TWO MEGAWATTS RF POWER TETRODE

Sterling G. McNees
EIMAC, Division of Varian
San Carlos, CA. 94070

Several years ago EIMAC with in-house funds undertook to develop a super power tetrode capable of generating 2MW RF power continuously at frequencies up to 50 MHz. The design of this tube, called the X2159, Figure 1, is based on the successful concepts which were developed for the 4CW50,000E and the 4CW100,000E. Although the super power tetrode uses proven design concepts a scale up of approximately ten times in power presented its problems. These can be summed up as increased power per unit area and the mechanical problem of maintaining close tolerances.

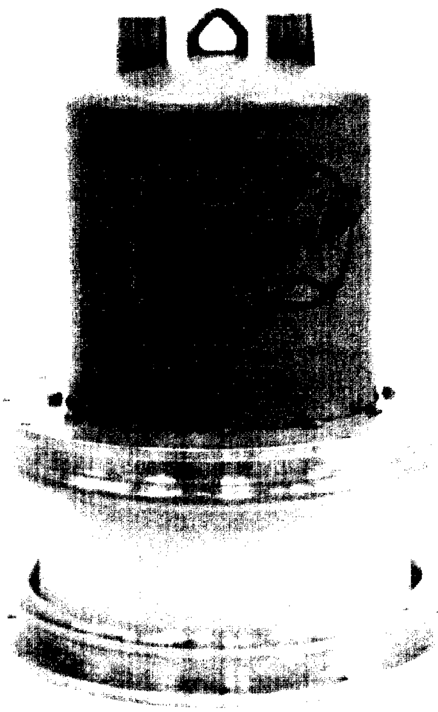

FIGURE 1. X2159 2MW Continuous RF Output.

In the design of any power grid tube there is a compromise between many conflicting electrical and mechanical parameters. It usually begins with a desired power output and a given plate voltage. In the case of the X2159 these were 1.25MW output with a plate voltage of 15kV. These figures are easily translatable into the more meaningful numbers for the tube engineer of a DC plate current of 125 Amps and a peak instantaneous plate current of 750 Amps, which takes care of both peak RF and peak modulation currents. For CW operation it is permissable to increase the plate voltage. For larger power tubes using thoriated tungsten the rule is 5 Amps DC/kW of filament heating power.

Output spacing involves several factors such as voltage holdoff and capacity, but for a tetrode the spacing is as large as possible consistent with space charge limitation. Computer programs which solve Poisson's equation are usually used in the final determination of output spacing. An approximate determination is to use the Childs Langmuir equation:

$$X = \frac{1.528 \cdot 10^{-3} V^{3/4}}{J^{1/2}}$$

For the X2159 J is 400ma/cm^2 for a total plate current of 750 Amps. Solving the above equation first with a typical screen voltage and then adding this to the result when using the instantaneous value of the plate voltage at its minimum point will give a somewhat higher than practical output spacing. The output spacing for the X2159 is 1cm. Input spacing is determined approximately by:

$$d_{cg} = \frac{1.528 \cdot 10^{-3} \left(Vg + \frac{Vs}{\mu}\right)^{3/4}}{\left(J\ (1+1/\mu)\right)^{1/2}}$$

where V_s is the screen voltage and μ is the so-called grid screen μ which is 3 for the X2159, and J is 2 Amp/cm^2 for the current density at the filament when a peak current is 750 Amps. This gives a value for the input spacing of 1mm. This represents the preliminary work that is done in designing a tube. After this comes the detailed work of refining, calculating various forces and eliminating mechanical vibrations, temperature calculations and thermal expansion.

So much for the design of a tube. It is in the applications that its performance is judged.

