10.5.2 Push-pull class-A operation

The single-ended power stage introduced in Chapter 10.5.1 turned out to be relatively weak in terms of power delivery: With a 12-W-tube we could get at most 6 W output power from it. For a greater output power more powerful tubes would be available, but then there is another disadvantage of the single-ended circuit: even without any drive signal, a relatively strong DC-current runs through the output transformer, and the latter needs to operate under unfavorable conditions due to the resulting DC-**pre-magnetization**. We could insert an air gap into the iron core of the transformer and reduce the DC-field dependency of the reversible permeability – but then we would in total reduce this permeability to a value smaller than the one for the core without air gap. Moreover we need to consider that the load on the power supply is independent of the drive levels for the single-ended class-A power stage. In other words, even at rest, the power supply experiences maximum load, and therefore the supply voltage is not constant but oscillates around a mean value with a frequency of 100 Hz (given a two-way rectifier). This AC-component generates an AC-current through the output transformer, the output tube being of high impedance but still no ideal current source. The result is an undesirable interference tone at 100 Hz or 120 Hz (depending on the local power).

Using a push-pull class-A circuit (**Fig. 10.5.8**), some of the disadvantages of the single-ended class-A circuit can be avoided. The term "push-pull" is derived from the opposite-phase grid-drive of the two output tubes. The rising grid-voltage at one tube increases its plate-current while at the same time the decreasing grid-voltage at the other tube reduces the plate-current there. Ideally, the former plate-current increases by the same ΔI that the latter plate-current decreases by; the sum of the currents sourced from the power supply $I_=$ remains constant (DC current), independently of the drive levels. At rest, this DC-current splits up into the two plate-currents of equal strength that each generates a magnetic DC-field in the transformer core. Since the two DC-fields have opposite directions, they compensate each other within the core, and the latter remains field-free (without pre-magnetization). No **air gap** is necessary. A corresponding compensation also happens for the residual ripple in the supply voltage: the 100-Hz AC-current generated by it causes opposite-phase AC-fields that cancel each other out, and cannot result in **hum in the loudspeaker**.

An entirely different situation exists for the AC-currents at the plate that are created by the opposite-phase **grid-drive**: they are, in terms of the reference-arrows defined in Fig. 10.5.8, of opposite phase, but therefore correspond in-phase to the primary AC-current (defined in *one and the same* direction): $I_{aa} = I_{a1\approx} = -I_{a2\approx}$. The equality of these two AC-currents also results from the power supply (ideally) delivering pure DC: if no AC-current is leaving the winding at the tap of the primary winding, both primary AC-currents need to be equal. Assuming an ideal transformer with identical primary windings, the total primary voltage will be double the AC voltages at the plate; the two tubes thus operate *in series*.

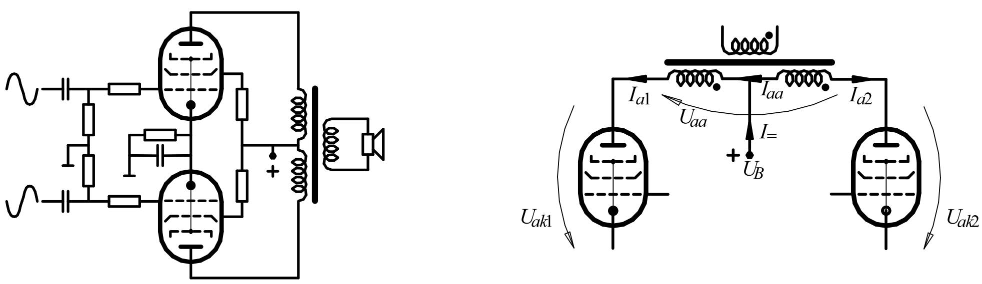

Fig. 10.5.8: Push-pull class-A power stage; on the right, the phases of currents and voltages are illustrated.

In **Fig. 10.5.9** we see the idealized voltages and currents relating to Fig. 10.5.8. Each individual tube operates in single-ended class-A mode with the operating point located in the middle of the useable load line (Chapter 10.5.1). The two tubes are driven by opposite-phase signals. With the reference-arrows defined according to Fig. 10.5.8, both the AC-voltages at the plate and the AC-currents at the plate are of opposite phase, as well. The (overall) primary voltage U_{aa} is the difference between these opposite-phase AC-voltages $U_{aa} = U_{ak2} - U_{ak1}$, and the AC-current flowing through both primary windings is $I_{aa} = I_{a1\approx} = -I_{a2\approx}$.

