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On the mythic sound of vacuum tubes

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ABSTRACT
Vacuum tube audio preamplifiers have recently found renewed interest. This study recalls the main requirements that this type of equipment must meet and analyses an example. The experimental approach followed to measure performances is described. These performances are exposed, and the associated uncertainties are determined. The reviewed example meets the advertised specifications.

Section: RESEARCH PAPER

Keywords: acoustical performance; applied mathematics; audio preamplifiers; distortion; hearing tolerance; vacuum tubes

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1. INTRODUCTION

We recently saw a large offer develop for audio amplifiers and preamplifiers equipped with vacuum tubes. Advertisement for these devices generally emphasise the specific sound obtained thanks to the presence of vacuum tubes. Moreover, a part of the user reviews published on social networks tend to acknowledge this property.

To be complete with the context, we observe that the technology of vacuum tubes in the audio domain is still very topical, as evidenced by the publication of a number of recent books [1], [2], [3].

The purpose of this paper is to explain to what extent a metrological approach can help to get an objective opinion on the subject. In this prospect, we first recall some considerations related to the amplification process, to some specificities of hearing. Then we shall examine properties resulting from the use of the considered technology, and finally report some measurement results obtained with a preamplifier sample.

We indeed concentrate here more on preamplifiers, first because they are very affordable, and hence subject of a much wider diffusion, and secondly because although several tens of brands can be found today; the technical design implemented is largely common to most models available.

1.1. A preliminary product analysis

The external appearance of those products is in general pleasant, even aesthetic. In fact, such products are of hybrid nature, making use along with the vacuum tubes, of operational amplifiers, high density integrated circuits, surface mounted components.

Functionalities include USB and Bluetooth inputs, which can be very efficient for listening to some music stored in a smart phone or in a computer.

Here, the product chosen as an example appears to be rather a DAC (Digital to Analog Converter) than an amplifier. The voltage gain A_v is too small for instance to handle directly a magnetic turntable cell. The typical maximum value is: $A_v = 2.5$ at medium frequencies.

The make looks satisfactory, with a heavy metal case, and good quality wave soldering (see Figure 1, Figure 2, Figure 3).

2. CONSIDERATIONS ON TONALITY

2.1. General

An electronic amplifier or preamplifier is supposed to be strictly linear.

If it is, it is not possible to identify it from its response to an input signal.

If it is not, it gives a specific tonality to the response, and then can be identified; it is sometimes appreciated as such. At the same time, it also slightly modifies the signal. This non-linear effect is called distortion.

The operation domain selected for an amplifier is in practice divided into classes: class A is the most linear of them but implies a high and constant energetic consumption; class B corrects this efficiency problem but introduces some crossover distortion;

Figure 1. External view of preamp: front and top panel with vacuum tubes.

Figure 2. View of rear panel showing connectors and bluetooth antenna

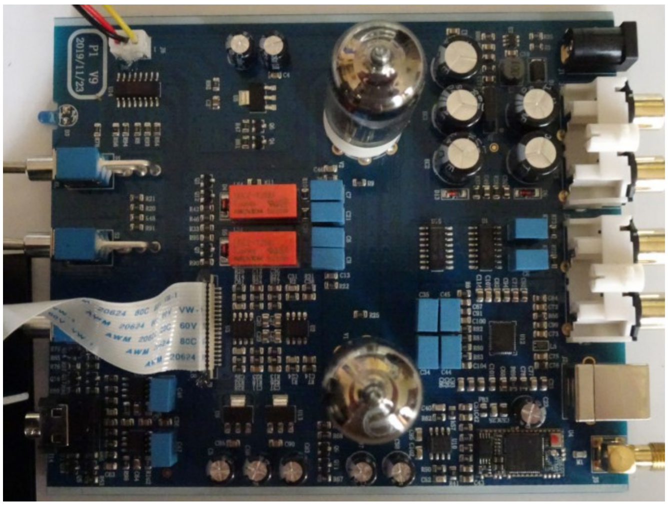

Figure 3. Printed Circuit Board

class AB is a compromise between both; and class D corresponds to recent high efficiency digital amplifiers.

Whatever its class, an amplifier has necessarily limits for voltage and intensity output. When the input signal reaches such a limit, a phenomenon of signal clipping occurs, in other words a distortion.

2.2. Distortion

Distortion can be in fact desired or not.

Pure tones are dull and uninteresting. A little distortion may render a sound more pleasant. By the way, we are dealing here with psychoacoustics, and not with pure physics.

Every electric guitar player for instance knows that a "*warm sound*" is obtained with tube power amplifiers, at moderate distortion level. On the other hand, specific musical effects can also be obtained with high level distortion.

2.3. Definitions

A general definition of distortion should take into account any component of the output signal not present in the input signal.

The distortion is well defined in the electronic field which is in relation with the shape of signal where both amplitude and phase are considered.

The notion of **inter-modulation distortion** is much used in the sector of telecommunications, where complex modulated multi-frequencies signals are handled.

Inter-modulation distortion may be significant due to the emission of audible sound components by the combinations of simultaneous input frequencies.

Let us consider an example: an input signal constituted by two pure sounds f_1 = 98.00 Hz and f_2 = 123.47 Hz, building a major third G_1 - B_1; frequency ratio $\sqrt[3]{2}$ = 1.2599 (Figure 4). In the case of a 3 % distortion, we observe on the output signal the presence of supplemental frequencies, such as (f_1 - f_2) (Figure 5)

Inter-modulation is NOT just an electronic artefact. It also exists in the nature, a musical instrument such as a violin, can produce inter-modulation (the "*Tartini*" sounds).

Some authors also consider **transient distortion**.

