10.6.2 Impedance-matching and transmission

Frequently, the term “impedance matching” is interpreted such that, for a maximum of power-yield, the source- and the load-impedances need to be equal (or conjugate). The datasheet of the power-tetrode 6L6-GC lists an internal impedance of 35 kΩ so that we could conclude that the primary impedance of the output transformer should also amount to 35 kΩ. At the same time, however, the datasheet specifies a so-called “optimum load impedance” at no more than 1.4 kΩ. What follows is this: the 6L6-GC is (like all tetrodes♣) a high impedance source and operates approximately as a current source. The power delivered by a current source is proportional to the load-impedance: the higher the latter the higher the power-yield. However, this simple relation is limited by three non-linear conditions: the maximum allowable plate-dissipation, the maximum allowable plate-voltage, and the residual voltage at the plate. The **optimum load-impedance** (= external impedance) results from these non-linear conditions, and not from the equality of internal- and load-impedance. It is sufficient, as a rule, to assume the internal impedance of the tube to be large relative to the load-impedance; the optimum load-impedance (per plate) for push-pull stages usually is about 1 – 2 kΩ.

The output transformer enlarges the secondary load-impedance (typically, this is the loudspeaker impedance) by the square of the turns-ratio, for example:

An 8-Ω-load-impedance is transformed – for $TR = 12$ – into 144 x 8 Ω = 1152 Ω.

Usually, there is no need to distinguish between the turns-ratio of the windings $TR = N_1/N_2$, and the transmission ratio TR_i in the equivalent circuit diagram, because in most cases the respective values differ by less than 1% (Fig. 10.6.3). The internal impedance R_i of the tube is transformed with TR^2, as well: the internal impedance of the replacement source driving the loudspeaker amounts to R_i / TR^2 (in the example 35 kΩ / 144 = 243 Ω). As long as the power stage is not overdriven, it will operate the loudspeaker approximately as a **stiff current-source** – if the power stage does not involve **negative feedback** (NFB). The voltage/voltage-NFB implemented in many amplifiers reduces the internal impedance of the power amplifier. Still, perfect behavior as a stiff voltage-source is not accomplished by tube power-amps (however, most transistor power-amplifiers will achieve this – but they are not a object of the present investigations).

Fig. 10.6.5 shows the family of output characteristics for a power-pentode known from Chapter 10.5, plus some load-dependent transmission characteristics. Given the secondary impedance (e.g. 8 Ω), the slope of the operating characteristic may be changed as needed.

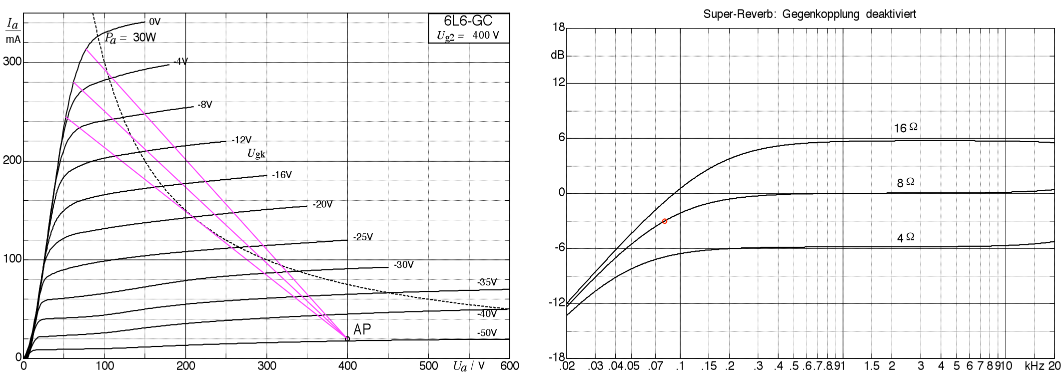

Abb. 10.6.5: Transmission characteristics (left), frequency-response at the 8-Ω-output for a load of 4/8/16 Ω.

♣ As far as they are not operated in triode-mode (triode-mode: g2 and plate are directly connected).

