LB-902

DESIGN CONSIDERATIONS FOR SERIES HEATER STRINGS IN TELEVISION RECEIVERS

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Approved

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Introduction

In transformerless television receivers, the operation of tube heaters in series presents several engineering problems which may be classified under the headings of (1) steady-state heater voltage; (2) voltage unbalance during receiver warm-up; (3) heater-cathode voltage; and (4) multiple tube failures. This bulletin discusses each of these problems and evolves some rules which are generally applicable.

It is often difficult to weigh the engineering considerations against the more commercial considerations. It is clear, however, that the average life of tubes in series heater operation cannot be as great as would be obtained with the conventional parallel heater connection. In series strings, the variations from the normal heater power are increased, the incidence of open heaters and heater-cathode shorts is increased, and the chance of one tube failure causing damage to other tubes is increased. However, the careful application of good design practices will greatly enhance the chance of obtaining satisfactory tube life and receiver performance.

Steady-State Conditions

Perhaps the least troublesome problem in the design of a transformerless television receiver is the arrangement of the tube heaters so that each has the proper voltage under steady-state conditions. Although many arrangements can be devised, other design considerations in a particular receiver, some of which will be discussed in this bulletin, usually narrow the choice to a very few. The usual tube requirements of television receivers suggest that, in general, the most promising arrangement consists of two 300-milliampere strings joined to form a small common 600-milliampere section, as shown in Fig. 1. The 600-milliampere section is needed to accomodate the kinescope, the damper tube, and any 450-milliampere tubes (with a shunt resistor). When this general arrangement is used, little, if any, series resistance is required to establish the proper steady-state heater voltages.

The resistance-temperature characteristic of the heater material has some effect on the steady-state operation of the heaters in a series string. The resistivity of tungsten, for example, increases by a factor of more than seven between room temperature and 1500 degrees Kelvin, which is the approximate operating temperature of most tube heaters. Because some tolerance must be allowed in the manufacture of heaters, the wire diameter in different heaters is certain to vary slightly, causing the resistance and operating temperature to vary. This variation is aggravated in a series string. A heater in which the wire diameter is larger than normal, for example, has lower resistance and assumes less than its normal voltage; as a result, such a heater operates at lower temperature, and its resistance becomes still lower with respect to that of heaters having normal or smaller-than-normal wire diameter.

The extremes in cathode temperature, therefore, are increased beyond the extremes resulting from the normal ten per cent variation in supply voltage, and a slight reduction in average tube life may result.

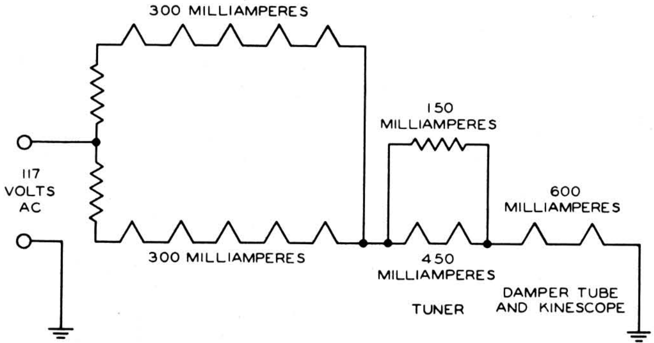

Fig. 1 - A typical series heater arrangement for television receivers.

Voltage Unbalance During Warm-up

Although the heater voltages in a series string may be properly balanced under steady-state conditions, severe unbalance may occur during receiver warm-up. Normal considerations in tube design require that heaters of different material, size, mechanical arrangement, and thickness of insulating coating be used in various tube types. Such differences in construction cause differences in the rate at which the heaters warm up. One heater may reach its normal operating temperature and resistance while other heaters are still relatively cool and have relatively low resistance. The fast-heating tube, therefore, is subjected to a heater voltage and temperature considerably higher than the normal value until the entire string reaches stable condition. It is important, of course, to avoid the placement of a fast-heating tube in series with several slow-heating tubes. The heating time referred to, however, is primarily a characteristic of the heater and its insulation and may bear no relation to the time required for the start of cathode emission. The maximum heater voltage occurs before the cathode is heated much, usually within the first five seconds of warm-up.

A test on a very simple heater string, shown in Fig. 2, illustrates typical differences in heating characteristics of three tube types. A voltage of 18.9 volts was applied to three 6.3-volt tubes in series. Two of the tubes were 6CB6's; the third tube in one test was a 6AL5 and in the other test was a 12AU7 with heaters connected in parallel. The heater-voltage variation with time after the switch was closed is shown in Fig. 2 for each tube type. It is significant to note that, although the heater-cathode structures of the 6AL5 and the 12AU7 are quite similar, the results for these two tubes are quite different.

