10.9 General operating characteristic

The topic of the previous chapters was the performance of individual tube stages or individual circuit sections; in the following the focus shall be shifted to higher-level considerations. The operating characteristic of a guitar amplifier can be looked at from two different angles: from the point of view of the circuit design (i.e. how does the circuit function?), or from the point of view of auditory acoustics (i.e. how does the amp sound?). Of particular interest is to causally interconnect the two approaches – that, however, is also the most difficult task.

10.9.1 Tube sound vs. transistor sound

In fact, transistors seem to have only advantages over tubes: they are smaller, cheaper, have no fragile glass containers, do not need heating. Apparently, they have the single disadvantage that guitar amps designed using them do not sound good. Of course, this is a highly subjective judgment, and of course there are other opinions – however, in particular the early transistor amps had few advocates, and aside from all mysticism there are without a doubt differences from the point of view of systems theory. Still, there is no "tube sound" *as such*, just as there is no "transistor sound" *as such*. A guitar amplifier does not sound better merely because it is fitted with tubes, and a transistor amp does not need to inherently sound bad. It might, though. Fender's Solid-State-Series – the one advertised in 1968 with *'superb sound'* letting you *skim the waters of musical greatness* – was rather unsuccessful. *'Curious refrigerators'* was the term used by the German Gitarre&Bass-magazine in their Fender special edition. To vindicate the name "Fender", one could argue that "this wasn't Fender, this was CBS"; however, after the sale of his company to CBS, the same Leo Fender designed and produced (with his new company Music-Man) hybrid amplifiers featuring a transistor pre-amp and a tube power-amp. These amps – at least today – by far fail to achieve the fame and glory of Fender's black-faced heroes. The same with VOX: the company did not become famous with the transistorized Defiant, but with the all-tube AC30. Guitarists and transistor amps: not a love at first sight.

Transistor amps sound sterile, impersonal, lifeless, they buzz, crackle, sound scratchy, and on top of everything, at the same wattage they are not as loud as tube amps. These subjective judgments elude any circuit analysis. Who wants to stipulate how a guitarist should perceive his guitar sound? Plus: even if this is pure imagination, it is easily conceivable that this kind of imagination has repercussions on the virtuosity. Electrical engineering with its many disciplines is actually only challenged when causal links are brought in: *'hot tubes for a warmer sound'*, or: *'tubes do a rounder limiting and thus sounds less sharp'*, or: *'tube amps sound better because 2nd-order-distortion dominates in them'*. Still, it is not that simple. If the audible differences in sound could be traced to a single reason, we would probably see exclusively transistor amps today. As is the case for public address systems: who would make the effort to stage several hundred tube power amps? But nine tube amps lined-up behind a guitar player: even today, that is not very strange. "Very loud" in the case of nine AC30, and "VERY LOUD" if six Super-Twins are stacked to a pyramid. Why do they do that – what is the secret of the tube? With such a presumptuous question, the answer can only end up in hybris … anyway: the secret i.e. the undiscovered country is in the diversity, in the interaction of a multitude of non-trivial components and characteristics, respectively.

Harmonic distortion, slew-rate, frequency response, input- and output-impedance, shifts of operating points … and all that in combination. What is the effect of the level-dependency of the 4th-order harmonic-distortion on the sound? Does the 4th-order distortion have to be even considered at all, and if yes, up to which order are distortions relevant? To measure the distortion is simple, but to determine its effect on the sound is difficult. For one, comprehensive auditory tests are required, and then each judgment is dependent on many boundary conditions: on the setting of the tone controls, on the loudspeaker, on the listening location, on the guitar, and of course on the generated tones. Because this variety of parameters is vast, the developers of transistor amplifiers do not only have to develop circuits but also “survival strategies”.

One of these strategies is: *as long as the frequency response is identical, the sound has to correspond, as well*. That thought is too simple. Here’s another: *since it is unknown how the characteristics of each individual tube stage affects the sound, every detail of the tube circuit needs to be modeled*. Sounds as if it would be on the safe side – and it would be if indeed every detail were known. And another variant: *we tune and retune until everybody is satisfied, even if the new circuit has no relations to anymore to tube circuits*. Possible, but easily subject to diffuse criticism: something is missing! No one knows exactly what it is that’s missing, but everybody is convinced: that is not the ideal tube-sound. Or the opposite approach: the designers are happy (sounds quite good and doesn’t go up in smoke anymore), the management as well (remained even 2% below the pre-calculation), and the sales department agrees (finally they finished it). It’s juts that not only the calculation but also the turnover is below plan. It is a difficult market: the original Bassman is a legend but the Music-Man is not. Despite the fact that behind both the mastermind was Leo Fender.

