10.5.13 Comparison of power tubes

What happens if the two 6L6GC in a Vibroverb are swapped for a pair of KT66 – or for a pair of EL34? Citations of how these tubes allegedly sound have already been given on the preceding pages. Let us first disregard the sound – how do the electrical data change? First, there is the **heating**: two 6L6GC require a filament current of 1.8 A, two KT-66 demand 2.6 A, and two EL34 already push this to 3 A. The mains transformer is therefore put under different strain, but let us insinuate by all means that it can take the additional load for the short term. The bias voltage at the grids (i.e. the bias current) needs to be adapted, of course – and now what? Does the frequency response change substantially due to the tube-swap? What about the harmonic distortion? More generally: which part do the tubes play in the operating behavior of the power stage?

The simple solution: it is the output power that depends on the power tubes – and that's it. You may or should add a few bits here and there, but in essence, this is the sobering answer. We do find differences already with regular instrumentation, but the relevance to the sound remains very modest. The measurements discussed in the following were taken from a Marshall power stage that was, however, operated via a stabilized 400-V-power-supply. One of the two plate resistors of the differential amplifier was adjustable in order to balance out different gain of the power tubes. The primary impedance of the output transformer was R_{aa} = 3.5 kΩ; the resistors at the screen grid had 1.5 kΩ each. To emphasize any differences, the negative feedback in the power stage was deactivated. **Nominal load** implies that an 8-Ω-resistor (purely ohmic) was connected to the 8-Ω-output. The signal generator was directly connected to the input of the differential amplifier (→ v_U).

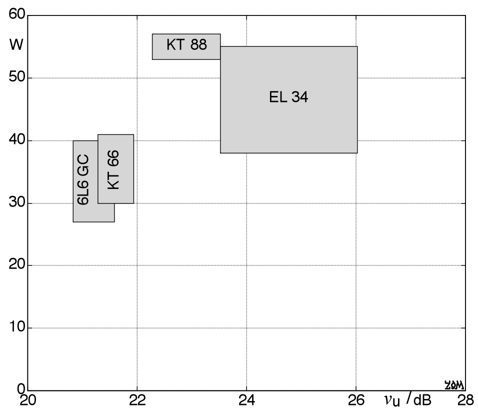

Fig. 10.5.65: Output power vs. voltage gain.
6L6GC from GEC, TAD, JJ, Ultron, TungSol, Sovtek;
5881 from Sovtec, TungSol;
KT66 from TAD, TungSol, Marconi;
EL34 from TubeTown, TAD, JJ, EH, Valvo;
KT88 (and 6550) from Sovtek, GEC, EH, SED;

Power measurements were taken at 500 Hz at the onset of clipping and with nominal load. Any influences due to the power supply were eliminated using a stabilized plate-voltage (400 V)

Fig. 10.5.65 gives an orientation regarding the output power and the gain of the power stage with different tubes. The sample was very small (20 6L6GC, 10 EL34, 10 KT66, 8 KT88), and therefore it is to be expected that the market will offer specimen with data lying outside of the grey areas. Already the tubes measured here show considerable scatter in the maximum power: a fresh pair of 6L6GC may yield the datasheet-conform 40 W, or a meager 27 W. For the EL34, the span extends form 38 W to 55 W, and consequently the changeover 6L6GC → EL34 could bluntly double the power … or reduce it some. In any case, the probability that the voltage gain goes up by about 2 – 5 dB is high. The higher maximum power could lead to stronger distortion in the connected loudspeaker – but this should not tempt us to generally attest more distortion to the EL34. If at all, these would be indirect tube characteristics. How much the power stage itself distorts, that will be subject to the following analyses.

All these analyses were done at **500 Hz and with nominal load**. Before we investigate the harmonic distortion, let us take a look at the **transmission characteristic** i.e. the mapping of the generator voltage onto the output voltage generated across the 8-Ω-load-resistor. With a small bias-current (20 mA), we see a saddle-point for small drive levels, in other words a progressive curvature of the characteristic. This changes into a degressive curvature with high bias-current (60 mA). All three curvatures are depicted in **Fig.10.5.66** in an idealized manner.

