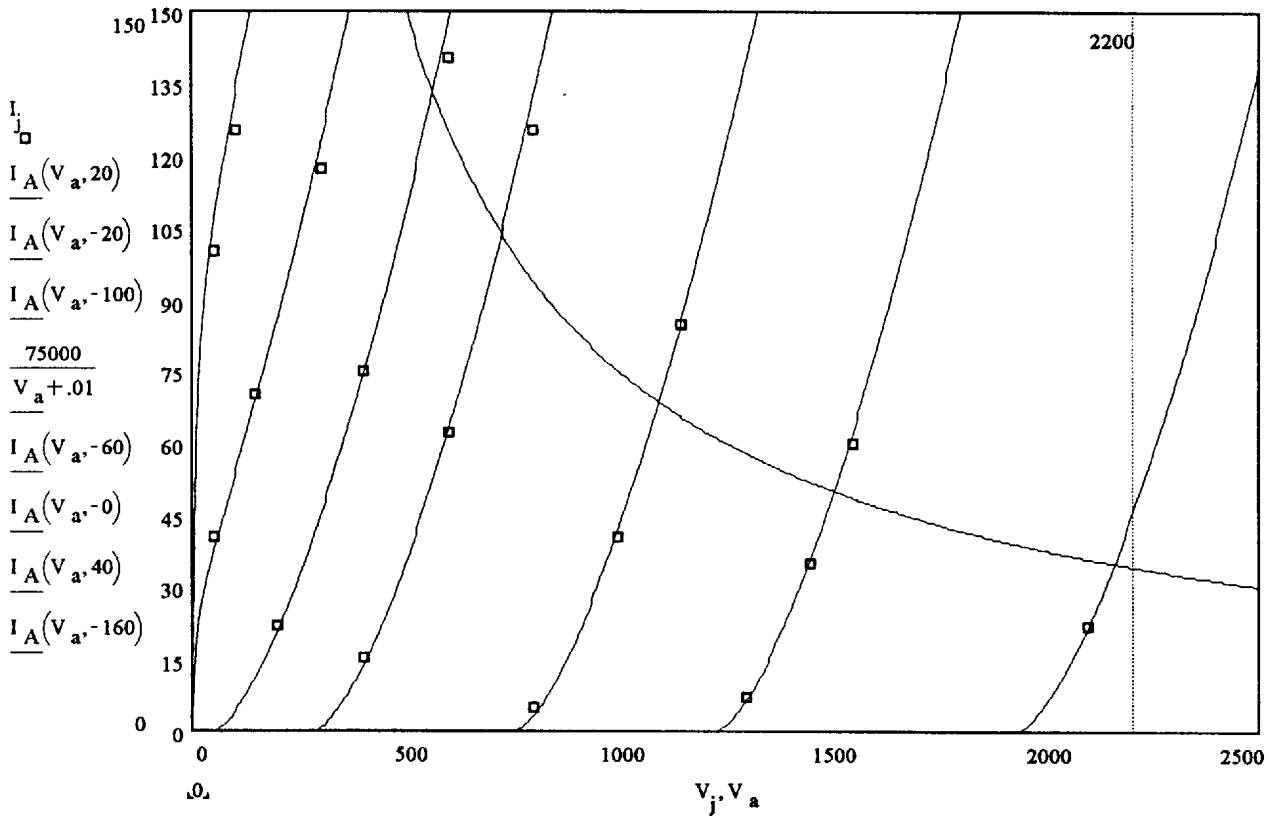


# Vacuum Tube Modeling Package Vol. 1

## User's Guide (Electronic edition)

EXCEM



VT4C or GL211 Triode (Transmitting Tube)

Vacuum Tube Modeling Package Vol. 1  
User's Guide  
(electronic edition)

