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**Technical White Paper – Development of Class D Power Amplifiers for HiFi**

**Issue 1.0**

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## Objective

To design a power amplifier using a class D topology that sonically matched Cyrus current range of class AB amplifiers, surpassing all other class D evaluation boards and chipsets when used in a domestic environment.

## Overview

A class D amplifier is defined by the output transistors being hard switched between conducting and non-conducting. This differs to other amplification classes that operate the output transistors in the linear operating range.

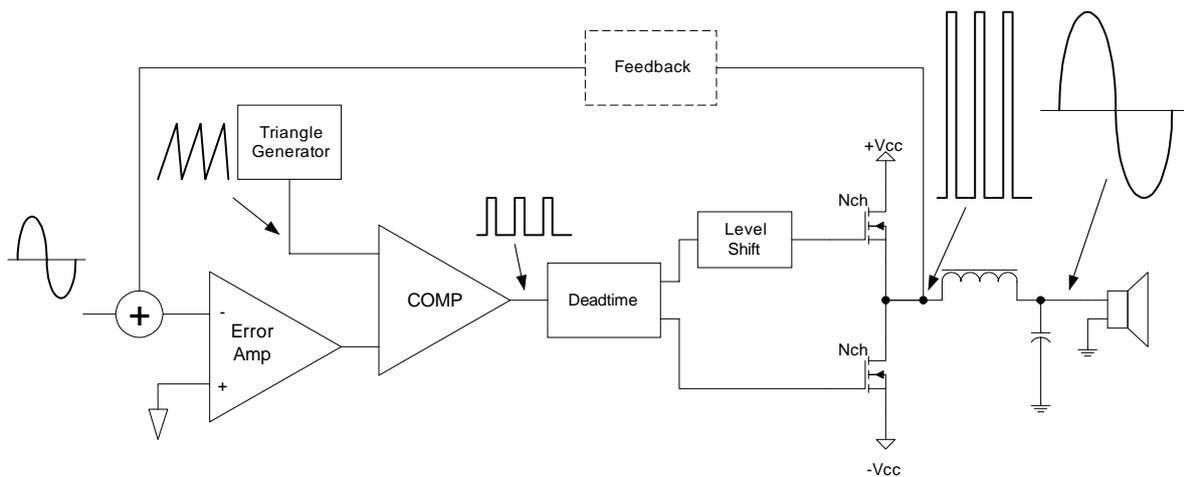


Figure 1 – Simplified Class D amplifier

The benefits of class D amplifiers are very well known and have been used in high power live sound reinforcement systems for many years, outweighing the disadvantages in their application. Traditional problems of designing class D amps include:-

1. Conducting radio frequency noise onto the speaker cables and into the mains.
2. Poor immunity to radio frequency noise.
3. Output impedance affects frequency response and therefore sonic predictability with different speakers.
4. Amplifiers become unstable with no load attached or low impedance loads attached.
5. Harsh clipping and uncontrolled high frequencies.
6. Limited high frequency range due to high order low pass input filters.
7. Suffer thermal dissipation limitations.
8. Floating supplies can create very high DC voltages at the speaker terminals.
9. Poor THD at high frequencies.
10. THD and power measurements are often taken at 'sweet spots' for marketing reasons and not representative of a product under normal operating levels.
11. Cross channel modulation and beating artefacts.
12. Power supplies not designed to drive class D collapse or overshoot regulation.

In the home environment, the long list of disadvantages has kept the technology limited to people who are not critical listeners in products such as micro systems, car audio etc. At Cyrus Audio, we have spent the last 36 months identifying the cause of these problems and solving them.

The following paper deals with these issues and addresses the point in question within a pair of brackets “( )”

## Issue 1 - Optimisation for normal listening levels

In the domestic environment, most high-end audio equipment never reaches its full output power during normal (or even high) listening levels. Class B/AB amplifiers rate their THD+N at full output to give the best number spec however, under normal listening this distortion is never achieved as it is impossible to run an amplifier at that level with a music signal without causing severe clipping.