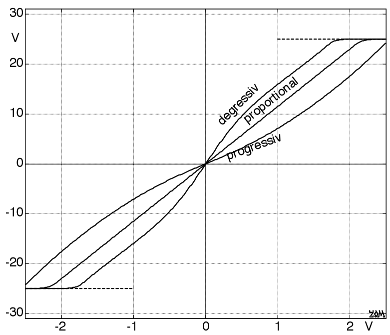

Fig. 10.5.66: Transfer characteristics

The progressive characteristic rises from the origin with increasing slope, the proportional dependency shows a constant slope, and for the degressive curve the slope decreases with increasing drive. At 25 V the so-called clipping (limiting of the ordinate values) sets in. These curves are, however, idealized; for the real tube there is no perfect proportionality: all curves are “somehow bent”. The exact shape depends on the geometry of the tube-electrodes and on how equal or unequal the two power tubes are; it will therefore be different for each push-pull power stage. See Chapter 10.5.3 for the basics of push-pull operation.

From the idealization on to real tubes: **Fig. 10.5.67** shows three transmission characteristics of a Sovtek 5881♣. It corresponds best to the above idealization (which does not necessarily hold for all tubes of this type, and much less for Sovtek in general). Seeking the least distortion, we would have to choose the middle curve (40 mA). The Groove-Tubes 6L6GC shown next also allows for a good proportionality, although it requires 60 mA cathode-current, which makes – at 400 plate-voltage – already for a pretty hot operation. The Tung-Sol 5881 again is more similar to the Sovtek 5881 – so much so that the conjecture finds support that the two tubes may differ only in the labeling. The next tube, an old Marconi, can keep up well with the others although this is not a 6L6GC but a KT-66.

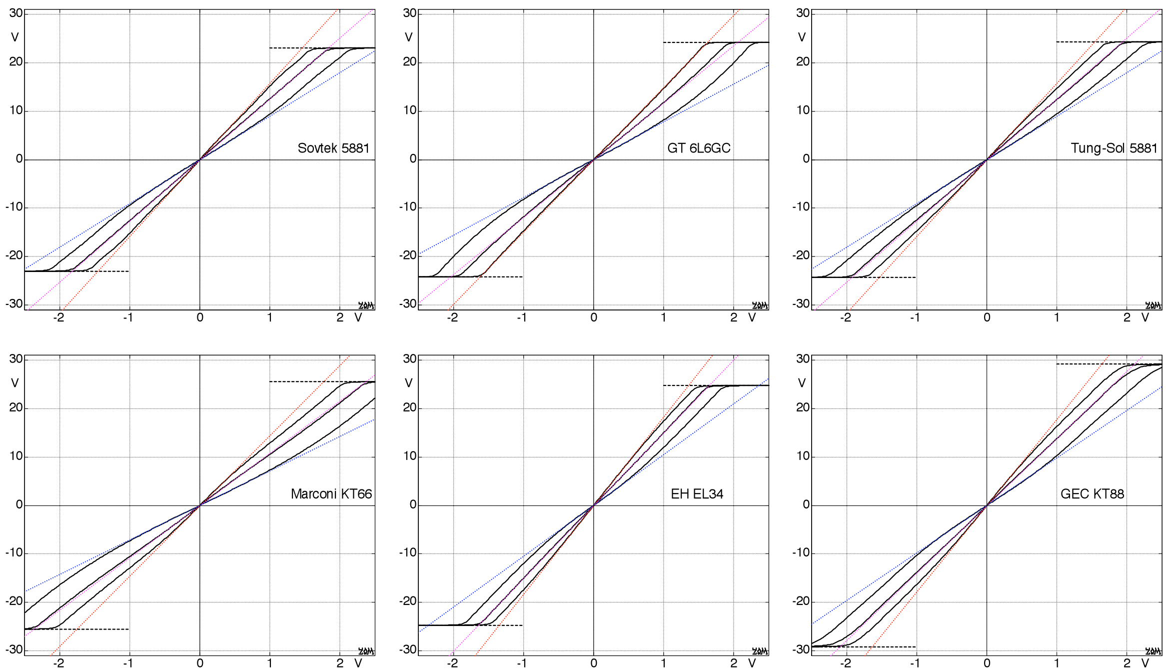

Fig. 10.5.67: Measured transmission characteristics, nominal load, I_K = 20, 40, 60 mA.

♣ The 5881 is the professional variant of the 6L6GC.

For the next tube, the family of characteristic curves looks similar, too, as it does for the last specimen in this overview. These are entirely different tubes, however: here we have a pair of EL34's and a pair of KT-88's. We do see some differences at the drive limit but the basic curves are very similar indeed. For these 6 pairs, that is! The tubes from **Fig. 10.5.68** show that more strongly bent curves exist, as well – to a varied degree. For the JJ-6L6GC we see a pronounced ripple while the TAD has a more degressive characteristic – this shows that the difference between a 6L6GC and a KT-66 is not necessarily bigger than the difference between two KT-66's.

