

Letters to the editor

Dear Editor,

I thoroughly enjoyed Frank Blöhbaum's article "A New, Low-Noise Circuit Approach for Pentodes" in LJA Vol 0, pp 46. Thanks to his remarkable article I might overcome my aversion to pentodes in low-noise audio applications. I will check his new and thrilling approach with my favourite pentode, the C3m, as soon as possible.

Concerning the design and invention approach I agree with most findings of the article. However, when studying the Tables 1 and 2 I stumbled over the ECC808. This raised some concerns on the value of these tables that will become outlined below. I will use this chance to demonstrate that we should not underestimate the influences on the total noise production of valve gain-stages that are produced by various noise sources at the low-end of the audio frequency range.

1. Noise resistance. Based on Frank's measurement results the noise resistance of the ECC808 becomes lower in value than the Table 1 value: 1,333Ω instead of 2,305Ω.

The reason for my claim needs some math and I've chosen the below given approach:

In a particular bandwidth $B > 1\text{Hz}$, with the measured gain G_m and the noise voltage density $e_{n,rN}$ of the valve's noise resistance rN the ideal rms value of the output noise voltage $e_{N,o,id}$ of a gain-stage formed by that valve can be calculated by:

$$e_{N,o,id} = e_{n,rN} G_m \sqrt{B} \quad (1.1)$$

I call it ideal because Eq. (1.1) does not include any additional noise effect (eg. $1/f$ -, $(1/f)^2$ -, shot-noise, etc.), noise created by the un-bypassed operating point setting resistors and the input and output loads. By definition rN relates only to the white noise region of the triode's noise spectrum and it is constant throughout the entire white noise region, up to many MHz.



A totally different picture of the real rms output noise voltage $e_{N.o.re}$ will come up by inclusion of eg. $1/f$ -noise (to simplify things a bit I only take the $1/f$ noise with its -3dB/oct. character) and the noise from all relevant resistors:

$$e_{N.o.re} = e_{n.r.N} G_m \sqrt{B} W_z \sqrt{F_c} \tag{1.2}$$

Based on the $1/f$ noise and its corner frequency f_c the additional Eq. (1.2) factor $\sqrt{F_c}$ describes the noise increasing effect of the noise voltage of the valve's noise resistance and F_c describes the same effect concerning the noise resistance, hence with

$$F_c(f_c) = \frac{f_c \ln\left(\frac{f_{hi}}{f_{lo}}\right) + (f_{hi} - f_{lo})}{f_{hi} - f_{lo}} \tag{1.3}$$

the average noise resistance r_{Nc} and the corresponding average noise voltage density $e_{n,rNc}$ in B become [(")] should signal a certain dependency on f_c that leads to the average values in B]:

$$r_{Nc} = r_N F_c \tag{1.4}$$

$$e_{n,rNc} = \sqrt{4kTr_N B} \sqrt{F_c} \tag{1.5}$$

In contrast to Eq. (1.1), Eq. (1.3) shows, that the above given formulae become valid in a particular bandwidth $B = (f_{hi} - f_{lo})$ only. In our case here it's $B_{22k} = 21,918\text{Hz}$.

The relationship between F_c and f_c in B_{22k} is given in the Fig. 1 diagram:

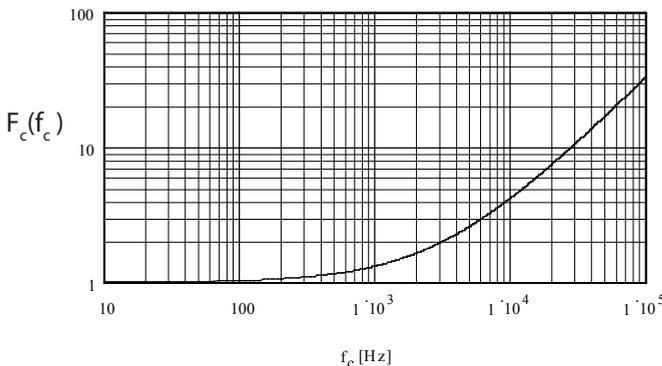
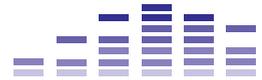


Fig 1: Ratio $F_c(f_c)$ as function of the $1/f$ noise corner frequency f_c in a 22 kHz bandwidth

Assuming that we could find an f_c value for the ECC808 we could determine F_c . Based on Figs. 14 and 15 of the article I estimate $f_c = 1,500\text{kHz}$, hence, F_c becomes 1.479.

