THE FEASIBILITY OF CLASS D AMPLIFIERS FOR ACTIVE LOUD-SPEAKER APPLICATIONS

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In 2002 the author made a comparison of the audio quality, audio quantity and cost of some commonly available power amplifier modules. This paper will investigate the hypothesis that today the best value can obtained using Class D amplifiers. This will be studied by comparing four topologies. The amplifiers have been measured in the same controlled conditions representing an application in an active loudspeaker. To make a fair cost comparison the amplifiers have been assembled on PCBs from components in-house rather than using complete ready power amplifier modules. In addition to the audio and cost criteria, energy efficiency will be considered.

INTRODUCTION

This study compares amplifiers in a controlled, objective manner simulating normal use with music material. The measurements are concerned with the frequencies below 3 kHz which typically limit the headroom of a loudspeaker and are reproduced by a woofer/midrange driver representing a more demanding load on the amplifier than a tweeter.

Since the author's previous work [1], there has been much research work to improve Class D performance e.g. [2] and other comparisons of Class AB and Class D amplifiers [3].This study can be seen as a continuation of the author's previous work but with a slightly shifted focus and simpler methodology.

1 AMPLIFIER DESCRIPTIONS

The four amplifiers in the study have configurations and performance typical of commercial designs. For a simple comparison, they have been assembled with the same feedback/input resistors, setting the gain to 29.2 ± 0.2dB, the minimum gain recommended for the thick film hybrid. This is not an ideal situation for the other amplifiers –the integrated circuit amplifier can operate at 26 dB gain, while the discrete Class AB and Class D amplifiers could operate at much lower gains.

1.1 Discrete Class AB design

An inverting design that can easily be tailored for a certain gain, distortion, noise and voltage and current handling. It can be configured with a bandwidth of over 200 kHz and operated with gain down to unity which can result in very low noise. It is sensitive to the layout of the input traces and it needs its DC offset and bias current adjusted. Heat sinking is simple to arrange, though the bias tracking is not very fast. It is a robust design on a two layer circuit board. It has 86 components, of which 7 are through hole mounted. The design is quite future proof because obsolete transistors can be replaced with pin compatible parts.

1.2 Thick Film Hybrid (TFH) Class AB design

A non-inverting amplifier with an almost datasheet configuration. It is very simple to use if kept within voltage and load impedance specifications, but the minimum gain is too high in many applications. The hybrid is a stereo device, so only half its cost is included in the cost calculations. It is assembled on a two layer PCB with 23 components, of which 3 are through hole mounted. The availability and longevity of TFH amplifiers is not as good as that of many transistors and ICs that are used in audio amplifiers. In the author's previous study [1] the TFH offered the best value of the compared amplifier types.

1.3 Integrated Circuit (IC) class AB design

A non-inverting amplifier with an almost datasheet configuration. In this study two ICs are paralleled, running at the limit of their voltage handling. The circuit and layout are extremely easy to implement, the ICs protect themselves for high reliability, but thermal design is a challenge because of the ICs' small surface area. It is tested here on a four layer PCB, using just 16 components, of which the two ICs are the only through hole mounted parts. The most common Class AB audio power amplifier ICs have been in production for many years, suggesting that they are fairly future proof.

1.4 Class D design

This contains ICs and a discrete output stage for a total component count of 69, of which four parts are through hole mounted – the output coil, output capacitor and two bypass capacitors. It is assembled on a four layer PCB. It needs no heatsink. It is an inverting, analogue, self oscillating half-bridge design with feedback taken before the output LC filter. It does not represent the intellectual property minefield of the best performing Class D amplifiers. It has a strong similarity to datasheet designs, but is not trivial to implement because of potential EMC issues. A common mode choke is necessary on the mains connection with this amplifier. This cost is included in the calculations.

Unlike the class AB amplifiers, the frequency response peaks so that at 20 kHz it has risen about 1 dB.