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### Table of Contents

1. Introduction . . . . .	4
1.1 Thank You . . . . .	4
1.2 Software compatibility . . . . .	4
1.3 Getting started . . . . .	4
1.4 Software simulation of vacuum tube circuits . . . . .	5
2. Modeling of vacuum tubes . . . . .	6
3. Files and installation procedure . . . . .	8
3.1 Files . . . . .	8
3.2 Installation . . . . .	9
4. The lampes.lib library file . . . . .	10
5. License agreement . . . . .	12
References . . . . .	13

*"We have not even begun to explore seriously the ways  
in which computer techniques may be married to electron tube amplification  
to derive the latent resources  
still possible with the thermoionic valve"*

Edward T. Dell, Jr.  
94-95 World Tube Directory.

## 1. Introduction

### 1.1 Thank You

Thank you for your interest in the first vacuum tube SPICE library available (the original edition was published back in 1995). The *Vacuum Tube Modeling Package Vol. 1* contains more than 40 vacuum tube models for various type of tubes (transmitter tubes have not been included though) including old and recent devices. As far as we know, such models have never been published. Their creation required an extensive effort, including research work, tests and various validations.

The author of the models in the *Vacuum Tube Modeling Package Vol. 1* is Mr. Charles Rydel. The corrections for version 1.3 were prepared by Frédéric Broydé. The *User's guide* was written by Frédéric Broydé and Charles Rydel.

Our vacuum tube modeling package can help you check your new ideas and to better understand and improve your vacuum tube circuits. May this tool help you to get the best from them and unleash their still uncovered potential.

### 1.2 Software compatibility

Excem's vacuum tube modeling package was created with Intusoft's ICAP/4 packages. It has been successfully tested on ICAP/4DOS (IsSpice3) and ICAP/4Windows (IsSpice4) up to version 7.6. Once installed, our models can directly be used in the SpiceNet schematic entry module, and can be accessed through the browse menu.

As far as we know these Spice programs are no longer available, and a potential user will have to port our SPICE library to his specific SPICE program.

### 1.3 Getting started

It may be a good idea to read this short User's guide. However, you can also skip to Chapter 3 for the installation procedure. The license agreement for the files of the *Vacuum Tube Modeling*

*Package Vol. 1* appears in Chapter 5 hereafter.

Please note that Excem will not provide a full support service for the free *Vacuum Tube Modeling Package Vol. 1*. However questions by e-mail are welcomed, in french or in english. If relevant, they will be posted on the site. Please note that our security policy states that we will not open files attached to e-mails.

## **1.4 Software simulation of vacuum tube circuits**

Because of the lack of appropriate simulation tools, the design of vacuum tube amplifiers and similar circuits was up to now still a matter of breadboarding. Because innovative development is difficult, most equipment marketed today has been based on old designs, with little thought given to their adequacy in meeting today's expectations. This is for instance often the case with high-end audio amplifiers. We believe that such a conservative stance is not justified, and that accurate analysis of old and new designs will help generate valuable improvements and reveal new possibilities in vacuum tube technology.

The *Vacuum Tube Modeling Package Vol. 1* will help you to easily compute device bias, small signal gain vs frequency, harmonic distortion, pulse and step response for small or large signals. You will be able to investigate the consequences of changes in the characteristics of critical components : What if the output transformer leakage inductance is higher than expected ? What if a 12AT7 is replaced by a 12AU7 ? What if a KT88 is used instead of an EL34 ? What is the peak current in a GZ34 if the tank capacitor is increased from 22  $\mu\text{F}$  to 47  $\mu\text{F}$  ? You will easily find answers to questions which are difficult to address in the lab. Also, you might be interested in studying circuits which combine both semiconductors and tubes.

As an example, Excem developed a cost-effective MOSFET/beam tetrode wide-band amplifier for measuring the radial electric coupling coefficient of shielded cables [1]. This work was done in our research on electromagnetic compatibility (EMC), one of our areas of expertise. This amplifier was simulated during the design process [2], [14] in order to meet an output amplitude requirement of 900 V peak-to-peak with adequate linearity.

