10.4.3 Differential amplifier (long-tail)

This type of circuit unites two different basic tube-amplifier-concepts: the first tube works in a common-cathode configuration with current-based negative feedback; the second tube operates in common-grid configuration and is driven by the first tube via the cathode. In Fender-history, the differential amplifier represents the final step in series of developments: paraphase (1946 – 1951), paraphase with negative feedback (1951 – 1954), cathodyne (1955 – 1957), and differential amplifier (from 1956). Other manufacturers, such as e.g. VOX (1958) or Marshall (1962) that start amplifier production more than a decade later than Fender, use the differential amplifier right from the start.

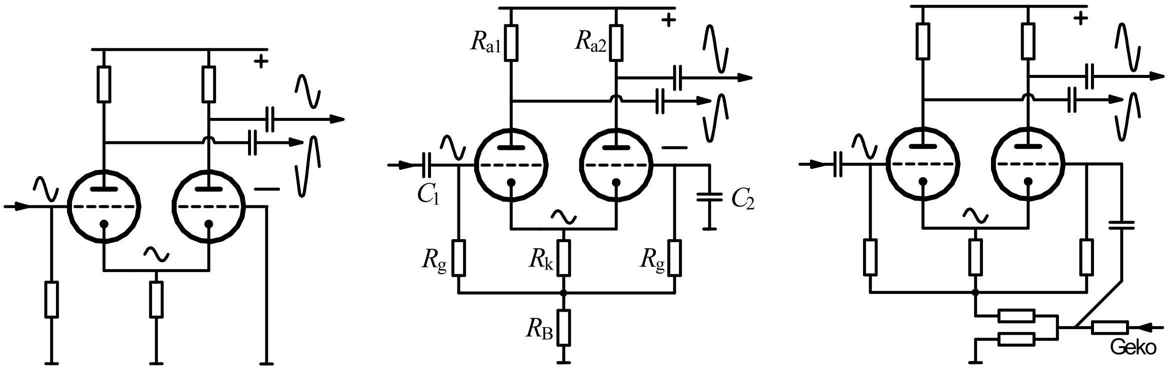

Fig. 10.4.8: Differential amplifier with negative feedback via the cathode (Geko = negative feedback).

The left section of **Fig. 10.4.8** shows the basic arrangement of the differential amplifier. Driving the left tube with an AC-voltage changes its plate- and cathode-currents and thus creates a voltage-drop at the plate- and cathode-resistors. The cathode-voltage of the left tube changes the drive-voltage of the right-hand tube, as well, and also here causes changes in the plate- and cathode-currents (common-grid-circuit). An **example**: if the grid-voltage (defined against ground) of the left tube rises by 2 mV, the cathode-voltage increases by 1 mV. Its grid-to-cathode-voltage therefore has increased by 1 mV while the grid-to-cathode-voltage of the right tube has decreased by 1 mV. For identical transconductances of the tubes, the result would be plate-voltages of the same amplitude but opposite phase. Text-books like to use this example – but it does have a flaw: the sum of the *changes* of the plate-currents would be zero, and the cathode-potential would remain constant, i.e the right tube would not receive a drive signal. We can introduce a small correction to make the example work: the left grid-potential rises by 3 mV, the cathode-potential by 1 mV, the plate-voltages are of opposite phase … but not of the same amplitude anymore! Given typical component values, the AC-voltage-gain of the right tube would be only about half of that of the left tube, plus it would be rather strongly dependent on individual tube data. For this reason, the cathode-resistor is increased. This reduces the gain of the two tubes, but also the dependency on the individual tube (current-based negative feedback). The middle section in Fig. 10.4.8 shows such a circuit (VOX AC-30), the right-hand section also presents an input for a negative-feedback (NFB) loop that would be closed via a line from the output transformer (Marshall, Fender from 1956).

For the typical tube for the differential amplifier, Fender uses the **12AX7** (7025, ECC83) first but then changes (in the Blackface era) to the lower-impedance **12AT7** (ECC81). VOX uses the ECC83 (12AX7); Marshall does, as well.

DATA-SHEET SPECIFICATIONS: Internal impedance = 30 kΩ (ECC81) and 63 kΩ (ECC83).

