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An Improved Method of Finding Vacuum Tube Model Parameters

Designers and others who work with tubes will find this program handy to determine VT models.

By Bill Elliot

I first became interested in vacuum tube models when I needed good triode and pentode models to use with my SPICE circuit simulator to simulate an audio power amplifier I was designing. Searching the Internet, I discovered the vacuum tube model work of Norman Koren[1]. I then began to produce some model netlist equations based on Koren's phenomenological triode equations using Texas Instruments' Derive 6 math software.

At first, I used trial-and-error methods to find the parameter val-

Table 1.

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PENTODE PARAMETER PROGRAM (6550 EXAMPLE)

 PENTODE_PARAM(P) :=
   Prog
     [ik :=, ip :=, Vt :=, Vp :=, Gk :=, n1 :=, μ :=, k1 :=, k2 :=, a :=, b :=, n2 :=, vg2 :=, vg1 :=, vp :=, P :=]
     [A1ik :=, A1vp :=, A1vg1 :=, A2ik :=, A2vp :=, A2vg1 :=, B1ik :=, B1vp :=, B1vg1 :=]
     [B2ik :=, B2vp :=, B2vg1 :=, Cik :=, Cvp :=, Cvg1 :=, Dvg2 :=, D1ip :=, D2ip :=, D3ip :=, D3vp :=, D4ip :=, D4vp :=]
     A1ik := 0.502
     A1vp := 300
     A2ik := 0.176
     A2vp := 150
     B1ik := 0.005
     B1vp := 80
     B1vg1 := -10
     B2ik := 0.035
     B2vp := 520
     B2vg1 := -70
     Cik := 0.065
     Cvp := 300
     Cvg1 := -30
     Dvg2 := 300
     D2ip := 0.455
     D2vp := 300
     D3ip := 0.425
     D3vp := 80
     D4ip := 0.15
     D4vp := 20
     LN(A2ik/A1ik)/(LN(A2vp) - LN(A1vp))
     ASSIGN(u, SOLVE(B1ik = A1ik/A1vp^n1·(B1vp·(LN(P^(B1vg1·μ/√(B1vp^2 + k2) + 1) + 1)/LN(P + 1)))^n1, u, Real))
     u := RHS(u)
     ASSIGN(k2, SOLVE(B2ik = A1ik/A1vp^n1·(B2vp·(LN(P^(B2vg1·μ/√(B2vp^2 + k2) + 1) + 1)/LN(P + 1)))^n1, k2, Real))
     k2 := RHS(k2)
     ASSIGN(P, NSOLVE(Cik = A1ik/A1vp^n1·(Cvp·(LN(P^(Cvg1·μ/√(Cvp^2 + k2) + 1) + 1)/LN(P + 1)))^n1, P, Real))
     P := RHS(P)
     Gk := A1vp^n1/A1ik·(LN(P + 1)/(μ·LN(P)))^n1
     ASSIGN(a, SOLVE(D2ip = (a + Dvg2)/(1 + b + Dvg2)·(A1ik/A1vp^n1)·Dvg2^n1, a, Real))
     a := RHS(a)
     ASSIGN(b, SOLVE(D3ip = (a + D3vp)/((Dvg2/D3vp)^n2 + b + D3vp)·(A1ik/A1vp^n1)·Dvg2^n1, b, Real))
     b := RHS(b)
     ASSIGN(n2, NSOLVE(D4ip = (a + D4vp)/((Dvg2/D4vp)^n2 + b + D4vp)·(A1ik/A1vp^n1)·Dvg2^n1, n2, Real))
     n2 := RHS(n2)
     Vt := vp·(LN(P^(vg1·μ/√(vp^2 + k2) + 1) + 1)/(μ·LN(P)))
     Vp := vg2·(LN(P^(vg1·μ/√(vg2^2 + k2) + 1) + 1)/(μ·LN(P)))
     D1ip := A1ik/A1vp^n1·Dvg2^n1
     [Gk := Gk, n1 := n1, u := u, k2 := k2, P := P, a := a, b :=b, n1 := n1, n2 := n2, D1ip := D1ip]
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ues until they matched five chosen points on the plate curves. Despite the tediousness, I managed to produce a fair number of netlists for the tube types that interested me.