The additional Eq. (1.2) factor W_z describes the amount of noise produced by the operating



point setting resistors and the input and output load resistors of a gain-stage. Here we get only $W_z = 1.055$. This is not a surprise, because of the valve's linearity and high μ . In B_{22k} W_z can simply be calculated by division of the measured rms output noise voltage $e_{N.o.m}$ with the measured gain G_m that got multiplied by the noise voltage of the two paralleled triodes ($= e_{n,rNc} * \sqrt{B_{22k}} / \sqrt{2}$), hence:

$$W_z = \frac{e_{N.o.m}}{G_m \frac{e_{N.rNc}}{\sqrt{2}}} \quad (1.6)$$

As long as the input load is chosen rather small the most influential factor comes from the excess noise of the anode resistor. Maybe you've chosen an 110k Ω / 0.6W metal film resistor with a current noise index NI = 0.063 μ V/V (= 24dB according to the respective Vishay Application), maybe one with a lower or higher NI.

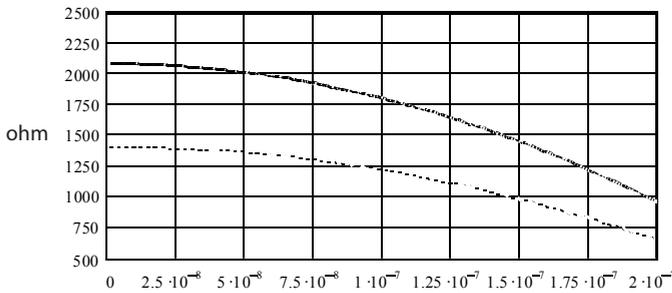
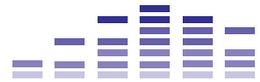


Fig. 2: Noise resistance expression for white noise: r_N (dotted line) and its corresponding 1/f-noise dependent average B22k noise resistance r_{Nc} (solid line, $f_c = 1,500\text{Hz}$) of one ECC808 triode as function of NI

Two plots in Fig. 2 show the dependency of the noise resistances r_N and r_{Nc} from the current noise index: with $f_c = 1,500\text{Hz}$ the dotted line shows the white noise based noise resistance r_N as part of the 1/f-noise dependent average noise resistance r_{Nc} (solid line). The quotient is F_c at any NI value.

In Fig. 2 at NI = 0.063 μ V/V we can pick-out the dotted line r_N value of 1,332.9 Ω . Hence, the average noise resistance r_{Nc} of one ECC808 triode in B_{22k} becomes:

$$\begin{aligned} r_{Nc} &= r_N F_c \\ &= 1,332.9 \Omega * 1.479 \\ &= 1,971.4 \Omega \end{aligned} \quad (1.7)$$



At $NI = 0.063\mu\text{V/V}$ this value could be picked-out from the Fig. 2 solid line too.

Note: In Fig. 2 the NI value close to $0\mu\text{V/V}$ ($\leq 0.01\mu\text{V/V}$) represents a bulk metal foil resistor, $NI = 0.2\mu\text{V/V}$ is the corresponding value of a carbon composition resistor.

Multiplication by W_z should lead to the noise resistance value for one triode of the article's Table 2. With Eq. (1.7) this results in the comparable figure $r_{Nc.gs.calc}$:

$$\begin{aligned} r_{Nc.gs.calc} &= r_{Nc} W_z \\ &= 2,079.9 \Omega \end{aligned} \quad (1.8)$$

The difference between the Table 2 average noise resistance value in B22k of the entire gain-stage ($2,305\Omega$) and $r_{Nc.gs.calc}$ becomes 225.1Ω (appr. 10% of $2,305\Omega$) and it is triggered by three sources:

- My estimation of f_c .
- My estimation of NI.
- Frank's page 55 multiplication of the whole measured output voltage by $\sqrt{2}$ (this leads to the total input referred gain-stage noise voltage density of $e_{n.i} = 6.18\text{nV}/\text{rtHz}$, shown in Table 1), instead of performing this multiplication only with the triode related noise voltage part of the whole output noise voltage. Automatically, this chosen process will lead to a higher $e_{n.i}$ and consequently to a higher r_{Nc} compared with the one of Eq. (1.8).