Whether you are interested in the development of high-end audio, RF, or specific instruments, simulation is the right thing to do, to get the right vacuum tube design, on time.

## 2. Modeling of vacuum tubes

Mr. Rydel's vacuum tube modeling approach is to reproduce accurately the data as given in various data books [5]-[8], with an implementation of a least squares algorithm. A good example of the resulting quality is shown on the plot of the cover sheet of this user's manual. On this plot, the squares are anode current versus anode voltage data of the VT-4-C/GL211 power triode and the curves are computed from its model. The result is evidently accurate.

This approach has been described by its author at the 98th AES convention [9], [15]. This kind of model is significantly different from the one of Broyd  and Clavelier which includes, for instance, the effect of space current saturation and filament voltage [2]-[4], [14]. Two of these models have been included in the ICAP/4 package. The models obtained from the Rydel approach and the Broyd  and Clavelier models are very accurate, and greatly differ from the simpler models introduced by Meares [10], and later by Reynolds [11] and Marshall Leach [12]. These simpler models lack the description of important tube phenomena, and are for instance unable to give realistic distortion results.

A triode model is based on the following equations :

$$I_a = G \left( 1 + \frac{V_g}{v_B} \right) \left( V_g + \frac{V_a + v_C}{\mu} \right)^{\frac{3}{2}} \quad (1)$$

and

$$I_g = \begin{cases} \alpha V_g^{1.5} & \text{when } V_g > 0 \\ \frac{\beta}{v_D - V_g} & \text{when } V_g < 0 \end{cases} \quad (2)$$

where

$V_g$  is the grid voltage,  
 $I_g$  is the grid current,  
 $V_a$  is the anode voltage,  
 $I_a$  is the anode current,  
 $G$  is the tube permeance at zero bias,  
 $\mu$  is the tube amplification factor,  
 $v_B, v_C, v_D, \alpha$  and  $\beta$  are parameters characteristic of the given tube.

For some triodes exhibiting an unusual behaviour like the Russian 6C33C-B, (1) is replaced by :

$$I_a = G \left( 1 + \frac{V_g}{v_B - \frac{V_g}{v_E}} \right) \left( V_g + \frac{V_a + v_C}{\mu} \right)^{\frac{3}{2}} \quad (3)$$

where  $v_E$  is an additional parameter, characteristic of the given tube.

The pentode models are based on the following equation :

$$I_a = G \left[ V_{g1} + \frac{V_{g2}}{\mu_{12}} \left( \frac{V_a - k_3 V_{g1}}{V_a + \frac{V_{g2}}{v_1}} \right) + \frac{V_a}{\mu \left( 1 - \frac{V_{g1}}{v_2} \right)} \right]^{\frac{3}{2}} \quad (4)$$

and

$$I_{g2} = K \left( \frac{v_5 + V_a}{v_6 + V_a} \right)^3 \left( V_{g1} + \frac{V_{g2}}{v_4} \right)^{1.5} \quad (5)$$

where

$V_{g1}$  is the control grid voltage,

$I_{g1}$  is the control grid current,

$V_{g2}$  is the screen grid voltage,

$I_{g2}$  is the screen grid current,

$V_a$  is the anode voltage,

$I_a$  is the anode current,

$G$  is the perveance at zero bias,

$\mu$  and  $\mu_{12}$  are respectively the plate and screen grid amplification factors,

$v_1, v_2, v_4, v_5$  and  $v_6$  are constant voltages, characteristic of the given tube,

and where  $K$  and  $k_3$  are two parameters of the given tube.

The beam tetrode model is derived from the pentode model, and takes into account the device behaviour when the virtual cathode disappears, with the formula :

$$I_a = \min \left( G \left[ V_{g1} + \frac{V_{g2}}{\mu_{12}} \left( \frac{V_a - k_3 V_{g1}}{V_a + \frac{V_{g2}}{v_1}} \right) + \frac{V_a}{\mu \left( 1 - \frac{V_{g1}}{v_2} \right)} \right]^{\frac{3}{2}}, k_7 V_a^{k_8} \right) \quad (6)$$

where  $k_7$  and  $k_8$  are two additional parameters of the given tube.

