The 6L6 Beam Power Tetrode …by Earles L. McCaul

• Applying Child-Langmuir to the 6L6

The Child-Langmuir 3/2's "equivalent plate voltage" equation is a powerful tool for vacuum-tube circuit design and is commonly employed in SPICE modeling. To apply the equation, however, the specific tube parameters contained in the formula must be known. This article describes methods of determining these parameters for the 6L6 family of beam power tetrodes, which includes the 6L6[1], 6L6GB[2], 6L6GC[3], 7581[4], and 7581A[5]. The techniques described can easily be adapted to other tube families.

For a vacuum-tube diode the Child-Langmuir equation relates plate current to plate voltage:

$$\mathbf{I_P = K(V_P)^{3/2}}$$

where the parameter **K** is called "perveance." For triodes the equation is expanded to include the grid voltage:

$$\mathbf{I_P = K(V_G+V_P/\mu)^{3/2}}$$

where the parameter $\boldsymbol{\mu}$ is the triode's amplification factor. For tetrodes and pentodes the space current within the tube includes both plate and screen current, and screen voltage must also be considered:

$$\mathbf{I_P+I_S = K(V_G+V_S/\mu_1+V_P/\mu_2)^{3/2}}$$

where $\boldsymbol{\mu_1}$ and $\boldsymbol{\mu_2}$ are separate amplification factors. Usually $\boldsymbol{\mu_1}$ is much less than $\boldsymbol{\mu_2}$**,** reflecting the fact that the space current is much more dependent on screen voltage than plate voltage.

In this article I will introduce methods for determining the parameters **K,** $\boldsymbol{\mu_1}$**,** and $\boldsymbol{\mu_2}$ for the 6L6GC beam power tetrode. Moreover, I will describe a technique that I have developed to determine the ratio of plate current $\mathbf{I_P}$ to screen current $\mathbf{I_S}$**.** The results will enable the reader to make full use of the Child-Langmuir equation for circuits that use the 6L6GC.

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1 RCA – 6L6 Beam Pentode Amplifier (1937), pages 87-89.

2 RCA – 6L6-GB Beam Pentode Tube (4-57).

3 GE 6L6-GC Beam Pentode ET-T1515A (3-59), pages 1-10.

4 Tung-Sol 7581 Beam-Power Pentode (September 1, 1962).

5 GE 7581-A Beam Pentode (4-63), pages 1-10.

• 6L6 Perveance and Amplification Factors

The perveance **K** of a vacuum tube is the ratio of its cathode area to its anode distance-squared:

$$K = (2.33 \times 10^{-6})A/d^2$$

These physical measurements are not usually included in a datasheet, so this equation is not particularly useful to a circuit designer. Instead we will take advantage of the fact that datasheets for the Tung-Sol (7581) and GE (7581A), which have nearly identical characteristics as the 6L6GC but contain short-term (less than 2 seconds), zero-control grid (full conduction) parameters that can be used to determine the perveance. From the characteristic curves we pick a data point where the control grid is at zero volts (the "diode-line"):

$V_P = 70$ **volts**
$V_S = 300$ **volts**
$V_G = 0$ **volts**
$I_P = 210$ **mA**
$I_S = 25$ **mA**

From the datasheets we see that in a triode configuration the plate resistance $r_p = 1.7k$ ohms and the transconductance $g_m = 4700\mu mhos$. From this we conclude $\mu_1 = r_p g_m = 7.99$. In a pentode configuration $r_p = 22.5k$ ohms and $g_m = 6000\mu mhos$, from which $\mu_2 = r_p g_m = 135$. The triode computation was performed at $V_P = 250$ whereas $V_P = 300$ for the pentode, but the results are close enough.

When these values are plugged into the Child-Langmuir equation for tetrodes/pentodes, the perveance **K** for the 6L6 family can be solved and found to be

$$K = 0.001 \text{ amps}/(\text{volt}^{3/2})$$

The results (solid **red** line) are compared to the equivalent 6L6GC datasheet points (**blue**/white plots) in Figure 1 in the following graph, where plate voltage is on the X-axis and space current is on the Y-axis. The top line corresponds to a screen voltage of 400 volts.

