Distortion in Class AB without Negative Feedback

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Introduction

This article shows that for a class AB push-pull output stage with ideal pentodes, driving a resistive load via an ideal centre-tapped transformer, there is inherent waveform distortion.

Ideal Transformer Model

Consider the push-pull transformer shown in figure 1.

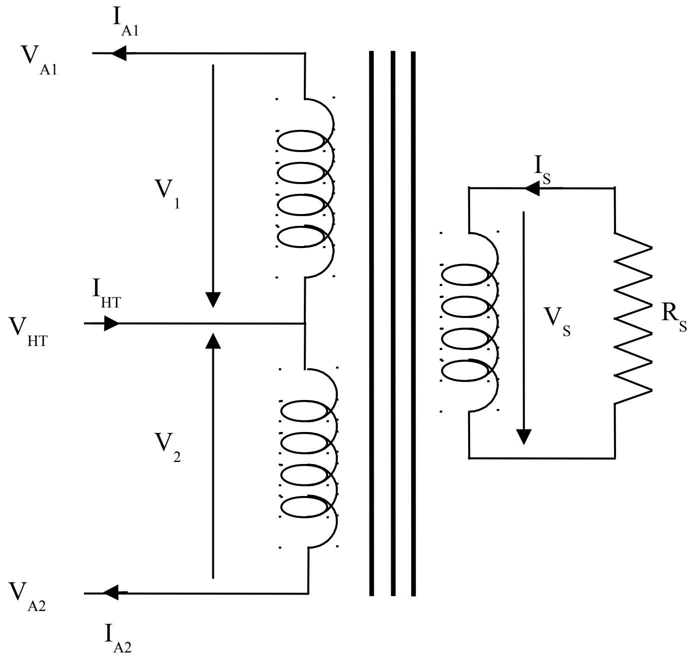

Figure 1: Push Pull Transformer

The primary winding is centre tapped with N_P turns between the centre-tap and anode connection, giving 2 x N_P turns for the whole primary winding. The secondary winding has N_S turns. R_S is a resistive load representing the loudspeaker (to keep things simple).

The transformer has 'ideal' behaviour according to the following equations:

$$V_S = V_1 \times N_S / N_P = V_2 \times N_S / N_P \quad \text{(eqn. 1)}$$
$$I_S = I_{A1} \times N_P / N_S - I_{A2} \times N_P / N_S \quad \text{(eqn. 2)}$$

Also:

$$V_1 = V_{HT} - V_{A1}$$
$$V_2 = V_{HT} - V_{A2}$$

$$I_{HT} = I_{A1} + I_{A2}$$

$$V_S = I_S \times R_S$$

Assume a very 'stiff' power supply so that V_{HT} always stays constant.

As the simplest possible model, consider the ideal (fictitious) pentode characteristics illustrated in figure 2.