This book with its focus more on guitars will not answer the question which type of distortion will render the sound sparkling-creamy-wooden-throaty – that topic belongs to a book exclusively dedicated to amplifiers. Still, there is room for a few basic thoughts. The previous chapters dealt with the non-linear behavior of the amplifier; from the point of view of the author, this is a main theme. In tube amplifiers, several linear and non-linear systems interact: *high-passes* in the coupling-capacitors, in the output transformer and in the loudspeaker, *low-passes* in every tube, in the output transformer, in the loudspeaker. In every tube, in the output transformer, and in the loudspeaker we also find non-linearity. It all makes for an almost unfathomable system – even without negative feedback. It’s not that we couldn’t describe the individual sections of the system – it is the overall judgment that is so difficult. Something that is routine in the LTI-system develops into a vast problem for coupled non-linear systems. For example, it is only in the linear system that it makes no difference whether filter-poles are realized in the electrical of the mechanical domain – here we can compensate e.g. a treble-loss of a loudspeaker by an electrical filter. If indeed linear behavior is desired, equal-sounding amplifiers can easily be built with both tubes and transistors. With non-linearity entering the picture it gets very complicated, though.

After several decades of searching for the right sound, transistorized guitar amps today have matured to the point where the acceptance can to said to be good. Nevertheless there are still innumerable tube amps on the market, and many guitarists are likely not to buy anything else for decades to come, ready to invest those 200 € now and again in a quartet of tubes. The manufacturers have learned from the mistakes of the early years, and offer well-sounding circuits and amps. However, the guitarists have also educated themselves and now can hear details that 50 years ago would have been classified as unsubstantial.

What adds to the problems that non-linear amplifier circuits can pose are **psychometric** issues: how do we measure auditory perceptions? Here, the range starts with “plug in, turn up, listen” and ends with round-robin-tests carried out on a global scale. For guitar amps, we mostly find the former experimental method: listening test in the store, in the rehearsal room, in the editorial office. The results of such test are often ignored or contested on the side of the acousticians (who typically have a scientific background) – not so much because of the involved jurors (normally not that wee known) but because of the unscientific approach lacking objectivity and reproducibility. Is the hand-wired boutique-amp praised primarily because it hails from California and sets you back 5000.- €, as every person testing the amp is made to know first of all? Would the amp be as convincing if it would remain unknown and hidden behind a curtain? We find a nice example for such a scenario described by Uli Emskötter in SOUND-CHECK magazine [issue May, 2000]: in a test of guitar cables, all involved perceive “*pronounced differences in sound*”. A week later, in a repetition – this time as a blind-test – shows: “*bewildering result – the judgment came out as entirely different*”. It is nothing new to psychologists that the type of presentation procedure will influence the result of perceptional tests. The insights these experts have regarding **experimental methodology** are beneficial for listening experiments, as well (see Chapter 10.9.4).

Guitarists not only perceive the sound of their guitar but they also evaluate it. For the **perception process**, a relatively small inter-individual variance may be assumed, however the **evaluation process** always depends on various boundary conditions. We all know this: first the new CD by the latest superstar is lauded to be among the 10 best releases of the year, next thing we know it appears in a TV-show listed among the most embarrassing oeuvres. Although the auditory event remains exactly the same, the evaluation of it changes. Another example that every studio musician is familiar with: you do a mix-down, find a suitable mixer-setting, everybody is delighted and calls it a day. The next day you listen again – without any changes to any setting – and everybody is disappointed: the vocals are too loud, the drums are trebly, the bass too fat … or the other way round. The reasons for this change are rarely found the technical issues (loudspeakers cooled down, humidity different) but with all likelihood the difference is found in the changed judgment-standard. The underlying processes may develop over minutes or even hours, but time-invariant, systematic differences (bias, offset) are also known: there is a tendency to set a value controlled by the subject to high [12, loudness scaling].

Here is an episode showing how much our value judgments are affected by cognitive processes. It may be a singular case, but is likely to happen quite often in a similar way. After a gig, a young musician addressed me speaking in highest terms of the *"super-sound"* my guitar-rig had: *"You can’t beat the good old AC-30 – that’s pure tube-sound."* I am sure the people at VOX would have loved to hear that – although I wasn’t using an AC-30. At the beginning of the 21st century, this legendary amp is not as ubiquitous as it used to be, and the younger generation apparently is not as familiar with it. Indeed it was a VOX I was playing through, as the gilded badge on the front of the amp confirms, however it rather was a AD-60-VT. That amp features a transistor-preamp and a transistor-supported 1-W-tube-output-amp. It doesn’t sound that horrible, either, in fact it sounds pretty darn good, and its **AC-30TB** model cooperates most harmoniously with the Historic Les Paul. In any case, associating the terms *VOX = AC-30 = tube amp = super sound* appears to be hard-wired into many (though not all) a musician’s brain. Had the amp-label not read VOX but Solid-State-MOSFET, the judgment could easily have been “*doesn’t sound too bad – for a transistor amp*”. Indeed the psyche plays an important partner-role in the wide and colorful world of psychophysics. The psyche’s counterpart in this area, i.e. physics, and more specifically circuit technology, will now get some attention as well.

