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.

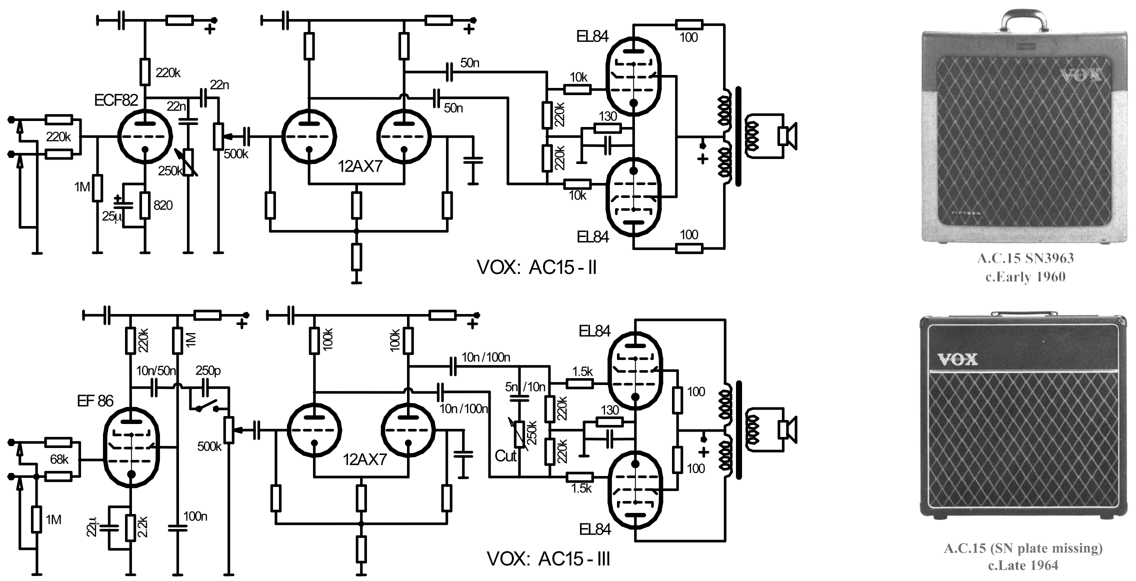

Fig. 10.10.35: VOX AC15, Normal-channel; "second circuit" (1959, top), "third circuit" (1960, bottom). The built-in vibrato channel is not shown in the figure, supplements: Chapter. 10.8.2. Pictures: Elyea.

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*".

 Translation into English by Tilmann Zwicker

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.

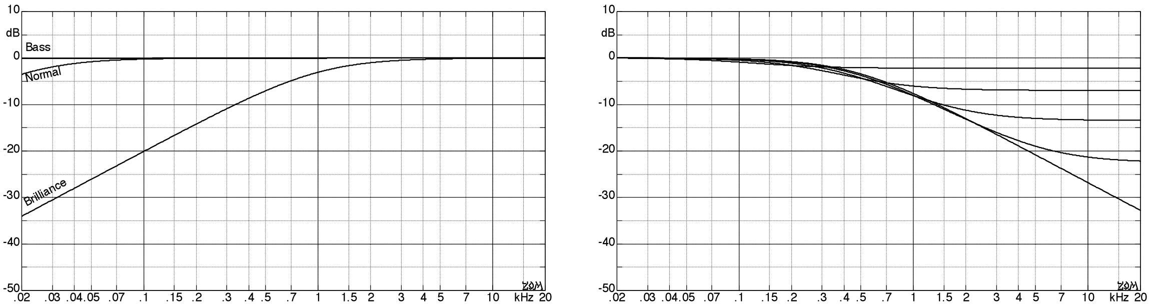

Fig. 10.10.36: Coupling preamp/phase-inverter (Brilliance switch, left); Cut-Filter ("Normal", right)

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.