 Translated by Tilmann Zwicker

An exact analysis of the differential-amplifier circuit shows that the voltage gains of the two tubes are different, despite the negative feedback. In a typical Fender configuration (Pro Amp AA763: R_a = 100 kΩ, R_g = 1 MΩ, R_k = 470 Ω, R_B = 27 kΩ), this difference is about 7%. It is likely that for this reason one of the plate-resistors (R_{a1}) was changed to 82 kΩ in a later model (Pro Reverb AA 165). For the following variant (AB 668), the plate-resistors are again equal in value but have merely 47 kΩ – and this arrangement remains for some time. VOX uses two resistors of equal value (and completely dispenses with any overall negative feedback!), while Marshall mostly employs the 82k/100k-pairing, and a frequency-dependent overall negative feedback.

The grid-resistor R_g of the first tube usually has 1 MΩ; this value was probably also seen as the input impedance. With a 10-nF-coupling-capacitor (e.g. Fender Twin 5F8A), a high-pass cutoff-frequency of 8 Hz would result – that is very low for a guitar amp but certainly compatible with the HiFi-preachings of the day. The negative feedback (R_B), however, does not only decrease the voltage gain, but it also increases the input impedance (bootstrap) from 1 MΩ to 2 MΩ, pushing the cutoff-frequency to a subsonic 4 Hz. That would more than suffice even for a bass amplifier, and indeed the 5F6-Bassman includes the 20-nF-coupling-capacitor, as well. But: a few years later the 6G6-B-Bassman receives a coupling-capacitor of a mere 500 pF! The calculation would yield a high 160 Hz as the lower cutoff-frequency, but we must not overlook that a second negative feedback loop is operating besides the feedback via the cathode. This complicates the calculation because further phase-shifting RC-circuits are in the game, and in particular the output transformer requires consideration. We had only the schematic of the 6G6-B-Bassman and no original amplifier at our disposal so no quantitative elaborations shall be included here. Just this general statement: Fender used very different capacitances (250 pF – 20 nF) for the input capacitor (C_1) of the differential amplifier; the actual high-pass cutoff-frequencies of these different circuits should be measured and not just calculated from the schematics. By the way: C_1 is 47 nF in the AC-30 and 22 nF in the Marshall.

In **Fig. 10.4.9**, the grid-voltages of a Fender Super-Reverb are shown for three different drive levels. For a small drive level, the two signals show minor differences in their amplitudes but at high drive levels there is a significant asymmetry. We could ignore the differences in the limiting towards negative voltages because the respective output tube will be in cut-off state anyway; however, due to the differences in the DC-component in the two drive-signals the two coupling-capacitors are polarized differently, leading to different duty-cycles in the plate-currents of the power amplifier. In Chapter 10.4.4, we will take an in-depth look at this asymmetry caused by the grid-current.

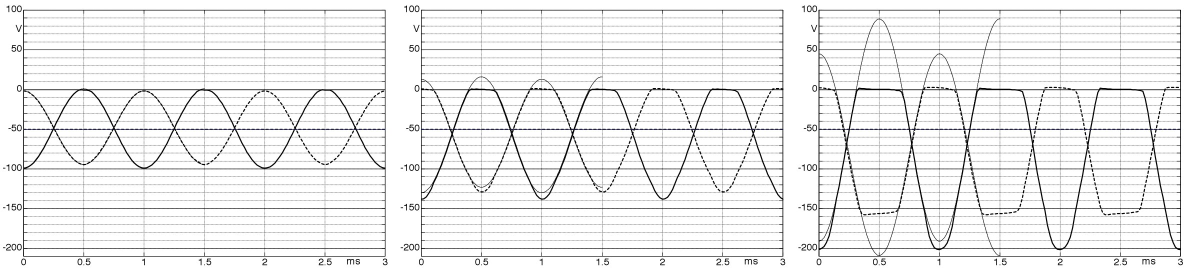

Fig. 10.4.9: Measurements at the differential amp of a Fender Super-Reverb (AB-763, negative feedback deactivated). Power-tube bias = –50V. Grid-voltage of the 1st power tube (V7 = ——), and of the 2nd power tube (V8 = ----). On the left, undistorted cosine-oscillations are shown for comparison.