10.10 Comparative Analyses

For the most part, the chapters so far dealt with the analysis of special partial circuits. From now on we will look at guitar amps as a whole. To begin with, the large variance in old amplifiers should again be stressed: passive components could have tolerances of up to 20% or even 30%; same-type tubes vary in their transmission parameters, circuits were modified by the manufacturer without notice. Thus, Tweed Deluxe amps, for example, come within a considerable scatter range – even if they carry one and the same 5E3 designation.

10.10.1 … for they knew what they did?

An old Princeton is comprised of no more than 3 tubes, 2 transformers, 11 resistors, 10 capacitors, 2 potentiometers – and many see it as ingenious miracle work of a brilliant circuit designer whose genius-ideas to this day deny any analysis. The same holds for old Voxes, rare Parks, original JTMs, or whatever else is called up as a precious gem. Well, while it may not have been entirely trivial to develop a power amplifier, and to run a series production for it, during war- or post-war-times, this did not require superhuman ingenuity, either. In most cases, the basis was probably not much more math than $U = RI$ und $P = UI$, supplemented by the knowledge that a capacitor conducts the better the higher the frequency. Isn't this what distinguishes the circuit expert, oh dear editors of musicians' magazines? During the war the following could easily happen: a chap more or less enthusiastically joined the Royal Air Force, was really annoyed with the wireless constantly breaking down, enjoyed a surprising success after replacing a blown capacitor, was as a result promoted to technician (or even engineer) – and had laid down all the groundwork for a later career as circuit designer. Not that the actual theory was unknown: in the Langford-Smith compendium – published for the first time in 1934 – there are hundreds of pages of the basics of circuit design that to this day is worthy of being taught at university. But times were difficult and not everybody who wanted to go to college could do so. Back then, that is. That in 2007 a circuit-"expert" at a well known German musicians' magazine makes a statement along the lines of "*more than 400 V flow through such plastic stuff*" … shows a kind of congeniality, somehow ...

For the old circuits, it is impossible today to know what was the result of an intentional development towards a clear aim, and what "just happened". Presumably, the designers back in the day were not entirely sure themselves what exactly they soldered together. For one, the technical education probably left something to be desired in many cases, and the same was most likely true for the available equipment, as well. There were no PCs in 1950, and neither had "electronic calculators" been developed yet. Transistors were available merely as prototypes in R&D – the lab equipment was exclusively tube-powered. That did work pretty well for a tone-generator and an oscilloscope, but already distortion measurements posed a serious challenge. It wasn't impossible – HP (from 1939) and B&K (from 1942) offered audio measurement equipment – but it was *expensive*. For a small Brüel&Kjaer audio measuring station, even as late as 1987 one had to shell out (in €-equivalents) 13 grand for a level recorder, 8 grand for a sine-generator, 13 grand for an FFT-analyzer, 30 grand for a distortion analyzer and another 60 grand for a 1/3-octave analyzer … summed-up € 124,000.-. The two-channel version would have set you back another 21 grand, and had you decided to go for a printer … that luxury (color? Dream on, my friend: black only) would have added 14 grand more. The printer alone would have been the equivalent of three brand-new, fully gassed-up VW Beetles. At the time when the famous amp-forefathers were put together, their designers were mostly ham-radio "amateurs", just barely beyond their teens. In no way could they have afforded a full set of the wonderful light-green B&K-equipment. At best, they operated a tone-generator, an oscilloscope, and one or two "MaVoMeters" - plus a soldering iron.

 Translation into English by Tilmann Zwicker

Indeed it was possible to build an amp with only little equipment; the circuits were known. In his book about VOX, **Jim Elyea** relates that it was customary to nick left and right from the competitors. Well, he doesn't actually write "nick": *"JMI, like everyone else, borrowed literally wherever appropriate... It was not uncommon for the engineers at JMI to bring in the equipment of other manufacturers, take them apart for ideas, put them back together, and sell them in the shop"*. Ideas were "borrowed" … an approach in practice as late as 1984: just before the Frankfurt music fair, a CEO (who shall remain unnamed, as shall his company) had "his own" face plate mounted on a Japanese competitor's device, and proudly presented it at the fair as the newly developed reverb. Just to be safe, and to avoid that somebody else would nick it in turn, he took it to his hotel room every evening. '**Knowhow-Transfer**' was and is common – and not just in the Far East. Marshall's JTM is a copy of a Bassman, the tremolo-effect for guitars previously was used in organs, the VOX tone control is derived from the Gibson GA-70 (in turn inspired by the Fender Pro 5E5-A), Marshalls 18-Watt amp previously was already successful on the market as Watkins Dominator. Gibson *'disassembled every Fender-Amp'* [Elyea /Smith]. Of course these were mostly not actual 100-%-copies: one's own ingenuity has to come out somewhere. (**Fig. 10.10.1**).

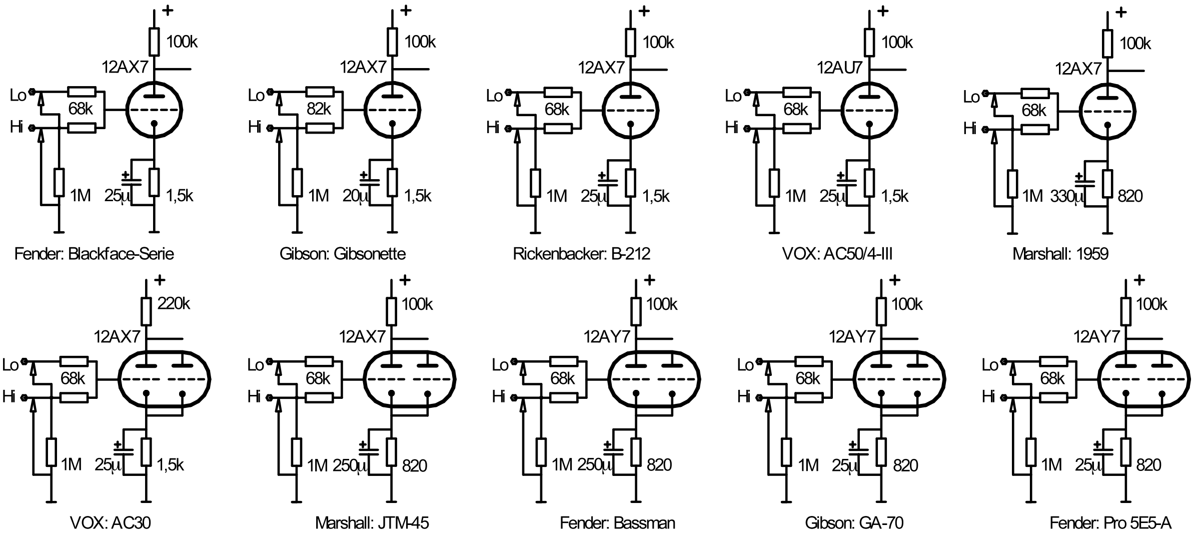


Fig. 10.10.1: Input circuits of various guitar amplifiers.

In Elyea's VOX book we repeatedly find hints that Dick Denney's prototypes were "bird's nests" – heaps of components artfully soldered together. *'Dick's working was a more organic approach, involving endless fiddling with individual parts until he got the sound he was after. He didn't care what the value of a part was; all that mattered was if it sounded right.'* Denney had a severe hearing loss but that did not get in the way. No, not because that would have put him on the same "ear-level" as his customers, but because despite the damage in his ears he was aware of what the marked demanded. He was not always aware of the inner workings of his circuits. Only when he dropped his screwdriver into the circuit (shorting two wires) did he discover that his Wurlitzer-inspired **phase modulator** also could accomplish amplitude modulation [Elyea]. Indeed, that Vib/Trem-channel ... it includes a 500-Hz-highpass followed by a further high-pass of a cutoff frequency of 8 Hz (0,8 Hz for the bass version). That's how it's done and that's how it is passed down from generation to generation. Or the **JTM-45**, Jim Marshall's holiest cow: nowadays available as reissue, but with a changed electrolytic capacitor at the cathode. Our musicians' magazine recommends: "*the 330-µF-cap should be replaced by one with 250 or 220 µF. This minimizes the bass a bit.*" The explanation with a better match would have been: since it was that way in the original circuit. Let's do a simple estimate: with an internal resistance ($1/S$) and the cathode resistor of 820 Ω we get a polefrequency of 2 Hz (330-µF), and 2,7 Hz (220 µF) respectively. For a more exact calculation we would have to consider the plate resistor, as well … however: is that really necessary? How relevant is the operation at 2 Hz in a guitar amp? We might look into the issue of transient phenomena – had not our author in the expert journal written in another passage that jumper wire would sounds differently compared to stranded wire, and that silver wire had a *"cruel"* sound. Here we touch the world of HiFi, where wire with blue insulation sounds more airy, while wire with brown insulation sounds somehow … shitty. Side-note: for electrolytic capacitors, the exact capacitance was never really of much importance – it is not uncommon to find tolerances of e.g. +50/-20% printed on the housing.

So, how did that **250-µF-cathode-cap** arrive? That's truly difficult to assess and we can only speculate. The circuit of Leo Fender's very first Bassman (5A6) is shrouded in time and mystery – it seems nobody has actually seen a drawing of this circuit[⊗]. In any case, the closely related Pro Amp (allegedly delivered with the very first P-Basses since the Bassman Amp was not ready yet) had double-triodes (6SC7) with joint cathodes in the input circuits, and it included normal 25-µF-caps. The second variant Bassman (of which the circuit diagram 5B6 *is* available) also featured the same-type double-triode with joint cathodes, but sported the infamous 250-µF-biggie – almost as big as the power-supply filter cap. Why was that? Some thoughts about that:

1. While in the active channel (of the two-channel input configuration) the signal from grid to plate is inverted, it also reaches the anode via the other channel (2nd half of the tube). This common-grid signal path is non-inverting such that in the plate two out-of-phase signal are summed and thus there will be an attenuating effect. However this happens only at very low frequencies since the route via the cathode is a low-pass. With 25 µF a loss of 3 dB would have occurred at 2 Hz – more than adequate even for a bass guitar, and not really any reason to up the cap by a factor of 10.
2. The big cap was supposed to eliminate hum induced by the tube heater. That may actually be a possible reason – however the Pro Amp did quite well with 25 µF at the cathode.
3. A bass amp needs to operate at low frequencies. O.k. – but as much as 250µF? Both output transformer and speaker are far from able to carry such infrasound to any extent.
4. Someone in logistics misread Leo's handwriting and accidentally ordered 1000 pieces of 250-µF caps instead of 25 µF. Hm … maybe not.

The mystery remains – from other angles as well: why does Leo keep the 250 µF as he switches to the 12AY7? Now he's got a modern double-triode with totally separate systems, but still he maintains the big 250-µF cap in the Bassman. He holds on to it for years – until the completely redesigned 6G6-Bassman, when suddenly the "small" 25-µF cap suffices. Just as it suffices in the Deluxe, but there it had held its own from the very start (5D3). Same as for the Pro (5D5), as mentioned above, and for the Super (5D4). They all got by with 25 µF. Only the Bassman features the 250 µF. It's a bass amp, after all, so let's accept it. Next, however, Marshall's Ken Bran copies the Bassman and it becomes a guitar amp – and naturally keeps the 250-µF-cathode cap. Since then, all Bluesbreaker imitators adamantly insist on that cap … most likely because, now as it was then, they may not always exactly know what they are doing. Because the cutoff frequency is so excessively low, we could look for other criteria: for example for transient phenomena that play a role as the tube is overdriven. Still, no find – Marshall will use the 820-Ω-resistor for the two cathodes

[⊗] The circuit „Old Bassman" or even „5A6" found on the internet at the time of this writing can NOT be a Bassman but is highly likely to be a Dual Professional in view of the two speakers, the dual output transformers, the three inputs, and two volume controls (contrasting a single speaker, one output transformer, two inputs and one volume control on the Bassman).

connected in parallel, and then again also for single-cathode operation. Shouldn't they have brought in 1600 Ω for the latter? No, they didn't. Not that Fender looks much better: they change from the 12AY7 to the 12AX7 without matching the cathode resistor although these are quite different tubes. Who cares, as long as the contraption doesn't go up in flames. The RCA-Receiving-Tube-Manual recommends 1,5 kΩ as cathode resistor for the 12AX7 (at 300V/100kΩ) – that may have been the starting point for it all, and that was then somehow copied, and copied again, and again …

With respect to the design approach of early guitar amplifiers, the VOX book gives interesting insights: *1935 for the first time an effort was made to do more than amplify the signal of an electric guitar. Rather, the idea was to alter the tone, both making the electric guitar a different instrument, not just a louder guitar, and also making the amplifier itself an important part of the sound [Elyea]*. Some manufacturers, however, arrived at this realization only much later: *In late 1957, it was a natural to apply the Hi-Fi designation to the new amplifier (VOX AC2/30)*. Similarly, Dave Funk reports about the early Bassman: *Everything was very technical, hi-fi, and by the book.* The first guitar amps either included no possibility at all to influence the sound, or merely included a primitive tone control to attenuate the treble range. Dick Denney's **VOX AC15** followed this design approach, as well, and was supposed to reproduce as "**HiFi-like**" as possible. At first, the "Normal" channel sported merely a control to diminish the treble. The lower cutoff frequency of lower than 20 Hz was determined by the values of the coupling capacitors, while the upper cutoff frequency of about 17 kHz resulted from unavoidable stray capacitances. This configuration would have done a good job in a music box, as well. It was only the power amp that refused the trend – to include negative feedback. Apparently the amp worked better without it, as had the amps of Fender, Gibson, and many more. Indeed, dispensing with negative feedback was not an invention that VOX came up with. To have a 500-Hz-highpass in the Vib/Trem-channel be followed by a further 0,8 Hz high-pass – well, that actually may be "VOX-typical".

In **Fig. 10.10.2** we see the frequency responses of two Bassman amps (are these then 'Bassmen'?) from input to the second stage. Compared to the fundamental of the (regular) lowest string of an electric bass (E_1 = 41.2 Hz), the 5B6 appears quite a bit 'oversized'. For the later 5F6-A, the lower cutoff frequency even depends on the position of the volume control of the "other" channel, which would appear to push the significance of the lower frequency limit even further into the background.

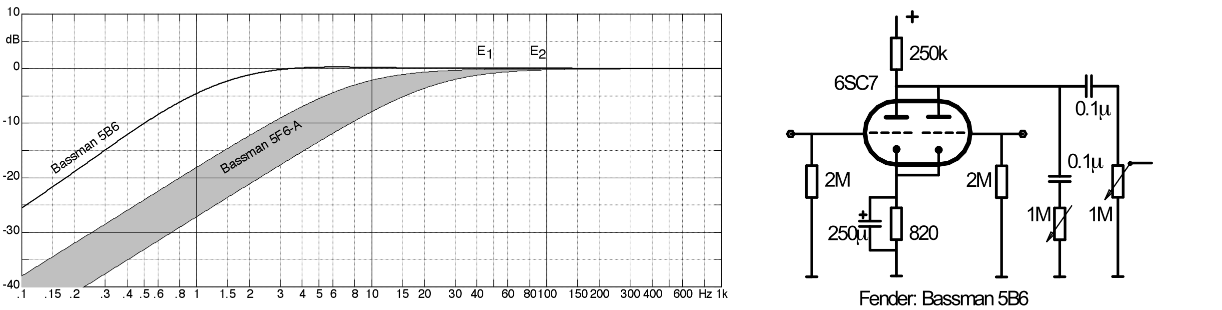


Fig. 10.10.2: Frequency responses of two Fender Bassman amps. String-fundamental: Bass (E1), guitar (E2).

Thus we shouldn't look for reasons that never existed. Much resulted from circumstances that cannot clearly be seen anymore today, or happened due to pure chance and by accident.

(Translator's note: at this point Manfred Zollner makes a comparison to processes which may have influenced how literature was written. As an example, he relates to the well-known poem "**Der Erlkönig**" written in 1782 by famous German poet Johann Wolfgang von Goethe. Since this passage "works" only in German, it was not translated and is not included here – please see the German version of this book if you are interested.)

10.10.2 Stage-topology, level-plan

A guitar amplifier contains several consecutive amplification stages, in a sequence typical for the respective amp type. The total frequency response results from the commutative multiplication of the individual transmission-functions. As such the order of the sequence would be irrelevant; however this only holds for linear operation – and that is not the only operational state of a guitar amp. Whether preamp- or power-tubes are overdriven makes a difference, and in which frequency range this happens, plays a role, as well. When comparing different amps, we therefore need to consider the sequence of the stages.

General differences were already highlighted in Chapter 10.2; now special amplifiers are at the center of attention. When comparing, we run into a huge number of parameters, and we need to simplify rigorously. Because 3 to 5 tube stages follow each other in a typical guitar amp, a multitude of combined nonlinearities may exist. In addition, filtering in and between the stages happens – the effect of which we may not be able to account for at the first glance. For example, a simple volume control may also have the effect of a treble filter with the frequency response depending on the position of the wiper, and also on the input capacitance of the subsequent tube. If at that point there is also a summation of two channels, the volume control of one channel may influence the frequency response of the other channel, as well. To limit the number of representations, we decided to measure all amplifiers with a **standard setting**. The volume control was positioned such that for an input voltage of **90 mV** (at 500 Hz) the power stage was just starting to clip. Why 500 Hz? Well, a choice needs to be made – 673 Hz or 1000 Hz would also have been o.k., as is 500 Hz. Why 90 mV? Your run-of-the-mill singlecoil pickup will confidently reach that voltage: Telecaster, neck pickup, normal picking strength – 90 mV. Maybe a bit more or a bit less, but – again – we need to pick a value. Some arbitrariness is unavoidable here. The same holds for the terms "*maximum level*" and "*clipping*". For an operational amplifier, the clipping limit is clearly definable, but not for a tube featuring a continuous increase of distortion. Since for a guitar amp, HiFi-standards are out of place, we chose as the limit the level at which the **total harmonic distortion (THD) products are 25 dB below the primary signal**.

The **tone controls** were adjusted to generate a treble boost typical for the genre. The general frequency response was dictated by the amplifiers that offered only few possibilities of control (Tweed Deluxe, AC15). The other amps had to comply as far as possible. You may ask: "*why would I want to adjust a VOX such that it sounds like a Fender?*" While that is a legitimate question, it also tempts to go the second step before the first. Not to have to evaluate at the same time different distortion sounds and different frequency responses is highly conducive for a comparison. It is helpful to be able to concentrate on the non-linearity while keeping the linear behavior similar. As mentioned before: there are myriads of possibilities, and other priorities may be purposeful, after all – but they would push beyond the present scope.

Fig 10.10.3 shows the block diagrams of some amplifiers; the differences in the sequence of stages are striking. The tone filter (the oval with arrows) is located after the first tube in one amp, after the second tube in another, and in some cases it is driven by a cathode-follower (two overlapping circles). In some amplifiers, the volume potentiometer is bridged with a capacitor that is switchable in some cases (Bright Switch). Coupling capacitors were only included here if they caused a very high lower cutoff frequency (VOX). Additional second channels are indicated via a resistor with a free end. The last stage included in the diagrams is the phase inverter (PI). The respective gain of each stage is indicated in dB and given at the standard setting (f = 500 Hz).

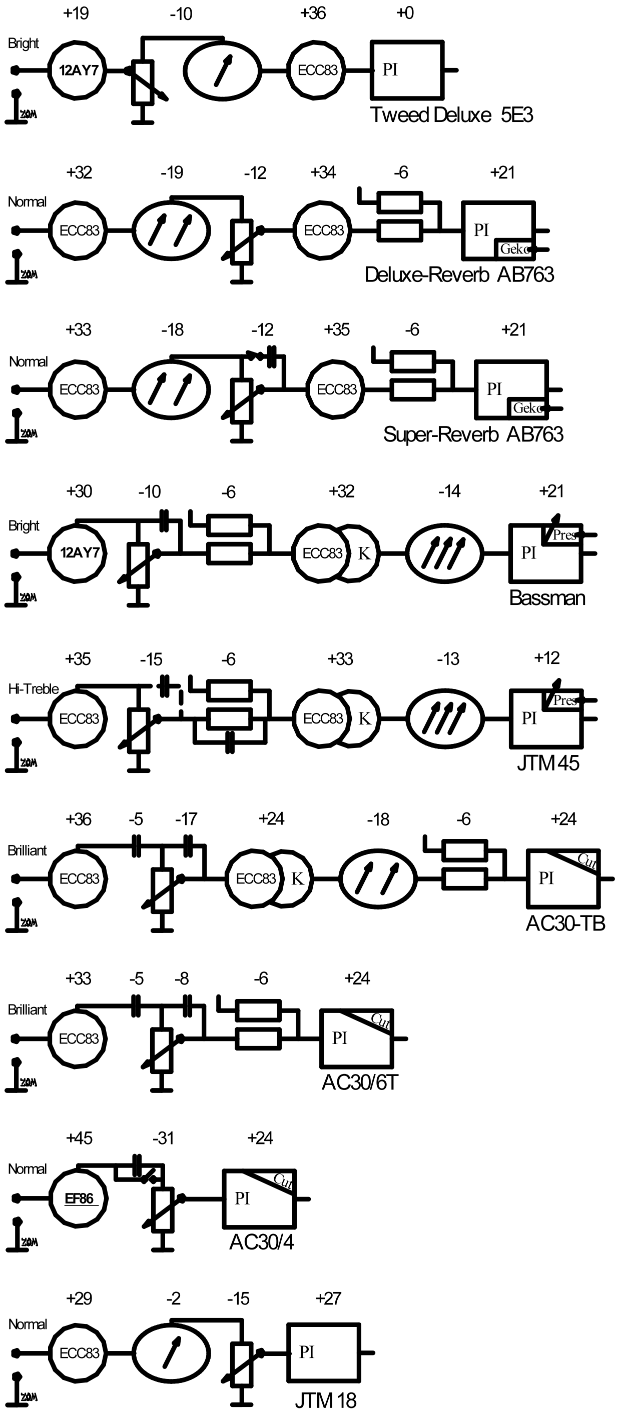


Fig. 10.10.3: Block diagrams

Fender's **Tweed Deluxe** (5E3) has only a single tone control as sound filter boosting or cutting the treble. The phase inverter is a cathodyne-circuit with a gain of 1. Fender's **Deluxe Reverb** (AB763) already sports the widespread Treble-Bass-filter, and uses the differential amplifier as phase inverter (as do all the following amps). In both Deluxes, the push-pull power stage employs the 6V6-GT, with a cathode resistor in the 5E3, and with negative grid voltage in the AB763. The **Super-Reverb** (AB763) is similar to the Deluxe-Reverb in many details, but has two 6L6-GC working in the power stage. We will not expand on the fact that in all these amps, the loudspeakers are different as well. The **Bassman** (5F6-A) – in fact intended to be a bass amp – is highly regarded by guitar players. It is the only Fender amp considered here that includes a cathode-follower, and it distinguishes itself in other ways, as well, over its colleagues. The Treble-Bass-Middle-filter, for example, is located towards the end of the signal chain; it is supplemented with a presence filter integrated into the negative feedback loop. Jim Marshall's **JTM-45** looks very similar – no surprise there since it is a Bassman copy. Only the tubes are different: instead of the 6L6-GC we find the KT66 as power tubes, and in the input amp the slightly more "gainy" ECC83. Several developmental stages are documented for the **VOX AC30**: the four-input AC30/4 features merely a switchable high-pass as a tone control, plus a low-pass within the phase inverter. In the input stage there is a high-gain pentode that is however replaced already in the AC30/6 with the ECC83. The AC30/6 looses the high-pass-switch but adds a "Normal" and a "Brilliant" channel (on top of its "Vib/Trem"-channel. Finally, the AC30-TB adds a Bass-Treble-filter to the Cut-filter, and also includes the distortion-promoting cathode-follower. Similarly simple as the AC30/4 was the AC15 (with only the power section being different), and Marshall's **18-Watt** shares this approach: there is only single tone control offering a choice of treble- or bass-cut.

For all these amps, the sequence of the sections in the system determines their (over-) drive levels and thus determines the sound. Even if the behavior (i.e. the frequency response) at low signal levels (with a single coil pickup) is similar, connecting a humbucker (i.e. a higher drive level) will make differences in the sound audible. The same may happen with a single-coil as the volume is turned up. Here, some amplifiers offer a surprising, even incomprehensible reserve: fully cranked, 3 mV at the input of the AC30/4 is sufficient to fully drive the power stage. No, there was no Heavy Metal at the time of the debut of the AC30 (around 1960). But back then they may have used the amp as all-around PA system, i.e. for microphones, as well.

The so-called **level plan** offers a possibility to depict the voltage levels as they pass through the amplifier, but unfortunately it has a distinctive disadvantage: showing only one frequency is insufficient, and showing multiple frequencies is confusing. The approach may be adequate in studio technology where clean (and often similar) equalization stages (such as the Baxandall tone control) abound – for the multitude of filters we meet in guitar amps supplementary representations are required. For the AC30-TB and the Super Reverb, the level plans are shown in **Fig. 10.10.4**. From these we can see that differences occur particularly in the second amplifier stage: while both power stage and cathode-follower start limiting at the same input drive level in the AC30, the second stage in the Super Reverb still has a reserve of 17 dB when the power amp goes into saturation. The result is that in the VOX both power and intermediate stage significantly contribute to distortion while in the Fender the distortion is predominantly generated by the power stage. At 500 Hz, and with the chosen setting, that is … because as we turn the knobs, the level plan changes, as well.

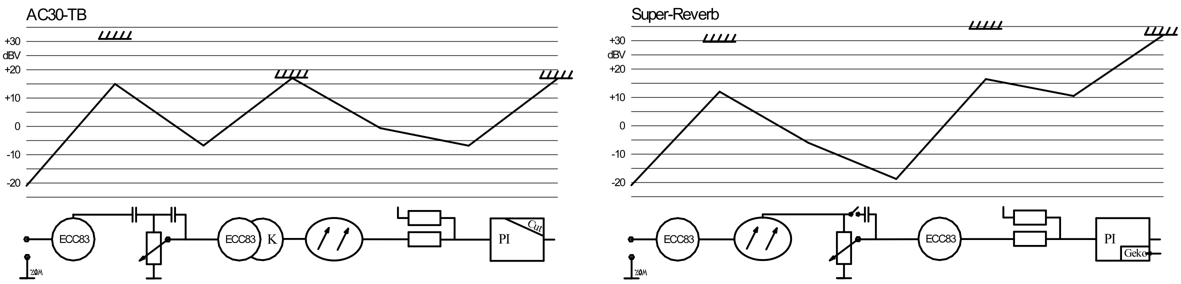


Fig. 10.10.4: Level plans for the VOX AC30-TB and the Fender Super-Reverb, f = 500 Hz.

There are only a few amplification stages but many frequencies, and therefore we will not set up a level plan for every frequency. It is more conducive to present the frequency dependence of the drive-limit every stage has (headroom chart, chapter 10.10.3), and to include only the tube stages since passive RC-circuits do not show any distortion in the context of the present investigations. **Fig. 10.10.5** reveals that in fact one drive-limit is not sufficient: the drive-dependency of the HD (harmonic distortion) has many variants (more on this in Chapter 10.10.4). The right-hand section of the figure shows the frequency response from input to output (loaded with a speaker). The small resonance spikes and part of the treble boost are caused by the speaker-impedance. The two frequency responses are not identical but at least they are similar, something that cannot be said of the HD: as the Super-Reverb goes into overdrive, it generates strong 2nd order distortion (on top of the k_3 not shown here) while for the VOX, the k_2 may be neglected in comparison to the k_3. By the way: so much for the statement "compared to transistors, 2nd order distortion is dominant in tubes". Again: more on that in Chapter 10.10.4.