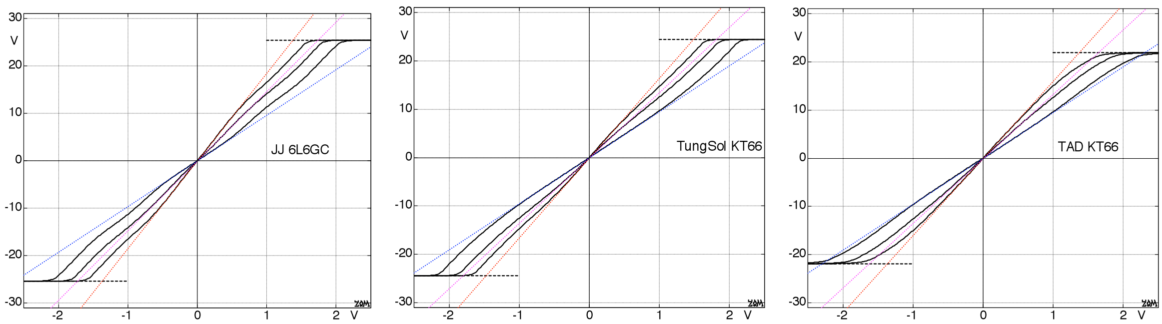

Fig. 10.5.68: Measured transmission characteristics; nominal load, I_K = 20, 40, 60 mA.

The x-vs.-y-depiction is not very suitable to clarify how well the transmission characteristics can follow the ideal proportionality – the **analysis of the harmonic distortion** delivers better results here. The level of a 500-Hz-tone was increased by 30 dB over the course of 4 seconds, and at the same time the levels of the first 20 harmonics were extracted from the output signal of the power stage (software Cortex VIPER). The results are shown in **Fig. 10.5.69**.

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Fig. 10.5.69: 3rd-order harmonic distortion vs. output power, 500 Hz, nominal load, NFB deactivated.
These figures are reserved for the printed version of this book.

In Fig. 10.5.69, a maximum of the distortion attenuation (= distortion minimum) appears around 40 W. This is an effect of the change in curvature in the range of the clipping-onset; the 3rd harmonic changes its algebraic sign here. As different the curves may look – the non-linear distortion can be easily reduced to inaudible levels by choosing the appropriate bias-current. However, "appropriate" means a whopping 60 mA for the GT-6L6GC, but no more than 30 mA for the JJ-6L6GC. In the case that distortion is heard when comparing power tubes: that may simply be due to an inappropriate bias-current!

We have all heard or read opinions related to the 'tube-sound': *"simply unplug the two 6L6GC and plug in two KT-66 – you gotta hear that difference!"* Just like that, without considering the bias-current? It is almost certain that, with such a makeshift setup, differing modes of operation are evaluated rather than the difference in the tubes per se. Setting the bias-current via the bias-voltage at the grids will not remove the problem: mind you, for the same bias-voltage at the grids, three "premium matched" 6L6GC-pairs show sizeable variance in the bias-current (30 mA vs. 40 mA). The voltage gains for the two half-waves did not match, either[♣], with 10% difference. This problem persists in particular with the famed NOS-tubes because normally there will not be 20 of them available to choose the ones matching best.

Fig. 10.5.69 compared four beam-tetrodes. Does the EL34, a real pentode, show other curves? Yes and no, as we see from **Fig. 10.5.70**. In the details, there are strong differences and in particular there is more power, but we cannot speak of a generally different behavior. If we take k = 3% as the limit for audible non-linear distortion in a guitar amp, all tubes generate audible distortion only just before going into clipping, if the bias-current is set correctly. They also show the same type of increase of the THD. Moreover, we must not forget that the THD will decrease significantly as we (re-) activate the negative feedback.

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Abb. 10.5.70: As Fig. 10.5.69, but for EL34 and KT-88; without NFB, 20 – 60 mA.
These figures are reserved for the printed version of this book.

[♣] Amongst tube retailers, the readiness to match and pair (up) does not seem to be particularly distinct ...