The pentode and beam tetrode control grid currents are both given by (2).

The models aim at reproducing the plate, screen grid and control grid currents for various voltages on these electrodes, and inter-electrode capacitance values. However, it should be emphasized that the tube manufacturing process allows a wide dispersion of the device characteristics, a spread of 30 % being typical. Moreover, vacuum tubes are subject to aging, resulting in a slow drift of some of their characteristics mostly related to cathode emissivity (related to the perveance), and to the residual internal pressure. Hence, experimental results may occasionally differ from simulated ones, especially when the design is very sensitive to device parameters (for instance when little feed-back is used). This is not unique to vacuum tubes : bipolar transistor gain and field effect transistor threshold voltage, typically have higher tolerances, and integrated circuits are nevertheless simulated and manufactured !

## 3. Files and installation procedure

### 3.1 Files

The *Vacuum Tube Modeling Package Vol. 1* version 1.3 is contained in three files,  
the **usergui5.pdf** file,  
the **examples.pdf** file,  
and the **tubes\_13.zip** file,

which you must personally download from the <http://www.excem.fr> web site or from the <http://www.eurexcm.com> web site (see chapter 5).

The first two files are Acrobat Reader compatible files intended to be used with Acrobat reader 3.0 or later versions. Acrobat Reader 4.0 or later version is recommended because of its superior printing and page rotation capabilities, two useful features when dealing with schematics. The two files respectively contain

the *Vacuum Tube Modeling Package Vol. 1 — User's guide* document  
and the *Vacuum Tube Modeling Package Vol. 1 — Examples* document.

The third file, once unzipped, will give birth to four directories :

tubes\_13\circuits,  
tubes\_13\dbase,  
tubes\_13\models,  
tubes\_13\symbols.

- The **tubes\_13** directory contains a short readme.txt file, in ASCII format.
- The **tubes\_13\dbase** subdirectory contains the dbase.add file, which is used for recompiling ICAP/4DOS and ICAP/M databases in such a way that our vacuum tube models appear in the parts menu and browse submenu of SpiceNet. DBASE.ADD is not needed for ICAP/4Windows.
- The **tubes\_13\circuits** subdirectory contains schematic (Spicenet) files for the test circuits, as well as the IsSpice4 input files containing the test circuits' netlists.  
Each circuit *name.cir* has 7 files in the subdirectory:  
*name.cir*, *name.c1* (netlists created by SpiceNet),  
*name.cnt*, *name.con* (control statement for SpiceNet),  
*name.ckt* (SPICE compatible netlist),  
*name.d1*, *name.lnk* (schematics).  
There is 7 different circuits *alim.cir*, *riaa.cir*, *serial.cir*, *williams.cir* [13], *oscbf.cir*, *testrio.cir* et *testetro.cir*. The tubes\_13\circuits subdirectory therefore contains 49 files. The presentation of these 7 circuits is the subject matter of the *Vacuum Tube Modeling Package Vol. 1 — Examples* document.
- The **tubes\_13\models** directory contains the Lampes.lib library file.
- The **tubes\_13\symbols** directory contains six tube symbols for schematics:  
valve.sym for diodes,  
triodelp.sym, triodedh.sym, and triode.sym for triodes  
tetrode.sym for tetrodes  
penthode.sym for pentodes.



## 3.2 Installation

We assume that the *Vacuum Tube Modeling Package Vol. 1* files have been downloaded and unzipped, and that ICAP/4 is installed in the \Spice or \Spice4 directory of the current drive. Please follow the five steps below applicable to ICAP/4 Windows (Please note that some deviation from this procedure might be needed according to your version: please check your manual) :

**Step 1** : copy the Lampes.lib file from **tubes\_13\models** into the PR directory (\Spice\PR or \Spice4\PR).

**Step 2** : copy the six \*.sym files from **tubes\_13\symbols** into the SN\Symbols directory (\Spice\SN\Symbols or Spice4\SN\Symbols).

