Yamaha Power Amplifier

White Paper

August 2008

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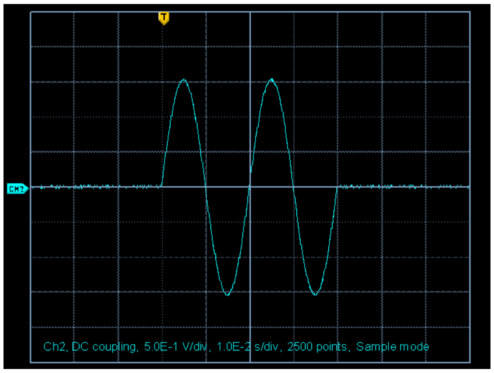
1. About EEEngine

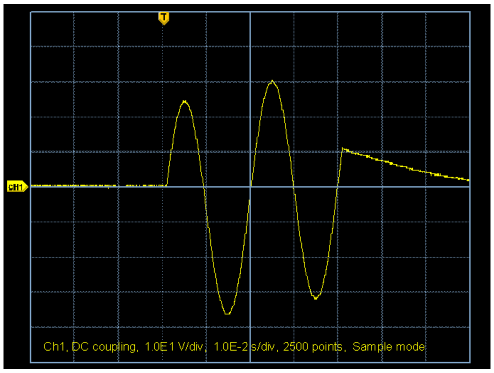
1.1. Introduction

Yamaha Power Amplifier Philosophy

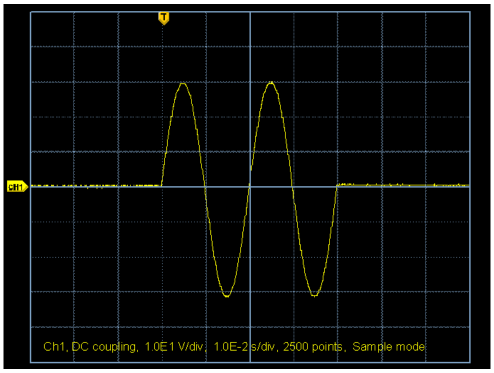
Our approach to manufacturing power amplifiers is simple; pure and natural amplification of the input signal. Mixed audio is sent to the amplifier from the mixing console, to be amplified before final "coloring" or "flavoring" through the loudspeakers. The role of amplifiers in a sound system should not be to add its own color, but to be faithful to the input signal to give you maximum control over the final sonic performance.



[Fig.1] The input signal, 70Hz burst sine wave.



[Fig.2] Output signal of a typical competitor amplifier.



[Fig.3] Output signal of Yamaha T5n amplifier; Natural and true to the input

Reliability is another important feature of Yamaha amplifiers. All Yamaha products are also tested under severe conditions and must comply with Yamaha's strict quality assurance standards. Read more about Yamaha's quality assurance testing and standards at: http://www.yamahaproaudio.com/topics/leading_technology/quality_control/index.html

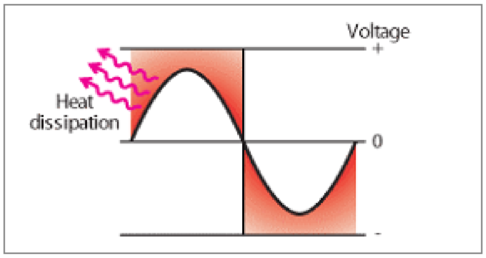
1.2. Explanation of different amplifier topologies

There are many different amplifier topologies, or circuit design principles that are used in professional power amplifiers. The majority of the high power amplifiers seen in the professional audio industry today can be classified as derivatives of three major technologies; Class H, Class D or a hybrid of Class AB and Class D such as Yamaha's EEEngine (Energy Efficient Engine).

Class AB

Class AB technology is the foundation of professional amplification. Even to this day, Class AB amplifiers can be found in many professional audio applications. This topology, which had been the norm in the industry for decades, offers a simple circuit configuration and superb sound quality. Yamaha's older amplifiers such as P2200 released in 1976 and PC2002M, released in 1982 were Class AB amplifiers. Class AB topology, however, has a drawback of always requiring its output stage to drive at maximum voltage output, resulting in a great deal of heat dissipation. This low efficiency is the reason why Class AB amplifiers are comparatively limited in output power considering their unit size and weight. When driven with typical program material with occasional clipping (1/8 power), Class AB topology typically achieves around 20% efficiency*, meaning that 80% of power drawn is lost as heat. Various methods have been developed to overcome this drawback which led to the development of Class H and Class D topologies.

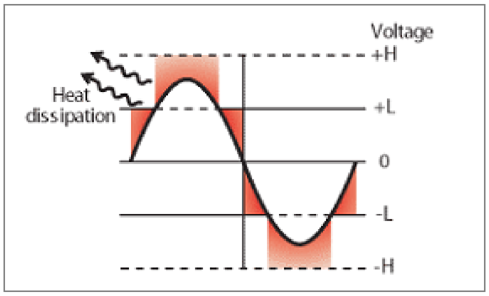
* Efficiency rate within this document refers to overall efficiency of the power amplifier including its mains power supply. Efficiency is calculated at 1/8 of rated output power, which is a reference of typical program material with occasional clipping.



