Operating Principles of the Z504S Stepping Tube

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The characteristics and mode of operation of a conventional ten-position, thirty-cathode stepping tube are described. Three forms of guide pulse drive are given; double rectangular pulse drive; rectangular guide A and integrated guide B pulse drive; differentiated guide A pulse and integrated guide B pulse drive. These waveforms are generally used with stepping tubes and they are discussed in conjunction with the requirements to ensure that the waveforms meet the Z504S characteristic operating areas. Reliability figures obtained from circuits employing practical waveforms are presented. Only one tube failure per one million tube hours has been observed.

INTRODUCTION

The conventional central-anode, thirty-cathode stepping tube has been used successfully for a number of years in circuits requiring visual indication of a counting operation at low cost, combined with low power consumption. An example of this type of tube is the Z504S selector shown in Fig. 1.

This article (which is based in part on material drawn from References 1 and 2) describes the transfer mechanism, the mode of operation and the characteristic working areas for the Z504S selector tube. When considering the working areas the approach has been to study the individual main characteristics and assess the stability of these characteristics, at their natural limits, under a number of life test conditions. These life test experiments enabled reliable working areas for the Z504S to be established.

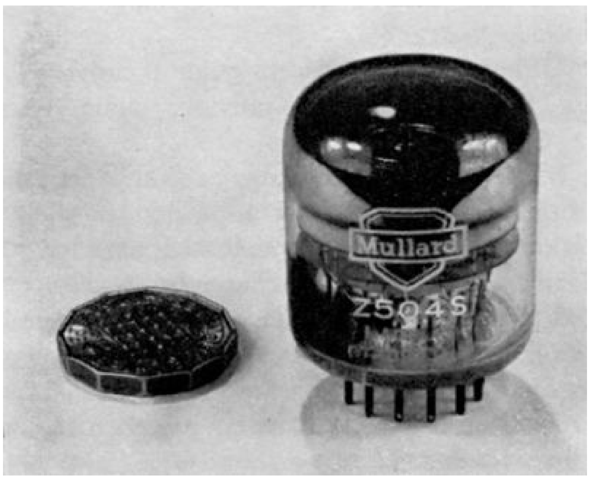

Fig. 1—Z504S selector tube

Stepping tube circuits have the advantage of using only one tube per decade as opposed to a number of active elements as in alternative circuits. Thus, to achieve a similar reliability to that of the Z504S stepping tube, an alternative device would require a considerably lower failure rate for the individual elements in each decade.

The three most common guide waveforms required to transfer the discharge are given. The recommended values are carefully derived from the characteristics discussed later in this article, which ensure that full advantage is taken of the inherent reliability of the Z504S selector tube.

STEPPING TUBE CONSTRUCTION

The Z504S selector tube consists of thirty rod-shaped cathodes which are equally spaced in a circle around a central anode disc. The structure is enclosed in a glass envelope which contains a mixture of inert gases at low pressure.

Fig. 2 shows the connections of the thirty cathodes. They are divided into three interleaved groups of ten, termed main cathode (k_1, k_2, . . .); guide A cathode (GDA_1, GDA_2, . . .); and guide B cathode (GDB_1, GDB_2, . . .). The guide A cathodes are connected together

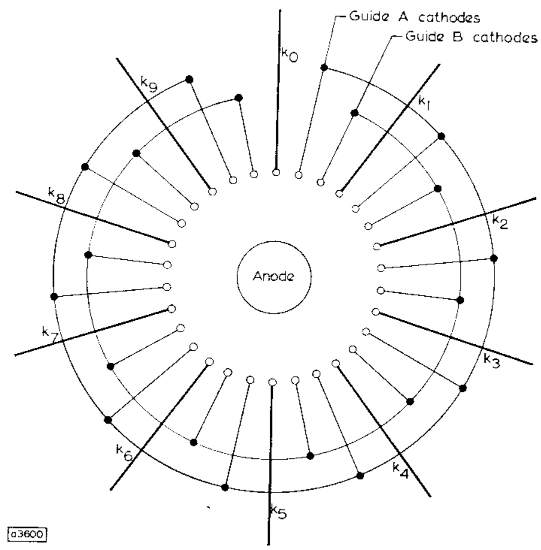

Fig. 2—Schematic diagram of selector tube electrodes

and brought out to the base as a single connection. The guide B cathodes are similarly brought out to a single connection, while each main cathode has a separate base connection. Thus an output signal may be taken from any cathode as required. Fig. 3 shows the sequence of cathodes k_7 to k_9 inclusive, which, viewed from left

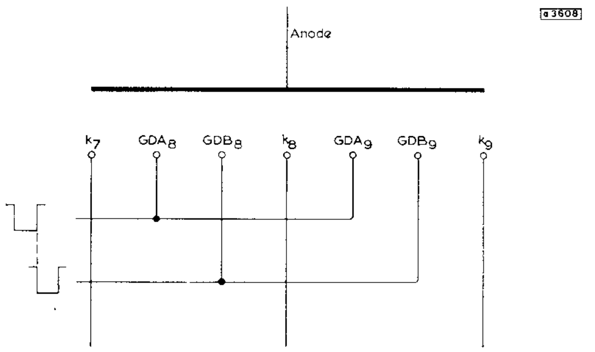

Fig. 3—Sequence of cathodes in the Z504S selector tube

to right, gives the clockwise order of the cathodes around the tube.

VISUAL INDICATION

In operation, a discharge is set up between the anode and a cathode, and appears as an orange-red glow at the tip of the cathode. With a suitable drive circuit, which is connected to the guide cathodes, the glow is made to travel from one main cathode to the next. The position reached by the glow can be seen through the top of the tube and can be read off from an external escutcheon which bears the numbers 1 to 9 and 0 opposite the appropriate main cathodes. The glow is usually driven clockwise (k_1, k_2, k_3, ...), but anticlockwise rotation may be used if it is desired. The tube is, in fact, completely bi-directional.

MODE OF OPERATION

The most common method of driving a stepping tube is to apply a pair of negative pulses to the guide cathodes as shown in the basic stepping tube circuit of Fig. 4.

In considering the operation it is assumed that the glow discharge is resting, for example, on the main cathode k_8 and that the two adjacent guide cathodes GDB_8 and GDA_9 are primed by the discharge on k_8 (see Fig. 3). The breakdown voltage required between the anode and these two guides, is, therefore, substantially less than the voltage which would establish breakdown between the anode and any unprimed guide A or B cathode.

On applying a negative pulse to the guide A cathodes, so that the voltage between the anode and the guide A cathodes exceeds the minimum voltage for primed cathode breakdown, a discharge is established between the anode and GDA_9 but not between the anode and the unprimed guide A cathodes. The anode voltage then falls to a lower value and the previous discharge path to k_8 is extinguished. The discharge now primes the adjacent GDB_9, and GDB_8 deionises. When the guide A pulse ends a negative pulse is applied to the guide B cathodes, a discharge is formed between anode and GDB_9, and the GDA_9 discharge is extinguished.

At the end of the guide B pulse the guide B cathodes return to the positive guide bias level, and the anode potential rises towards the h.t. supply. When the anode potential reaches a level greater than the anode-to-k_9 breakdown potential (k_9 now being primed by the discharge to GDB_9), a discharge is formed to k_9. The anode potential then falls to the maintaining potential of the anode-to-k_9 path, and the discharge to GDB_9 is extinguished.

The process of moving the glow discharge from one main cathode to the next has now been completed. It can obviously be repeated for transfer to the next main cathode, and so continue round the tube. For clockwise rotation of the glow, guide A must be pulsed negatively before guide B. Reversal of the order of pulsing will produce anticlockwise rotation.