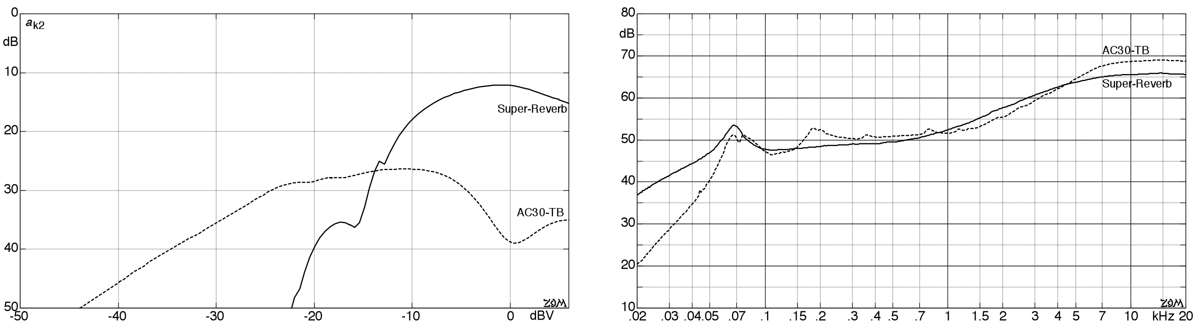


Fig. 10.10.5: 2nd order harmonic distortion a_{k2} (500 Hz) from amplifier input to power-amp output (left), frequency responses in standard setting from amplifier input to power-amp output (right). $a_k = 20\lg(1/k)$dB.

10.10.3 Headroom-chart

“Headroom” means drive margin i.e. “how much more gain until overdrive”. The headroom-chart is the graphic representation of the frequency response of the headroom. This chart shows a frequency response for each amplifier stage – it is not “transmission frequency response” but the frequency response of the headroom relative to the drive limit (clipping) of the power-amplifier. Since this clipping is the reference, it is represented by a horizontal line at 0 dB. If, for example, the curve for the 1st stage *at a specific frequency* is indicated to be at 12 dB, then this1st stage can be driven with 12 dB more until clipping than the power amp. In other words, as the power amp goes into overdrive at this frequency, the 1st stage still has a reserve of 12 dB, or, as the 1st stage goes into overdrive, the power amp has already been pushed into overdrive by 12 dB. In **Fig. 10.10.6** we see four headroom charts. For the **Super-Reverb** (normal channel) the curve for the 2nd stage runs almost constant at -17 dB indicating that this stage starts distorting only as the power amp is already overdriven by 17 dB. Conversely, the 2nd stage of the **VOX** (AC30-TB, brilliant channel) at 100 Hz has a mere 4 dB margin, and at 1 kHz, the 2nd stage and the power amp go into overdrive at approximately the same input signal level. The drive margin of the 1st VOX-stage decreases towards low frequencies because a high-pass between 1st and 2nd stage attenuates the bass transmission.

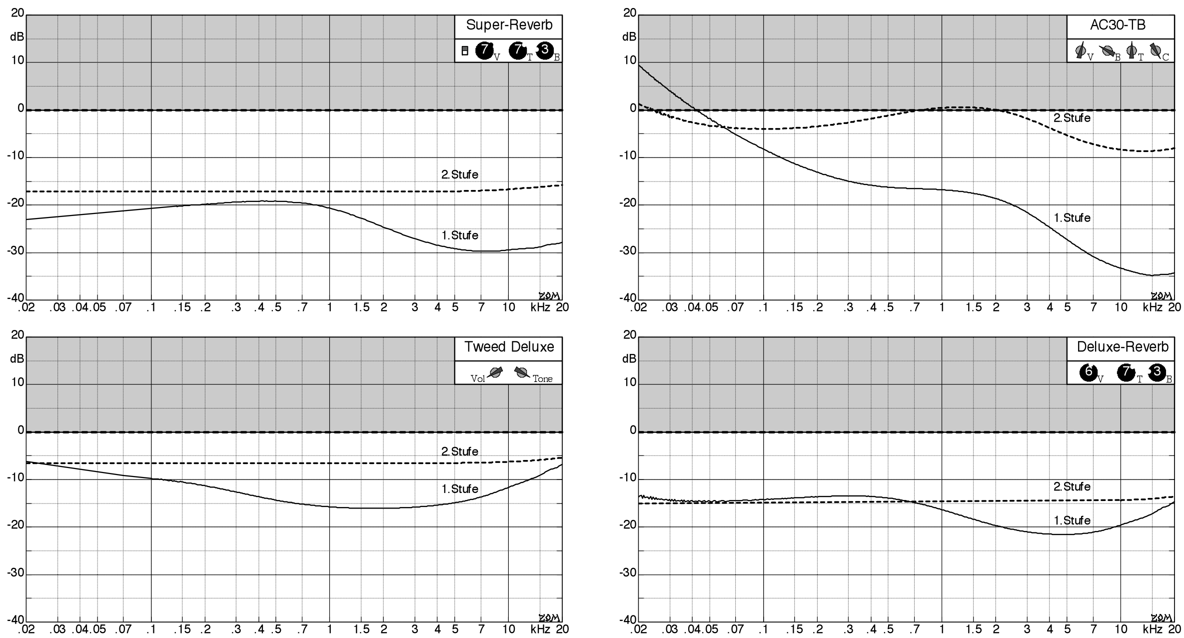


Fig. 10.10.6: Headroom-Chart for Fender Super-Reverb (AB763, upper left), VOX AC30-TB (upper right), Fender Tweed Deluxe (5E3, lower left), and Fender Deluxe-Reverb (AB763, lower right).
The higher the curve is located in the chart, the smaller the drive margin is relative of the power-amp clipping.

The 2nd stage of Tweed **Deluxe** directly feeds the phase inverter (via a capacitor), and the headroom chart therefore runs in parallel to the horizontal power-amp-line. However, with the cathodyne-circuit of the Tweed Deluxe not having any voltage gain, there is much less margin compared to e.g. the Super-Reverb. The **Deluxe-Reverb**, on the other hand, is much closer in circuit design to the Super-Reverb than it is to its ancestor Tweed Deluxe. It does not quite reach the high margins of the Super-Reverb due to its lower supply voltage. As we change the setting of the **volume potentiometer**, it is only the curve for the 1st stage that also changes: the larger the amplification, the more this curves sinks to the bottom (= larger drive margin re the power amp). With no control located between the 2nd tube and the phase inverter, the curve for the 2nd stage cannot be changed. This is in contrast to the Fender Bassman and its Marshall-clone, the JTM-45.

For most Fender amplifiers, the tone control is located *ahead of the 2nd tube stage* – but from 1954 to 1956 some amplifiers were designed with the (in-) famous cathode-follower as 2nd stage, and the tone control *positioned behind it*. We may surmise that the RCA Receiving-Tube-Manual in its 1954 issue (RC 17) is the source; it introduces for the first time a 12AU7 with cathode-follower and *"Bass and Treble Tone-Control"*. Incidentally, the Twin (5D8) receives a very similar circuit that year, and designers at Gibson take up the same idea and include a cathode-follower into the GA70/77 (although they do change the tone control circuit). VOX, however, does not really bother with alterations and simply adopts the Gibson tone control 1:1. The cathode-follower driving the tone control is deployed in the 5D6-Bassman, as well – that amp spawned the inspiration of Marshalls Ken Bran and his JTM-45. The respective tubes are all configured in the common-plate-circuit (= **cathode-follower**) but the tubes themselves and the details of the circuits vary. RCA shows the 12AU7, Fender initially includes the 12AY7, with Gibson, VOX and Marshall, the 12AX7 is found. All amps use a double-triode, i.e. a tube containing two independent triodes within one glass container – independent but equivalent. This is actually not that advantageous because the first tube system operates on common-cathode mode (no AC at the cathode) but the second tube system operates in common-plate mode. The first tube system is to amplify the voltage, and the second should amplify the current (**Fig. 10.10.7**).

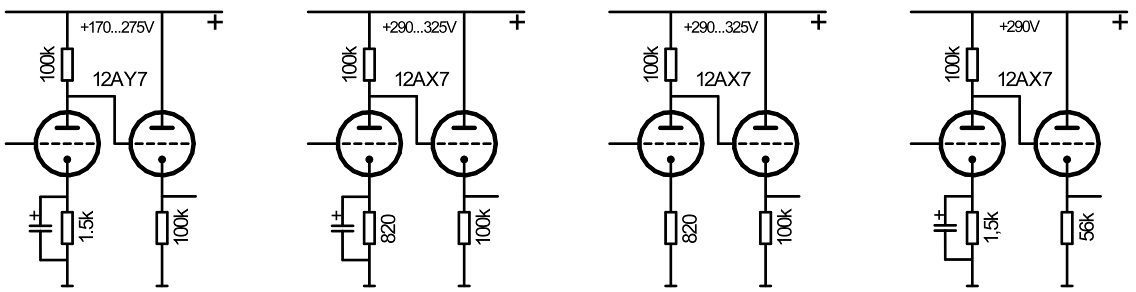


Fig. 10.10.7: Double-triode w/cathode-follower (Chapter. 10.2.2). On the right: circuit of the AC30-TB.

Fender first deploys the 12AY7 (**Fig. 10.10.8**) but then changes over to the 12AX7, the amplification of which is somewhat larger but which features less drive margin. The reason: the first tube can reduce its plate voltage (and correspondingly the output voltage) only down to about 120 V. This is what drives the second tube as it conducts. At the output we thus have available no more than about ±35 V (for modest distortion). The subsequent tone control circuit attenuates the signal by about 15 dB, and now there might not be enough signal strength left to fully drive the power amplifier.

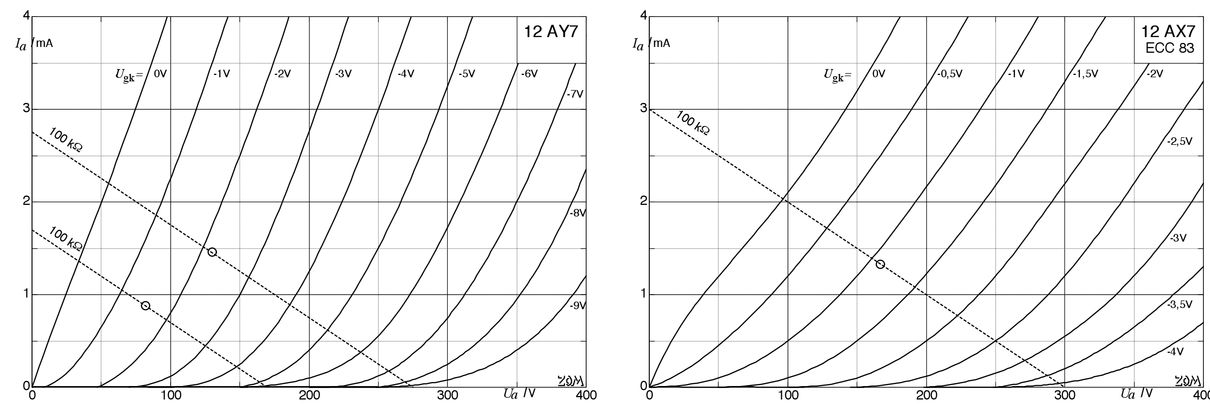


Fig. 10.10.8: Output characteristics of the double triodes used for the cathode-follower (Fender).

In the Fender amp, the cathode-follower therefore generates merely just about the voltage required to fully drive the power amplifier – that may be the reason why it is not used anymore from ca. 1960. Not so at VOX, where the cathode-follower enters the picture at the time when it is shed at Fender. VOX, however, does not "borrow" the circuit from Fender but from Gibson where the cathode-follower is first included in the GA70 and GA77[♣]. It receives a rather astonishing dimensioning, too: with the changeover from the 12AY7 to the 12AX7, it is not the first cathode resistor that is halved in value but the second – for whatever reason. With this resistor, the quiescent current of the second triode (**Fig. 10.10.9**) becomes large enough to cause a considerable grid current to flow, which again has consequences on the drive situation and on non-linearity (chapter 10.2.2).

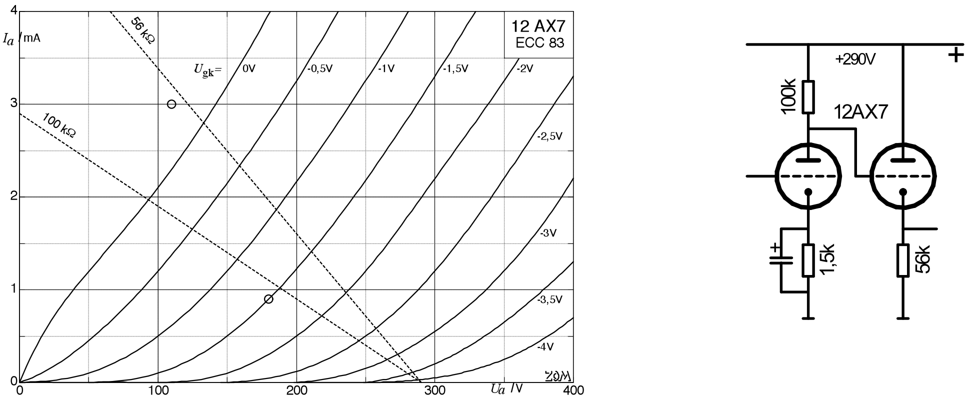


Fig. 10.10.9: Output characteristics of the double triode used in the cathode-follower (VOX AC30-TB).

Of course, we may surmise that it is exactly this non-linearity that is required for a good guitar-sound. But then: why do Fender and Gibson not continue with the approach, why does Leo Fender try, shortly after the debut of the cathode-follower, to decrease this non-linearity via negative feedback (e.g. Super 5E4 – 5F4)? Why does it disappear from all Fender amps after about 1960? Mind you: that was still pre-CBS! In retrospect, many decisions are glorified into strokes of genius – which they probably weren't. Elyea's book on VOX can easily live with such discrepancies: on one hand Dick Denny designed that AC30 exactly according to his own ideas, on the other hand the TB-circuit (cathode-follower and tone-filter) is an exact copy of the Gibson amp. On one hand it is the EL84-power-amp that creates the sound, on the other hand the originally used EL34 was discarded not because of the sound but because it would have made the amp "two inches too tall". On one hand Dick's amp had "more clean headroom than most other amplifiers", on the other hand it featured "high harmonic content" and "plenty of even numbered harmonics". Measuring the output voltage reveals something else altogether: lots of odd-numbered harmonics (chapter 10.10.4). Besides all speculation, there is an objective reason: for full drive levels, the phase-inverter of the AC30 requires less than 10% of the voltage necessary in a Fender (EL84 vs. 6L6GC), and consequently the inferior drive situation created by the cathode-follower could be more easily tolerated compared to a Fender amp. So what about Marshall? Ken Bran does not copy the VOX approach but adopts the Fender circuit. The situation here is rather tight with regard to maintaining sufficient level so the tone stack fed by the cathode-follower is optimized to have low basic attenuation (Fig. 10.3.12). Marshall's PA-amplifiers document the fact that the cathode-follower was not regarded as a special guitar distortion device: all microphone signals – not something you would want to distort - had to pass through the cathode-follower, as well. Gibson advertised their amp (with cathode-follower) as having "unusual clear bell-like treble". What else indeed – it was 1958! Distortion was called for only later.

[♣] A variant of the Gibson GA30 temporarily featured a cathode-follower, as well.

Let's speculate some more. Possibly, some designers believed that a tone filter would only work properly if driven by a (actually or only supposedly) low-impedance cathode-follower. That would explain why in the **AC-30TB** it is only the "brilliant"-channel that has the c-follower but not the "normal" – or the "Vib/Trem"-channels – the latter do not feature such a filter. Would the cathode-follower have been considered important to the sound, surely all channels would have been fed to it. Only with the **AC50** both the "brilliant"- and "normal"-channels each receive their own c-follower – because each channel has its own tone filter. In the **JTM-45**, Marshall's first amplifier, the power amp includes strong negative feedback and therefore requires a relatively high voltage to be fully driven. The preceding cathode-follower therefore had to be strongly driven and might have caused distortion. Was this intended? Apparently not, because very soon the negative feedback is reduced[♣], and the c-follower distortion decreases. Is this why all over the planet the very old Marshalls are sought after most? Maybe. Or maybe not.

Both triodes (12AX7) in the c-follower of a JTM-45 (Fig. 10.10.7) need to be driven strongly and may distort. This distortion, however, is highly dependent on the individual tube, as can be seen from **Fig. 10.10.10**. In particular, the 2nd order distortion may change by a factor of more than 10 as one 12AX7 is replaced by another12AX7. Thus "the first tube is the most important"-rule (as it can be read here and there) is not correct here – it is the second tube that's important. At the same time, we must not make a connection to particularly old tubes since while these may be great, they may also be bad just as well and do not justify any surcharge. As has been shown already in Chapter 10.1, tube characteristics show different curvature and therefore give different distortion. It would be helpful if some of the "expert" writers in various magazines would for once support their monthly elaborations ("*for Marshalls from early 64 to late 65 use only Brimar tubes in the input stage*") with a measurement of the tube characteristics or distortion. It may be that in a particular specimen of a Marshall the individual Brimar 12AX7 makes for a super sound. It shall also not be questioned that a guitar player who has been writing tests and other reports eventually can judge what a good sound is. What needs to be criticized, however, is the approach to turn such insights into undocumented sweeping judgments that are incorrect in this generalization.

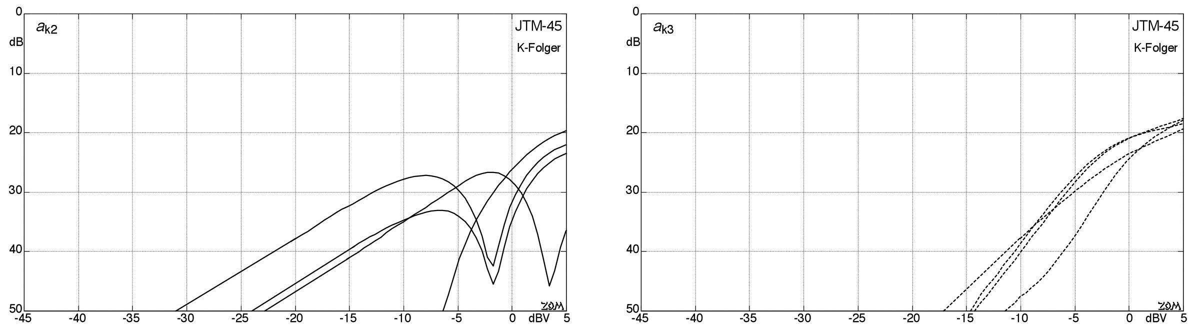


Fig. 10.10.10: JTM-45, harmonic distortion of the cathode-follower; four individual 12AX7. R_Q = 200 kΩ.

At this point, we will not continue discussing harmonic distortion of the individual amplifier stages. Details on this will be included in Chapter 10.10.4. First, the headroom-charts of a few more amplifiers need to be analyzed – these are amps in which the tone filter is not located after the input valve but immediately ahead of the phase inverter (Fender, Marshall).

♣ First taken from the 16-Ω-tap via 27 kΩ, then via 47 kΩ, finally via 100 kΩ from the 8-Ω-tap. Tubes (KT66, EL34) and primary impedance (8 kΩ, 3.4 kΩ) varied, as well.

An objective analysis of Marshall-distortion is hampered by not only *four* tone controls that need to be considered, but also by the fact that Marshalls came with two different output tubes, two different output transformers, different negative feedback, various shunt-capacitors – just to name the most important versions … there were additional issues for short time periods. **Fig. 10.10.11** shows some selected examples: on the upper left there is a standard setting matching Fig. 10.10.6. On the right we see the ancestor, on the lower left the setting for forgetful guitarists (all on 10). On the lower right there is a variant deriving its treble boost mainly from the power amp (Presence control set to 8).

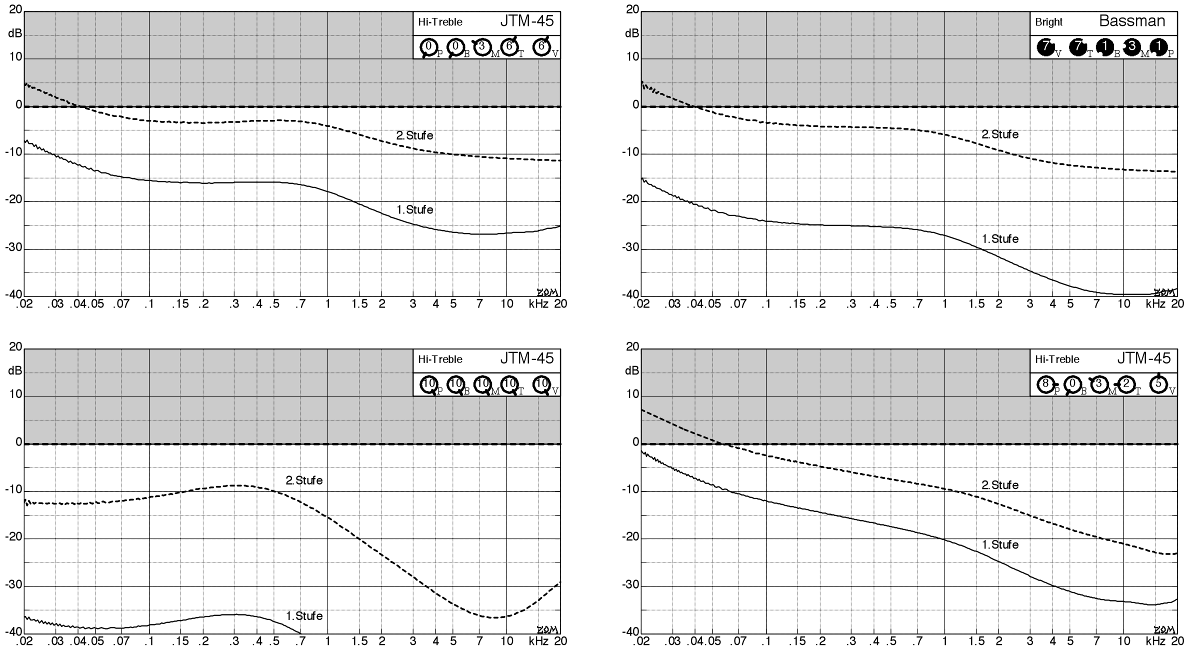


Fig. 10.10.11: JTM-45, headroom-chart. In this amp, the volume-control was not bridged by a capacitor. As a comparison, measurements of the Fender Bassman (5F6-A) are given at the upper right.

The weak dynamic range of the second amplifier stage is striking. As the tone controls are turned up, the filter attenuation drops and the second stage is given a larger dynamic range. With increasing amplification the first tube reaches a larger range (N.B.: re the power amp!). **Fig. 10.10.12** clarifies the step from the JTM-45 (KT-66) to the JTM-50 (EL34): swapping the output tubes (with bias adjustment) and the output transformer slightly reduces the gain margin for the 2nd stage. Additionally decreasing the negative feedback in the power amp cuts back drive levels to the 2nd stage and improves the dynamic range. (Supplemental info on this in chapter 10.10.4).

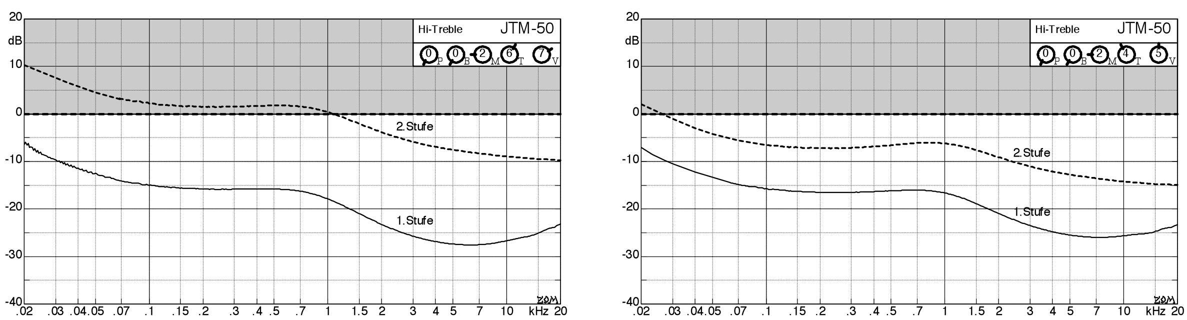


Fig. 10.10.12: JTM-50 (EL34), power-amp feedback 27 kΩ / 16 Ω (left), 100 kΩ / 8 Ω (right). Over the years the negative feedback was reduced and thus the gain margin of the 2nd stage increased.

To conclude, let us have a look at a few amplifiers without intermediate stage: in **Marshall's 18-Watt** amp (built from 1965 – 1967), the plates of the two input triodes are simply connected together which is the source of considerable preamp-distortion (L. Fender had tried this already 13 years earlier in the 5B6-Bassman). Apparently, that was not desirable (at least then!) since the 20-W-successor sums in the conventional manner. The **VOX AC15** sports a pentode in the input circuit, just like the successor **AC30/4** with 4 inputs; it is said to have been microphonic and unreliable. For this reason, there is a swap to the ECC83 in the **AC30/6** (extended to 6 inputs). There were 3 versions of this amp: Normal, Bass, Treble, and it is not yet the actual **AC30-TB** – that then finally received the distorting cathode-follower as the 2nd amplifier stage.

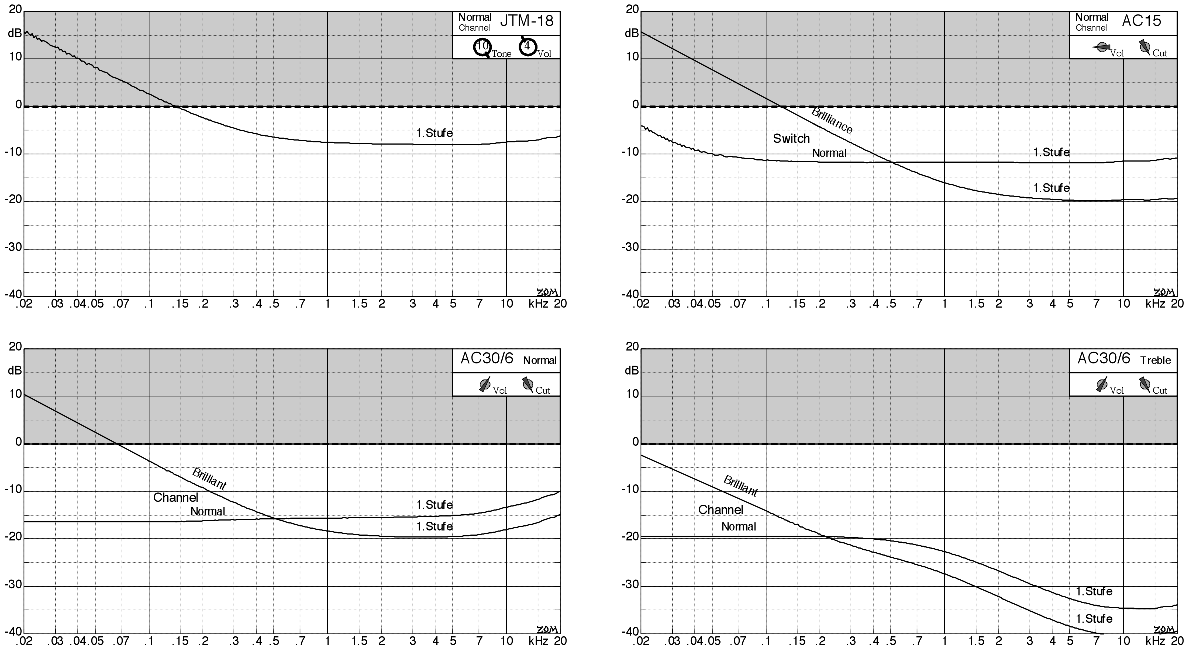
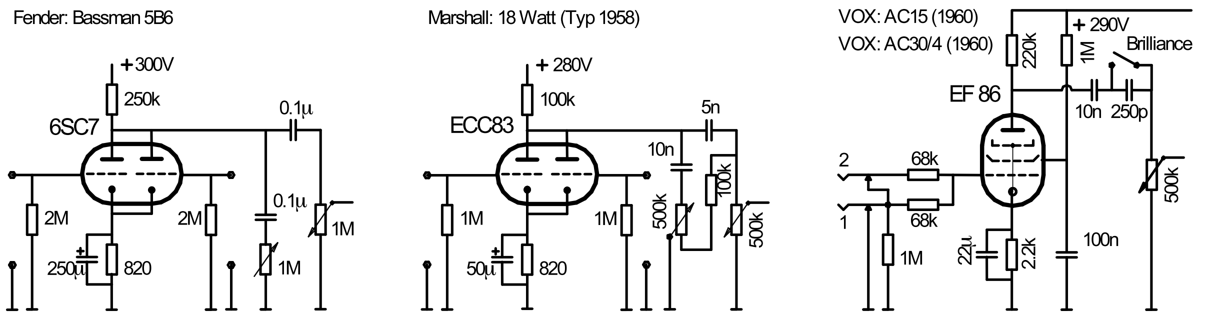


Fig. 10.10.13: Comparison Marshall JTM-18, VOX AC15_1960, VOX AC30/6_Normal, VOX AC30/6_Treble.



