages which may occur between the heaters and cathodes of the three diodes used in the input and fly-back circuits as small as possible, the heaters should be fed from a separate filament winding, one side of which should be connected to the +156 V line.

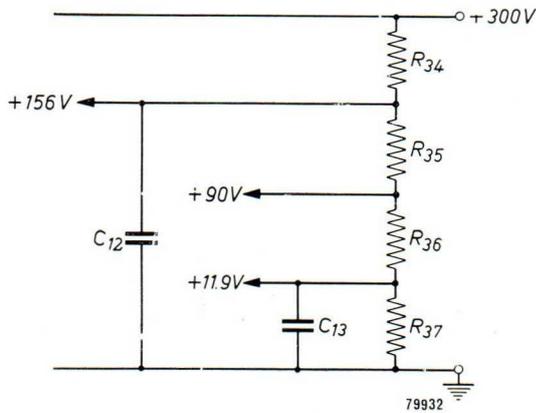


Fig. 41. Common voltage divider for feeding all counter stages and the input pulse shaper.

Component values

- $R_{34} = 33 \text{ k}\Omega \pm 1\%, 1 \text{ W}$
- $R_{35} = 15 \text{ k}\Omega \pm 1\%, \frac{1}{2} \text{ W}$
- $R_{36} = 18 \text{ k}\Omega \pm 1\%, 1 \text{ W}$
- $R_{37} = 2.7 \text{ k}\Omega \pm 1\%, \frac{1}{4} \text{ W}$
- $C_{12} = 0.47 \mu\text{F}$, paper
- $C_{13} = 0.47 \mu\text{F}$, paper

The voltages of 11.9 V, 90 V and 156 V required for the decade counter and the preceding pulse shaper can be derived from the common voltage divider shown in fig. 41. (The nominal value of the voltage at the lowest tap is actually 11.8 V instead of 11.9 V, but this is of no consequence.) The supply voltage need not be stabilized.

TOLERANCES

Since the amplitude of the pulses applied to the first counter tube may not exceed a given value, the obvious condition is imposed that the slope of their trailing edge is not too low, for in that case there would be a risk that the total duration of the pulses exceeds $10 \mu\text{sec}$, in which case the counting rate of 100 000 pulses per second could not be reached. On the other hand, this slope should not be too high either, because the maximum available current I_C may then be unable to discharge the anode by-pass capacitance of the counter tube at the required rate.

It is mainly this slope of the trailing edge of the pulses which determines the performance of the counter circuit, and the values of the components indicated in the captions of figs 33, 37 and 41 should be strictly adhered to, in order to avoid this slope from assuming excessive values. The $\pm 1\%$ and $\pm 2\%$ tolerance resistors should therefore be of high stability. The circuit has been so designed that the nominal total duration of the pulses produced by the input pulse shaper is approximately $9 \mu\text{sec}$, whilst the duration of their trailing edge is approximately $8 \mu\text{sec}$, which at a pulse amplitude of 13.6 V amounts to a slope of $1.7 \text{ V}/\mu\text{sec}$.

This slope depends mainly on the value of the resistors $R_{14} + R_{15}$ in the pulse shaper (see fig. 33). Due to ageing effects of these resistors, the slope may change by about 2% , so that there is little risk of the pulse duration exceeding the value of $10 \mu\text{sec}$ even at the maximum tolerances of the components.

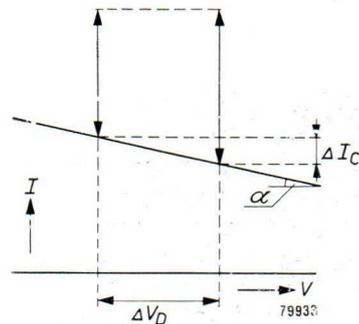


Fig. 42. Diagram showing the influence of the $I_{a2} = f(V_{d', a2})$ characteristic being shifted with respect to the load line for $V_{a2} = 1 \text{ M}\Omega$ as a result of a variation of the left-hand deflection electrode voltage V_D .

Although ageing of the counter tube will have little influence due to the considerable negative feed-back which is caused by the high value of the cathode resistor and the fixed value of the control grid voltage of the E 1 T, the maximum permissible value of the slope of the pulses required by the counter tube may be subject to greater changes and may be estimated to be $\pm 10\%$. This is mainly due to ageing of the resistors which form the common voltage divider (see fig. 41). This may be explained by means of fig. 42, which shows the variation ΔI_C as a result of the voltage V_D at the left-hand deflection electrode changing by an amount ΔV_D , the load line corresponding to that plotted in fig. 31 (cf. figs 6a and b). It follows from the graph shown in fig. 42 that:

$$\Delta I_C = \Delta V_D \tan \alpha,$$

or, since $\tan \alpha = 1/R_{a2}$,

$$\Delta I_C = \frac{\Delta V_D}{R_{a2}}.$$

Since the load resistance $R_{a2} = 1 \text{ M}\Omega$, this means that a variation of the left-hand deflection electrode voltage of 2% (approx. 3 V) results in I_C varying by $3 \mu\text{A}$, which is comparatively large for tubes whose value of I_C is already fairly small. The slope of the trailing edge of the pulses must therefore be sufficiently low to cope with this effect.

If the particular counter tube in the first stage has a comparatively low value of I_C , it may occur that false counts are produced under marginal conditions. In that case it will, to all intents and

purposes, be possible, by interchanging the counter tubes, to equip the first stage with a tube that has a sufficiently high value of I_C .