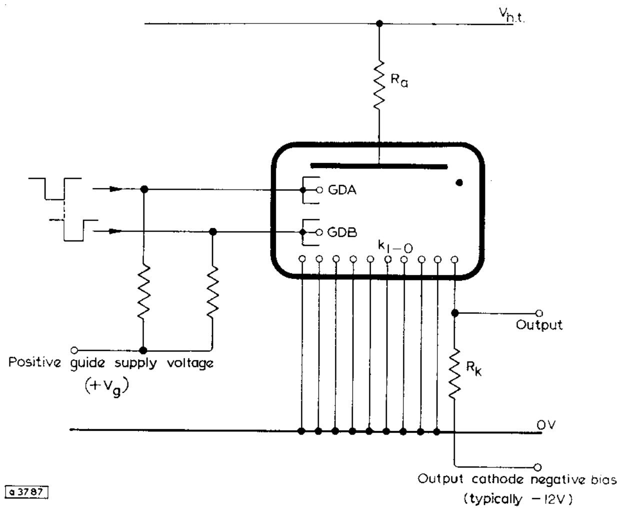

Fig. 4—Basic stepping tube circuit

DETAILS OF TRANSFER MECHANISM

To transfer the discharge from a main cathode, for example, k_8, to the adjacent guide A cathode GDA_9, the guide pulse must be applied for a period long enough to allow three processes to take place:

1. Formation of the discharge to the guide A cathode GDA_9 and extinction of the discharge to the main cathode k_8.
2. (*a*) Priming of the adjacent guide B cathode GDB_9.
   (*b*) Deionisation of the previous guide B cathode GDB_8.

The last two processes commence simultaneously after completion of process number 1.

The time required to form the discharge to the guide A cathode and extinguish the discharge to the main cathode is related to the voltage difference between the anode and the guide A cathodes, and this time decreases as the voltage difference is increased. After the discharge is formed, a period of rest on the guide A cathode is then required to prime the adjacent guide B cathode GDB_9 and to permit the previous guide B cathode GDB_8 to deionise.

Fig. 5(*a*) shows the voltage required for breakdown to each of the guide B cathodes GDB_8 and GDB_9 as a function of the time for which negative voltage has been applied to the guide A cathodes. Before the crossover point 'X' in the diagram, the breakdown voltage of the unwanted guide GDB_8 is less than that of GDB_9. After the crossover point, however, the directional priming properties of the tube are set up and breakdown will occur to the guide B

2. (*a*) Priming of the adjacent main cathode k_9.
   (*b*) Deionisation of the preceding main cathode k_8.

As shown earlier in this article (page 132), the discharge is transferred from GDB_9 to k_9 when the GDB_9 potential

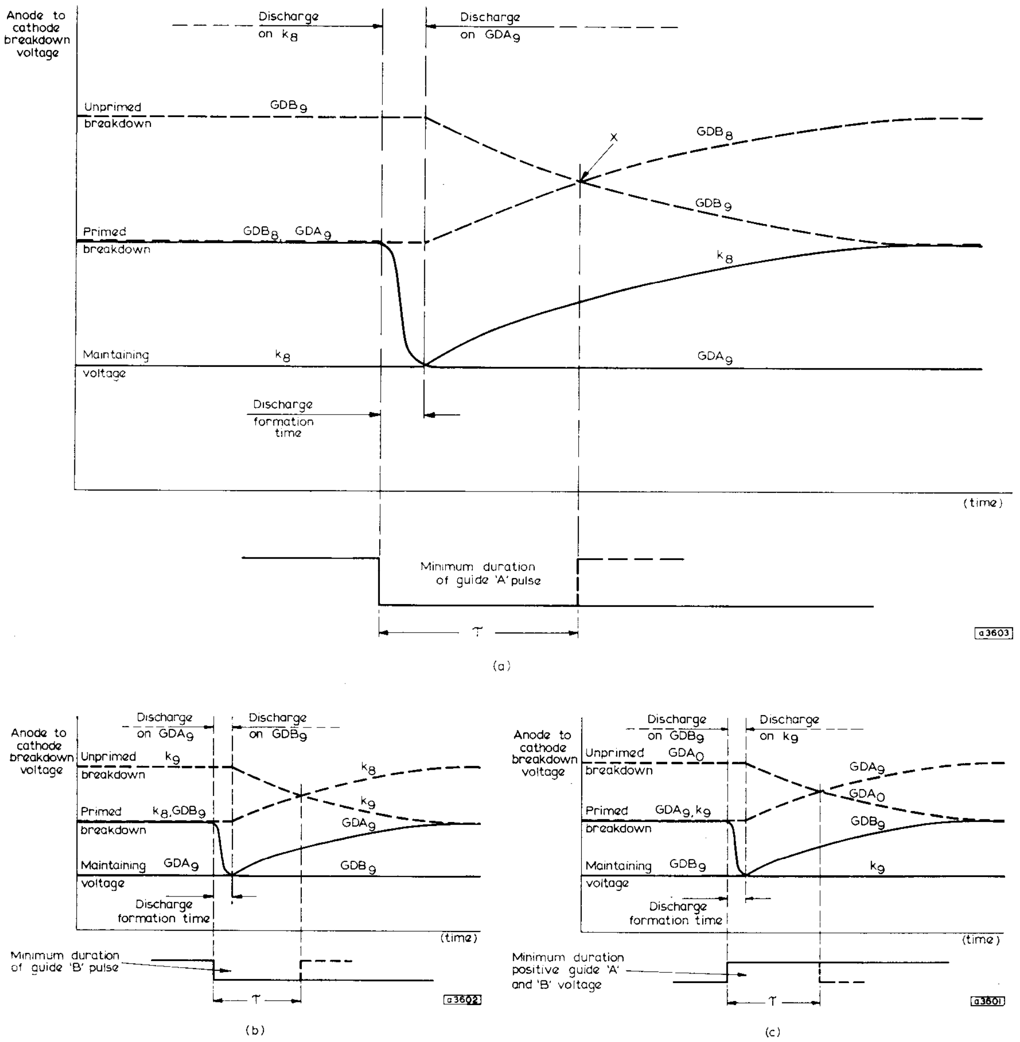

Fig. 5—Breakdown voltage of anode-to-cathode gaps—
(*a*) during main cathode to guide A cathode transfer
(*b*) during guide A to guide B transfer
(*c*) during guide B to main cathode transfer

cathode GDB_9 in preference to any other guide B cathode in the tube, on application of a guide B pulse. Consequently, when a negative voltage is applied to GDA_9 the duration of the pulse must be sufficient to allow the discharge to form to GDA_9, and to allow the breakdown voltage of GDB_9 to fall to a lower value than that of GDB_8.

Since the thirty anode-to-cathode gaps in the tube are identical, the same requirements must be met to step the discharge to any of the cathodes. Therefore, the negative voltage applied to the guide B cathodes to transfer the discharge from GDA_9 to GDB_9 (Fig. 5*b*) must be applied for a period long enough to ensure:

1. Formation of a discharge to the primed GDB_9, and extinction of the discharge on GDA_9.

approaches the positive supply voltage such that the sum of the positive guide supply voltage and the maintaining voltage of the anode-to-GDB_9 gap is greater than the primed breakdown of k_9. The main cathode, k_9, should be at a negative potential with respect to the guide cathodes for a period long enough to ensure that the discharge is formed to k_9, and that the breakdown potential of the succeeding guide A cathode GDA_0 can fall to a lower value than that of the preceding guide A cathode GDA_9, by the instant when a negative potential is to be applied to the guide A cathodes (Fig. 5*c*).

In the following sections it has been assumed that the minimum period for which a pulse may be applied to the guide electrodes to transfer the discharge from k_8 to GDA_9

or from GDA_9 to GDB_9 and to ensure that the correct priming levels are obtained, is 60µs. The minimum time to transfer the discharge from GDB_9 to k_9 and to ensure that the discharge will step to GDA_0 on receipt of the next negative pulse being applied to the guide electrodes, is 75µs. Therefore, a period of 195µs must elapse between successive signals to the guide drive circuit. This corresponds to a maximum counting frequency of 5kc/s. It will also be shown in the subsequent sections that under certain conditions an increase in the guide B pulse period is required for reliable operation, which slightly reduces the maximum permitted counting frequency.