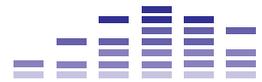
Nevertheless, a cross-check recalculation that is based on $r_N = 1,332.9\Omega$, $F_c = 1.479$ and $W_z = 1.055$ leads to his measured output noise voltage within a max. deviation of $<0.01\text{dB}$, the gain difference becoming $<0.2\text{dB}$.

Finally, for comparison reasons, let's check the data-sheet approach. It gives a noise resistance representing white noise and it does not include any additional noise influences like $1/f$ noise, etc.:

$$\begin{aligned} g_{m.dat} &= 1.33 \text{ mS} \\ r_{N.dat} &= \frac{3.06}{g_{m.dat}} \\ &= 2,301 \Omega \end{aligned} \quad (1.9)$$

Thus, with the chosen assumptions the calculated r_N value of $1,332.9\Omega$ would be approximately 2.4dB better than the value based on the data sheet.

I agree, this would be an ECC808 that produces less noise than the average ECC808 that is represented by the data-sheet. However, with an r_N of $1.333\text{k}\Omega$ or an r_{Nc} of $1.917\text{k}\Omega$ the ECC808 is not a



very low-noise type of triode. There are better ones on the market, but paid for it with lower gains and higher energy consumption.

2. Shot-noise becomes suppressed by FFT analysis. As far as I know shot-noise only occurs in the frequency range $<100\text{Hz}$ and it forces the pointer of an analogue measurement instrument to dance heavily around a midpoint on the scale. Only this mid-point level is shown by the averaged trace of the FFT-analyzer and nothing else shows the peaks of that dance. However, in case of a RIAA phono-amp that amplifies the lower end of the audio band much more than the other frequency regions, these peaks become essential because they always destroy good signal-to-noise ratio pictures that could be produced by non-weighted measurements. To get a stable result we are forced to use A-weighting or D. Self's S-filter. In so far, concerning shot-noise of the pentodes, it would be good to get some additional information from Frank. I would never design a phono-amp with a 1st stage type of massive shot-noise producing pentode.

By the way, what is the FFT resolution of Figs. 14 and 15?

3. Concerning noise production there is a lack of a common basis for comparisons between the different valves of the study. It seems to me as if Frank included the $1/f$ -noise and all other low-frequency range noise effects into all results shown in Tables 1 and 2. Based on the shown graphs and on my own experience I assume that the valves of his study show very different corner frequencies based on $1/f$ -noise and other low-frequency noise effects. For only one type of valve my own studies on triodes show a huge f_c range from $<300\text{Hz}$ up to $>50\text{kHz}$; eg. the respective corner frequency of your EF86 must be $>20\text{kHz}$. I don't criticize the usage of the EF86 here. However, just for comparison reasons, I recommend a look into the depths of the web-site of jogi's Roehrenbude www.jogis-roehrenbude.de. There you'll find some EF86 noise voltage density charts that offer much lower f_c values. As long as the f_c spread is of such a huge amount it makes no sense to compare different types of valves without separation of the low-noise ones from the less low-noise ones by setting a specific boundary as in my fourth comment further down.

Anyway, I feel you're not comparing apples with apples. I know that setting a standard that could neutralize these effects would become an immense effort. However, having done this would create a better and rather equal basis for all comparisons.

4. We need additional and guaranteed data-sheet specs on the valve noise production. Today, nearly 100% of all valves are used for audio purposes. In the meanwhile, only a few people can afford buying the rather expensive low-noise types. The additional negative point is that the manufacturers only offer so-called manufacturer selected low-noise devices and that selection is not based on a guaranteed data-sheet spec. Therefore, your bandwidth limited average noise resistance approach could be very helpful by convincing the valve manufacturing industry to improve and to complete their data-sheets of low-noise triodes or pentodes by a strong quality aspect: they guarantee the average noise resistance in B20k or B22k.

