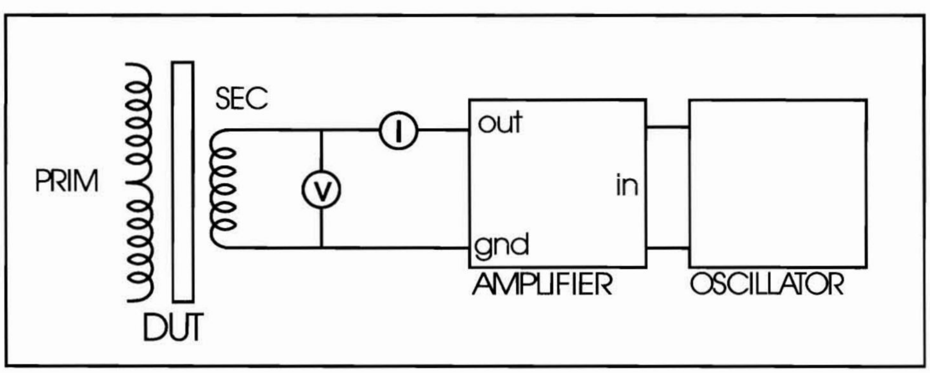
7 Output Transformer Low-Frequency Tuning

The previous chapters show how the frequency range of the amplifier is determined by the close interaction of the power valves, the output transformer and the loudspeaker load. This chapter addresses the low-frequency behaviour of a valve amplifier. We study the influence of the primary-winding inductance of the output transformer on the bass response, and we look at how to achieve optimum low frequency coupling between the power valves, the output transformer and the loudspeaker. We also consider how to minimize low frequency distortion.

7.1 Measuring the primary inductance

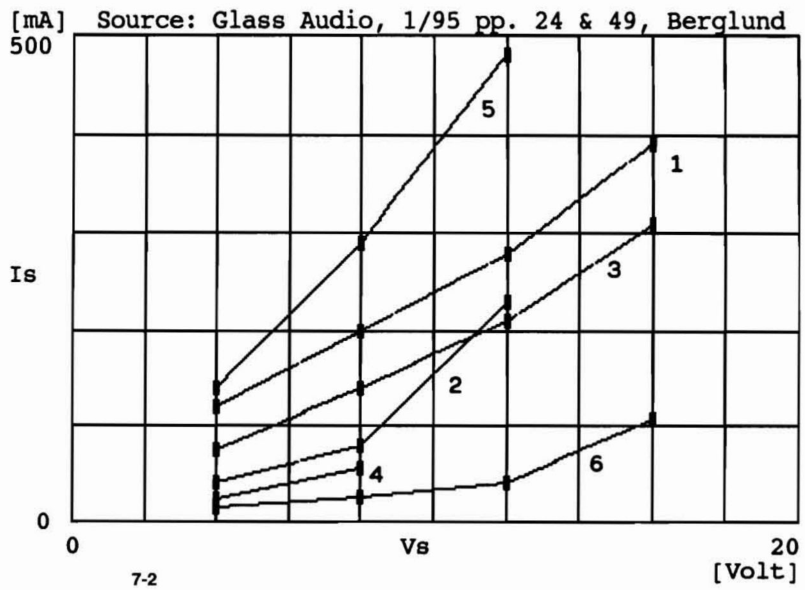
The value of the primary inductance L_p of an output transformer is not constant. It depends on the frequency and the voltage of the signal applied to the primary winding. This varying inductance affects the response of the amplifier. To study this, we start with measuring the primary inductance.

Figure 7.1 shows the measurement setup. We measure the secondary inductance, which can be converted into the primary inductance by using the square of the transformer turns ratio A sine wave oscillator is used to make the measurement, along with a good amplifier having a large damping factor.



◀ ***Figure 7.1*** *Measurement setup for L_p.*

A sine wave voltage at a frequency of 20 or 25 Hz is connected to the secondary winding of the transformer. The voltage across the secondary is measured, together with the current that flows in the secondary. There is no load on the primary side of the transformer. Be very careful not to touch the primary leads during the measurement, since they can carry a high voltage! The measurement results are shown in Figure 7.2 for several different output transformers (see Table 7.1 for the associated model numberss).



