WHITE PAPER

Direct Digital Amplification (DDX®)

Pure Digital Sound from Source to Speaker

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DDX Technology Overview

Direct Digital Amplification (DDX) is a patented, all-digital, high efficiency amplifier architecture developed to meet the needs of a wide range of audio applications, from PC multimedia to home audio systems to MP3 playback devices. Today's entertainment systems, including those that claim to be digital, use analog amplifiers to boost analog signals produced by digital to analog converters (DACs). DDX technology eliminates the DAC by using a patented signal processing technique to digitally control a high efficiency power device. This approach directly connects to digital audio sources, eliminates analog signal corruption and increases amplifier efficiency by over a factor of three compared to analog designs. The technology enables manufacturers to produce truly digital audio products that provide pure digital sound reproduction from the source to the speaker.

DDX Compared to Analog Designs

Figure 1 compares the DDX amplifier architecture to an analog architecture. The primary difference is that the analog design requires a DAC prior to the amplifier stage. In the case of analog Class A/B amplifiers, the amplifier stage has very poor efficiency due to the power consumed in the amplifier's active components. Class D amplifiers were developed to improve amplifier efficiency by discretely connecting the load to the power supply. While higher efficiency is achieved, these solutions are essentially analog because they utilize an analog interface and analog power stage control.

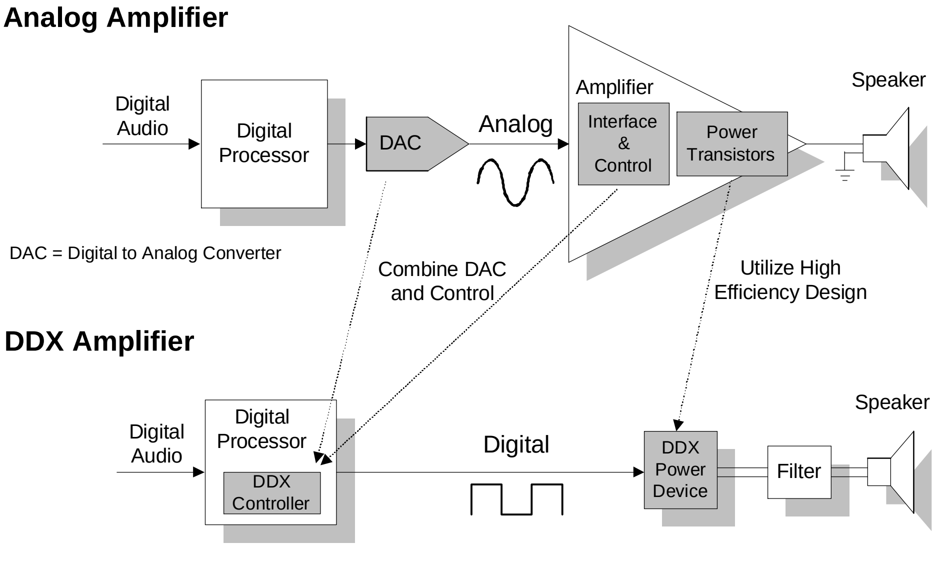

Figure 1 – DDX and Amplifier Architecture Comparison

DDX utilizes an all-digital approach that consists of a DDX Controller and a digitally controlled Power Device. This approach eliminates the DAC and analog signals, and increases efficiency by over a factor of three compared to Class A/B designs. The DDX Controller converts digital audio data into Apogee's patented damped ternary pulse width modulated (PWM) timing signals. These signals are used to control the switching of high efficiency power transistors in a full-bridge configuration. A passive low pass filter is utilized to remove the high frequency component of the PWM output prior to the load.

DDX reduces product system cost because it eliminates the need for the DAC required in analog designs. In addition, DDX eliminates problems with analog noise as there are no low-level analog signals; only digital and power signals are used, which are much less sensitive to corruption. This simplifies circuit board design and improves audio performance in the high noise environments typically found in digital audio products.