In order to check whether reliable operation of the first counter tube is ensured, a simple device has been incorporated to carry out a marginal test. For this purpose the switch shown in the circuit of fig. 33 has been provided. By means of this switch, the resistor R_{15} can be short-circuited, the slope of the trailing edge of the pulses applied to the first counter tube being thereby increased by approximately 18%. This marginal test should preferably be carried out at several input repetition frequencies, for example with sinusoidal input voltages of 20 c/s, 1 kc/s and 100 kc/s, and may be repeated from time to time. When the counter operates satisfactorily under these conditions, an ample safety margin is available.

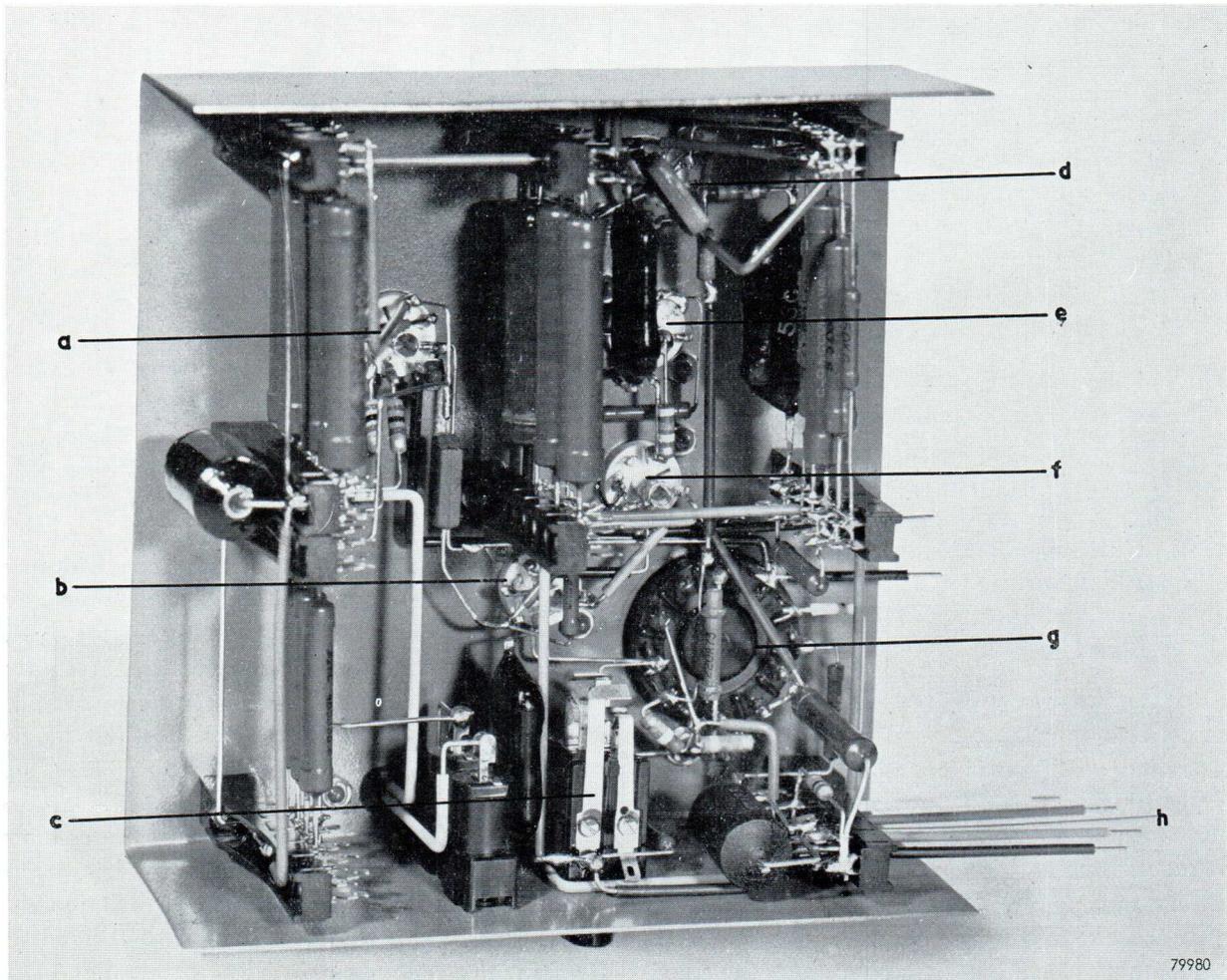


Fig. 43. Bottom view of the squarer and input shaper followed by the first counter stage with fly-back circuit. *a* - E 92 CC of the squarer, *b* - double diode EAA 91, *c* - switch for marginal test, *d* - E 92 CC of the interstage shaper, *e* - additional E 92 CC of the fly-back circuit, *f* - double diode EAA 91, *g* - decade counter tube E 1 T, *h* - leads to subsequent stages.

CONSTRUCTIONAL DETAILS

Fig. 43 shows by way of illustration the bottom view of a squarer and input pulse shaper followed by a counter stage with fly-back circuit, according to the circuits of figs 33 and 37 respectively. The top view is depicted in fig. 44.

In order to minimize the stray capacitances, the double diode $D_1 + D_2$ and diode D_3 have been mounted close to the counter tube. The switch for carrying out the marginal test has been mounted close to the resistor R_{15} , to avoid the stray capacitance at the junction between R_{14} and R_{15} to be unduly increased.

For further details, reference is made to the caption of fig. 43.

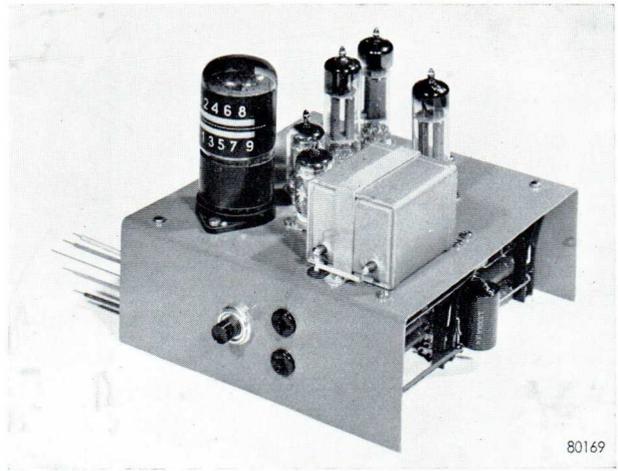


Fig. 44. Top view of the chassis shown in fig. 13.

