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**.

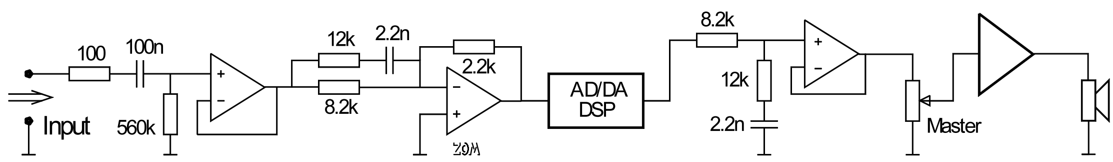

Fig. 10.10.56: Signal-processing in the VOX AD60VT (simplified).

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.

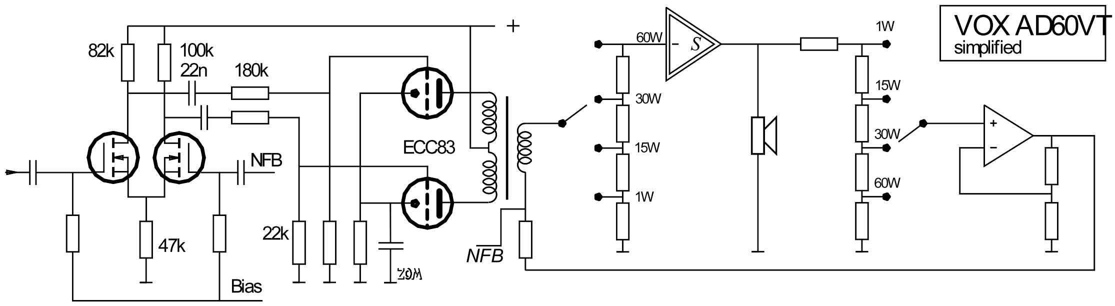

Fig. 10.10.57: Power-stage circuit of the VOX AD60VT Valvetronix (simplified).

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 $kS\underline{Z}_L$ 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).

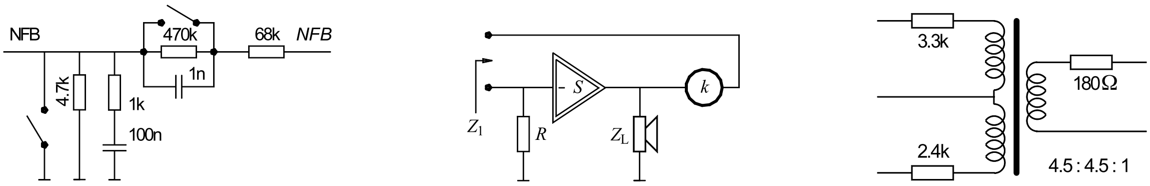

Fig. 10.10.58: Negative feedback circuit (left), "Vari-Amp-circuit" (middle), transformer (right).

[♣] 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.