CHARACTERISTICS OF THE Z504S

This section discusses the characteristics of the Z504S and describes how the operating areas given in Fig. 6 have been obtained from tests designed to investigate the changes in the Z504S characteristics over life. The degree to which the characteristics change during life depends upon the operating conditions of the tube.

Variations in maintaining and breakdown voltages which may occur during life tend to reduce the characteristic operating ranges. These changes are generally due to cathode material being sputtered from the cathode on which the discharge rests on to the other cathodes in the tube. This sputtered material has the effect of contaminating these cathodes. The changes are, in general, reversible and when the discharge is moved to a contaminated cathode the sputtering process cleans the cathode surface again.

Fig. 6 gives the permitted guide operating voltages for reliable operation as a function of the main cathode and guide B rest periods.

The life performance of the tube has been examined with the discharge at rest on one cathode for a long period to determine the rate of deterioration in the tube characteristics. Other life tests were performed with the discharge cycling continuously around the tube at various frequencies to determine the operating frequency at which deterioration commences.

OPERATING REQUIREMENTS

In these subsequent sections of the article, all voltages are referred to the most positive supply voltage to which any main cathode is returned. When setting-up life tests and obtaining measurements, for Sections (*a*) and (*b*), the main cathode circuit employed has cathodes 1 to 9 inclusive returned to zero potential and k_0 has a negative voltage of 12V applied to it as shown in Fig. 4. Conse-

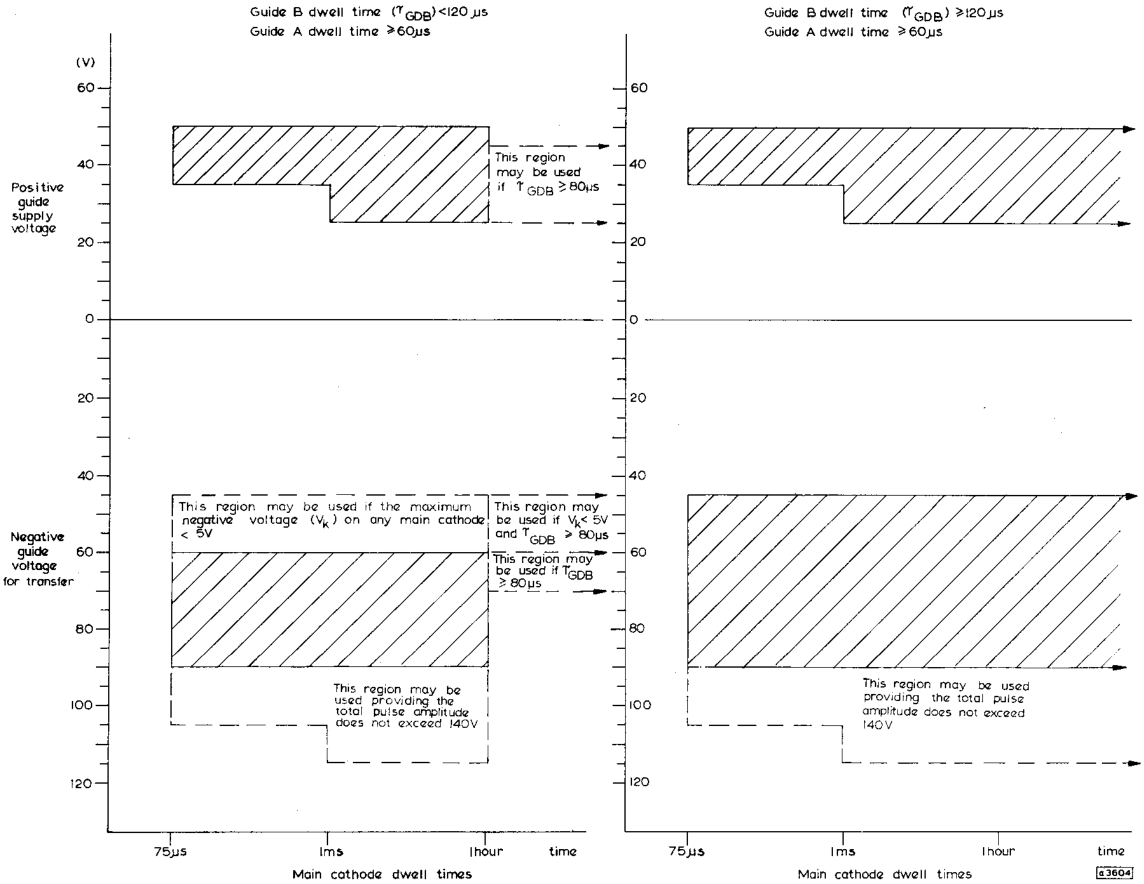

Fig. 6—Guide operating voltages. The shaded areas represent regions where the tube may be used without restriction initially and during life

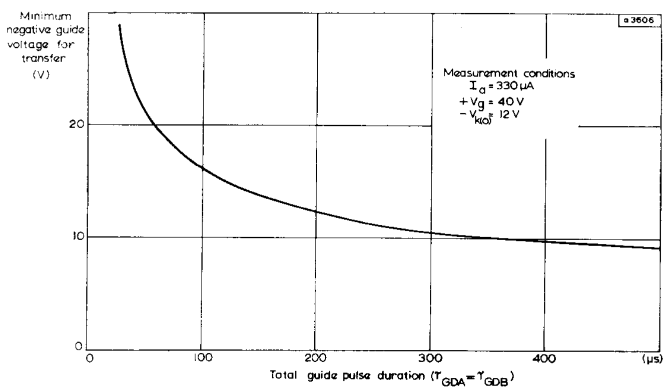

Fig. 7—Typical variation of minimum negative guide voltage for transfer with guide pulse duration

quently the reference potential in these particular cases will be zero volts. In Section (*c*) the same reference voltage is used and consideration is given to the effect of varying the negative voltage applied to k_0.

The requirements for reliable operation are discussed under four headings:

(*a*) Negative guide voltage to step the discharge from a main cathode to the guide A and B cathodes.

(*b*) Positive guide voltage to transfer the discharge from the guide B to the next main cathode.

(*c*) Derivation of main cathode voltage output signal.

(*d*) Anode current range.

NEGATIVE GUIDE VOLTAGE RANGE

The negative guide voltage is discussed and the minimum and maximum limits are defined separately.

Minimum Negative Guide Voltage

At the start of life, the minimum negative guide voltage required to step the discharge in the Z504S, with 60μs guide pulses, is approximately 20V (see Fig. 7). During life, however, an increase in this value may be expected when the discharge rests for long periods on one main cathode, and the adjacent guide cathodes become contaminated by material sputtered from the main cathode.

To examine the change in stepping voltage 27 tubes were measured after a 14 000-hour life period of continuous cycling. During this life period, input signals ranging from one every 10ms to one every 276 hours were fed to the tubes. Each tube was operated at a specific frequency within the given range. The results show a gradual increase in minimum negative guide voltage as the operating speed is reduced. In all except one tube, however, a negative guide voltage of 45V was sufficient to step the discharge.

The results and the end of life measurement conditions are given in Fig. 8.

The requirements for stepping the discharge after long periods of rest on one cathode with guide pulses of 60μs duration have been examined in more detail under standby life conditions. In one experiment 20 tubes were operated for 1700 hours during which time the discharge was stepped from one cathode to the next at 85-hour intervals. Each step was made with a negative guide voltage of 40V, and only two tubes failed to step correctly at all times. A group of ten tubes was also measured after a 9000-hour life period with the discharge in each tube resting on one cathode. In this case eight of the tubes operated successfully at the end of the life period with a negative guide voltage of 45V.

