amateur service newsletter
W6SAI

TRANSMITTING TUBES - How To Use and Abuse Them

The story has been told at hamfests that the data sheet enclosed in a vacuum tube box was included with the intention that it should be thrown away with the box and packing material. Contrary to this little story, the data sheet has been placed therein with good reason: to inform the user of the tube of the capabilities and limitations of the tube. The data sheet is a summation of the functions of the tube and covers the **electrical and mechanical characteristics**, the **maximum ratings**, and the **typical operating conditions**.

The rugged individualist usually ignores the data sheet and runs his tube at a temperature just below that at which the plate will start to melt. This may be fun, and may even evoke "oh's" and "ah's" from the visiting hams, but it violates the old "watts-per-dollar" evaluation of the vacuum tube!

After all, let's face it: There is an economic point beyond which it is impractical on a "watts-per-dollar" basis to push a tube. In general, the harder the tube is pushed, the shorter will be its life. This is analogous to the story of the cowboy who wandered into a western saloon and saw an old, grizzled prospector at the bar, drinking whiskey neat from a bottle, and smoking a huge, black cigar taken from a box of stogies at his elbow. Striking up a conversation, the cowboy learned the old gent drank three quarts of booze a day, and smoked five boxes of cigars a day, too. Said he, "You are amazing! All this hard living at your age! You look like you must be ninety years old!"

"Ninety!" screeched the prospector slamming his drink on the bar and reaching for his gun, "I'm only twenty-two!"

So it is with the vacuum tube. Moderation is the secret to a happy, long tube life. The tube manufacturer sets maximum ratings on a basis of expected tube life. Each rating has been determined as the maximum value which will permit a reasonable life expectancy for the tube. The enemy of unlimited tube life is **heat**, but unfortunately heat is a natural consequence of making the tube work. A compromise of some kind must thus be made, and this is the purpose of the data sheet. Let's look into the compromise and see what establishes the various ratings given for transmitting tubes.

Plate Dissipation

The **plate dissipation** (rated in **watts**) of all radiation (air) cooled tubes is limited by the maximum safe temperature of the plate, and the effects of this temperature on parts of the tube other than the plate. In general, the plate of radiation-cooled tubes will withstand several times its maximum rated plate dissipation **for a short period of time**. Other parts of the tube, however, are affected greatly by excessive heat radiated by the plate. High levels of plate temperature cause the grid, filament, and glass envelope to become over heated, while the heat conducted away from the plate by the plate lead contributes to the heating of the plate seal.

These effects are not instantaneous, and short overloads do not usually overheat the adjoining tube structure to a damaging extent. However, the user has no way of telling to what degree he can safely exceed the plate dissipation, or over what length of time this abuse can take place. The maximum plate dissipation rating is intended to set a point at which **continuous** operation may be carried out without damage to any part of the tube, even though the other tube elements may at the same time be operating at their maximum ratings.

Regardless of other conditions, the maximum plate dissipation should not be exceeded in continuous operation.

Maximum Plate Voltage

Voltage limitations are set at a point above which the internal insulators of the tube may arc over, or above which the glass envelope will become damaged from dielectric losses. In addition, a plate voltage ceiling tends to set a limit to the r.f. **charging current** flowing in the plate and filament leads. The charging current is a function of the r.f. plate voltage, which in turn is a function of the d.c. plate voltage; this makes it possible to set a limit on r.f. charging current without the difficult task of determining the current directly.

Tube envelopes having grid and plate leads in close proximity are subject to a greater degree of glass stress than those having widely separated electrode terminations. In general, however, most glass tubes have maximum plate voltage ratings that fall in the r.f. charging current limit category.

Minimum Plate Voltage

Each tube has a particular plate voltage below which it is uneconomical to operate the tube. That is to say, the filament power consumed by the tube (and the initial cost of the tube) are so high that the cost of power developed by the tube is high in comparison to the same power generated by a cheaper tube. Of course, if the tube is purchased "surplus" at low cost, the economic picture changes so that the initial cost is of secondary importance. Even so, tube efficiency tends to drop when extremely low values of plate voltage are employed. In addition, multi-element tubes, such as the tetrode (the 813 or 4-250A, for example) have a definite **minimum** plate potential below which it is not wise to operate the tube. As the plate potential is lowered, the average screen current tends to rise and the screen dissipation increases accordingly. It can be possible to thereby damage a tube by excessive screen dissipation by operating it at a low plate potential.