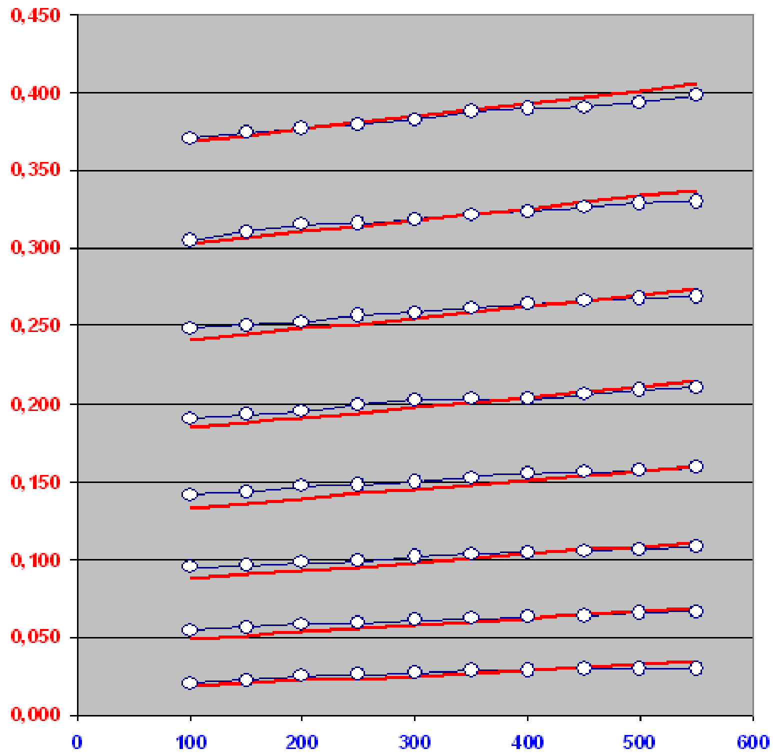

Figure 1 - 6L6GC actual vs. calculated plate curves.

• 6L6 Screen and Plate Current

We now have all we need to determine the space current based on the tube's electrode voltages but we don't yet know how much of the space current is going to the plate and how much is going to the screen. Using trendline analysis I have been able to accurately estimate the ratio of plate current to screen current in the 6L6 using the following approximation:

$$\mathbf{I_P/I_K = B[1\text{-}exp\{\text{-}A(V_P\text{-}100)\}]+C}$$

By manually measuring (using dividers and a scale) $\mathbf{I_P}$ and $\mathbf{I_S}$ at 50V intervals between $\mathbf{100 \leq V_P \leq 500}$ and $\mathbf{50 \leq V_S \leq 400}$ on the "scaled-up" characteristic curves for the GE 6L6GC, I determined the following values for the coefficients:

$\mathbf{A = (0.000014)V_S+0.00503}$
$\mathbf{B = (0.000068)V_S+0.01915}$
$\mathbf{C = (1.160)V_S^{-0.0460}}$

The following graph (Figure 2) shows the calculated ratio of plate current to space current $\mathbf{I_P/I_K}$ versus plate voltage for $\mathbf{50 \leq V_S \leq 400}$. The points, which are in very close agreement, are extracted from the 6L6GC datasheet.