[Fig.4] Class AB operation waveform.

Class H

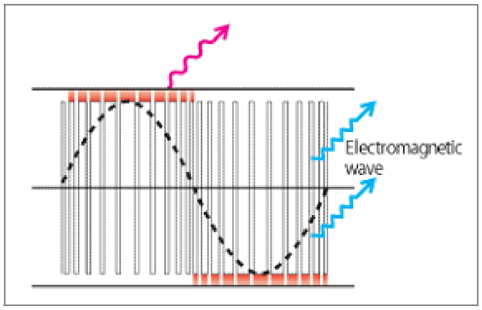
Class H uses a method that switches the power supply voltage level according to the input signal. This can vastly improve output stage heat dissipation by providing low voltage when the signal level is low. However, as the signal level increases, the system functions in the same way as a Class AB system, and efficiency is lost. Class H loses efficiency when fed music signals with a wide dynamic range. A system that uses a multi-step voltage switching method may easily come to mind to overcome this problem, but this would create many complications such as increased switch loss, making it impractical as a solution. Class H amplifiers typically have efficiency of around 30%. Yamaha's P5002 amplifier released in 1982 was an early adopter of Class H topology.



[Fig.5] Class H operational waveform.

Class D

Often misunderstood as an abbreviation for "digital", Class D utilizes PWM, or Pulse Width Modulation. First, a PWM signal is created from the input audio signal. The power supply voltage is then switched according to the pulse width, creating a high power PWM signal to drive the loudspeaker. The elements used for the switching operation require only a minimum of voltage, allowing vast improvements in efficiency compared to previous amplifier topologies. Class D amplifiers typically have efficiency of around 60%. However, to convert the audio signal to a rectangular wave PWM signal, a high power consuming low-pass filter must be used at the output stage to eliminate pulse, or the original audio signal cannot be recovered. The audio signal's frequency response, distortion, and damping factor are affected by the low-pass filter. High power PWM signals also have the side effect of emitting harmonic electromagnetic (EMC) waves within the radio frequency range of up to a few megahertz. Class D amplifiers may be convenient on the efficiency side, but often face difficulties in achieving optimal sonic quality and many manufacturers are attempting to work their way around this problem.



[Fig.6] Class D operational waveform.

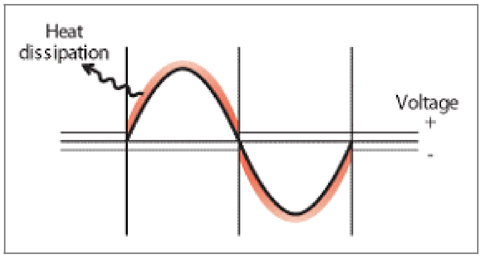
EEEngine

EEEngine combines the sound quality of Class AB circuitry while maintaining the efficiency of Class D circuitry. Combining positive aspects of both Class AB and Class D may seem simple by concept, but it took years of extensive engineering efforts to achieve this technology on a mass production base.

EEEngine overcomes problems conventional amplifier topologies while providing advantages in all areas, offering a dramatic leap in power amplifier design. It realizes efficiency that matches Class D without compromising the sound quality of a Class AB amplifier. The patented EEEngine technology is scalable and can be found on a wide range of Yamaha power amplifiers from the value class P series to the flagship TXn series.

EEEngine tracks the audio signal to always provide the minimum power needed for the final output stage, allowing for surprising improvement in efficiency. It utilizes Class D operation to provide the power at the final output stage of Class AB operation. Almost all of the current energy is output as the audio signal, and just a small fraction of the remaining energy is emitted as heat dissipation through the heatsink.

With the final output stage operating as Class AB, the output signal is of remarkably high sound quality. There is none of the deterioration of frequency response and damping factor or unwanted EMC, as conversion of the audio signal to a PWM signal does not take place. Plus, EEEngine is designed to operate perfectly while keeping the power amplifier heat generation to a minimum, regardless of the load requirements. All together EEEngine offers Class AB sound quality with efficiency that matches Class D. EEEngine circuitry was uprated for TXn and Tn series amplifiers with a new high efficiency electrical current buffer FET driver circuit to withstand the power and 2 ohm loads that the amplifiers will drive.



[Fig.7] EEEngine operational waveform

EEEngine vs competitor technology

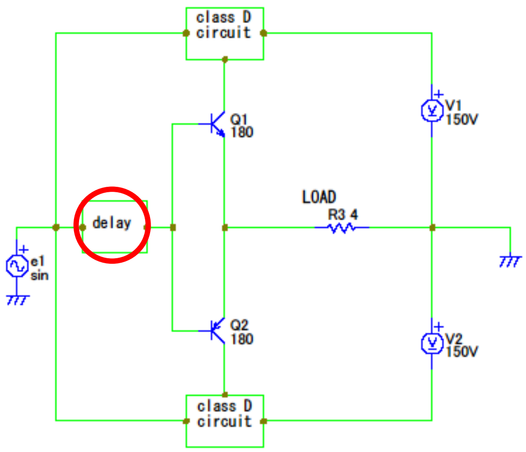
There is one well respected amplifier manufacturer with a proprietary amplifier topology which shares the same concept of combining Class AB amplification and Class D power supply operation. Both technologies track the audio signal to always provide the minimum power required for the final output stage. Two technologies are different however, in its tracking operation methods.