Some general rules may be used for guidance in devising series strings to minimize the voltage unbalance during warm-up. First, tubes with large heater power usually warm up more slowly than tubes with less heater power. This fact suggests that in receivers having two nearly independent strings as shown in Fig. 1, tubes with large heater power can be placed in one string and tubes with smaller heater power in the other. There may not be enough tubes with large heater power to fill one string, however; it is then usually preferable to divide the slower heating tubes evenly between the two strings.

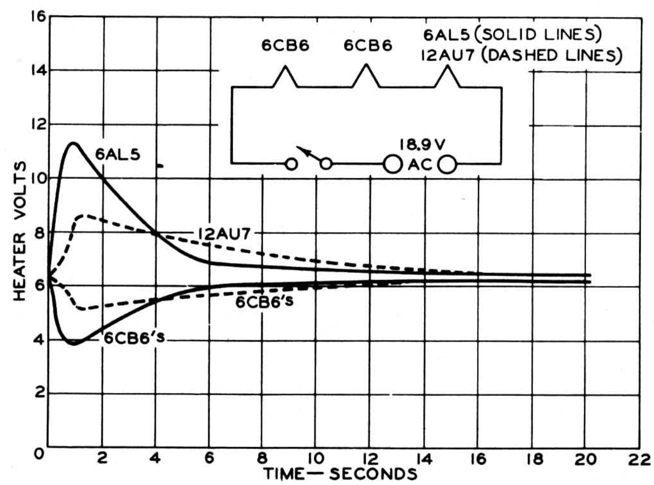

Fig. 2 - Variation in heater voltages during warm-up of two simple series strings.

A second general rule is that the use of fixed resistance in series with a string is one of the most effective ways to reduce the voltage unbalance. The use of fixed series resistance increases the warm-up time of the receiver, however, and this method has practical limitations.

A third general rule, the converse of the second, is that the use of fixed resistance in parallel with a tube heater aggravates voltage unbalance during warm-up. It would be unwise, for example, to place a 150-milliampere heater with parallel resistor in a 300-milliampere string. The use of a 450-milliampere tube and parallel resistor in a 600-milliampere string, as shown in Fig. 1, is also undesirable, but may be required when existing tube types are fitted to television circuit requirements.

Probably the most important thing to remember about these general rules, however, is that their usefulness is limited to guidance. Extensive voltage measurements are required for proper evaluation of a string arrangement. Even with television receiver string arrangements adhering to the recommended general principles, warm-up voltages on some types have averaged more than twice their rated heater voltages. In fact, the far simpler strings used in ac-dc radio receivers have proven so complex in warm-up behavior that the tube industry has been forced to rely on voltage measurements rather than analytical methods, despite years of experience. Furthermore, variations between individual tubes require that some quantity of tubes be used in the evaluation of a string arrangement, and that tubes from various manufacturers be included. The tubes should be allowed to cool for a minimum of 10 minutes between tests.

Meters used in warm-up voltage measurements must respond quickly. Although most precision instruments are too sluggish for the job, they can be used to check the calibration of faster-acting meters such as some a-c vacuum-tube voltmeters. A calibrated oscilloscope is also a suitable measuring instrument.

Heater-Cathode Voltages

In the design of the series-string arrangement, it is important to consider the maximum heater-cathode voltage ratings of the tubes. Heater-cathode voltage ratings are usually given in terms of peak voltage; the pertinent voltage, therefore, consists of the d-c voltage plus the peak a-c voltage, including any signal voltages.

The damper tube often presents the most serious problem, and it should usually be placed near the ground end of the string. The ratings of tubes intended for damper service acknowledge the capability of the heater-cathode insulation for withstanding voltage pulses better than d-c voltages. The heater-cathode voltage rating, therefore, includes a maximum peak pulse-voltage value, with the duration and repetition rate of the pulse defined, and a maximum d-c voltage value. Any 60-cycle sine-wave component added by the series string arrangement is almost as dangerous to the insulation as d-c voltage, and the sum of the d-c voltage and the peak 60-cycle sine-wave voltage should not exceed the d-c heater-cathode voltage rating.

Because the kinescope also has considerable d-c heater-cathode voltage, its heater, too, should be placed near the ground end of the string. Attention to a design for conservative kinescope operation is warranted because of the relatively high replacement cost.