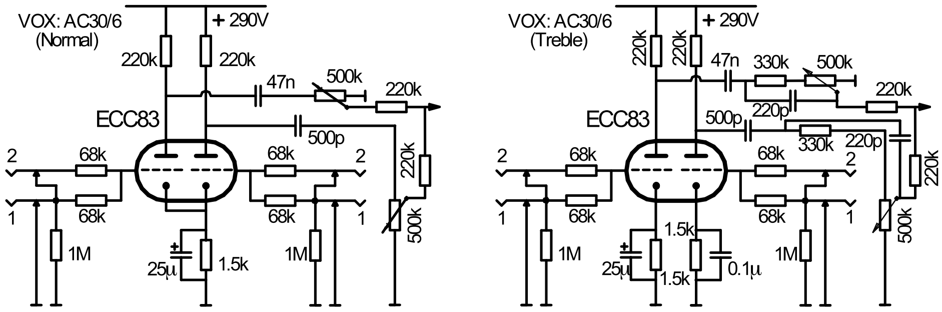


Fig. 10.10.14: Circuit diagrams of the input stages of several amplifiers.

The exact identification of **VOX**-amplifier or their channels in not entirely easy: first, there is a **Brilliance-Switch** allowing for attenuating the bass. The AC30/6 separates this switching-option into 2 channels (with two input jacks each): the **Normal-Channel** and the **Brilliant Channel** (also called Bright-Channel). Consequently, the sound-characteristics available merely as alternative switching-options in the AC15 are permanently both available in the two parallel channels. For a good measure of confusion, the AC30/6 was issues in three different model variants: Bass/Normal/Treble. “Normal” may therefore indicate the **channel** (as opposed to “Brilliant” or “Vib/Trem), or it may designate the model (as opposed to “Bass” or “Treble”). That “Bass” and “Treble” moreover characterize the tone filter controls of the AC-30TB feels somehow almost normal, again.

The **conclusion** of the headroom analysis is somewhat ambivalent: on one hand the charts reveal characteristic differences between the drive margins of various amplifiers, but then again, they do not – because the diversity of the parameters is simply too large even when setting aside the diversity of models. The unmanageable hodgepodge starts with the tubes, continues with the settings of the controls and the definition of a reference condition, and ends with the will (or lack thereof) to add another 100 diagrams to the 50 already cluttering the table. While the frequency response curves show delightfully little change when swapping one **tube** against another of the same type, the harmonic distortion can change drastically. This is true not only as we plug in a well-kept Siemens ECC83 but also as we change from one 12AX7-AC to another 12AX7-AC. The much-lauded carbon film resistors join in with a zest: some do not even fall into the 10%-tolerance range (which in itself is quite intolerable). It is annoying that a 100-kΩ-resistor in cosmetically fine condition found in a 50-yeal-old VOX measures a full 300 kΩ - but it is understandable. However, the brand-new replacement (“absolutely high-end”) had 117 kΩ rather than 100 kΩ, and this caused a few not-printable eruptions. After a successful chill-down, and after arriving at the assumption that this might simply be a single out-of-the-tolerance-range case, the realization followed: all 10 carbon-composition resistors of this “High-End” batch read similarly far away from their nominal value. It is thus recommended not to interpret the diagrams shown here to the 10^{th} of a dB, but use them as an “orientation”. The significant result we can retain is that the **cathode-follower** creates considerable distortion. Was this the reason why the designer of the famous AC-30TB told Jim Elyea that he in fact preferred the AC30/6 [Elyea, Section 4]?

10.10.4 Comparison: harmonic distortion

Transistors generate 3rd order distortion (= bad) while tubes generate 2nd order distortion (= good) – that's correct, isn't it? Nonsense. Some things may be square (aka 2nd order), and others hip, but tubes are … well, they are cylindrical. Tube as well as bipolar transistor as well as field-effect transistors have progressively curved characteristics and therefore generate both 2nd *and* 3rd order distortions (and many more). A big difference is that for the tiny transistor, very soon extended circuits established themselves that included negative feedback across several stages. Meanwhile, for tubes, the single stage with little negative feedback (or none at all) continued to dominate. There are exceptions (e.g. power stages), but in input stages we almost always find single tubes – mostly with a cathode resistor bridged by a capacitor i.e. without any substantial negative feedback. The contrary happens in an **operational amplifier (OP)**: here there are 20 or more transistors concentrated in a tiny space – something entirely impossible with tubes but doable with transistors in an "integrated amplifier" on a chip of 1 mm^2. The strong negative feedback in typical OP-circuits results in symmetrical signal clipping i.e. in strong odd-order distortion (k_3, k_5, k_7, ...). Thus, it is the circuit that determines how an amplifier distorts, and not primarily its amplifying elements.

The transfer characteristic of a bipolar transistor from base-emitter-voltage (U_{BE}) to collector-current (I_C) may be approximated by an exponential function:

$$I_C = K \cdot e^{(U_{BE}/26\text{mV})}$$ Simplified transistor characteristic

The constant K is the value on which the blocking behavior of the transistor depends. The collector current rises progressively with increasing base-emitter-voltage, and since this function is not point-symmetrical to any strong degree, the dominant distortion is the 2nd order one and not the 3rd order one (**Fig. 10.10.15**).

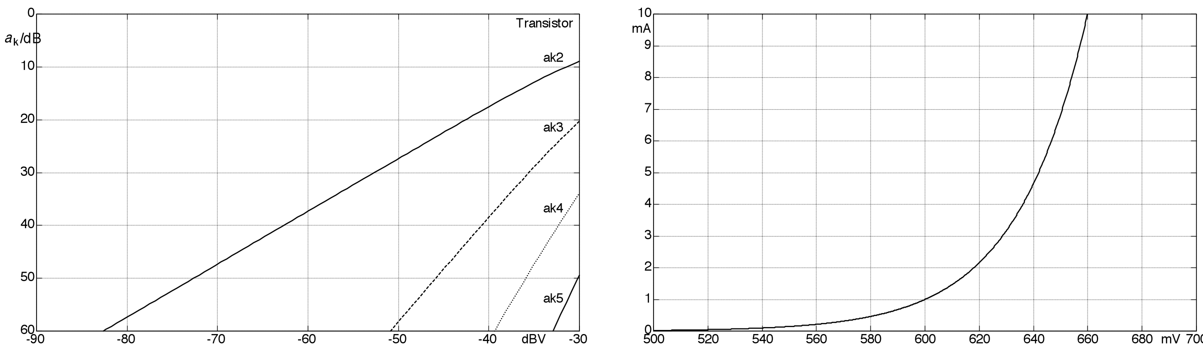


Fig. 10.10.15: Harmonic distortion for a bipolar transistor (left); transfer characteristic (right) .

The figure shows that the 2nd order harmonic distortion increases proportionally to the drive level while the 3rd order distortion rises with the 2nd order of the drive level. At $U_{BE} \approx 2.5$ mV the 2nd order distortion exceeds 3%; the 3rd order distortion amounts to merely 0,1%. It needs to be considered, however, that the above equation holds for the small-signal behavior that reaches its limit at the latest when the collector voltage approaches the residual voltage (when the transistor conducts best). The collector current cannot increase indefinitely and as it reaches its limit, the characteristic (initially arched to the left) turns to the right. As a consequence of this change in the direction of the arch, the collector-current receives a limitation in *both directions* and odd-order sections of the function gain in weight, and with them the odd-order distortion products. For strong overdrive, the dominant harmonic distortion will generally not be the 2nd order distortion but the 3rd order distortion.

 Translation into English by Tilmann Zwicker

A **triode** distorts similarly, although the functional relations are of a different kind (Fig. 10.1.12), and the following analysis will be dedicated not to the transistor but to this triode. The basic behavior has already been presented in Chapter 10.1.4; now special guitar amplifiers will be targeted. Fender's **Super-Reverb** (AB 763) features a 7025 (ECC83) at the input in a typical wiring – at low drive levels the 2nd order distortions dominate (**Fig. 10.10.16**). Fig. 10.1.13 has already demonstrated that the drive-level-dependency of the harmonic distortion varies with the individual tube-specimen but at low signal levels (e.g. -20 dBV, equivalent to 0,1,V) the 2nd order distortion always is stronger. "Typical for tubes", one could think, however this holds true only for the first tube stage. The right hand picture shows the distortion measured at the second plate, and here the 3rd order distortion dominates that – according to some gazettes for musicians – is reserved for the transistor. Taken individually, each triode generates predominantly 2nd order distortion at low drive levels. However, since the **signal phase is inverted** from grid to plate, the 2nd order distortions compensate each other to a large degree for two tube stages. In other words: the first triode generates a concave downward characteristic while the second triode generates a convex upward characteristic, and the result in a series connection is an S-shaped overall characteristic that predominantly generates 3rd order distortion products (odd functions result in odd-order distortion).

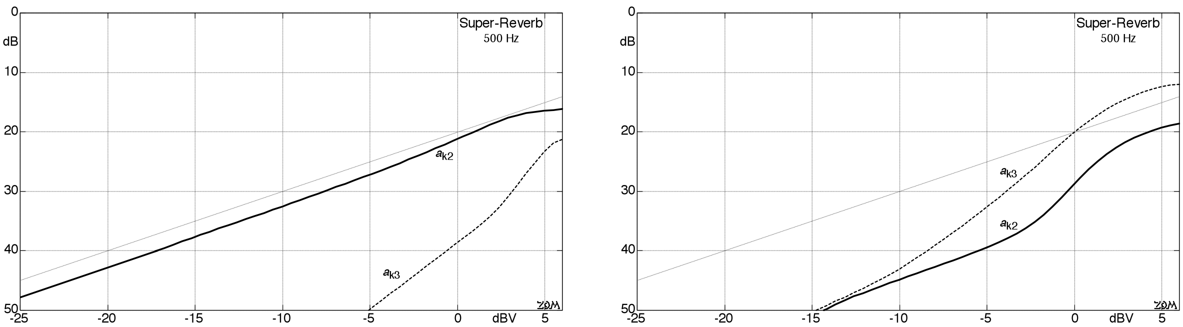


Fig. 10.10.16: Super-Reverb, harmonic distortion: input to 1st plate (left), input to 2nd plate (right).

Of course, the details of this k_2-compensation depends on the network located between first and second tube (in this case the tone stack and the volume control); the measurement was done at the not untypical setting of B = 2, T = 7, V = 7.

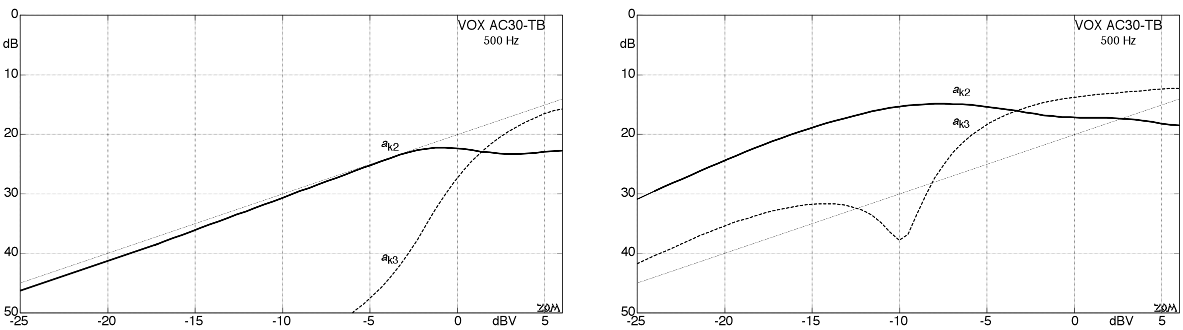


Fig. 10.10.17: VOX AC30-TB, harmonic distortion: input to 1st plate (left), input to 2nd plate (right).

An entirely different harmonic distortion situation is seen in the **VOX AC30-TB** (**Fig. 10.10.17**): although the first tube stage behaves similarly to the Super-Reverb especially at low drive levels, the distortion rises dramatically in the second stage (cathode-follower, Chapter 10.2.2). These are the effects of a very unusual choice of component values that leads to a nonlinear operation with strong grid-current (control setting: V = 12:00 h, B = 10:00 h, T = 12:00 h).

Another again different situation is found at the loudspeaker output (**Fig. 10.10.18**). For the VOX, 3rd order distortion dominates for strong drive levels ("… it's a tube amp so it has to be k_3." ☺), for the Fender we find k_2 and k_3 to be of a similar magnitude ("... strange, are there any transistors in the Super Reverb?" ☺). The details of this behavior depend on the specific individual tubes used and, for the Fender, additionally on the quiescent current and the degree of asymmetry in the phase-inverter. As the latter's plate resistors are changed (100 kΩ and 82 kΩ, respectively), the k_2 changes, as well. Altogether we see a rather "multivariant" scenario.

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Fig. 10.10.18: Harmonic distortion, input to loudspeaker: Super-Reverb (left), AC30-TB (right).
This figure is reserved for the printed edition of this book.

What is the reason for the basic difference? The Fender uses the **6L6-GC** while the **EL84** is deployed in the VOX. The offset voltage of the grid is about -10 V for the EL84 and -45 … -50 V for the 6L6GC. In the Fender, the phase-inverter thus needs to deliver five times the voltage and, for high drive levels, is not able to do this as well compared to the VOX. Consequently, the operating points shift (chapter 10.4.3, 10.4.4, 10.5.12), the duty cycle changes, and the 2nd order distortions differ. In summary: with a typical singlecoil pickup, the Fender generates pure power-amp distortion with a dominant k_3. Conversely, in the VOX both the cathode-follower (k_2) and the power amp (k_3) distort. The distortion rises somewhat more steeply in the Fender but still more gentle compare to the clipping of a transistor power amp with strong negative feedback (Fig. 10.10.19, lower left).

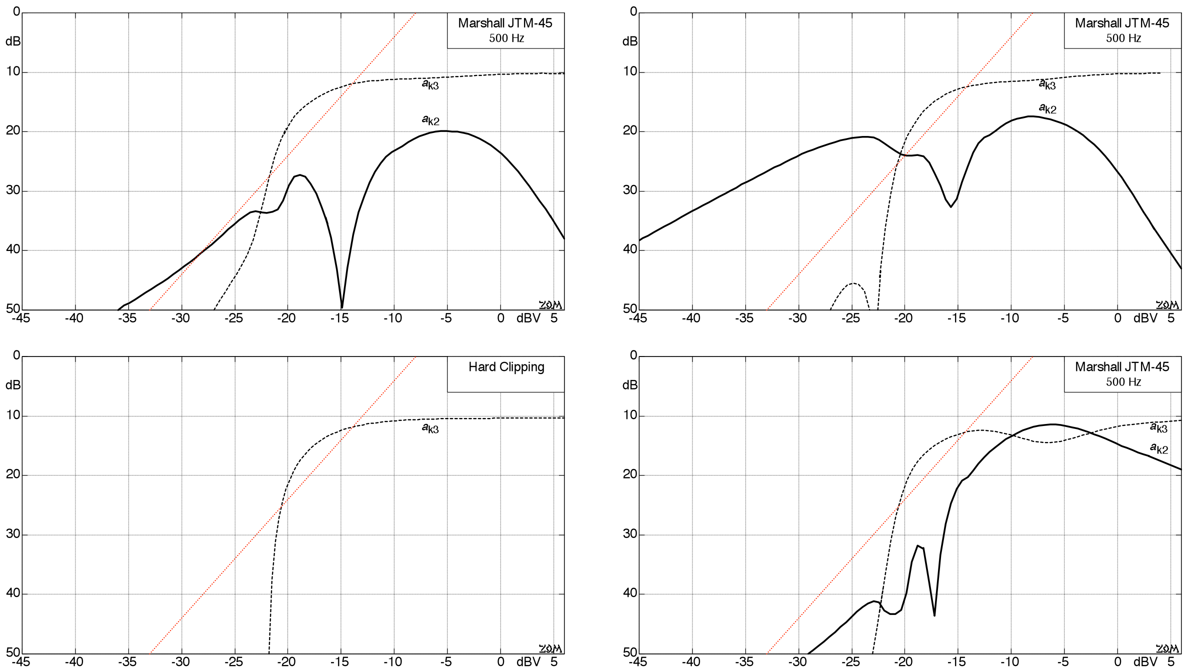
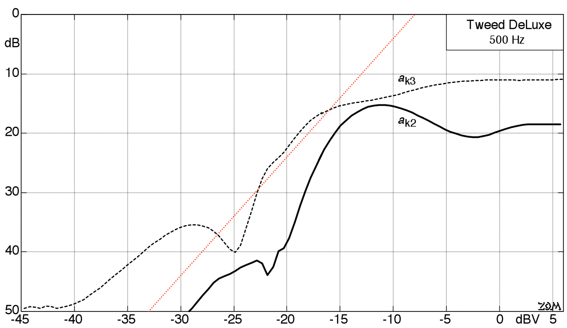


Fig. 10.10.19: harmonic distortion, input to loudspeaker: Marshall JTM-45 (KT-66, R_{aa} = 8 kΩ). Measurements with different tubes in the impedance converter (cathode-follower).

It was already noted in Chapter 10.5.12 that the **JTM-45** power amplifier has strong negative feedback and that the drive-level-dependent rise of the 3rd order harmonic distortion (k_3) consequently has similarities to a transistor power amp. **Fig. 10.10.19** shows the "overall" measurement from preamp input to loudspeaker output. Symmetric limiting should generate exclusively odd-order distortion but the measurement reveals even-order distortion (in particular 2nd order components a_{k2}), as well. These k_2-distortion-products are generated by the power amp but also in particular by the preceding tubes – and here the cathode-follower enters the picture. Its strange operating point with an uncommonly high grid current can make for strong distortion. "Can" – doesn't "have to", though. Swapping the cathode-follower-ECC83 for another ECC83 may change the 2nd order harmonic distortion by a factor of as much as 10 (or even more). We are not talking about damaged tubes here – no, these are brand new. Or they may have 100 h of "burn-in" under their belt, or be switched on in accordance with the moon-cycle, whatever. Take out one tube, put in another: 10 times the distortion. Or 10 times less if it's the other way round. Weird, ain't it? One might think that the developer was clobbered with this circuit botchery, but no, countless "expert"-journalists around the globe rave about it. Yes, it may indeed sound damn good. It may ……

Here a little story from way back in the day: at the Siemens R&D lab there was an infamous head of department who – as a tube circuit design was completed – took from his closet two borderline specimen for each tube type. He plugged them in and personally took measurements. If the great new circuit did now not perform so great anymore, the designer received a great talking-to and was sent back to rework the circuit. Well, Marshall & Son was not Siemens, apparently. Thank God, many will say: otherwise these distorting, screaming monsters would never have seen the light of day. Also, it is only fair to spread some blessing of early birth over 50-year-old developments – however why are there still no tubes in this century that are selected for just this strange c-follower? Rather, the "experts" elaborate about changing a transformer (RS vs. Drake), or whether yellow rather than orange capacitors should be used, or metal-film rather than carbon resistors, or 250 µF rather than 330 µF, even whether solid wire or stranded wire sounds better. No one ever thinks of better specifying the nonlinearities of the c-follower-tube that may actually make a real difference, for a change.

Finally, let us look at two amplifiers that do not include the cathode-follower: Fender's **Tweed Deluxe** (cathodyne, 6V6-GT), and the **Deluxe Reverb** (differential amplifier, 6V6-GT). Die Tweed power-amp has no negative feedback, and therefore the k_3 is stronger at low drive levels compared to the Deluxe Reverb (AB763) that does have feedback.



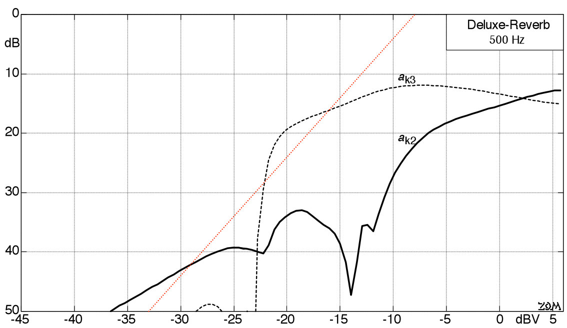


Fig. 10.10.20: harmonic distortion, input to loudspeaker: Tweed Deluxe (5E3), Deluxe Reverb (AB763).

Conclusion: clipping on both sides <u>will</u> generate odd-order distortion. With increasing negative feedback the k_3–rise will be steeper, but the really big differences are in the k_2: there is compensation of pre-amp-tube distortion as well as extreme dependency on individual tubes in the c-follower. Plus, of course, the individual push-pull-anti-symmetry plays a role.

The filter circuit in VOX amps known as **Cut-Circuit** merits special consideration. It was already an established custom to connect a small capacitor between the plates of the differential amplifier used as phase-splitter (Chapter 10.4.3); this reduces the gain in the highest frequency region. As this capacitance is increased into the nF-range, the treble is rigorously “cut”! However, in contrast to the treble controls used otherwise, this is a **non-linear low-pass**!

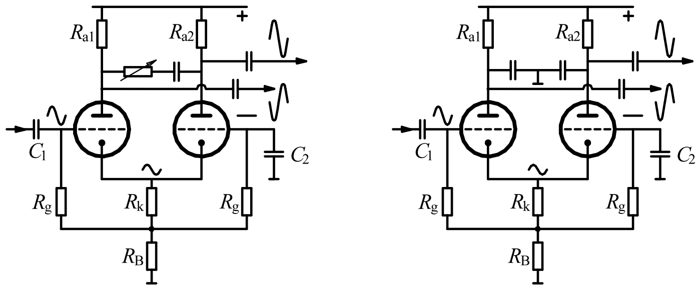


Fig. 10.10.21: Cut-circuit. With the pot turned down, the remaining capacitance may be interpreted as series circuit with intermediate grounding (Fig. 10.4.8).

Fig. 10.10.21 shows how the capacitance connected between the plates may be seen as series circuit (this works the same way with an RC-two-terminal-network, if the pot is not fully turned down). Both plate voltages are approximately equal in amount but out-of-phase so that “between them” we find zero volts. The large plate loading dramatically reduces the **slew-rate**, and therefore this low-pass has a non-linear effect. Another consequence is that the treble-loss cannot be compensated for in any further intermediate stage: the power amp generates less treble *even when overdriven* (!). ‘Turning down Cut’ therefore is different from ‘turning down Treble’.

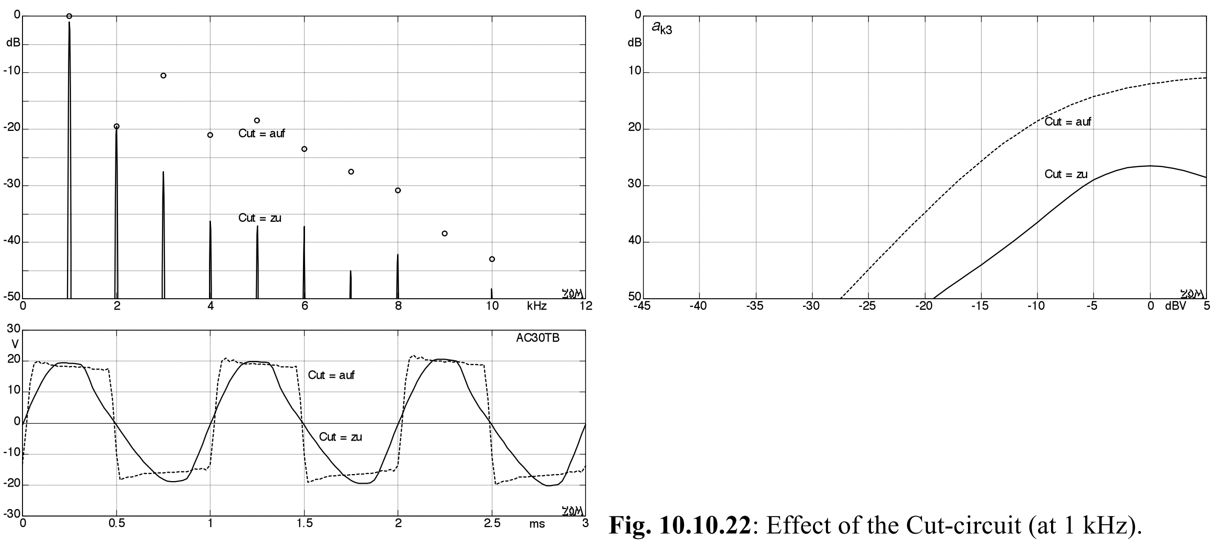


Fig. 10.10.22: Effect of the Cut-circuit (at 1 kHz).

In **Fig. 10.10.22** we see the results of measurements taken from an AC30-TB (from Normal-input to power amp). Even with strong overdrive, the power amp cannot do any “hard clipping”: the shape of the curve is round and the high frequencies are attenuated. Conversely, if the Treble knob were turned down on e.g. a Fender amp, and the power amp strongly overdriven at the same time, the result would be a square output wave-shape. Here, the VOX offers an interesting alternative.

10.10.5 At which strength is harmonic distortion audible?

This is a difficult topic because there are so many details influencing it that a single number is not even close to doing the job. We can merely state: "somewhere between 0,03% and 10%." For synthetic test signals it will be more towards the lower value while for guitar sounds, it will be more towards the upper.

Nonlinear distortion of a **sine-tone** can be detected only at strong distortion levels because the new (higher-frequency) partials generated by the nonlinearity are masked to a large extent [12]. **Two-tone signals** are more critical since their nonlinear transmission generates (on top of the masked summation tones) low-frequency difference tones, as well – and these can relatively easily be detected. Webers writes in his book "Tonstudiotechnik" (recording studio technology) that tones of flutes are seen as particularly problematic. He notes a threshold of detection of k_2 = 1% for 2nd order distortion and of k_3 = 0.3% for 3rd order distortion. Rossi lists even smaller limits of audible distortion but feels that 1% intermodulation-distortion is acceptable. Our guitar amps? No, they do not fit at all into this system of (mostly purposeful) rigid values of audibility thresholds found in recoding studio technology. Still, it would be helpful to have an understanding of the distortion levels at which *clean* becomes *crunch*, of the characterization of *strong* and *ultra* distortion, respectively, and of what *even* and *odd* distortions are.

Nonlinear distortions happen at curved transmission characteristics, i.e. predominantly in tubes and semi-conductors. Curved characteristics may be developed into mathematical series expansions, and if these expansions include odd powers only (x, x^3, x^5, ...), they generate odd distortions. If only even powers occur (x^2, x^4, ...) on top of the linear term (x), even distortions result [Taylor/MacLaurin, Fourier-series, communication technology]. To start with a simple signal (even if it barely shows any similarities to a guitar tone): in **Fig. 10.10.23** a sine-tone receives nonlinear distortion via the characteristic $y = x - x^3$.