In practical, we shall limit here to **harmonic distortion**, i.e. the generation of harmonic frequencies as the effect of non-linearity; this concept is well adapted for the audio and musical domains, insofar the human ear is rather tolerant to distortion on complex sounds. By the way, musical sounds are complex ones.

The reference value can be either the overall RMS value of the signal or the RMS value v_1 of harmonic one, or fundamental; the difference between the two definitions is negligible in the case of low distortion. We shall retain the first expression for THD Total Harmonic Distortion

$$THD = 100 \frac{\sqrt{\sum_{h=2}^{N} v_h^2}}{\sqrt{\sum_{h=1}^{N} v_h^2}}, \quad (1)$$

where h is the harmonic order, N the number of harmonics considered.

For most people, the final goal of an amplifier is to allow listening to music rather than to reference signals. In the same time, it has been observed that the performance of human ears is much lowered with complex sounds, i.e. musical ones. This is due for instance to a masking effect, combined with the poorer ear sensitivity at low frequencies. Detectability of distortion can thus raise from .2 % to 6 % in normal use of an audio equipment [4].

Observation of distortion can be either visual or auditory. On the screen of an oscilloscope, distortion becomes visible around 3 % (see Figure 6). But it can be detected by hearing for lower values, provided the hearing conditions are optimal, i.e. loud enough sound, and pure tones. In this case the ear can be superior to the eye!

In the past, in catalogues of vacuum tubes, the nominal output power was indicated for a distortion of 10 %: this means that

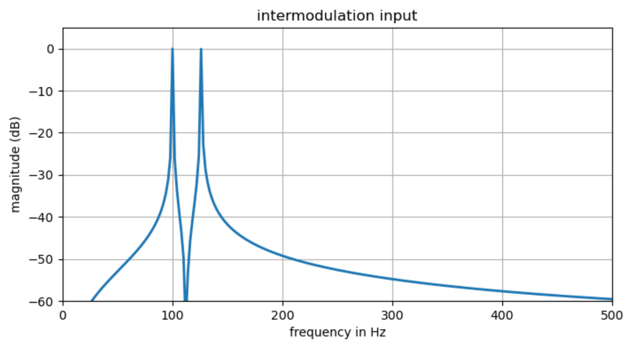

Figure 4. Input signal

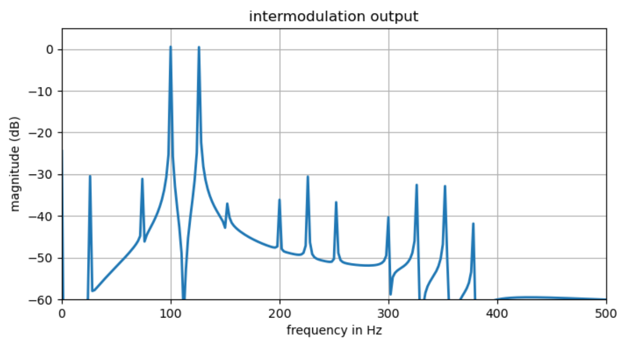

Figure 5. Output signal with intermodulation

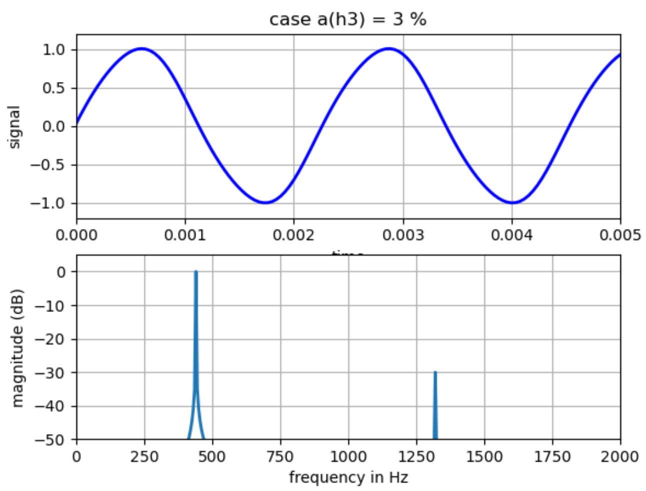

Figure 6. Sinusoidal signal with visible 3 % distortion

such a high value was then considered as tolerable.

If the ear can be a better expert about distortion, it nevertheless needs a transducer, whereas the eye doesn't. This transducer can be a loudspeaker, or a headphone. It will unfortunately introduce its own distortion. Also, an ear only picks up a power spectral density.

The qualitative content of distortion is also important for the auditory feeling. For example, a loudspeaker with 5 % THD and few high order harmonics will seem to sound better than another loudspeaker with only 2 % THD but many high order harmonics [5]. A global distortion indicator, although scientific, does not take into account the preference for lower harmonics.

The most efficient technique for objective evaluation of the harmonic distortion remains spectral analysis.

3. NON-LINEARITIES

3.1. Types of non-linearities

If a signal is stationary, the effect of a non-linear amplification is the production of harmonics. This effect is easy to observe on a purely sinusoidal input.

If the signal includes a transient part, i.e. the note from a musical instrument, the effect of distortion is more complex to describe, although the qualitative result is the same (addition of fictive frequencies with different damping coefficients).

Depending on the electrical phenomenon in play in the amplifier, distortion can affect either low level or high level signals. Crossover distortion will be detected at low levels, clipping distortion on the contrary will be mainly heard at high levels. Crossover corresponds to switching phenomena inside active elements (transistors or vacuum tubes) at the change between positive and negative half-periods of the signal. Clipping is a sort of saturation. Crossover introduces no significant difference between vacuum tubes and transistors, contrary to clipping. We shall hence come back to clipping a bit further.