Damped Ternary Architecture Minimizes EMI

All switching amplifier designs produce unwanted carrier band energy at and above their switching frequency. Minimizing this electromagnetic interference (EMI) is one of the key design issues faced when implementing switching amplifier designs.

DDX is based on a unique, three-state or damped ternary modulation, which produces less carrier band energy than conventional switching amplifiers that use two-state or binary modulation.

As shown in Figure 2, binary systems generate a small output signal produced by the cancellation of two large signals. Thus, even for low-level signals (i.e. where music usually resides) binary modulation continuously provides energy to the filter and the load.

In contrast, damped ternary operation only supplies energy to produce a signal. When no signal is required, the load is connected to ground, providing damping to the loudspeaker – hence the name damped ternary. In tests on the same hardware, damped ternary's carrier energy was measured to be 16 dB lower than a binary design. This reduction in energy enables some applications to eliminate the need for an output filter, resulting in a lower system cost.

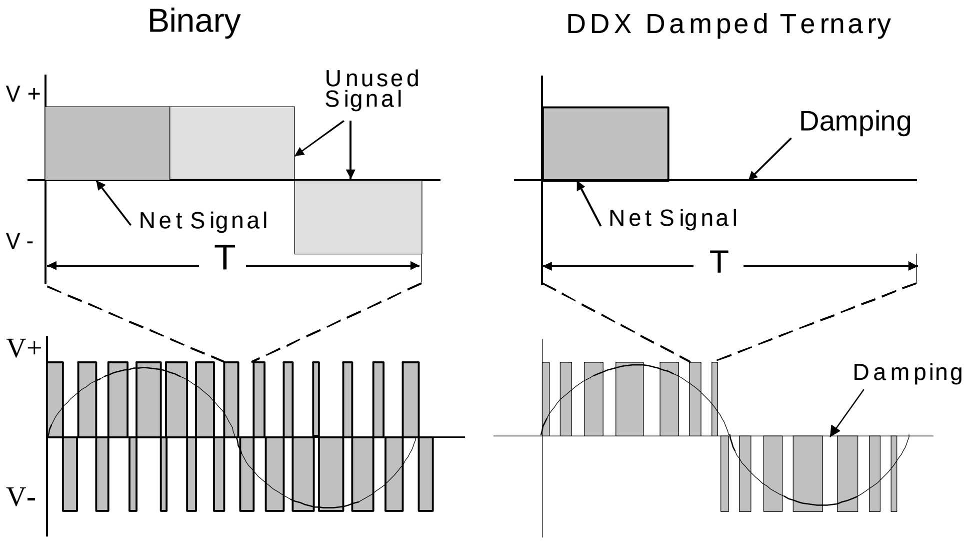

Figure 2 – Comparison of Binary and DDX Damped Ternary Modulation

Increased Efficiency

In addition to lowering carrier band energy, damped ternary modulation has a higher overall efficiency compared to binary designs. This is because binary designs are continuously switching and consequently dissipating more energy in the power transistors and passive components. As shown in Figure 3, this difference gives DDX a 20% efficiency advantage over binary Class D amplifiers at low signal levels. For Class A/B amplifiers, the difference is as much as 300%.