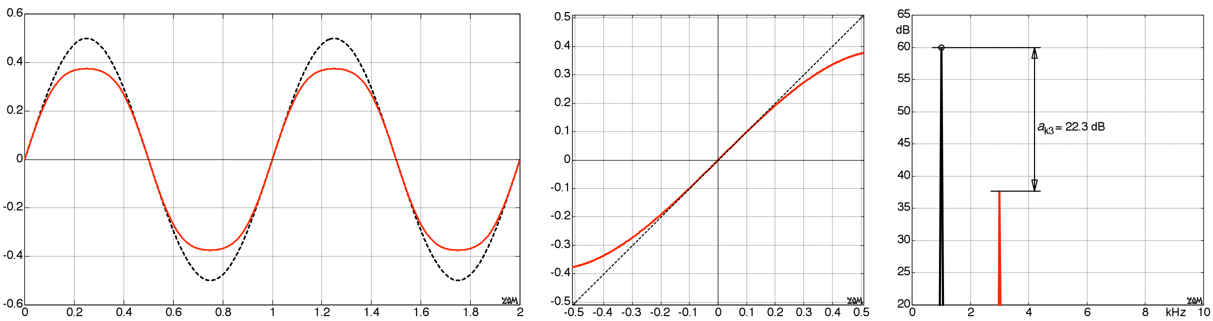


Fig. 10.10.23: Nonlinear (3rd order) distortion of a sine-tone; time function, transfer characteristic, spectrum.

Inserting for $x = \sin(\omega t)$ into the characteristic and calculating the equation immediately shows the result as seen in the spectrum: we obtain a new spectral line at three times the fundamental frequency with a level-distance of 22 dB re the level of the fundamental. In the following formula, the index i stands for the order of the partial tones (i = 1 marks the fundamental), u is the distorted voltage, and u_i is the voltage of the i-th partial (all voltages are RMS-values). Consequently, k_3 is the 3rd order "Harmonic-Distortion"-factor (HD), and a_{k3} is the difference level between the fundamental and the distortion products. This approximation works the better, the smaller the HD is.

$$k_i = \frac{u_i}{\sqrt{u_1^2 + u_2^2 + u_3^2 + \ldots}} = \frac{u_i}{u} \approx \frac{u_i}{u_1} \qquad a_{ki} = 20 \cdot \log(1/k_i)\,\mathrm{dB} \qquad \text{Harmonic Distortion}$$

Fig. 10.10.24 shows the corresponding results for purely 2nd order distortion; the chosen characteristic was $y = x - 0.3x^2$. The new partials generated are now at twice the fundamental frequency and at 0 Hz. The DC-component is usually blocked using coupling capacitors because it may disadvantageously shift the operating point depending on the signal.

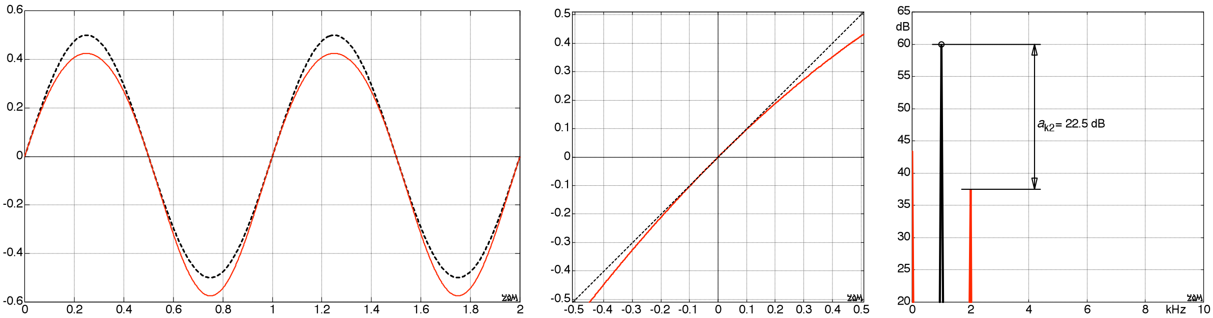


Fig. 10.10.24: Nonlinear (2nd order) distortion of a sine-tone; time function, transfer characteristic, spectrum.

Using **two-tone signals** we achieve a step towards more natural signals, but we also increase the number of degrees of freedom: we may now choose the frequency relation between the two primary tomes, the difference in their level and the difference in their phase. For **Fig. 10.10.25**, a frequency relationship of 6/5 is chosen, with the levels of the primaries being equal. For **3rd order distortion**, new lines are generated at the frequencies $2f_1 - f_2$, $2f_2 - f_1$, $3f_1$, $2f_1 + f_2$, $2f_2 + f_1$, $3f_2$. At $2f_1 - f_2$ we find the **3rd order difference tone**.

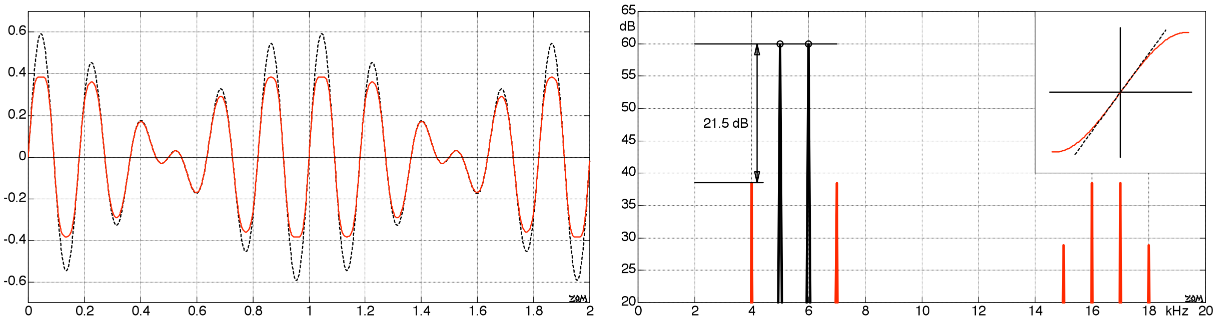


Fig. 10.10.25: Nonlinear (3rd order) distortion of a two-tone signal; time function, transfer function, spectrum.

With **2nd order** distortion (**Fig. 10.10.26**), a DC-component results, as well as new lines at $f_2 - f_1$, $2f_1$, $f_1 + f_2$, $2f_2$. At $f_2 - f_1$ we find the **2nd order difference tone**.

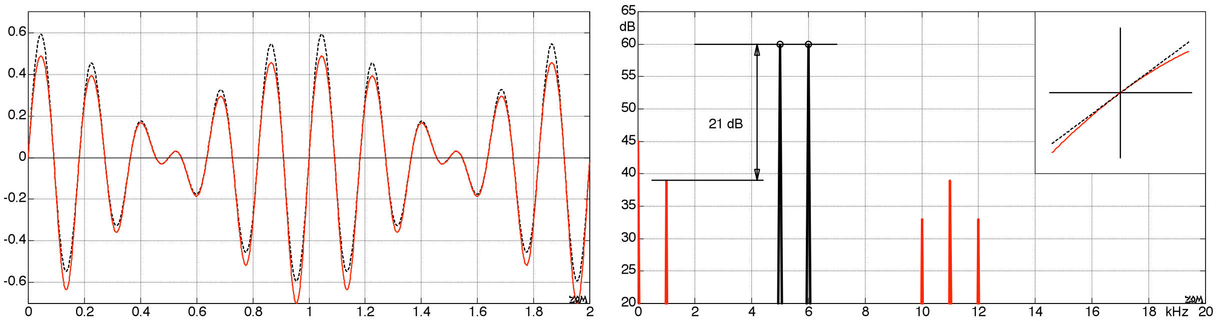


Fig. 10.10.26: Nonlinear (2nd order) distortion of a tow-tone signal; time function, transfer function, spectrum.

The distortion does not only generate lines at new frequencies but also at the frequency of the primary tones. The level and phase of the latter is correspondingly changed.

 Translation into English by Tilmann Zwicker

A tone from a guitar is much more complex than the signals just looked at, and therefore the multitude of parameters explodes. The HD is not a fixed value but dependent on the drive level. Doubling the input signal makes the 2nd order HD grow by a factor two and the 3rd order HD by a factor of four; k_2 is proportional to the drive level while k_3 is proportional to the square of the drive level. Changing the phases of the partials changes the crest-factor (peak-value/RMS-value) and thus the HD even if the drive level remains constant. For a guitar signal, this drive level is of course not constant but decreases quickly after a strong attack. So, what should we reference the HD to? To the maximum value that lasts only a few milliseconds? Or some kind of average value defined one way or another? For sine-shape drive signals it is easy to specify the HD but driving a system with a guitar signal creates a problem.

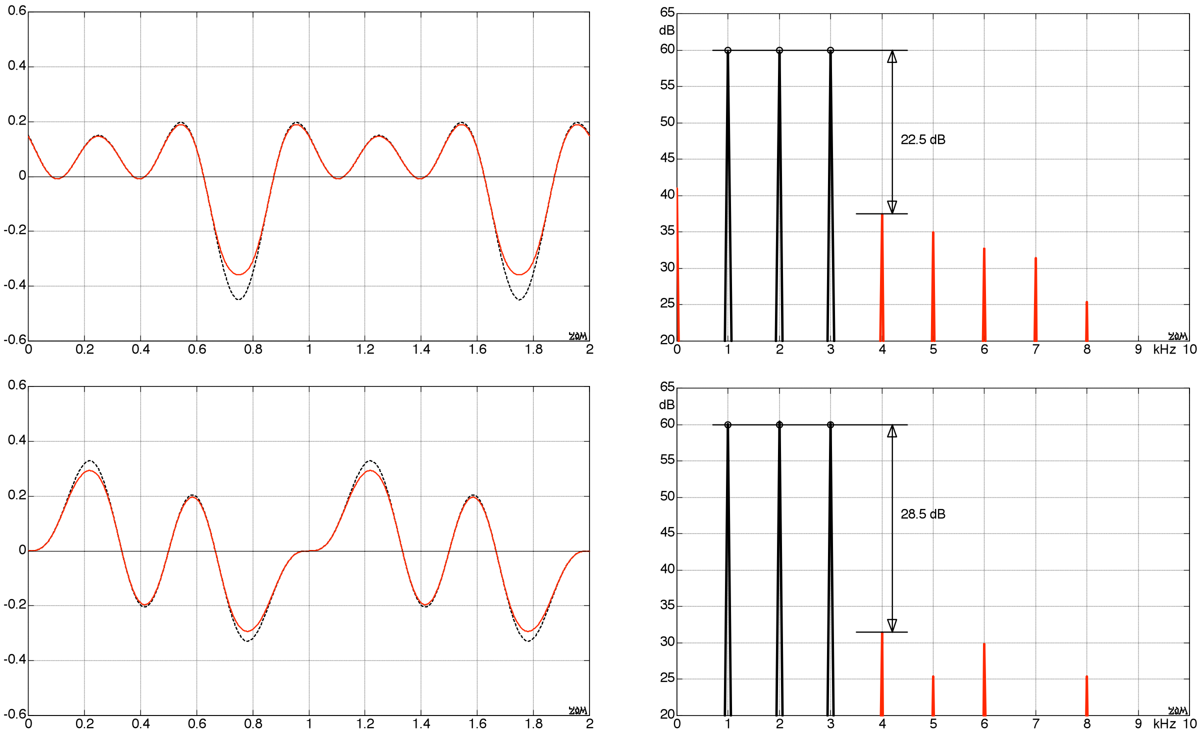


Fig. 10.10.27: Changes in the 3rd order distortion spectrum as the phase of the partials in a three-tone signal is changed. The RMS-value, and thus the level of the primary signal is identical for both cases.

For **Fig. 10.10.27**, a signal consisting of 3 partial tones is distorted. Changes of the phases of the partials do change the level of the strongest distortion product by no less than 6 dB. This does not mean that measuring of (T)HD (or intermodulation- or difference-tone-distortion) is not purposeful – in fact these measurements are highly suitable to describe the nonlinear behavior of a system. An approximate estimation of how strongly a specific signal is distorted by this system is possible, but does not really indicate how the resulting distortion in fact sounds.

After this introduction we will now look at real **guitar signals**, using the pickup voltage of a Telecaster. As a string is plucked with little force, the levels of the partials decay approximately linearly over time, as it has been shown in Chapter 7.7. For strong plucking (with the string hitting the frets - Chapter 7.12.2) we find a strong level-decay of up to 10 dB during the first 20 – 50 ms, and a slow decay afterwards, similar to weak plucking. In a simple model generating merely 3rd order distortion, the HD would change by a factor of 10 during the first 50 ms. For such time-variant signal a single HD-limit is not very purposeful.

In **Fig. 10.10.28** we see the time functions of two pickup voltages. A non-linear amplitude limiting to e.g. ±0.5 V would have very different implications for the two signals. This example clarifies that for HD-limit-values not only amplitude limits are significant, but durations in time, as well.

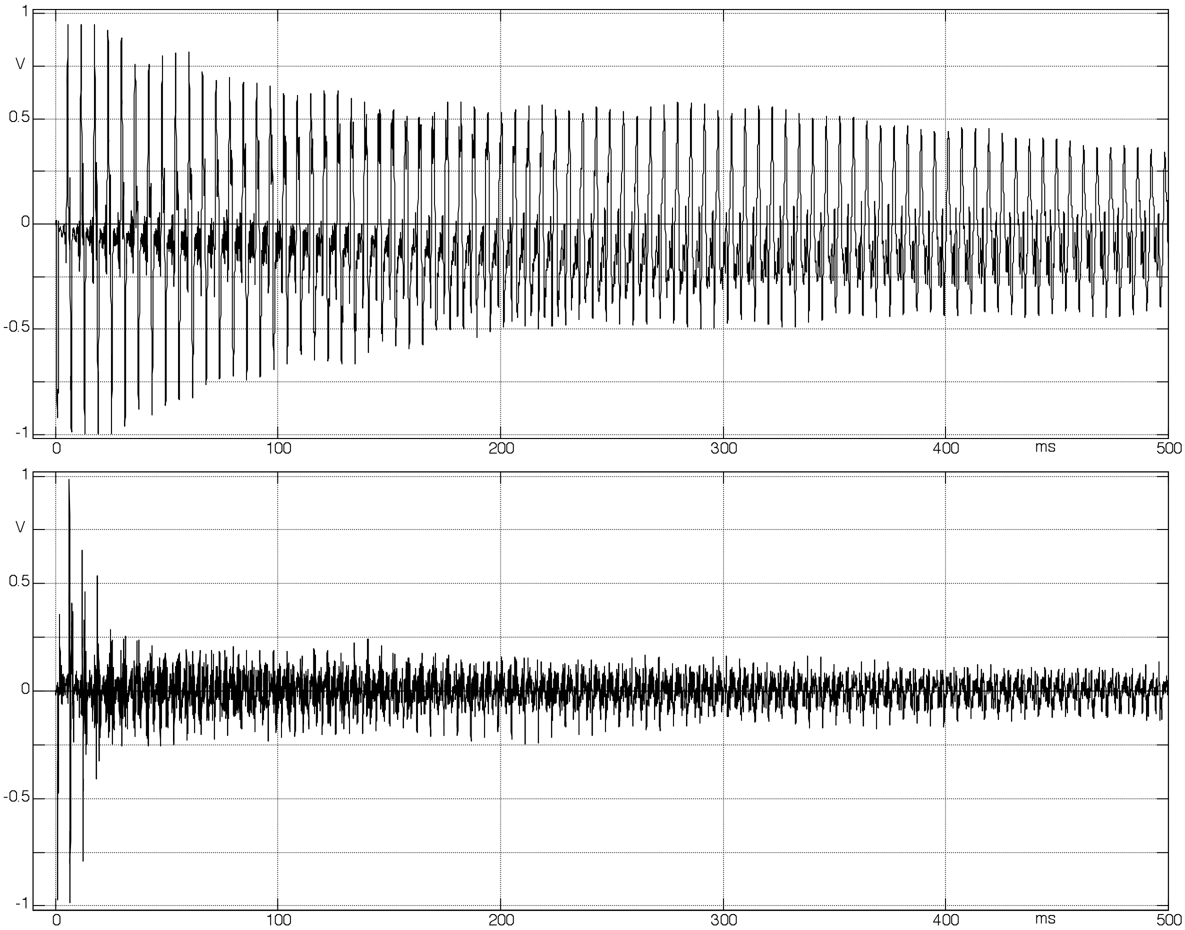


Fig. 10.10.28: Two different pickup voltages normalized to the same maximum value. In the upper section the string was weakly plucked, and strongly on the lower section. Telecaster, bridge pickup, E3 on D-string.

Before we subject these pickup voltages to distortion, we first return to the series expansion of the characteristic curve. For small HD it is purposeful to study the behavior of purely 2nd order and purely 3rd order distortion. In guitar amplifiers, however, strong distortion occurs, as well, and therefore the model using purely 2nd order and purely 3rd order distortion is incomplete. Tubes (as well as semi-conductors) **limit** on **both sides** for strong drive levels – this is the domain of **odd** distortions. A straight, symmetric characteristic (such as $y = x^2$) cannot generate limiting to both sides. A 3rd order characteristic can do this – however only within a small range, as shown in **Fig. 10.10.29.** The blue line approximates the characteristic of a tube close to the origin, but it turns off in the opposite direction as it moves away. And it continues to grow without any limiting.

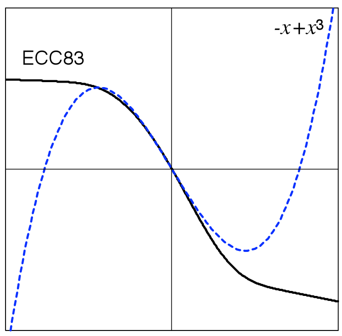


Fig. 10.10.29: Tube characteristic (ECC83); third-order parabola.

To better adhere to the tube characteristic depicted in Fig. 10.20.29, the approximation-polynomial would require further odd-order members in the series (x^5, x^7, ...), and in addition series-members of even order would be necessary, because the amounts of the limit-values differ (tube-characteristics are not exactly point-symmetrical). Therefore, the distortion in the following is done not by a polynomial characteristic but by a real tube characteristic (ECC83).

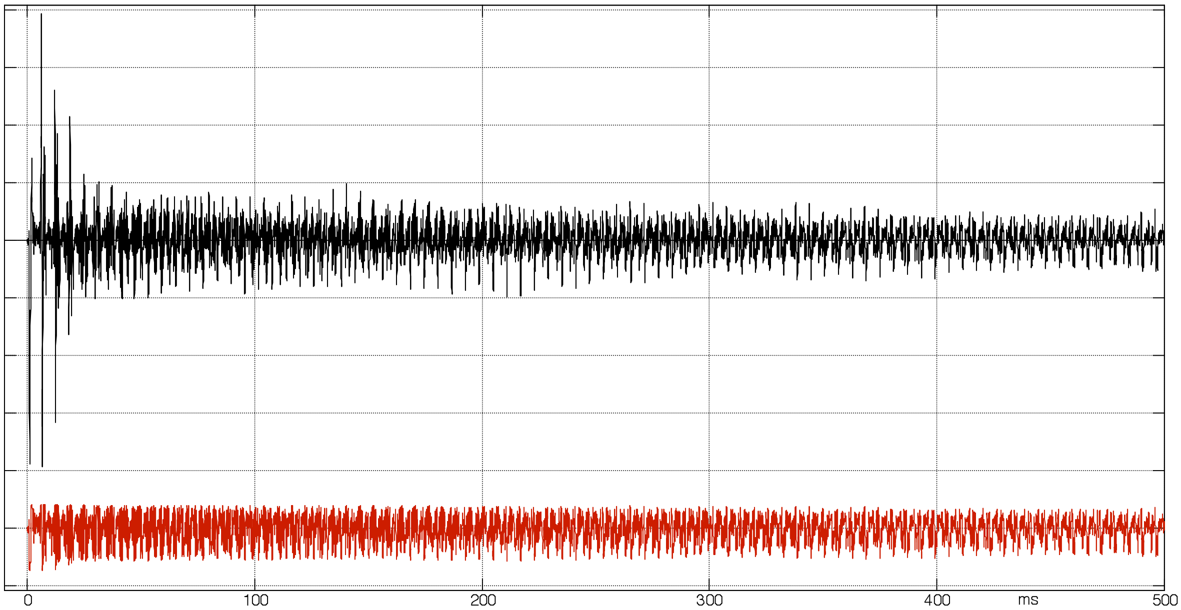


Fig.10.10.30: Pickup voltage, **without** (top) and **with** non-linear tube-distortion (bottom). String strongly plucked, Telecaster, E3 on D-string, bridge pickup.

In **Fig. 10.10.30** we again see the signal from Fig. 10.10.28, with and without tube-distortion. It may be hard to believe, but these two guitar signals do not in fact sound that different. One does hear differences but not in terms of "undistorted/distorted". The attack is louder for the undistorted signal, but afterwards there is no audible difference. This may be due to post-masking [12], and/or due to the fact that any limiting in the subsequent development affects merely very short signal peaks. Another reason: for a **strongly plucked string**, contacts between string and frets occur for a relatively long time period, and these sound similar to slight overdrive and hamper the recognition of actual tube distortion. A value for the HD in the signal shown in Fig. 10.10.30 cannot be established since there is no definition of a HD for such a multi-tone-signal. It is however possible to create a sine-tone with the same envelope, and to distort it in the same way (i.e. feed it through the same tube characteristic). The result is that at first 3rd order distortion dominates with k_3 reaching 28%. From 50 ms the 2nd order distortion starts to dominate with $\boldsymbol{k_2 \approx 5\%}$. It is noted again, however, that despite these large HD's the guitar does not actually sound distorted but is limited in its dynamic range. The "thud" at the beginning is softer – and that's it.

We obtain an entirely different result as the string is merely **lightly plucked**. Without distortion, it sounds weaker in the treble range than the strongly plucked string. Therefore, and also because the level does not decrease as fast, distortion can be heard clearly as the signal is fed to the same characteristic as the strongly plucked string (with both signals normalized – pre-distortion – to the same maximum drive.

For the lightly plucked string, **Fig. 10.10.31** shows the time function of the undistorted and distorted pickup voltage. Despite the same maximum drive level and the same distortion characteristic, the subjective degree of distortion is different. This is because the hearing system does not exclusively evaluate the attack, after all. It is well known from experiments on loudness scaling [12] that the loudness of short bursts decreases: the hearing integrates over 100 ms.

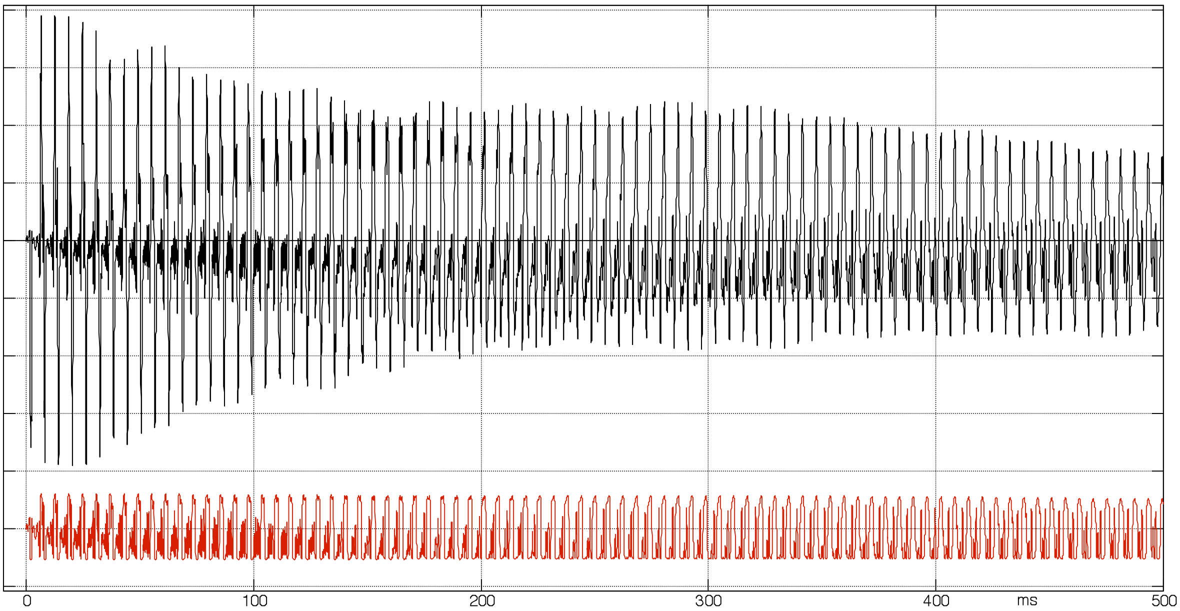


Fig.10.10.31: Pickup voltage, **without** (top) and **with** non-linear tube-distortion (bottom). String lightly plucked, Telecaster, E3 on D-string, bridge pickup.

It has already been elaborated repeatedly that the inharmonicity of the guitar signal plays a role, as well (Chapter 1.3, 8.2.5, 10.8.5). For a strictly harmonic sound, all spectral lines generated by the distortion fall onto already existing lines, and it is merely level and phase of the frequency component that changes. However, for an inharmonic sound the non-linearity will cause new spectral lines at frequencies where no partial was present in the undistorted signal. The subjectively perceived sound may change considerably due to this, depending on the circumstances. It will obtain a more stochastic character and sound as if noise had been added (Fig. 10.8.23). Because the inharmonicity depends on the type of string, on characteristic of the circuitry, and on the individual tubes, and on the guitarist, it is not possible to give a single threshold value for the audible HD. It may be noted as an orientation, though, that we are not talking about values in the range of or even below 0,1% here. There are investigations comparing capacitors with a THD of below 0,0001%. This is extremely sophisticated metrology but entirely without meaning for auditory acoustics.

Well then – despite all constraints, the reader will expect a number here, and now. And so, to the best of our knowledge: ***k* = 3%**. This would be the orientation value – and surely a basis for splendid discussions. Guitar-distortion becomes just audible as a sine-tone of the same level distorts with a THD of 3%. "The same level" should be interpreted such that not the level at the attack of the guitar tone is measured, but the level of a purposeful section of tone following the attack region. This puts the responsibility back to the esteemed reader and hopefully helps to avoid a discussion in internet fora (e.g. dedicated to the question of whether the threshold of audibility is not at 2,6%, after all).

10.10.6 Comparison: frequency responses

Let’s now go for the full enchilada: the mapping of the input voltage onto the sound pressure. We will not check the transfer function of individual parts to the circuit (as in Chapter 10.3) anymore, but the transfer behavior of the whole “**amp-plus-speaker**”-system. For the associated measurements, the speaker enclosure (for combos including the amplifier) was set up in an anechoic chamber (AEC), i.e. a room with fibrous wedges of 80 cm length mounted to all six boundary surfaces to substantially suppress any reflections. The sound pressure was picked up axially in front of the speaker using a precision microphone (B&K 4190), and analyzed with a workstation (Cortex CF 100). Beaming effects were not captured here – Chapter 11.4 is dedicated to the associated effects.

The ancestors of modern guitar amps did not differ much from other audio amps of the time. The design objective was apparently a reproduction as broadband and as frequency-independent as possible. Simple amps did not have any tone filter at all (e.g. early Fender Champs), or they sported – what luxury – a *single* tone knob (Fender Deluxe). Later, two-, three and even four-band tone filters were included, as well as tremolo and reverb – but, again, that came later. These old amps did not sound bad because the transmission was in fact not frequency-independent, after all – due to the frequency dependency of the **loudspeaker impedance** (Chapter 11.2), whether the designers were aware of this or not. Early power amps did not have any negative feedback (e.g. Champ 5C1, Princeton 5D2, Deluxe 5B3, Super 5B4, Pro Amp 5C5, VOX AC15, Gibson GA-20, Gibson GA-40, Rickenbacker M11, Epiphone EA-50, and many more), giving the pentode-power-stages a high-impedance output that leads, in combination with the speaker impedance, to a characteristic frequency-response. **Fig. 10.10.32** shows this exemplarily for the AC30 – this amp is not that old but it never had any negative power-amp-feedback in any of its incarnations. With a 16-Ω-resistor serving as load, the transmission is independent of frequency. However, as the speaker replaces the resistor, the speaker resonance appears at 65 Hz, an enclosure resonance shows up at 170 Hz, and towards the high frequencies we see the contribution of the voice coil. This situation is quite different for power amps including strong negative feedback such as the **JTM-45**: unless the presence control is turned up, the voltage levels for resistor- and speaker-load do not differ by more than ±1 dB. For the overall frequency response, three main sources can be identified: the tone filter (as far as it is present), the speaker-impedance, and the frequency response of the speaker. In addition, there are high-pass filters (the coupling capacitors) and low-pass filters (the Miller-capacitance), as already described earlier. The overall frequency response depicted in Fig. 10.10.32 shows a pronounced treble boost although there is no special filter for this – it is the result of the high-impedance power-amp-output + speaker impedance + frequency-response of the speaker. In the AC30, the treble could be attenuated with the Cut-filter but that is not in fact desirable. For many users, the Normal-channel featured too little treble – that is why the Treble-version and the TB-channel were developed.