▲ ***Figure 7.2***
Measurement results for several models of output transformers (see Table 7.1).

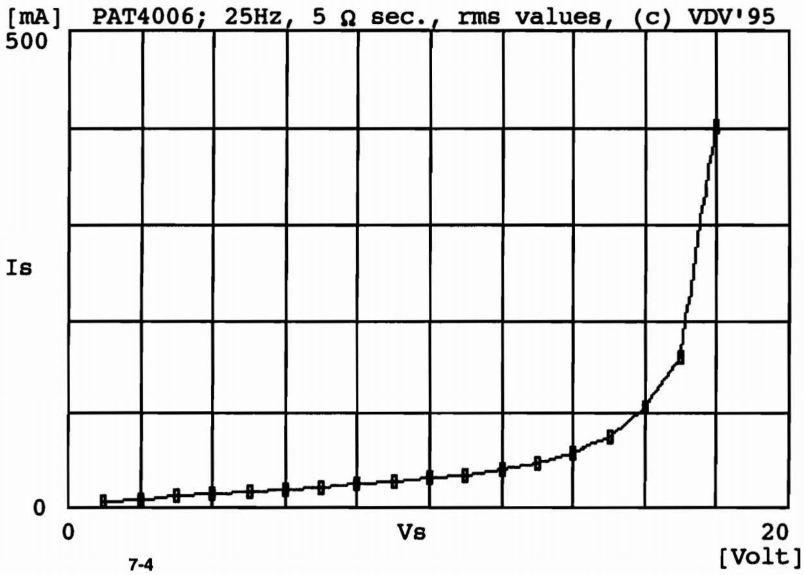
No.	Model	
1	Copland	—
2	Dynaco	ST70
3	Dynaco	MK III
4	Luxman	MQ-360
5	Luxman	MQ-80
6	VDV2100 (PAT4006)	

▲ ***Table 7.1***
Output transformer model numbers.

Measurements 1 through 5 were made with a 25 Hz test voltage connected to the 8 Ω secondary taps. Measurement 6 was performed with a 20 Hz test voltage connected to the 5 Ω secondary taps. The lower frequency compensates for the lower secondary impedance, so that the core loading is equal for all measurements.

Figure 7.2 clearly shows that the various sample transformers behave differently. The reason lies in their construction and the materials used. The samples with the lowest currents have the highest inductances. The linearity of the i_S–v_S curves can be estimated by comparing each characteristic curve to a straight line. However, since the currents were measured for only four test voltages, it is not that easy to check the linearity. For that reason, sample 6 was also measured at several additional secondary voltages. Figure 7.3 shows the results.

Figure 7.3 clearly shows that the i_S–v_S characteristic looks like a straight line over most of the measurement range. An old adage regarding output transformers is that

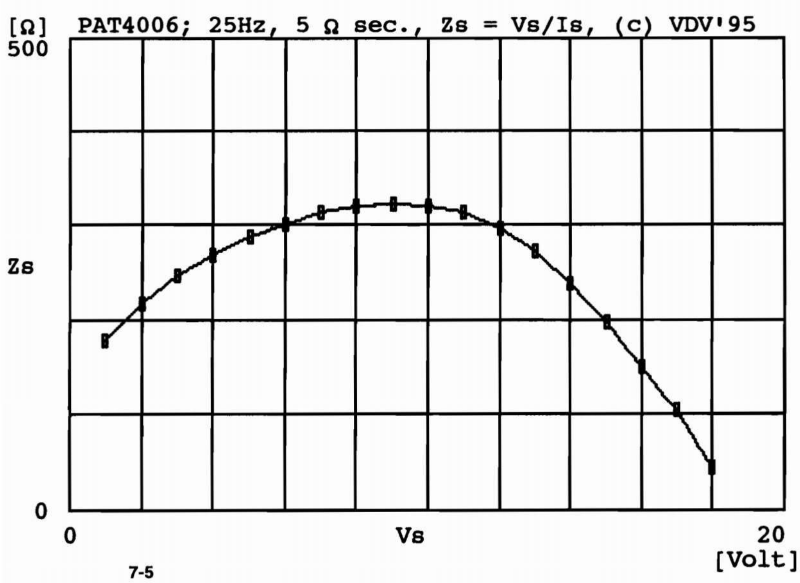


◀ *Figure 7.3*
Detailed measurement results for sample transformer 6.