 Translated by Tilmann Zwicker

Time for an **interim statement**: yes, the tubes under investigation show variances, but in essence this is limited to power output and gain. While we find differences between 6L6GC and EL34 regarding the individual distortion characteristics, similar differences are observed between two pairs of 6L6GC. Is it, however, sufficient to analyze only these parameters? What about the **internal impedance** (also termed source impedance)? **Fig 10.5.71** shows the corresponding measurements. Pentodes are of high impedance, the frequency dependency mainly stems for the output transformer (Marshall). The resonance of the winding receives differing dampening from the power tubes; this makes for a different height in the maxima. The left-hand picture depicts the impedance curves for six pairs of 6L6GC (lines), two pairs of 5881 (dashed), and one 6L6WGC-pair (dotted). The right-hand picture shows the results for two KT-66-pairs and for three pairs of EL34. What's interesting: the lines close to each other are the dashed line (KT-66) and solid line (EL34) i.e. they are not the ones that would "belong" together. So again, we do not see a general difference.

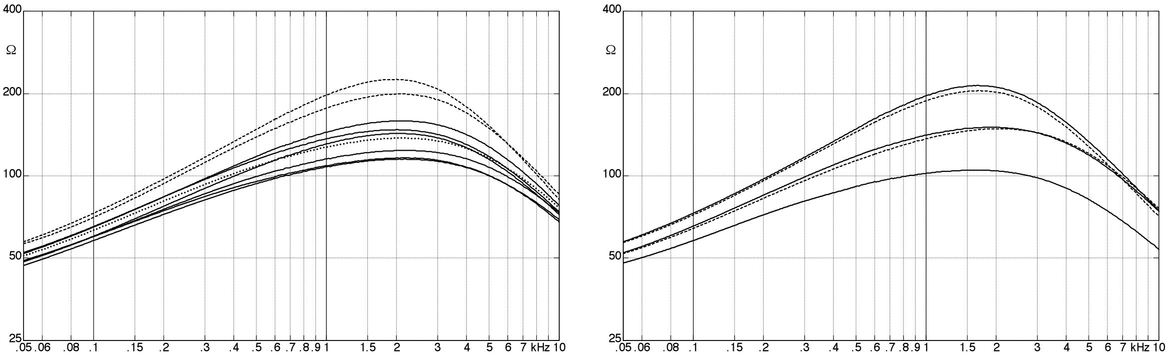

Fig. 10.5.71: Frequency response of the internal impedance measured at the 8-Ω-output; I_K = 40 mA.

The internal impedance (which is also dependent on the bias-current) influences the dampening of the loudspeaker and thus the transmission frequency response. This however holds mainly for power stages without negative feedback. Chapter 10.5.14 elucidates how much this effect looses its significance as soon as the negative feedback is in action.

Was that it? No! It is a widespread error to limit testing of power amplifiers to merely the nominal impedance as a load. Loudspeaker impedances are frequency-dependent[♣], and therefore supplemental measurements with a **load of 32 Ω** follow here. The main difference occurs between beam-tetrode and pentode (**Fig. 10.5.72**): with a true pentode (e.g. the EL34), the current through the screen grid increases within the distribution area towards much higher values. This conversely implies a reduction of the plate-current i.e. a pronounced sharp bend.

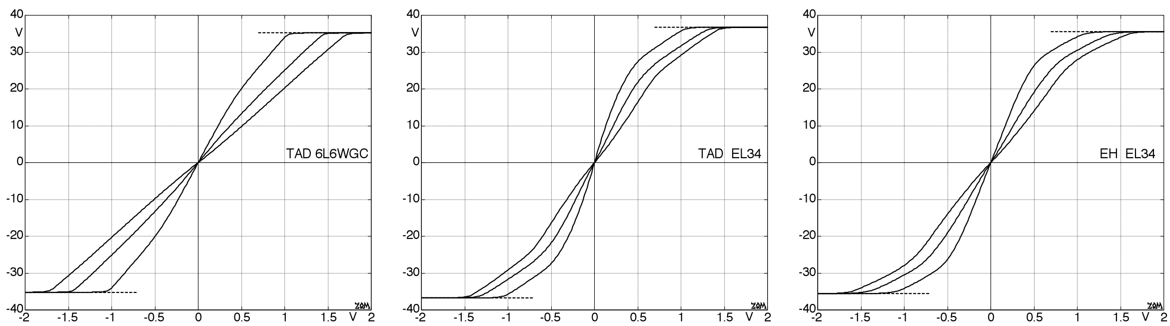

Fig. 10.5.72: Measured transfer characteristics, 32-Ω-load at the 8-Ω-output, I_K = 10, 30, 50 mA.