From these life experiments it is concluded that with the absolute minimum recommended guide pulse duration of 60μs, the region of reliable operation commences with a negative guide voltage ⩾45V.

To confirm that the reliability increases as the negative guide voltage is increased, a discrete pair of 60μs pulses with negative excursions of 60V were applied to 16 tubes every 24 hours and to a further 16 tubes every 168 hours. No failures occurred in 3500 hours.

Maximum Negative Guide Voltage

The maximum negative guide voltage, where main cathode dwell periods of less than one hour or guide B pulses greater than 120μs are used, is limited only by the necessity to restrict the voltage difference between any pair of guide or main cathodes to below 140V. This limit avoids spurious breakdown between the lead-in wires at the base of the tube. The limit is not life-dependent unless the voltage is repeatedly exceeded, when there is a danger that the 140V breakdown level will be reduced.

Fig. 6 shows that if the discharge dwells upon a main cathode for periods in excess of one hour – and the tube

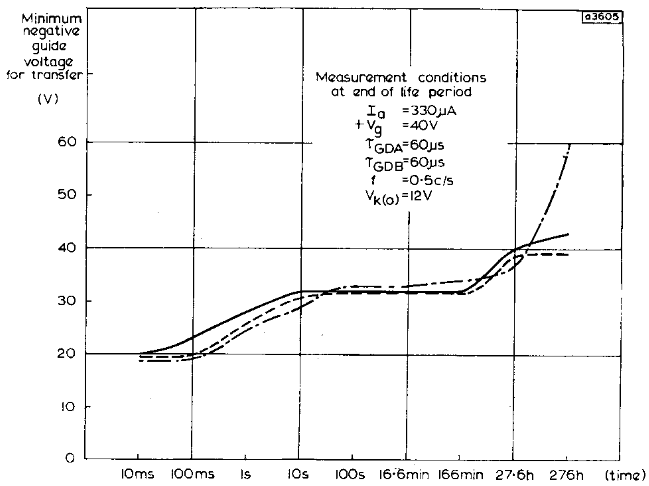

Fig. 8—Minimum negative guide voltage for transfer after a 14 000-hour life period. (The horizontal axis represents the input signal frequency during the life period.)

is subsequently required to operate with the minimum permitted guide A pulse of 60µs and with a guide B pulse rest periods greater than 1ms – and at least 35V for rest periods less than 1ms.

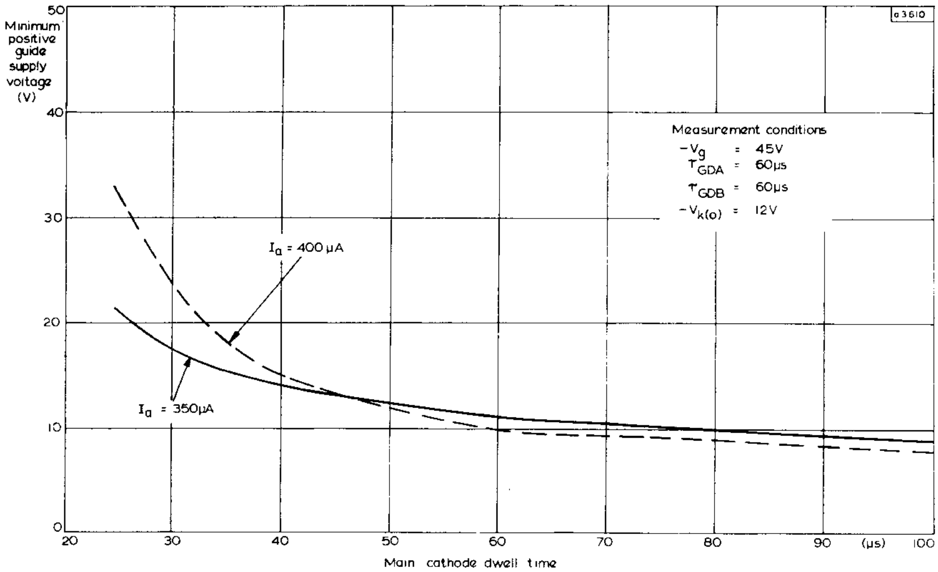

Fig. 9—Typical variation of minimum positive guide supply voltage with main cathode dwell time

between 80µs and 120µs – the maximum negative guide voltage for stepping is reduced to 70V. As the mechanism of failure in this instance for values >70V has to be considered in conjunction with the positive guide supply voltage, it will be described in a separate section.

POSITIVE GUIDE SUPPLY VOLTAGE RANGE

The positive guide supply voltage excursion is discussed and the minimum and maximum limits are defined separately.

Minimum Positive Guide Supply Voltage

The minimum positive guide supply voltage is related to the discharge period of rest on the main cathode as shown in Fig. 9. To examine the extent of the positive guide voltage change over life, 14 tubes were measured after a 25 000-hour life period of continuous cycling. During this life period, input signals ranging from one every 195µs to one every five hours were applied to the tubes. Each tube was operated at a specific frequency within the given range. The measurements made with 60µs guide and main cathode dwell times showed that all 14 tubes would step correctly provided that a positive guide voltage greater than 19V was employed.

In addition, ten tubes were also measured after a 9000-hour standby period on one cathode. Only one tube required a positive supply voltage greater than 35V when measured with a main cathode rest period of 75µs. On increasing the rest period to 1ms, nine of the ten tubes operated with values of positive guide bias ⩽25V.

The conclusion drawn from these experiments is that the minimum positive guide voltage for stepping does not increase with life, when the discharge is operated at speeds greater than one pulse in five hours. With long-term standby life, the possibility of failure is remote if the positive guide voltage is at least 25V – with main cathode

Maximum Positive Guide Supply Voltage

There are two factors which limit the maximum permitted positive supply voltage in the Z504S stepping tube. First, as the voltage is increased, the guide cathode probe current from the main discharge is reduced, and the guide cathodes are contaminated more rapidly by material sputtered from the discharge cathode.

When the tube is operated with minimum permitted duration guide pulses, however, a second factor becomes predominant in defining the maximum positive guide voltage.

A small number of failures may occur when, after a long standby period on one cathode, the discharge is stepped with 60µs guide pulses and a positive guide bias ⩾50V. The failure is seen as re-ignition of the previous main cathode at the end of the guide B pulse. This re-ignition is thought to be the result of the positive guide voltage focusing the residual positive ions to an area closely surrounding the deionising main cathode. Thus, the processes of deionisation are inhibited.

The maximum positive guide voltage for reliable operation with 60µs guide pulses has been investigated over a 5000-hour life period. Three batches of ten tubes were operated at positive guide voltages of 45, 50 and 60V. The discharge was stepped with 21 pairs of 60V guide pulses at 12-hour intervals throughout the life period. Eleven pulses were applied in a clockwise direction and ten pulses were then applied in an anticlockwise direction, so that all the cathodes in the tube were investigated.

No failures were observed with values of positive guide voltage less than 50V, but the reliability decreased at 60V. It was also observed that the tubes stepped correctly again if the guide B pulse duration was increased to 80µs, thus allowing a longer deionisation period for the previous main cathode. As this mechanism also determines the maximum output voltage which may be obtained at a main cathode – described in the next section – it is recommended that the maximum positive guide voltage is restricted to 50V under both standby and continuous cycling conditions.

As stated earlier in this article, few failures have been observed after the discharge has remained on a main cathode for long periods. These failures have been observed when the tube is operated with negative guide voltages greater than 70V and with guide pulses of short duration together with high values of positive guide supply voltage. Reliability of operation increases as the positive guide supply voltage decreases, and for positive guide voltages $\leqslant$50V the failure rate is very small. It may be eliminated by restricting the negative guide voltage to a value $\leqslant$70V.