A DECADE COUNTER STAGE WITH A COUNTING RATE OF 2000 PULSES PER SECOND

INTRODUCTION

The interstage circuit in the decade counter for a maximum counting rate of 30 000 pulses per second serves two purposes, namely resetting the beam to zero when the tenth pulse is applied to the preceding counter tube, and simultaneously applying a counting pulse of the required shape and amplitude to the following counter tube. It will be clear that omission of this interstage circuit with its accessory components would greatly simplify the counter, and means have therefore been sought to perform these two functions by other methods.

The beam can, indeed, be *reset* to zero by capacitively coupling the reset anode a_1 to the inter-connected main anode a_2 and right deflection electrode D' . In brief, the operation of this mechanism can be explained as follows. When the beam is shifted from position 9 to the reset anode, which is connected to the H.T. supply $+V_b$ via a series resistor, the reset anode voltage V_{a_1} will obviously decrease. This voltage drop is transmitted to the right deflection electrode via the reset capacitor, as a result of which the beam is moved still further to the left. This transient continues until V_{a_1} has reached its minimum value. The voltage $V_{a_2, D'}$ at the anode and right deflection electrode will subsequently gradually rise to $+V_b$. This causes the beam to move back in the direction of the right deflection electrode, thus impinging again on the anode a_2 . Provided the value of the reset capacitor is large enough, the voltage $V_{a_2, D'}$ will nevertheless keep rising because the reset anode voltage V_{a_1} now increases again to $+V_b$, this voltage increase being transmitted to the right deflection electrode by the reset capacitor. It is true that this increase of $V_{a_2, D'}$ is counteracted by the beam current now flowing to the anode a_2 , but since the beam current is not capable of recharging the reset capacitor entirely without a certain time delay, $V_{a_2, D'}$ will finally reach the value corresponding to position 0 of the beam, in other words: the beam will be reset to zero.

It will be clear that the maximum counting rate of such a stage with a reset capacitor depends, among other things, on the value of this capacitor. The maximum counting rate becomes higher as the value of this capacitor is decreased, but if the capacitance is chosen too small, the reset action will be incomplete, the beam returning to a higher position than 0.

The required counting pulse for *advancing* a counter tube one position when the preceding counter tube is reset to zero, can, in principle, be supplied directly by the preceding counter tube. It is, for example, possible to use for this purpose the voltage variation produced at the slotted electrode g_4 during the reset action.

Assume the beam of the counter tube to be in position 9. When the next pulse is then applied, the beam will leave the slotted electrode g_4 , and since the latter is connected to the H.T. supply via a series resistor, its potential V_{g_4} will rise from the value corresponding to position 9 of the beam to the H.T. supply voltage $+V_b$. At the end of the reset action, the beam will return to the slotted electrode, as a result of which its voltage will suddenly drop to a value corresponding to position 0 of the beam. By differentiating the voltage at this electrode, a positive pulse followed by a negative pulse can thus be obtained. This is illustrated by fig. 45, in which the voltage V_{g_4} and the corresponding differentiated voltage V_{g_4}' have been plotted as functions of time, it being assumed that the counting pulses applied to the left deflection electrode D are regularly spaced. After the negative pulses have been suppressed by means of a diode, the remaining positive pulses could be used for operating the following counter tube.

The counting pulses must, however, comply with certain conditions, to ensure reliable operation of the counter tube. At a supply voltage of 300 V, the positive pulses required for proper operation of the counter tube should have an amplitude of $13.6 \text{ V} \pm 15\%$. Moreover, the slope of the leading edge

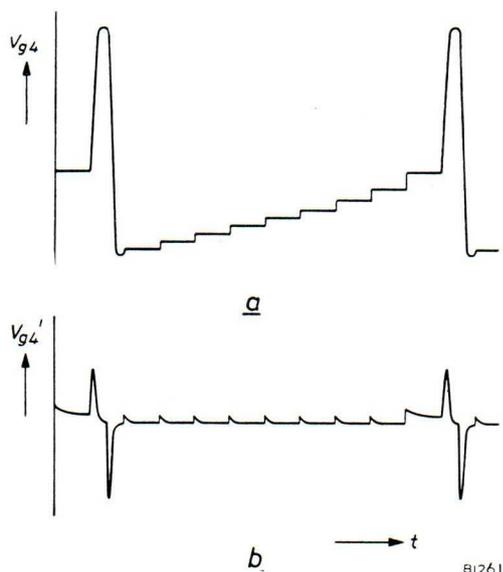


Fig. 45. (a) Voltage V_{g4} occurring at the slotted electrode when equidistant pulses are applied to the counter tube; (b) corresponding differentiated voltage V_{g4}' .

of the pulses applied should exceed a certain minimum value, whereas the slope of the trailing edge may not exceed a certain maximum value. Both these values are inversely proportional to the total capacitance C between the anode a_2 (and the right deflection electrode D' with which it is interconnected) and earth, and it will be clear that in high-speed counters care is taken to keep C as small as possible, because in that case the counter tube can be operated by pulses the trailing edge of which has a comparatively steep slope, i.e. by pulses of short duration.