We here voluntarily keep for convenience the terminology normally reserved to linear systems such as "gain" and "response". The experimental behaviour of an amplifier established around a given operating point P can always be modelled by a polynomial function $v_{\mathrm{out}} = \mathrm{F}(v_{\mathrm{in}})$, i.e. by a sum of power functions (see Figure 7, Figure 8, Figure 9).

If the non-linearity has an odd symmetry around point P, odd terms will appear in function F (most common case, for example when both positive and negative half-periods are clipped); if there is not such symmetry (example of only one half-period clipped), even harmonics will also appear.

If F includes odd power terms, odd harmonics will be generated; if F includes even power terms, even harmonics will be generated. A combination of both is clearly possible.

The signal patterns may be different according to the time lag between the frequency components (Figure 7, Figure 8). But the human ear does not make any difference, since it reacts not to the sound signal itself, but to its power spectral density.

A non-linear behaviour may present two forms; we limit ourselves here to one main linear term of coefficient a, and one non-linear term of coefficient b, n being an integer number:

- "concave" model : $V_{\mathrm{out}} = a\,V_{\mathrm{in}} + b\,(V_{\mathrm{in}})^{\mathrm{n}}$
- "convex" model : $V_{\mathrm{in}} = a\,V_{\mathrm{out}} + b\,(V_{\mathrm{out}})^{\mathrm{n}}$.

If the convex model can be analytically rearranged as $V_{\mathrm{out}} = \mathrm{f}(V_{\mathrm{in}})$, which is not always possible, we shall find fractional powers instead of integer powers. Qualitatively, there is no consequence on the distortion generated (Figure 10).

Why does non-linearity create harmonics? The answer is given by the Moivre formula

$$(\cos\theta + \mathrm{i}\sin\theta) = \cos(n\,\theta) + \mathrm{i}\sin(n\,\theta)\,, \tag{2}$$

otherwise written, in polar coordinates

$$\left(e^{i\,\theta}\right)^{n} = e^{i\,n\,\theta} \tag{3}$$

If the non-linearity can be modelled by a power function, its effect on a sinusoidal signal will be the generation of harmonic frequencies.

A rigorous and detailed approach of this subject can be found in [6].

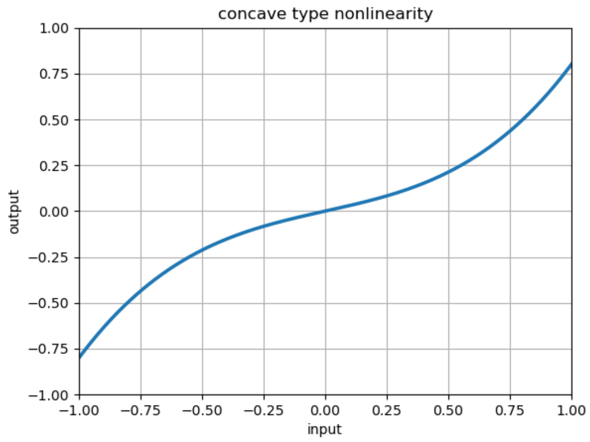

Figure 7. Symmetrical non-linear response: concave type - case a.

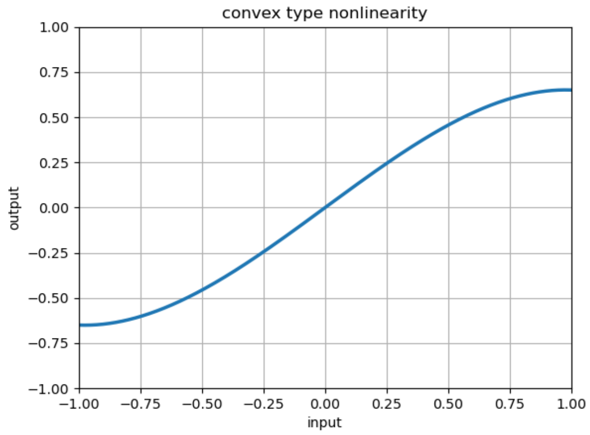

Figure 8. Symmetrical non-linear response: convex type - case b.

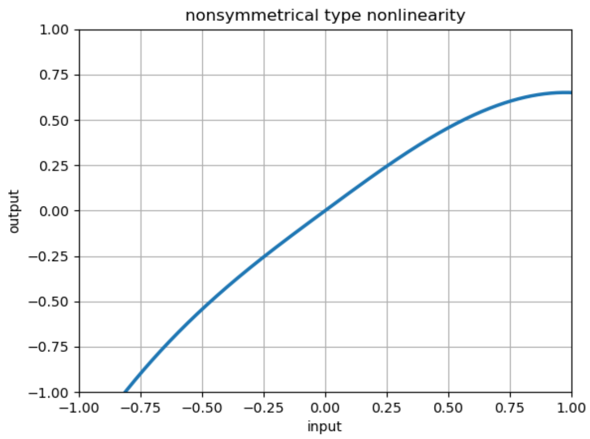

Figure 9. Non symmetrical non-linear response - case c.

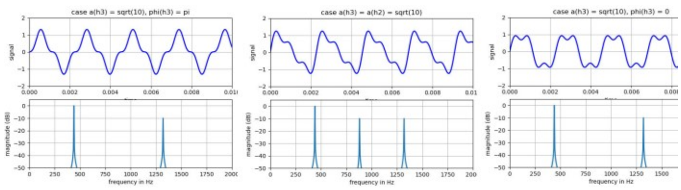

Figure 10. time domain and frequency domain corresponding signals for cases a, b, and c.