The Cyrus class D amplifiers have had the THD+N optimised for musical signals at normal to high listening levels, meaning the listener enjoys the lowest possible level of distortion for the greatest amount of time.

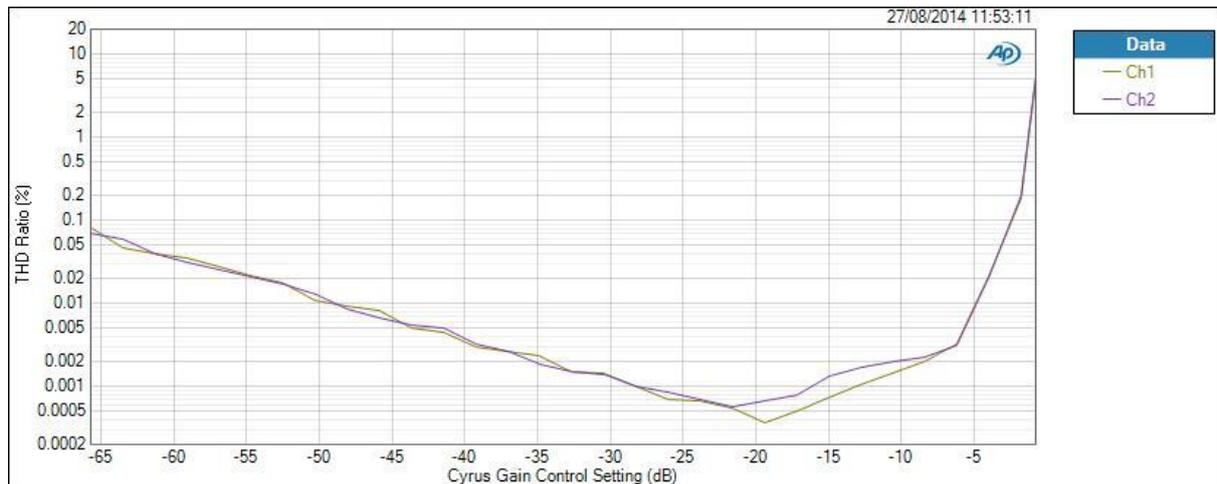
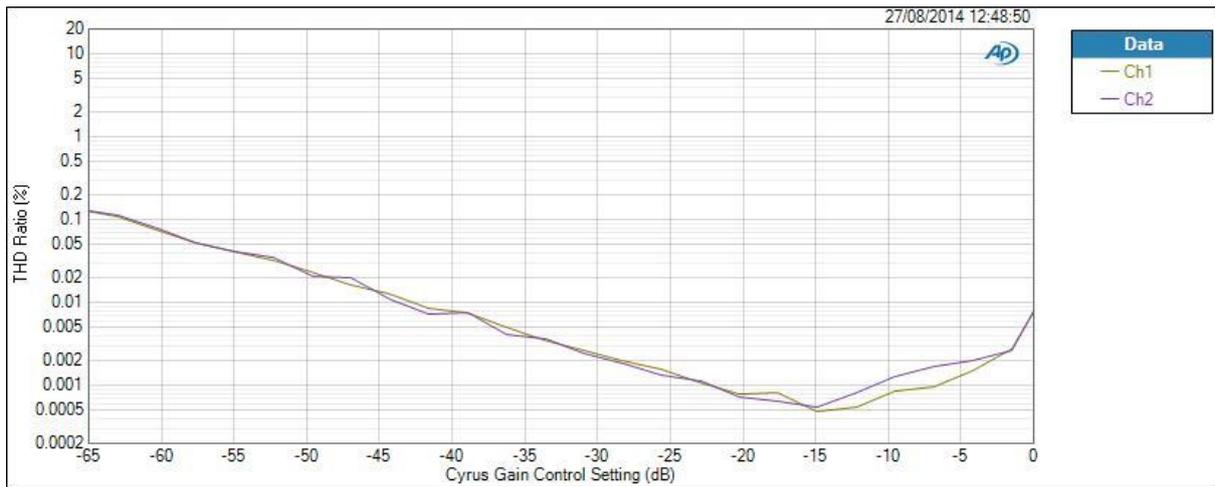