 Translated into English by Tilmann Zwicker

From the many amplifier circuits we chose a Fender- and a Music-Man-circuit (**Fig. 10.9.1**) because Leo Fender was involved both. He probably was not the only designer but at the very least the responsible patriarch. Starting out from the RCA-application-notes, the circuit of the **Twin-Reverb** – as it is presented here – was developed over the years into an internationally recognized standard that inspired competitors, as well. Once the era of the octal-tubes had passed, noval-tubes entered service at Fender in the mid-1950's, and in particular the high-gain 7025 (and its colleagues, the 12AX7 and the ECC83) won the pole-position that they never relinquished again.

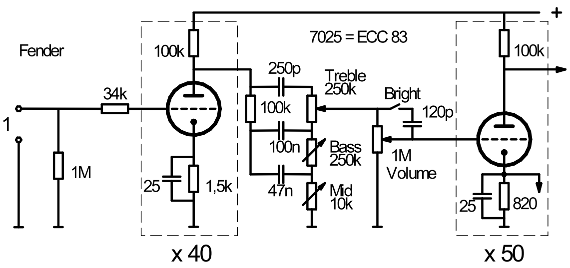

Fig. 10.9.1a: Fender AA763 (Twin-Reverb).

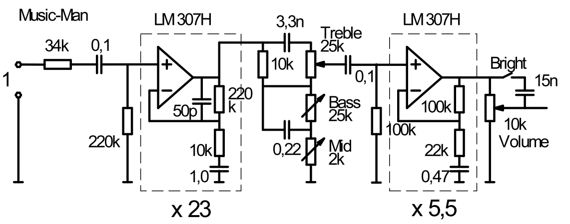

Fig. 10.9.1b: Music-Man 2100

The Fender-circuit starts with a triode-input-stage of a gain factor of about 40. Tone-filter, volume control and intermediate amplifier follow. The Music-Man circuit shows considerable similarity although the input OP-amp has only a gain factor of 23 – a concession to its lower supply voltage that leads to earlier limiting. Despite small differences, the effects of the tone-filters are comparable. The volume pot, however, is connected not directly after the filter but inserted after the intermediate amp. First, these circuits will be compared regarding their linear behavior.

Differences show up already at the input: the MM has lower impedance than the TR: the pickup-resonance receives a stronger dampening. On the other hand, the input capacity is lower in the MM (do consider the Miller effect!). The series-capacitance in the MM-input has barely any effect on the signal, and no shift of the operating point need to be feared, either (due to the symmetrical limiting in the OP-amp input). The 50-pF-capacitor is there to reduce the gain at high frequencies, it has an effect from about 10 kHz The 1-µF-cap reduces the gain at very low frequencies (below 20 Hz). Compared to the TR, the impedance level in the MM-tone-filter is lowered by a factor of 10 to normal OP-amp-typical values. Disregarding this change, the two tone-filters are indeed very similar, despite one missing capacitor in the MM – however such variants with only two capacitors did exist at Fender, as well (e.g. the Super-Amp, see Chapter 10.3). These circuits were modified again and again.

The small-signal transmission factors of both circuits are shown in **Fig. 10.9.2** (referenced to 1 kHz for both). This similarity is not likely to have been an accident; rather the Fender circuit will have been the given objective. The only significant difference in the small-signal behavior is the different input impedance; we can only surmise that the design process was possibly checked with a low-impedance generator such that this aspect did not become apparent. Large differences are apparent, however in the behavior for strong signals i.e. at high drive-levels.