the transformer with the highest and most nearly constant primary inductance will have the best bass performance.

Sample 6 seems to best meet this criterion. However, we can more precisely investigate its linearity. If the i_S–v_S characteristic is absolutely linear, then the ratio of v_S to i_S will be the same for each measurement point in Figure 7.3. Figure 7.4 shows the calculated values of Z_S (= v_S/i_S), plotted as a function of v_S.

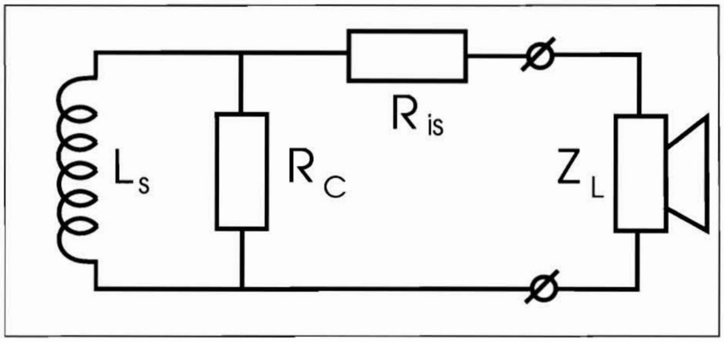
The secondary impedance is large, but it shows a clear variation. The curve plotted in Figure 7.4 is not a straight horizontal line, so the i_S–v_S characteristic is not absolutely linear. This shows that the best way to test the linearity of an i_S–v_S characteristic is to plot the calculated value of the secondary impedance Z_S versus v_S.



◀ *Figure 7.4*
Secondary impedance Z_S as function of v_S.

7.2 Calculating the primary inductance

What causes the nonlinearity seen in the measurement results shown in Figure 7.2? To answer this question, we must investigate the behaviour of the core. The measurements suggest that some effect in the core causes a deviation from linearity. We can start investigating this effect by examining the low-frequency equivalent circuit of the output transformer, as seen from its secondary side (see Figure 7.5).



▲ ***Figure 7.5***
Low-frequency equivalent circuit on the secondary side of the transformer.

In Figure 7.5, R_{is} is the resistance of the secondary winding. R_c represents the core losses due to hysteresis and eddy currents in the core. The third element is the secondary inductance L_s. For a simple but adequate explanation we can disregard the effects of core losses, since they only become important at high output levels where the transformer approaches core saturation. If we keep to moderate power levels, R_c in Figure 7.5 can be ignored.

The relationship between v_s and i_s at a frequency f is given by Formula 7-1:

$$\frac{v_s}{i_s} = R_{is} + j2\pi f L_s \qquad \text{where } j = \sqrt{-1} \text{ and } \pi = 3.14\ldots \qquad [7\text{-}1]$$

The imaginary unit j can be eliminated by calculating the magnitude of v_s/i_s and then finding the value of L_s. Formula 7-2 shows how to do this:

$$\left|\frac{v_s}{i_s}\right| = \sqrt{R_{is}{}^2 + (2\pi f L_s)^2} \qquad [7\text{-}2a]$$

$$L_s = \frac{1}{2\pi f} \cdot \sqrt{\left(\frac{v_s}{i_s}\right)^2 - (R_{is})^2} \qquad [7\text{-}2b]$$

The value of R_{is} can be directly measured. Since we know π, f and the values of v_s and i_s for each measurement point, we can calculate the secondary inductance L_s at each point. The results are shown in Figure 7.6. Figure 7.7 shows the inductance on the primary side, calculated as $L_p = L_s(N_p/N_s)^2$, where N_p and N_s are the number of primary and secondary turns, respectively.