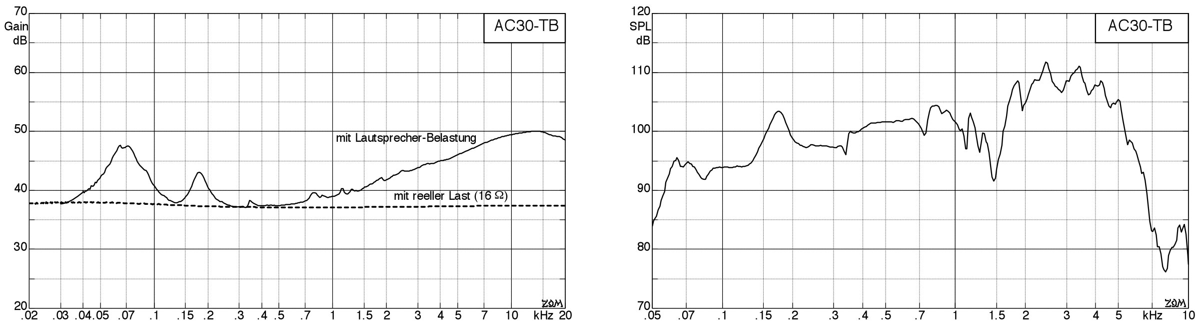


Fig. 10.10.32 left: VOX AC30-TB, transmission from phase-inverter-input to loudspeaker-output; dashed: with resistor; solid: with speaker; **right:** transmission from Normal-input to SPL in the AEC, volume = 12:00 h.

The frequency responses of some power amps (with corresponding loudspeaker) are shown in **Fig. 10.10.33**. For these measurements, the sweep-generator was directly connected to the input of the phase-inverter, and the microphone (B&K 4190) was at 2 m distance from the speaker. The lower curve shows the level of the speaker-voltage, referenced to 500 Hz (for the frequency dependency of the speaker impedance see Chapter 11.2). For power amps with strong negative feedback (e.g. the JTM-45) there is only little mapping of the speaker impedance maps onto the voltage level, while for power amps with weak or no negative feedback (Super Reverb, AC30), the speaker impedance strongly influences the voltage level. Moreover, the speaker itself and the enclosure construction (open or closed) of course influence the transmission behavior (Chapter 11).

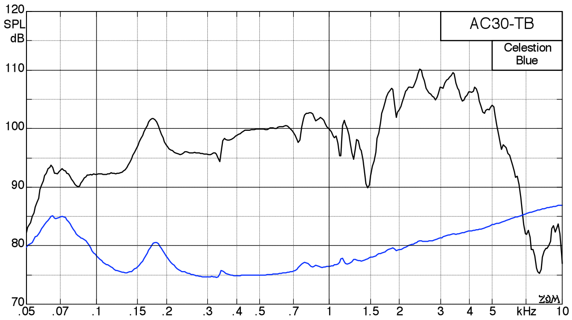


Fig. 10.10.33: SPL (d = 2m) and voltage level (lower curve). Reference: 1 W at 500 Hz.
SPL measured in the AEC on axis, sine sweep impressed onto the phase-inverter.
(N.B.: the parts of the figure not shown are reserved for the printed edition of this book.)

Taking the measurement not starting with the PI-input (as in Fig. 10.10.33) but starting with the input jack, the **tone filter** and other parts of the circuitry determine the transfer characteristic, as well. For the following measurements (**Fig. 10.10.34**), the tone filters were adjusted such that all amps had a similar, treble-heavy transmission; due to the limitations of some filters this was only possible as a rough approximation for several cases.

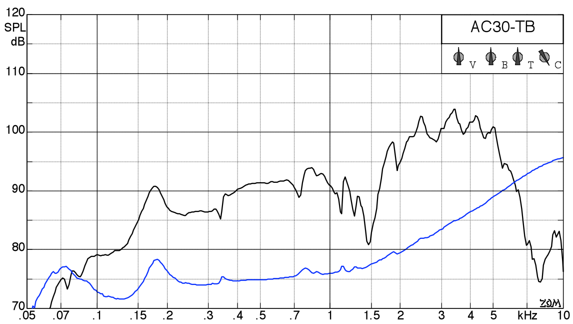


Fig. 10.10.34: SPL (d = 2m) and voltage level (lower curve).
SPL measured in the AEC on axis, sine sweep impressed onto the amplifier input.
(N.B.: the parts of the figure not shown are reserved for the printed edition of this book.)

As expected we find differences between the individual measurements. However, a comparison to the headroom-charts (Chapter 10.10.3) shows that the differences in the non-linear behavior are at least as big. As soon as an amplifier reaches substantial distortion, it is not sufficient anymore to merely determine the frequency-response (which, as stipulated by theory, is then anyway not defined anymore, either).

10.10.7 Special amplifiers: VOX, Fender, Marshall

VOX amplifiers AC15, AC30

The character of VOX-amplifiers is most readily understood starting the analysis with the **output stage**. This part of the amp shows extensive similarities for the AC30/4, the AC30/6 and the AC30-TB, and the AC15 from 1960 is based on this circuit, as well, albeit with only two power tubes. **Fig. 10.10.32** depicts the gain measured from the phase-inverter input to the 16-Ω-loudspeaker output: once with a resistive load (16 Ω), and a second time with the VOX-loudspeakers (Celestion Blue). Due to the high source-impedance, the loudspeaker impedance maps onto the output voltage, and local maxima appear in the overall transmission characteristic: around 70 Hz (speaker-resonance), at 180 Hz (Helmholtz-resonance of the enclosure) and in a broad band towards the high frequencies (speaker inductance, details in Chapter 11). With the resistive load, the power amp shows very little frequency dependence – there is merely a tiny bass-boost resulting from the Cut-filter. The characteristic frequency-response in the SPL is therefore generated not by the circuit per se but by the interaction between power amp (sans negative feedback), the speaker impedance and the radiation characteristic of the speaker. For all frequency responses shown here it is important to consider that all resistors in the circuits may have tolerances[⊗] of up to 10%, and the capacitors occasionally up to 20%. Since the total frequency response is due to the interaction of many components, substantial "overall"-deviations are possible.

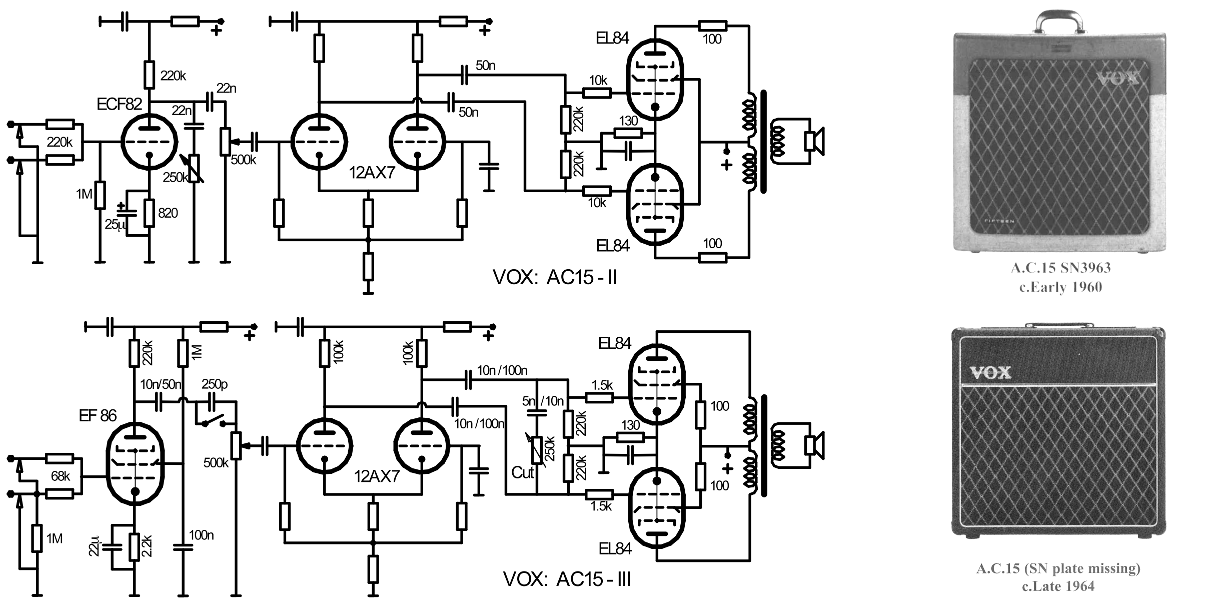


Fig. 10.10.35: VOX AC15, Normal-channel; "second circuit" (1959, top), "third circuit" (1960, bottom). The built-in vibrato channel is not shown in the figure, supplements: Chapter. 10.8.2. Pictures: Elyea.

In **Fig. 10.10.35** we see two variants of the AC-15-circuitry. Rather outlandish in the '59 circuit: the 100-Ω-series-resistors in the plate-connections of the power tubes. Did somebody confuse plate and screen grid here? This was not an error in the drawing – this did go into production, as photos in Elyea's book show. In the 1960-successor, the resistors show up where they belong: in the screen-grid-connections. The 60's-circuit was issued as Normal- and as Bass-model, with corresponding coupling caps. Opening the **Brilliance**-switch attenuated the low frequencies, and the **Cut**-control decreased the treble (**Fig. 10.10.36**).

[⊗] Two 100-kΩ-resistors bought from a tube-distributor each had 117 kΩ although specified with 10% – probably a concession to the black carbon-soul that supposedly ensures „*absolute high-end in the signal path*".

The treble could not really shine in the ’59 because the input circuit was inappropriate. In the series branch it had a high impedance (noise!), and in the parallel branch it was a bit too low-impedance due to the second 220-kΩ-resistor connected to ground. The modulator (not shown here) necessitated the **ECF82** (a combination of triode and pentode). This RF-tube (oscillator, mixing stage) was a bit out of place in the given environment and its gain is rather moderate. There was, however, not much choice if a triode was required for the Normal-channel and only a single pentode was foreseen for the whole of the modulator. Only in 1960 does the AC15 receive the deluxe-modulator (Chapter 10.8.2) and, in the Normal channel, the high-gain **EF86**. The latter had to yield to the **ECC83** in the same year for the AC30/6.

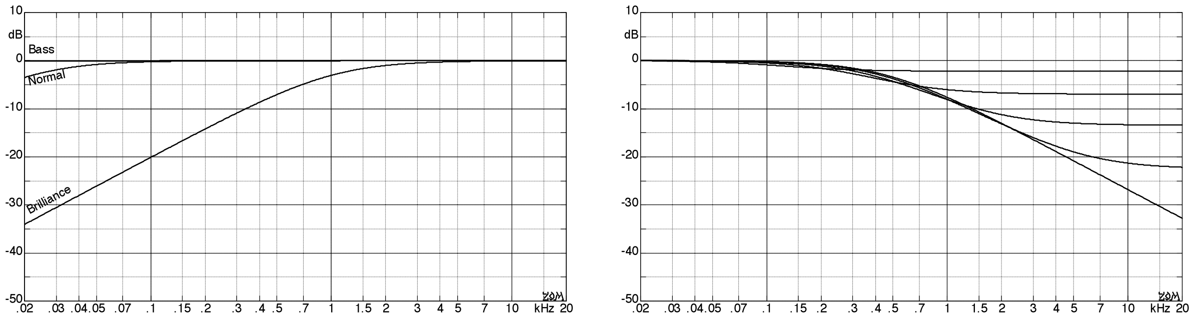


Fig. 10.10.36: Coupling preamp/phase-inverter (Brilliance switch, left); Cut-Filter ("Normal", right)

As we have established, the special transmission characteristic of the AC15, AC30/4 and AC30/6 amps results from the frequency response of the power-amp/loudspeaker interaction – tone filters are present to only a very modest degree in these amps. With increasing drive, the compression of the power stage comes into play (Chapter 10.5.12), plus the dominance of the 3rd order distortion (Chapter 10.10.4). Whether an EF86 or an ECC83 is placed in the preamp should only very indirectly affect the frequency response. Both **tubes** work from 0 Hz up into the MHz-range. Still, Elyea notes: *"The 12AX7 had a narrower frequency range, with a bit more treble, but less bass response than the EF86. The EF86 gave a wider frequency range"*. “More treble”, but less bandwidth? Well, of course that depends how you define *treble* … but in any case: if there is any effect at all, then this is not due to the tubes themselves but the result of the circuits around the tubes. By the way: regarding the comparison AC30/4 vs. AC30/6, Petersen/Denny opine: *"The AC30/4 seemed to have a clearer tone"*. And they add *"An EF86 has five elements as opposed to the three of a triode, so it can have up to 25% more gain"*. One is tempted to comment: but 5/3 is 67%! Of course the number of the electrodes is correct – it is the word “*so*” that rubs the wrong way because it implies the gain depends on the number of electrodes. Both percent-quotations are nonsense; the increase in amplification (EF86 vs. ECC83) is more than 100% (v_U = 140 to 180 vs. 70).

The “direct” influence of the input tube relates to the input capacitance, the amplification and the channel linkage. The pentode features a smaller **grid-to-plate-capacitance** resulting in a measureable difference to the ECC83 (Miller-effect). That is no reason to go into drama-mode, however, because a similar influence would result from shortening (or increasing) the length of the cable between guitar and amp by ½ a meter or so. On the other hand, the difference in gain is considerable: : +43...45dB for the EF86 (tube-specimen dependent) compared to +37dB for the ECC83 (each in VOX-typical environment). A further 6-dB-loss is due to the channel addition, and consequently an AC30/4 will yield the four- to five-fold amplification compared to an AC30/6. Furthermore, in the AC30/6, the frequency response of the Normal channel depends on the position of the volume control of the Bright channel, plus the coupling capacitors are different. The same for the loudspeaker, by the way: the change from Goodmans to Celestions in 1960 happens in the same year when the AC30/4 and the

AC30/6 were both concurrently on the market. There are, in summary, many reasons why one may hear differences in the sound of the amps. Not to forget: the **microphonics** of the EF86 which was the main reason for its retirement, and for a change in the circuit: many EF86 were configured as triode via the circuitry (*to reduce microphonics; also lowered were the gain and the frequency response* [Elyea]). In some AC15, the EF86 was swapped with a ECC83 in the factory. While the **AC15** was not subject to radical redesigns that other amps had to undergo (e.g. the Bassman), there still were changes. Of the 17 versions listed by Elyea many differ only in cosmetics or minor details; there are, however, three documented circuit variants. The obscure EL34-AC30 existed in 5 versions, and the bestseller AC30-Twin in 15 Versions during the JMI-period (1960 – 1967): there was the **AC30/4** in the Normal- and Bass-variants, the **AC30/6** in Normal, Bass-, and Treble-versions, pre and post the so-called *'List of changes'*, with 80-Ω- or 50-Ω-cathode-resistor, or with included Top-Boost-circuit. After that we see semiconductor diodes arriving replacing the GZ34, ceramic-magnet-speakers, and even pure transistor amps … but that was after the golden era that the JMI-period is sees as today. **Fig. 10.10.47** documents the change from the AC30/6 to the AC30-TB: originally installed as a retrofit, it was included ex-factory from 1963/64. Thus, the most important representatives of the VOX-flagship were the AC30/4, the AC30/6 and the AC30-TB, each as "Twin" since fitted with two loudspeakers, and occasionally as "Super-Twin" if the amp and speaker resided in separate enclosures. The AC30/4 sported 2x2 inputs; the AC30/6 and the AC30-TB had 3x2 inputs. The **AC30/4-circuit** largely corresponds to the "third" circuit of the AC15 shown in Fig. 10.10.35 but boasted, on top of four instead of only two output tubes, other transformers and two speakers♣ instead of just one. In the **AC30/6**, the EF86 is replaced by an ECC83 – resulting in an additional channel with two inputs (connected in parallel). The two *Normal*- and *Brilliant*-channels differ in the coupling-capacitors in the input-stage: 47 nF vs. 500 pF, i.e. a bass-attenuation in the *Brilliance*-channel (Fig. 10.10.37). The AC30/6 emerges into the **AC30-TB** by the addition of the *Brilliance*-Unit. The cathode resistor of the latter was first bridged with a capacitor – this was later omitted.

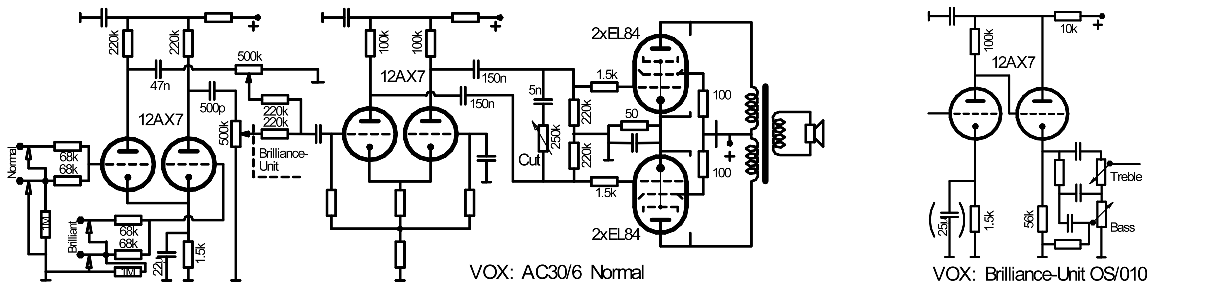


Fig. 10.10.37: VOX AC30/6. Of the in total 4 power tubes (2 each in parallel) only 2 are shown. The circuit at the right was inserted into the Brilliant-channel behind the volume pot at the marked position; in addition, this pot had a bright-C (100 pF) shunting it. Result: the **AC30-TB**.

First, the AC15 and AC30 were available as a "Normal" model and also as "Bass" model. The "Bass" model included enlarged coupling-C's: in the AC30/6, for example, 100 nF instead of 47 nF, and 1000 pF instead of 500 pF, respectively, were used. Moreover, the Cut-capacitor was doubled in value. The "Treble" model experienced further changes, as exemplified in Fig. 10.10.38. On top of the separation of the cathodes and Bright-C's, the coupling-C's feeding the output tubes were decreased to 47 nF, and the Cut-C reduced to 2,2 nF. The separation of the cathode circuits in the input tube, however, shifts the operating point of this tube! While in the "Normal" version the currents of *both* triodes run through the 1.5-kΩ-resistor, only one of these currents remains in the "Treble" version. To maintain the operating point, a 3-kΩ-resistor should have been included into the cathode connection. It was not done …

♣ The AC15 was also available as Twin, fitted with two (low-cost) Goodman loudspeakers [Elyea].

The high-frequency boost in the "Treble"-model is predominantly caused by the 220pF-capacitor while the smaller cathode capacitor generates a mere 3-dB-treble-increase. The 330-kΩ-resistor ensures that the Bright-C does not become entirely ineffective as the volume control is turned up fully, but the possible maximum gain is reduced by 7 dB.

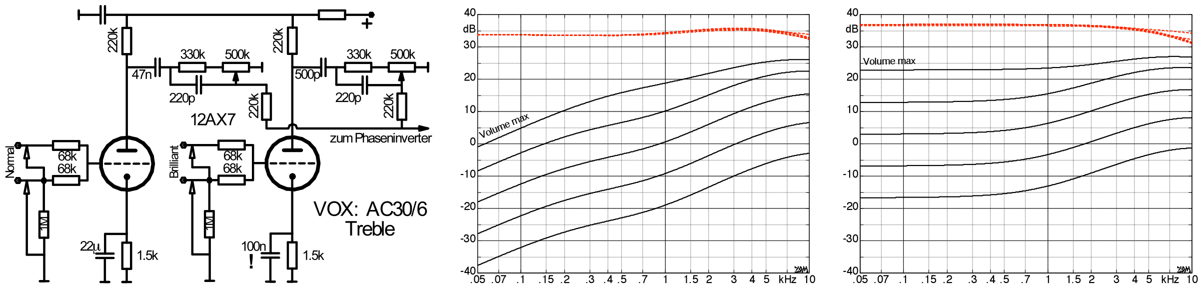


Fig. 10.10.38: VOX AC30/6 "Treble". Frequency response from input to the first plate (-----), and to the phase-inverter-input respectively; Brilliant-channel (middle), Normal-channel (right).

Fig. 10.10.39 shows the frequency response from the input all the way to the power-amp output (loaded with speaker), and to the resulting SPL in the anechoic chamber – a simple "sound scale", perfectly balanced. The more elaborate filtering in the AC30-TB was already introduced in Chapter 10.3.1.

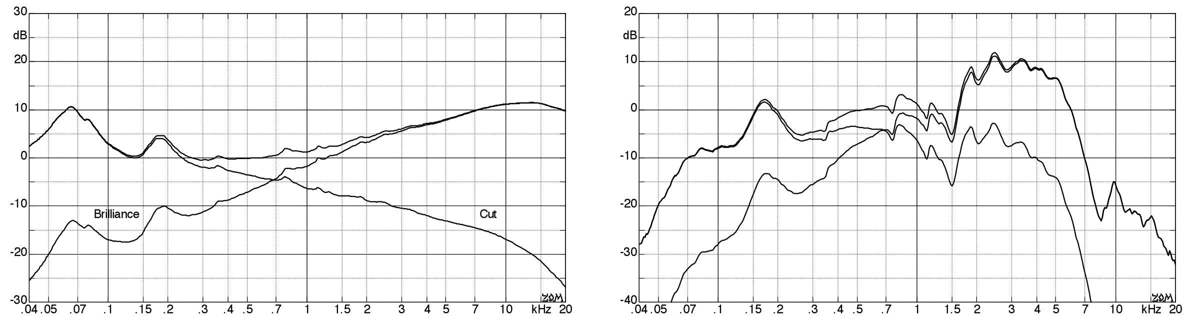


Fig. 10.10.39: VOX AC30/4. Frequency response up to the power output (left), and including the resulting SPL (right).

A specialty of the early days that is rarely used today is the **Vibrato**-channel. Already the second AC-15 version included it in its deluxe-incarnation, as did all AC30. The function is discussed in Chapter 10.8.2. Brilliant- and Normal-channel require one single triode each, but the Vibrato-channel needs no fewer than six. Six sells here, as well – it was a powerful sales argument. The only problem was that the low-frequency modulation signal could not be fully suppressed – despite the carefully designed bridge circuit. This is why already the Gibson GA70 included a multi-stage high-pass, that VOX "borrowed". The frequency response of the high-pass is shown in **Fig. 10.10.40**.

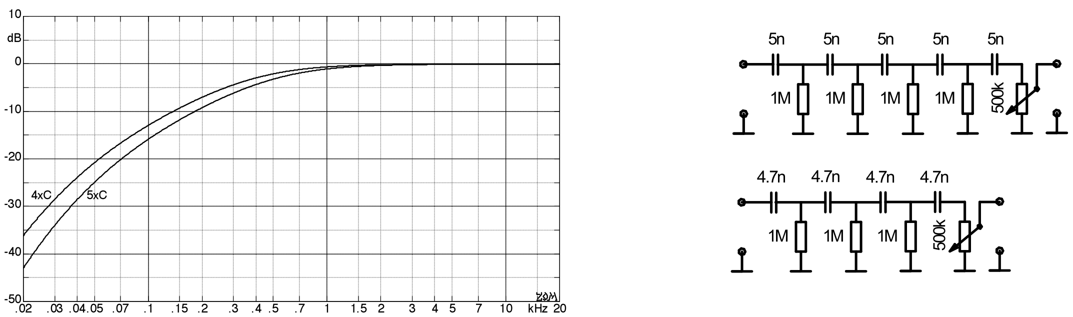


Fig. 10.10.40: High-pass in the Vibrato-channel (VOX AC15, AC30/4 five-stage, VOX AC30/6 four-stage).

The attenuation of the bass that this high-pass caused as well in the guitar-signal had to be accepted; this channel corresponded approximately to the *Brilliance-Switch*. Why, however, this 500-Hz-high-pass is followed by yet another high-pass (at the PI-input) with a cutoff-frequency of 8 Hz (in the Bass-AC30/4 even as low as 0,8 Hz) probably only Dick Denny would have been able to explain that. Or not. Doesn't matter – these are the myths from the past, emanating from the billowing mists of the dionysiac 1960's, and having found a new home in the thicket of the WWW, the world-wide-wilderness.

Around 1967 the golden times of the original VOXes comes to an end. Turnovers come crashing down, and chucking company founder Tom Jennings does not help. In March 1969 it's almost curtains – VOX is "*in preparation for its liquidation* [Elyea]". From then on, one owner follows the next: 'Corinthian Securities', 'Birch Stolec', 'Dallas Arbiter', 'Rose Morris'; they all buy and sell the remains … and at the very end **Korg** takes over. And they do revive the production of the AC30 (from 1993) – at Marshall, of all places, thanks to good relations. The re-launch is successful and VOX is back (Chapter 10.10.7), drumming up business via advertizing the glory-days back then.

In view of all the different variants of the AC30 it is clear that "the"AC30-sound does not exist. Just as there is not "the" Fender-sound – although the EL84-power-stage missing any negative feedback, and the speaker/enclosure-construction do create commonalities. Too simple: the equation ***Beatles-Sound*** = *VOX-Sound* even if advertising does go down that path. But then, just as valid would be the derivatives of the equation: *Beatles-Sound* = *Stones-Sound*, or – in the extreme – *Shadows-Sound* = *Queen-Sound*. No, that doesn't work. Jim Elyea dedicates 20 pages to the question: when did the Shadows receive which amplifier, and what was recorded when using what? And it becomes even more extensive (and confusing) for the Beatles. That was not "the" VOX – the next larger amp was grabbed and used as soon as it hit the market. Verifiably, Lennon did play an AC15 … but he also played through AC30's, AC50's and AC100's. And even though the 7120 and the Conqueror, although the latter were – dare we write it – hybrid- or transistor amps. Even THAT is the *VOX-sound*, however.

Fig. 10.10.41: Various AC30 [Jim Elyea: VOX Amplifiers, The JMI Years].

Fender-Amplifiers

"*In the 20's, Leo Fender was a bookkeeper who got into ham radio as a hobby*". That's how Dave Funk, in his TUBE AMP WORKBOOK, starts the description of an extremely influential bookkeeper whose amplifiers and instruments were to write history. After a short collaboration with Doc Kaufman, Leo Fender started his own **Fender Electric Instrument Company** in 1946, located in Fullerton, California. First, he built amplifiers based on circuits from the "Radiotron Designer's Handbook", and from 1950 also electric guitars and basses. A plethora of different amplifiers originated on his workbench – Dave Funk requires no less than 250 pages for the circuit diagrams alone, and doesn't even go beyond the 1970's. Skipping the uncalled-for question "*were there actually any Fender amps worth considering after 1964?*" throwing in a concise "*yes*", we will try to bring some order to the diverse range. Fender amps of the early period used a **number system** the first character of which denotes the decade: 5 for the 50's, 6 for the 60's. The second character is a letter indicating the change variant, and the third position specifies the model. A 5B3 is a Deluxe from 1952; its successor is the 5C3. The Bassman of 1952 is the 5B6, the Twin of that year is the 5B8. It is assumed that the letter was supposed to code the year, but this system broke down in 1955 because it was not possible to revise every amp every year. For some it is of the utmost importance to be able to date the production to the respective month – we shall not go into that here, but approximately: A = '51, B = '52, C = '53, D = '54, and from E = '55 we loose coherence, until the G-variants arrive around 1960. From 1963, a simplification spanning across the models arrives with the AA763-circuit. It receives a revision in the AB763.