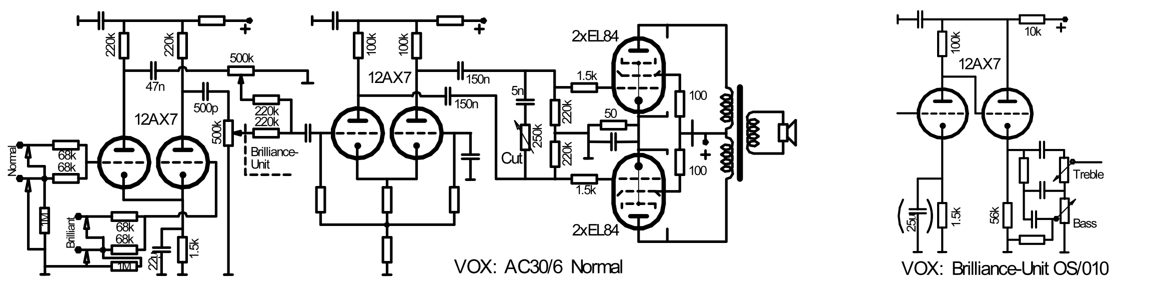

Fig. 10.10.37: VOX AC30/6. Of the in total 4 power tubes (2 each in parallel) only 2 are shown. The circuit at the right was inserted into the Brilliant-channel behind the volume pot at the marked position; in addition, this pot had a bright-C (100 pF) shunting it. Result: the **AC30-TB**.

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.

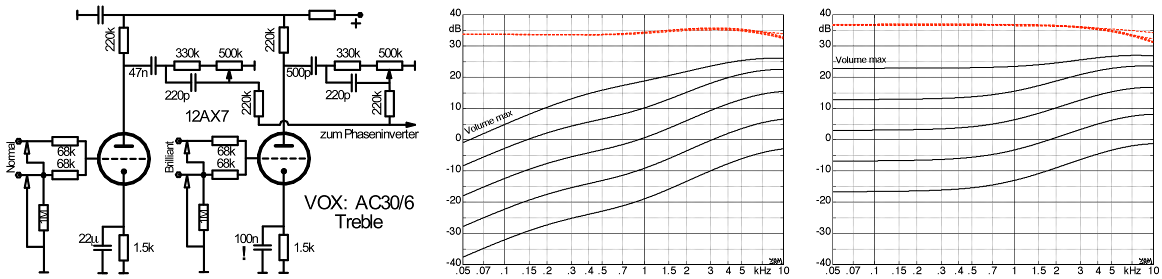

Fig. 10.10.38: VOX AC30/6 "Treble". Frequency response from input to the first plate (-----), and to the phase-inverter-input respectively; Brilliant-channel (middle), Normal-channel (right).

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.

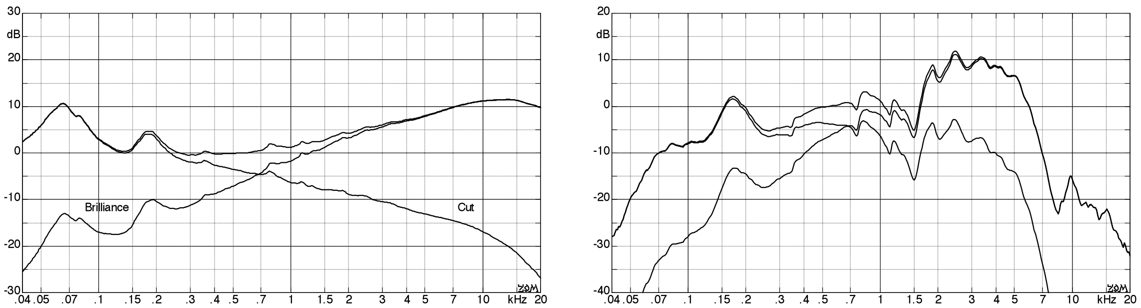

Fig. 10.10.39: VOX AC30/4. Frequency response up to the power output (left), and including the resulting SPL (right).

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**.

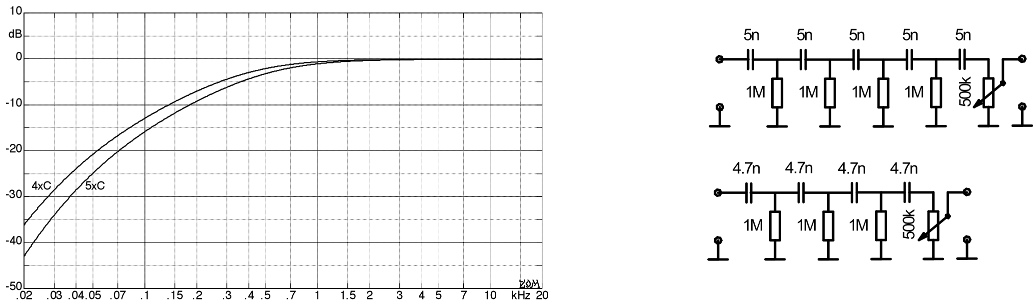

Fig. 10.10.40: High-pass in the Vibrato-channel (VOX AC15, AC30/4 five-stage, VOX AC30/6 four-stage).