[♣] It was already documented in Fig. 10.5.28 that the speaker does not have of a real but a complex characteristic.

The sharp bend appearing in the EL34-characteristic (Fig. 10.5.72) generates a different curve of the harmonic distortion – see **Fig. 10.5.73**. Still, we again need to heed here that the negative feedback is deactivated. As typical NFB is brought in, this effect looses its significance, as can be seen from the dashed lines.

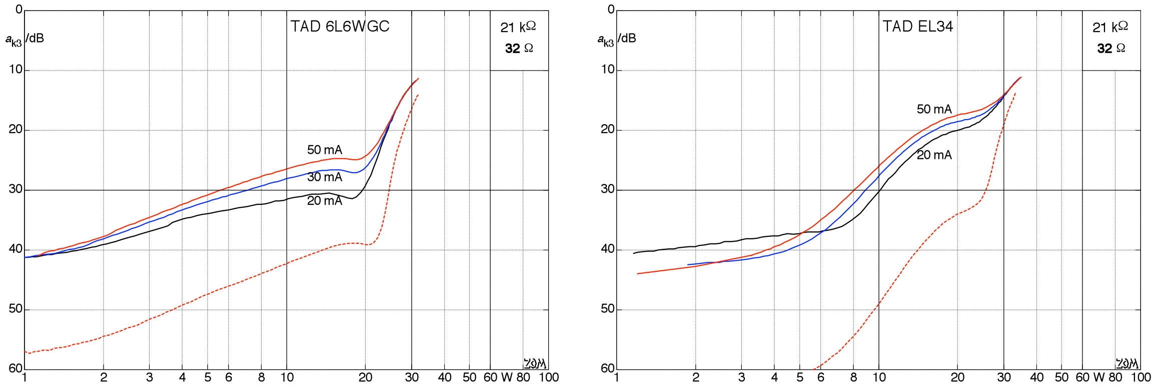

Fig. 10.5.73: 3rd order distortion attenuation vs. output power, 500 Hz, 32 Ω at the 8-Ω-output.
Negative feedback activated (dashed) and deactivated (solid line).

As different as the individual distortion attenuations might be: if we take 30 dB as audible limit, only maximum power and gain are left as main criteria (with the NFB activated). Because the EL34 has (in the present series of measurements) 2 – 5 dB more gain than the 6L6GC, the frequency response of the amp with active NFB changes somewhat. The higher the gain (or the transconductance) is, the stronger the effect of the NFB, and the smaller the influence of the loudspeaker impedance on the frequency response (**Fig.10.5.74**). In case you regard these differences as essential: simply change the negative-feedback circuit ☺.

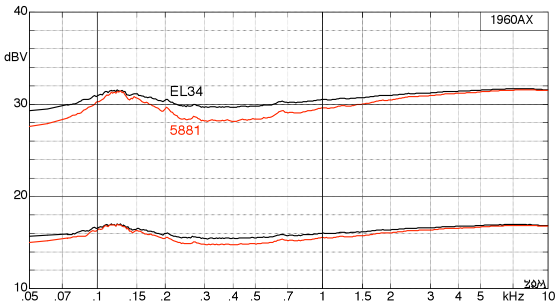

Fig. 10.5.74: Transmission frequency response.
Power stage with negative feedback, 16-Ω-output,
Voltage level at the Marshall-Box (1960-AX).
Sovtek 5881 (red), TAD El34 (black).
For the upper two curves, the power stage is overdriven.

Conclusion: a representative comparison is not possible because even the data of selected tubes include a scatter, and because the vendors do not guarantee any limit values. The sample analyzed above shows measurable differences between various 6L6GC, 5881 (6L6WGC) und KT66, but these will most probably lie within the assumed production scatter. They are also of secondary importance in everyday studio- and stage-operation. Within the sample, the EL34's distinguish themselves regarding maximum power and transconductance, and from this a marginal difference in the frequency response results. No investigation could be carried out regarding the **lifetime**. For example, in order to check the 10.000 h propagated by MOV, 14 months would be needed! If we would set up 15 power stages per tube-type in order to meet the minimum statistical requirements, the cost for mains power alone would amount to 20.000 Euro – that is not reasonable. Who can guarantee that after the conclusion of the test, the tube vendor will not have "his" special 6L6-WGC-STR-XXL-premium-selected built by another manufacturer? Due to the even better offered quality, as the vendor writes … or rather because he did not buy a sufficient quantity off the first manufacturer…

For the “small” power tubes **6V6GT and EL84**, another degree of freedom is added: besides amplifiers with a fixed offset-voltage at the grid (e.g. the Deluxe reverb), there are also amps with a cathode resistor (e.g. the AC-15). This resistor has several effects: the DC current flowing through it generates the offset-voltage, the power dissipated in it is lacking in the loudspeaker, and in overdrive mode it changes the operating point.