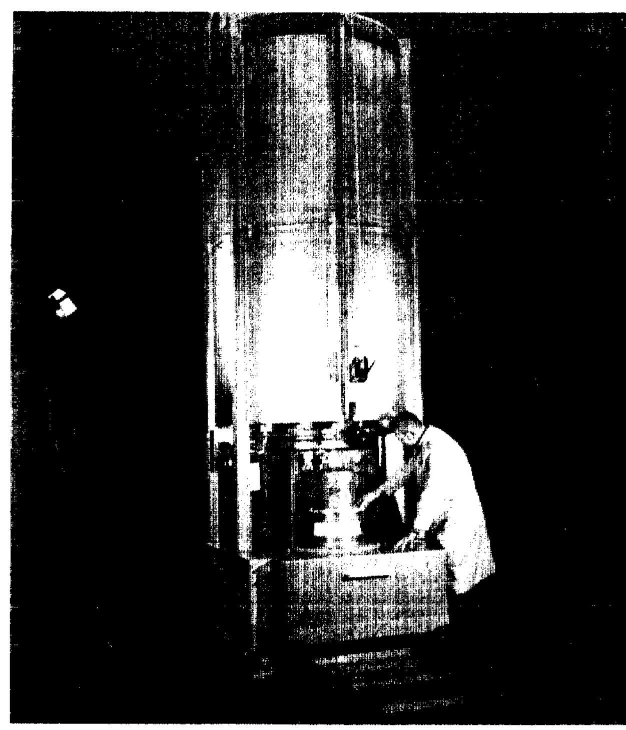

FIGURE 2. Test Setup for the X2159 2MW Tube

The reason for using a large tube rather than several smaller ones is circuit simplicity. However, this advantage is largely lost if one does not maintain the same electrode spacing as in the smaller tubes so that there is no loss in performance.

The X2159 uses a two section thoriated tungsten mesh filament and requires 25kW of filament power supported on a fully liquid cooled stem.

Although requiring additional circuitry a tetrode was chosen in preference to a triode because of its high stage gain, high isolation between input and output and the fact that plate current is largely independent of plate voltage. It is essentially a constant current device. Another advantage is the ability of a tetrode to take punishment. The screen grid is made of 0.020 inch specially coated molybdenum wire, if internal arcs occur it is extremely unlikely that the screen will be damaged and at the same time it acts as a good protection to the more fragile filament and grid wires.

The X2159 is tested at 16 MHz in a test set, Figure 2, designed by Continental Electronics. The initial evaluation program has gone smoothly. Typical tube characteristic curves are shown in Figure 3, and typical operation is given in Table I. The re-entrant type anode permits a very short filament stem, thus minimizing the inductance in the ground return. The all coaxial construction is so arranged as to make external bypassing, such as between screen and filament, possible with low inductance connections and at the same time permit a high degree of shielding between input and output circuits.

TABLE I

Operating Characteristics for X2159

Class C Typical Operation	
Plate Voltage	20kV
Screen Voltage	800V
Grid Voltage	-600V
Plate Current	125A
Screen Current	17A
Grid Current	7A
Driving Power	6kW
Plate Output Power	2100kW
Pulse Modulator or Regulator	
Typical Operation	
DC Plate Voltage	50kV
DC Screen Voltage	500V
DC Grid Voltage	975V
Pulse Rate Volt. (Tube drop)	4500V
Pulse Positive Grid Voltage	300V
Pulse Plate Current	800A
Pulse Length	10msec
Duty	20%

The present tube is rated at 60kV for hard tube modulator service, but variants are possible which would increase this rating to 125kV.

The low cost of the X2159 makes it the most economical way to generate large amounts of RF power throughout the entire HF and MF bands.

\- - - -

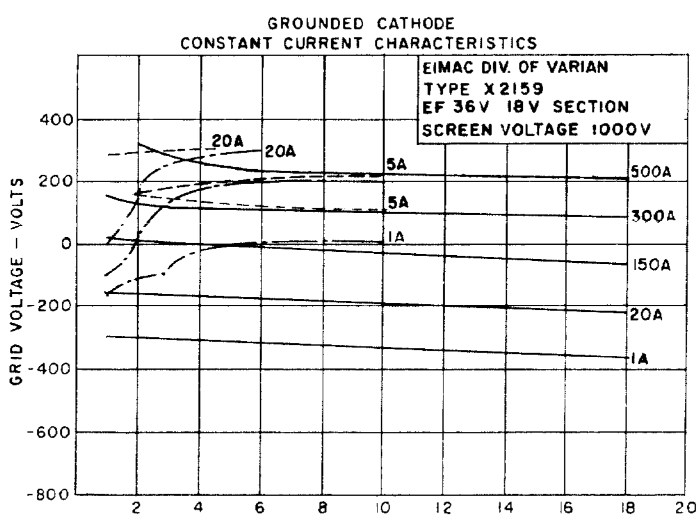

FIGURE 3. Tube Characteristics for X2159.