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 ...

 Translation into English by Tilmann Zwicker

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.

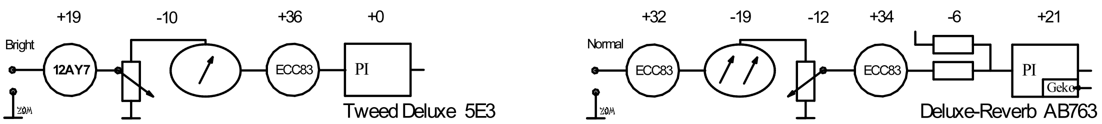

Fig. 10.10.42: Comparison 5E3-Deluxe (Tweed) vs. Deluxe-Reverb (Blackface). The respective given gain values relate to the reference condition from Chapter 10.10.2 (90 mV / 500 Hz for full drive (not overdrive)

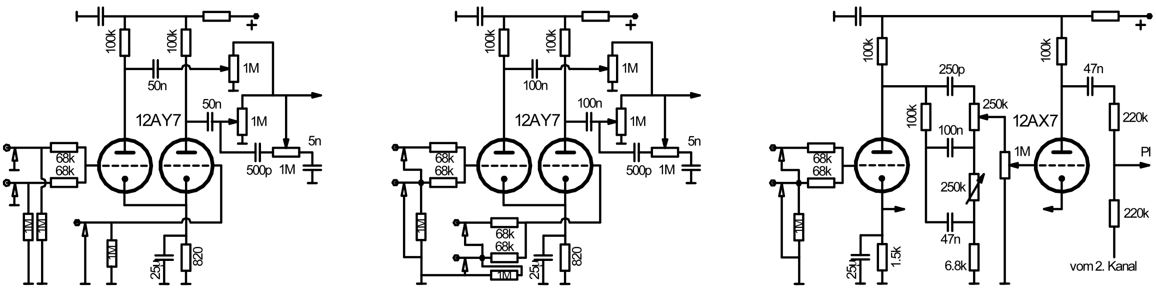

Fig. 10.10.43: Deluxe-input-circuits: 5D3 (1954), 5E3 (Tweed, 1955), AB763 (Blackface, 1963).