In the AC15, the **cathode-resistor** has a value of 130 Ω generating about -10 V offset voltage, and somewhat more than 40 mA per tube. The tweed Deluxe has 270 Ω, -23 V and more than 40 mA, respectively (depending on rectifier tube and power tubes). With increasing drive level, the average cathode-voltage rises (due to the non-linearity in the tubes), and the operating point shifts towards the ”cooler” range. The transfer characteristic becomes flatter. The following measurements were again taken using a stabilized power supply (300 V), with R_{aa} = 6.2 kΩ, no negative feedback, R_{g2} = 470 Ω, ohmic nominal load.

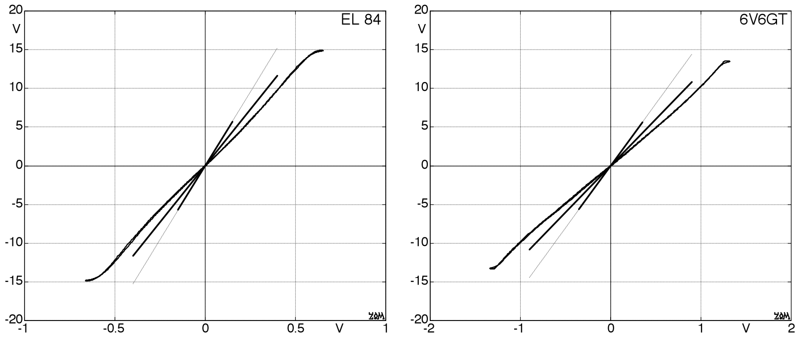

Fig. 10.5.75: Transmission from the phase-inverter to the load-impedance. Power stage with cathode-resistor.
EL84: 120 Ω, 6V6GT: 270 Ω,
bridged with 250 µF.
Three different drive-levels.

We can see from **Fig. 10.5.75** that the EL83 and the 6V6GT differ in gain by 7.5 dB, and that the gain drops by 4 dB with increasing drive-level. With a fixed bias-voltage, such a gain-reduction cannot be observed (compare to Fig. 10.5.45). As the overdrive increases, a saddle point in the origin appears for both tubes – here the true pentode differs from the beam-tetrode, though: in the EL84, the characteristic has an almost horizontal slope in the origin (**Fig. 10.5.76**) while for the 6V6Gt, this gain-decrease is much weaker.

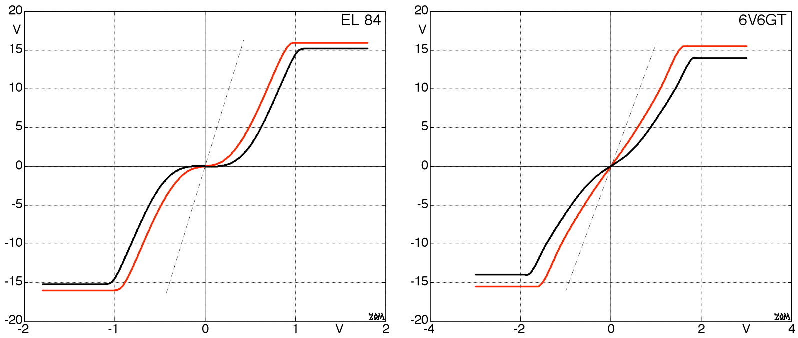

Fig. 10.5.76: Transmission from phase-inverter to load impedance.
With R_K (black) and without (red).
Overdriven power stage.

This *dip* in the transmission curve has several reasons in a guitar amplifier: as the drive-level increases, the supply voltage decreases, and U_{g2} with it; the coupling capacitors towards the phase-inverter change their polarization; if a cathode resistor is present, the voltage drop across it increases. All three effects build up in the same direction and shift the operating point towards the “cooler” range, and consequently the crossover distortion close to the origin increases. Last, the screen-grid resistor needs to be considered, as well: in the EL84, the currents through the screen grid are larger than in the 6V6Gt, and therefore the voltage drop across the screen-grid resistors is bound to be different.

