10.4 Phase-Splitter

A single power tube (class-A operation) allows only for small output power. High power needs push-pull operation (Chapter 10.5). A push-pull output stage requires two drive signals shifted by 180° relative to each other. These two anti-phase signals are generated in the so-called phase-splitter circuit using one or two tubes. In essence, there are three circuit-concepts: the tube operating with v = –1 in common-cathode configuration (paraphase-circuit), the cathodyne circuit, and the differential amplifier in common-grid configuration.

10.4.1 Common-cathode circuit (paraphase)

This is a simple concept: one triode provides amplification with its plate-voltage serving both as drive-signal for one of the two output tubes, and – attenuated via resistors – as drive signal for the other triode. The latter feeds its (opposite-phase) plate-voltage to the other power tube (**Fig. 10.4.1**).).

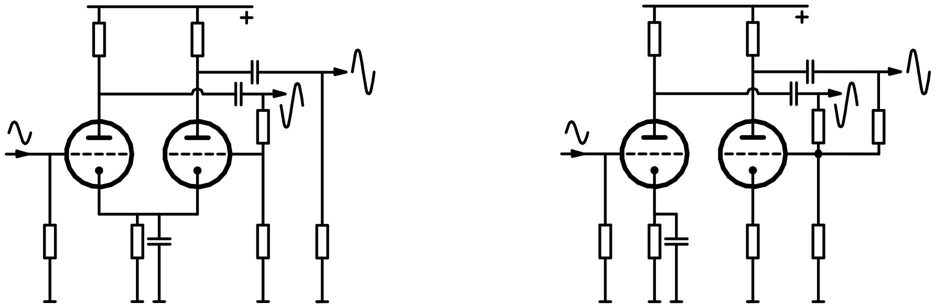

Fig. 10.4.1: Phase-inverter in common-cathode configuration. Right: modified version with negative feedback.

This basic **paraphase circuit** is predominantly found in early guitar amplifiers (e.g. the 1947 Fender Deluxe). It was soon first modified and then replaced by the cathodyne circuit. The advantage of the paraphase circuit lies in its high voltage gain and the relatively large output voltage swing of the two tubes. Disadvantageous is that the magnitudes of the output voltages are not exactly equal but depend significantly on the individual tube data. Matching the divider resistors leads to an individual symmetry, but this would have to be checked and re-checked as the tube ages. Of course, it is an entirely different question whether a guitar amplifier actually sounds best with complete symmetry of the output stage – however even if a lack of symmetry would be desired, this would have to be specific and not subject to random tube-variance.

The typical paraphase circuit – as it is found e.g. in the old **Fender Deluxe** (5B3) – attenuates the output AC-voltage of the first tube with a 250-kΩ/7.0-kΩ-divider by a factor of 1/44. For a precise calculation, the internal impedance of the first triode must be added in – this is approximately 50 kΩ. The second triode amplifies this attenuated voltage by a factor of -44, making available two AC-voltages of equal amplitude and opposite phase that drive the output tubes. That would be the ideal case, anyway – in reality, however, the gain of the second tube has significant scatter.

If the voltage gain of the second tube is not at its nominal value but e.g. too small by 20%, the two half-waves generated by the power amp also differ by 20%. The consequence is that this effect alone is cause for **harmonic distortion** of 4%. One may feel good or bad about such asymmetry – at Fender, it was not liked. The voltage divider at the grid of the second triode was replaced by a current/voltage **negative feedback**: the plate-voltage is tapped (via 270 kΩ) and generates an additional current in the grid-circuit. **Fig. 10.4.2** depicts the circuit of the Fender Deluxe 5D3; it is also found on other Fender amps of the same era (Super Amp 5D4, Pro Amp 5D5, Twin 5D8).