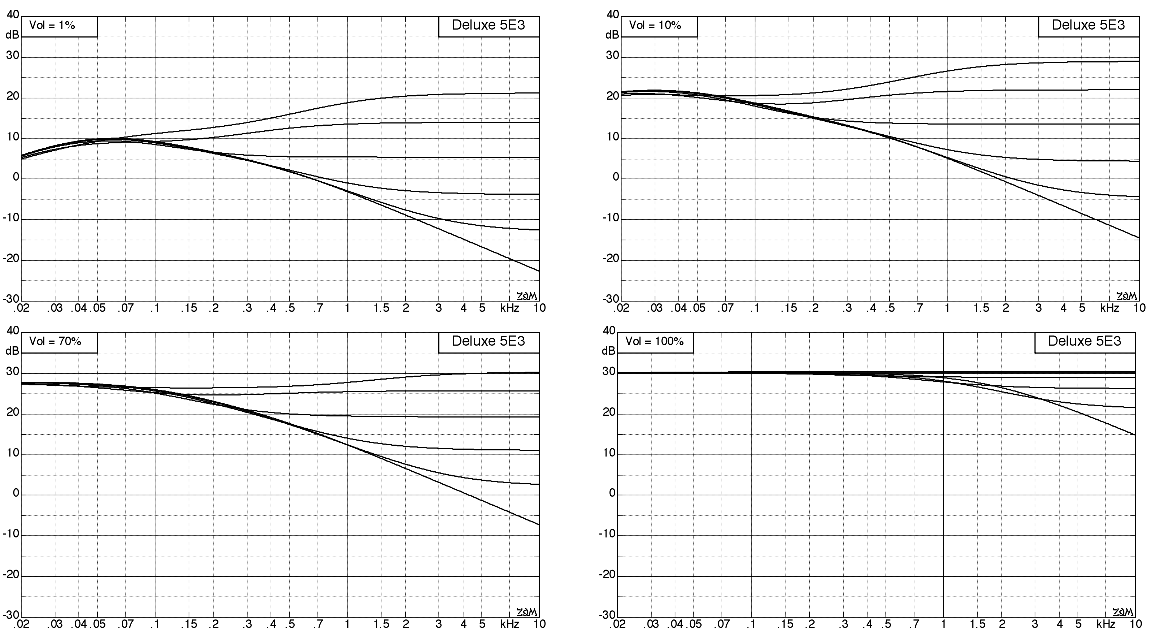

Fig. 10.10.44: 5E3-Deluxe, first-stage-transmission, Tone-pot; volume-pot of "the other channel" turned down.

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.

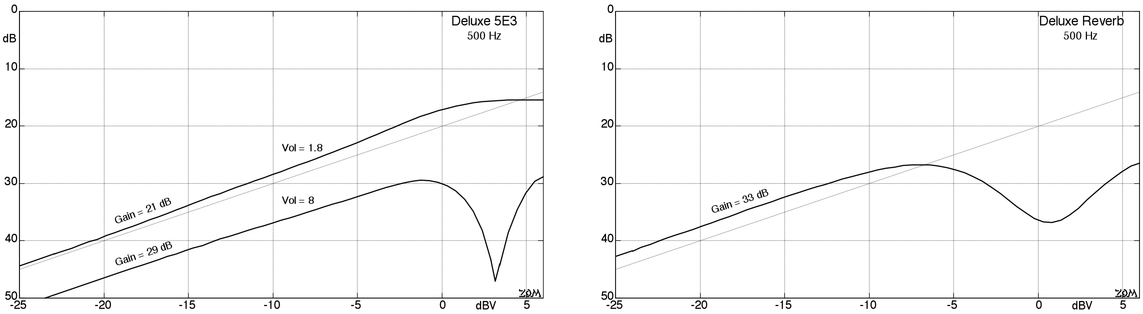

Fig. 10.10.45: 2nd order harmonic distortion from amplifier input up to the first plate. The *reverse*-connected volume-pot is also found in other Fender amplifiers, e.g. in the Pro, the Princeton, and in the Super.

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.

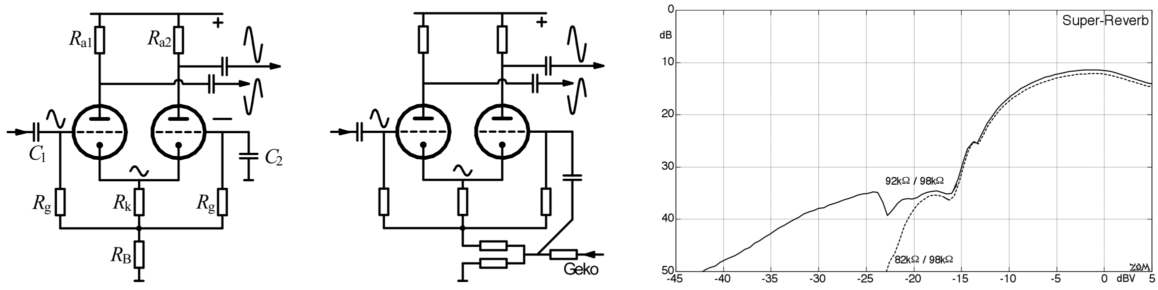

Fig. 10.10.46: Differential amplifier with and without overall-negative-feedback; 2nd order HD.

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.

