10.1.6 Time variance

Many theorems of systems-theory are valid only for linear and time-invariant systems. Guitars amplifiers are neither the former nor the latter. There is non-linear distortion, and the characteristics are time-variant: they change due to aging of the components (this being a well-known aspect), and they are subject to short-term shifts of the operating points (this aspect being not recognized much). Trivial time-variances relate to components that change their characteristics dependent on temperature, or that age relatively quickly (such as tubes). These time-variances will not be addressed here – for the present consideration, all components are assumed to be time-invariant. Short-term shifts in the operating point, however, can nevertheless occur, because non-linear processes lead to a re-charging in capacitors. If there were no capacitors, this chapter would be omitted – or the other way round: every capacitor is a potential source for variances.

Tubes in guitar amplifiers are often overdriven – they are non-linear systems. Even for seemingly undistorted (“clean”) sounds, the attack may easily be slightly distorted♣. All even-order distortions (k_2, k_4, k_6 ...) generate an additional **DC-component** that shifts the **operating point** for a short time – the transfer behavior thus becomes time-variant. For example, the **cathode-resistor** is often bridged by a capacitor in order to reduce the negative feedback. The DC-component generated by even-numbered distortion of the cathode current changes – in a time-variant manner – the cathode-voltage and correspondingly the operating point. A further variable is the **supply-voltage** fluctuating (“sagging”) dependent on the power fed to the loudspeaker. While these shifts are low-pass-filtered, they are not regulated out; they have a backwards effect on the plate-voltages of preamp and intermediate amp. In **Fig. 10.1.28**, we see measurements of the supply-voltage of a Fender amplifier (Deluxe). The amp is fully driven from t = 0,3 to 1,7 s and the supply-voltage drops from 247 V to 210 V. As a consequence, maximum signal level and harmonic distortion change as already shown in Fig. 10.1.12. Many guitar players demand this effect since they feel that it renders the guitar sound livelier. However, measures are also taken to reduce this sagging – via changes in the filter capacitors and associated resistors. In early amps, the filter capacitor (C_B) was rather small (8 µF) and was later increased to up to 50 µF. For full removal of the effect, a stabilizer-tube is required. The sagging is not primarily caused by the larger current consumption of the preamp-tube but by the current used up by the power stage that reduces the voltage of the power supply. The exact shape of U_B over time therefore depends on many parameters.

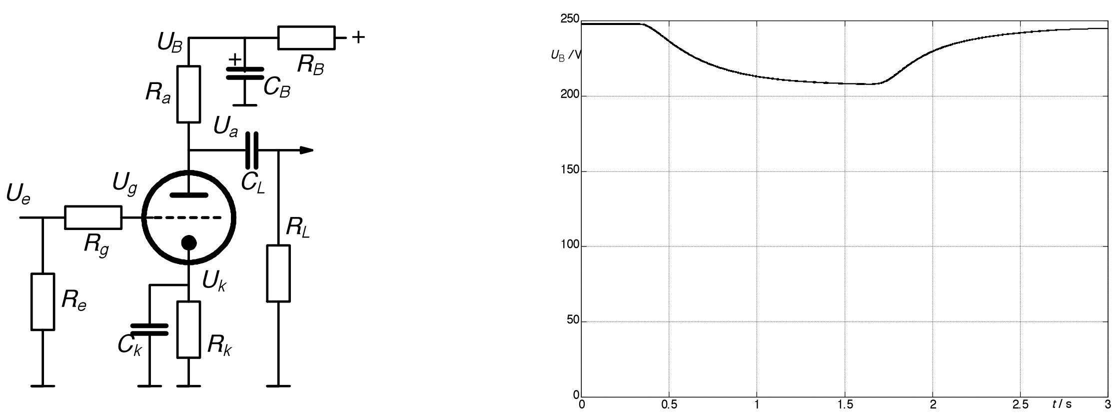

Fig. 10.1.28: Tube input stage (left); drive-dependent sagging of the voltage supply (right).

♣ It is the high art of amplifier-design to make such distortion sound good.

Another variance shows for the **coupling capacitors**. Only for a negative grid-offset does driving a tube not require any power (i.e. no current at the input is required). Typically, we find an offset of $U_{gk} = -1{,}2$V in preamplifier tubes, and thus strong pickups can drive the tube into the range of non-negligible grid-current. The subsequent tubes are all the more likely to experience grid-current. Most amplifiers do not use a coupling capacitor at the input; the pickup is usually connected via a resistance of 34 kΩ to the grid of the first tube. If the pickup were connected via a capacitor, only the grid-current could charge it (as a unipolar current creating a negative voltage at the grid) and shift the operating point towards a smaller plate-current. Of course, this is only temporary because the capacitor could discharge via the grid-resistor and the internal guitar-impedance – but exactly these transient processes are NOT present in the input stage of the classic guitar amps (Fender, VOX, Marshall), if we disregard some very early variants using the splash current (i.e. using grid-current bias).

We find a much different situation in the coupling circuits between the individual tubes: here there is almost always a coupling capacitor (the only exception actually being the galvanic coupling in cathode-follower circuits). Since the AC-plate-voltages can be much larger than the voltages allowable for operation without grid-current, a temporary re-charging of the coupling capacitors is almost inevitable. The grid-currents themselves will not in principle lead to audible effects, but the shift in the operating point can lead to audible changes in the harmonic content. We can roughly estimate the speed with which the re-charging processes run: for the "charging" (grid-current flowing) there is a non-linear process because the input-impedance of the tube becomes non-linear. As an approximation, the load-resistance of the preceding tube may serve – in conjunction with the capacitance of the coupling capacitor. Depending on the specific amplifier, the re-charging will happen over the course of a few milliseconds. The "discharging" cannot happen via the grid but only via the leak-resistance (in the order of at least 1 MΩ). This leads to an effect occurring over a time of 20 ms i.e. a time comparable to what is used in studio-compressors (in a "fast" setting). Thus: even if the value of the coupling capacitor is large enough that the high-pass it constitutes is effective only at frequencies far below those of usual guitar signals – the recharging times are defined by these capacitances (and the resistors in the circuit).

Given the sheer variety of tube amplifiers available on the market, it is difficult to specify the typical cause for the "tube sound". Even when only asking about the typical characteristics, a range of different answers is offered; this will happen even more if we look for the corresponding causes. An often heard verdict would be: *the tube amp is alive, it plays more dynamically, sounds more lively, reacts better to changes in the expression*. The opinion regarding a transistor amplifier often is the opposite, it is said to sound *sterile, impersonal, analytical, dead*. The perceived "liveliness" connected to the tube may well have its base in the shifts of the operating point as described above. Even if a unidirectional current as small as 10 µA flows through a 22-nF-capacitor for a mere 1 ms, the resulting voltage change will be 0,45 V. Such a shift in the operating point would drastically alter the transmission behavior of an ECC83. It is not that such a behavior would not be possible to obtain with a semiconductor amplifier, as well – however "modern" circuit design sees big advantages in direct coupling between amplification stages (i.e. without capacitors). That is indeed a conducive approach to minimize artifacts, but in guitar amplifiers that is exactly NOT the issue (or at least not a main one).

P.S.: The term *time-variant* chosen here is valid for short-term considerations; in the long term the shifts in the operating point as discussed above are indeed time-invariant i.e. they run an identical course given identical excitation. This distinction is, however, only important in a strictly systems-theory-oriented approach.

 Translated by Tilmann Zwicker