Figure 2 - THD vs. Gain Control Setting on Cyrus Preamplifier

Figure 2 shows the THD ratio of the Cyrus class D amplifier whilst driving an 8 Ω load on both channels. The input level relates to the gain setting on a Cyrus preamplifier and the input signal is a 1 kHz sine wave at full volume.



**Figure 3 - THD vs. Gain Control Setting on Cyrus Preamplifier with -6dBFS Input**

Figure 3 shows the THD ratio of the Cyrus class D amplifier whilst driving an 8 Ω load on both channels. The input level relates to the gain setting on a Cyrus preamplifier and the input signal is a 1 kHz sine wave at -6dBFS, representative of typically highly compressed musical signal.

As can be seen from Figure 3, the user can enjoy very low distortion levels whilst listening to typical music over all of the operating range of the unit. (10)

Low noise components have been used throughout the signal path leaving a residual idle voltage of <math><200\mu\text{V}</math> on the speaker terminals when connected to an 8Ω load. This gives an inky black background to the sound stage.

## Issue 2 – Distortion

Distortion has always been the biggest drawback of the class D topology for home use. The main causes of distortion in a class D amplifier are poor power supply ripple rejection, the amplifiers switching frequency related harmonics, the output reconstruction filter and stray electromagnetic fields. This can be experienced as a brittle sound, sometimes described as hard clipping.

The Cyrus class D amplifier uses a second order sigma delta oscillator with a very tight feedback path directly from the amplifiers switching output stage, allowing the closed loop gain of the amplifier to offer large amounts of power supply ripple rejection.

Switching frequency related harmonics are minimised in the Cyrus class D amplifier by generating the carrier frequency external to the sigma delta oscillator and injecting dither at an infrasonic frequency. This causes most of the switching frequency harmonics to be band shifted well out of the audio frequency range or removed altogether. It also eliminates the possibility of beating artefacts and cross channel modulation. (11)

The Cyrus class D amplifier employs a unique clock dither technology that constantly changes the frequency of the 2<sup>nd</sup> order delta-sigma sampler. This constant movement ensures that quantisation jitter cannot exist within the amplifier and high-resolution audio can be enjoyed at levels right down to the noise floor.

The output reconstruction filter has had its components optimised for ultra low distortion and minimised non-linear inductance and capacitance. The coils used are ferrite shielded and wound with high current oxygen free copper wire to minimize power losses and maximize the amplifiers damping factor. The polypropylene metal foil capacitors used in the output reconstruction filter have a highly overrated working voltage and ripple to maintain the flattest response under the most demanding loads and temperature variations.

The circuit has been manufactured from a high density 4 layer copper PCB. The layout has been optimised for audio performance using a hybrid star-plane grounding method. This layout, along with carefully optimised mains and power filters helps reduce any stray radio frequency electromagnetic fields within the amplifier and speaker cables and helps give the amplifier a good rejection, stopping external fields affecting the audio performance of the amplifier or connected equipment. (1&2)

Clipping characteristics of the amplifier have been modified so the unit does not instantly hard-clip when overdriven.