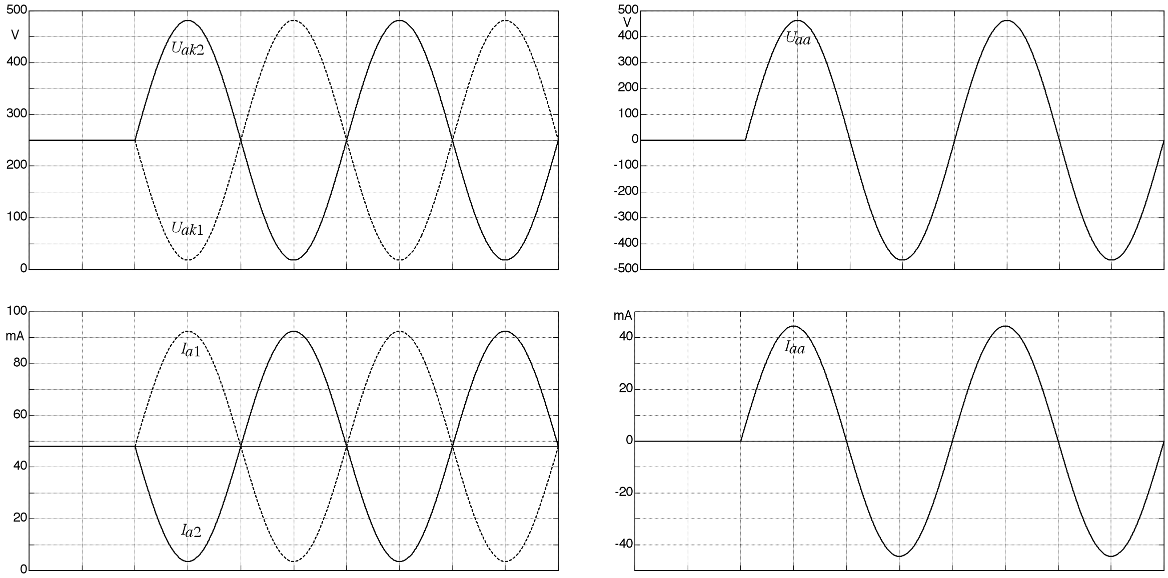

Fig. 10.5.9: Voltages and currents of the individual tubes (left); primary AC-voltage and -current (right)

If we neglect the residual plate-voltage (for $U_{g1} = 0$) and assume an ideal output transformer, the obtainable **effective power** corresponds to the maximum power dissipation in one tube; two EL84 will thus yield 12 W at the most (and in the ideal case). In practice (i.e. considering residual voltage and transformer losses), about 10 W may be expected. Ideally, the power taken from the power supply is independent of the drive level and corresponds to the maximum dissipation of both power tubes – for 2 x EL84 that would be 24 W due to the plate-currents, plus about 2.8 W screen-grid dissipation, plus about 0.8 W dissipation in the joint cathode resistor. This resistor should be chosen such that in idle the cathode-current (0.11 A in this example) generates just the required grid-bias (7.3 V).

The optimum load-impedance at the plate, and with it the transformation ratio of the transformer, is to be derived from the gradient of the load line, just as it would have to be for a single-ended class-A amplifier. For both the latter and the push-pull class-A amp, every tube needs to "see" the same load impedance R_{opt}. When designing the push-pull class-A amplifier, consideration needs to be given to the fact that both (half) primary windings "see" two load impedances: the secondary winding as passive load, and the other (half) primary winding as **active load**! For this reason, the load of the individual tube in the push-pull class-A circuit may not be simply calculated from the transformation ratio (**impedance paradox**, Chapter 10.5.5)! If the transformation ratio for a single-ended class-A amplifier is e.g. $N_p : N_s = 24 : 1$, it will be $N_{p1} : N_{p2} : N_s = 17 : 17 : 1$ for the push-pull class-A amp (given otherwise equal conditions). The datasheet specifies an optimum load-impedance at the plate of $R_{opt} = 5.2$ kΩ for single-ended class-A operation of an EL84-amplifier with $U_B = 250$ V, and thus the (overall) primary impedance for the push-pull class-A amp amounts to $R_{aa} = 10.4$ kΩ.

Examples for specific amplifiers are presented at the end of the chapter.