FETs, coils and other parts can be replaced if they are discontinued. FET replacement appears likely given the rate of FET development. An applicable integrated circuit for a half bridge FET driver will probably always be available in some package.

2 AMPLIFIER COSTS

Costs (Table 1) have been normalized to the cost of the Class D amplifier. The first row concerns only the parts and circuit board. The second row includes the cost of a flat sheet metal heatsink and mounting hardware. The same heatsink and hardware has been specified for all Class AB amplifiers. The class D amplifier needs no heatsink. The heatsink is large enough for normal music listening with and active loudspeaker, but not for sine waves at continuous full output. Both lines are included since there are times when it is fair to ignore the heatsink cost if it is anyway no more than just the necessary amplifier enclosure.

	Disc. AB	TFH AB	IC AB	Class D
PARTIAL: Parts, PCB	1.23	**0.73**	0.86	1.00
FULL: Parts, PCB, mounting, heatsink	2.25	1.75	1.88	**1.00**

Table 1: Normalized amplifier costs.

3 GENERAL TEST CONDITIONS

The amplifiers are powered by a 130VA toroidal transformer, a 6 A bridge rectifier and 10,000 µF capacitance per rail, at an idle voltage of ± 52 V.

Signals used are sinusoidal or multitone. The multitone signal, used to represent wideband spectrum music, contains 31 tones at equal amplitudes from 20 Hz to 3 kHz. The frequency range is sufficient for the woofer range of typical two way loudspeaker.

The loads used were a 7.7 Ω resistive load or an 8 inch woofer loudspeaker in a bass reflex enclosure with an average impedance of 7.7 Ω from 20 Hz to 3 kHz. With this power supply and loads, the amplifiers can be considered nominally 100 – 120 W amplifiers. A common approximation of the normal use power level for audio amplifiers is 1/8 of continuous output power [4, 5], equating to 12.5 W in this case.

All measurements were made using Audio Precision SYS-2722 with the measurement bandwidth set at < 10 Hz – 20 kHz using the AES17 brick wall filter. A 20 Ω, unbalanced, floating input signal connection was used.

4 TEST MEHODS AND RESULTS

4.1 Noise

The idle noise of an audio system is subjectively very important, more so than even the signal to noise ratio, since potential buyers will often place their ear right next to a loudspeaker to listen for noise. The amplifiers were measured with no load because the extra load cabling can pick up low frequency noise in a laboratory situation. The input cable was connected but the signal was turned off. Amplifier output voltage was measured.

Swept bandpass filter measurement curves for the TFH and IC amplifiers were very similar with peaks at 50 Hz, then almost straight increase from 100 Hz to 20 kHz. The discrete Class AB amplifier had extra peaks at 100 Hz and 200 Hz, but was otherwise the same level. The Class D amplifier was similar to the TFH and IC amplifiers below 100 Hz but its increasing noise level was 2 – 3 times higher.

The total unweighted noise in the audio bandwidth (Table 2) is highest for the Class D amplifier, even when compensated by the full cost of the amplifiers. This is a serious concern, but the amplifier is responsible for only part of the total noise in any system. The input/feedback resistor values are best suited to the TFH amplifier and least well suited to the Class D amplifier. In practice the Class D amplifier can still be better optimised for noise performance whilst the TFH amplifier cannot.

	Disc. AB	TFH AB	IC AB	Class D
Noise (µV)	55	**44**	58	127
Noise × normalized full cost	124	**77**	109	127

Table 2: Total unweighted audio band noise.

4.2 Distortion

There is no widely accepted single figure for measuring distortion to predict subjective quality [6, 7], but THD+N comes closest [7]. For the purpose of simple comparison, only a few frequency points at normal listening level, 12.5 W, are presented. These are 20 Hz and 3 kHz, the highest and lowest frequencies in this study, and 1 kHz, the most common single frequency used for showing audio amplifier performance in datasheets.