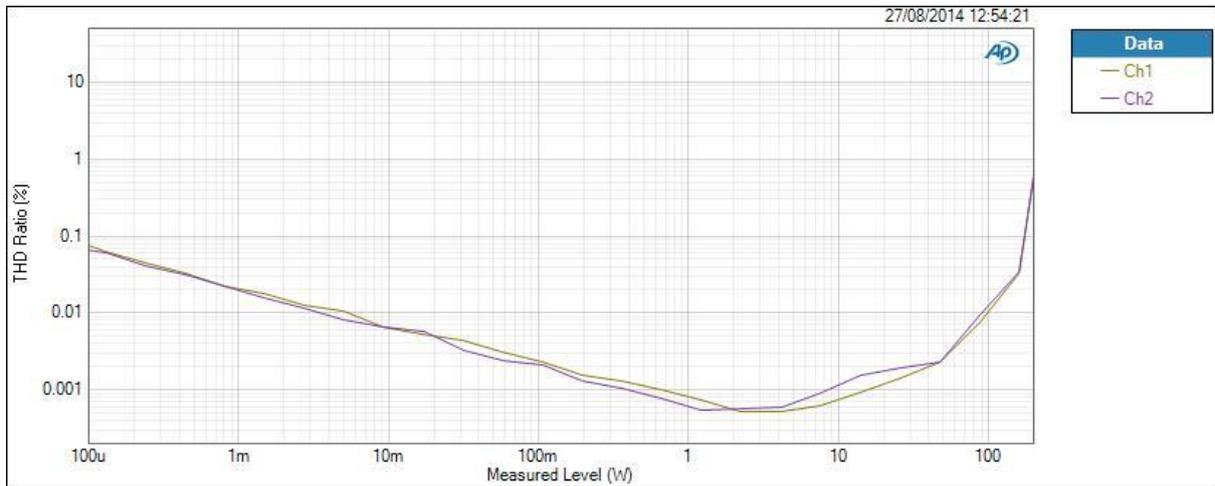


Figure 4 - THD vs. Continuous Output Power

As can be seen in Figure 4, the clipping profile up to 200W into 8Ω for a continuous 1 kHz sine wave can be seen. (5)

Load Impedance	0.1% THD+N	1% THD+N	10% THD+N
<b>8Ω</b>	175W Per Channel	270W Per Channel	335W Per Channel
<b>4Ω</b>	325W Per Channel	495W Per Channel	600W Per Channel
<b>2Ω</b>	180W Per Channel	330W Per Channel	960W Per Channel

Table 1 – Maximum Output Power of Cyrus Stereo 200 Class D Amplifier

Table 1 shows the maximum output power (1 kHz CEA-2006/490A 20Hz-20kHz) of the Cyrus Stereo 200 class D power amplifier with both channels driven into resistive loads. Measured using Audio

Precision APX525 audio analyser and AUX-0025 measurement filter. It can be seen that the Cyrus class D amplifier is capable of delivering dynamic peaks, even into difficult to drive loudspeakers.

