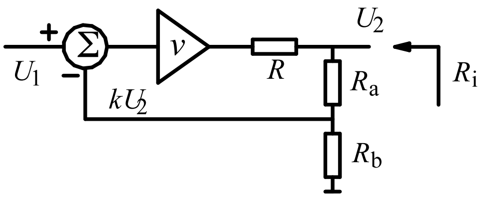
10.5.6 Negative feedback

We talk about **feedback** if a part of the output signal of an amplifier is channeled back to the input and superimposed there onto the input signal. Same-phase feedback is termed **positive feedback** while the designation of opposite-phase feedback is **negative feedback** (sometimes abbreviated with NFB in the following). Since there are two output signals (current and voltage), and correspondingly two input signals, four different ways of negative feedback may be defined. In a typical guitar-amp power-stage we predominantly find negative feedback of the voltage-voltage kind: a percentage of the output *voltage* is fed back and superimposed on the input *voltage*. This superposition results in a **control circuit**: as the output voltage decreases (e.g. due to loading), less voltage is fed back – resulting in more gain so that the voltage loss is partially compensated. This special negative feedback (termed g_{21}-negative-feedback in circuit-design) stabilizes the voltage-gain factor and reduces the linear internal impedance♣, and also broadens the small-signal-bandwidth, and reduces harmonic distortion.



$$R_i = (R_a + R_b) \,//\, R_{gk}\,, \quad R_{gk} = R/(1+kv)$$

$$v_U = U_2 / U_1 = \frac{v}{1 + kv + R/R_L}$$

Fig. 10.5.15: Basic schematic of a feedback loop (left). For positive gain v, negative feedback results. The most important values are the internal impedance R_i and the voltage-gain-factor v_U.

In **Fig. 10.5.15**, k determines the degree of the negative feedback i.e. its effectiveness. For k = 0, the negative feedback is without effect; with rising k, the effect of the negative feedback increases. R represents the internal impedance of the power stage without feedback; in tube amplifiers, this is considerably larger than the load impedance. The **Fender Super Reverb**, for example, reveals $R_i = R = 180\ \Omega$, and $v = 160$; with a load of 8 Ω[1] (R_L) the voltage gain will be $v_U = 6.8$. The factory-set negative feedback is $k = 0.056$; with it R drops to $R_i = 18\ \Omega$, and the gain to $v_U = 4.9$ (measurement: **Fig. 10.5.16**). The low-frequency range reveals an interesting twist: due to phase-shifts, a positive feedback comes into play here! Enlarging the input capacitor of the differential amplifier (from 1 nF to e.g. 100 nF) will, however, keep the output impedance in the low-frequency region (with NFB) almost constant (Chapter 10.4.3).

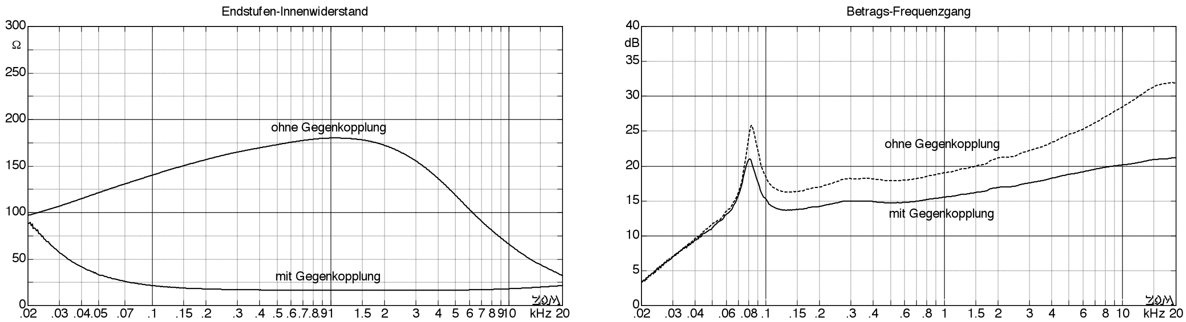


Fig. 10.5.16: Left = magnitude of the output impedance. Right = frequency-response, from the input of the differential amplifier (ahead of the 1-nF-capacitor) to the loudspeaker (4xP10-R).
"Endstufen-Innenwiderstand" = power stage impedance; "Betrags-Frequenzgang" = magnitude frequ. fesponse;
"ohne Gegenkopplung" = without NFB; "mit Gegenkopplung" = with NFB.