	Disc. AB	TFH AB	IC AB	Class D
20 Hz	0.030	**0.0017**	0.0044	0.0018
1 kHz	0.010	**0.0011**	0.0020	0.0032
3 kHz	0.011	**0.0018**	0.0028	0.012
20 Hz × normalized full cost	0.068	0.0030	0.0083	**0.0018**
1 kHz × normalized full cost	0.023	**0.0019**	0.0038	0.0032
3 kHz × normalized full cost	0.025	**0.0032**	0.0053	0.012

Table 3: THD+N percentage at normal listening level.

At 20 Hz the THD+N of the Class D amplifier is as good as the best of the Class AB amplifiers in the test. By 3 kHz it is at the level of the worst of the Class AB amplifiers. When cost-compensated, the Class D amplifier is only advantageous up to about 400 Hz. The best absolute THD+N performance of these amplifiers is given by the TFH amplifier.

If the harmonic distortion of a good active loudspeaker [8] is less than 0.5 %, an amplifier can be considered good enough if its distortion is insignificant in comparison to that, say 0.05 %. All of the amplifiers in this study are more than good enough even up to 7 kHz, beyond which third harmonic distortion is inaudible.

4.3 Output power

Maximum continuous sinewave output power was measured during the THD+N vs output power tests. The results at 1 % THD+N are presented (Table 4) for 100 Hz sinewaves. The Class AB amplifiers gave the same output at 1kHz and 6.67 kHz. The Class D amplifier showed less output power at higher frequencies, but this is because the clipping point is less well defined with a more rounded knee. For music material in an active loudspeaker, the 100 Hz value is more significant.

	Disc. AB	TFH AB	IC AB	Class D
Power to 7.7 Ω (W)	83	92	101	**113**
Power to 7.7 Ω / normalized full cost	37	52	54	**113**

Table 4: Sine wave output power comparison.

The Class D amplifier gives more output power than the Class AB amplifiers. Per unit cost the Class D amplifier is around three times better value for output power than the discrete Class AB amplifier and about twice the value of the TFH and IC amplifiers.

Since sine waves and THD+N measurements are not a realistic representation of music signal quality, a different approach was required. The multitone signal was fed to the amplifier and the multitone distortion was measured. This is drawn as a function of frequency, not a single number, so for comparison the signal level was increased until the amplifier output compressed by 0.5 dB. At this level the higher frequency part of the plot was at about -45 dB relative to the full output signal.

	Disc. AB	TFH AB	IC AB	Class D
Power to 7.7 Ω (W)	53	57	62	**73**
Power to 7.7 Ω / normalized full cost	24	33	33	**73**
Power to loudspeaker (W)	53	57	62	**73**
Power to loudspeaker / normalized full cost	24	33	33	**73**

Table 5: Multitone output power comparison.

The first thing to notice is that all the amplifiers give the same output to the loudspeaker load as to the resistive load. This information makes future power testing with multitone or other music-like signals much simpler because a resistive load can be used. As expected, the Class D amplifier delivers considerably more power to the load than the Class AB amplifiers in both absolute terms and per unit cost.

4.4 Efficiency

The mains power of the complete power supply and amplifier system was measured (Table 6) at different audio power output levels from 0 W to 100 W into both resistive and loudspeaker loads. The power supply efficiency is included in the measurements, but it is the same power supply, so the measurements can be fairly compared with each other. The TFH amplifier has two idle channels included in the measurement.

	Disc. AB	TFH AB	IC AB	Class D
Idle consumption (W)	8	7	7	**6**
Idle consumption × normalized full cost	18	12	13	**6**

Table 6: Idle power consumption.

The Class D amplifier has the lowest idle consumption both in absolute terms and per unit cost.

The multitone signal was applied to the amplifier. Below 40 W output power, the power consumption was the same for both the resistive and loudspeaker loads. It was not possible to measure fast enough to avoid heating the loudspeaker voice coil, so that above 40 W, the loud the amplifier seemed more efficient in to the loudspeaker load than it actually is. For this reason the efficiency plot below was measured with the resistive load. Efficiency is given as the output power divided by the power consumption and is expressed as a percentage.