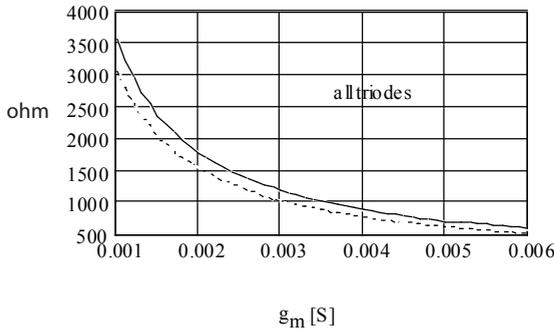
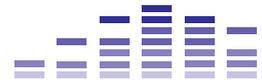


Fig. 3 r_N (solid) and r_{Nc} (dashed) vs. g_m in B20k - low g_m -range and $f_c = 1\text{kHz}$

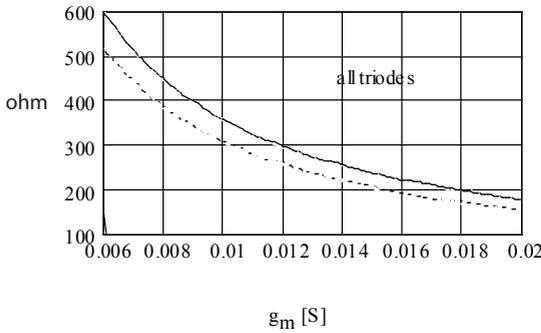


Fig. 4 r_N (solid) and r_{Nc} (dashed) vs. g_m in B_{20k} - high g_m -range and $f_c = 1\text{kHz}$

Of course, this average noise resistance is dependent on the valve's mutual conductance. Therefore, this guarantee should become a noise resistance vs. mutual conductance graph, including the valve's 1/f-noise effect (solid line in the following graphs, example $f_c = 1\text{kHz}$, hence $F_c = 1.346$ in B20k!). Additionally, they could include the trace of the noise resistance without 1/f-noise effect (dotted line, $f_c = 0\text{Hz}$, hence $F_c = 1$). This graph could look as follows and the manufacturers should guarantee that their low-noise valves always show average noise resistances lower than the boundary set by the solid trace of the graph at any value of mutual conductance.

The creation of these two graphs can be performed by application of the following two equations, reflecting a usage in B20k = 20Hz ... 20,000Hz:

$$r_{Nc}(g_m, F_c) = \frac{3.06}{g_m} \cdot F_c \tag{1.10}$$

$$F_c(f_c) = \frac{f_c \ln\left(\frac{20,000\text{Hz}}{20\text{Hz}}\right) + B_{20k}}{B_{20k}} \tag{1.11}$$

5. Closing remark. Because there are so many other noise sources in a valve amp one might argue that the difference between 1,917Ω and 2,305Ω of the 1st comment is not a big issue and it could simply be ignored. However, we always need a sound basis for calculation and simulation purposes



and it's always better performing a non-trimmed calculation first and doing the rounding or simplification at the end of the process. Generally, this works well, even with valves. How? In the next edition of my "The Sound of Silence" book I will describe methods that allow calculating double-triode driven phono-amps with deviation from the measured noise results within ± 1 dB only.

Burkhard Vogel, Stuttgart, Germany.

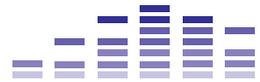
Dear Editor,

May I congratulate you on an excellent zeroth edition. One minor point: could we have larger diagrams, please? (of course, see this issue – ed). I'd like to give some comments on pentode noise, arising from the article by Frank Blöhbaum. The article is very interesting, but I fear that it may contain measurements errors. I did not realise just how much $1/f$ noise dominates the EF86 at audio frequencies; the corner frequency seems to be about 20kHz. It rather swamps the effect he was trying to measure, hence there is only a small improvement from pentode to triode mode. I am puzzled by the further improvement of "bestpentode" over triode. Incidentally, are the tables correct; some show pentode as being less noisy than triode connection, which cannot be right? I suspect that there may be an extra noise source somewhere in the output, as that would give preference to higher gain configurations when the noise is referred back to the input. When a measurement seems wrong, it probably is! Is the g3 connection introducing an extra change - it should be connected to the cathode in each case, as specified in the Philips data sheet, otherwise we are not comparing like with like.

What is the input capacitance of the output cable plus measuring device? If it is greater than about 100pF then it will reduce the measurement bandwidth for pentode and "bestpentode" connection, because of the higher anode impedance. Comparing fig. 6 with fig. 9 there is a hint that maybe the pentode noise is declining faster than $1/f$ from 10kHz, but the triode noise is levelling off. This is exactly what would happen if there is too much capacitance. I think a buffer may be necessary.

In most pentodes partition noise dominates over shot noise, in spite of the screen-grid current being significantly lower than anode current. This is because shot noise is heavily suppressed by the space charge around the cathode, but partition noise is unaffected. If this were not the case, shot noise would dominate and triodes would be nearly as noisy as pentodes with both much noisier than we find.