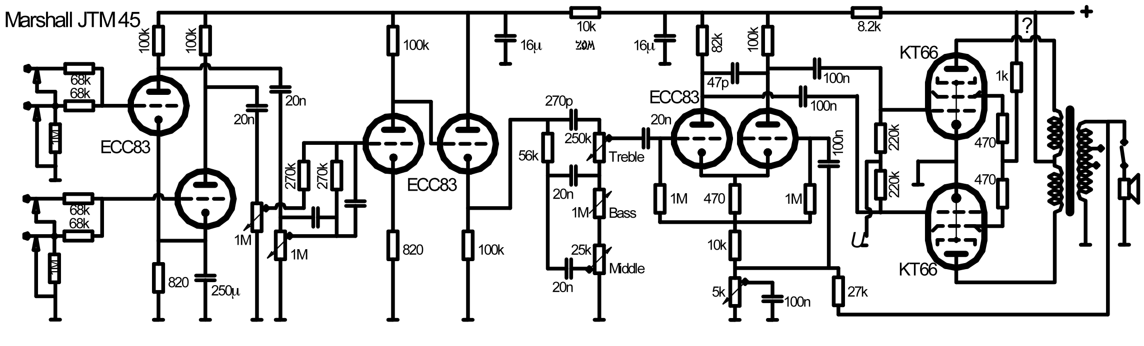

Fig. 10.10.48: Marshall JTM 45. The capacitors across the Volume pot depend on the type (100pF – 500pF). In Doyle's Marshall-book, a choke (20 H) is included in the power supply: for some schematics this choke is connected between plate and the remaining circuitry; there is a large difference with respect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

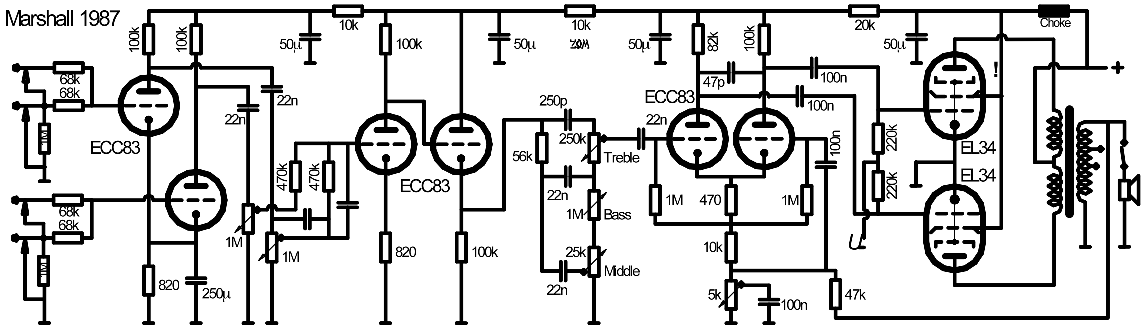

Fig. 10.10.49: Type 1987, a 50-W-amp from the golden era, with shared pre-amp cathode.

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).

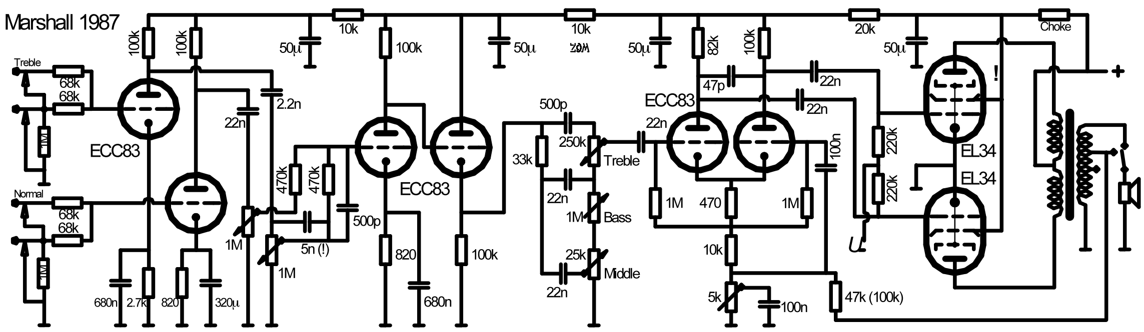

Fig. 10.10.50: Marshall 1987, the development with the split-cathode in the input stage.

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.

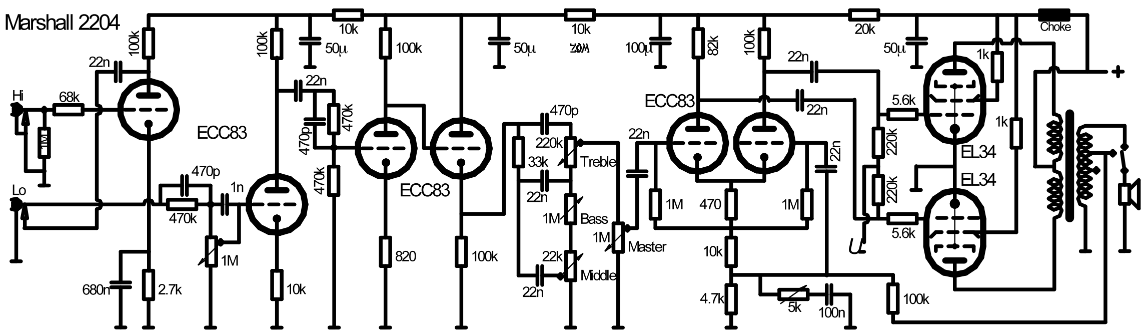

Fig. 10.10.51: Marshall 2204, 50 W Heavy-Rock with Master-Volume. The 2203 is the 100-W-variant.

