Single Ended Load Lines: A Simple Explanation

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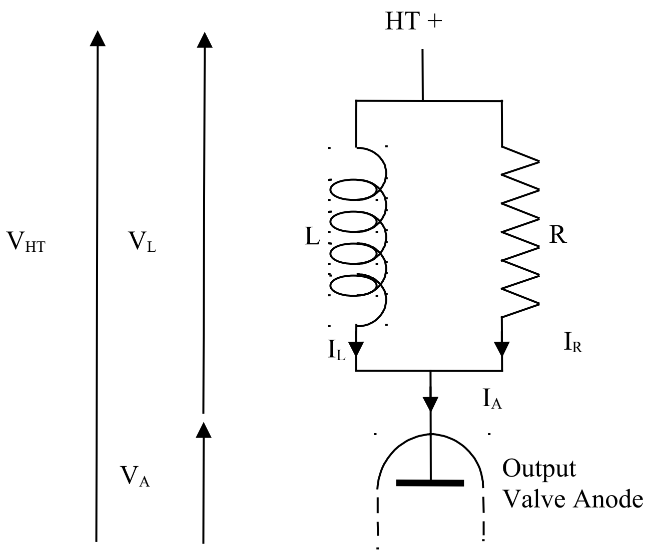
Introduction

Load lines for single-ended output stages (with transformer load) are slightly more difficult to understand than resistive load lines. This article attempts to explain what is going on, using a simple circuit model. Reference [1] gives an excellent explanation of how to create and use load lines for single ended output stage design.

Circuit Model

The circuit model, shown in figure 1, replaces the transformer and speaker load at the anode of the single-ended (class A) output stage by a simplified equivalent model.



(all voltages are relative to ground)

Figure 1: Approximate Equivalent Circuit Model

In the circuit model, R represents the impedance of the loudspeaker referred to the primary side of the output transformer. For the sake of simplicity we will assume a purely resistive speaker load. R is then the speaker impedance multiplied by the square of the transformer turns-ratio. The inductance L represents the magnetising inductance of the transformer (a very high inductance). The voltages shown in the figure represent the HT voltage (V_{HT}), voltage across the inductance and the resistance (V_L), and the anode voltage of the output valve (V_A).

Discussion of Circuit Model Behaviour

The equation for inductance is: $v = L\,\dot{i}$

where v is the voltage across the inductance (volts),

L is the inductance (henrys), and
$i^{\bullet}$ is the 'rate of change of current' (amps per second).

For a very large inductance, the equation shows that we need a high voltage to cause the current in the inductor to increase (or decrease) even by a small amount. The current in a large inductor tends to remain constant, in the same way that the voltage across a large capacitor tends to remain constant.

In our simple circuit model, **under quiescent (DC) conditions**, the current is not changing, so $I_L^{\bullet} = 0$ and the voltage across the inductor V_L must be zero. (Although $I_L^{\bullet} = 0$, the current I_L will be a constant value controlled by how we bias the valve.) So V_A is the full V_{HT} at quiescent conditions. Also, $I_R = 0$ and $I_A = I_L$ because the inductor is ideal and has no resistance at DC- it's just a piece of wire that bypasses all the current away from R.

If we now consider **full output AC conditions** (just before clipping) we can assume that the output valve will vary from highly conducting, to cut-off (not conducting). Because we are assuming a very large inductance L, the current through the inductance will stay constant at I_L however.

When the valve is fully conducting, we expect the valve to carry about twice its quiescent current.
So, $I_A = 2 \times I_L$ and hence $I_R = I_L$, in other words, since I_L does not have time to change, any extra current must flow in R.
In this condition the voltage V_L must be $I_R \times R = I_L \times R$. (Remember I_L is a constant throughout.) For a pentode valve with a well chosen transformer ratio and speaker impedance, the voltage V_A will now be close to zero, and V_L will be close to V_{HT}.

When the valve is at cut-off it carries almost zero current.
So, $I_A = 0$ and hence $I_R = -I_L$. Remember, we are assuming the current in the inductor does not have time to change, so it is still I_L. And since it can't flow in the valve for now, it must flow around R instead.
In this condition the voltage V_L must be $I_R \times R = -I_L \times R$, and the anode voltage will now be:

$$V_A = V_{HT} - V_L$$
$$= V_{HT} - (-I_L \times R)$$
$$= V_{HT} + I_L \times R.$$

Since we found that the voltage $I_L \times R$ was close to V_{HT}, we have shown that the anode voltage of the valve will peak at close to $V_{HT} + V_{HT}$, or $2 \times V_{HT}$.

Reference
[1] Merlin Blencowe, 'The Single Ended Output Stage', http://valvewizard1.webs.com/se.html

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