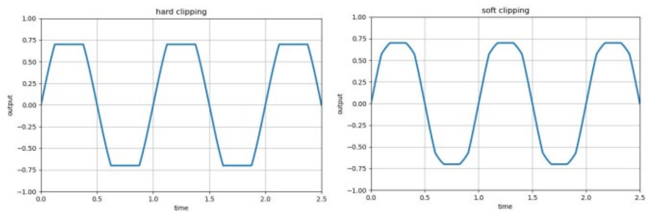

Figure 11. Hard clipping (transistors) left and soft clipping (tubes) right.

3.2. Vacuum tubes for audio: hard clipping and soft clipping

When the input signal in an amplifier reaches a limit of the linearity domain, a clipping phenomenon occurs.

The corresponding transition is much more progressive with vacuum tubes compared with transistors. Hence the corresponding "sound", so much appreciated (Figure 11).

A musician should take care of the dynamics of his play, to obtain exactly the desired effect; by definition the distortion rate is dependent on the input amplitude.

It should be noted that the development of digital electronics also offers today many ways for new sound effects, and possibilities of substitution to vacuum tubes.

If the use of the tube sound, which is in fact a distortion, is understandable for musical purposes, it cannot be justified in the case where exact sound reproduction is researched.

Tube power amplifiers also need to make use of magnetic components, such as transformers, mainly for impedance matching purposes.

These components may clearly be the source of some non-linearities, due to magnetic saturation.

4. VACUUM TUBES AMPLIFIERS

Vacuum tube amplifiers have been appreciated for years due to some favourable properties, and even still today despite the steadily growing performance of current solid-state amplifiers; this especially due to:

- a thermal inertia much higher than transistors, hence a capacity to tolerate long overloads
- a withstand capacity to high transient peak voltages.

Both properties mean: an enhanced reliability, useful for example for mobile sound equipment.

One might add that the construction of a tube amplifier requires fewer additional passive components. DIY developments are easier.

Paradoxically, it may be more difficult to replace some old transistors or integrated circuits than the counterpart tubes.

4.1. A bit of history

The history of vacuum tubes, in the field of amplification, began with the invention of the triode in 1906 by Lee De Forest. The principle of the vacuum tubes is based on the mobility of electrons in vacuum in the presence of an electric field. This technical application took place not long after the discovery of the electron as a particle by British Physicist Sir Joseph John Thomson.

Other derived types of vacuum tubes were since then commonly used in electronics, as they were essential components of radio receivers, television, radars.

In the particular field of computers were built, almost at the same time, the ENIAC (for Electronic Numerical Integrator Analyzer and Computer) in the United States (1946), and the MESM (Malaia Elektronnaia Schetnaia Machina) in the Ussr

(1950); these machines fully complied to Turing's definition, as they were completely reprogrammable.

The history of semiconductors began in parallel with the invention in 1947 of the transistor by Shockley, Brattain, and Bardeen, from the Bell laboratories. Nevertheless, the first computers relied heavily on vacuum tubes. A first transistor computer (the TRADIC) by the Bell Company occurred in 1954.

Between the 20s and the 70s, the vacuum tubes developed and became miniaturized. During the same period, electronic reviews for the general public currently proposed schematics for DIY domestic devices, such as radio receivers, TV sets, or recorders.

4.2. Present uses of vacuum tubes

Today, vacuum tubes are far from gone. They are used when either very high powers or very high frequencies are needed. Electronic tubes are also still found in microwave ovens, radio and television transmitters, radars and satellites, or for industrial heating by radiofrequencies. Being resistant to electromagnetic pulses, they are used to make so-called "hardened electronics"; they are designed to operate on battlefields where nuclear weapons are used.

Vacuum tubes also remain holding out in small but active areas, among which especially the domain of music creation and reproduction. Authors who have studied the comparison between solid state and tubes equipments underline the importance of the human, e.g. subjective, factors [7], [8].

A true recent innovation must be noted, which is the Nutube, of Korg and Noritake Itron. The Nutube makes use of a technology called vacuum fluorescent display and constitutes an interesting compromise between solid state devices (with their low dimensions, low voltages and energy consumption), and the classical tubes (with their specific "sound"). The Nutube has today gained extent and popularity especially among musicians.

An excellent and detailed analysis of the reasons of the continuing success of vacuum tubes equipment can be found in [9]. In terms of markets shares, it appears that beyond the musical domain, the high-end domain, i.e. the one of the highly demanding audiophiles, represents a still more significant part.

4.3. The future of vacuum tubes

The oldest among us may have retained a sentimental attachment to vacuum tubes.

The law of Moore gives a good representation of the permanent pressure to which the R&D in electronics is subjected. Computers for instance must be always more rapid and more powerful.

Electrons in the vacuum can travel much faster than in a solid like a silicium crystal.

Vacuum nano-electronics is thus developing at the moment. This technology will allow to work at higher frequencies than with solid state components. However, since vacuum tubes require high potential differences, it will not be possible to simply miniaturize vacuum tubes to really compete with transistors.

Examples for renewed implementations are available in the literature [10], [11]. One of the solutions presented for instance makes use of graphene (a mono-atomic layer of carbon atoms). To create miniaturised vacuum tubes, a graphene sheet is placed just above a silicon semiconductor, coated with a metal or an oxide, this allows the extraction of the electrons present in the form of a gaseous sheet just to the interface.

Vacuum tubes may have a bright future and could impose themselves again.

