10.5.5 The impedance-paradox

The output transformer matches the low-impedance loudspeaker (e.g. 8 Ω) to the higher-impedance tube circuitry. For push-pull circuits, this transformer has *two* serially connected primary windings. Could you say what the input impedance of these two windings is? Let's take as an example turns-ratios of 10:10:1, and 8Ω as secondary load: for the ideal transformer the input impedance of the whole primary winding is $R_{aa} = 20^2 \cdot 8\ \Omega = \boldsymbol{R_{aa} = 3200\ \Omega}$. Is now the input impedance of one of the two windings half of this value i.e. **1600 Ω**? For the push-pull class-A operation, we assume as much because here the same AC-current flows through both primary windings. However: calculating the impedance transformation for half the primary winding, we get: $R_a = 10^2 \cdot 8\ \Omega = \mathbf{800\ \Omega}$. What is the correct value?

The push-pull transformer is a **three-port network** i.e. a system with three pairs of connections. The two primary ports are connected in series so that overall only 5 connecting points show. To calculate the input impedance of one port, the two other ports need to be considered as loads. If we connect only *one* 8-Ω-load resistor to the secondary winding, and leave the one primary winding open, we will measure 800 Ω at the remaining other primary winding. This is because the transformer does now operate merely as a two-port network (= quadripole). However, if we connect *both* primary windings – as it is done for the push-pull class-A operation, then each primary winding "sees" *two* load impedances: the secondary load, and the other primary winding.

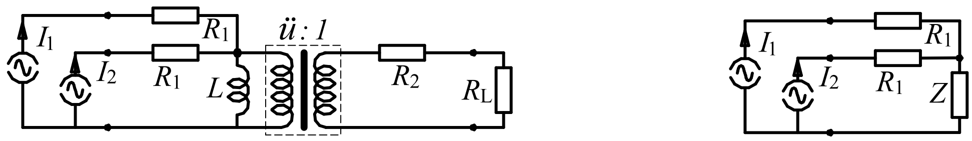

Fig. 10.5.14: The rigidly-coupled output transformer as three-port. Right: simplified circuitry; *ü* = *TR*.

Fig. 10.5.14 shows a simplified equivalent circuit of a transformer. R_1 and R_2 are the resistances of the windings, R_L is the secondary load resistance, L stands of the main inductance. In the middle frequency range the effect of the main inductance may be neglected, and the secondary resistances can be transformed via $(TR)^2$ into the equivalent impedance Z. The equivalent circuit given in the right-hand section of the figure can now easily be calculated:

$$Z_1 = R_1 + \left(1 + I_2 / I_1\right) \cdot Z \qquad\qquad Z_2 = R_1 + \left(1 + I_1 / I_2\right) \cdot Z$$

It is clear that for $I_2 = -I_1$ the input impedance becomes independent of Z (or rather of R_L), because here the voltage across Z approaches zero. In a push-pull class-A power stage, however, the two currents are in opposite phase (and ideally also equal in their magnitude) so that the input impedance is increased. Neglecting R_1, the input impedance doubles as we bring the second primary winding into the circuitry.

Let us include some numbers into the above **example**:
In the **push-pull class-A power stage**, the input impedance of (half of) the primary winding is half of the input impedance R_{aa} of the total primary winding, i.e. 1600 Ω. In contrast, only one winding is active at any given time in the push-pull class-B power stage: when one of the tubes is conducting, the other blocks. Therefore, in this case the input impedance of (half of) the primary winding is only a quarter of R_{aa}, i.e. 800 Ω. The impedance R_{aa} does not appear physically in the push-pull class-B power stage; it remains a pure calculation value.