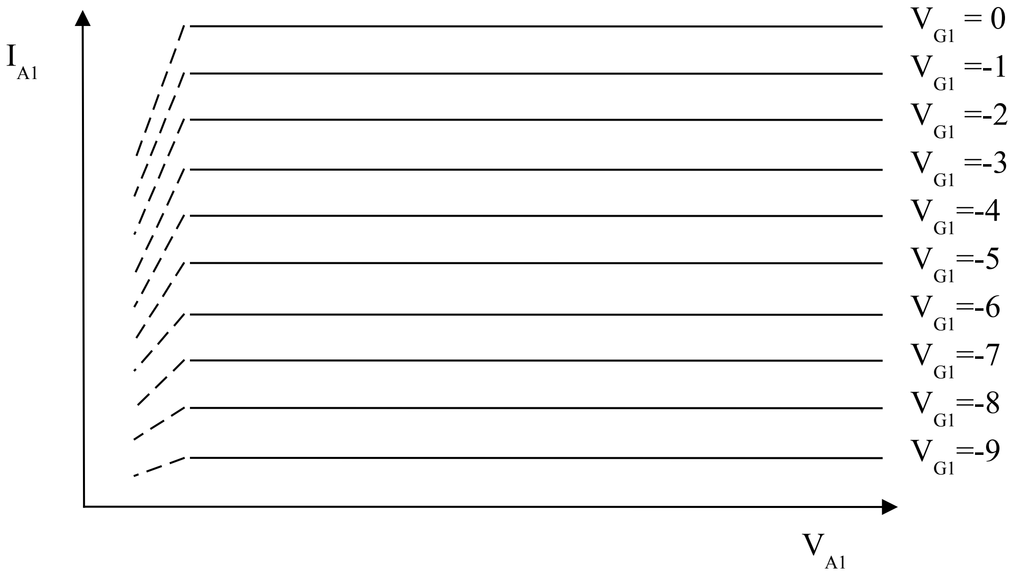

Figure 2: Ideal (Fictitious) Pentode Characteristics

The ideal pentode acts as a perfect current source, where the value of the current is set by the control grid voltage. This has important implications: the output current is completely fixed by the grid voltage. Also, the anode voltage V_{A1} can be at any value (above a certain minimum) for a given grid voltage and anode current. Assume that operation is always 'above the knee' so that the dashed curves in figure 2 do not come into play.

To keep all the numbers as simple as possible, take the turns ratio N_P:N_S to be 1:1 and R_S = 1 ohm. All voltages and currents can then be readily compared.

The ideal pentode is taken to be perfectly linear, cutting off at V_{G1} = -10 volts with I_{A1} = 0.0 amps, through to I_{A1} = 0.18 amps for V_{G1} = -4 volts. The valves are biased to give quiescent currents $I_{A1} = I_{A2} = 0.06$ amps. The control grid voltages are relative to the cathode, so the quiescent voltage between control grid and cathode is -8 volts.

If the control grids are driven by triangular waves, it is easy to deduce the anode currents I_{A1} and I_{A2}. These are illustrated in table 1 and figure 3. The secondary current I_S can then be calculated using equation (2).

A complete cycle of the triangular wave is shown in table 1, with each row representing a point in time. The cycle consists of 16 time steps of 0.1 millisecond each, giving a period of 1.6 milliseconds and hence a frequency of 625 Hertz.

Time (sec.)	V_{G1} (volts)	V_{G2} (volts)	I_{A1} (amps)	I_{A2} (amps)	I_S (amps)	V_S (volts)
0	-9	-7	0.03	0.09	-0.06	-0.06
0.0001	-8	-8	0.06	0.06	0	0
0.0002	-7	-9	0.09	0.03	0.06	0.06
0.0003	-6	-10	0.12	0	0.12	0.12
0.0004	-5	-11	0.15	0	0.15	0.15
0.0005	-4	-12	0.18	0	0.18	0.18
0.0006	-5	-11	0.15	0	0.15	0.15
0.0007	-6	-10	0.12	0	0.12	0.12
0.0008	-7	-9	0.09	0.03	0.06	0.06
0.0009	-8	-8	0.06	0.06	0	0
0.001	-9	-7	0.03	0.09	-0.06	-0.06
0.0011	-10	-6	0	0.12	-0.12	-0.12
0.0012	-11	-5	0	0.15	-0.15	-0.15
0.0013	-12	-4	0	0.18	-0.18	-0.18
0.0014	-11	-5	0	0.15	-0.15	-0.15
0.0015	-10	-6	0	0.12	-0.12	-0.12

Table 1: Triangular Wave Inputs and Outputs

By inspection of the table and the corresponding graphs, it can be seen that the secondary current is inherently distorted, although it could be said that it is rather a 'mild' form of distortion compared to clipping. The voltage across the resistive load will follow the same distorted wave-shape.

Discussion

The form of distortion described here seems to be seldom discussed in the literature, but has been referred to as 'Gm doubling' in the solid-state literature. Is it just a consequence of the idealised model that has been considered here? A more sophisticated model would be needed to clarify this, but it is not obvious how the inclusion of more realistic pentode curves, transformer magnetising reactance, leakage reactances, etc. could eliminate this distortion.