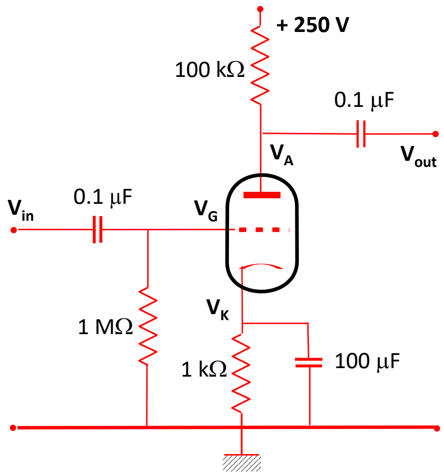

Figure 12. Typical external circuits associated to a triode.

Table 1. Values for the conventional 6J5 triode and for the 6AK5 pentode.

Parameter	Symbol	Triode usual values	Pentode usual values
internal resistance	ρ	10 kΩ	1 MΩ
anode load	R_A	100 kΩ	10 kΩ

5. BEFORE THE MEASUREMENTS: A LOOK BACK ON THE VACUUM TUBES PROPERTIES

5.1. Type of vacuum tubes and characteristics

Before presenting our measurements, let us have a brief look on the vacuum tubes physical principle, and on the different types of vacuum tubes.

Most common types for amplification are the triode and the pentode [12], [13], [14]

The triode has three electrodes: the cathode for electron emission, the anode, or plate, to collect the electrons, and the control grid to modulate the electrons flux I_A between cathode and anode. If the cathode is taken as voltage reference, the anode is polarised positively at V_A through resistance R_A, and the grid negatively at V_G (Figure 12).

Main internal parameters are

- the internal resistance, ρ (in kΩ)
- the transconductance, g (in mA/V)
- the amplification factor, $\mu = \rho \cdot g$.

According to these provisions the general formula for the voltage gain A_v is

$$A_V = \mu \frac{R_A}{R_A + \rho} . \quad (4)$$

5.2. Triode versus pentode

The pentode was developed later than the triode, with the aim to improve some of its characteristics. The pentode thus includes two supplemental grids with fixed potentials: the screen grid G_2 (positive) and the suppressor grid G_3 (potential close to zero) [15], [16].

A pentode could be controlled from any of its three grids. In practical, this is not used except in very special applications.

The physical properties, and the external design parameters recommended for use, have sensibly different values. The values for the conventional 6J5 triode and for the 6AK5 pentode are reported in Table 1.

The respective networks of characteristic curves of the two types appear to be very different. Those of the pentode are very similar to solid-state transistor characteristics (Figure 13 and Figure 14). The networks can be plotted either in the (V_A, I_A) plane (the Kellog network), in the (V_G, I_A) plane, or in both.

A triode can be modelled by a power law

$$I_A \sim \lambda \, V_A^{3/2} \, , \quad (5)$$

whereas a pentode is rather described by an exponential law

$$I_A \sim \lambda \, (1 - e^{-k \, V \, A}) \, . \quad (6)$$

A pentode can nevertheless be connected so as to simulate a triode (shield connected to anode and suppressor connected to the cathode). The goal is then to come closer to the triode properties. Some amateurs of high fidelity claim to be able to distinguish between "a triode sound" and a "pentode sound". This is theoretically possible, but implies in any case to benefit from an exceptional hearing acuity (see Figure 13 and Figure 14).

5.3. Thermal noise

A vacuum tube is a thermal noise generator, the average noise level V_n being linked to the internal resistance ρ

$$V_n = 2 \cdot \sqrt{k_B \, T \, \rho \, \Delta f} \, , \quad (7)$$

where T is the absolute temperature, Δf the bandwidth, and k_B the Boltzmann constant.

As ρ is generally much higher for pentodes, triodes are often preferred for low level input stages, and for preamplifiers: 1 µV instead of 10 µV [17].

Figure 13 and Figure 14 shows that, if the operating point P is well chosen, the tube can be considered as reasonably linear around P. This is the typical situation in a preamplifier, which handles normally small signals.

A good choice for polarisation means that one should take care to avoid diagram zones where the curves are not straight. In other terms, one should take a high anode load $R_A \gg \rho$ for a triode, and conversely a low anode load for a pentode $R_A \ll \rho$.

Typical conditions for use of a conventional 6J5 triode and for a 6AK5 pentode would be according to Table 2.
Hence, for the 6J5 triode a voltage gain according to equation (4) $A_v = \mu \cdot R_A/(\rho + R_A) \sim 20$, and for a 6AK5 pentode a voltage gain according to equation (4) $A_v \sim 100$.

The value 100 is also the gain value commonly adopted with operational amplifiers, with the difference that the gain of an op amp is entirely determined by its negative retroaction loop, whereas for a tube it is a gain in open loop.

Dispersion of intrinsic characteristics of op amps does not appear; it does for vacuum tubes.

5.4. A statistical approach

In this study, a test has been made on a batch of 20 identical vacuum tubes, to get an idea of the dispersion of the main functional parameters g, ρ, and μ (Figure 15).

The very common type EF 80 pentode has been chosen and tested under stable conditions V_A = 250 V, V_{G2} = 150 V. A sufficient heating time for stabilisation was respected.

The anode current I_A was measured for two values of the control grid voltage, V_{G1} and V'_{G1}, so as to determine the transconductance g

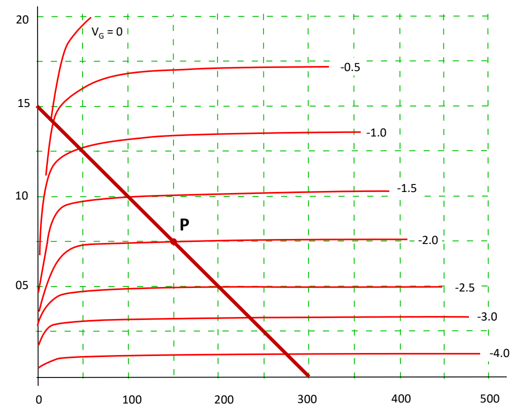

Figure 13. 6AU6 pentode.