The EF86 is unusual, in that it has a very low screen-grid current. This means that partition noise is lower than for most other pentodes. It adds about 2dB to the total, instead of the more typical 6-14dB. For the EF86 at the bias points he used, I estimate R_{eq} as 1250R (triode, bestpentode)



and 2125R (pentode), giving 4.5nV/RtHz and 5.8nV/RtHz respectively. These are much smaller than Frank's measurements, due to 1/f noise (shot and partition noise are mainly white).

I think what we should deduce from this is that for audio frequencies you can't calculate valve noise - you just have to measure it (but that is harder than you think). Low shot noise (i.e. high gm) is not as useful a criterion as many people seem to imagine. Partition noise is less of an issue than we think so "bestpentode" mode, although an obvious extension of the cascode, may be less useful for audio than the author hopes.

Dave Kimber, London, UK

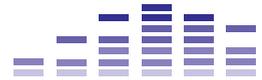
Frank Blöhbaum replies:

I thank messieurs Vogel and Kimber for their thoughtful comments to my article. It pleases me that my investigations of pentodes and their best wiring (in terms of noise) attracts so much interest. For decades the dogma was that pentodes are always more noisy than triodes. And as always it's difficult to say good buy to long established dogmas. Mr. Kimber as well as Mr. Vogel are still sceptic about my measured low noise values for pentodes. But how much noise one gets from a pentode amplifier depends from the tube type (high or low transconductance; $\mu\text{g}2\text{g}1$; cathode material etc.) and the circuitry around this particular tube. In the past the rather high noise of the power supply together with the almost no power supply rejection of a pentode-based grounded cathode amplifier blamed the noise on the pentode. But in fact, few measurements about pentode noise are available and many of them infected with this power supply problem. Please take note that 15uV of output noise means a S/N-ratio of the power supply of 120dB – at a power supply voltage of 15V only. For tubes having i.e. 150V we need 20dB more – 140dB !

On the other hand, high transconductance pentodes have not been used for audio amplifiers for one simple reason: they were much more expensive than the audio types like EF86 and 6SJ7. And they need much more anode (and screen grid) current, so that the power supply got even more costly. Needless to say that almost no reliable noise measurement values of these high-gm tubes for audio use exist.

Reply to Mr. Kimber:

Mr. Kimber wrote: "Incidentally, are the tables correct; some show a pentode as being less noisy than a triode connection, which cannot be right? I suspect that there may an extra noise source somewhere in the output, as that would give preference to higher gain configurations when the noise is referred back to the input. When a measurement seems wrong, it probably is!" Mr. Kimber is on the right track with this statement: „I suspect that there may an extra noise source somewhere in the output“. Yes, there is. It's the anode resistance R_a . This resistance produces two types of noise:



a) thermal noise and b) excess noise. The latter one is often overlooked, but very important. For the audio bandwidth of 20Hz - 20kHz (3 decades) and usage of a metal film resistor the calculation of excess noise voltage follows this equation:

$$e_{n_{ex}} Ra = U_{ra} * \text{SQRT}(3) * 0.06 \mu\text{V/V/decade} \quad [1]$$

U_{ra} = voltage difference across the anode resistance ($U_b - U_a$)

Some audio enthusiasts like to use carbon composition resistors. But this resistor type has an excess noise term of more than three times higher: about $0.2 \mu\text{V/V/decade}$! Please take note that this excess noise term is independent of the resistance value of the resistor! Let's take the measured EF184 as an example (see the table in LA Vol.0, p.57-59 and Fig.16). Solving [1] for the used R_a in my measurements gives for the triode mode:

$$e_{n_{ex}} RaT = 124.3\text{V} * \text{SQRT}(3) * 0.06 \mu\text{V/V/dec.} = 12.918 \mu\text{V} \quad [2]$$

For the BestPentode mode:

$$e_{n_{ex}} RaBP = 98.8\text{V} * \text{SQRT}(3) * 0.06 \mu\text{V/V/dec.} = 10.268 \mu\text{V} \quad [3]$$

[In triode mode the g_2 voltage is higher (g_2 is connected to anode) and therefore more current flows through the anode resistor R_a and higher potential difference occurs].