Model	Name	Start of production; typical power tubes	Power class
1	Champ	1946/47, 1x6V6-GT	*
2	Princeton	1946/47, 1x6V6-GT	*
3	Deluxe	1947, 2x6V6-GT (Model 26)	**
4	Super	1950, **2x6L6-GC** (Dual Professional)	***
5	Pro	1950, **2x6L6-GC**	***
6	Bassman	1951, **2x6L6-GC**	***
7	Bandmaster	1952, **2x6L6-GC**	***
8	Twin	1952, **2x6L6-GC ⇒ 4x6L6-GC**	*****
9	Tremolux	1955, 2x6V6-GT ⇒ **2x6L6-GC**	**
10	Harvard	1956, 2x6V6-GT ⇒ **2x6L6-GC**	**
11	Vibrolux	1955, 2x6V6-GT ⇒ **2x6L6-GC**	**
12	Concert	1960, **2x6L6-GC**	***
13	Vibrasonic	1959, **2x6L6-GC**	***
14	Showman	1961, **4x6L6-GC**	*****
15	Reverb Unit	1961, spring reverb, no power amp	-
16	Vibroverb	1963, **2x6L6-GC**	***

Table: Fender amplifiers; N.B.: the available sources are incomplete and to some degree contradictory.

In terms of cosmetics, distinguished are: the very early **K&F** amps (1945-46), the '**Woodies**' with their wooden look (from 1947), and subsequently the '**Twotone**-Vinyl-Amps'. After that we get to the famous '**Tweed**'-Fenders (from 1948), named after their lacquered cloth-covering. Then there's light and dark brown for the '**Brownface**' amps (1959 – 63), various white tones '**Blonde**', '**Cream**' (1960 – 64), '**Blackface**' (1964 – 67), and finally '**Silverface**' (1967 – 81). That's with some leeway in the dating – the source situation is kinda dubious.

For today's used-goods-commerce, establishing the production date to the day may be of importance. From the technical point of view, however, the circuits, components, enclosures and loudspeakers are more important. While there are some guidelines there, we also encounter many exceptions. It is understandable that not all amps could receive new tone filters at the same time, and that is was important to use up existing stock first before the new model was allowed to leave the factory. The amp versions are so extremely manifold that it is impossible to list them all even only approximately: a capacitor is deleted but rematerializes two years later again, capacitance values change without recognizable rules, negative feedback is incorporated but discarded again shortly afterwards, various tremolo-concepts are tested, and much more. No criticism here: this is how products evolve – but it makes documentation difficult. The old octal tubes give way to new noval tubes, a mercury-rectifier steps up – and steps down again right away, the phase-inverter stage mutates from the paraphase circuit (1946, from 1951 with negative feedback) to the cathodyne-circuit (about 1955) and on to the differential amplifier (about 1956, Chapter 10.4). The output power grows (e.g. for the Twin from 18 W to 185 W), and the speakers of course need to keep up: from the weak Alnico to the high-resilience ceramics. However, not everything intended as an improvement is seen as such by the guitar players, and consequently old concepts are reheated as "Reissues", and "Historic-" or "Vintage-Models" are revived.

On our search, we do find commonalities♣ in all Fender amps but then again hit exceptions right away. Indeed, Leo Fender liked Country music, so the assumption is probably correct that his amps were to do well in that music scene. And yes indeed, distortion presumably was a fault to his ears. Brilliant treble was desired and easily achieved in combination with the typical Fender single-coils. However, to attribute to all Fender amplifiers a common sound character – no, that would push it too far. Not just between models but also within a single development line (e.g. from the 5B3-Deluxe to the AB868-Deluxe) there are large sonic differences everywhere. And therefore there isn't even "the" characteristic Deluxe-sound.

It is not necessary to include the very old **Deluxe** from 1947 for comparisons because it exists today only in homeopathic doses. But it does get interesting from 1954: as the **5D3**, the amp receives the modern noval-tubes (12AY7, 12AX7, 2x6V6GT, 5Y3GT), a stable input circuit, and the paraphase circuit including negative feedback. Apparently, it works so well that the power-amp can dispense with any negative feedback. The biggest change in the **5E3** is the introduction of the cathodyne circuit, accompanied by small capacitance changes and other modifications. It is controversial whether there ever was a **5F3** – a schematic has not turned up. The 1960 **6G3** has an additional 12AX7 for the Vibrato-effect, and includes the change from the cathodyne PI to the differential amplifier. Moreover, the cathodes of the power tubes are now connected to ground (*fixed bias*) and the vibrato signal is superimposed onto the negative grid voltage. That ain't optimal 'cause this power amp does feature negative feedback. In the power supply, the 5Y3GZ has to yield to a GZ34, and in the pre-amp, both channels now include separate tone-filters. In the **AA763** from 1963 the LDR-modulator is deployed for the first time, each channel receives its own Treble/Bass-filter – and from the old 10-Watt-amp (5 tube stages, 3 knobs), a 21-Watt-amp (11 tube stage, 8 knobs) has now sprung. Is this the end of the line? No way: the **Deluxe-Reverb** trumps this and offers (as the name suggests) in addition a spring reverb: 15 tube stages, 9 knobs. It is understood that all these modifications will have an impact on the linear and (in particular) on the non-linear behavior, and thus onto the sound.

♣ no, just the shared Fender-logo is not sufficient ...

Fig. **10.10.42** shows the topological variations between two Deluxe amps. Already the input tubes differ (Chapter 10.11), as does the plate circuitry. In the 4E3, the volume pot is "*reverse*"-connected – a feature found in many very early amplifiers. Changes in the control setting directly change the amplification of the tube, and with the volume turned down fully, the tube operates into a short. It being a current source, this does not do any harm to the tube. The simple tone pot has backwards-effects on the plate, as well, and on top of this, both channels are coupled. This scenario is easy to analyze but very difficult to describe because everything depends on everything else. The AB763, on the other hand, sums the two channels only directly ahead of the phase-inverter (PI) and makes a much better decoupling possible (**Fig. 10.10.43**). The effect of the tone control is depicted in **Fig. 10.10.44**: it is a wide-band treble-filter dependent on the setting of the volume control, and the mid-range attenuation (Chapter 10.3) so characteristic of the later versions is absent. The reverse-connected volume pot is impractical because in its middle turn-range the amplification changes little (by merely 10 dB between settings 2 and 8). Plus the two volume pots influence each other in their effect.

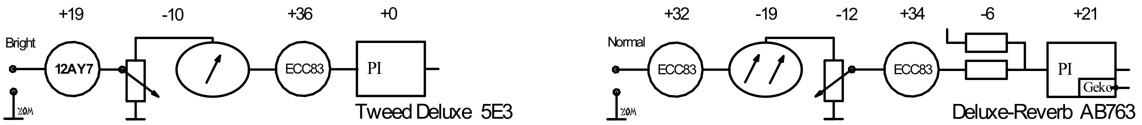


Fig. 10.10.42: Comparison 5E3-Deluxe (Tweed) vs. Deluxe-Reverb (Blackface). The respective given gain values relate to the reference condition from Chapter 10.10.2 (90 mV / 500 Hz for full drive (not overdrive)

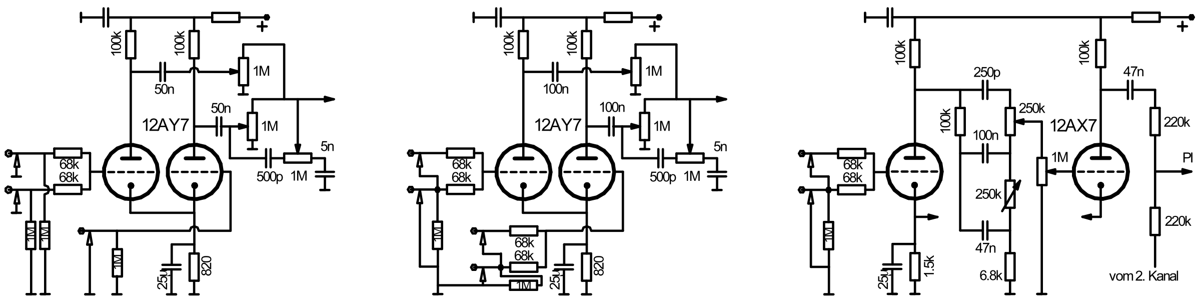


Fig. 10.10.43: Deluxe-input-circuits: 5D3 (1954), 5E3 (Tweed, 1955), AB763 (Blackface, 1963).

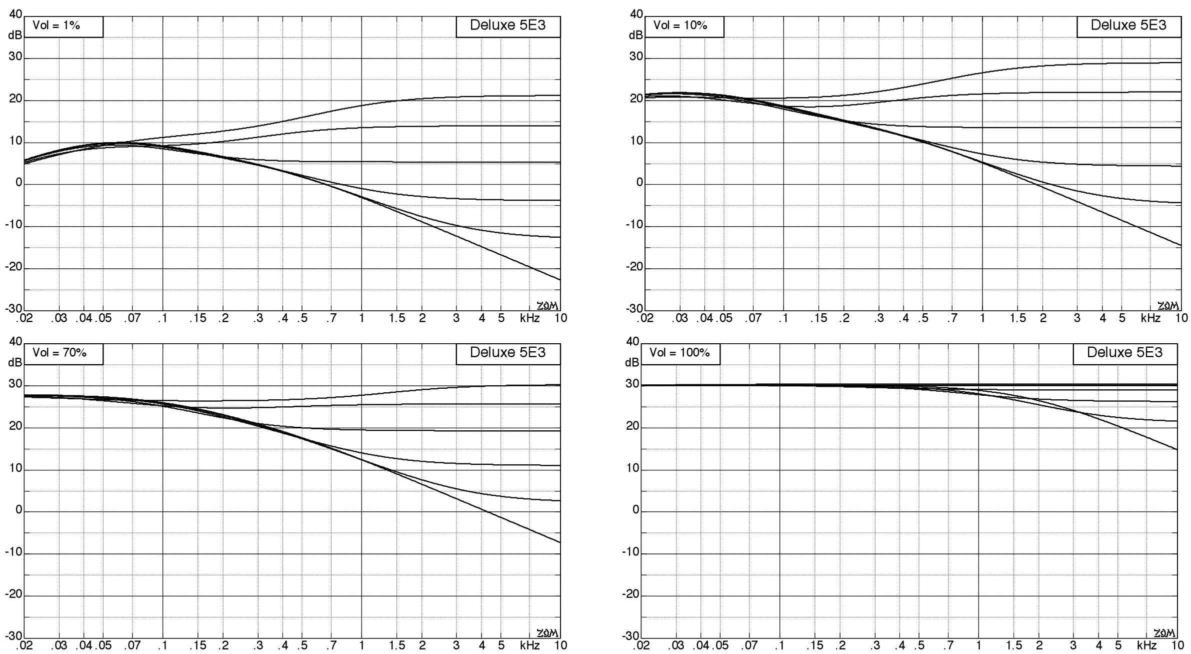


Fig. 10.10.44: 5E3-Deluxe, first-stage-transmission, Tone-pot; volume-pot of "the other channel" turned down.

Only from the 6G3-Deluxe produced in 1960 the two volume pots are *normally* connected, and from 1963 both channels receive a bass- and a treble-control each. The HD-a_{k2} of the 1st stage is shown in **Fig. 10.10.45**: for the 5E3-Deluxe, the plate-load decreases as the volume control is turned down – the gain drops and at the same time the distortion rises. Wide-open, the distortion is less than in the Deluxe Reverb, due to the lower gain of the 12AY7. It has already been noted (Chapter 10.1.4) that the distortion depends on the individual tube as well.

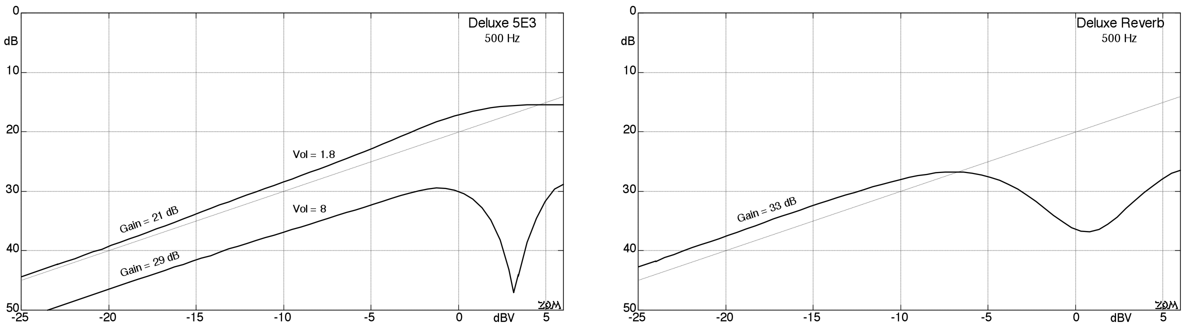


Fig. 10.10.45: 2nd order harmonic distortion from amplifier input up to the first plate. The *reverse*-connected volume-pot is also found in other Fender amplifiers, e.g. in the Pro, the Princeton, and in the Super.

We need to consider the distortion of the 1st tube only if the guitar pickup delivers a high output. Feeding 100 mV$_{eff}$ to the input of a 3E5 (with its volume set to 8) generates merely k_2 = 0.5%, while the power amp is already pushed far into overdrive, as also documented by the headroom charts (Chapter 10.10.3). The phase-inverter is always part of the power amplifier, in its respective variant (paraphase, cathodyne, differential amp; Chapter 10.4). The 5D3 had a paraphase with negative feedback while the 5E3 included the cathodyne-circuit, and the AB763 had the differential amp. The signal symmetry resulting from the cathodyne circuit is acceptable: for the 5E3, the overall k_2 is smaller than the k_3 across the whole dynamic range (Fig. 10.10.20). In the **differential amplifier** deployed from 1956, the symmetry depends i.a. on the plate resistors. Simply trusting the carbon resistors to be "absolute high-end" involves risking large tolerances, and thus a large scatter range in the k_2. In the 6G3-Deluxe, the **plate resistors** differ in value, in the AA763 they are equal, and in the AB763 again different. Equal means: both have 100 kΩ, different means: they have 82 kΩ and 100 kΩ respectively. For the Super Amp, the evolution is similar: in the G64 different, in the AA763 equal, and in the AB763 ??? According to the schematic, the resistors are equal, but the layout shows them to be different. Indeed, it may happen on top of everything that the documents include errors.

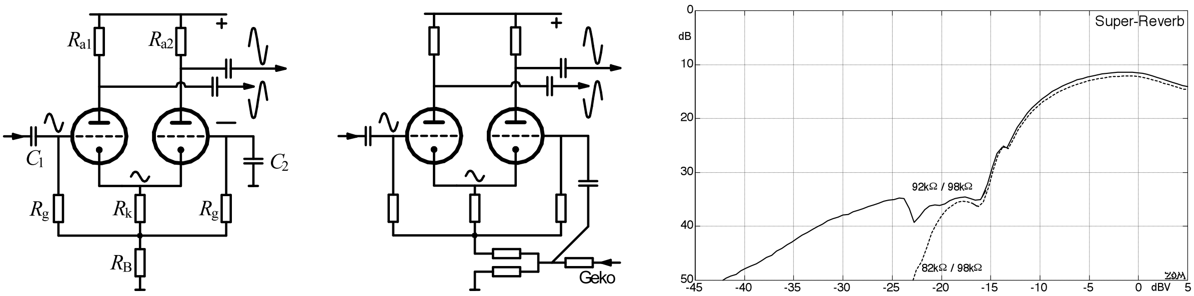


Fig. 10.10.46: Differential amplifier with and without overall-negative-feedback; 2nd order HD.

Because the right-hand triode in **Fig. 10.10.46** is driven by the cathode (common grid circuit), its gain is a little smaller than that of the left-hand triode – this may be compensated by increasing the right plate resistor a bit (e.g. 82 kΩ /100 kΩ). However, for the negative feedback signal arriving from the output transformer, the *left* triode operates in common grid configuration – equal resistors may serve as the compromise.

Do these small asymmetries actually play a role? **Fig. 10.10.46** shows related measurements for a Super Reverb (AB763). According to their color-coding, the plate resistors in the phase inverter should have 82 kΩ / 100 kΩ, but in fact the values were 92 kΩ / 98 kΩ; the 82-kΩ-resistance was too big by 12%. It was replaced by a resistor of the correct nominal value which reduced the k_2 at small drive levels considerably. Several opinions on this are possible:
1) The distortion in a guitar amplifier should be small and thus such a high degree of symmetry is purposeful. N.B.: power tubes and output transformer can cause asymmetry, as well!
2) Only with the 2nd order-distortion a guitar amplifier sounds typical for the genre. N.B.: as above.
3) A THD around 2% is not really that important (Chapter 10.10.5). N.B.: other pairings of resistors make larger distortion possible, too.

Fender schematics allow for a tolerance of 5% for the plate-resistors of the differential amplifier, but they also document different philosophies: 82 kΩ / 100 kΩ, 100 kΩ / 100 kΩ, 47 kΩ / 47 kΩ, both with the 7025 and the 12AT7. This is a considerable spread in the phase-inverter alone and exemplifies that a specific model (the Pro, the Deluxe) was built in very different variants. Some amplifiers (such as the Pro) at least kept their power tubes (6L6, later the non-identical 6L6GC), the operating point, however, changed from 'automatic' (cathode-resistor) to 'fixed'. The plate voltage changes, as well, from 350 V to 440 V. The Princeton started out with a single power tube (6V6) and later received a second one. The Twin had two 6L6 to begin with and changes to four 6L6GC (or four 5881, respectively). The Tremolux sports two 6V6GT first, and two 6L6GC later. The often yearly variations in the tone-filters has been documented in Chapter 10.3 already; that coupling capacitors and small blocking-C's were different from one year to the next goes beyond the scope of the present concise presentation.

There are, however, also similarities: the Pro corresponds to the Super with only the speakers being different: the Super had 2x10", the Pro 1x15". At first, that is – later this changes and the Super receives 4x10", the Pro 2x12". Both amps are again similar to the Bandmaster and the Concert; merely the speaker configuration (and therefore sometimes the output transducer) is different. The Tremolux is a Deluxe modified by the inclusion of tremolo (or vibrato – Fender uses both terms synonymously), the Vibrolux is a toned-down version of the Tremolux. The Showman is a head-only and the piggyback variant of the Twin. That's one side of the medal that after 70 years still shines brightly. The other side: not every difference is audible.

Fig. 10.10.47: Fender amplifiers [www.Fender.com]

Marshall-Amplifiers

The variety among the types of Marshalls is not as huge as it is for Fender, but still sufficiently big. Particularly confusing is the numbering: there is, for example, the type 1963 issued in 1966, the type 1987 from 1966, or the type 1964 produced in the year 1973. Marshall's type-numbering is not connected to the year of production at all! Doyle's book seeks to shed some light onto this and the special "Marshall"-edition of the German "Gitarre&Bass"-magazine dedicates itself to the topic, as well. One criterion allowing for a coarse classification is the output power: there are the small amps with 18 W (later 20 W), the medium line with 50 W and the big ones with 100 W. Additionally, we find some exotic birds such as the 200-W-behemoth, or the 1-W-dwarf, as well some odd mutants from the other side of the tracks such as transistor- and hybrid-amps. On top of all this, there were often guitar-, bass, organ, and PA-variants of each amp.

For many guitarists the "Marshall Stack" with its 100-W-amp sitting on top of two 4x12-boxes is the prototype per se. It came into existence as derivative of a Fender-clone put together around 1962 by Dudley **Craven** and Ken **Bran**: Bran copied the 5F6A-Bassman in almost every detail and labeled it MARSHALL, adding **JTM 45** shortly afterwards. There were some differences in the pre-amp-tube (ECC83 instead of the 12AY7), in the power tubes (KT66 instead of 5881), in the transformers and in the loudspeakers incl. the enclosure. The change in the pre-amp-tube increases the input gain by 4 – 5 dB, the different power tubes necessitate a change in the transformer (8 kΩ rather than the 4 kΩ customary for Fender) which also brings a change in the negative feedback (Chapter 10.5.2), and swapping the 4x10"-Jensen for 4x12"-Celestion influences radiation patterns and sound. Also, the guitar version of the amp received another capacitor to increase the treble. No circuit endured for long: in 1964 we see the changeover to two EL34, and shortly thereafter (or even concurrently) the power output explodes to 100 W. Any rumors that this was sponsored by the hearing-aid-industry could, however, never be verified.

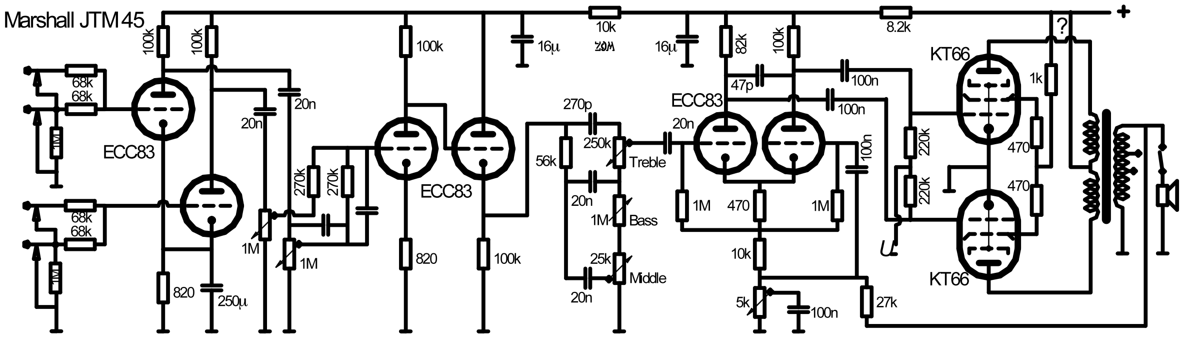


Fig. 10.10.48: Marshall JTM 45. The capacitors across the Volume pot depend on the type (100pF – 500pF). In Doyle's Marshall-book, a choke (20 H) is included in the power supply: for some schematics this choke is connected between plate and the remaining circuitry; there is a large difference with respect to the current.

Abb. 10.10.48 shows the schematic of the JTM 45 – it is nothing out of the ordinary. Old documents indicate a plate voltage of 440 V (idle), and with this the amp will give about 30 W (with R_{aa} = 8 kΩ). Allegedly the KT66 soon turned out to be too expensive, or too weak, or both, and from 1966 the **EL34** was used. A higher output power would in fact have been possible with the KT66, as well, if R_{aa} had been reduced, but … that was done only as the EL34 was phased-in. At this point, the opportunity arose to swap the **GZ34** rectifier tube for silicon diodes, and to adapt the name to **JTM 50**. Now name and power did match – the JTM 45 had failed in that discipline.

The JTM 50 was in production for just shy of one year when the era of the **JMP-**amplifiers began. Not wanting to list all type numbers in detail (this can be found e.g. with Doyle), a coarse classification would be: **JTM** (1962 – 1967), **JMP** (1967 – 1981), **JCM800** (1981 – 1989), **JCM900** (1990 – 1999), from then **JCM2000**. However, this rough structuring does not seek to imply that all JMP-amps would be similar. For exact specification the type number is required but not sufficient because even within one single type-number there were modifications.

The gold-colored plexi-glass screen of the early Marshall amps gave another grouping its moniker; the "Plexi-Marshalls", built until 1969, represent the pinnacle of Marshall-dom for many. (For many but not for all: others find this zenith in the JCM800-, or in the JCM900-amps, or in …). But we do not need to get into that here. **Fig. 10.10.49** shows the circuit of the 1987 with EL34 in the power-tube-position. The 1987-designation has surfaced already for the first JTM 45 and is not unambiguous. Compared to Fig. 10.10.48, some differences catch the eye: there are larger summation resistors, larger smoothing capacitors, a higher supply voltage from the Si-diode power supply (not shown here), and other power tubes with a changed negative feedback. The **screen grid** of the power tubes is connected directly – without resistor – to a big 50 µF electrolytic capacitor, leading to scary-big **grid-currents**. The changes in the capacitor values (22 nF rather than 20 nF) are due to the standardization starting around the time (e.g. DIN41426) and allowing merely for the values of 10, 15, 22, 33, 47 and 68 nF in the E6-series but not 20 µF (these would only be elements of the E24-series).

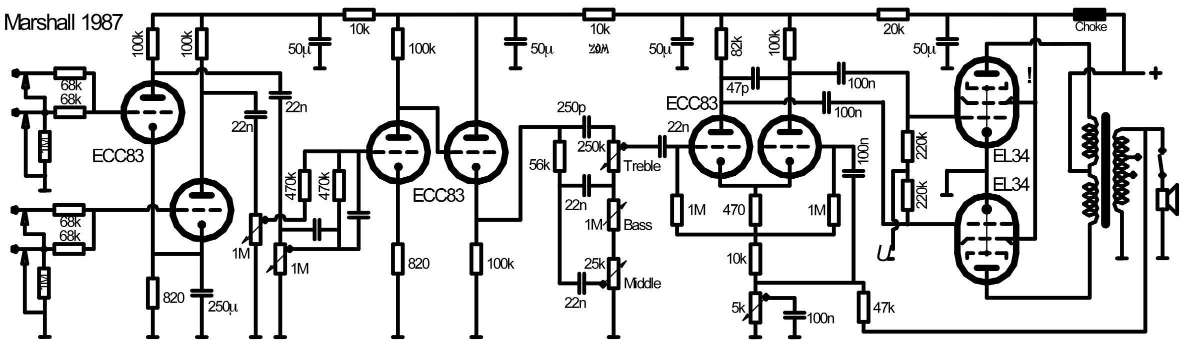


Fig. 10.10.49: Type 1987, a 50-W-amp from the golden era, with shared pre-amp cathode.

In **Fig. 10.10.50** we see a 1987-variant built from about 1969. The bass response in its "High Treble"-channel as radically thinned out: smaller cathode- and coupling-C's made for a more aggressive sound, along with an extremely large 5-nF-cpacitor across the volume pot, an altered tone-stack and a reduced negative feedback in the power amp. Corresponding details may be found in Bernd Meiser's article in the German Gitarre&Bass-magazine (07/2006).

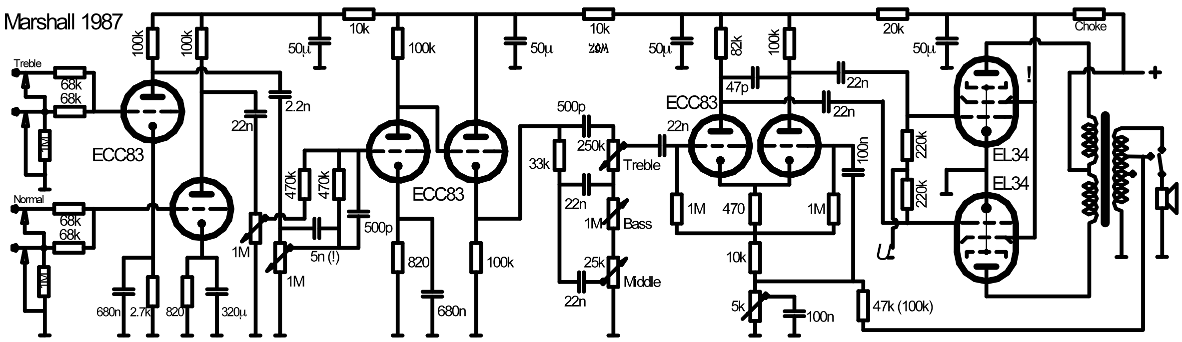


Fig. 10.10.50: Marshall 1987, the development with the split-cathode in the input stage.