**Step 3** : create a directory \Spice\tubes, and copy in it the 49 files of **tubes\_13\circuits**.

**Step 4** : compile an updated SpiceNet database. If you are using ICAP/4 Windows version 7.6, this is simply accomplished by running MakeDb.exe in SN (\Spice\SN or \Spice4\SN).

**Step 5** : test that you can access your new tube models under the "Lampes" heading in the SpiceNet browse dialog.

For earlier versions of ICAP, step 4 may require 3 substeps, for instance:

Substep 4.1 : update the Lib.@@@ file that contains the list of libraries. This is simply accomplished by adding the text "Lampes.lib", at the right spot in SN\Lib.@@@ (\Spice\SN\Lib.@@@ or \Spice4\SN\Lib.@@@) using a text editor, so that this file becomes :

```
...  
JFET.LIB  
LAMPES.LIB  
LIN.LIB  
MAGNETIC.LIB  
...
```

Substep 4.2 : with a text editor, add the content of **tubes\_13\dbase\dbase.add** at the end of \Spice\DATABASE.SRC.

Substep 4.3 : run SN\MAKEDB.BAT, which compiles an updated SpiceNet database.

If you want to know more about this five steps procedure, please read the "Updating the data base" entry in your ICAP documentation.

## 4. The lampes.lib library file

Let us say a few words on our selection of vacuum tube devices. Obviously some have been picked for their widespread use and for their performances :

EZ80, GZ32, GZ34  
12AU7, 12AX7,  
6FQ7, 6CG7,  
12AT7, 6DJ8/ECC88  
12BH7A  
EF86,  
EL34, EL84,  
KT66, KT88, KT90, 7581  
WE300B, 6C33C-B

We have also selected a few older American tubes, still implemented by audiophiles, such as :

6SL7GT, 6SN7GTB  
6SJGT,  
6V6GT, 6L6W, 5881  
6BX7GT, 2A3

We also have included some big triodes :

845, GL211/VT-4-C

For historical reasons, we finally included some European tubes (most of them are revered by enthusiasts, but hardly possible to find nowadays) :

A/EBC1  
NF2,  
45/VT52, PX25, DA30, R120, AD1, ED8000

Even though our tetrode and pentode models give satisfactory results when the screen grid is connected to the plate (triode connection), we found that it was better, for increased accuracy to use specific models. This is why the 6V6, 6L6, EL34, EL84, KT66,KT88, KT90 and 7581 tetrodes and pentodes have a specific model for the triode connection.

The following list contains all vacuum tubes in the library, as they are found on the **dbase.add** file in the **tubes\_13\dbase** subdirectory. The first two fields are the device name and a variation of this name. The third field is the library name (Lampe in our case, this being a French word for tube). The fourth field is the device type, and the fifth is the comment field. Note that tetrodes and pentodes connected as a triode keep their standard name, but with TR added at the end.