It may be matched to the family of characteristics discretionarily by varying the transmission ratio (*TR*): a larger *TR* results in a flatter curve for the load-line i.e. a smaller plate-current and a larger voltage swing.

The internal impedance of the tube transformed via TR^2 is, however, not the source impedance relevant for the loudspeaker across the whole frequency range. The equivalent circuit diagram presented in Fig. 10.6.2 shows that the parallel inductance L_1 determines the impedance at low frequencies: it shorts the source for low frequencies and has the effect of a **high-pass**. Moreover, we need to consider that this inductance is **non-linear**, and therefore we do not have a conventional high-pass here (Chapter 10.6.4). The transmission curves given in Fig. 10.6.4 involve a demagnetized transformer core; however, this can be achieved only at untypically small drive-levels of **about 1 μW**. Nobody will play a 45-W-amp at such a small power level – the tube amp will not be able to shape the sound in the way for which it is designed. Still, the curves shown in Fig. 10.6.5 had to be measured approximately at this power level, otherwise the main inductance L_1 would have become dependent on drive-level in a rather unbecoming way. The small-signal ECD so popular in communication engineering it in a bit of trouble due to this, but it can be rescued by a special modeling at low frequencies (Chapter 10.6.4). Basically, the parallel inductance looses its impact with rising frequency, and the transmission becomes frequency-independent (for an ohmic load). At very high frequencies (that can however barely, if at all, be reproduced by a typical guitar-loudspeaker), the incomplete field-coupling and the winding-capacitances may start to have an effect – but in all likelihood this will not be dramatic or noticeable at all.

Power amplifiers are always specified for a real (ohmic) **nominal load-impedance** although the impedance of a loudspeaker is always dependent on frequency. For this reason, **Fig. 10.6.6** depicts transmission frequency responses for loading with a loudspeaker; the mapping of the frequency-dependent loudspeaker impedance onto the frequency response is clearly visible. The power stage of a Super-Reverb normally has negative feedback but for these measurements it was deactivated – otherwise the characteristics of the output transformer would have been suppressed too much (operation with negative feedback: Chapter 10.5). The operation with a loudspeaker results in a treble boost (voice-coil inductance), and between 10 and 100 Hz we observe a narrow-band boost due to the loudspeaker resonance. For both operational states, attenuation shows up in the bass range for very small drive-levels ($P <$ 1mW): this is due to the main inductance (see also Chapter 10.6.4).

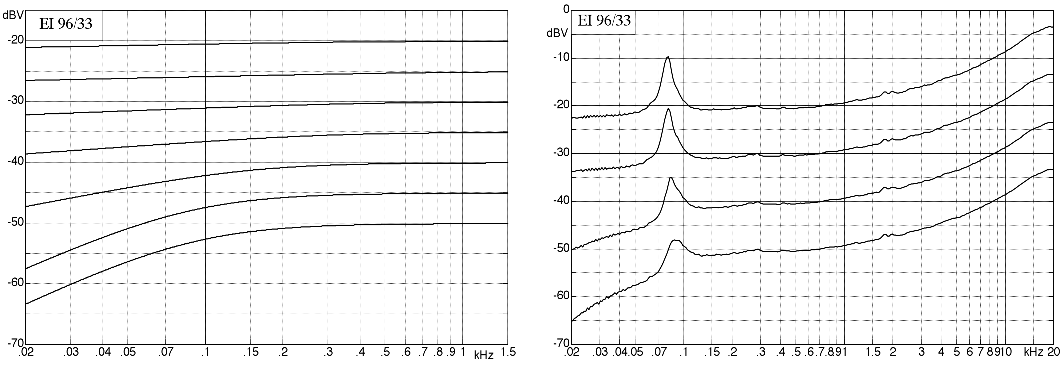

Fig. 10.6.6: Transmission frequency response; transformer with a secondary load of 8 Ω (left), and loaded with a real loudspeaker (right). NFB deactivated. 8-Ω-load yields a voltage level of –20 dBV ⇒ $P = 1.25$ mW.