When C is formed exclusively by the unavoidable stray capacitance between a_2, D' and earth, it will not be possible to operate a counter tube by the positive-going voltage swing occurring at the

slotted electrode of the preceding counter tube, due to the rate of change of this voltage being insufficient for the purpose aimed at. Reliable operation can, however, nevertheless be ensured by increasing the capacitance C artificially. It is true that the maximum counting rate is reduced thereby, but when the counting rate involved is fairly low, this need not be objectionable.

Another phenomenon related to the method of deriving the counting pulses from the slotted electrode of the preceding counter tubes is that the amplitudes of the positive pulses thus obtained may differ considerably from tube to tube. It may therefore be necessary to make provision that these pulses are clipped at the correct height (13.6 V).

EXPERIMENTAL CIRCUITS

Several experimental circuits based on the argument set forth above were investigated and are described below. It is stressed explicitly that the component values indicated in these circuit diagrams (figs 46 to 49) are purely indicative, since it was not the purpose in view to ascertain with which values optimum results are obtained.

Fig. 46 shows a circuit in which a germanium diode OA 51 is used in combination with each counter tube for cutting off the negative pulses. This circuit has the advantage of being particularly simple. It is, however, a serious drawback that the amplitude of the counting pulses which are derived from the slotted electrode voltage may vary considerably from one tube to another. This amplitude, moreover, depends to a large extent on the slotted electrode resistance, on the coupling capacitance and on the resistance in the differentiating

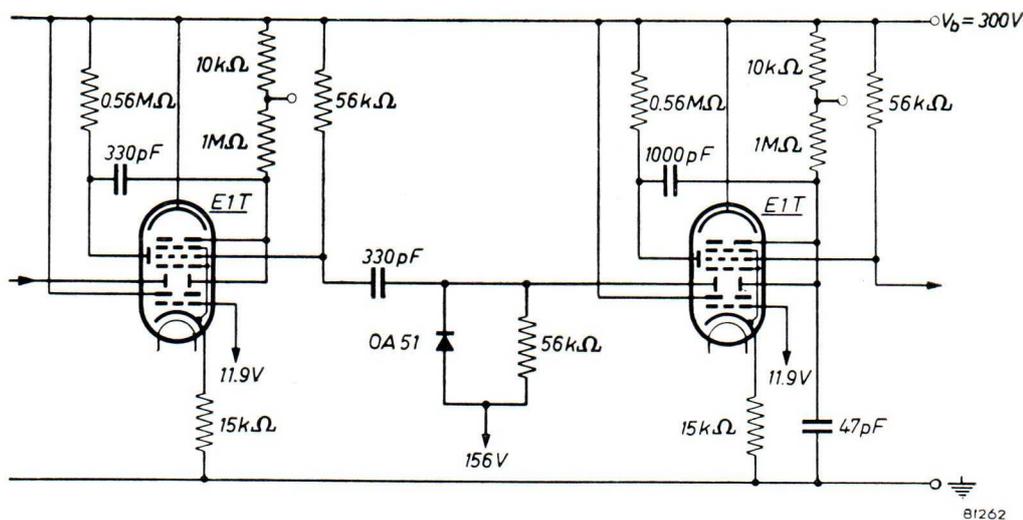


Fig. 46. Counter stage in which a germanium diode OA 51 is used for cutting off the negative pulses occurring at the differentiating network.

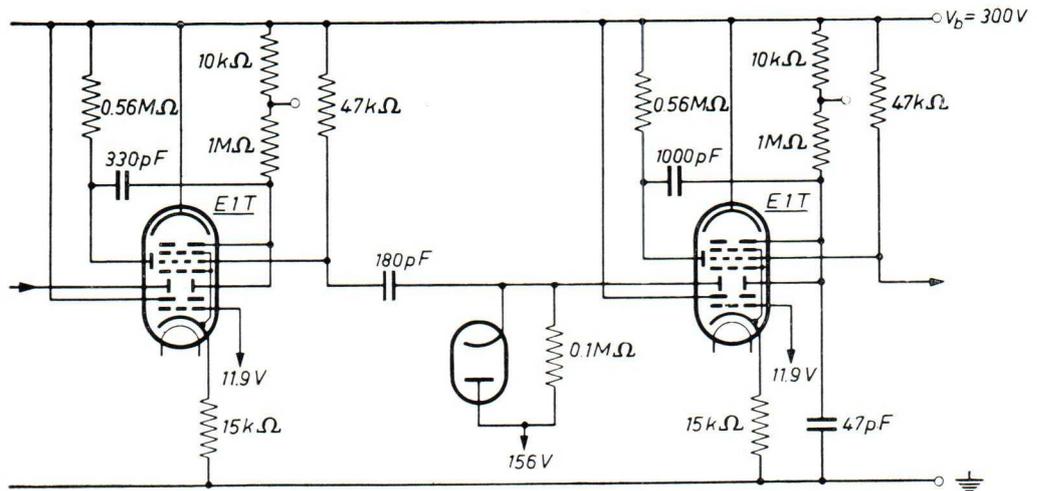


Fig. 47. Circuit similar to that shown in fig. 46, but with a vacuum diode instead of a germanium diode.

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network. The latter is composed of the $56\text{ K}\Omega$ resistor and the back resistance of the germanium diode to which it is connected in parallel. This back resistance depends to some extent on the temperature, and when the germanium diode is mounted in a closed cabinet, its back resistance may decrease to a value in the order of one third of the back resistance at room temperature.

The circuit according to fig. 46 can be modified to that shown in fig. 47 by replacing the germanium diode by a vacuum diode. The disadvantage of the variable back resistance is thus avoided. The circuit, however, still has the disadvantage that the amplitude of the pulse derived from the slotted electrode voltage is not constant, amplitude deviations of approximately $\pm 15\%$ from a certain

centre value being quite possible. Even when close tolerance components are used for the slotted electrode resistance, the coupling capacitance and the differentiating resistance, this would lead to critical operating conditions.