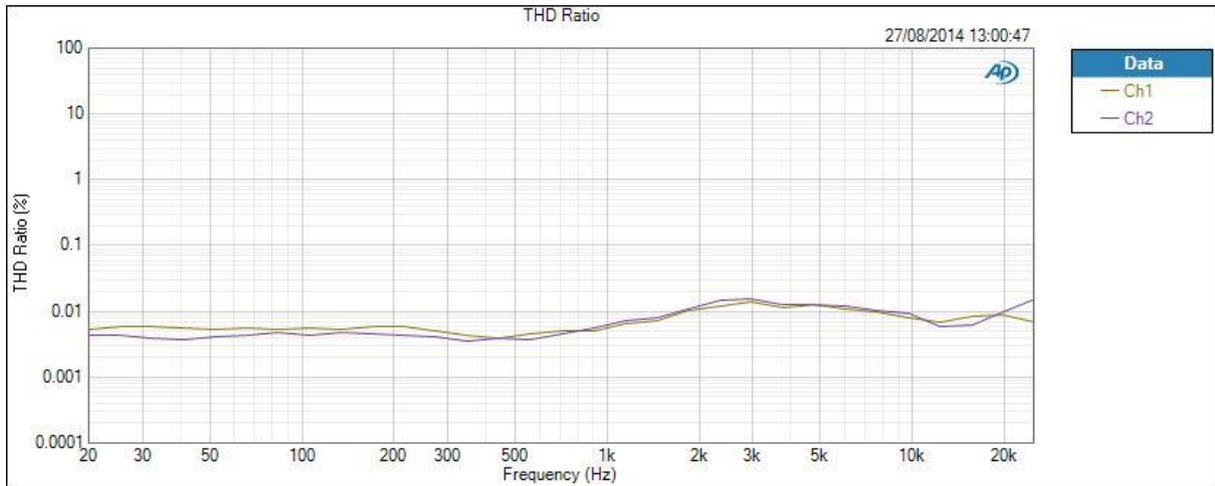


Figure 5 - THD vs. Frequency

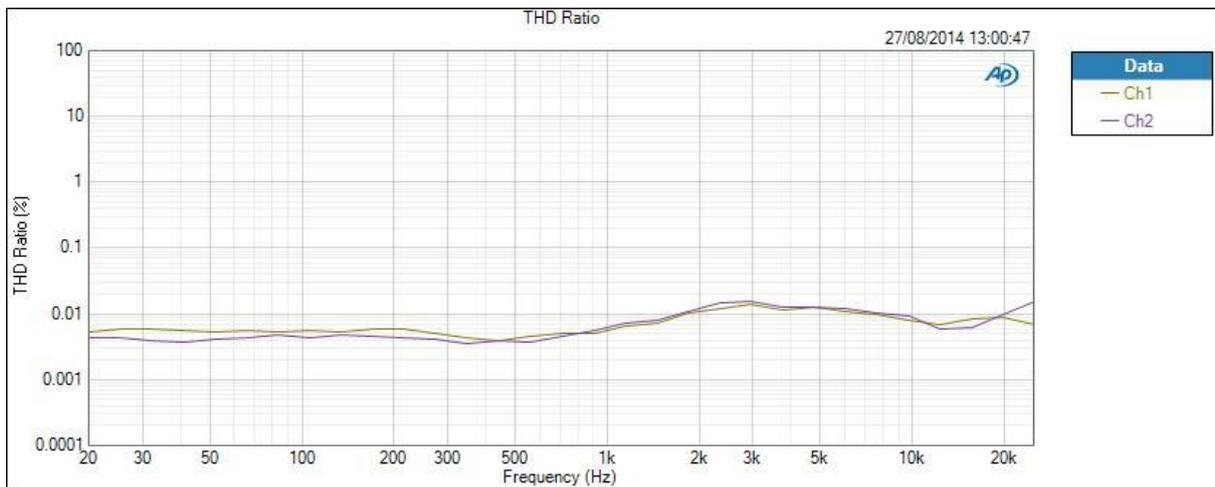


Figure 5 - THD vs. Frequency shows the THD+N of the Cyrus class D amplifier is consistent with frequency and does not shoot up at higher frequencies like many other class D amplifiers. This is due to the optimised PCB layout; feedback and reconstruction filter design along with the low error rate of the second order sigma delta modulator. (9)

### Issue 3 – Frequency Response to Different Load Impedances

Many class D amplifiers have an inaccurate frequency output response when connected to different loads and are only optimised for one load impedance. Other types of amplifier use feedback after the reconstruction filter to correct for this. Using feedback after the reconstruction filter creates a huge phase shift in the feedback and has a very negative effect on the amplifiers performance when playing musical signals and can cause them to become unstable, oscillate and distort.

During initial power up of the Cyrus class D amplifier, the unit actively measures the high frequency impedance of the load connected to the amplifier and adjusts its high frequency output level to ensure that the audio output response is always accurate. By using this method, we are able to optimise the amplifiers feedback without compromise and keep the feedback loop as tight as

possible. This method is also preferable as many manufacturers do not state the high frequency impedance of their speakers, only its “nominal impedance”.