The big brother of the 1987 was the **1959**. Rather than 50 W from 2xEL34, it generated 100 W from 4xEL34. Undistorted! At k = 10%, it had a remarkable 170 W up its sleeve, as noted in the Marshall data sheet. In the 100-W-versions, the output tubes were given a grid-resistor (1 kΩ) each; the 50-W-versions had to do without that for years and only received relief when the high-gain "Two-Inputers" were issued in 1975. In the latter, the two halves of the input-ECC83 could be connected in series, enabling them to offer an absurdly high overall gain. The 2204 data-sheet notes an input sensitivity of 0.1 mV – that should be enough for any pickup (which can generate – depending on the type – up to more than 1 V). The 50-W-variant of this Heavy-Rock-amp was designated **2204** (**Fig. 10.10.51**); the **2203** is the 100-W-version. To achieve strong overdrive at moderate loudness, the amps received a **Master-potentiometer**. With this, however, the power amps did not contribute to the distortion anymore, resulting in a different sound.

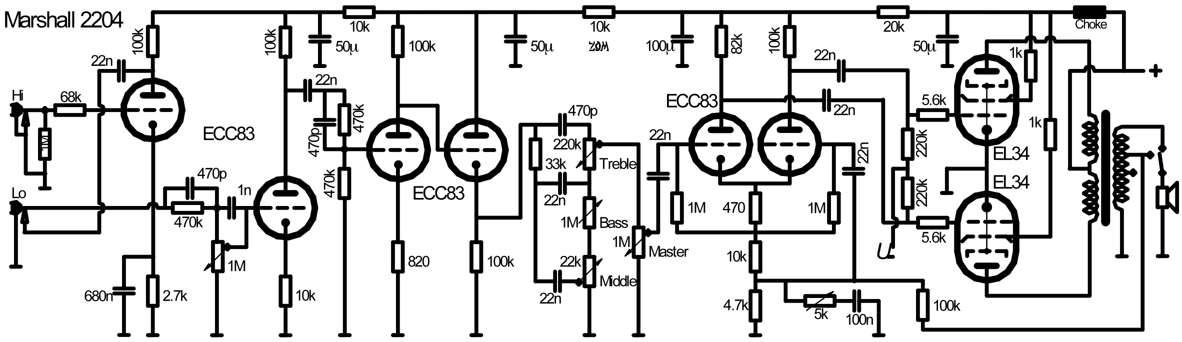


Fig. 10.10.51: Marshall 2204, 50 W Heavy-Rock with Master-Volume. The 2203 is the 100-W-variant.

What can be done to obtain strong distortion even at low loudness?

1) use an amplifier with small output power,
2) reduce the level ahead of the power amp (pre-amp-distortion),
3) reduce the signal between power amp and loudspeaker,
4) include a diode-distortion circuit.

The first variant (in the form of e.g. the 18-W-models) was thinkable for Marshall users but what do you do in case you suddenly do need more loudness, after all? Variant 2 was practiced e.g. in the 2204, the third option could establish itself only over the course of decades (impedance-emulation), and the forth variant? Solid-state-distortion? Yes, indeed, and for Marshall this era begins in the 1980's. First, switching-transistors and **1N4007-diodes** find their way into the signal path (2205, 2210), later we see whole diode arrays (2250, 2255), and then the OP-Amp-models with the alibi-tube (Valvestate) enter the picture. From time to time, there were experiments trying to include a bit of the power-amp-distortion. An example is the 4001 (as are the 4140, 4145, and 2150). Here, the master-volume is a dual-pot located after the phase-inverter that can now still have an imprint on the sound. This approach never enjoyed a wide-scale break-through, though. In the **2150** another detail is notable: it is a 100-W-amp with a single 12"-speaker, a Celestion Powercell 12-150. This speaker can withstand the 100 W – however: for it a white-noise-sensitivity of 89.8 dB (1W/1m) is listed, while for a G12-50 the corresponding number is 97.4 dB. It's the same old story: high-power speakers do not necessarily have a high efficiency. 7.6-dB-difference corresponds to a factor of 5.75 in terms of power. Recalculating: the noise produced by the Powercell with 100 W can be generated by the G12-50 with merely 17 W i.e. all that power is wasted! Marshall should have used the Powercell 15-250 specified with 95.5 dB. That would have been the true "Rock'n-Roll-Baby", especially if the 200-W-power-amp would have been included into this combo. The weight? Yeah, it would have been around 45 kg – the speaker alone weighs in with 14 kg.

An example for diode-distortion is shown in **Fig. 10.10.52**. The **2205** features two channels selectable via a footswitch: a ‘Normal-Channel’ and a ‘Boost-Channel’. The switching is performed by a transistor array (CA 3046) that however concentrates on that function and does not contribute to any amplification. The Normal-channel stands out due to a special, rather Marshall-un-typical, tone-filter. Its position (directly behind the input tube) and its filter characteristic are indeed extraordinary. The Boost channel is where things get really exciting: a diode in the cathode connection of the second tube stage increases the 2nd order distortion, a **bridge-rectifier** takes care of signal-limiting on both sides. As a first approach, the rectifier may be interpreted as an anti-parallel-arrangement of three diodes connected in series. The most astonishing aspect is, however, the explanation published by Marshall: *Critics have wrongly alleged that this amp creates “transistor distortion”. Fact: in the channel-switching of the head there is merely a voltage limiting via diodes – this however in no way works as a distortion device but only limits the signal level and thus prohibits unwanted overdrive in the following amplification stages.* [http://www.marshallamps.de/equipment/2210-%28milestones%29—289; available at the time; deleted from the Marshall website since]. Here, the statement “no transistor distortion” would have sufficed – indeed, there are no transistors in the signal path. However, why should a voltage-limiting not cause any distortion … no matter, there is good to report, as well: the amp had send/return-jacks for connecting external effects, and a built-in spring reverb. All in all a really advanced Marshall that receives special praise from Doyle: “*Over the years ... the 2210 had become one of the all-time great distortion amplifiers, and was consequently even outselling the classic 2203*.”

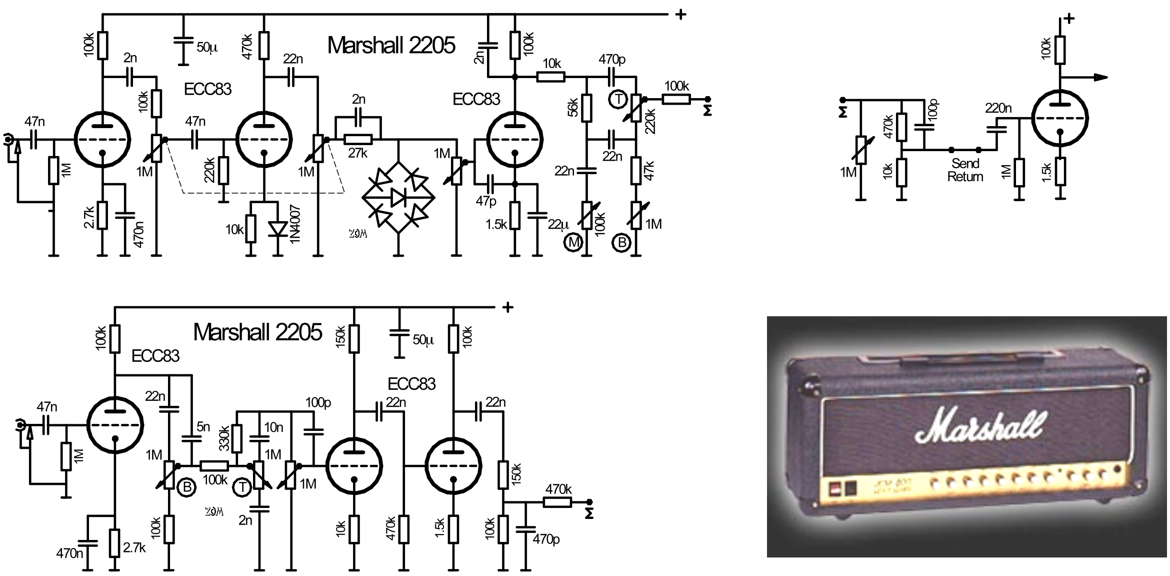


Fig. 10.10.52: Marshall 2205 (simplified). The 2210 has a 100-W-power-amp instead of 50 W. [Marshall.com]

In 1987 Jim Marshall celebrated 50 years in music and 25 years in amplification, Doyle introduces the Silver-Jubilee-chapter, and one is tempted to add: “… and then they discovered LED’s and parallel-negative feedback”. It is indeed possible to achieve distortion with two anti-parallel-connected diodes, but the resulting voltage is rather small in a tube environment. With a red light emitting diode (**LED**), a voltage approx. three times that of a Si-diode results in the flow-direction – this saves components. So what about the parallel-negative feedback? That has – in its entirety – the name parallel/parallel-negative feedback or I/U-feedback, and it has several effects: input- and output-impedance as well as amplification are reduced but also stabilized at the same time. And since it’s jubilee-time, here’s another feature: a switch brought the output tubes from pentode- into **triode-mode**, halving the output power.

Fig. 10.10.53 shows the circuitry of the **2550**. It already makes three basic settings available: a lead-channel, and a rhythm-channel that can be put into distortion mode by a "Rhythm-Switch". The first picture shows the Normal-mode with the anti-parallel diodes having little effect. This is because – watch out, here it comes – the subsequent tube operates in parallel-negative-feedback-mode reducing the input impedance to about 50 kΩ. The diodes are not entirely without effect but somewhat decoupled by the 47-kΩ-resistor (weakly distorting compressor). This is very different in the distortion mode (right-hand picture). Now the diodes are connected across the signal path and contribute hard limiting.

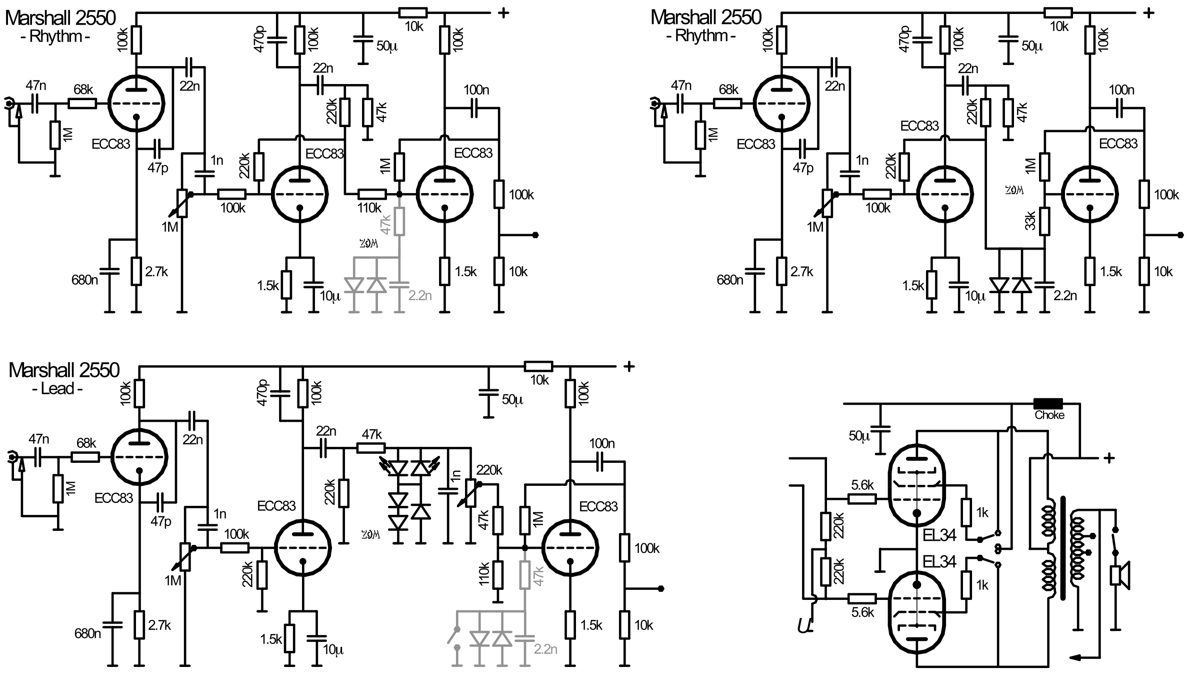


Fig. 10.10.53 Marshall 2550 (simplified). The 2555 has a 100-W-power amp instead of 50 W.

In the lead-channel two LED's and three diodes (1N4007) take care of limiting. Since the effective number of the diodes depends on the direction of the current, an asymmetric limiting is achieved that somewhat prefers even-order distortion. The effect of this asymmetry is not very strong and is only present for low drive levels just as the limiting starts. Compared with the anti-parallel diodes (that limit at about 1.2 V_{PP}), the LED/diode-combination has a limiting voltage at about 5.5 V_{PP}. The enables the lead channel to be louder than the rhythm channel.

At the lower right in Fig.10.10.53 we see the power-amplifier switching. For pentode-operation the screen-grids of the power tubes are connected to the supply-voltage (via a 1-kΩ-resistor to limit the grid-current). The high, almost constant U_{g2}-voltage accelerates the electrons nicely, and the cathode current can take on large values. In the **triode-mode**, the screen-grid is at the plate potential. As the plate voltage drops with increasing drive levels, the cathode current cannot increase to the same degree as in the pentode-mode. Gain and maximum power drop to about half. However, there is a further effect because the power-amp-impedance is reduced, as well (Chapter 10.5.14) – this is why amplifiers in the triode-mode are not only less loud, but also differ somewhat in sound. Still, this is a good alternative available at the discretion of the user. Inevitable, however, are the Si- and GaAs-diodes – is this the new, typical Marshall sound?

Tube purists will turn up their noses at such grossness: semiconductors in a Marshall! Others, however, buy and play and are happy. Doyle writes about the silver amps: *and many people – notably Slash, of Guns N' Roses – won't play anything else*. Of course, such statements will not remain valid for all eternity; rock musicians change their commitments as often as they change their shirts (is that every other year?) … but they do not entirely miss the point, these diode-Marshalls. The production numbers speak for themselves … or rather for the sound.

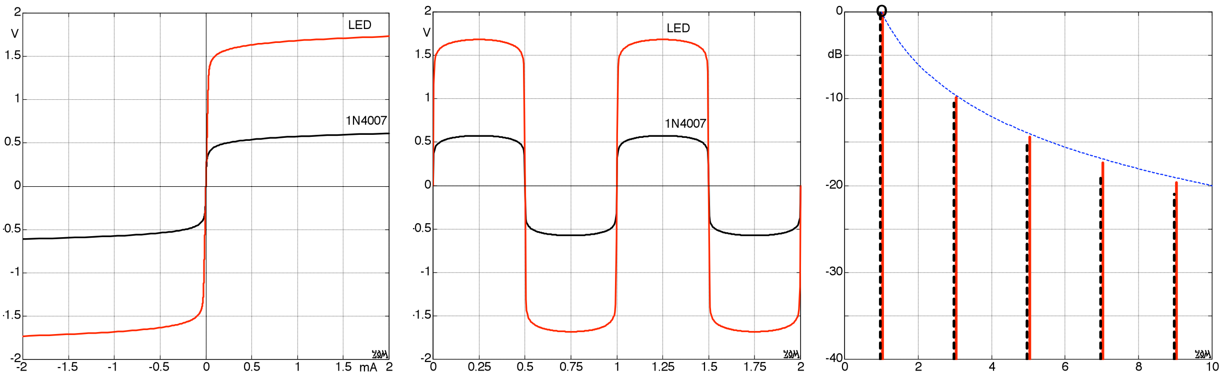


Fig. 10.10.54: Characteristic, time-function and normalized spectrum of the diode distortion circuit. Dashed in blue: the spectral envelope of a square-wave signal (1/*f*-spectrum).

In **Fig. 10.10.54**, the diagrams relating to the anti-parallel diodes are shown. For strong overdrive an almost square limiting results – for two LED's a bit more strongly pronounced than for two Si-diodes. The spectra diverge only little from the 1/*f*-envelope as long as one stays with the lower partials. The corresponding curves for the Si/GaAs-combination used in the lead-channel are depicted in **Fig. 10.10.55**. For strong overdrive (red), the main difference re. Fig. 10.10.54 is the DC-component appearing at 0 Hz. For smaller drive levels (blue) even-order distortion becomes visible, as well.

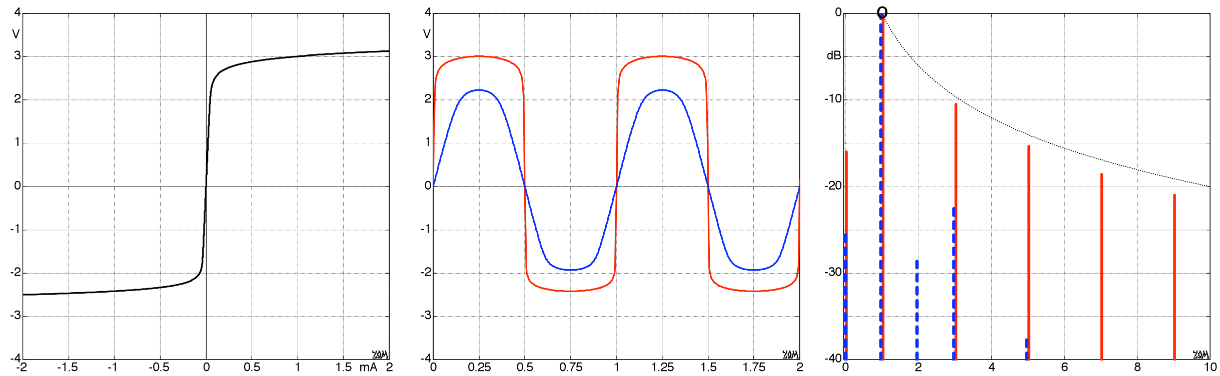


Fig. 10.10.55: Diagrams for the combination of 2xLED and 3x1N4007 (Marshall 2550).

After the generation of distortion had been successfully transferred to semiconductors, the latter now also had to amplify. The **8040**, for example, is a purebred transistor amplifier … uh-oh … almost overlooked that alibi-tube. It almost drowns in that sea of OP-amps. The circuits become more extensive, the model-variety, as well – too extensive for the present overview. In short: after the JCM800-series the JCM900-series followed, having even higher gain, and then the 2000-models. If it continues that way, the 3000's should be in sight, soon.

www.Marshallamps.com

www.mylespaul.com

10.10.8 Modeling Amps

Modeling amplifiers are guitar amps with a large variability of transmission parameters allowing for an approximate emulation of the sound of many well-known amplifiers. The linear and non-linear signal processing is usually done in a digital signal processor (DSP); the musician can call up different amplifier models from the program memory. First on the market were the Roland and Line6 companies, and by now many others have followed suit. The recipe: take a good AD/DA-converter, a low-cost switching-power-amp and a DSP-board – and you get 12 (or 24) of the most famous guitar amps in a little box. Is it actually that simple? No, it ain't! It is not sufficient to emulate the frequency responses of the famous predecessors; it is also their non-linear distortion and their operating-point-shifts that need to be modeled. It is here where the difficulties really begin: while it is possible to combine the linear characteristics of cascaded stages, the non-linear stages need to be emulated individually. It has already been mentioned repeatedly that the interface between tube power-amp and loudspeaker needs special consideration. To simulate every detail in the software is not helpful, either, since this increases the calculation time in the processor (i.e. the responsiveness of the amplifier becomes sluggish). The constant development of the algorithms has by now led to useful concepts which – in direct comparison to the original – still leave a bit to be desired, but which due to their unbeatable variability are preferred by musicians who need to cover a wide range of styles and sounds.

The following investigations were carried out on a **VOX AD60VT**, an amplifier that not only practices digital signal processing but also filters using an interesting power-amplifier circuit. The block-diagram is shown in **Fig. 10.10.56**.

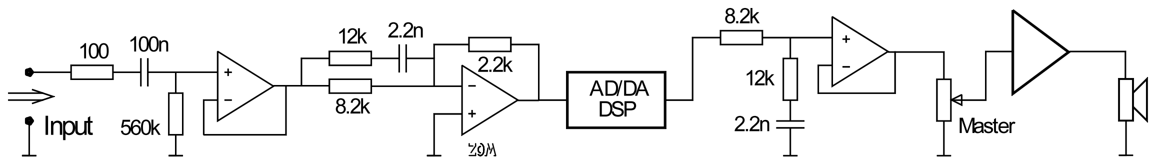


Fig. 10.10.56: Signal-processing in the VOX AD60VT (simplified).

The guitar signal reaches the digital signal processor via an impedance converter and a treble pre-emphasis, and is then fed via a complementary treble de-emphasis to the power stage. Immediately striking; the input impedance is not the 1000 kΩ typical for VOX but merely 560 kΩ, and the non-linearity of the grid found in tubes is not emulated. These characteristics are not the main reason why tube amps are much beloved, but this lack is not "perfect modeling", either. On the other hand, this VOX amp (as well as the more powerful AD120VT) scores due to its very special **power-stage**. The output impedances of tube amplifiers are high, even with the output transformers (Chapter 10.5). Due to this, the loudspeaker impedance influences the frequency-response of the transmission and thus the sound. The VOX does account for this scenario using an actual tube power-amplifier (incl. output transformer). No, that's not a high-power output-stage but a modest 1-W-power-amp making do with the two triodes of an **ECC83**. The resulting output voltage is not simply further amplified and fed to the speaker via a low-impedance transistor-amp; rather, the output of the midget tube amp is connected to a high-impedance power-amp. For the tube amp to catch something of the speaker behavior, the speaker voltage is fed back to the tube amp. This way the output transformer senses a load-impedance as it is typical for a loudspeaker, and the linear and non-linear characteristics of the push-pull output-stage take effect in the usual manner.

Fig. 10.10.57 shows details of the VOX power-amp. A very familiar phase-inverter is present as is even the 82k/100k-pair; there are two tubes in push-pull configuration, there is a transformer … and now it gets really interesting. Via a power-selector-switch we arrive at the power-amp that is best described by its conductance *S* (just like an OTA♣), and then we are guided to the loudspeaker and via a second power-selector back to the transformer. The power-OTA works in a substantially linear fashion, any overdrive happens in the triodes. A feedback circuit may be placed between the connectors designated with NFB (**Fig. 10.10.58**) but this is deactivated in the typical VOX-circuit. Because of the opposed effect of the two power-selection-switches, the loop gain (and thus the transformer load) is not (or only negligibly) dependent on the position of the switches – but the power fed to the loudspeaker is. With the dimensioning chosen in the AD60VT, the secondary winding of the output transformer "sees" approximately the 50-fold speaker-impedance, including the corresponding frequency dependency. And this, my friends, is indeed typical for a tube amp.

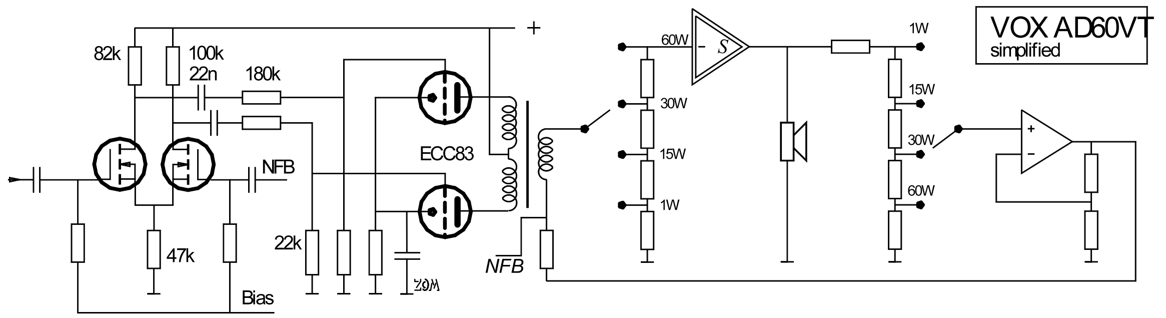


Fig. 10.10.57: Power-stage circuit of the VOX AD60VT Valvetronix (simplified).

Tube-amp-typical, however, does not generally imply guitar-amp-typical. In this VOX, two **triodes** are at work, while in the famed forefathers we had two or four **pentodes** doing that job. Nevertheless: it's a speaker-loaded tube power-amp. The basic principle of the load transformation is shown in **Fig. 10.10.58**: the input impedance $\underline{Z}_1$ calculates (in an idealized way) to $\underline{Z}_1 = R\cdot(kS\underline{Z}_L+1)$, and therefore is approximately proportional to the loudspeaker impedance $\underline{Z}_L$, as long as kSZ_L remains large relative to 1. This requirement is pretty nicely fulfilled: for 8 Ω speaker impedance, $\underline{Z}_1$ is 380 Ω, and *R* with about 30 Ω does not get in the way. The secondary resistance of the transformer (180 Ω) has a somewhat stronger effect, but the real culprit here is the rather high copper resistance of the primary winding that drastically reduced the model consistency. This is the result of the relatively small transformer (EI-42). And since we are looking closely now: the feedback network seeks to be a compromise between authenticity and effort, and e.g. fails to offer the continuous control possibility of a presence-pot. For modeling the AC15 or AC30, this is o.k., but with respect to emulating the Bassman or Marshall amps it is an issue. The grid circuit of the triodes, on the other hand, deserves praise with its switchable resistors, as does the switchable cathode-resistor (not included in Fig. 10.10.58).

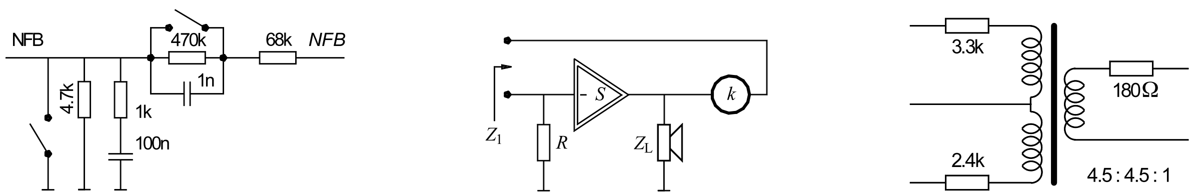


Fig. 10.10.58: Negative feedback circuit (left), "Vari-Amp-circuit" (middle), transformer (right).

♣ Operational Transconductance Amplifier

The switchable common cathode resistor creates the possibility to operate this power-amp in either A- or AB-mode. To emulate the AC30-power-amp, the triodes work with about 2.2 mA plate current, which is about the middle of the characteristic, and thus A-mode. The primary impedance is in total about R_{aa} = 50 kΩ for an 8-Ω-load, i.e. 25 kΩ per triode (cf. Chapter 10.5.5). Although pentodes are at work in the AC30, although especially in this amp the plate resistors are equal (100 kΩ / 100kΩ, not 100kΩ / 82 kΩ), although the non-linear **Cut-filter** is not modeled correctly even to begin with, and although the **transformer** is terribly high-impedance … that's an approach one can live with. The circuit of the transistor power-amp is shown in **Fig. 10.10.59**. The input-transistor operates in common-base-configuration and feeds a complementary Darlington-circuit. The emitter output could be interpreted as low-impedance – but that would not be correct. The driver transistor approximately works as current source and the output transistor as current amplifier, the current through *R* and through the loudspeaker being almost equal. Thus, this circuit has a high-impedance output just like a tube amplifier. It is only at very high frequencies that output impedance drops off due to the voltage feedback via the RC-circuit – and that effect is in fact rather purposeful.