A further improvement can be obtained by using a double diode per counter stage (see fig. 48). One diode system is again used for cutting off the negative pulses, whilst the other diode system is used for clipping the positive pulses, thus ensuring that these have the correct amplitude. In this circuit there is no need to use close tolerance components for the coupling elements, provided provision is made to ensure that the peak value of the positive pulses derived from the preceding counter tube always exceeds the clipping level.

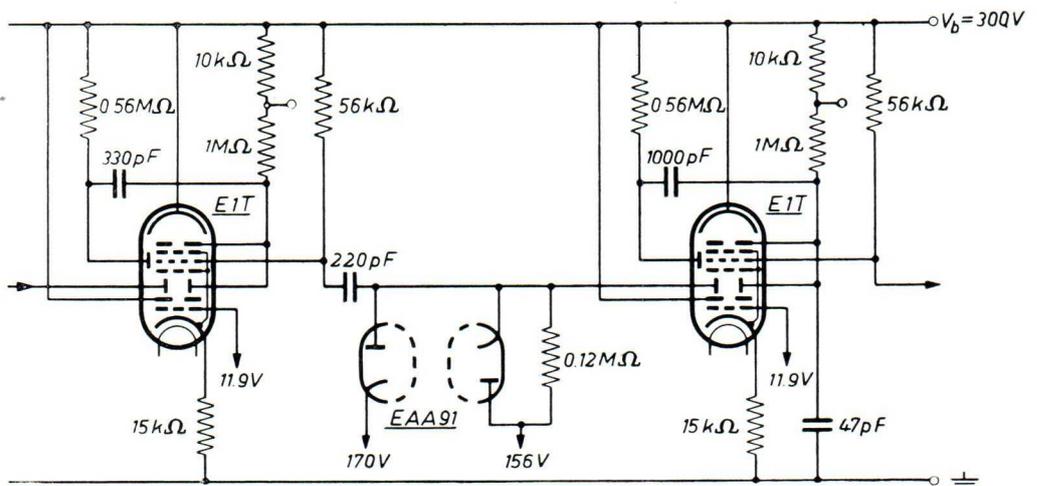


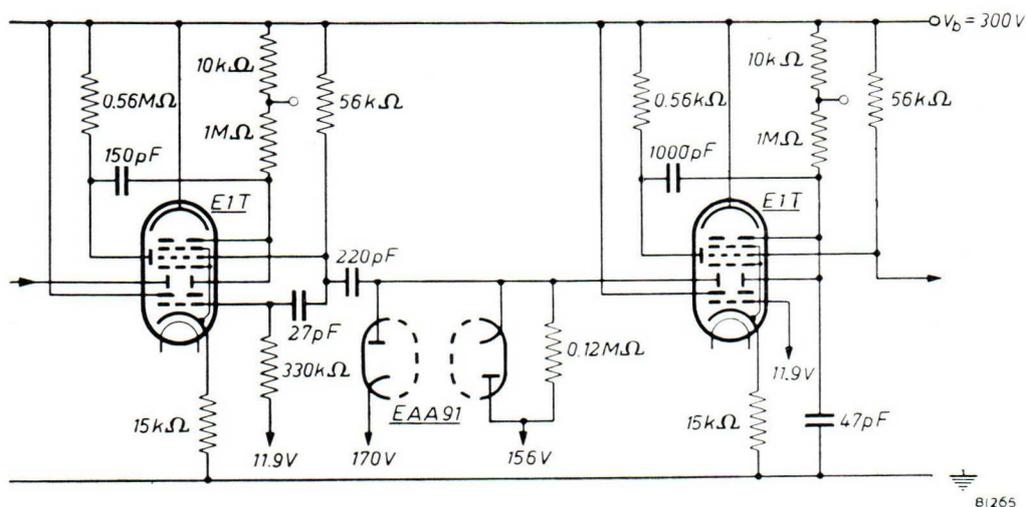
Fig. 48. Circuit similar to that shown in fig. 47, but with an additional diode system for clipping the positive pulses at the required level.

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The reset capacitor in the circuits of figs 46, 47 and 48 may not be chosen too low, to ensure that the beam is completely reset to zero with all standard production tubes. As explained above, this sets a limit to the maximum counting rate. If it were possible to reduce the value of this capacitor, higher counting rates could be obtained. The value of the reset capacitor may, however, be reduced without impairing operation of the counter tube if the beam current is reduced during the flyback. This can be achieved by applying the differentiated slotted electrode voltage to the grid g_1 of the counter tube, as shown in the circuit of fig. 49. When the beam returns to the slotted electrode after having left the anode, a negative pulse is thus applied to the control grid, thereby reducing the beam current. It will be clear that the beam cannot be suppressed completely in this way, but the

tion 9 may become quite appreciable. This voltage drop is transmitted to the right deflection electrode via the reset capacitor and causes the beam to move further beyond position 9 in the direction of the reset anode. When this voltage drop is of the same order as the minimum required value of the counting pulses, there is a risk of the reset action being initiated too early. This will particularly be the case at low values of the supply voltage due to the focusing of the beam then being less satisfactory than at a high supply voltage. For the circuits discussed above, the minimum supply voltage at which satisfactory operation was still obtained appeared to be between 200 V and 250 V for most standard production tubes, but for a few tubes the supply voltage had to be raised to 350 V, to avoid position 9 being skipped. A supply voltage of 400 V may thus be considered as a safe value.

Fig. 49.
Counter stage in which the reset capacitor is reduced and the differentiated voltage derived from the slotted electrode g_4 is applied to the control grid g_1 for reducing the beam current during the flyback.



substantial reduction of the beam current prevents the reset capacitor from being recharged too rapidly. As a result, there is less tendency of the beam being caught in one of the stable positions during the flyback, and the maximum counting rate can be approximately doubled*).