In conclusion, no failures have been observed with a 50V positive guide supply voltage in conjunction with 60V negative pulses of 60μs duration after main cathode rest periods > one hour. However, it is recommended that the maximum positive guide bias should be restricted to 45V and the guide B rest period increased to $\geqslant$80μs to obtain the best reliability. This additional rest period ensures complete deionisation of the previous main cathode. It is also recommended that the negative guide voltage is reduced to $\leqslant$70V for guide B rest periods <120μs.

VOLTAGE OUTPUT SIGNAL AT A MAIN CATHODE

When a resistor is connected in series with a main cathode to generate a voltage output signal, care must be taken to ensure that the positive excursion at the cathode is restricted to a value below the positive guide voltage level.

The curve can be separated into two distinct regions, A-B and B-C, and the maximum voltage in these regions is limited by separate failure mechanisms. In region A-B, the value of the output resistor may be increased until the cathode voltage becomes almost equal to the guide voltage; and current sharing takes place between the output cathode, say k_8, and the adjacent guide cathodes GDB_8 and GDA_9. If the current flow to GDB_8 is large enough to prime the previous guide A cathode GDA_8, the discharge may then be formed to this guide A cathode on receipt of the next input pulse, instead of to the desired guide A cathode GDA_9.

In region B-C, where the maximum positive output voltage falls as the positive guide voltage is increased, failure occurs in the following way. As the discharge is stepped from the previous main cathode k_7, correct transfer takes place to the succeeding guide A and B cathodes, GDA_8 and GDB_8. At the end of the guide B pulse, however, the discharge transfers to the output cathode k_8 but immediately jumps back to the previous main cathode k_7. This occurs because the sum of the maintaining voltage of the anode-to-k_8 gap and the voltage developed across the output cathode resistor exceeds the breakdown voltage of k_7. It is thought that the reduced breakdown voltage to the k_7 cathode is caused by the high value of positive guide bias focusing the residual positive ions to an area closely surrounding k_7, thus inhibiting the deionisation process in this region. This theory is supported by the fact that when the duration of the guide B pulse is increased, thus allowing a longer deionisation time for the previous main cathode, the maximum permitted positive excursion at the output

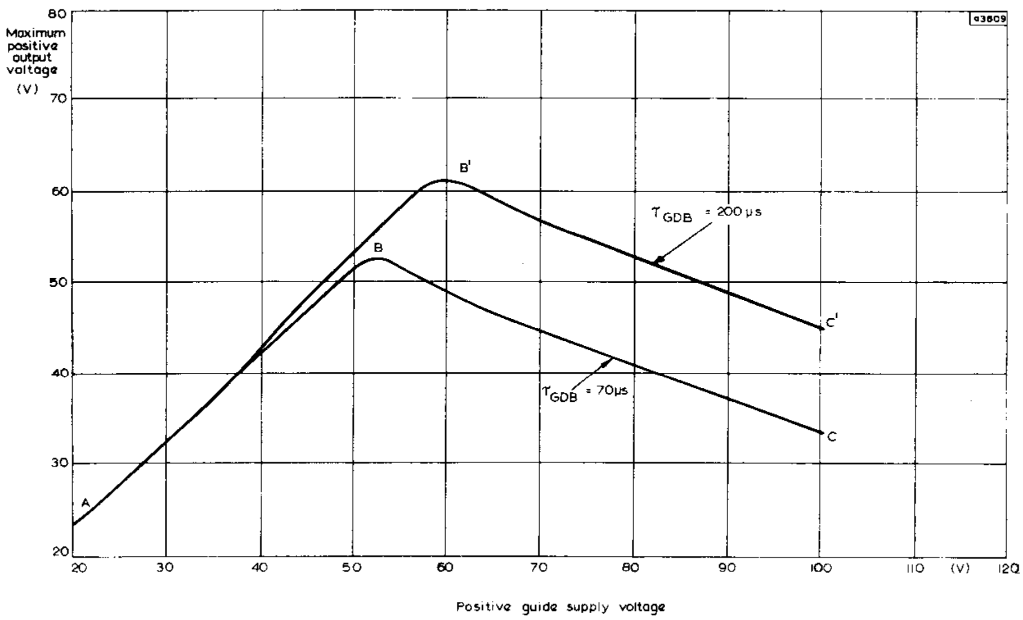

Fig. 10—Typical variation of maximum positive output voltage with positive guide supply voltage

The maximum permitted positive voltage is related to the guide supply voltage as shown by the typical curve given in Fig. 10. The output voltage shown in this curve is measured with respect to the potential of the previous main cathode.

cathode increases considerably as shown by the line B′–C′ in Fig. 10.

The maximum permitted positive excursion at a main cathode has been investigated with ten tubes, which were measured after a 5000-hour life period. The results, presented graphically in Fig. 11, show the maximum output voltage as a function of guide supply voltage for two operating currents. For values of positive guide voltage $\leqslant$ 50V the cathode potential can be increased to a value within 5V of the guide voltage before failure occurs. This figure increases to 15V as the guide bias is raised from 50 to 60V.

Two conclusions may be drawn from these experiments. For positive guide voltages up to 50V failure to step is extremely unlikely provided that the maximum positive excursion of any output cathode is limited to a value of at least 10V below the positive guide voltage level, so that current sharing cannot occur. Secondly, there is little advantage in operating the tube with a guide voltage greater than 50V, as this voltage corresponds to region B-C in Fig. 10, where no additional output is obtained.

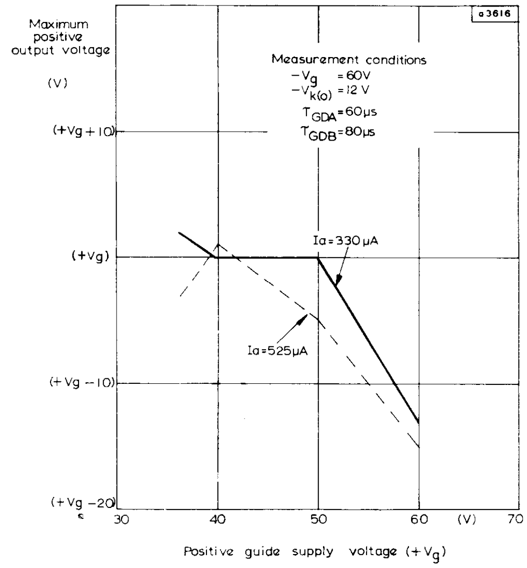

Fig. 11—Maximum permitted positive output voltage after a 5000-hour life period

Maximum Main Cathode Negative Voltage

When an output voltage signal larger than that permitted in the above section is required at a cathode, the cathode resistor can be returned to a source of negative bias. The maximum value of the negative bias is largely determined by the difference in breakdown voltage between the output main cathode, for example k_8, and the next main cathode, k_9, at the end of the GDB_9 discharge period. As the guide B rest period is increased, the time available for more complete deionisation of the output cathode increases, which permits a rise in the maximum negative bias. A typical relationship for a new tube between the guide B pulse duration and the maximum permitted negative bias is given in Fig. 12.