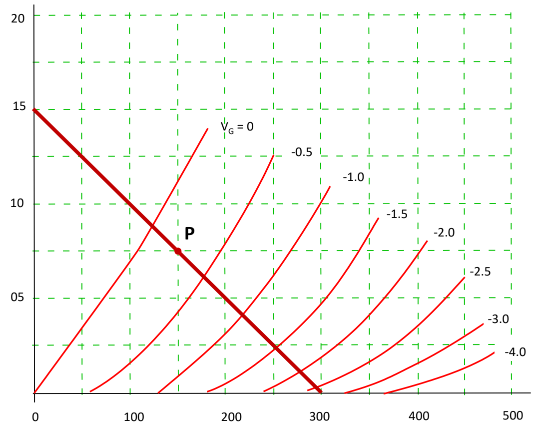

Figure 14. same tube (6AU6) used as a triode.

Table 2. Typical conditions for use of a conventional 6J5 triode and for a 6AK5 pentode.

V_A	ρ	g	μ	R_A
250 V	7.7 kΩ	2.6 mA/V	20	100 kΩ
180 V	690 kΩ	5.1 mA/V	3500	20 kΩ

$$g = \frac{\Delta I_A}{\Delta V_{G1}} = \frac{I_A - I'_A}{V_{G1} - V'_{G1}} \, . \quad (8)$$

5.5. Measurement uncertainties

Uncertainty causes here were mainly the voltmeter/ammeter calibration uncertainties. Ambient test conditions were close enough to reference conditions. Although the same instruments were utilised twice, their measurements are considered to be independent.

From equation (8) we derive the expression of global uncertainty $u(g)$

$$\begin{aligned} u^2(g) &= \sum_{i=1}^{N} \left[\frac{\partial g}{\partial x_i}\right]^2 u^2(x_i) \\ &= \left[\frac{\partial g}{\partial I_A}\right]^2 u^2(I_A) + \left[\frac{\partial g}{\partial I'_A}\right]^2 u^2(I'_A) \\ &+ \left[\frac{\partial g}{\partial V_{G1}}\right]^2 u^2(V_{G1}) + \left[\frac{\partial g}{\partial V'_{G1}}\right]^2 u^2(V'_{G1}) \end{aligned} \quad (9)$$

$$u^2(g) = \sum_{i=1}^{N} \left[\frac{\partial g}{\partial x_i}\right]^2 u^2(x_i)$$
$$= 2 \cdot \left[\frac{u(I_\mathrm{A})}{V_{\mathrm{G1}} - V'_{\mathrm{G1}}}\right]^2 + 2 \cdot \left[\frac{(I_\mathrm{A} - I'_\mathrm{A}) \cdot u(V_\mathrm{G})}{(V_{\mathrm{G1}} - V'_{\mathrm{G1}})^2}\right]^2. \quad (10)$$

The voltmeter, although having a 3-digit display, was considered as class 1 ($u(V_{\mathrm{G1}}) = u(V'_{\mathrm{G1}}) = 0.01$ in volts (V)) ; the ammeter of the tube tester was considered as class 2 ($u(I_\mathrm{A}) = u(I'_\mathrm{A}) = 0.02$ in amperes (A)) (Figure 16).

Figure 15. batch of vacuum tubes for dispersion test

Figure 16. Experimental setup with tube tester Metrix 310B (EM84 indicator tube under test)

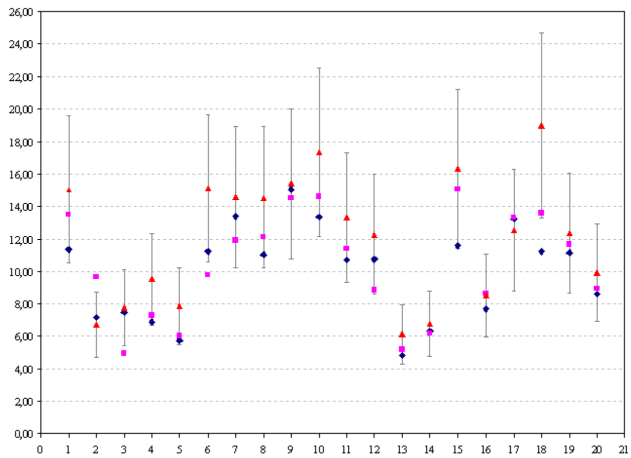

Figure 17. experimental data for transconductance g

The measurement dilemma was to choose an adequate variation of grid polarisation ΔV_{G1}, high enough to minimise errors, and not too high to be sure to remain in a linear domain.

Hence with $\Delta V_{\mathrm{G1}} \sim 1$ V an upper bound value for expanded uncertainty $U(g) = 0.06$.

To confirm the experimental results, three series of measurements were made (Figure 17 - abscissa = sample number).

Two main tendencies appear :

1) a noticeable dispersion of the transconductance is observed on the vacuum tubes batch

2) the properties of the vacuum tubes are not totally stable in time; thus for g, in mA/V

max value	15.06
mean value	10.35
min value	4.94
standard dev.	3.28.

Results are consistent with the tolerances announced by tube manufacturers. Values when acknowledged are around 30 %.

The uncertainty calculation above confirms that this dispersion is not to be attributed to the measurements themselves. However, these test results should not be extrapolated to vacuum tubes of very recent make, or to severised series of tubes. Also, in the case of a stereophonic equipment, one may make use of paired vacuum tubes.

Because of uncertainties, it was not possible to measure the internal resistance ρ the same way (using $\rho = \Delta V_\mathrm{A}/\Delta I_\mathrm{A}$), the anode current I_A being almost insensitive to anode voltage V_A in the case of a pentode.