The output noise voltage of the measured EF184 in Triode-mode (Gain-Triode = 45,358; see table 3 in the article) :

$$e_{n_{out}} T = 3,96\text{nV/RtHz} * \text{SQRT}(21918) * 45,358 = 26,6 \mu\text{Vrms} \quad [4]$$

The output noise voltage of measured EF184 in BestPentode-mode (Gain-BP = 168.86; see table 3):

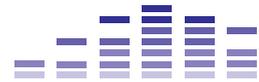
$$e_{n_{out}} T = 3,45\text{nV/RtHz} * \text{SQRT}(21918) * 168,86 = 86,25 \mu\text{Vrms} \quad [5]$$

In both measured output noise values [4] and [5] the excess noise term is included! Now Mr. Kimber has what he was looking for: The excess noise term of $12.918 \mu\text{V}$ in triode mode is this „extra noise source somewhere in the output“. Let's do the math for verification: The total output noise is always the square root sum of the squared individual noise sources.

So the isolated noise value of the tube itself would be:

$$e_{n_{Triode}} = \text{SQRT}(26.6^2 - 12.918^2) = 23.25 \mu\text{V} \quad [6]$$

$$e_{n_{BestPentode}} = \text{SQRT}(86.25^2 - 10.268^2) = 85.64 \mu\text{V} \quad [7]$$



The equivalent input noise density for the EF184 itself is thus:

$$e_{\text{nin}}^T = 23.25 \mu\text{V} / (45.358 * \text{SQRT}(21918)) = 3.46 \text{ nV/RtHz} \quad [8]$$

$$e_{\text{nin}}^{\text{BP}} = 85.64 \mu\text{V} / (168.86 * \text{SQRT}(21918)) = 3.43 \text{ nV/RtHz} \quad [9]$$

Comparing [8] and [9] we see that the „Inner noise values“ of the measured EF184 in triode mode as well as in BestPentode mode are pretty much the same – which would be expected. Please take note that I haven't included other noise sources i.e. thermal noise of Ra and thermal noise of Rin (50 Ohm). But these terms have a much less impact.

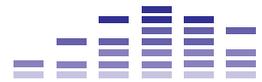
In practice we can never use the tube itself in isolation; we always need some kind of anode load. If we use simple resistors the BestPentode mode will pay off because of its much higher gain while having no extra noise compared to the triode mode. If we spend a bit more effort like low noise current sources based on semiconductors the excess noise term could even be lower. But even then the BestPentode mode will excel because it will have at least the same low noise like the triode mode but much higher gain – which is very welcome in low level gain stages like for phono amps.

Cables: I used shortest possible and capacitance qualified cables. The capacitance of input as well as output cable is less than 50pF each.

Shot noise: Mr. Kimber states that the noise of the pentode will reach a much higher value than that of the $\lg 2 / I_a$ ratio and he blames the shot noise for this: „In most pentodes partition noise dominates over shot noise, in spite of the screen-grid current being significantly lower than anode current. This is because shot noise is heavily suppressed by the space charge around the cathode, but partition noise is unaffected. If this were not the case, shot noise would dominate and triodes would be nearly as noisy as pentodes with both much noisier than we find.“

This statement surprises me. Shot noise occurs by definition when an electrical current hits a potential barrier. I don't know any method which can separate (or filter) out shot noise from other noise sources. If this method exists, many real world problems in electronic systems could be solved. As an example the digital camera chips could be improved immensely, because the shot noise term is the unavoidable dominating term in these devices. All my measurements – and I have measured more than 100 different pentodes – verify that the noise difference between triode- and pentode-connection is just related to this $\lg 2 / I_a$ ratio and therefore the partition noise term. I never found this magic „6–14 dB improvement“ in my measurements if one and the same tube is connected in triode mode instead of pentode mode. This „6-14dB“ improvement is a myth and not reality and I cannot find any theoretical explanation for this number.