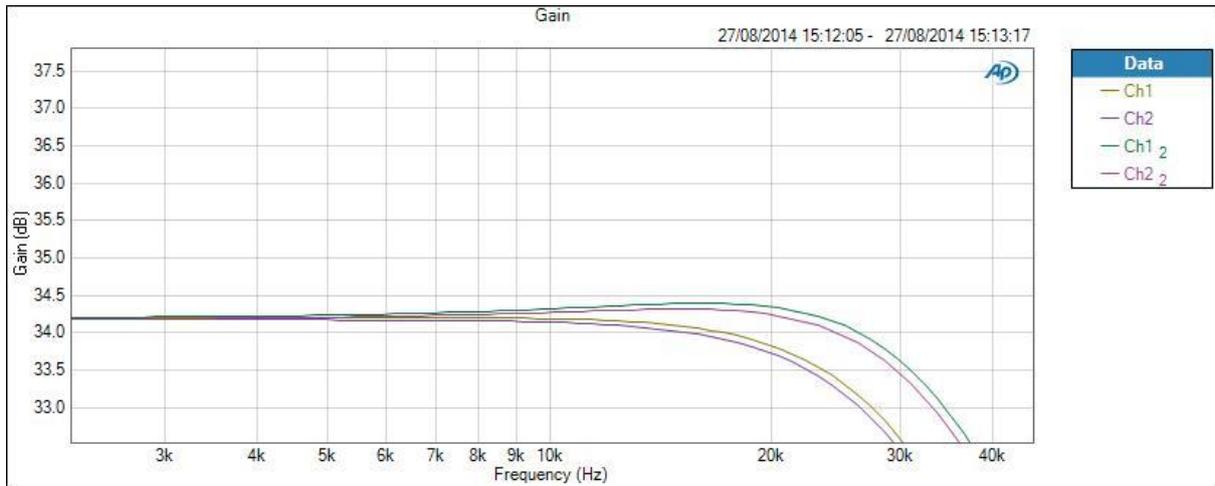


Figure 6 - Gain vs. Frequency 4 Ω Load

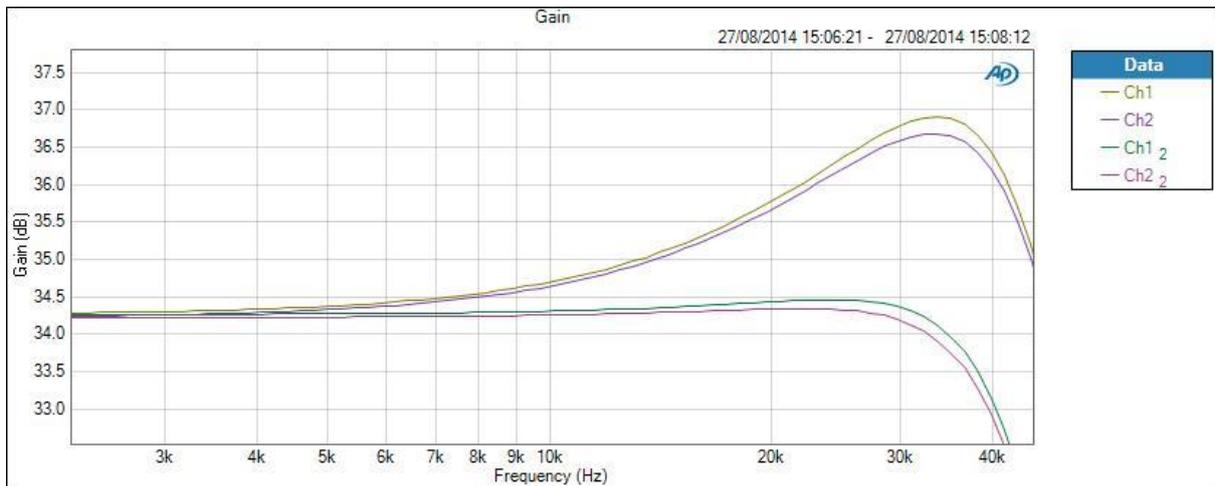
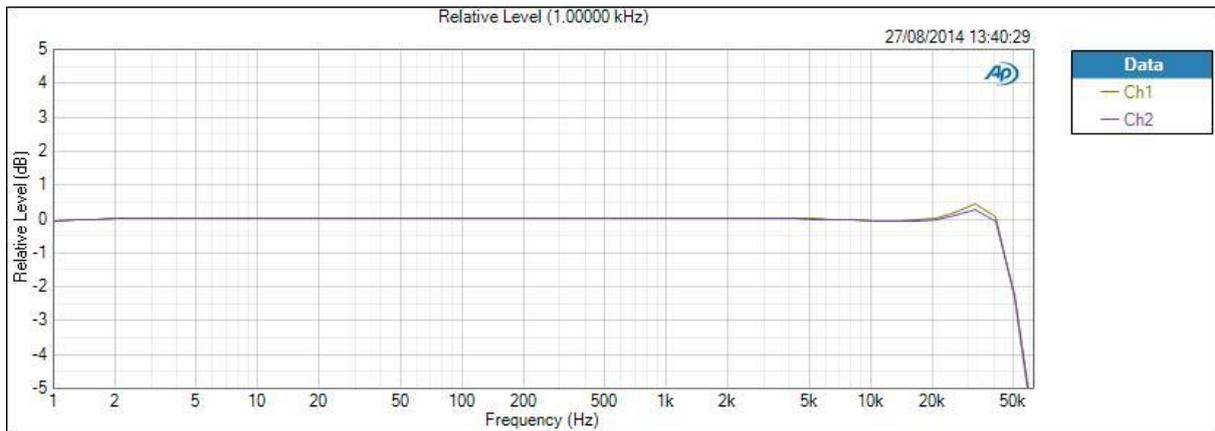