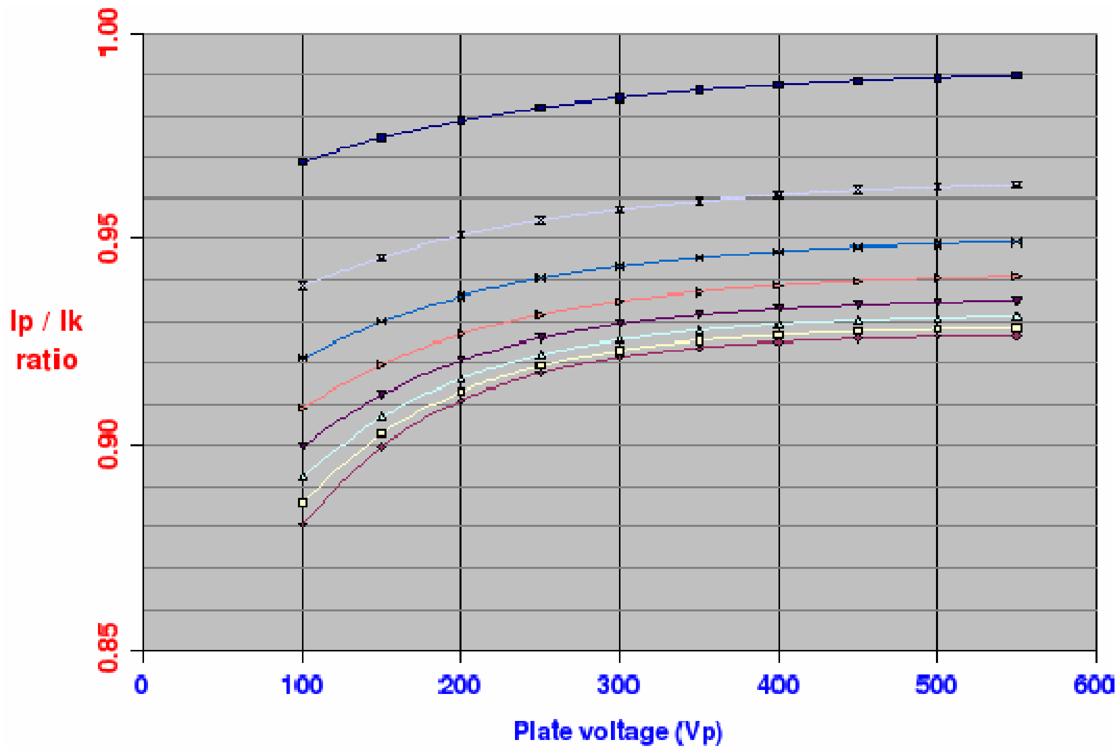

Figure 2 - Ip/Ik ratio vs. plat voltage (Vp).

An alternative approach is to apply the Child-Langmuir equation to only the screen grid:

$$\mathbf{I_S = K(V_G+V_S/\mu_1+V_P/\mu_2)^{3/2}}$$

In this case the tube parameters relate electrode voltages to screen current instead of space current.

• The Spangenberg Method

For many tubes, zero-control grid (full conduction) parameters are not published. For these situations Karl Spangenberg provides an alternative method in his book[6]. His method estimates plate-to-cathode $\mathbf{I_P/I_K}$ and plate-to-screen $\mathbf{I_P/I_S}$ current ratios from the ratio of plate voltage to screen voltage $\mathbf{V_P/V_S}$**:**

$$\mathbf{I_P/I_K = D(V_P/V_S)^m}$$

$$\mathbf{I_P/I_S = G(V_P/V_S)^n}$$

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6 Karl R. Spangenberg, **VACUUM TUBES**, (1947), McGraw-Hill.

where $\mathbf{D = I_P/I_K}$ and $\mathbf{G = I_P/I_S}$ are measured from the tube's datasheet at $\mathbf{V_P = V_s = 250V}$ and where **m = 0.02** and **n = 1/3.** For the 6L6GC beam power tetrode, for example, **D = 72mA/77mA = 0.935** and **G = 72ma/5mA = 14.4.** From these relations we see that as the plate voltage increases, the proportion of plate current to screen current increases, as we would expect.

• 6L6GC Screen Current Example

These formulas can be used to estimate the peak screen current at maximum power. For the 6L6GC, for example, if $\mathbf{V_S = 400V}$ and the peak plate current is $\mathbf{I_P = 300mA}$ at $\mathbf{V_P = 80,}$ the ratio of plate to screen current is

$$\mathbf{I_P/I_S = 14.4(80/400)^{(1/3)} = 8.43}$$

From which $\mathbf{I_S = 300/8.43 = 36mA}$, corresponding to an RMS value of 25mA. From the 6L6GC datasheet the actual value is 22mA. This is fairly close considering we're making an estimate at the extremes of plate voltage swing.