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).

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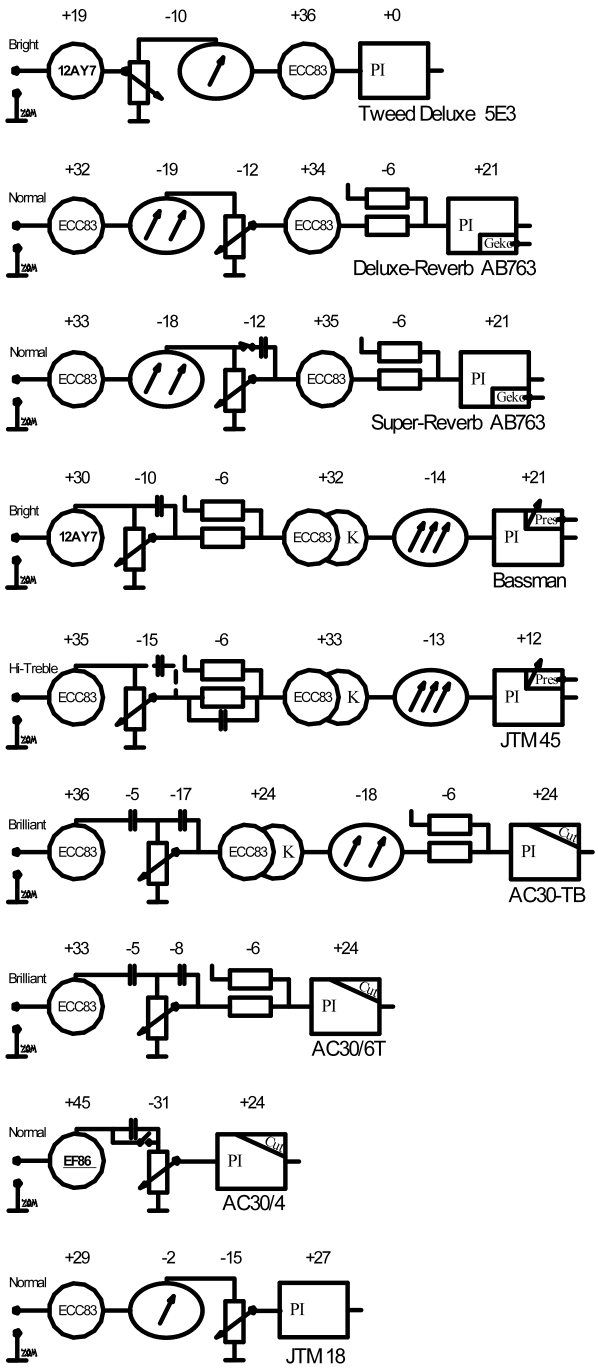

Fig. 10.10.3: Block diagrams

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.

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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.

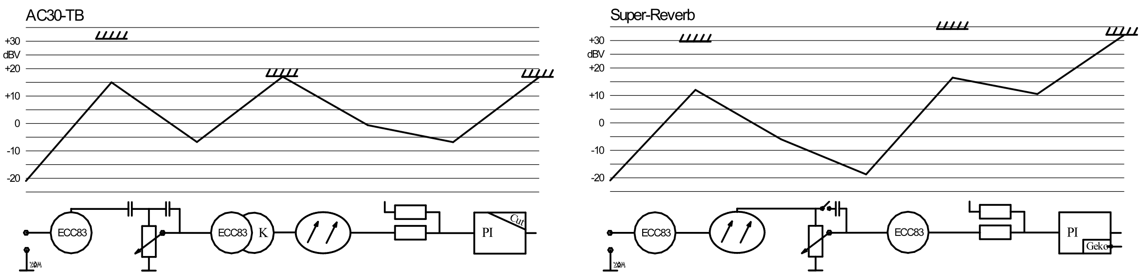

Fig. 10.10.4: Level plans for the VOX AC30-TB and the Fender Super-Reverb, f = 500 Hz.

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.

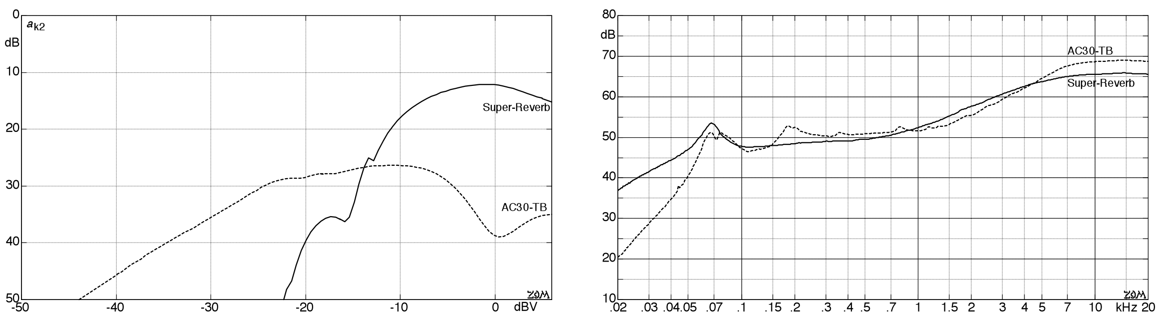

Fig. 10.10.5: 2nd order harmonic distortion a_{k2} (500 Hz) from amplifier input to power-amp output (left), frequency responses in standard setting from amplifier input to power-amp output (right). $a_k = 20lg(1/k)$dB.

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