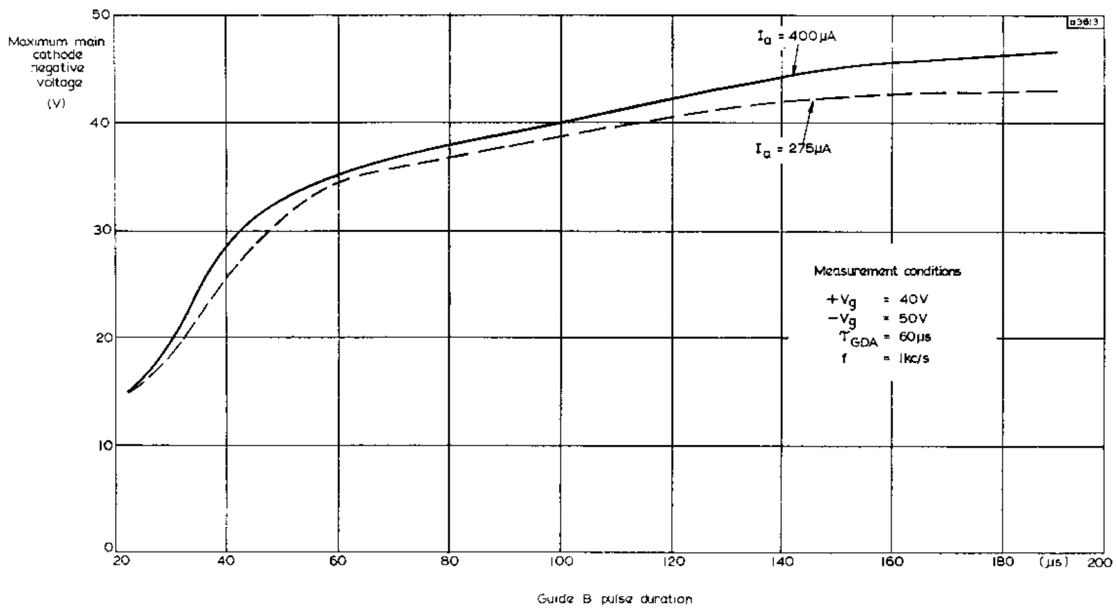

Fig. 12—Typical variation of maximum negative voltage at a main cathode, with guide B pulse duration

conditions the period available to deionise the previous main cathode is reduced, and the maximum negative cathode bias which may be employed is also reduced.

When measuring the life stability of this characteristic, the tubes were assessed using the minimum permissible guide B pulse duration of 60µs. A short formative time was required to ensure that the maximum period was available under these conditions for deionising the previous main cathode. It was achieved by employing a negative guide voltage of 60V.

A second factor which influences the maximum negative bias is the formative time of the discharge on the guide B cathode. When a tube is stepped with the 45V minimum negative guide voltage necessary to form the discharge to the guide B cathode, the discharge may rest on this cathode for only part of the full guide B period. Under these

When a sample of nine tubes from a 25 000-hour cycling life test was examined, a direct relationship was observed between the maximum usable negative bias voltage at an output cathode and the operating frequency during life. Fig. 13 shows the maximum negative voltage increasing from 16V after operation at 5kc/s to a constant level of approximately 30V at stepping rates slower than one step in three minutes. Ten tubes were operated for 9000 hours on one cathode and confirmed the high values obtained at low stepping speeds. In this case the maximum and minimum values obtained in ten tubes were 25V and 42V, as indicated by the double arrow in the diagram.

It is therefore concluded that the Z504S operates reliably throughout the permissible frequency range when the maximum negative cathode bias voltage is limited to less than 16V. These operating conditions occur provided that the tube is stepped with negative guide pulses at least 60V in amplitude.

In the previous section concerning the minimum negative guide voltage required to step the discharge, it has been shown that when a negative bias of 12V is applied to an output cathode, the minimum negative guide voltage required to step the discharge is 45V. As stated in that particular section this is the value at which the region of reliable operation commences. To ensure that the maximum reliability is obtained it is recommended that the main cathode negative bias should be reduced to <5V if the tube is stepped with 45V negative pulses of 60μs duration. By extending the guide B pulse duration to $\geqslant 120$μs an additional period is available for deionisation of the previous main cathode. With this increased guide B pulse duration it is permissible to increase the maximum negative cathode voltage to 14V when stepping the discharge with negative guide voltages <60V.

ANODE CURRENT RANGE

An unused Z504S stepping tube is capable of operating over a wide current range, in some cases from 100 to 1300μA. However, to obtain stability in the various tube characteristics it is desirable to restrict operation to a smaller part of this initial range.

A minimum anode current of 250μA is necessary to obtain sufficient adjacent cathode priming for reliable operation at maximum counting speeds. In applications where continuous cycling of the discharge occurs, the tube can be operated with currents up to a maximum of 525μA. Above this value a rapid deterioration in the stability of the tube characteristics is observed.

Under standby conditions, however, it is desirable to keep the anode current as low as possible because the life becomes steadily shorter as the nominal anode current approaches 525μA. This reduction is probably due to an increase in contamination of the adjacent guide cathodes as the main cathode sputtering rate increases. An indication of the sputtering rate is given by two 9000-hour standby life tests, one conducted at a nominal anode current of 330μA and the other at 525μA. In the high current case the main cathode concerned was sputtered away completely, whereas at 330μA over half the original cathode length remained.

The final consideration concerns the visibility of the discharge through the dome of the tube envelope. At a nominal anode current of 330μA difficulty arises in viewing the discharge under normal lighting conditions after some 15 000 hours of cycling life because of sputter deposition on the inner surface of the tube. The comparison between the sputter rates at 330 and 550μA suggests that this condition would be reached at only 8000 hours with an operating current of 525μA.

SUMMARY OF THE RANGES OF INHERENT RELIABILITY

When the Z504S stepping tube is operated in circuits where the discharge is stepped from one main cathode to the next at intervals of less than one hour, there is no evidence of deterioration in any characteristic other than the maximum permitted output cathode negative bias. In this case the deterioration is apparent only at high counting speeds where the maximum value falls to some 16V after a life of 25 000 hours. The characteristic operating ranges given in Table 1(*a*) may therefore be used, and the life expectation is limited only by obscuration of the viewing dome at some 15 000 hours. Where a visual

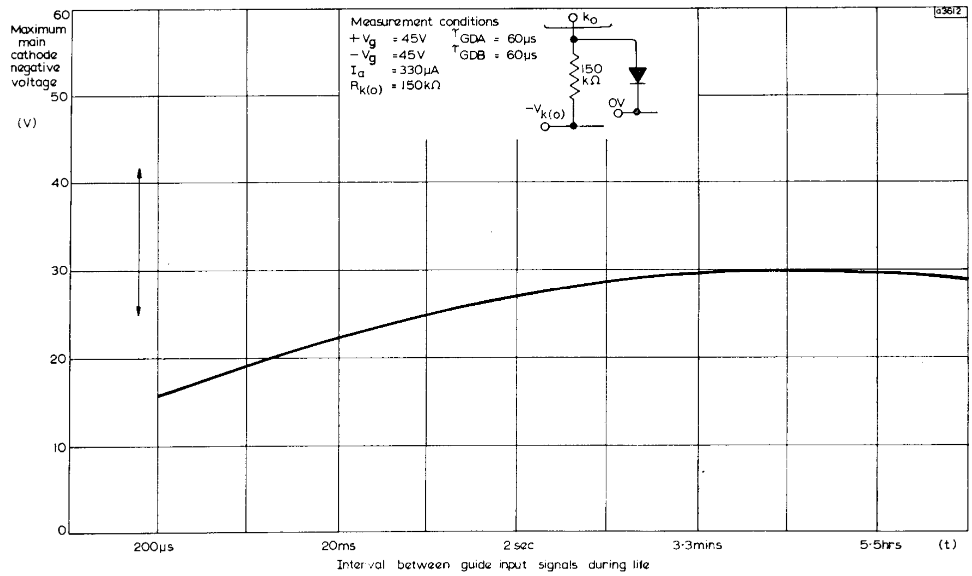

Fig. 13—Maximum permitted main cathode negative voltage after a 25 000-hour life period

output indication is not required a life in excess of 25 000 hours may be expected.

In applications which require long periods of standby life on one cathode, the operating ranges should be slightly restricted to obtain maximum reliability. The optimum operating area is now dependent on the circuit conditions described below.

Where the maximum counting speed is required and the main and guide cathode rest periods are small, the tube should be operated in the ranges given in Table 1(*b*), where the minimum guide B rest period is limited to 80μs and the maximum positive guide voltages to 45V to avoid failure after long standby periods. Where an output cathode negative bias greater than 5V is used, it is recommended that the minimum negative guide voltage for stepping is increased to 60V to reduce the discharge formative time to a minimum and ensure an adequate period for main cathode deionisation.

