10.5.14 Pentode/Triode/Ultralinear

Pentodes are at work in the power stage of a typical guitar amplifier: EL-34 in the Marshall, EL-84 in the VOX, 6L6-GC in the Fender; or comparable tubes (5881, KT-66, KT-88) – but always pentodes, and not triodes. That some of these tubes actually are beam-tetrodes shall not bother us here, because their beamforming plates are in fact some kind of fifth electrode, as well – even though differences to a true suppressor-grid remain if we apply strict theory. Since these differences are of no significance in the following, we will treat pentodes synonymously with beam-tetrodes.

In a triode, the drive-level-dependent plate-voltage accelerates the electrons, and therefore the gain of the tube is small for low plate-voltage. Conversely, the plate-voltage has only little influence on the emission-current in the pentode because the screen grid is on a high potential independently of the drive-level. The output characteristics of the pentode are therefore almost horizontal (except for the initial distribution area), and the internal impedance is larger compared to triodes. From an overall investigation of efficiency, internal impedance and harmonic distortion, HiFi-developers noticed that both pentode and triode were operating in a sub-optimal border range, and they looked for a compromise. The latter could be found in the **ultra-linear circuit**: here, the screen grid of the power tubes is connected neither to a constant potential (pentode operation) nor to plate potential (approximately corresponding to triode operation), but in between. Since all voltages between supply voltage and plate-voltage are available at the output transformer, it is merely necessary to include a suitable "tap" from the primary winding. This is why an ultra-linear output transformer does not have three but five connections on its primary side. The back-channeling of the signal to the screen grid (g_2) has the effect of a negative feedback that was seen as advantage in HiFi-amplifiers. It appears the same did not happen for guitar amps since only few experiments made the jump to production, such as the 1979 Twin Reverb, some Sunn-variants or – will wonders never cease! – the **200-Watt-Marshall**: yep, there's an ultra-linear power stage, designed for the least amount of distortion. Later, though, the JCM-800-series amps went after their business again without ultra-linearization.

Due to the reduction of the screen-grid-voltage, the obtainable maximum output power drops. This can be used to convert a 100-W-amp into a 50-W-amp. Two switches are installed at the screen grids such that either the full supply voltage or the plate-voltage is connected to the screen grids. Sure, it would also be possible to simply reduce the gain if it gets too loud, but power-stage distortion happens only when overdrive occurs. If the screen grids are connected to the (corresponding) plates, the power pentodes operate in a kind of **triode-mode**: with smaller maximum power, but also with smaller internal impedance. The switch from pentode- to triode-mode therefore does not only change the maximum power (loudness) but also the sound. The operation with high internal impedance emphasizes treble and speaker-resonances, and in the triode-mode the sound looses brilliance and volume. To which extent this is in fact audible depends on (besides the screen-grid-voltage) the negative feedback of the power stage. Changing the screen-grid-voltage implies changing the gain (i.e. the loop-gain) and therefore changing the negative-feedback-factor. It may consequently be that, besides the screen-grid-voltage, the NFB-loop needs to be switched as well. The pentode/triode-switch has no bearing on the **operating point** because at idle, the plate-voltage is almost the same as the supply voltage (the primary winding is of low-impedance of DC current).

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Fig. 10.5.80 shows an example for the difference between pentode and triode. An **EL34-power-stage** with Marshall-transformer (JTM-50) is operated with a stabilized voltage of 400 V, and a Marshall-Box 1960-AX as loudspeaker. First, the investigation targets the influence of the screen-grid resistor at 1.5 kΩ, 470 Ω, or 0 Ω. A small effect shows up with the gain: for R_{g2} = 0 Ω, the gain is 1.3 dB larger than for R_{g2} = 1.5 kΩ. The strain on the screen grid is heavily affected: with overdrive, the screen grid **glows** barely visibly♣ for R_{g2} = 1.5 kΩ, but lights up to **bright red** with R_{g2} = 470 Ω, and to **bright yellow** at R_{g2} = 0 Ω**!** In the interest of a long tube life, a sufficiently large R_{g2} should always be used. The flipside is that the power stage generates, with R_{g2} = 0 Ω, 1/3 more power compared to R_{g2} = 1.5 kΩ. Let's now look at the figure: the triode configuration reduces the internal impedance, which makes the gain drop in a particularly strong manner for a high-impedance load (Chapter 11.2). The gain is smaller by about 5 dB at 400 Hz in the triode-mode; in the figure, this was balanced out for small drive level (normalization to 400 Hz).