I have been using Derive since its early DOS days and have found it to be reliable, easy to use, and, above all, it does everything I need and more. It is also very inexpensive—about $115. I know other math programs are very good, but they are way out of my price range. I suggest anyone interested in Derive 6 read the article on the Internet titled "Derive 6: Far too good for just students."[2]

Because of the tedious work and resulting inaccuracies, I decided I needed to find a better way and wondered whether I could use Derive 6 to calculate the values of the parameters.

SOFTWARE SOLUTION

Examining Koren's triode equations, it would seem that the five unknown parameters can only be found using trial-and-error methods or some sort of program using iterative techniques.

Koren's Triode Equations:

$$Ip = (E1^X/kG1)*(1 + sgn(E1))$$

where:

$$E1 = (Ep/kp)*\log(1 + \exp(kp*(1/u + EG/\sqrt{(kVB + Ep^2)})))$$

Upon closer examination of Koren's equations, I saw that there are really two separate sets of parameters. The first set of two, kG1 and X, are independent of the second set and are quite easily found using the zero bias line of the triode plate curves. The second set of three, kp, u, and kVB, are more difficult to find, but can be directly calculated using algebraic and numerical programming techniques.

After numerous attempts, I wrote three very simple Derive 6 programs that directly calculate triode, pentode, and diode model equation parameters based on Koren's triode equations.

The triode and pentode programs run in 15–60 seconds on my computer, depending on tube type and data point selection. Some tube types and data point selections may run on and on without giving a result. You may even get negative or complex numbers for results. In these cases, check your data entry numbers first. If the numbers are OK, then try moving data points B1, B2, and C to higher current levels. I cannot promise that these programs will work on any tube type, but I think they will work on most.

Table 2.

$$(1)\quad ik = \frac{1}{Gk}\cdot\sqrt{\left(\left(\left|\frac{Vt}{2}\right| + \frac{Vt}{2}\right)\cdot Vt^{2\cdot n1 - 1}\right)}$$

Where:

$$(2)\quad Vt = vp\cdot\frac{LN\left(P^{\left(\frac{vg1\cdot\mu}{\sqrt{(vp^{2} + k2)}} + 1\right)} + 1\right)}{\mu\cdot LN(P)}$$

PENTODE CONNECTION EQUATIONS

PLATE CURRENT

$$(3)\quad ip = \frac{a + vp}{\left(\frac{vg2}{vp}\right)^{n2} + b + vp}\cdot\frac{1 + SIGN(vp)}{2}\cdot\frac{1}{Gk}\cdot\sqrt{\left(\left(\left|\frac{Vp}{2}\right| + \frac{Vp}{2}\right)\cdot Vp^{2\cdot n1 - 1}\right)}$$

SCREEN GRID CURRENT

$$(4)\quad ig2 = \left(1 - \frac{a + vp}{\left(\frac{vg2}{vp}\right)^{n2} + b + vp}\right)\cdot\frac{1 + SIGN(vp)}{2}\cdot\frac{1}{Gk}\cdot\sqrt{\left(\left(\left|\frac{Vp}{2}\right| + \frac{Vp}{2}\right)\cdot Vp^{2\cdot n1 - 1}\right)}$$

Where:

$$(5)\quad Vp = vg2\cdot\frac{LN\left(P^{\left(\frac{vg1\cdot\mu}{\sqrt{(vg2^{2} + k2)}} + 1\right)} + 1\right)}{\mu\cdot LN(P)}$$

(6) vg2 :=

The Pentode Program is shown in **Table 1**. All the programs plus the step-by-step equation development are available on my URL[3] in Rich Text Format (RTF) and Derive 6 format (DFW). You can download and read RTF files with Windows Wordpad. If you have Derive 6, you can download the Derive files and run them on your computer.

The pentode equations for a pentode netlist are shown in **Table 2**. Normally, you would use only equations 3 and 4 in the netlist because a triode can be obtained by connecting a plate and screen together. The pentode-triode connection equations are used to check the triode curves using the Derive 6 curve plotter. *aX*

REFERENCES

1. www.normankoren.com/Audio/Tubemodspice_article.html.

2. www.scientific-computing.com/scwmarapr04derive6.html.

3. www.knology.net/~billelliot.