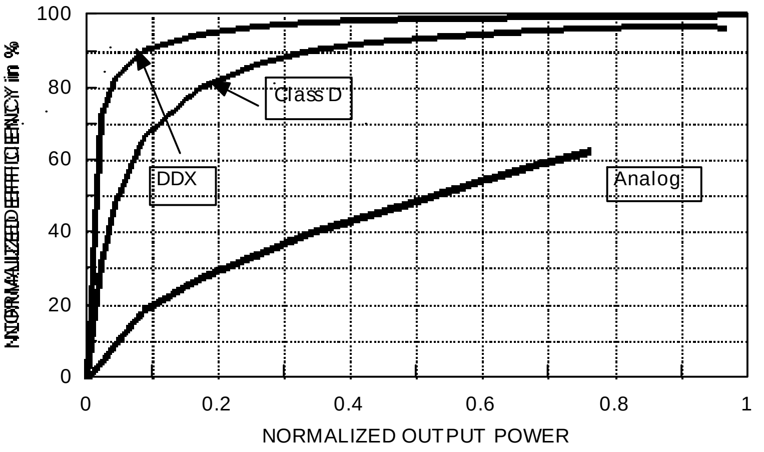

Figure 3 – Efficiency Comparison, Damped Ternary and Binary Modulation

Signal to Noise Ratio (SNR)

DDX provides an excellent signal to noise ratio due to its digital design. With analog designs there is always an input signal present that is amplified through the power stage. With DDX, a zero digital input signal will transition the output to a damped state, grounding the load. This results in an almost infinite SNR. Since this transition from the damped state to a small signal is inherent to DDX modulation, it does not have the “pop and click” problems associated with analog designs.

Power Supply Rejection

Conventional amplifiers require a high power supply rejection ratio because at small signal levels power supply variations can produce audible distortion. DDX modulation, operating in an open loop mode, has inherent power supply rejection that makes most errors inaudible. This is because most of the time the load is connected to ground (i.e. in the damped state) and not to the power supply. In fact, this rejection characteristic provides the most benefit where power supply variations are most audible during the reproduction of low level signals.

Amplifier Stability

In closed loop amplifier designs, stability problems can create significant design challenges in low impedance applications. DDX's open loop design can never be unstable when driving low impedance or widely variable loads. As an example, DDX designs have been demonstrated operating in an automotive application driving a 0.7-Ohm load to produce over 100 watts.

Voltage Insensitivity

The high efficiency of DDX obviously benefits battery-powered applications, but in addition the performance does not degrade as the battery voltage drops. This contrasts with Class A/B amplifiers that use output biasing and feedback to reduce distortion. DDX takes an open loop approach that linearizes the output using specialized digital signal processing (DSP) to achieve low distortion.

Damping Factor and Sonic Performance

One of the performance comparisons associated with an amplifier is the damping factor. This parameter is the ratio of the amplifier output impedance to the load impedance and generally indicates the amplifier's ability to control the load. It is assumed that the higher the damping factor, the better the speaker control and consequently the better the sonic performance.

DDX contradicts the relationship between damping factor and performance. DDX open loop designs have a low damping factor (around 16) but score better in audio listening tests compared to amplifiers with damping factors over 100. This apparent inconsistency is due to DDX's damping and the open loop architecture that eliminates feedback-related performance issues.

Design Scalability

DDX is scalable in terms of both signal processing and power stage. DDX processing can be readily scaled to 24 bits for high-end audio applications or reduced to 8 bits for voice or lower performance audio applications. Because DDX includes a function to increase the input rate by a factor of eight, higher input sample rate standards being adopted by the audio industry (e.g. 96 kHz) can be easily accommodated. Likewise for reduced bandwidth applications, such as subwoofers, the over-sampling stage can be limited to take advantage of a reduced switching speed. Finally, DDX's digital architecture allows the same Controller to drive power stages that can provide from milliwatts to over 120 watts of full bandwidth audio power.

DDX Products and Applications

DDX products include core designs intended for System-on-Chip (SOC) applications and semiconductor products for moderate audio power applications (e.g. digital powered speakers/soundcards and integrated home theater systems). A summary of the current DDX products is provided below:

> **DDX-S200:** Two-channel DDX processing logic core (VHDL and test vectors) that includes volume, mute, and dynamic gain compression functionality.

DDX-2000: Two-channel DDX Controller that includes a multi-mode serial interface, digital volume and balance control and specialized processing to reduce distortion associated with signal clipping.

DDX-2060: Stereo DDX power IC that provides over 35 Watts/per channel of full bandwidth audio power into an 8 Ohm load. The device performance when operated with the DDX-2000 is summarized in Table 1.