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*.”

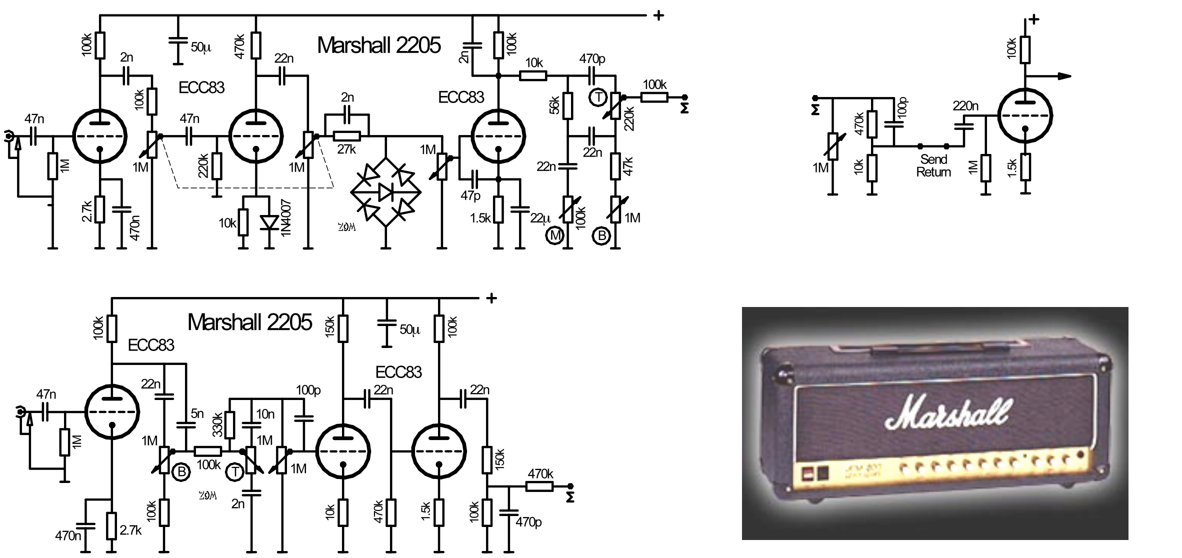

Fig. 10.10.52: Marshall 2205 (simplified). The 2210 has a 100-W-power-amp instead of 50 W. [Marshall.com]

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.