5.6. Modelling approach

The design of amplifiers and other similar devices today makes a large use of CAD tools. One of the most popular of these tools is SPICE and its various releases. SPICE allows for specific sub-models taking into account the particular physics of active components. A recent study has proposed such models applied to current types 12AX7, 12AU7, 12AY7, 12AT7 of triode tubes [18].

6. MEASUREMENTS ON THE PREAMPLIFIER

The measurement setup used consists in a Vellemann PCSGU 250 combined digital signal generator and digital two-channel oscilloscope. Signals are displayed on the screen of a Personal Computer (Figure 18, Figure 19, Figure 20).

6.1. Linearity affected by frequency

Two types of signals have been used: sinusoidal and square.

The frequencies selected were limited to four: 20, 200, 2 000 and 20 000 Hz.

The amplitude response is correct on the 4 frequencies, although some phase lag appears at extreme frequencies.

for each case V_{in} = blue, peak amplitude = 1 Volt;
V_{out} = red;

time scale indicated in Figure 20.

Square signals at 20 and 20000 Hz show a typical response of a first order filter, likely of R-C type. The scales of the Figure 21 allow to estimate the corresponding time constants.

Figure 22 gives a synthetic view of the frequency response of the preamplifier.

An adjustment of the gain at both low frequencies and high frequencies is possible thanks to "bass" and "treble" knobs, thus modifying the tonality according to listener's taste.

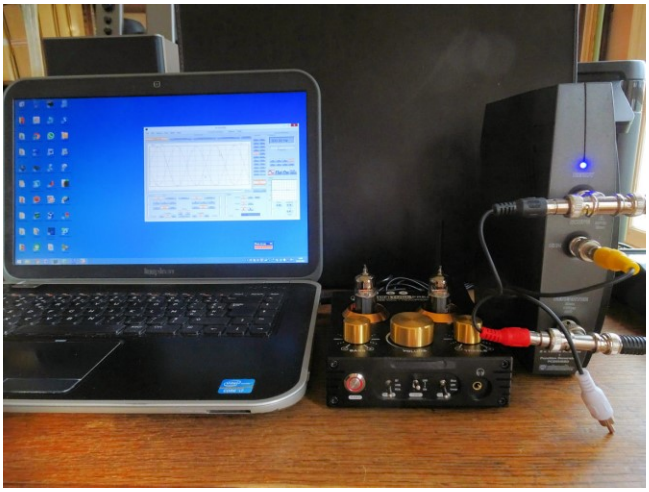

Figure 18. Overall view of test setup.

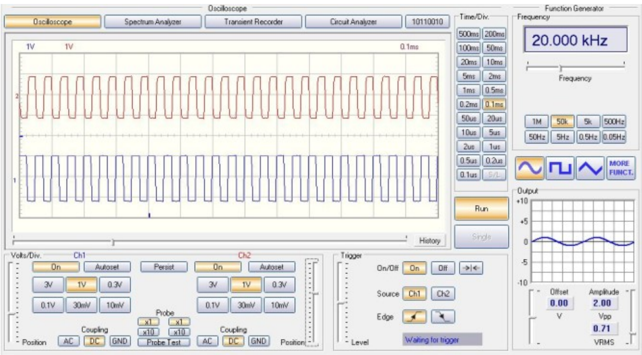

Figure 19. Oscilloscopic display.

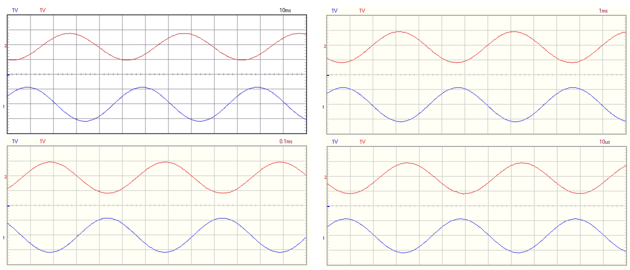

Figure 20. Input and Output sinusoidal signals at 20 Hz, 200 Hz (on top), 2 kHz, and 20 kHz (bottom)

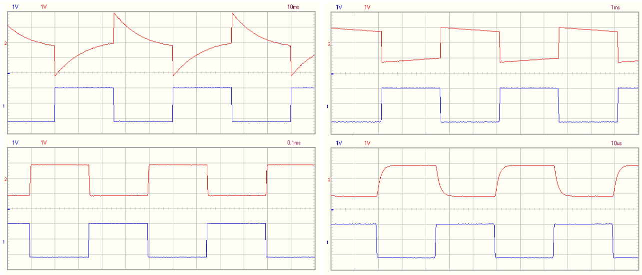

Figure 21. Input and Output square signals at 20 Hz, 200 Hz (on top), 2 kHz, and 20 kHz (bottom).

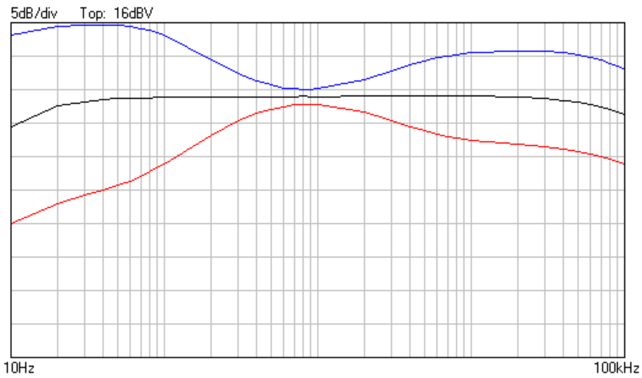

Figure 22. Frequency response with the action of the tonality correctors.

