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Vg1 Correlations

Next time you design a power amp, try this mathematical model to predict the required bias voltage for your pentode or tetrode output tubes.

Words have different colorations for different people. We often associate a word with a remembrance from our lives—be it a person, a place, an emotion, or a piece of music. Experience is what gives a word personal meaning.

It's difficult to imagine something other than rationality when you think about the word *correlation*. From a mathematical perspective, it means the degree of relative correspondence between two or more sets of variables. But it also reminds me of one of the courses I enjoyed the most while I was studying finance at the University.

To put this into context, I was taking my final course of finance, the most advanced and difficult one, and half the session was dedicated to a very singular task: To find a correlation that would describe the evolution of the stock market.

I will always remember how Professor Farrell answered the legitimate question a student asked: "Sir, how are we going to find such a correlation?" He drew a huge spiral on the blackboard, starting from the outside and terminating in the center. Nobody understood what he was doing until he looked at us and said, "Search." That was his last word on the matter until we revealed the outcome of our work in front of the class at the end of the session. That was it, no other guidelines.

The metaphor of the spiral speaks for itself. When you start searching for something, you don't know in which direction to go. But the more you search, the more you learn and the more you understand your subject. From one idea to another, you get closer and closer to the objective and, sometimes, as in the case in this article, you are fortunate enough to reach the center of the spiral.

THE PROBLEM

Have you ever found yourself in a situation where you wanted to design a power amp with a pentode/tetrode tube, operating in the triode mode or the ultralinear mode, but did not know the voltage bias required beforehand? The reason for this is quite simple: Most manufacturers publish the plate characteristics for only the pentode/tetrode mode.

This situation bothered me because it deprived me of the possibility of designing and optimizing a driver stage on paper before I committed to building the amplifier. I wondered whether it would be possible to predict the value of bias voltage in the triode and the ultralinear mode, from the pentode/tetrode mode plate characteristics. In other words, is there a correlation between Vg1 in the pentode/tetrode mode, and the triode and ultralinear modes?

SEARCHING FOR A CORRELATION

My search for a model was rewarded by the discovery of two very significant correlations that combine in a mathematical equation. The correlations apply to the various power tubes I studied, namely, the EL34, KT66, KT77, KT88, and the 6550A. Odds are good that the correlations also work for other power tubes such as the EL84, the 6550, and the SV6550C.

FIRST CORRELATION

The first correlation concerns the value of Vg1 in the triode mode when the plate voltage Va is set to 425V. For each type of tube I analyzed, I found that Vg1 varied by approximately 10% of its value at Va = 425V, for each plate voltage variation of ±25V around the median of 425V. **Table 1** shows the results from the datasheets of the power tubes I studied. Note that I limited the scope of the study to high tensions ranging between 350V and 500V, which covers the vast majority of the design operating points for these tubes.

Mathematically, the first correlation may be expressed in the following form:

$$Vg1_T = Vg1_{T425V}\left[1 + \left(\frac{Va - 425}{250}\right)\right] \quad (1)$$

where : $\mathbf{Vg1_T}$ is the value of Vg1 in the triode mode for a specific plate voltage Va; $\mathbf{Vg1_{T425V}}$ is the value of Vg1 in the triode mode when Va=425V; **Va** is the value of the plate voltage.

* *Note: Only the numeric value of Va is retained in this equation.*

If you have a datasheet that publishes the plate characteristics in the triode mode, then you can predict quite accurately any values of $Vg1_T$ using equation 1. Note that this correlation also applies to the ultralinear mode because Va and Vg2 are at the same potential under DC conditions, just as in the triode mode.

All this was very interesting but not

very useful, because there is no need to calculate the value of $Vg1_T$ if the information is readily available in the datasheet. What I needed was a way to predict a value of $Vg1_T$ from the pentode/tetrode mode because this information is always present in all datasheets. The second correlation solved this issue with surprising accuracy.

SECOND CORRELATION

Building on the revelation of the first correlation, my objective was now to find an equation that would make it possible to determine the value of $Vg1_{T425V}$ from the pentode/tetrode plate characteristics.