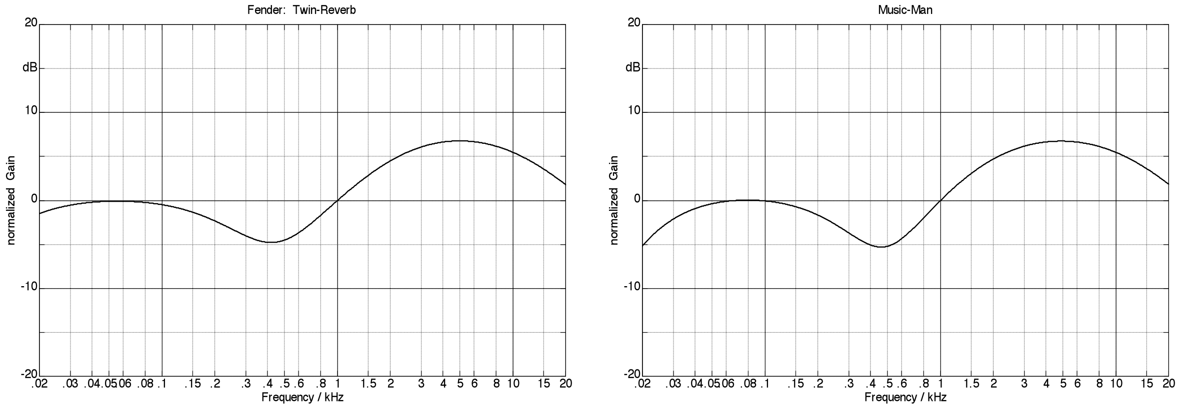

Fig. 10.9.2: Frequency responses referenced to 1 kHz. Bright-switch in “off”-position for both cases.

The drive limit of the amplifying element (tube, OP-amp) is the significant factor for the behavior at high drive-levels. Differences pop-up right at the input: in the TR we have grid-current distortion that is not there in the MM. From about 5 kHz, the MM shows slew-rate distortion but the TR does not. Highly significant: the TR has the volume control positioned after the first tube while the MM has it only after the second OP-amp. With the treble-control turned up fully, the gain factor in the MM from input of the first OP-amp to output of the second OP-amp is about 126. To maintain distortion-free operation, the input voltage must not increase beyond 70 mV. For the TR, this is quite different: assuming 35 V as limit of the first tube for hard clipping, the permissible input voltage would be about 900 mV. Having said that: as already mentioned in Chapter 10.1.4, it is difficult to compare tube- and OP-amp-distortion. Below the clipping-limit, the OP-amp works practically distortion-free, while for a tube, distortion rises continuously across the drive-level-range. **Fig. 10.9.3** shows, for the MM, the maximum input level for undistorted operation. Especially in the brilliance-range (3 – 5 kHz) that is so important for Fender guitars, distortion can very easily occur even though the volume pot may turned up only a bit. In Fender amps, the **Bright-switch** most often is located at the volume control, but for some MM-amps this is included into the negative feedback of the first OP-amp – possibly to reduce OP-amp-noise. Switching-on the Bright switch in the latter case further decreases the treble headroom (right picture), independently of the position of all tone pots and of the volume control. This marks a difference to the Twin-Reverb and to similar Fender amps. The MM-amps therefore do show clear differences in their behavior at high drive-levels compared to typical tube amps.

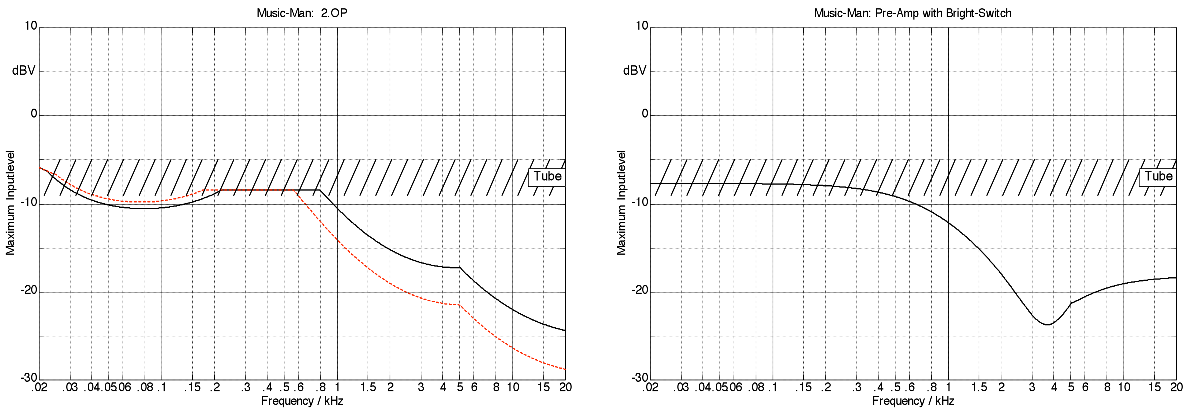

Fig. 10.9.3: Music-Man: maximum input level for undistorted operation. **Left:** solid line = tone controls as in Fig. 10.9.2, dashed line = treble control turned up fully. **Right:** amplifier in which the Bright-switch changes the gain of the input-OP-amp. Hatched area: tube input-stage.