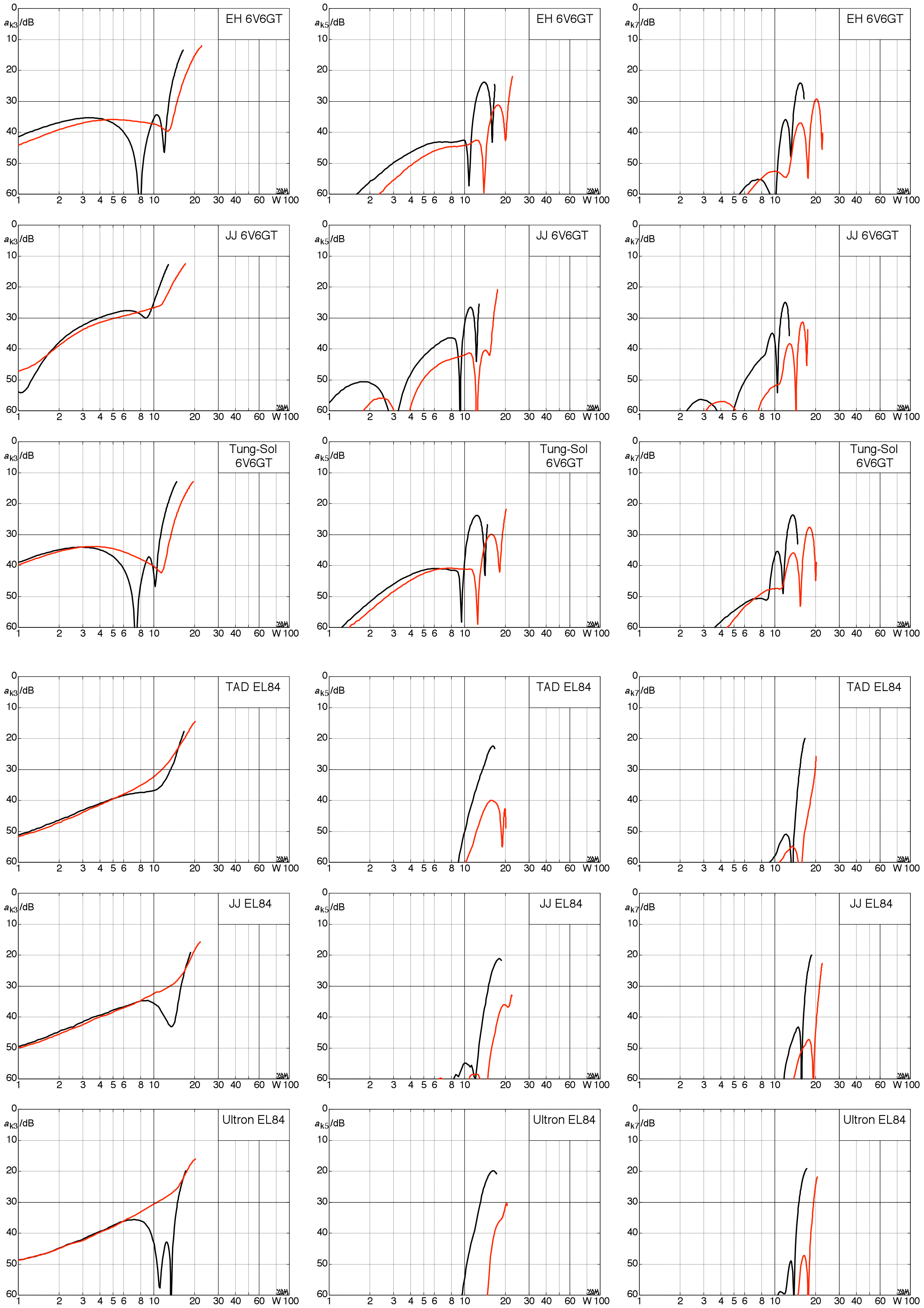

Fig. 10.5.77: Attenuation of distortion a_{k3}, a_{k5} and a_{k7} with nominal load. With (black) and without (red) R_K.

In **Fig. 10.5.77** we see the first three odd-order distortion attenuation characteristics. For k_5 and k_7, the situation is clear: *without* cathode resistor, the power stage distorts more than *with* this resistor, and the EL84 distorts less than the 6V6GT. For the 3rd-order distortion, such tendencies are less pronounced. Strongly overdriven, the amp again has the larger output power without R_K. At around 10 W, however, k_3 is subject to strong fluctuations that are different from tube to tube.