Close inspection of various datasheets revealed general relations between the triode mode and the pentode/tetrode mode at the operating point of Va = 425V. After developing and testing numerous models, I finally reached the center of the spiral with the following equation:

$$Vg1_{T425V} = Vg1_{P425V} \left(\frac{4 - Vg2}{100} \right) \frac{5\sqrt{P}}{19} \tag{2}$$

where : $\mathbf{Vg1_{P425V}}$ is the value of Vg1 in the pentode/tetrode mode for Va = 425V; **Vg2** is the value of Vg2 in the pentode/tetrode mode as indicated in the datasheet; **P** is the maximum plate dissipation of the tube as indicated in the datasheet.

** Note: Again, only the numeric values of Vg2 and P are retained in this equation.*

It is important to mention that you must use plate characteristics exhibiting a value of Vg2 = 250V or Vg2 = 300V. Other values of Vg2 simply don't work with this model.

Substituting $Vg1_{T425V}$ of equation 1 with equation 2 leads to this final mathematical model:

$$Vg1_{T/U} = \left[Vg1_{P425V} \left(\frac{4 - Vg2}{100} \right) \frac{5\sqrt{P}}{19} \right] \left[1 + \left(\frac{Va - 425}{250} \right) \right] \tag{3}$$

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Tube Type		Plate Voltages (Va) 350	375	400	425	450	475	500
1- KT88 Genalex 1959	Vg1	-33	-38	-43	-47	-52	-57	-61
	Variation (V)	-14	-9	-4		5	10	14
	Variation (%)	**30%**	**19%**	**9%**		**-11%**	**-21%**	**-30%**
2- KT88 MOV 1974	Vg1	-32	-36	-41	-46	-50	-55	-58
	Variation (V)	-14	-10	-5		4	9	12
	Variation (%)	**30%**	**22%**	**11%**		**-9%**	**-20%**	**-26%**
3- KT88 Reflector	Vg1	-33	-38	-42	-47	-52	-56	-61
	Variation (V)	-14	-9	-5		5	9	14
	Variation (%)	**30%**	**19%**	**11%**		**-11%**	**-19%**	**-30%**
4- 6550A GE 1972	Vg1	-30	-35	-38	-43	-47	-52	-56
	Variation (V)	-13	-8	-5		4	9	13
	Variation (%)	**30%**	**19%**	**12%**		**-9%**	**-21%**	**-30%**
5- KT77 MOV	Vg1	-20	-22	-25	-28	-31	-34	-37
	Variation (V)	-8	-6	-3		3	6	9
	Variation (%)	**29%**	**21%**	**11%**		**-11%**	**-21%**	**-32%**
6- KT66 GEC	Vg1	-28	-32	-36	-39	-43	-47	-52
	Variation (V)	-11	-7	-3		4	8	13
	Variation (%)	**28%**	**18%**	**8%**		**-10%**	**-21%**	**-33%**
7- KT66 Marconi 1956	Vg1	-28	-32	-36	-39	-43	-47	-51
	Variation (V)	-11	-7	-3		4	8	12
	Variation (%)	**28%**	**18%**	**8%**		**-10%**	**-21%**	**-31%**
8- EL34 Mullard 1964	Vg1	-25	-28	-31	-33	-37	-40	-43
	Variation (V)	-8	-5	-2		4	7	10
	Variation (%)	**24%**	**15%**	**6%**		**-12%**	**-21%**	**-30%**
	Average Variation (%)	**29%**	**19%**	**9%**		**-10%**	**-21%**	**-30%**

TABLE 1: First correlation: When Va varies by increments of ±25V around the median of 425V, Vg1 varies approximately by 10% per increment.