Reply to Mr. Vogel:



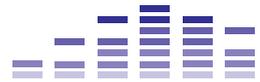
Mr. Vogel recalculates the values for the ECC808 extensively. Please take note that I made these measurements to get an idea of the quality of my measurement setup only, because the ECC808 is one of these rare tubes having real world audio noise data in the databook. The comparison between the databook and my measurements is surprisingly good. Mr. Vogel notes the difference between the average noise resistance value in B22k of the entire gain-stage ($2,305\Omega$) and $rNc.gs.calc$ becomes 225.1Ω (appr. 10% of $2,305\Omega$). He also notes that “this would be an ECC808 that produces less noise than the average ECC808 that is represented by the data-sheet. However, with an rN of $1.333k\Omega$ or an rNc of $1.917k\Omega$ the ECC808 is not a very low-noise type of triode. There are better ones on the market, but paid for it with lower gains and higher energy consumption“. I am pleased that Mr. Vogel verifies with his extensive use of detailed formulae the quality of my practical measurement setup. I would be happy if all of my tubes show such a small deviation of 10% only – especially in terms of noise – from the data book values. Most high-gm tubes vary more than 50% from one tube to the other. And again: I haven’t use the ECC808 for a best noise recommendation neither would I use it for any of my amplifiers – it was just a verification of the test setup against know data sheet values, which was successful. The same is true for my investigations of the EF86.

Pentode shot noise: Mr. Vogel writes, „In so far, concerning shot-noise of the pentodes, it would be good to get some additional information from you. I would never design a phono-amp with a 1st stage type of massive shot-noise producing pentode“.

Mr. Vogel might miss something if he ignores the advantages of pentodes. At the ETF2010 I presented a working new phonostage having for the first gain stage the D3a wired in BestPentode mode and working onto low noise current source as a transconductance amplifier. It is so dead quiet, that I can run it together with my Benz MC Gold pickup without an input transformer. The details might follow in one of the next coming issues of Linear Audio (yes please – ed). In the meantime I invite Mr. Vogel to compare his triode based amplifier – if the real amplifier exists and not simulation results only – with my new pentode based transconductance amp in measurements and listening tests. By the way, I used the best possible resolution of the UPL spectrum analyzer: 8192 points @ 21918 Hz Bandwidth.

Next Mr Vogel remarks “Concerning noise production there is a lack of a common basis for comparisons between the different valves of the study“. That was specifically NOT my goal. As I stated on page 51 of the article, my first(!) goal was: Verification of the advantages / disadvantages of circuit structures, not tube types!

Of course the different tubes I used have different $1/f$ corner frequencies and so on. But that was one proposed part of the story: to investigate the noise properties of different circuit structures using different tubes inside one and the same circuit consisting of one and the same parts – in other words: well defined and constant conditions. If I had to find one tube having the lowest noise possible I would have fine-tuned the individual working points of every tube. But that would have



meant: no constant conditions – and the results would have been worthless in terms of the investigation of circuit structures.

Mr Vogel's comment on this aspect makes absolutely no sense regarding my article.

I do agree wholeheartedly to Mr Vogel's plea for guaranteed noise specs of actual produced tubes. I follow your recommendation.

In general the main trust of Mr. Vogel's letter is to refer to his book „The Sound of Silence“. This book includes many formulae from different sources in a systematic manner. I recommend reading it for an in-depth theoretical understanding of preamplifiers. Regarding tubes, the drawback of his book is, that the formulae as well as the tube data are based on old books like the Telefunken „Laborbuch“ only – and not of modern measurements using state of the art power supplies and measurement tools. As an example Table 3.6 in his book shows „Data Sheet“ values for the noise of pentodes, but these values are just theoretical values for high frequency use (>1MHz) based on the transconductance number only! For use in audio amplifiers, especially phone stages, these values might be indications – in the best case. In the worst case it's just an academic calculated number. In practice many tubes show an unexpected behaviour especially regarding $1/f$ noise and the noise variation which is caused by the different cathode materials of different tube manufacturers.

Closing remarks. Of course I calculate and simulate all my circuits first. Otherwise it would not have been possible to design an amplifier like the TEM3200 floating bridge high power amp. And I have developed a lot of different Spice models for triodes and pentodes. If the simulation looks promising I build the real amplifier. But my simulations are not a goal in itself. As an example Spice doesn't include shot noise calculations. So nearly all Spice calculated noise values are worthless. Regarding noise we don't have any reliable model of triodes and pentodes. As Mr. Vogel might know, producing tubes means 90% chemistry and 9.5% fine-mechanics. The rest is electronics... About the chemical structure of the cathode material and their impact onto the noise behaviour we don't know much. But the detailed knowledge about this particular problem is essential for developing a reliable noise model of tubes. And to complicate it furthermore: we don't have and will not get any information about the chemistry of the cathodes of a given tube. So the only way for working with tubes is measuring the real thing – and than fine-tune the models.

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