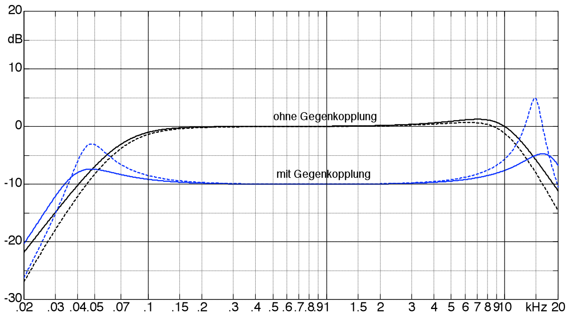
♣ For non-linear operation (overdrive), any negative feedback will loose its effect since the control value (here: output voltage) can practically not change anymore.

[1] Note that the Super-Reverb-specimen investigated here had an output transformer with not just the customary 2-Ω-output, but also an additional output for 8-Ω speaker-matching.

Not all power stages include negative feedback: the VOX AC-15 and AC-30 (and some others, too) completely dispense with any feedback. In Fender amps, the situation is mixed: very early power stages have no feedback, the Bassman 5B6 receives NFB around 1952, the Deluxe 5E3 only as late as 1955 [D. Funk]. The Bassman acquires special significance due to its Presence-control included in the negative-feedback circuit: it enables the frequency dependency of the feedback to be set by the user (Chapter 10.3.3). Legend has it that Jim Marshall and Ken Bran were particularly inspired by the late 1950's Fender Bassman when they developed their amps, and therefore we find a power stage with integrated presence potentiometer in Marshall amps, as well.

As early as 1943, Frederick Terman describes, in his remarkable "Radio Engineers' Handbook", the effects of power-stage feedback on gain, internal impedance, and harmonic distortion. The reduction in gain that accompanies negative feedback certainly was not an express objective of the circuit designers, but they put up with it in order to reduce the non-linear distortion of tubes and output transformers. In the 1950's, there was no Heavy-Metal music scene, and playing was mostly "civilized" i.e. undistorted. Presumably, the pioneering developers observed the output signal of their amplifiers with an oscilloscope, and tried to reproduce sine curves as perfectly as possible: "*by the book*", as D. Funk writes. The more negative feedback is introduced, the less an amplifier distorts – that's what the book said. It was also known that strong phase shifts may turn NFB into positive feedback – although not every designer would or could do much of the required calculating. In any case, the designer would soon discover that, with too strong a negative feedback, the amp would start to self-oscillate, and so the NFB was adjusted empirically to a degree that would avoid instability within the framework of the given manufacturing tolerances.

In **Fig. 10.5.17**, we see the frequency responses of a bandwidth-limited system: in the left-hand section for slightly different filter flanks, and with and without negative feedback. The more narrow-band system (dashed lines) does not only receive the expected gain-reduction but also considerable resonance peaks at the frequency limits. "Negative feedback" means superposition of an opposite-phase signal. However, the phase-shifts that live in every circuit with bandwidth-limiting will have the effect that around the band-limits, the opposite-phase correction-signal can turn into an (almost) same-phase positive-feedback-signal that increases gain. Increasing the gain in the forward branch (right-hand section of the figure) will disproportionally increase the overall gain (blue) in the fringe ranges. In fact, this may occur as an effect of just a tube change. The new power-stage tubes will generate a stronger bass response due to their slightly higher transconductance, and right away the test report in the music-mag will read: "the KT-X delivers more bass than the 6L-Y". This characteristic, however, needs to be always seen in connection with the specific individual circuit. Power tubes will transmit from 0 Hz to about 100 MHz – but only the teamwork also including transformer, speaker-load and NFB-network will result in the individual frequency response!



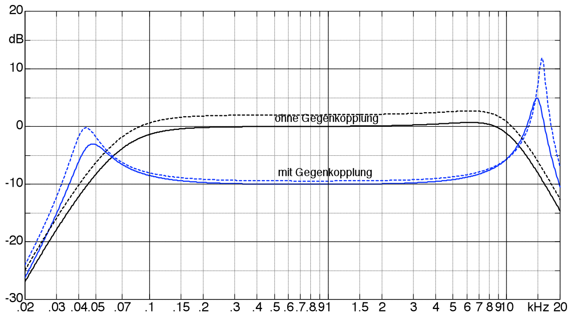


Fig. 10.5.17: Effects of negative feedback when a bandwidth-limitation is present. "Gegenkopplung" = NFB; "mit" = with; "ohne" = without.