For circuits designed to operate at speeds below 3kc/s with long standby periods, the operating ranges given in Table 1(*c*) are recommended. Maximum standby-life reliability will be obtained if the guide pulse duration and the negative guide voltage for stepping are increased above the minimum values given.

GUIDE WAVEFORMS

The main difficulty in stepping tube circuit design occurs in the interpretation of the published-data guide drive requirements into practical circuit waveforms. The life experiments and the published data are based on the use of negative rectangular drive pulses, where the negative guide voltages for stepping and the rest periods available on each of the thirty cathodes are precisely defined. The guide B pulse also commences before the end of the guide A pulse to ensure that no gap exists between the pulses.

The next section describes three typical guide waveforms in conjunction with the recommended characteristic operating ranges given in Table 1.

Double Rectangular Pulse Drive

When the stepping tube is used in conjunction with transistor blocking oscillator drive and coupling stages, or alternatively, where the input signal is derived from mechanically operated switches or photosensitive devices, the input pulse drive often consists of two negative rectangular pulses as shown in Fig. 14.

For clockwise or 'ADD' rotation of the discharge, the first pulse is applied to the guide A cathodes followed by the second pulse to the guide B cathodes, and the

TABLE 1

Recommended Characteristic Operating Ranges

(*a*) All operating speeds where a standby period ≤1 hour is expected
(*b*) For maximum counting speeds and where a standby period >1 hour is expected
(*c*) For counting speeds ≤3kc/s and where a standby period >1 hour is expected

		(*a*)	(*b*)	(*c*)
Nominal anode current	(μA)	330	330	330
Minimum dwell time:				
guide A cathode	(μs)	60	60	60
guide B cathode	(μs)	60	80	120
main cathode	(μs)	75	75	75
Negative guide voltage for stepping:				
minimum	(V)	−45	−45	45
maximum	(V)	−140 minus the positive guide supply voltage	−70	−140 minus the positive guide supply voltage
Positive guide supply voltage for stepping:				
minimum				
main cathode dwell time >1ms	(V)	25	—	25
main cathode dwell time ≤1ms	(V)	35	35	35
maximum	(V)	50	45	50
Maximum negative bias voltage on any main cathode	(V)	−14*	−14*	−14
Maximum positive voltage excursion on any main cathode	(V)	Positive guide voltage −10V		

*where a 14V negative bias is used with guide B rest periods <120μs the minimum recommended negative guide voltage for stepping should be increased to −60V.

N.B. The characteristics rapidly return to their original values if the discharge is rotated around the tube for a few seconds. It is recommended that this process should be carried out whenever possible after standby periods in excess of one hour.

discharge transfers: main cathode – guide A – guide B – next main cathode at the times shown in the figure.

For satisfactory operation it is necessary that the gap 'A' between the termination of the guide A pulse and the arrival of the guide B pulse is less than 3μs; otherwise at the end of the guide A pulse, the anode voltage may rise sufficiently to cause breakdown to the heavily primed

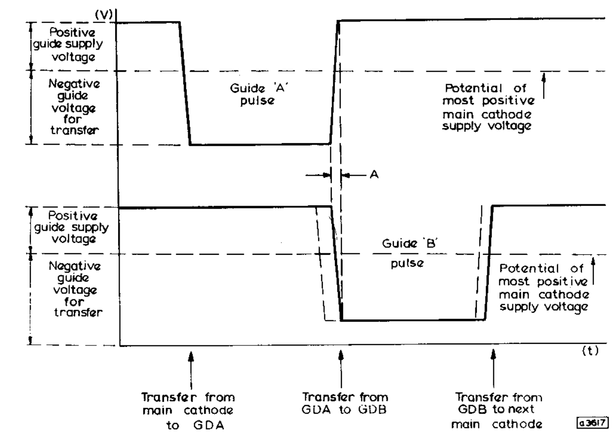

Fig. 14—Double rectangular pulse drive

previous main cathode. This means either that the pulse rise and fall times should be short, or that the guide B pulse is initiated before the first pulse ends. Fig. 14 shows the latter alternative, indicated by the dotted line guide B pulse.

Double rectangular pulse drive has the great advantage that the discharge period of rest on each cathode can, if necessary, be precisely defined by the duration of the guide pulses. In addition, the leading and trailing edges of the output pulses at the main cathodes can be short and well defined, and thus these output pulses are ideal for driving further logical circuits.

Rectangular Guide A and Integrated Guide B Pulse Drive

In a number of applications, only one negative rectangular pulse is available to drive a stepping tube. In such cases the input pulse can be applied direct to the guide A cathodes and also to an integrator circuit, which forms a

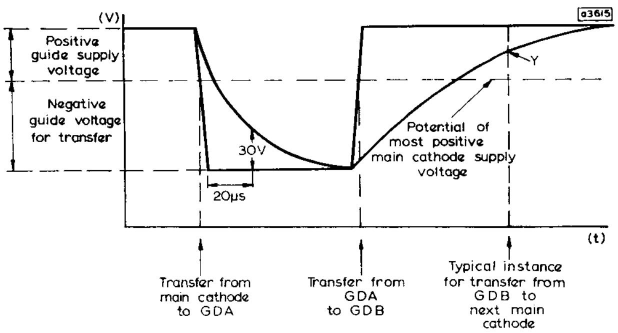

Fig. 15—Rectangular guide A and integrated guide B pulse drive

delayed pulse for the guide B cathodes. Typical guide waveforms for an integrator circuit are given in Fig. 15.

In operation, the discharge transfers to a guide A cathode when the rectangular pulse is applied to the circuit. At the same time the guide B potential commences to fall exponentially towards the potential of the guide A cathodes. Thus, at the end of the guide A pulse, the discharge transfers immediately to the next guide B cathode because the guide B cathodes are already at a negative potential. The potential of the guide B cathodes then rises as the integrator network charges again, until at the time shown as Y in Fig. 15, the guide B cathodes assume a positive potential and the discharge steps to the next main cathode.

The following requirements must be satisfied during the guide A conduction period if reliable operation is to be achieved. First, the guide A potential must drop to a value of at least minus 45V and a period of 60μs must elapse before the guide A pulse is terminated. Second, the guide B potential should still be some 30V more positive than the guide A cathode for at least 20μs after the rectangular pulse has been applied to the guide A cathode (see Fig. 15). This latter precaution prevents the discharge from stepping back to the previous guide B cathode.

This method of operation can be used in circuits designed for speeds up to 3kc/s, where exact control of the output pulse shape and duration from the tube is not required. Also, as there is no possibility of a gap between the guide pulses, close control of the input pulse shape is not usually necessary.

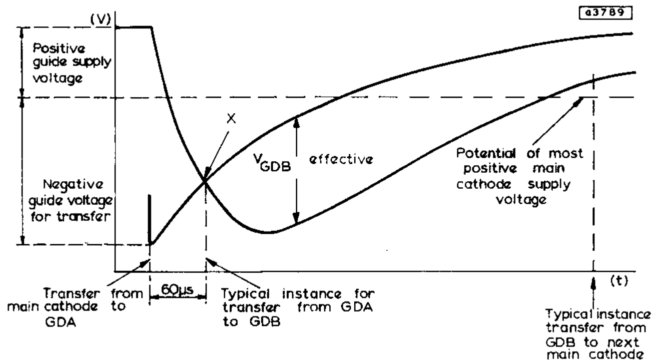

Fig. 16—Differentiated guide A and integrated guide B pulse drive

Differentiated Guide A Pulse and Integrated Guide B Pulse Drive

The final and most common guide pulse drive is given in Fig. 16. The input to the guide A cathodes is a differentiated negative pulse, and the input to the guide B cathodes is an integrated negative pulse. These pulses can be obtained by amplifying a single voltage or current step function. For example, the positive output voltage step at a main cathode can be shaped to provide pulses for a succeeding stepping tube. To ensure that the discharge rests for at least 60μs on the guide A cathodes during transfer, the guide A potential should remain negative compared with guide B, for this period. Therefore, the voltage crossover point X in Fig. 16 should occur at least 60μs from the start of the guide pulses.