Lowering the screen voltage to decrease the screen dissipation is but a make-shift cure, as the power gain and efficiency of the tetrode tube drops sharply as the screen voltage is lowered beyond the normal operating range.

Maximum Plate Current

Maximum plate current is based upon the available supply of electrons emitted by the filament of the tube. **Filament emission** is therefore the controlling factor determining maximum allowable plate current. The maximum plate current figure is intended to set a value which may be easily realized throughout the life of the tube. If operating conditions are chosen which require the maximum plate current limitation to be exceeded at the start of tube life, it may become increasingly difficult to maintain the desired plate current as the tube ages. To have ample filament reserve, it is important to make sure that filament voltage is "up to snuff" at all times.

Filament Voltage

Proper **filament voltage** and the allowable departures therefrom are usually specified in the tube data sheet. In general, quick-heating thoriated tungsten filaments used in the larger power tubes may be operated over a range of plus or minus 5-percent of the recommended voltage. Slower heating cathode-type filaments used in small power tubes usually have a filament operating range of plus or minus 10-percent of the recommended voltage. External anode tubes have a filament voltage range of plus or minus 5-percent. Some variation in power output must be expected as the filament voltage is varied in this range. Lower than normal filament voltage will impair the power output of the tube, and higher than normal voltage will cause critical parts of the tube to run at an excessive temperature, and may even cause damage to the grid structure in extreme cases. In passing, it should be noted that an inexpensive a.c. type meter of plus or minus five-percent accuracy can tell the operator little about filament voltage, when the voltage must be held to the same value of accuracy. Use a **good** filament voltmeter of known accuracy.

Element dissipation sets the grid and screen power limits. Excessive dissipation can result in electron emission from the element (termed **primary emission**), or can cause deformation or melting of the structure through overheating. In addition, the grid and screen structures can be overheated by excessive radiation from the plate.

A common type of screen damage results when the tube is operated with full screen voltage and low or nonexistent plate voltage. The screen then tends to act like the plate, and excessive screen current quickly boosts the screen dissipation to the point where the structure is permanently damaged. Thus, the tetrode should be protected against loss of plate voltage. Either the screen and plate voltage should be taken from a common supply, or some form of overload relay or safety device should be used that will break the screen voltage lead when the screen current exceeds a predetermined value. When such a device is used, a ground return should exist between the screen and the negative of the plate supply. Otherwise, when the screen circuit is broken, the screen will "float" above ground at some high potential and the screen bypass capacitor may fail due to excessive voltage (figure 1).

Bulb Temperature

The glass envelope and lead seals of the transmitting tube must be maintained below a temperature at which the glass will soften, or the seals "leak" air. Tubes and components tend to become smaller year by year, but nobody has yet been able to miniaturize the watt, and assemblies run hotter as they are reduced in size. Also the tube's glass envelope will act as a conductor when it is too hot. Adequate ventilation is very important if maximum tube life is to be achieved. Heat is the great enemy of the vacuum tube and pains should be taken to conduct the heat away from the tube as efficiently as possible.

The most popular tubes used in amateur service are air cooled. The smaller tubes (and the larger, old ones having long element support stems) may be cooled by **convection**, the heat rising from the envelope creating sufficient air movement to ensure that excessive element and seal temperatures are not reached. Compact, higher power tubes that have to dissipate large quantities of heat in a small area must have assistance in the form of air blown across the envelope, seals, and pins by an auxiliary fan or blower.

Short, squat tubes may require more cooling air than long, thin tubes as the lead seals of the "shorties" are nearer the elements and are thus exposed to higher temperatures.

For most tubes the flow of cooling air is upward, consistent with the normal flow of convection currents. Large transmitting tubes have an open base structure and a matching socket which permits cooling air to enter the base end of the tube. The grid circuit area under the chassis, therefore, may be pressurized and the air introduced into this chamber by means of an external blower. The plate circuit area may have a mesh cover which permits the air to vent out readily, yet which provides a degree of circuit shielding. No holes in the chassis should be provided for the air to pass from the lower to the upper compartment other than by passage through the socket and tube base (figure 2).