It should be recognized that the beam may partly impinge on the reset anode when it occupies position 9, thus producing a certain voltage drop across the reset anode resistor. This resistor must have a certain minimum value, say 0.47 MΩ, to ensure complete flyback of the beam, and because of this high value the voltage drop which is produced when the beam is shifted from position 8 to posi-

*) It might be suggested, that a further reduction of the beam-current could be obtained by by-passing the cathode-resistor of the counter-tube, but actually this does not give any substantial improvement.

PRACTICAL CIRCUIT OF A DECADE COUNTER

In the preceding sections, several experimental circuits have been discussed, and it should now be decided upon which of these are most suitable for general use. For the first counter stage it will be convenient to use a stage with beam current reduction according to the circuit of fig. 49. This should be preceded by a simple input stage. The subsequent stages may be of a type similar to that of the first counter stage, but without beam current reduction and with increased anode by-pass capacitance, because their maximum counting rate is considerably smaller. To minimize the risk of premature reset of the stage, the supply voltage is increased to 400 V as compared to the value of 300 V indicated in the circuits previously described.

Input stage

Fig. 50 shows the circuit diagram of a simple input stage which converts the applied signal into counting pulses of the required shape and amplitude. This input stage incorporates a double triode which operates as a squarer, and a double diode acting as a pulse shaper.

Section *I* of the double triode is normally conducting, section *II* then being cut off. When a negative-going voltage is applied to the input terminal *A*, the squarer is triggered and triode section *II* becomes conducting. Because of the negative-going voltage at the anode of this section, a negative pulse would be produced at point *B*, but this pulse is cut off by diode section *II*. When the input voltage rises again, the squarer returns to its original state; triode section *II* then becomes non-

conducting again, its anode voltage increasing to its original value. The resulting positive pulse thus produced at its anode is differentiated and subsequently clipped at the correct amplitude by diode section *I*.

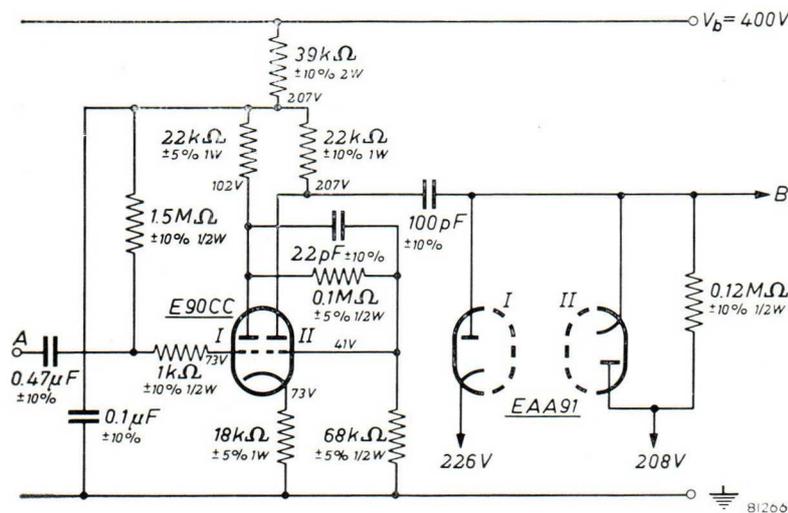


Fig. 50. Input stage incorporating a double triode which operates as a squarer, and a double diode acting as a pulse shaper. The voltages indicated are those occurring in the quiescent condition.

conducting again, its anode voltage increasing to its original value. The resulting positive pulse thus produced at its anode is differentiated and subsequently clipped at the correct amplitude by diode section *I*.

The input stage can be operated by a sine-wave voltage, by negative pulses or by a square-wave voltage. If a sine-wave voltage is applied, its r.m.s. value should exceed 15 V; the frequency may range from 20 c/s up to 2 kc/s. At frequencies below 20 c/s it might be necessary to increase the value of the input capacitor. If negative pulses are applied, their amplitude should be at least approximately 20 V; the repetition frequency may range from zero to 2 kc/s. If negative pulses of rectangular waveform are applied, the minimum duration of the pulses should be approximately 3 μsec, to avoid the slope

of the leading edge of the pulses produced at point *B* from becoming insufficient. Point *B* should be connected to the identically marked point of the first decade counter stage according to fig. 51. The E 90 CC double triode may be replaced by an E 92 CC. The nominal voltages occurring in the quiescent condition are indicated in fig. 50.

First counter stage

Fig. 51 shows the circuit diagram of the first counter stage with beam current reduction as explained above. The circuit has a maximum counting rate of 2000 pulses per second. Point *C* should be connected to the identically marked point of the subsequent counter stage according to the circuit of fig. 52.

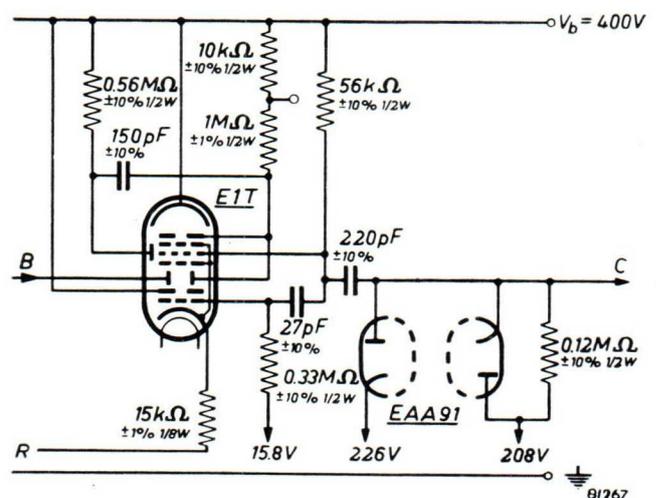


Fig. 51. Circuit diagram of the first counter stage with beam current reduction.