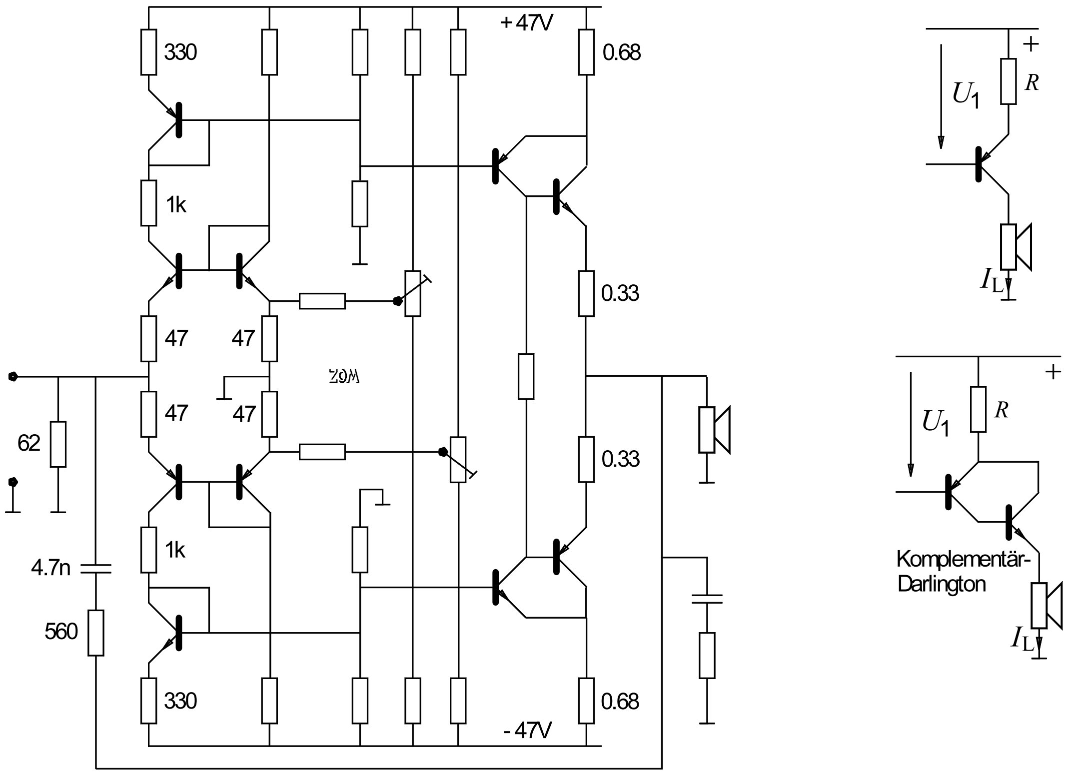


Fig. 10.10.59: AD60VT-power-amp (left), effect of the complementary-Darlington-circuit (right).

So, the AD60VT-ouput-stage has received considerable tube-like-qualities – but what about the digital modeling? Unfortunately, that is as inadequate as it is found in other DSP-amps: there's some filtering, some distortion, and that's it. It might be understandable that the input stage does not emulate a tube-input – the effort must not too big, and the DSP-board found in the Amp seems to be a rather universal one. It has already been mentioned that the input impedance is not 1 MΩ. One could get over the quite small input capacitance of a mere 75 pF, but that the Lo-input also features 560 kΩ, that wouldn't have to be: for almost all amplifiers, this input is – at usually 136 kΩ - of clearly of lower impedance compared to the Hi-input. Be sure: this has significant effects on the dampening of the pickup resonance.

Even more problematic: as a **floor-pedal**-model is chosen, the 560-kΩ-input-impedance still remains. For all 16 amp models and for all 10 "Effect Pedals": always 560 kΩ. Conversely, especially distortion pedals and treble boosters often have very low input impedances (some down to as low as 10 kΩ), but this was apparently not grasped by the VOX-people or whoever came up with this *korg*-promize. The uPC4072 used for the input does not feature any tube-like clipping, either – all non-linearity happens in the DSP. Alright then, let's analyze the distortion that the latter provides and let's see how it models different amps, for example the AC30TB compared to the AC30. **Fig. 10.10.60** shows the corresponding HD. Big surprise: VOX apparently did not catch that these two amps are distinguished by the infamous cathode-follower (in the AC30TB). Or maybe they sought to emulate the Normal channel in the AC30TB? No, that would have been a laughing matter, and the manual does specify the "Brilliance unit". Apparently an additional treble boost was thought to be sufficient. A measurement of the AC15-model can be seen as the third curve in Fig. 10.10.60, and it is barely different from the two "colleague"-models. These are not untypical distortion characteristics, and one can get by working with them – it is however not an actual distortion model of the famous ancestors.

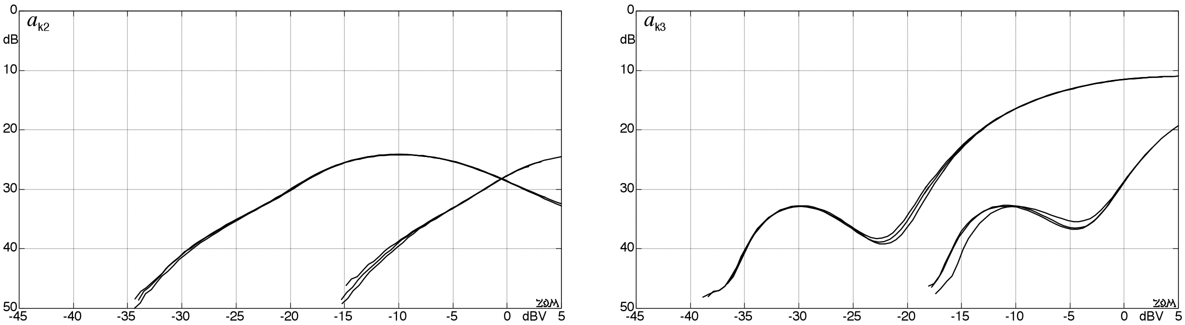


Fig. 10.10.60: Harmonic distortion (AD60VT-DSP) for the AC15, AC30 & AC30TB-models. 2 gain settings.

Apparently, the differences between the amplifier models are limited to modifications of the frequency responses, as they are documented in **Fig. 10.10.61**. A few ripples, more gain and more treble for the AC30TB-model – that's it. One criterion that apparently was seen as deserving some more attention: the sequence of filtering and limiting. For some models the treble content of a distorted 500-Hz-tone can be strongly altered (i.e. the filter is located post-clipping) while for others almost no effect is present. Model-specific characteristics are recognizable in the time-functions of the distorted sine-wave, as well, and there are large model-specific differences in the behavior of the tone controls. However, there are inconsistencies, too: the VOX-manual states that "*Presence*" is a "*feature in the power-amplifier*", but there is no Presence-potentiometer anywhere in the VOX-power-amp – the effect is calculated in the DSP.

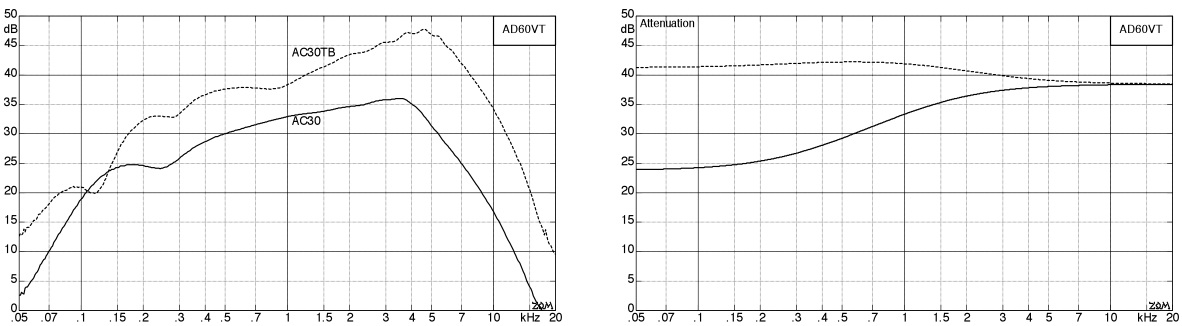


Fig. 10.10.61: Transmission characteristic (AD60VT-DSP) from input to an 8-Ω-load; (B = min, M = 12:00, T = 13:30, Pr = 12:00). On the right is the dampening of the power-amp feedback (Fig. 10.0.58, AB-models only).

The negative feedback in the power-amp of the AD60VT is simply not variable as it is the case in amplifiers with Presence-function. It has only 3 variants (Fig. 10.10.58): off, slight treble cut and strong treble boost. The results of the measurements♣ depicted in Fig. 10.10.61 were taken with a resistive 8-Ω-load – connecting the speaker results in a (desirable) treble emphasis. And again, as we look closer: the two variants in the grid-circuit are a well-meant, nice try to start; however, the recharging of the coupling capacitors (Chapter 10.10.4) happens in real life (i.e. with the EL84, 6V6, 6L6 or EL34) with more than two variants.

So, what does remain of the promise, that *each and every one of our models is as tonally authentic as possible - as opposed to the usual "close but definitely no cigar" norm of digital modeling* [VOX-Manual]? A definitely useful, versatile amp with purposeful control concept (let's not talk about the VC-4, though). The AD60VT certainly is not an amplifier in which its 16 different amp-models perfectly imitate the corresponding real amplifiers. That simply cannot work since – for a start - the loudspeaker cannot emulate all of the sound radiation patterns of an 8x12"-Marshall stack, a 4x10"-Bassman, a 2x12"-Twin and a 1x12"-Deluxe. And because the amp (for economic reasons?) does without certain special circuits (Cut, Presence). And because the nonlinear distortion is emulated in a rather simple fashion in the DSP. And because the speaker is a typical Celestion, and not a Jensen or Eminence or JBL. Still: useful. That the distributor resolutely shoots down any inquiry regarding schematics: forget it – the manual for the AD120VT can be found on the internet, and the printed circuit for the power-amp is single-layer and thus easily analyzed ☺.

Model	presumably	Tubes	AD60VT-pwr-amp	sequence	Pwr-amp-FB
Boutique CL	Dumble	4x6L6GC	A	CF	no
Black 2x12	Twin-Reverb	4x6L6GC	AB	FC	
Tweed 1x12	Deluxe	2x6V6GT	A	FC	no
Tweed 4x10	Bassman	2x5881	AB	FC	
AC15	AC15	2xEL84	A	FC	no
AC15TB	AC15TB	2xEL84	A	FC	no
AC30	AC30-6	4xEL84	A	FC	no
AC30TB	AC30TB	4xEL84	A	FC	no
UK Blues	JTM-45	2xKT66	A	FC	
UK '70s	Marshall Plexi	4xEL34	AB	FC	
UK '80s	80's Marshall	4xEL34	AB	CF	
UK '90s	90's Marshall	4xEL34	AB	CF	
UK modern	Marshall	4xEL34	AB	CF	
Recto	Mesa Tri-Rectifier	6x6L6GC	AB	CF	
US HiGain	Soldano	4x6L6GC	AB	CF	
Boutique OD	Dumble Overdrive	4xEL34	A	FC	no

Table of the amp models in the VOX AD60VT (to the best of our knowledge). FC = Filter -> Clipping, CF = Clipping -> Filter.

♣ Attenuation in the negative-feedback branch results in gain in the forward branch.

Let us move now from "Valvetronix" on to "**Valvestate**", i.e. from VOX to **Marshall**. Because here, as well, there are (besides the famed all-tube amplifiers) – watch out! – *transistor* amplifiers in existence. Ouch!! Fear not, though, dear guitarists: they do include an alibi-tube. "*The new Advanced Valvestate Technology (AVT) is the fruit of years of development and innovation since the birth of the original Valvestate amplifiers. The resulting new hybrid technology outclasses in one stroke all 'virtual' and 'modeling' amp concepts, and is therefore today the best possible alternative to all-tube amplifiers"* [Marshall]. This is because: *"All AVT-preamps work with a ECC83 (12AX7) preamp tube. This tube makes for authentic bell-like clean-sounds and harmonically rich overdrive that cuts through".* Indeed, that had to be said – finally. What is rather not said is that the actual non-linearity is generated by two anti-parallel LED's. And it is only the IC-data-sheet that tells us that the power-amp – previously the undisputed territory of the EL34 – is now dominated by a solid-state power circuit that was developed *"for use as audio class AB amplifier in HiFi field applications (Home Stereo, Top Class TV)".* Marshall only writes that the AVT-power-amp is unique. We happily take their word for it. Marshall also could have written in the brochure that the typical THD of this power-amp-IC is a possibly record-breaking 0.005% (IC data sheet), but this remains unmentioned – maybe they took this as a given. That, on the other hand, the boucherot-resistor tends to throw in the towel – this info is obtainable via the internet. It seems not that easy to exorcise RF-oscillations from this Marshall power-amplifier in the framework of series production … sounds familiar, many a service-technician will think to him- or herself.

If we trust Marshall, a single ECC83 is sufficient for an authentic tube sound. An *ECC83 preamplifier tube*, but that doesn't mean that it is employed in the first amplifier stage. In the latter an NMJ072 takes care of business, followed by an M5201. The M5201 is a so-called "switching-OP" i.e. a switchable operational amplifier that activates either the Clean- or the Overdrive-channel. This NMJ072 has a rather modest 2V/µs-slew-rate, but the fan base thankfully offers advice: a swap for an NJM2121 boasting 4V/µs. That's actually not a lot, either … whatever – the priorities seem to be shifted elsewhere. They might lie, for example, with the anti-parallel light-emitting diodes connected in the negative-feedback-branch: **3mm, red**. Would yellow sound different? Affirmative! And let's not even talk about green or blue. Marshall: only genuine sporting the red distortion LED's. At last, the ECC83 is called up for service now, fired up using a terrifying 109V supply voltage and a series-heating-voltage of 13.5 V. 13.5 V? Yep – in Marshalls, tubes always had to suffer. However, the circuit of the ECC83 in not the infamously distorting cathode-follower pressed into service since the JTM45-days (i.e. it is impossible to imagine a true Marshall without it). No, both triodes operate in common-cathode-configuration, without the cathode-capacitor – they are really well-behaved. "*Authentic*", as the brochure notes. They feed their signal to a further OP-amp (i.e. a whole lotta transistors – and why not?); then another two anti-parallel LED's (3mm, red) spring to action, and two more OP-amps (the reverb needs to connected with befitting style, as well), and off the signal goes to the power-module (the output IC). It must not have been easy to get a handle on all this with respect to RF-stability: there is a C93 so it probably wasn't doable with only 92 capacitors. And in the middle of the whole shebang: the tube – with its photo in the top position in the brochure. Tube amp, advanced technology! Now if we would replace this ECC83 by two FET's … ÿÿÿÆ¿¿ĐþĄĦĶŦǿǿ .... no, even WORD cannot deal with this anymore. Marshall with transistors only … shudder ….,

Over the years many manufacturers have tried to emulate that sought after all-valve sound using solid state technology. All such attempts failed miserably up to now. Enter Marshall's Valvestate technology [Marshall].

Translator's note: the following 3 pages contain an ironic send-up of the interaction between "experts" in the media and resulting legal issues. The included specifics and terms used work best in German and are therefore left un-translated.

Anwälte, oder: Wenn die Sau läuft

So schnell kann's gehen. Es gab ja Zeiten, da wünschte man Thorben ein paar Probleme an den Hals, aber Anwälte – so bösartig war keiner der Kollegen. Anwälte! Wir betreten gerade die Kanzleiräume von Winklhofer & Winklhofer, herrlich am See gelegen, und während Thorben die 5 cm dicken Acrylglastüren zu öffnen versucht, murmelt er nur ein verzweifeltes "so eine Scheiße." Dies betraf weniger die Türen, die ein dienstbarer Motor mit einem leisen "ffft" aufschwingen lässt, kaum dass man die Hand in Griffnähe bringt, nein, das betraf die Sache an sich. Die Sache (resp. die Causa) war Thorbens erster Versuch als Autor. Er, der durchaus begabte Fotograf, hatte sich in den Kopf gesetzt, zu seinen Bildern auch die Story zu fabrizieren, also nicht nur Pics, sondern auch noch Docs. Und hatte sich gleich als erstes eine Kolumne der bekannten Zeitschrift "Gitarre 4 U" vorgenommen, in der ein sehr von sich eingenommener (aber technisch noch nicht so ganz kundiger) Kollege Vermutungen über "Vintage Guitar Amps" unter die Leser brachte. Thorbens Meinung hierzu schlug ein wie das Ding, das man in Zeiten weltweiter Krisen nicht mehr gern beim Namen nennt, und rief zuerst den erbosten G4U-Autor, und dann dessen Anwälte auf den Plan. *Winklhofer & Winklhofer, Wessling/Moskau/Tokio/NewYork*.

Lektion 1: Tritt dir jemand auf die Füße, hol dir den größten Bruder, den du kennst. Das anwaltliche Schreiben, 1½-zeilig auf handgeschöpftem Papier, war einer dieser Binnenbriefe: Wennse nicht binnen 2 Wochen eine Erklärung abgeben, könnense gleich mit der Zahnbürste in SantaFu antreten. Natürlich besser formuliert, und 5 Seiten lang, aber im Prinzip: Entweder jetzt viel zahlen, oder später viel mehr zahlen. Denn mit den 5 handgeschöpften Seiten war's ja nicht getan, als Anlage fanden sich auch noch ein paar weniger-wertige DIN-A4-Blätter, die ganz unverhohlen dazu aufforderten, die Traumlage am See mit 3591,- Euro zzgl. MWSt. mitzufinanzieren. Immerhin wurde ohne direkt ersichtliche Mehrkosten ein Gesprächstermin mit Herrn RA Gerhard O. Winklhofer angeboten, dem Juniorpartner der Sozietät (der Senior kam wohl erst bei Fünfstelligem in die Puschen). So schnell kann's also gehen.

Wer weiß, was dezent getöntes Acrylglas kostet, kann verstehen, warum die Herren Anwälte die Hände ihrer geschätzten Mandantschaft hiervon gern fernhalten und Servomotoren einbauen lassen. Aber mal ehrlich: Man könnte sich auch ans Harlachinger Krankenhaus erinnert fühlen, da gehen die Türen nämlich auch von selbst auf, kaum dass man in ihre Nähe kommt. Doch der Boden beseitigt jeden Zweifel: Carrara – also nicht maroder Münchner 60er-Jahre-Charm, sondern: Wessling! (Moskau/Tokio/NewYork war's allerdings auch nicht ganz). Eine Blonde in perfekt sitzender Business-Kombi hob ihr entzückendes Lockenköpfchen und fragte strahlend: *"Ja bitte?"* 'Guitar-Lix-and-Trix-zu-Herrn-Winklhofer-Termin' schnarrte Thorben herunter, der sowas von angefressen war, dass man Tätlichkeiten nicht ausschließen wollte. "*Wenn Sie bitte einen Moment Platz nehmen möchten? Darf ich Ihnen einen Kaffe anbieten?*" Thorben unterdrückte ein 'wir nehmen alles was nix kostet' und nickte nur, und dann versanken wir einen kurzen Moment in den Besuchersesseln.

Den wollte ich nutzen, um Thorben etwas einzubremsen, aber schon kam eine weitere Blondine in Business-Kombi mit zwei Tassen Kaffee (und $2cm^2$ großem Keks) sowie ein perfekt gestylter Endzwanziger mit affenscharfer Designerbrille. *"Von Greiffenklau – wir gehen ins B8, Herr Winklhofer kommt dann hinzu"*. Da konnte man nicht mäkeln, das war schon irgendwie perfekt, wenn auch nicht ganz billig. Das Acryl zwischen Foyer und Arbeitstrakt schwang auf, und Thorben folgte dem Rat, nicht gleich in medias res zu gehen. Doch, das verstand er schon, er hatte nämlich früher einmal 2 Semester Philosophie studiert. In Passau ... bevor's dort zum Eklat kam.

Thorben, bitte, wenn schon einmal ein Bischof zu Besuch in der Uni weilt, sollte man halt nicht gleich loskrakeelen, dass ja wohl nicht Gott den Menschen, sondern wohl eher der Mensch sich einen Gott geschaffen hat. Mensch Thorben, Passau! Und dann noch nachzufragen, ob sich Luthers *in der Woche zwier* auch auf die Missbrauchsfälle ... nein, Thorben, Philosophie wäre sicher nicht dein Ding geworden. Also nicht gleich in medias res, Thorben – Smalltalk!! *'Schönen Boden hammse da, kommt gut zu der Art Deco.' "Ja, das sagen viele. Schiffseiche!"* Erklärend wandte sich Thorben mir zu: *'In Bayern spricht man von schiffen und von Seiche, wenn...'* Es war nicht zum Aushalten, nein – ich hätte es wissen müssen! Von Greiffenklau, eindeutig außerbayerischer Provenienz, guckte sehr verwirrt, und wollte schon nachfragen, als von rechts unerwartet eine Acrylgläserne in den Gang schwang und mir fast das Kaffeetässchen aus der Hand geschlagen hätte. *"Bitte nicht zu nahe rangehen, die Electronic ist hier sehr sensitiv"* warnte von Greiffenklau, und man spürte förmlich, dass er Electronic mit *"c"* aussprach. *"B8, wir sind da, ich darf mal vorgehen."* Diesmal blickdichtes Acryl, achtsitziger Teak-Tisch, Leder, Kunst, Seepanorama: B8. Achtsitzig! Das war uns schon früher aufgefallen, sie kommen selten allein, die Herren Advokaten. Meist in Rudeln, wie die Waschmaschinenmonteure. Ein kurzes Telefonat (*die Herren von der Zeitschrift sind jetzt da,... ja,... B8, nein, danke*), und Tröstliches: "*Herr Winklhofer kommt sofort.*" Man hätte nun eigentlich erwartet, dass ein Sensor unsere Anwesenheit automatisch entdeckt und der Herr W im nächsten Moment von unten mitsamt seinem Sitz durch den Boden geschossen kommt, aber das wäre wohl doch zu James-Bond-mäßg gedacht. Stattdessen schwang die Blickdichte auf, und Herr W trat selbstlaufend herein. Begleitet von einer weiteren Blonden in der Kombi (das war jetzt schon die dritte), die sich mit einem Stuhl Abstand neben dem Herrn W niederließ und ermunternd lächelnd den Laptop aufklappte. Beeindruckend.

"Wir wurden von unserer geschätzten Mandantschaft beauftragt, gegen Sie eine Abmahnung vorzubringen und eine Erklärung aufzusetzen, gemäß der Sie es künftig bei Androhung einer Konventionalstrafe in Höhe von 250.000,- Euro unterlassen, das Ansehen unserer Mandantschaft verächtlich zu machen. Sie haben unseren Entwurf erhalten?" '250 Mille für G4U? Das sind bei denen doch drei Jahresumsätze?' Thorben war schon wieder auf 180, doch sein Gegenüber blieb geschäftsmäßig kühl: "*Ich bitte Sie, gleich in Ihrem ersten Absatz schreiben Sie, der Autor sei dumm wie ein Stück Scheiße ... das ist doch kein elaborierter Code, das ist schlicht ein Insult.*" "Was für ein Kot soll das sein?" maulte Thorben, dem der Adelige mit der Affenbrille schon mächtig auf den Geist ging. *"Meine Herren, versuchen wir doch, die Angelegenheit schnell und professionell hinter uns zu bringen."* Auch der Herr W verteilte nun ein paar seiner teuren Worte. *"Ich will ja nicht das Sprachniveau Ihrer Zeitschrift im Allgemeinen kritisieren, aber ihr Artikel gegen unsere Mandantschaft ist definitiv beleidigend. § 185 StGB – um konkret zu sein."*

Nun musste ich auch mal ein paar Worte sagen, Thorben ging die Sache einfach zu emotional an: "Ich finde nicht, dass sich aus diesem Satz eine beleidigende Absicht herauslesen lässt. Mein Kollege schreibt ja: 'Wüsste man es nicht besser, man könnte glauben, der Autor sei dumm wie ein Stück Scheiße'. Daraus ergibt sich nach den Regeln der Logik doch zweifelsfrei, dass Ihre geschätzte Mandantschaft, eben gerade kein Stück Scheiße ist. Also zumindest diese eine, geschätzte..." Nun gut, der Halbsatz war auch nicht ganz emotionsfrei, aber das mit der Logik, das hatte doch was, oder? Und gleich nachgesetzt: "Zur Juristenausbildung gehört doch noch immer Fausts Collegium Logicum, oder?" *"Florian Faust, BGB?"* wollte von Greiffenklau wissen, und war damit endgültig raus, wie ein entsetzter Blick seines Herrn W verriet. Auch die Blonde, die gelegentlich Notizen machte, verdrehte kurz die Augen. Sie war gar nicht ohne, und bei jedem "Scheiße" musste sie an sich halten, um nicht unschicklich loszukichern. Gleichzeitig schien sie sehr fasziniert von Thorben, der immer, wenn keiner der Beanzugten herschaute, minimalmimische Signale an sie sandte, was jedes Mal ein ganz kurzes Lächeln auf ihre Lippen zauberte. Thorben gab den Proll, ja schon, aber mit zwei Semestern Philosophie im Rücken. "Sie wissen ja" begann er gerade zu erläutern, "dass die Nichtbeleidigung, die nicht unabsichtlich vermieden wird, schwerer zählt als die vorsätzlich vermiedene Unterlassung einer Beleidigung. Schon Kant hatte ja in seiner Kritik der ..." *"Würden Sie bitte nochmals Ihre..."* fiel ihm von Greiffenklau ins Wort, womit die Situation endgültig aus dem Ruder lief. Dem Herrn W war dieses Tamtam die ganze Zeit über schon zuwider, seine Farbe wechselte schlagartig in ein dunkles rot, und im Business-Kombi entlud sich ein unkontrolliertes "mmpff", sofort gefolgt von einem sehr verlegenen Händchen-vors-Mündchen-Halten.

Doch – wär's nicht so teuer, man könnte sich von den Herren Advocaten und ihren Maskottchen schon ganz elaboriert unterhalten lassen. Und von Thorben, der gerade nachsetzte: "Und das mit dem Aufhängen war ja auch von einer Art Mentalreservation begleitet." Das-mit-dem-Aufhängen, das hatte so richtig Schwung aufs Pleuel gebracht, und den G4U-Autor dazu veranlasst, zwei Hefte später zu schreiben, er ließe sich nicht von diesem neofaschistischen Gehirnamputierten seine Amp-Clinic-Kolumne kaputtschießen. Da konnte man geneigt sein, schon wieder ein Intelligenzdefizit festzustellen: Denn während Thorben (ganz im Sinne Kants?) meinte, früher hätte man derartige Schriften auf der Straße verbrannt und den Autor an der nächsten Laterne aufgehängt, schrieb der G4U-Autor 'von diesem neofaschistischen Gehirnamputierten'. Ohne jede Einschränkung, Direttissima, dant genommen. Nun ist es ja eigentlich sinnlos, einem Juristen etwas erklären zu wollen, ein Oxymoron sozusagen, (wie z.B. auch 'Frankenschnellweg'), aber Thorben versuchte es trotzdem: "Das Temporaladverb FRÜHER ist ja in seiner Tempusspezifikation eher unbestimmt, und schließt auch sehr frühe Zeitvorstellungen ein, sodass ohne ergänzende Konkretisierung 'nach erstem Anschein' auch Verjährung nicht auszuschließen wäre". *"Mord verjährt nicht"*, versuchte der Hochwohlgeborene die Situation zu retten, kassierte aber postwendend ein "aber Totschlag schon, gelle?" Was man in Philosophie so alles lernt – und noch dazu in Passau – faszinierend. Nun war Thorben auf Betriebstemperatur, hatte vielleicht Lektion 2♣ im Kopf, als er nachsetzte: "Da mich Ihre sehr geschätzte Mandantschaft in Heft 07 öffentlich als 'Gehirnamputierten' bezeichnet hat, werde ich wohl als nächste Maßnahme von meinen Anwälten Gegenklage einreichen lassen. Konkret: § 185 StGB – sie erinnern sich?"

Dann ging alles ganz schnell: Man werde sich mit Herrn Winkladvokat Senior besprechen, und die geschätzte Meinung der geschätzten Mandantschaft im nächsten Schriftsatz mitteilen. Falls sich die Geschätzten tatsächlich diesem Vorschlag anschließen könnten, würden sich die geschätzten Kosten dann lediglich um die Vergleichsgebühr erhöhen. Und Tschüss.

Wieder draußen, blickte Thorben gedankenverloren auf die gerade erbeuteten Visitenkarten. "FLORA GARLEITNER – geiler Name. Ich wollte sie ja noch fragen, ob ich ihr behilflich sein kann, falls sie sich mal in *Deflora* umbenennen will." Thorben sui generis, wie immer halt.

♣ Konfuzius sagt: wenn die Sau läuft, lass sie laufen