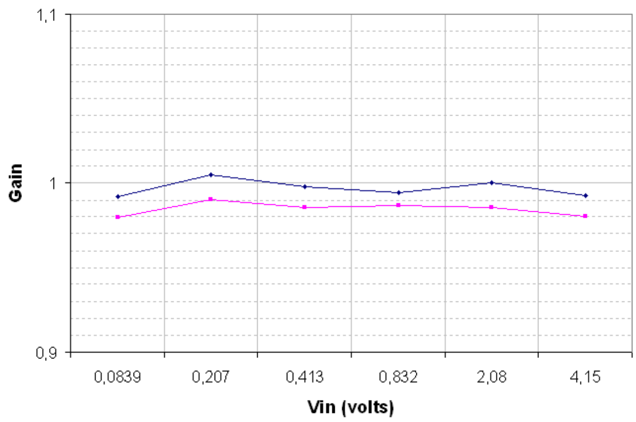

Figure 23. Gains of preamp channels (RMS inputs in volts).

6.2. Linearity affected by amplitude

Linearity on a broad voltage range was checked by gain measurements for both right and left channels.

Measurements were made at the frequency of 200 Hz. This was done so in order to avoid interference with the supply frequency at 50 Hz, and also in order to minimise error effects at a higher frequency due mainly to connection cables.

The measurement device was a Metrix MX573 digital multimeter (3½ digits). The preamp gain control knob was positioned so as to have a gain close to 1. Results are reported in Figure 23.

Uncertainties are not presented here in detail, while the equipments were very similar to those in § 4.3.1, and so the values.

The approach did not allow to decide about the presence of weak non-linearities, as the gain of both channels at the diverse signal amplitudes remain in the range of ± 1 %. The goal was also to detect a possible clipping. Associated oscillograms show that there is no clipping even at the highest levels of input voltage, to which a preamp should normally not be subjected.

In none of the frequency and amplitude tests, a non-linearity could be observed.

6.3. Vacuum tubes substitutions

About vacuum tube preamps, it is frequently recommended, even by the manufacturer, to replace for higher performance the original 6J5 triodes with 6AK5 pentodes and even with 6BE6 heptodes[1].

[1] Equivalence between European codes and American codes for tubes are as follows : 6BA6 ≡ EF 93, 6AU6 ≡ EF 94, 6AK5 ≡ EF 95 = 5654, 6BE6 ≡ EK 90, and Chinese 6J5 ≡ 6AH6 ; power pentode 6AK6 also accepts the same socket.

Opinions reported by reviews on the Internet about the relevance of such substitutions are sometimes enthusiastic, but mostly diverse. They usually rely on auditory impressions rather than on objective measurements.

Although these vacuum tubes are not of the same type, their connection diagrams remain compatible.

As we disposed of none of the substitution vacuum tubes suggested, we borrowed a pair of 6BA6 pentodes from the radio receiver of our grand-parents.

Performances have then been compared using the original 6J5 triode on one channel and a 6BA6 pentode on the other channel of the preamplifier. The 6BA6 pentode is designed as a variable transconductance tube, normally intended for radio reception, but this will not be an inconvenience here, provided the amplitude of the signals remain small.

The tests above on pure frequencies were repeated and showed no difference.

During all the tests, no significant difference linked to the tube types could be observed.

7. DISCUSSION: CAN METROLOGISTS CONTRIBUTE TO THE DEBATE?

They certainly do, insofar an objective approach is adopted.

The choice of an audio equipment, preamplifier or other, is a personal matter.

But the decision is a complex one; it can basically follow two approaches: either objective (measurements), or subjective. One can eventually try to combine the two.

Subjective approach would seem to be more relevant, in the sense that the final satisfaction of the user is the point that counts: in our case, the happiness of the listener to an audio equipment. But unfortunately, a subjective decision, taken by a human brain, is subject to numerous influential parameters, including ambient conditions, opinions of other people, and it has a poor repeatability and is hence unreliable.

An attempt to handle rationally the information provided by the human five senses is developed in the scientific research area called "soft metrology". Concerning sound, it seems that until today only the negative aspects of it (disturbance by noise) have been studied, and not yet the positive ones, such as satisfaction from listening [19], [20].

Thus for the moment, current metrology remains the adequate tool to assess the reality of the technical properties attributed to the audio equipment by their manufacturers, retailers, users may it be through advertisement, technical literature, or social networks.

8. CONCLUSION

No non-linearities were observed during the tests of the preamplifier sample.

These tests also confirm that the technical specifications announced are respected.

What are the lessons to be learned from this study?

1) thanks to the huge, and fast, progress of electronics, and especially those of integrated components, the totality of audio reproduction systems today comply easily to usual performance needs, if we take as a reference the average human hearing capacities. This applies especially to bandwidth and transient response (which is more of less the same thing), as well as signal-to-noise ratio. The remaining tough point is the one of musical dynamics (covering in practice a very large range, say around 100 dB, hence high output electrical power should be available whenever the music demands it)

2) a musical instrument may have a specific sound. An electronic reproduction device is not a musical instrument. When such a device shows a specific response, then this necessarily implies a distortion. An audio device should be as neutral as possible. One should bear this in mind, listening to audio amplifiers or preamplifiers.

3) one can attempt to compare audio reproduction devices between them on a scientific basis. But ranking those devices in such an approach can only be very difficult, because technical criteria to consider are many. Moreover, the most determining criterion will be the taste of the listener, i.e. a subjective parameter. Although some research has already been made in the field of "soft metrology", it seems to date unavoidable to accept that in this field the final decision belongs to the auditor.

4) a vacuum tube preamplifier may definitely constitute a decorative object.

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