High Power Stage Design: Reference power stage design with discrete bridge drivers and FETs that can provide over 100 Watts into an 8-Ohm load.

Parameter	Performance
Power Output (W, RL=8Ω)	
THD = 1%	42
THD = 10%	52
Efficiency (%)	
1 W	50
30% FS	84
FS	89
THD+N (%)	
1 W, 1 kHz (Typical)	0.08
Max (20 Hz-20kHz)	0.20
IMD (%, 19kHz+20kHz, 1:1 IHF)	0.13
SNR (dB A-weighted)	93
Freq. Response	20Hz-20kHz
PSRR/SVR (dB, Vr=0.5V,fr=100 Hz)	60
Cross talk (dB, 0dB=1W, f=1kHz)	70

Table 1 – DDX-2000/2060 Amplifier Performance

System-on-Chip Designs

The DDX 2000 Controller can also be ported as a digital process to System-on-Chip (SOC) audio designs. The DDX Controller provides a low cost development path for digital SOC audio designs such as AC-3 decoders, USB/1394 receivers, and MP3 decoders.

Analog-based designs require a mixed signal approach to integrate the DAC or other analog functions. Although this can be accomplished in 5V and 3.3V semiconductor processes, performance generally suffers as the semiconductor feature size/process voltages decrease. In contrast, DDX directly scales with feature size and the amplifier performance is insensitive to the digital process voltage.

The Future of DDX

Apogee plans to develop a variety of new DDX semiconductor and core products. The DDX Controller can be readily optimized for specific applications such as voice band systems for the communications market. New digital functions (e.g. equalization) can be added to the design. In addition, the DDX core can be combined with other functions digital audio functions to optimize silicon area. New power devices can be developed from the DDX-2060 reference design to address lower and higher power applications.

Conclusion

DDX is a patented, all-digital, high efficiency amplifier architecture developed to meet the needs of a wide range of audio application and power output levels. DDX's unique features position it to be the future amplifier technology for existing products while meeting emerging audio industry amplifier requirements.

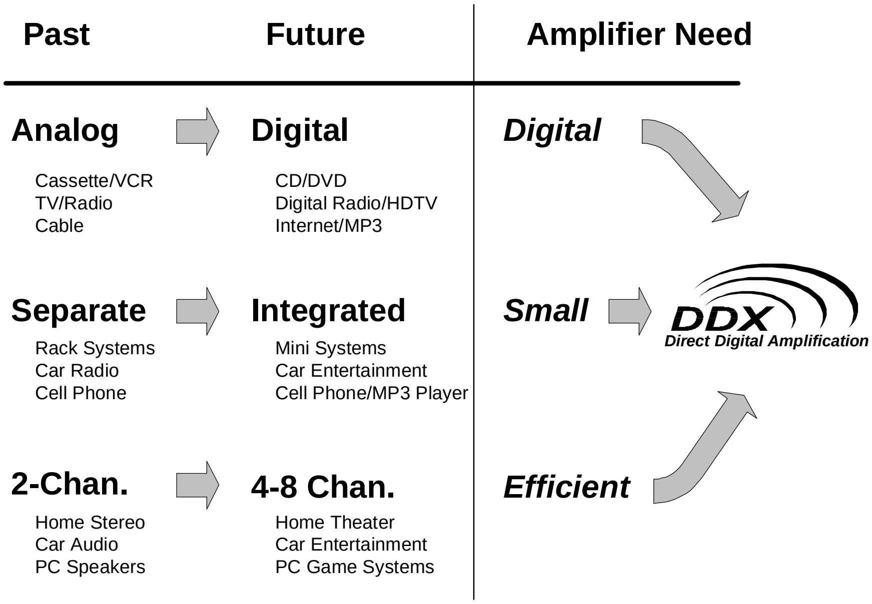

Figure 4 – Audio Market Trends and Amplifier Requirements