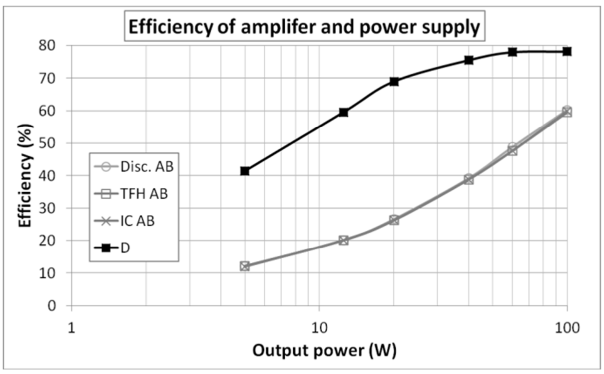

Figure 1: Efficiency at different power levels.

	Disc. AB	TFH AB	IC AB	Class D
Normal level (%)	20	20	20	**60**
0.5dB compression level (%)	48	48	48	**78**
Nominal maximum level (%)	60	60	60	**78**
Eff. normal / normalized full cost	9	11	11	**78**
Eff. 0.5 / normalized full cost	21	27	26	**78**
Eff. max / normalized full cost	27	34	32	**78**

Table 7: Efficiency percentage at different levels.

The Class AB amplifiers (Figure 1, Table 7) are almost indistinguishable in their efficiencies, being only 20 % efficient at the normal 12.5 W output, and increasing to around 48 % at the 60 W level at which their output compresses 0.5 dB. The Class D amplifier has efficiencies of 60 % and 78 % at the same output levels. Therefore in normal music listening conditions the Class D amplifier would be three times more efficient than the Class AB amplifiers.

Table 7 describes the data in Figure 1 and also includes cost compensated data. The Class D amplifier is very much more efficient at all output levels and when compared per unit cost the difference between the Class D amplifier and a Class AB amplifier can be over eight times.

5 CONCLUSIONS

Four nominal 100W audio power amplifiers with basic design were assembled and evaluated to test the hypothesis that the Class D amplifier offers the best value today.

The thick film hybrid and integrated circuit amplifiers are the simplest to design if heatsinking can be arranged. The Class D amplifier is the most complex to implement because it must not radiate or conduct radio frequency energy above internationally accepted limits.

The cheapest to implement in a practical situation with sufficient cooling is a Class D amplifier. The Class D amplifier offers higher output power and efficiency with both resistive and reactive loads. Its efficiency can be three times greater than that of the Class AB amplifiers. This has particular relevance in today's world where consumers make purchasing choices based also on environmental reasons.

Below 400 Hz the Class D amplifier offers THD+N performance similar to the best Class AB amplifiers. Up to 3 kHz Class D amplifier still fits in with the range of THD+N performance offered by the Class AB amplifiers, being easily good enough for a high quality active loudspeaker.

The noise performance of the Class D amplifier was the worst of the amplifiers on test, .even when compared to the full cost of the amplifiers. However, the gain setting used in the tests was better suited to the Class AB amplifiers, particularly the thick film hybrid and integrated circuit amplifiers. The noise of an audio system is somewhat easier to control than distortion, and can be distributed throughout the whole system design by careful gain structure design, so this is not a bad result for the Class D amplifier.

The output power test results suggest that it would have been fair to use a smaller, cheaper power supply transformer for the tests and include the cost of the power supply in the comparison, which would have improved the per unit cost for the noise and distortion performance.

An interesting result was that the amplifier efficiency was the same using both resistive and reactive loads when a wideband signal was used. The expectation was that the amplifiers would be less efficient when loaded by a reactive driver load.

This was not an exhaustive test. The amplifiers used do not represent the absolute best possible audio quality available. No listening tests are presented. There is no attempt to measure momentary output power or intermodulation distortion.

Though simple, the study does indeed prove the hypothesis that Class D amplifiers can offer the best value today.

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