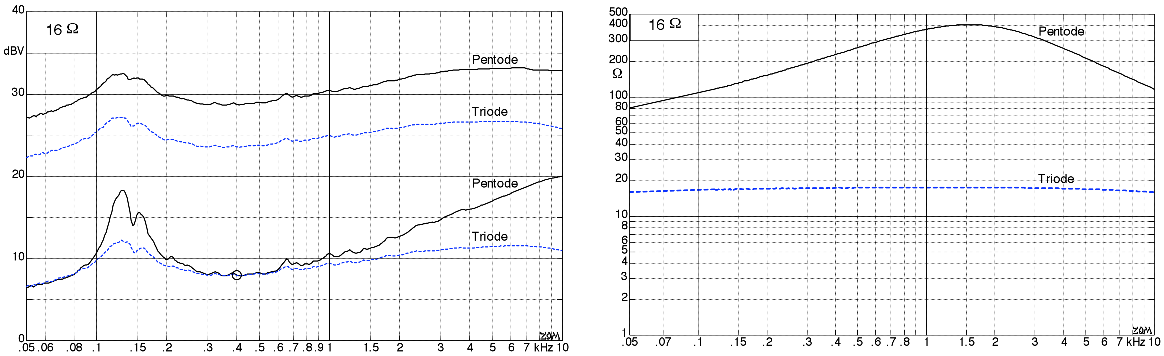

Fig. 10.5.80: Voltage transmission for pentode- and triode-operation of the power tubes (EL34, 1960AX).
The measurement curves at small drive level were normalized to 400 Hz; no normalization was done for high drive level. On the right the frequency responses of source-impedances of the power stage are shown (internal impedance at the output transformer). For all these measurements, the negative feedback was deactivated.

At small drive level (i.e. for linear operation), the power tubes are of high impedance (about 30 kΩ) in pentode-mode, and the source impedance measured at the output is co-determined by the output transformer. In triode-mode, the internal impedance of the tubes drops to about 1.2 kΩ: now, the source-impedance is predominantly determined by the internal impedance of the power tubes. As the power stage is driven to the extent that limiting occurs (measurement curves for high levels), we see the differences in maximum power output. On the other hand, the characteristics of the curves clearly become more similar. **Conclusion:** In triode-mode, brilliance and emphasis of the speaker-resonance drop for undistorted operation. The maximum power-output drops to about 1/3, and when overdrive occurs, the frequency responses become similar.

For the **power stage with active negative feedback**, the differences in the frequency responses is much smaller for linear operation while the differences in the maximum power output remain similar. It is well known that negative feedback has no effect on the maximum power yield: the non-linear distortion is reduced somewhat but the limit values of the tubes cannot by modified via NFB. However, even merely moderate NFB decreases the source impedance so strongly that differences in frequency response between triode- and pentode-mode become meaningless. **Simply put**: negative feedback transforms the power stage from a current source to a voltage source.

♣ As seen with the JJ-EL34; different strain-situations can occur with other tubes.

Fig. 10.5.81 shows how gain and source impedance are reduced by the negative feedback. The **NFB-factor** (= 1 + loop-gain) depends, for a tube amplifier, on the load (speaker impedance). Measurement and calculation (circles at 400 Hz) match very well. For an NFB-factor of 1, the power stage has no negative feedback, while an NFB-factor of 6.73 already represents a strong feedback for power stage based on tubes. The frequency characteristics of **pentode- and triode-mode** become very similar already for moderately strong NFB, and therefore in practice all that remains is a small difference in gain.