Tube Type		Input Parameters $Vg1_{P425V}$	P	Vg2	Plate Voltages Va 350	375	400	425	450	475	500
1- KT88 Genalex 1959	*Vg1 (datasheet)*				-33.0	-38.0	-43.0	-47.0	-52.0	-57.0	-61.0
	$Vg1_{T/U}$ (model)	-30	35	300	-32.7	-37.4	-42.0	-46.7	-51.4	-56.0	-60.7
	Deviation (V)				**-0.3**	**-0.6**	**-1.0**	**-0.3**	**-0.6**	**-1.0**	**-0.3**
	Deviation (%)				**0.9%**	**1.7%**	**2.2%**	**0.6%**	**1.2%**	**1.7%**	**0.5%**
2- KT88 MOV 1974	*Vg1 (datasheet)*				-32.0	-36.0	-41.0	-46.0	-50.0	-55.0	-58.0
	$Vg1_{T/U}$ (model)	-27	42	300	-32.2	-36.8	-41.4	-46.0	-50.7	-55.3	-59.9
	Deviation (V)				**0.2**	**0.8**	**0.4**	**0.0**	**0.7**	**0.3**	**1.9**
	Deviation (%)				**-0.7%**	**-2.3%**	**-1.1%**	**-0.1%**	**-1.3%**	**-0.5%**	**-3.2%**
3- KT88 Reflector	*Vg1 (datasheet)*				-33.0	-38.0	-42.0	-47.0	-52.0	-56.0	-61.0
	$Vg1_{T/U}$ (model)	-27	42	300	-32.2	-36.8	-41.4	-46.0	-50.7	-55.3	-59.9
	Deviation (V)				**-0.8**	**-1.2**	**-0.6**	**-1.0**	**-1.3**	**-0.7**	**-1.1**
	Deviation (%)				**2.3%**	**3.1%**	**1.3%**	**2.0%**	**2.6%**	**1.3%**	**1.9%**
4- 6550A GE 1972	*Vg1 (datasheet)*				-30.0	-35.0	-38.0	-43.0	-47.0	-52.0	-56.0
	$Vg1_{T/U}$ (model)	-25	42	300	-29.8	-34.1	-38.4	-42.6	-46.9	-51.2	-55.4
	Deviation (V)				**-0.2**	**-0.9**	**0.4**	**-0.4**	**-0.1**	**-0.8**	**-0.6**
	Deviation (%)				**0.5%**	**2.5%**	**-1.0%**	**0.8%**	**0.2%**	**1.6%**	**1.0%**
5- KT77 MOV	*Vg1 (datasheet)*				-20.0	-22.0	-25.0	-28.0	-31.0	-34.0	-37.0
	$Vg1_{T/U}$ (model)	-19	32	300	-19.8	-22.6	-25.5	-28.3	-31.1	-33.9	-36.8
	Deviation (V)				**-0.2**	**0.6**	**0.5**	**0.3**	**0.1**	**-0.1**	**-0.2**
	Deviation (%)				**1.0%**	**-2.9%**	**-1.8%**	**-1.0%**	**-0.4%**	**0.2%**	**0.6%**
6- KT66 GEC	*Vg1 (datasheet)*				-28.0	-32.0	-36.0	-39.0	-43.0	-47.0	-52.0
	$Vg1_{T/U}$ (model)	-18	30	250	-27.2	-31.1	-35.0	-38.9	-42.8	-46.7	-50.6
	Deviation (V)				**-0.8**	**-0.9**	**-1.0**	**-0.1**	**-0.2**	**-0.3**	**-1.4**
	Deviation (%)				**2.7%**	**2.7%**	**2.7%**	**0.2%**	**0.4%**	**0.6%**	**2.7%**
7- KT66 Marconi 1956	*Vg1 (datasheet)*				-28.0	-32.0	-36.0	-39.0	-43.0	-47.0	-51.0
	$Vg1_{T/U}$ (model)	-27	30	300	-27.2	-31.1	-35.0	-38.9	-42.8	-46.7	-50.6
	Deviation (V)				**-0.8**	**-0.9**	**-1.0**	**-0.1**	**-0.2**	**-0.3**	**-0.4**
	Deviation (%)				**2.7%**	**2.7%**	**2.7%**	**0.2%**	**0.4%**	**0.6%**	**0.8%**
8- EL34 Mullard 1964	*Vg1 (datasheet)*				-25.0	-28.0	-31.0	-33.0	-37.0	-40.0	-43.0
	$Vg1_{T/U}$ (model)	-17	25	250	-23.5	-26.8	-30.2	-33.6	-36.9	-40.3	-43.6
	Deviation (V)				**-1.5**	**-1.2**	**-0.8**	**0.6**	**-0.1**	**0.3**	**0.6**
	Deviation (%)				**6.1%**	**4.1%**	**2.6%**	**-1.7%**	**0.2%**	**-0.7%**	**-1.4%**

TABLE 2: Comparison of different values of Vg1 extracted from the datasheets to the predicted values of $Vg1_{T/U}$. The overall standard deviation σ is 1.6%.