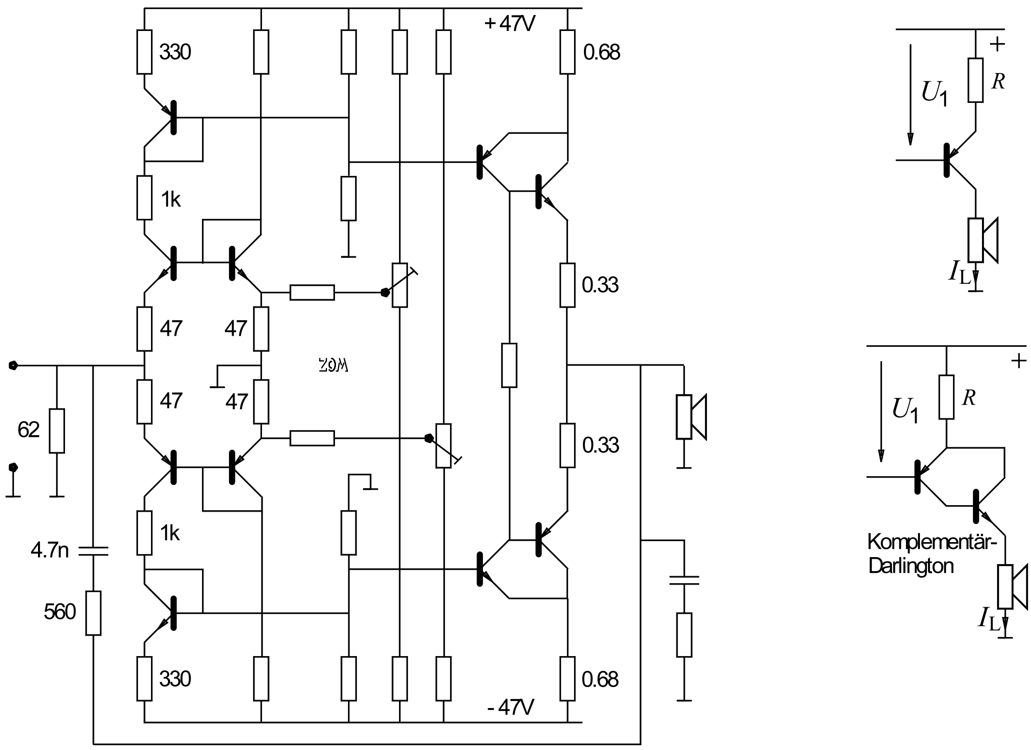

Fig. 10.10.59: AD60VT-power-amp (left), effect of the complementary-Darlington-circuit (right).

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.

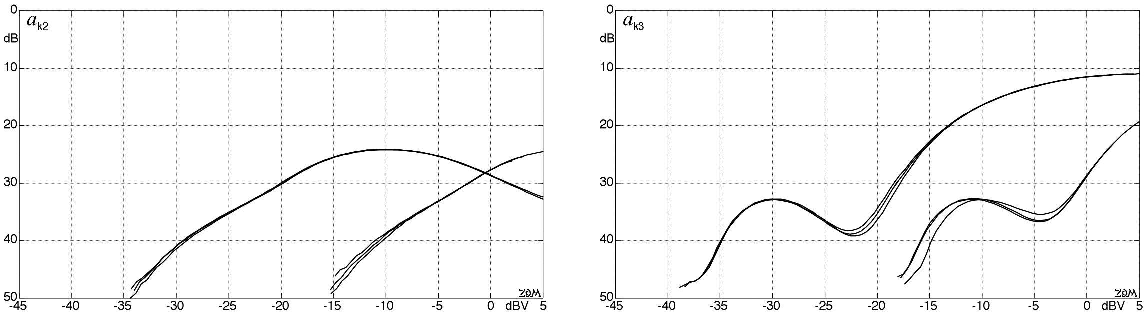

Fig. 10.10.60: Harmonic distortion (AD60VT-DSP) for the AC15, AC30 & AC30TB-models. 2 gain settings.

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.

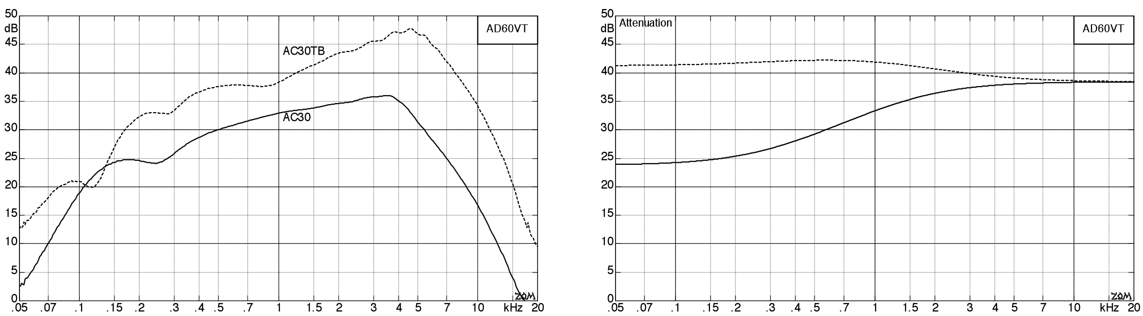

Fig. 10.10.61: Transmission characteristic (AD60VT-DSP) from input to an 8-Ω-load; (B = min, M = 12:00, T = 13:30, Pr = 12:00). On the right is the dampening of the power-amp feedback (Fig. 10.0.58, AB-models only).

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¿¿ÐþĄĦĶŦǿǿ .... 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].

 Translation into English by Tilmann Zwicker