TP-122
Power Tube

Application Note

Screen-Grid Current, Loading, and Bleeder Considerations

During the evolution of electron-tube voltage amplifiers, four-element (tetrode) tubes received scant attention from textbooks and educators. This condition has permitted the existence of misunderstandings and misconceptions about some aspects of their operating characteristics. This Note attempts to clarify some of these characteristics, especially the metered current, the effects of tube loading, and the size of the power-supply bleeder as they relate to the screen grid (grid No. 2) of a tetrode power-amplifier tube.

Of prime importance is the fact that the metered screen-grid current (I_{c2}) is the algebraic sum of the intercepted current (electron flow from the cathode resulting in positive current) and the primary and/or secondary emission from the screen grid (electron flow from the screen grid resulting in negative current). However, the heating effect of these currents on the screen grid is not the product of the screen-grid voltage times the metered screen-grid current. In actual operation, with zero metered screen-grid current, the actual screen-grid dissipation can be considerably higher than zero as measured calorimetrically.

In operation, stable performance can be obtained with either positive or negative metered screen-grid current. To demonstrate this condition, **Figure 1** shows that a tube with a load line as in curve C yields a negative screen-grid current because the instantaneous screen-grid current is negative over the entire plate-voltage swing from m to n. The load line m-n is a straight line based on an assumed linear tube characteristic. The negative screen-grid current is obtained when the screen-grid secondary emission ratio is greater than unity. That is, for every intercepted electron striking the screen grid, more than one electron is liberated as secondary emission from the screen grid and collected by the plate. This net electron flow away from the screen grid constitutes a negative current flow.

With lighter loading (a higher load-resistance value), as in curve B, the screen-grid-current meter reading either can be positive and static or it can initially be positive and then drift to a lower positive value or even a negative value. These effects occur as the meter averages the instantaneous values and the screen-grid structure achieves temperature stability. If the screen-grid current is low positive or negative and the screen grid is not being overdissipated, stable operation will be obtained.

With loading as in curve A, the screen-grid current is initially positive and then decreases toward a negative value, the rate of change depending upon the heating of the screen grid by the intercepted screen-grid current and the resultant primary emission. If the A-type loading is very light, the positive screen-grid current can be very high and the screen grid can be **overdissipated,** with resulting distorted or burned-out wires. The latter damage frequently causes a short circuit between control grid and screen grid as loose wires are attracted by the electrostatic field between the grids.

As a result, there is a question of how the actual loading can be determined and what the critical parameters are. The following discussion helps to clarify the cases illustrated.

BURLE Electron Tubes

Plate Loading Too Light

When the tube is driven along load line A, the plate current increases slowly along the load line with a corresponding plate-voltage swing. The metered screen-grid current increases rapidly with decreasing plate voltage to a high positive value. Under this condition, a low minimum plate voltage occurs and the screen grid is likely to be overdissipated by the very high screen-grid current. The screen-grid heating effect is the product of the screen-grid voltage and the intercepted current. This total dissipation is not reduced appreciably by the screen-grid emission current much as a hot cathode is not cooled appreciably by the electrons that are emitted. The screen grid is definitely overdissipated when the screen-grid current rises rapidly to a high positive value and after a few seconds starts to decrease toward an unstable condition. At the very least, the screen-grid dissipation is higher than in the following two cases, but the highest power output is achieved under the light loading conditions.

Plate Loading Too Heavy

Load line C is indicative of heavy loading (a low value of plate load resistance). As the drive signal is applied, the plate current increases rapidlywhile the metered screen-grid current remains essentially constant or decreases to a more negative value. This metered negative screen-grid current is a result of the instantaneous screen-grid current values being negative over the entire RF swing of the instantaneous plate voltage. This case is representative of least screen-grid dissipation, low power output, and high plate dissipation.

Plate Loading Normal

For preferred performance, the plate loading should be adjusted for operation along load line B. The plate current, metered screen-grid current, and power output all increase with increasing grid drive signal. Large power output is achieved with both the plate and the screen-grid dissipation remaining at safe levels. The metered screen-grid current will be the average of the instantaneous negative and positive values.

Empirical Method

An empirical method to determine the appropriate loading is as follows: With the tube operating and delivering power output, the plate voltage is reduced gradually while the metered screen-grid current is observed. Alternatively, the plate voltage can be maintained at aconstant value and the loading can be reduced. The screen-grid current increases as the plate voltage is reduced, until heating of the screen grid causes primary emission of sufficient magnitude to counteract the increased positive screen-grid current. At this point, the screen-grid current shows no further positive increase and starts to decrease as the primary emission of the screen grid increases. This behavior indicates that operation is now between A and B. The proper plate voltage for stable operation is approximately 5 to 10 percent above the lowest plate voltage determined above. This value varies for different tube types; therefore, the tube manufacturer should be consulted for appropriate operating conditions for specific applications.