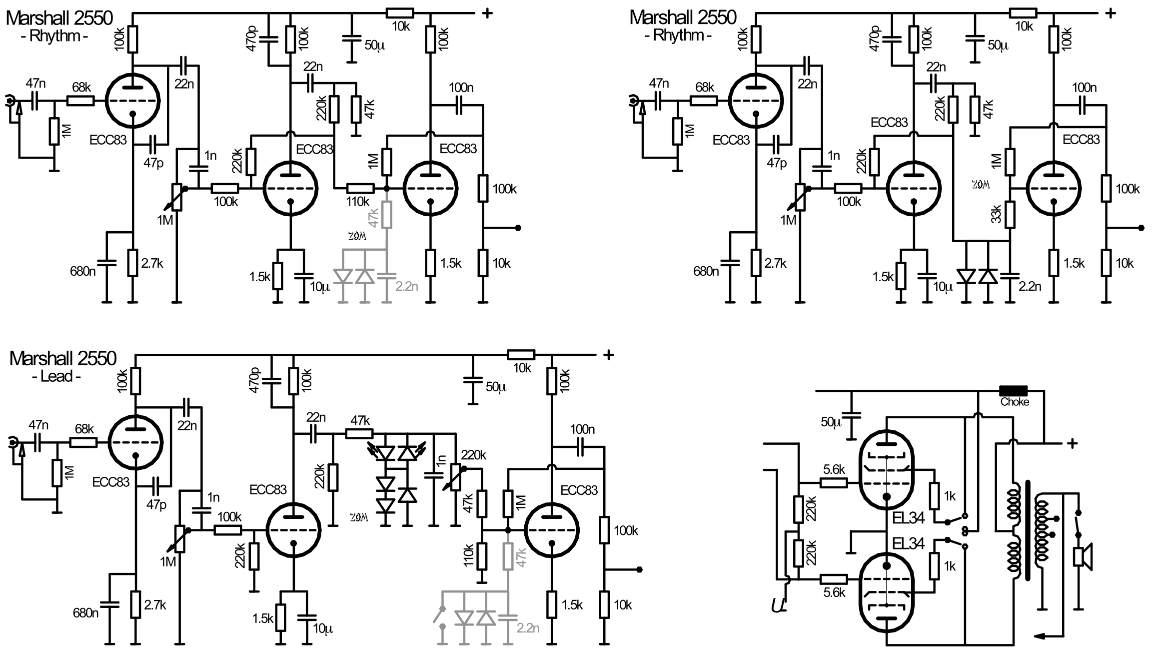

Fig. 10.10.53 Marshall 2550 (simplified). The 2555 has a 100-W-power amp instead of 50 W.

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.

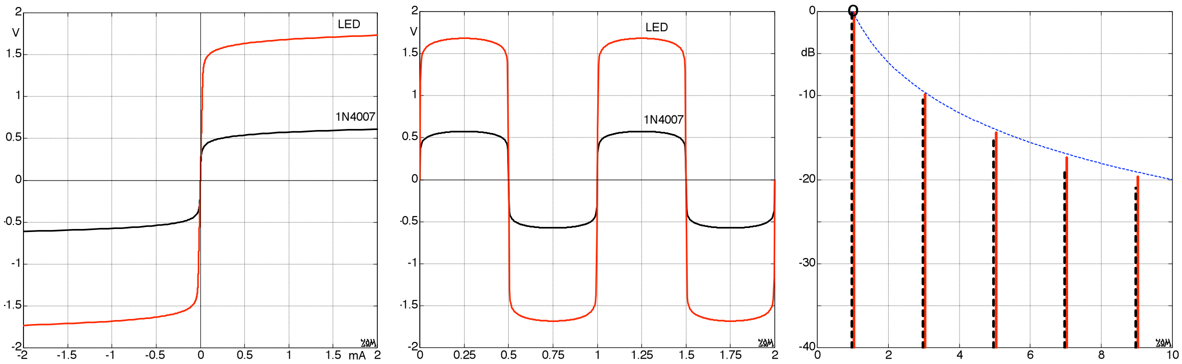

Fig. 10.10.54: Characteristic, time-function and normalized spectrum of the diode distortion circuit. Dashed in blue: the spectral envelope of a square-wave signal (1/*f*-spectrum).

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.

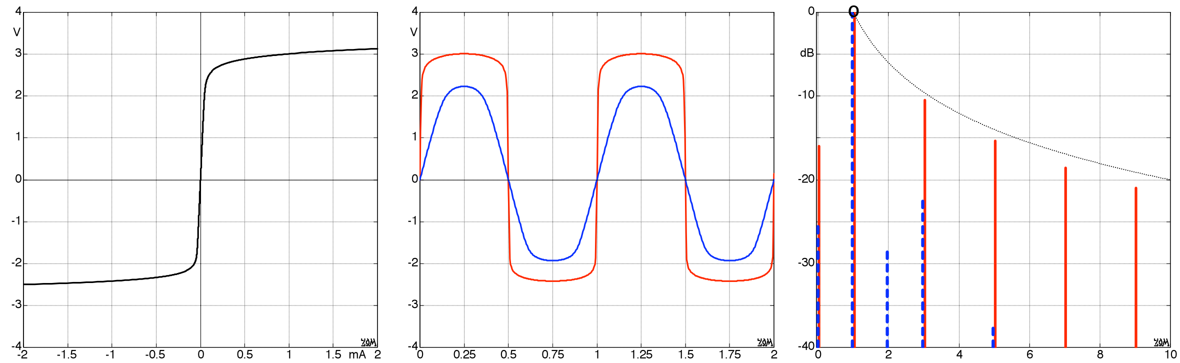

Fig. 10.10.55: Diagrams for the combination of 2xLED and 3x1N4007 (Marshall 2550).

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