Figure 7 - Gain vs. Frequency 8Ω Load

Figure 6 and Figure 7 show the output response with and without load correction for 4Ω and 8Ω loads. After correction, the response deviates less than 1/3<sup>rd</sup> of a dB, irrelevant of load impedance. (3)

The amplifiers output stage and reconstruction filter have been carefully designed to prevent them from becoming unstable, even with no load connected or speakers with low impedance dips in their response. (4)



**Figure 8 - Amplifier Bandwidth**

Figure 8 shows the Cyrus class D power amplifiers bandwidth with the -3dB frequency roll-off points at 50 kHz and less than 1 Hz. (6)

## Issue 4 – Power Supply Requirements

Class D amplifiers draw their power very differently from other amplifiers; they draw high current pulses for short amounts of time. The power supply in the Cyrus class D amplifier uses an oversized, low stray field, custom wound torroid core transformer and a 240A peak rectifier to provide rectified AC to the capacitors. The capacitors are an optimized mix of bulk electrolytic, ceramic and polypropylene to optimize the filtering and current delivery speed to the output stages. There is a total of approximately 50 Joules of almost instantaneously available energy stored in the capacitors alone – equivalent energy to dropping 1kg weight into a pond at 10m/s. (12) For greater amplifier efficiency, the moving mass energy from stopping a speaker cone is recovered and fed back into the amplifiers capacitors instead of just being turned into heat by the output transistors in a more traditional amplifier.

The single ended output configuration used in the Cyrus class D amplifier ensures that the speaker outputs should never have any high voltage DC present on them. (8)

As the amplifiers efficiency has been maximised, not just at high power levels but at normal listening levels as well, the product stays cool and does not suffer from any thermal dissipation limitations – even without using a fan. The switching output stage and voltage regulators are bolted directly to the inside of the aluminium chassis, providing more than enough convection cooling, even at high music levels. (7)

## Conclusion

Class D amplifiers can perform very well in the domestic environment but only if they have been optimised to do so. With careful design, application and optimisation, the sonic presentation and performance starts to approach that of the Cyrus Signature series Zero Feedback Mono X200 amplifiers.

This achievement is only possible by taking the time to research and identify the operation of every area of the amplifier topology, and to precisely understand the technology and then reduce and remove parasitic behaviours.

The new Cyrus class D amplifier will debut in the Cyrus Stereo 200 Power amplifier, due Q4 2014.