KT90;KT90;Lampes;Beam Tetrode;made by EI 50W  
 KT88;KT88;Lampes;Beam Tetrode;Alias 6550 40W  
 KT66;KT66;Lampes;Beam Tetrode;GEC close to 7581 30W  
 6L6WGT;V6L6WGT;Lampes;Beam Tetrode;Alias 5881 25W  
 6V6GT;V6V6GT;Lampes;Beam Tetrode;Octal like 6AQ5 13.5W  
 7581;V7581;Lampes;Beam Tetrode;close to KT66 25W  
 EL84;EL84;Lampes;Power Pentode;Noval 14.5W  
 EL34;EL34;Lampes;Power Pentode;Octal 25W  
 EF86;EF86;Lampes;Sign.Pentode;Alias 6CF8 2W  
 NF2;NF2;Lampes;Sign.Pentode;Transco 2W  
 E80F;E80F;Lampes;Sign.Pentode;Low Noise 2W  
 6SJ7GT;V6SJ7GT;Lampes;Sign.Pentode;Octal 2.8W  
 2A3;V2A3;Lampes;Power Triode;close to 6A3/6B4 4 pins 15W  
 AD1;AD1;Lampes;Power Triode;Transco 16.5W  
 WE300B;WE300B;Lampes;Power Triode;4 pins 25W  
 6SL7GT;V6SL7GT;Lampes;Sign.Triode;Octal 2.5W  
 6SN7GTB;V6SN7GTB;Lampes;Sign.Triode;Octal 2.75W  
 ED8000;ED8000;Lampes;Power Triode;Noval 17W  
 ECC81;ECC81;Lampes;RF Triode;Alias 12AT7 2.5W  
 ECC82;ECC82;Lampes;Sign.Triode;Alias 12AU7/6913 3W  
 ECC83;ECC83;Lampes;Sign.Triode;Alias 12AX7 1W  
 6DJ8;V6DJ8;Lampes;RF Triode;Alias ECC88/6922 1.8W  
 6BX7GT;V6BX7GT;Lampes;Power Triode;Octal 13.5W  
 12BH7A;V12BH7A;Lampes;Sign.Triode;noval 3.5W  
 845;V845;Lampes;High Power Triode;Jumbo 4 pins 75W Huge  
 GL211;GL211;Lampes;High Power Triode;like VT4-C Jumbo 4 pins 75W  
 ABC1;ABC1;Lampes;Sign.Triode;Transco 1W  
 KT66TR;KT66TR;Lampes;Pow.Triode Connect.;30W GEC Near 7581  
 KT88TR;KT88TR;Lampes;Pow.Triode Connect.;Alias 6550 40W  
 KT90TR;KT90TR;Lampes;Pow.Triode Connect.;made by EI 50W  
 6L6WGTR;V6L6WGTR;Lampes;Pow.Triode Connect.;Alias 5881 25W  
 6V6GTR;V6V6GTR;Lampes;Pow.Triode Connect.;like 6AQ5 13.5W  
 7581TR;V7581TR;Lampes;Pow.Triode Connect.;25W Near KT66  
 EL84TR;EL84TR;Lampes;Pow.Triode Connect.;Noval 14.5W  
 EL34TR;EL34TR;Lampes;Pow.Triode Connect.;Octal 25W  
 PX4;PX4;Lampes;Power Triode;Super 45 UF Pin Out 15W  
 PX25;PX25;Lampes;Power Triode;UF Pin Out 30W  
 DA30;DA30;Lampes;Power Triode;UF Pin Out 30W like PX25A  
 R120;R120;Lampes;Power Triode;Octal 15W  
 45;V45;Lampes;Power Triode;near VT52 4 pins 11W  
 6C33C-B;V6C33C-B;Lampes;Power Triode;Huge Soviet Triode  
 6CG7;V6CG7;Lampes;Sign.Triode;like 6FQ7 4W  
 GZ32;GZ32;Lampes;Dual Rectif.;Octal Alias 5V4 175mA  
 GZ34;GZ34;Lampes;Dual Rectif.;Octal Alias 5AR4 250mA  
 EZ80;EZ80;Lampes;Dual Rectif.;Alias 6V4 90mA

The first name in the above list is the commercial name and the name in the SpiceNet database. The second name is the name of the subcircuit in the Lampes.lib library.

## 5. License agreement

This is a legal agreement between you, the end user of the **tubes\_13.zip** file and Excem. Please read this license carefully. If you do not accept these terms, please destroy the tubes\_13.zip file. By using or retaining this file or the contents of this file, you acknowledge that you have read this agreement, that you understand it, and agree to be bound by its terms and conditions.

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