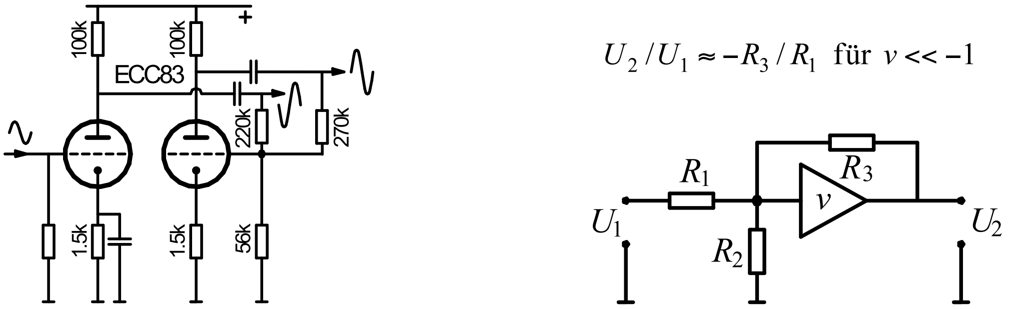

Fig. 10.4.2: Paraphase-circuit with current/voltage negative-feedback (Fender Deluxe 5D3, 1954).

The principle of the current/voltage negative-feedback is also used in the inverting OP (right-hand section of the figure): for an OP-gain approaching infinity, the voltage across R_2 becomes close to zero; U_2/U_1 is merely defined by the relationship of the resistances and not by the gain anymore [e.g. Tietze/Schenk]. For a tube circuit, this simplification holds only approximately – but the basic operation is the same: if the open-loop gain of the second triode changes by 10%, the ratio of the two (opposite-phase) output voltages changes by merely 1% due to the negative feedback. The latter stabilizes the ratio U_2/U_1 of the two output voltages – the circuit is termed “self-balancing paraphase circuit”.

The negative feedback has a further effect: it reduces the **internal impedance** of the right-hand triode. With a load, the plate-AC-voltage of the triode on the right becomes smaller and consequently the voltage fed back via the 270-kΩ-resistor decreases also, resulting in a overall larger voltage gain. To some extent at least, the load-dependent decrease in the plate-voltage is compensated. The internal impedance of the triode-circuit on the left (Fig. 10.4.2) is simply the parallel connection of the internal impedance of the tube (e.g. 63 kΩ) and the plate resistor (e.g. 100 kΩ) – i.e. about 39 kΩ in our example. Considering the load (about 220 kΩ), as well, brings us to $R_{i1} \approx 33$ kΩ for the overall circuit. For the right-hand tube, the calculation yields $R_{i2} \approx 12$ kΩ (including load). The negative feedback has therefore reduced the internal impedance of the second triode-system to about $1/3^{rd}$. As long as the loading of the two paraphase outputs is negligible, the differing internal impedances do not play any role. However, the input capacitances of the power tubes and the occurrence of grid-currents can lead to load situations that cause considerable asymmetries.

Furthermore, it is necessary to consider that the input signal to one output tubes passes *one* RC-high-pass, while the input signal to the other output tube passes though *two* such filters, causing phase shifts in the low-frequency range. Similar effects happen at high frequencies: the detour via the second triode-system acts as an additional low-pass that causes phase shifts in the high-frequency range.

Fig. 10.4.3 shows the output voltages of a paraphase circuit having no negative feedback. For small drive levels, we indeed get two phase-opposed voltages of approximately equal amplitude. With increasing drive levels, triode-clipping starts to become visible – this shifts the operating point across the coupling capacitor. In the lower line of the figure, we see power-tube grid-currents (occurring from about +20 V) that limit the voltage-curves in the direction of positive values. Because the signal of the second triode is derived from the clipped plate-voltage, the second output signal is limited towards negative values, as well. The overdrive of the output tubes consequently is asymmetrical.