To transfer the discharge to a guide B cathode the effective guide B pulse amplitude should exceed 45V for at least 60μs. This effective guide B pulse amplitude is the potential difference between the guides after crossover. Transfer to the main cathode is accomplished, as before, when the guide B potential becomes more positive than the main cathode potential.

Because of the long recovery periods associated with exponential waveforms, the stepping speed with this input drive is limited to around 500c/s. This speed is, however, adequate for coupling the Z504S stepping tube in decade scalers.

Measurement Points on Guide Waveforms

To achieve the high reliability of the Z504S it is important that the correct guide dwell times and voltages are maintained when pulses are applied to the guide electrodes. Thus, there are maximum and minimum voltage limits together with minimum dwell times which apply to the guide waveforms. These requirements can be met

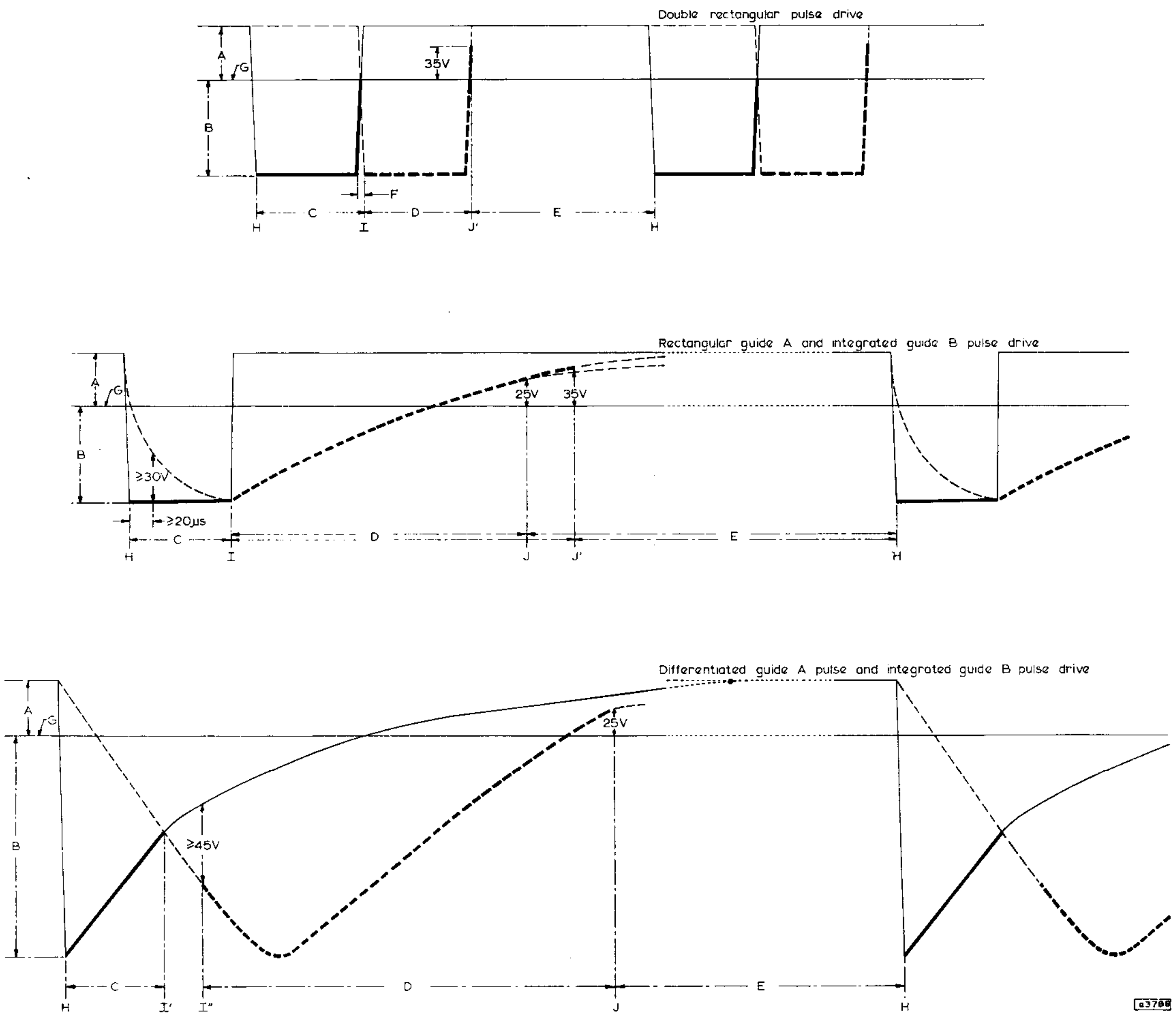

Fig. 17—Guide waveforms

A	Positive guide supply voltage	I	Discharge transfers from guide A cathode to guide B cathode
B	Negative guide voltage for transfer	I'	Earliest instant for discharge transfer from guide A cathode to guide B cathode
C	Guide A dwell time	I''	Latest instant for discharge transfer from guide A cathode to guide B cathode
D	Guide B dwell time	J	Latest instant for discharge transfer from guide B cathode to main cathode, for a main cathode dwell time > 1ms
E	Main cathode dwell time	J'	Latest instant for discharge transfer from guide B cathode to main cathode for a main cathode dwell time ≤1ms
F	Interval between trailing edge of guide A pulse and leading edge of guide B pulse		
G	Potential of most positive main cathode supply		
H	Discharge transfers from main cathode to guide A cathode		

provided the required dwell times or guide voltages are measured between two appropriate points on the waveforms. In Fig. 17, which gives the three drive waveforms described above, the guide A pulses are shown by full lines and the guide B pulses with dotted lines. Superimposed on these waveforms are shown the points between which the particular dwell times and guide voltages should be measured. The bold lines on the guide waveforms represent the duration for which the discharge is considered to dwell on a guide electrode. For example, in Table 1 it is stated that the minimum guide B dwell time, for all operating speeds where a main cathode dwell time $\leqslant$ 1 hour is expected, is 60µs. It is essential, therefore, that the periods described in the lines 'D' in Fig. 17 should be at least 60µs.

PERFORMANCE IN OPERATING CIRCUITS

In conclusion, the counting reliability obtained when the Z504S stepping tube is operated within the recommended characteristic working area is considered.

A number of life tests have been conducted on counter chains made up of transistor, cold cathode trigger tube, and valve coupling stages (Ref. 3, 4 and 5). In each experiment at least three counter chains were connected to a common pulse source so that errors or 'miscounts' in one count could be compared with the stored count in the others.

Three counter chains each consisting of six transistor coupling circuits have been operated for 18 000 hours at an input speed of 400c/s. No miscounts have occurred in any of the stages in this period.

A 14 000-hour life test has been carried out on three chains of trigger tube coupling circuits, when 17 miscounts occurred in the total of 27 stages during the life period. It is important to note, however, that twelve of the errors arose in the first stages of the counter and are probably due to spurious pulse pickup owing to the high input impedance of this stage.

Finally, a total of 56 tubes have been life tested with the use of a valve coupling circuit which has seven counter chains with eight tubes in each chain. In this arrangement only 5 miscounts occurred in a life period of 25 000 hours (that is, $25\,000 \times 56 = 1\,400\,000$ tube-hours).

The miscount rates given above should be considered as worst figures, as the errors obtained may be due to undetected spurious signals applied to the tube and not to tube characteristic changes.

When miscounts have occurred and the tubes have been measured, only two tubes failed to operate to the limits described earlier. This represents a failure rate in these life tests of one tube in one million tube hours.

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