There are at least two possible reasons why this distortion is not usually a concern. Firstly, a modest amount of negative feedback around the output and driver stage will easily reduce this type of distortion, by generating the necessary increase in grid voltage during the periods when one pentode is operating alone. Secondly, where class AB has been used for 'hi-fi' purposes, only a very small region of class A operation is generally designed in, to just eliminate the cross-over distortion associated with pure class B. Guitar amplifiers, on the other hand, usually operate with an extensive class A region before one of the valves cuts off (i.e. they have a relatively high quiescent current.) Many guitar amplifiers do incorporate negative feedback, but for those that don't (Vox AC30 etc.) perhaps this mild form of distortion is a contributory factor in the tone produced.

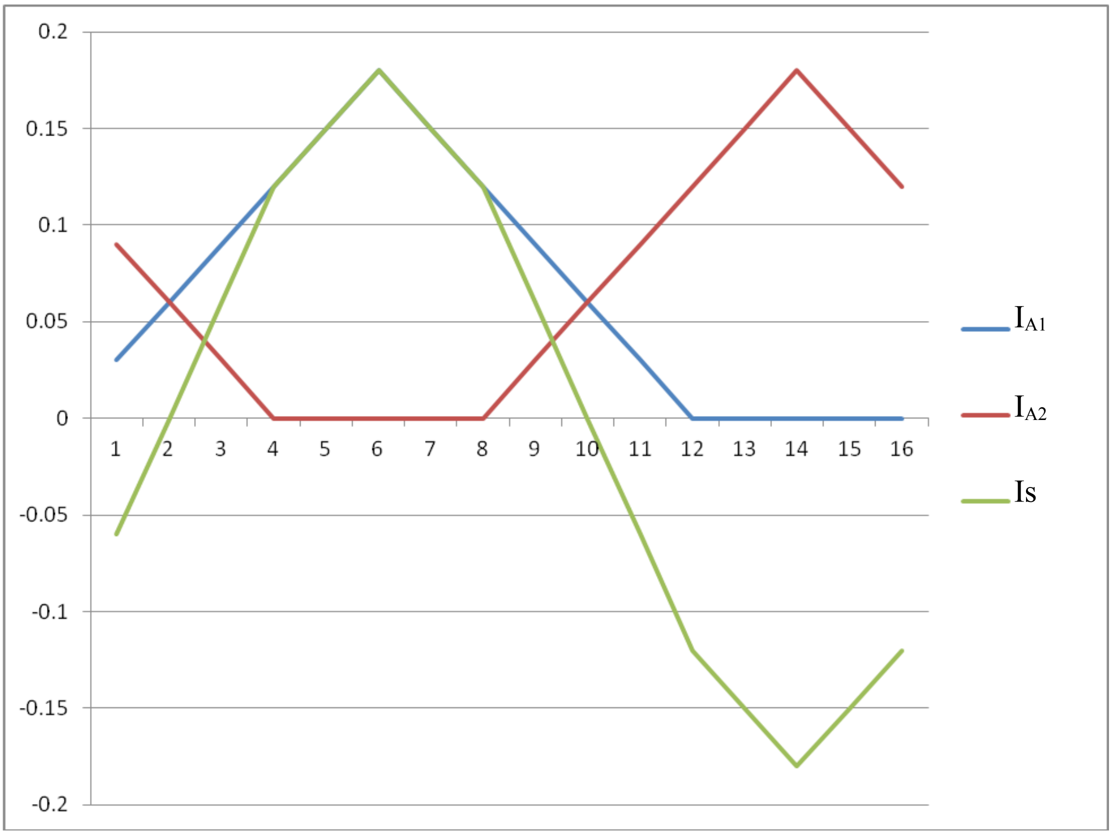

Figure 1: Current Waveforms