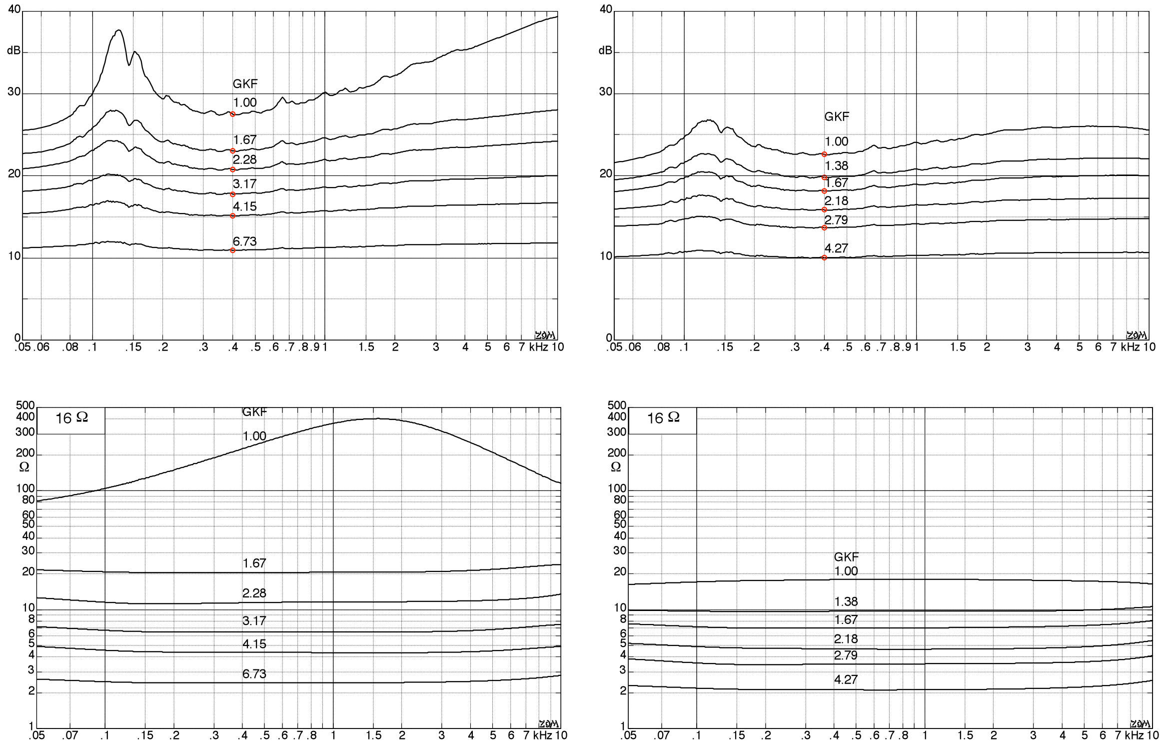

Fig. 10.5.81: Gain from the input of the phase-inverter to the output of the transformer (16 Ω, 1960AX).
Left: pentode-mode, right triode-mode. Lower line of pictures: source impedance; "GKF" = NFB-factor.

Besides the drop in output power and the change in frequency response, switching from pentode- to triode-mode brings a further consequence: the non-linear behavior changes. The triode-characteristic has multiple bends while the pentode characteristic is degressive. This has an effect on the **distortion-attenuation**: a reversal of the sign of the curvature (2nd derivative) leads to a zero in the harmonic distortion in triode-mode (**Fig. 10.5.82**).

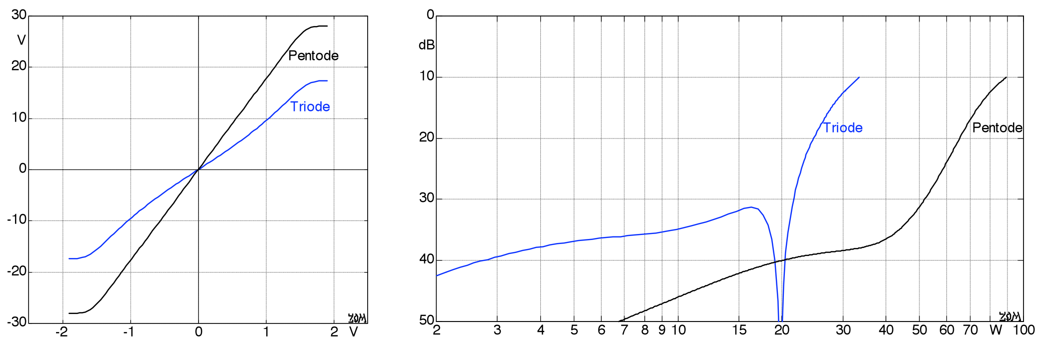

Fig. 10.5.82: Transmission characteristic (left), 3rd-order distortion attenuation (right). 2xEL34, nominal load (ohmic), no NFB. The exact curve depends on the individual tubes and on the bias-current.

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