Bleeder Selection

The next important point is the screen-grid-supply bleeder current. It is possible to monitor only the algebraic sum of the positive and negative components of the screen-grid current, and theoretically the bleeder current must be greater in magnitude than the most negative metered screen-grid current. This condition will prevent an increase in screen-grid voltage with negative current in the supply. However, the bleeder current is purposely made considerably greater to compensate for any increase in the screen-grid emission with time which may be caused by either contamination of the screen-grid surface by cathode material or the evaporation of protective materials from the screen-grid surface. A general rule of thumb is that the screen-grid-supply bleeder current should be ten percent of the average plate current during full-power operation.

Several variations of the effect of both positive and negative screen-grid current can be explained by reference to **Figure 2.** For illustration, it is assumed that the bleeder resistance is 2000 ohms and the supply is 400 volts (bleeder current = 200 mA). It is also good practice, as shown, to insert a series resistance between the screen grid and the power supply to reduce the peak surge current in the event of a tube and/or external circuit arc. Values up to several hundred ohms are adequate for most applications.

Case 1 If the metered screen-grid current is zero, the intercepted current and the primary and secondary emission current of the screen grid balance each other and the screen grid supply provides the bleeder current.

Case 2 If the metered screen-grid current is positive, the screen-grid supply will provide a current equal to the bleeder current plus the intercepted current as reduced by the screen-grid emission currents. The actual intercepted current determines the dissipation and this current may be greater than the metered screen-grid current because of the cancellation effects of the intercepted and screen-grid emission currents. In both cases (1 and 2), the screen-grid supply is loaded down and the screen-grid voltage varies only within its regulated limits. An additional voltage drop occurs across the series resistor in Case 2.

Case 3 If the metered screen-grid current is slightly negative and less (in magnitude) than the bleeder current, the screen-grid supply still supplies current but to a lesser degree. To the screen-grid supply, it appears as if a higher-resistance bleeder were placed across the output terminals, with a resultant lower current demand from the supply. Thus unloaded, the voltage of the screen-grid supply tends to rise and the drop across the series resistor further increases the voltage at the screen-grid.

Case 4 When the metered screen-grid current is high and negative and exceeds (in magnitude) the bleeder current, the screen grid supplies current to the screen-grid supply and the screen-grid supply ceases to function as a supply. In this case, the voltage of the screen-grid supply rises (unregulated) to a high positive value and the series resistor further increases the voltage at the tube. This higher screen-grid voltage (E_{c2}) may result in a still higher negative current; the situation is regenerative and results in a negative-screen-grid-current runaway. This runaway situation can occur very rapidly, too rapidly to be displayed on the meter. The use of an adequate bleeder current will prevent a catastrophe of this type. It is good engineering practice to use a spark gap with a breakdown voltage of not more than 1.5 times E_{c2} to prevent destruction of the tube and bypass capacitor if the tube should arc from plate to screen grid. This spark gap also limits the screen-grid voltage to 1.5 times its normal value during the negative-current runaway.

It should be noted that Case **4** is usually indicative of improper operation on a load line of type A in which the screen grid is overheated by excessive positive intercepted current with the resulting primary emission causing the negative current shown by the meter.

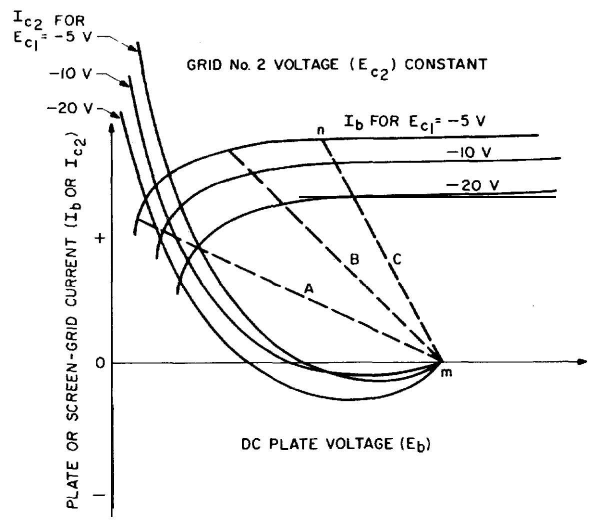

Figure 1 - Representative Tetrode Characteristics.

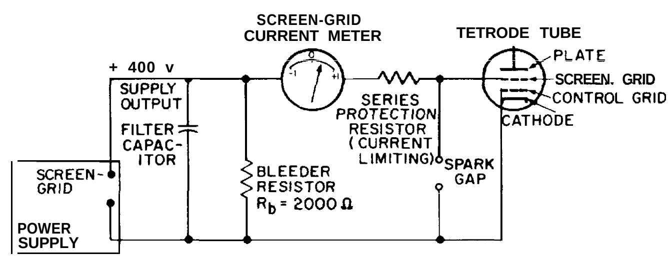

Figure 2 - Typical Screen-Grid Circuit.