Do not sub-mount a tube with a metal base shell so that the chassis comes above the vent holes of the base. **Do not** mount above the chassis a tube with a metal base shell or the proper circulation of air will be impaired (figure 3).

In the case of the external anode-style tubes (4X150A, for example) complete air system sockets are available that permit air to be blown axially on the base of the tube, past the base to the envelope, and then over the plate cooler. Use of other than such a special socket is "bad medicine" for the external anode tube, as tube temperatures cannot be adequately controlled.

Use of a receiving-type loctal socket with external anode tubes is not recommended, as dangerously high stem temperatures will be generated from the heat of the filament unless the base structure is cooled by an air blast, and the solid construction of the loctal socket blocks the normal flow of air above the tube stem.

Construction Techniques for Forced-Air Cooled Tubes

In general, the under-chassis area should be made air-tight, and a suitable fan or blower used to pressurize the compartment. The intake air vent should have a large area to provide a minimum resistance to the flow of air. Air holes may be screened as a TVI-preventive measure, but such impediment reduces the passage of the air by a large degree.

As it is difficult to measure the air flow to a tube, and even more difficult to measure the envelope and seal temperatures of the tube, the following "rules of thumb" may be observed in order to achieve optimum cooling and longest tube life.

1. Use the maximum amount of forced air possible. It is wise to employ a blower delivering at least twice the recommended volume of air. Turn the air blast on at the same time the filament is turned on, and leave it on as long as the filament is lit.

2. Inexpensive squirrel-cage blowers often do not work properly when delivering air into a back pressure "load" created by the socket, tube and chimney. A large quantity of air escapes through the sides of the blower. Make sure the air **enters** the socket and **escapes** via the tube chimney, and does not "windmill" in the blower cavity.

   See that the rotatable cage of the blower makes a close fit with the housing; otherwise, air will spill out of the unit when it is operated under back-pressure. In general, low speed blowers will lose pressure badly when subjected to back-pressure. A blower speed of at least 3,100 r.p.m. is recommended. Most transmitting tube data sheets reveal the required air pressure (in cubic feet per minute) and the back-pressure (in inches of water) that must be developed as pressure drop across the socket. Most blower manufacturers provide data sheets which show the blower output (in cubic feet per minute) that the unit develops for various values of back pressure (in inches of water, or static pressure). You can be reasonably sure your tube is adequately cooled if you choose a blower that develops about **twice** the required number of cubic feet you need at a specified back pressure. Beware of "midget" and "surplus", unmarked blowers, or blowers with loose-fitting housings!

3. Make sure the cooling air reaches the socket and make sure the exhaust air leaves the vicinity of the tube. It does no good to pump cooling air to a tube and then have no path for the warmed air to excape.

4. A large amount of heat escapes from glass tubes by radiation of energy from the tube plate. Placing the tube near polished metal surfaces that reflect radiant energy back to the elements of the tube is a sure way to raise the internal temperature of the tube. It is a good idea to space the tube away from such surfaces by at least the diameter of the tube envelope.

No simple rules can be given to accommodate all tube installations in all possible equipments. Tubes can be damaged by lack of air, but never by too much air, unless the blast is strong enough to lift the tube out of the socket and smash it against your ceiling! Use the largest blower you can afford. A great deal can be learned about air flow by puffing cigarette smoke into the blower and observing the path it takes in quitting the amplifier.

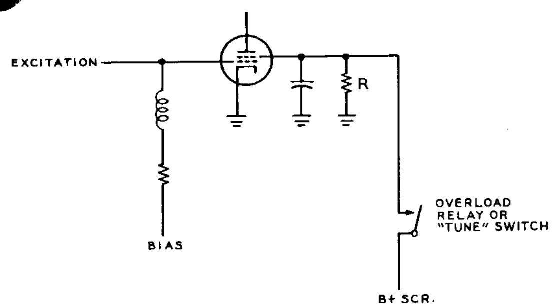
Connections to the Tube

Connections to the plate cap of transmitting tubes should be made with a section of flexible strap or braid to prevent any lateral strain from being placed on the tube electrode. Those tubes having a rod-type plate lead (such as the 304-TL) are prone to damage if the plate connector is forced on the rod until the connector touches the glass envelope. Under heat, the expansion rate of the glass, the plate rod, and the connector are all different, and it is possible for the connector to press against the envelope and cause a fracture of the glass at the point of contact.