The frequency response of the **internal impedance** is inconspicuous; the measurements did not lay open any significant differences between 6V6GT and EL84. With regard to the operation with and without cathode resistor, no significant differences in the internal impedance could be found, either – as long as the idle-currents were set comparably.

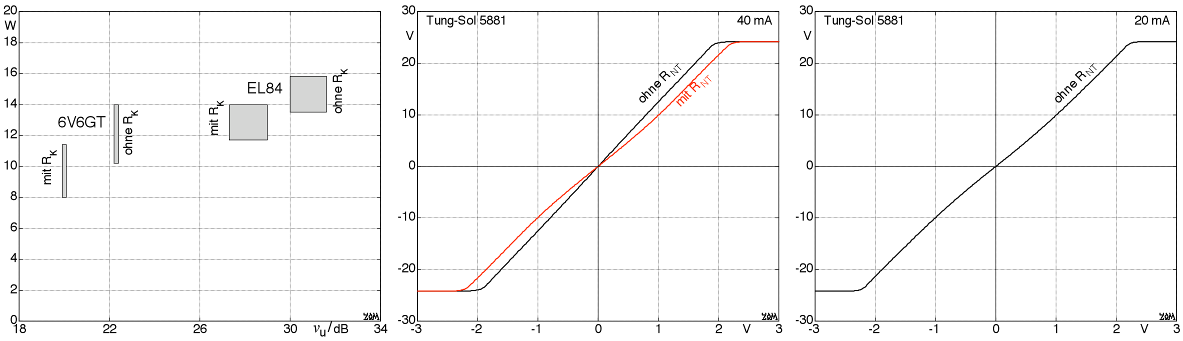

Fig. 10.5.78: Output power vs. gain (left); transmission characteristic (center, right). "ohne"=w/out, "mit"=with.

In the left-hand section of **Fig. 10.5.78**, output power (at 300 V) and gain are shown; again this is only for a small sample. The centre section depicts the effect of the internal impedance of the power supply (R_{NT}). "ohne R_{NT}" (without R_{NT}) indicates the stabilized 400-V-power-supply, being used; "mit R_{NT}" (with R_{NT}) indicates operation from a stabilized 460-V-power-supply, but via a 240–Ω-resistor, and buffered with 47 μF. With the internal impedance of the power supply present, the supply voltage to the power stage drops to 400 V at full power; the bias-current, however, is set for a supply voltage of about 440 V. As the drive-level increases, the operating range wanders off towards "cooler" regions – comparable to the operation without R_{NT}, but with a bias-current of only 20 mA (right). One highly essential difference remains: the red curve is not static! Its slope (= gain) drops with decreasing drive-levels.

Fig 10.5.79 again documents (for a_{k2}) how strong the scatter within new, selected tube pairs can be. Anybody who believes that a THD of 1% is relevant needs to buy better-selected/matched tubes.

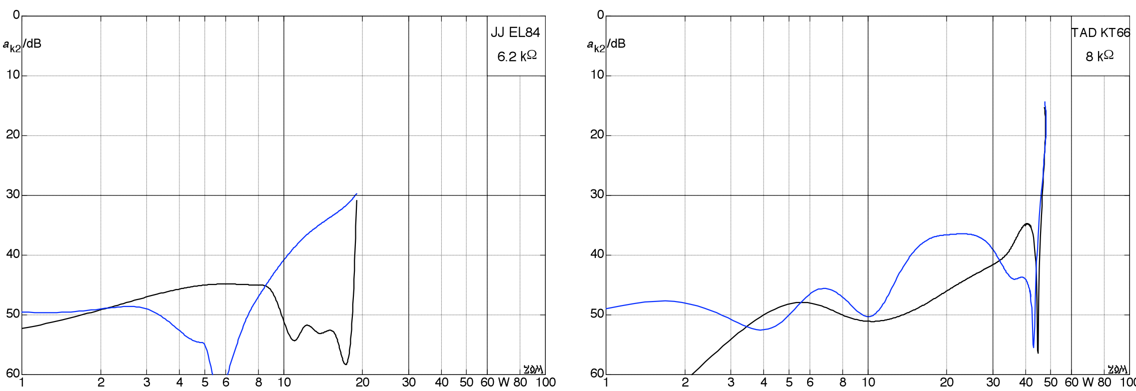

Fig. 10.5.79: 2nd order distortion attenuation; in each picture two newly bought, "matched" tube pairs.