Subsequent counter stages

Fig. 52 gives the circuit diagram of a low-speed counter stage with increased anode by-pass capacitance, as may be used for the second and subsequent stages. The maximum counting rate of this

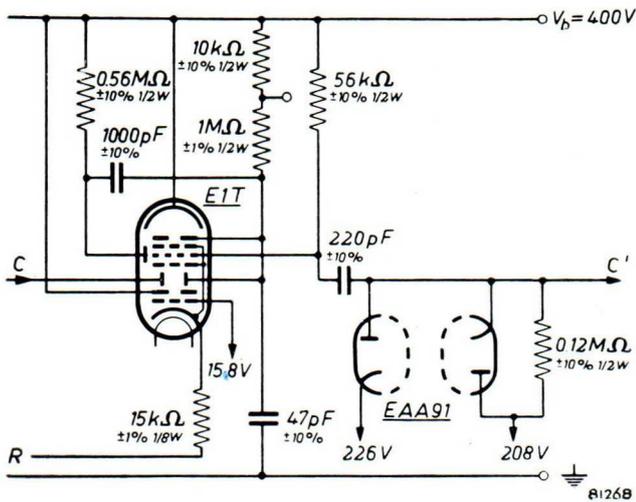


Fig. 52. Circuit diagram of the subsequent counter stages.

stage is 200 pulses per second. The shape and amplitude of the pulses produced at point C' are such that an identical stage can be operated thereby.

General remarks

Fig. 53 shows a simple circuit for manually resetting all tubes to the zero position.¹⁾ To this pur-

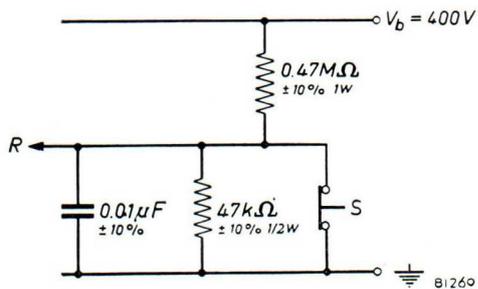


Fig. 53. Circuit for resetting all counter tubes to the zero position.

pose, point R of figs 51 and 52 should be connected to the identically marked point of the circuit according to fig. 53. Point R is normally connected to the common earth lead, but when the press-button switch S is opened, the potential of this point rises to approximately 36 V. All counter tubes are then cut off, so that their anode voltage rises to 400 V. Upon releasing switch S , the anode voltage of all counter tubes will drop to the correct zero position level.

The circuit of a common voltage divider for feeding up to four counter stages is given in fig. 54. If more stages are to be connected, the values of the

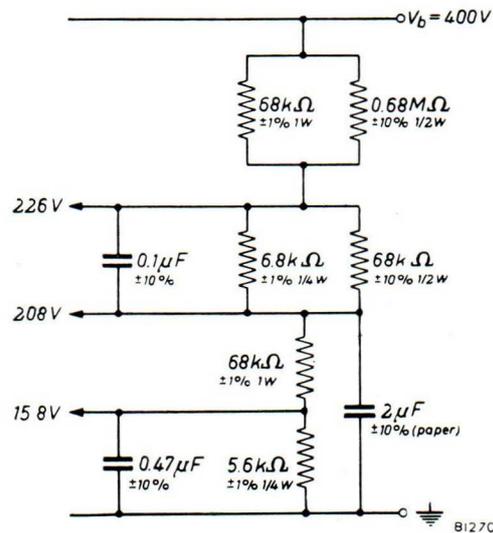


Fig. 54. Common voltage divider for feeding up to 4 counter stages.

resistors should be decreased accordingly. With an H.T. supply voltage with a nominal value of 400 V, deviations of $\pm 10\%$ from this value are permissible.

The heaters of the diodes (EAA 91) should be fed from a separate filament winding at a level of + 208 V.

¹⁾ This method of manual zero reset can also be applied to the circuits shown on pages 18 and 37.

MEASURING EXPOSURE TIMES OF CAMERAS BY MEANS OF A DECADE COUNTER

INTRODUCTION

It is only by electronic methods that it has become possible to measure exposure times of cameras. These methods were until recently usually based on one of the following two principles.

(a) Integration method

According to this method, a beam of light passes through the photographic shutter and impinges on a phototube. The resulting photo-electric current, which is obviously proportional to the luminous flux transmitted by the shutter, is used for charging or discharging a capacitor. The actual exposure time can be evaluated from the ratio of the voltages across the capacitor before and after the shutter has been operated.

This method has the disadvantage of being impracticable for measuring extremely short exposure times. It is, moreover, a quantitative measurement which depends on various factors such as the luminous flux of the light source, the sensitivity of the photo-electric cell and the supply voltages. Calibration is rather difficult and requires a standard shutter, the exact exposure times of which are known.

(b) Oscillograph method

This method differs from that described under (a) in that the voltage across the phototube is displayed by a cathode-ray oscilloscope. By modulating the electron beam of the cathode-ray tube with a known frequency, a time reference is obtained, so that it is possible to ascertain the operation of the shutter as a function of time with great accuracy.

Very good results are obtained by this method, which also gives information on the exact variation of the luminous intensity passed by the shutter. The main disadvantage is, however, that its use is restricted to laboratories, because the image displayed on the cathode-ray tube must be photographed to be studied.

A third method is discussed below. Use is made of the decade counter equipped with E I T counter

tubes. According to this method, the exposure time is indicated directly by the E I T decade counter tubes. The installation offers the particular advantage of being fool-proof, so that it can be used in the workshop for checking cameras during mass production. Its calibration by means of a stop-watch is extremely simple.