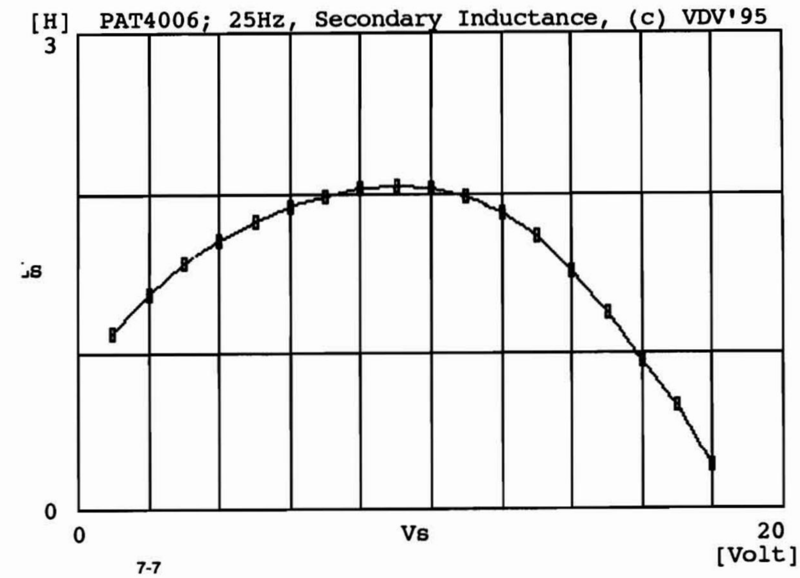


Figure 7.6
Secondary inductance as a function of v_S.

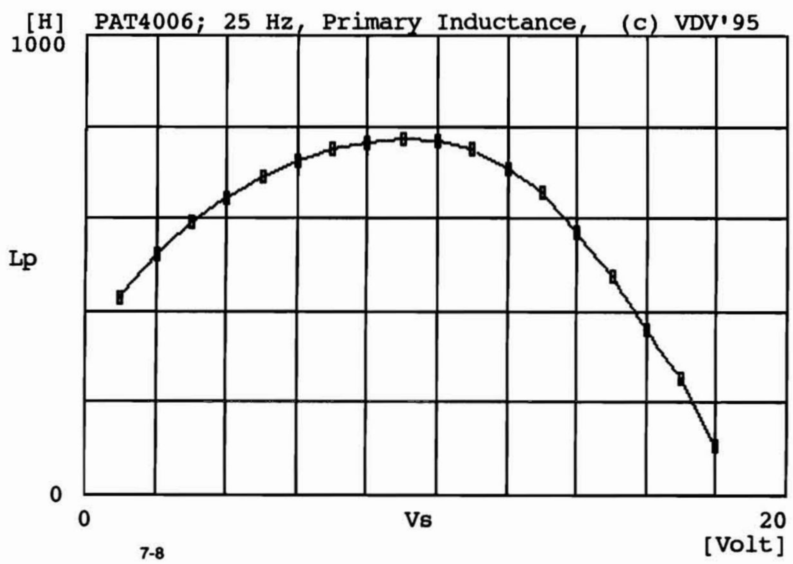


Figure 7.7
Primary inductance as a function of v_S.

These calculations clearly show that L_s is not constant. Since the value of R_{is} is very small (0.18 Ω), the L_s curve behaves identically to the v_s/i_s curve. We can now pose a more precise question regarding the cause of these variations in L_s.

7.3 Exploring the core

When a current passes through a winding around a core it creates a magnetic field, and the magnetic field tends to cause the particles in the core (and groups of particles, called *Weiss groups*) to move and rotate (this effect is called *magnetostriction*).The more easily this can happen, the stronger is the magnetic field generated in the core, since the strength of the field depends on the extent to which the Weiss groups are aligned to the magnetic field lines. The mobility of the Weiss groups