There Is Hope!

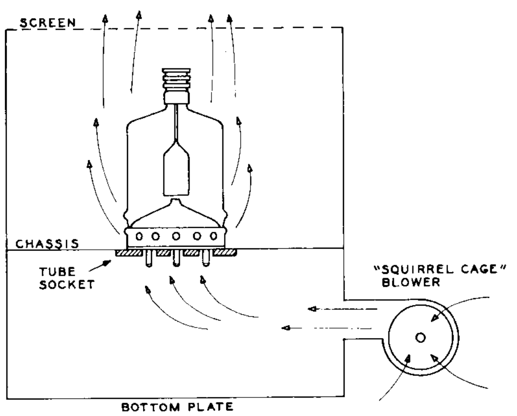
Don't let these warnings discourage you from building equipment and using modern high power transmitting tubes! It is merely that "forewarned" is "forearmed." By anticipating minor difficulties such as outlined in this article and eliminating the sources of trouble, the equipment in question can provide a long and happy life for the vacuum tube. This will make you (the owner and operator) happy, and - believe it or not! - make the vacuum tube manufacturer equally happy!

Figure 1



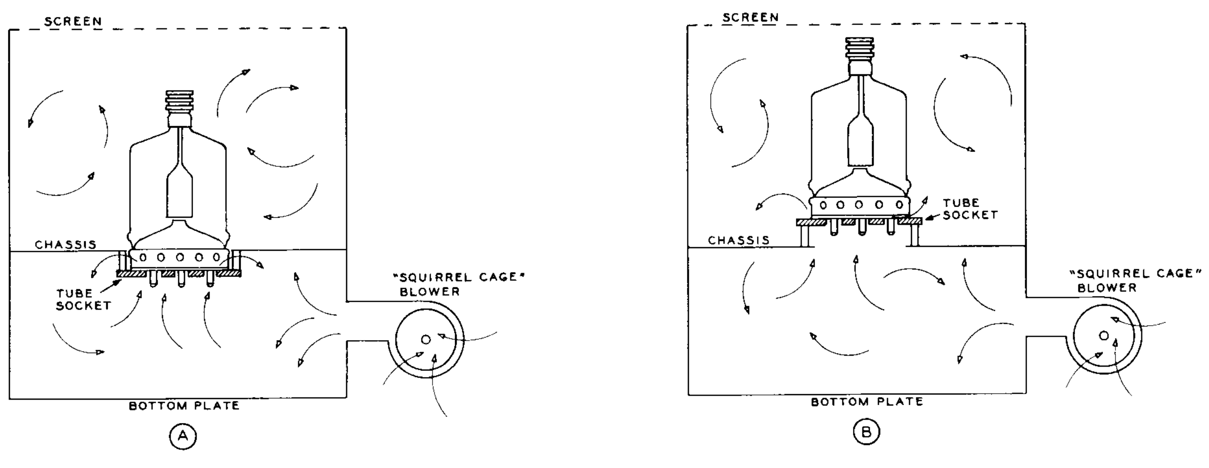
If the d.c. screen circuit is broken by an overload relay or a "tune-operate" switch, it is necessary to provide a d.c. return path from screen to ground. Otherwise, it is possible for the screen to assume the d.c. potential of the plate with the result that the screen bypass capacitor may be damaged. The screen resistor (R) should be chosen so as to "bleed" about 15 milliamperes per tube for the 4CX250B/4CX300A series tubes and approximately 70 milliamperes for the 4CX1000A.

Figure 2



Forced air enters the grid compartment below the socket through a screened opening, passes through the socket cooling the base seals of the tube, sweeps upward cooling the the glass envelope. The plate circuit compartment has a screened cover which permits the air to vent out readily. This arrangement applies whether the tube is cooled by forced air or convection circulated air.

Figure 3



Do not sub-mount a tube with a metal base shell so that the chassis deck comes above the vent holes of the base shell of the tube. This arrangement impedes the proper flow of air and does not improve circuit isolation (A). Do not mount above the chassis a tube with a metal base shell, as the same conditions apply as before (B). In addition, no holes should be provided for the air to pass from the lower to upper compartment other than the passages through the socket and the tube base.