Large a-c heater-cathode voltages are also conducive to heater-cathode hum in some circuits. It is advisable to place tubes used in circuits susceptible to heater-cathode hum near the ground end of the string.

One unfortunate result of high heater-cathode voltages is the fact that the incidence of breakdown of the heater-cathode insulation is certain to increase. Although it can be stated that the life of a tube used within its ratings will be satisfactory, the term "satisfactory" is a relative one. Tube operation will be more reliable if the heater-cathode voltage is minimized. A high heater voltage during warm-up is also conducive to heater-cathode failures because of the mechanical motion and stresses resulting from the large temperature variation in the heater.

Multiple Failures

In a series-string television receiver there are a number of ways in which one tube failure may bring about the failure of another tube. Such possibilities should be considered in the design of the string arrangement.

As an example of one type of multiple failure, heater-cathode shorts in certain tubes in the string could by-pass portions of the string and place excessive heater voltage on other tubes. No practical solution to this problem is apparent, although the use of fuses is a rather costly possibility.

Multiple failures may also result from an open heater. In complex arrangements in which two strings are brought together in a common section, as shown in Fig. 1, a heater failure in one string causes increased voltage on the heaters in the other string. As an extreme example of this effect, a string arrangement is shown in Fig. 3 in which two parallel 150-milliampere heaters complete a string of 300-milliampere heaters. If one of the 150-milliampere heaters failed, the total current in the string would change only slightly, but the other 150-milliampere heater would dissipate more than four times normal power. Even if this tube did not fail immediately, it would almost surely fail when the receiver was allowed to cool off and then switched on again. It follows logically that operation of tubes in parallel within a series string is undesirable, and that tubes should be arranged in separate strings to the greatest extent possible. The use of a common 600-milliampere section in the series string television receiver seems to be necessary at present, but the voltage across the common section should be made as small as possible.

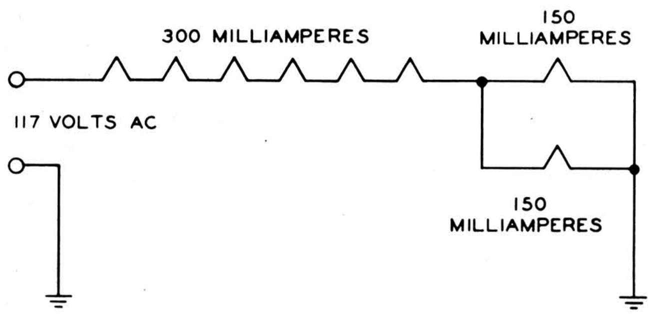

Fig. 3 - A series string illustrating the undesirable parallel operation of tube heaters within the string.

A similar problem arises when a resistance is placed in parallel with 450-milliampere heaters so that they may be fitted into the 600-milliampere section of the string. Failure of one of the 450-milliampere heaters sends almost 600-milliamperes through the shunt resistor which normally carries only 150 milliamperes, an increase in power approaching a factor of 16. In addition to the normal consequences of resistor overload, there is an insidious effect if the resistor opens. Replacement of the defective tube would restore the receiver to operation, and the open resistor might escape notice, causing greatly reduced life of the 450-milliampere tubes.

Multiple failures can also be caused by a heater failure damaging another tube through excessive current or dissipation in some electrode. Such a situation commonly arises in horizontal-deflection circuits. Failure of the circuit which supplies the grid-driving signal to the horizontal-output tube, or failure of any tube heater in series with the tube used in generating the grid signal, may cause several times the normal plate dissipation in the horizontal-output tube. Failure of the heater circuit of the damper tube, on the other hand, removes the plate voltage from the horizontal-output tube, causing excessive screen-grid dissipation. At first glance, it seems desirable to arrange the horizontal oscillator tube, the horizontal-output tube, and the damper tube in the same string. Frequently, however, such an arrangement is made impractical by other design considerations, and other protective techniques need to be devised. Fusing the circuit is one possibility. When the grid drive to the horizontal-output tube is removed, however, the plate current usually increases very little, seldom more than 50 per cent. A fuse in the plate or cathode circuits, therefore, is not a practical protective device. If the horizontal-oscillator and damper tubes can be placed in the same string (but a different string than the horizontal-output tube), however, a heater failure in that string will cause a large increase in screen-grid current in the horizontal-output tube and a fuse in the screen circuit would protect the horizontal-output tube.

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