PRINCIPLE OF OPERATION

Fig. 55 shows the principle of operation of this method. The light emitted by the light source *S* is projected on the film gate of the camera *P* via condenser lens *L*. For checking focal plane shutters, a special diaphragm *D*, which is dealt with later, must be fitted against the film gate. The light transmitted by the shutter impinges on the phototube *T*, which controls the gating circuit *G* to which the oscillator *O*, producing a signal of known frequency, is also connected.

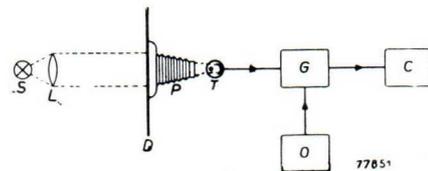


Fig. 55. Set-up of the measuring equipment for camera shutters. *S* - light source, *L* - condenser lens, *D* - special diaphragm for measuring focal shutters, *P* - camera, *T* - phototube, *G* - gating circuit, *O* - oscillator, *C* - decade counter.

So long as no light is transmitted by the shutter, no photo-electric current is produced by the phototube, and the gating circuit prevents the oscillator signal from being applied to the decade counter *C*, but when the shutter is opened so that the phototube is illuminated, the gating circuit passes the counting pulses produced by the oscillator to the decade counter, which starts to register the number of pulses applied. If the oscillator produces a signal of 10 000 c/s, the counter will indicate the exposure time in ten-thousandths of a second.

The accuracy of this method is extremely high, variations of the light source and mains voltage

fluctuations having no effect whatsoever. This is due to the fact that the device does not react to the *amplitude* of the signal, but to the *absence or presence* of the photo-electric current.

In the first instance, the accuracy depends on the constancy of the oscillator frequency, which can easily be kept within 2%. This frequency can, moreover, be checked with great accuracy in the following very simple manner, by means of a stop-watch. The camera shutter is opened during a fairly long period, for example 50 sec, to reduce the error which is introduced by inaccurate reading of the stop-watch. When the oscillator has been correctly adjusted, so that it operates at exactly 10 000 c/s, the decade counter will indicate the number 500 000.

Due to the fact that only complete counting pulses are registered by the decade counter, there may be an inaccuracy of plus or minus half a cycle. When very short exposure times must be determined with great accuracy, it may therefore be advantageous to choose a somewhat higher oscillator frequency of, say, 20 000 c/s to 30 000 c/s.

CONSTRUCTIONAL DETAILS

Checking focal plane shutters

As previously mentioned, a special diaphragm must be used for checking focal plane shutters. In order to measure the exposure time at a given point in the focal plane, this diaphragm should be provided with a very narrow slot, which must be exactly parallel to the slot of the shutter.

This may be explained by means of fig. 56. F denotes the focal plane shutter which is assumed to travel to the right, and D represents the diaphragm. The interval during which light passes through the slots is given by the expression:

$$T_{\max} = (d_F + d_D)/v,$$

where v denotes the rate of travel of the focal plane shutter, d_F is the width of the slot of the shutter and d_D that of the diaphragm. The actual exposure time of an elemental area of the film is on the other hand:

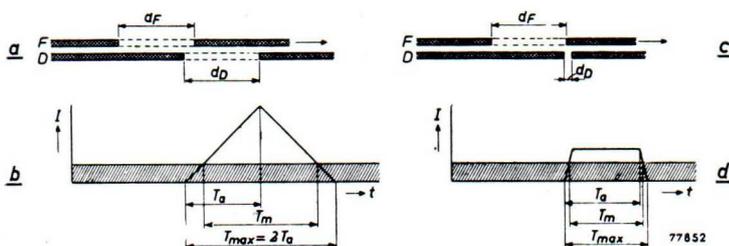


Fig. 56. Influence of the width d_D of the slot of the diaphragm D on the accuracy of the measurement. F represents the focal plane shutter and d_F its slot. T_a - actual exposure time of an elemental area of the film, T_m - measured exposure time, T_{\max} - value of the measured exposure time if no threshold (hatched area) were present.

$$T_a = d_F/v.$$

Since the photo-electric current I must exceed a certain level to operate the gating circuit, there will be a threshold below which the counting pulses produced by the oscillator are not passed by the gating circuit, and the decade counter remains inoperative (hatched areas in figs 56b and 56d), although some light passes through the two slots.

When d_D is made equal to d_F (fig. 56a), the situation represented in fig. 56b will arise. The quantity of light transmitted, and thus also the photo-electric current I , will gradually increase until the two slots coincide, after which this current gradually drops back to zero. Depending on the threshold value, the measured exposure time T_m may therefore range from almost T_{\max} , i.e. twice the actual exposure time T_a , to zero, so that the results are influenced to a large extent by conditions such as the luminous flux of the light source, the sensitivity of the phototube and the adjustment of the gating circuit.

The slot of the diaphragm should therefore be made no wider than necessary to ensure that a photo-electric current of sufficient strength is produced to control the gating circuit.

This situation is represented in figs 56c and 56d, where $d_D = 1/10 d_F$. The photo-electric current I now rises to a value exceeding the threshold value and remains constant during an interval $(d_F - d_D)/v$, after which it drops back to zero. The extreme limits between which the measured exposure time T_m may range are now much narrower, namely $T_{\max} = 1.1 T_a$ and $T_{\min} = 0.9 T_a$, the dependence on the threshold value being greatly reduced.

Particular care should be taken to ensure that the slots run truly parallel, since an obliquely mounted diaphragm corresponds to a slot with a greater effective width. For this reason there is little point in making the slot any narrower than is consistent with the accuracy with which the diaphragm can be applied to the camera, nor should the slot be made any longer than necessary for