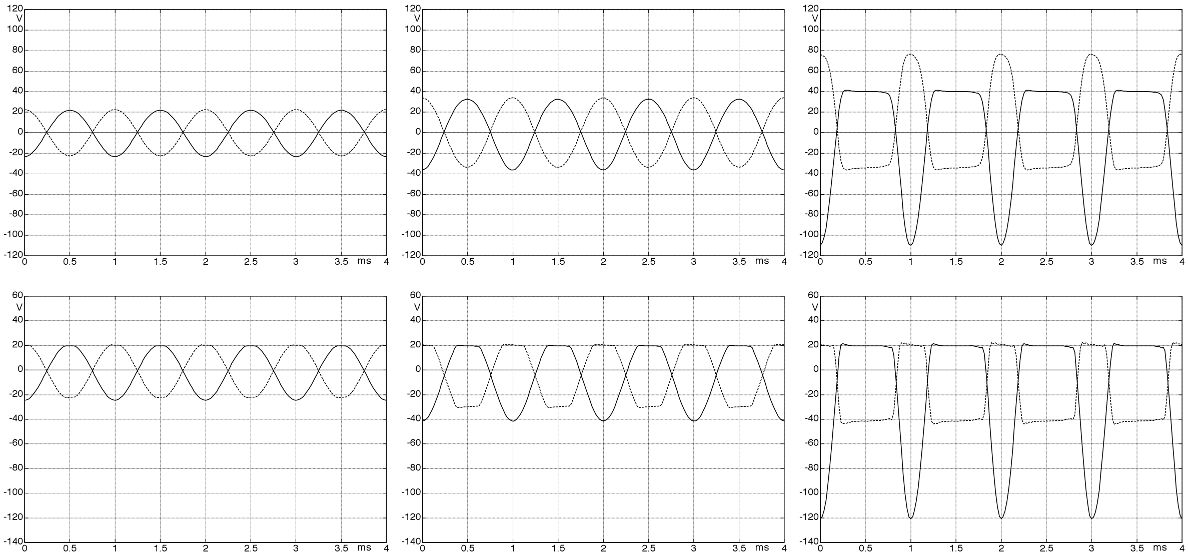

Fig. 10.4.3: Measurements on a paraphase-stage **without** negative feedback: 1st tube (——), 2nd tube (---).
Top: no grid-current limiting. Bottom; grid-current happening from 20 V. Supply-voltage for the triodes: 260 V.

Fig. 10.4.4 represents the corresponding measurements of a paraphase stage with negative feedback. We again see the different drive situations of the two power-tubes in non-linear operation. Also, the change in the duty-factor already recognizable in Fig. 10.4.3 reappears.

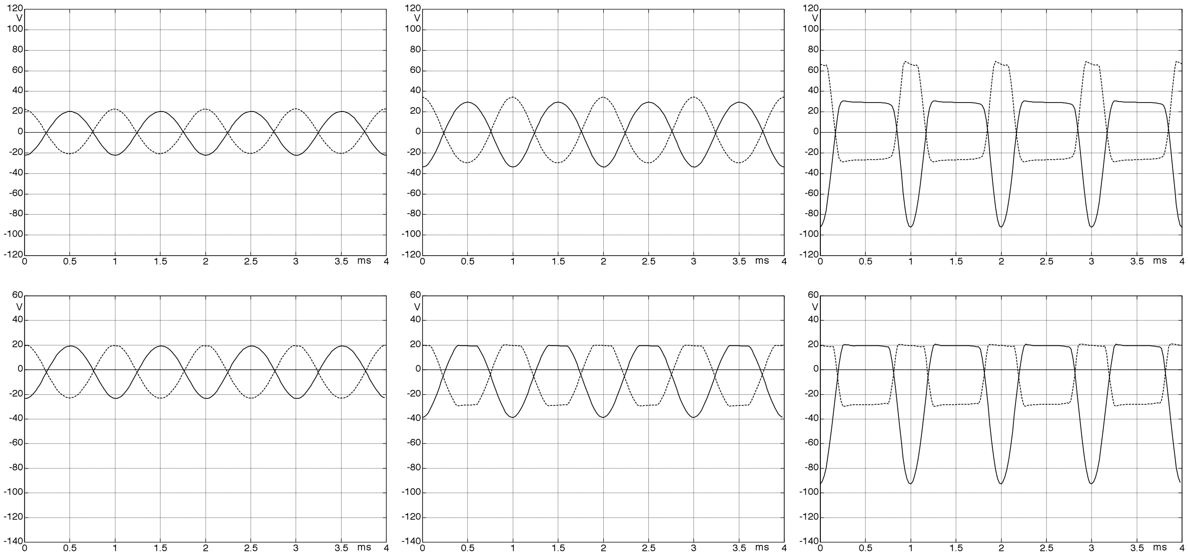

Fig. 10.4.4: Measurements on a paraphase stage **with** negative feedback: 1st tube (——), 2nd Tube (---).
Top: no grid-current limiting. Bottom; grid-current happening from 20 V. Supply-voltage for the triodes: 235 V.