Signals of higher frequencies require a higher slew rate*, and are harder to track. Slew rate is a measure of the ability of an amplifier to respond to very fast changes in signal voltage. To compensate for the inability to keep up with changes in signal voltage, this competitor technology adds a delay to the input signal. This delay gives the Class D power supply more time to respond to sharp changes in voltage, but it must be noted that manipulating the audio signal will inevitably have effect on the final sonic quality.

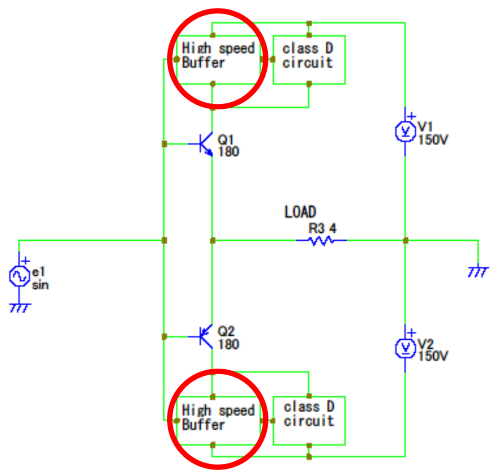
Yamaha’s EEEngine takes a different approach to compensate for Class D power supply’s limitation in keeping up with sharp changes in voltage by adding an auxiliary “high speed buffer” power supply. This high speed power supply circuit is activated only when Class D power supply alone is not able to keep up with the speed. This “high speed buffer” mechanism allows EEEngine to respond to quick voltage changes without manipulating the audio signal and degrading sound quality. The elimination of unwanted and excessive components to the audio line is a reflection of Yamaha’s philosophy of delivering natural output signal that is faithful to the input signal.

* Slew rate affects the ability of an amplifier to accurately render complex waveforms at high power levels. A higher

slew rate is however, preferable only to a point. A higher slew rate will give the amplifier a wider bandwidth, and when in excess it will ultimately result in amplification of signals even in the radio frequency range. This will waste energy, create distortion and also put undesirable stress on the speaker unit.



[Fig.8] Circuit of a competitor amplifier. To allow Class D power supply more time to respond to quick changes in voltage requirements, all audio goes through a delay. Effect on sonic quality cannot be avoided with this manipulation of the audio signal.



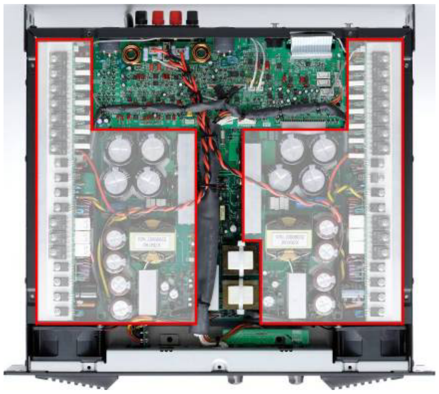
[Fig.9] EEEngine's "High speed buffer" is activated only when Class D power supply is not able to keep up with sharp increases in sound. This circuitry allows EEEngine to maintain a preferable slew rate without manipulating and degrading the audio signal.

2. Yamaha technology

2.1. Dual mono-amplifier structure

Yamaha power amplifier technology – mechanical design

The TXn, Tn and PC9501N series amplifiers are 2 channel amplifiers incorporating a symmetrical dual mono-amplifier design, with each mono amplifier having its own power supply. Dual mono-amp structure plays an important role in achieving separation between the two channels. Having a dedicated power supply on each mono-amplifier minimizes interference between the channels, preventing powerful bass notes on one channel from taking power away from the other channel, for example. The two power supplies operate in opposite phases, synchronizing to cancel noise and lowering electromagnetic interference.

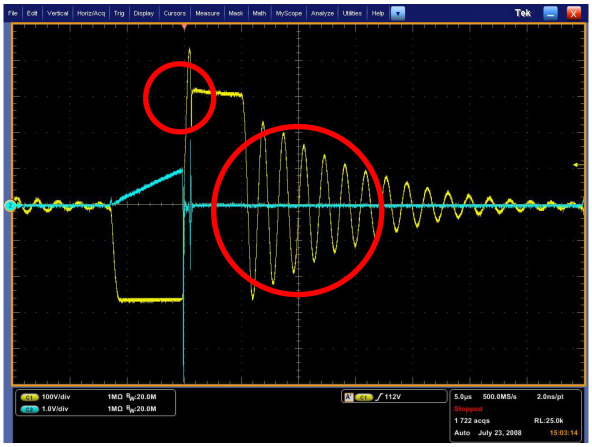


[Fig.10] Dual mono-amp structure. Each channel has a dedicated power supply.

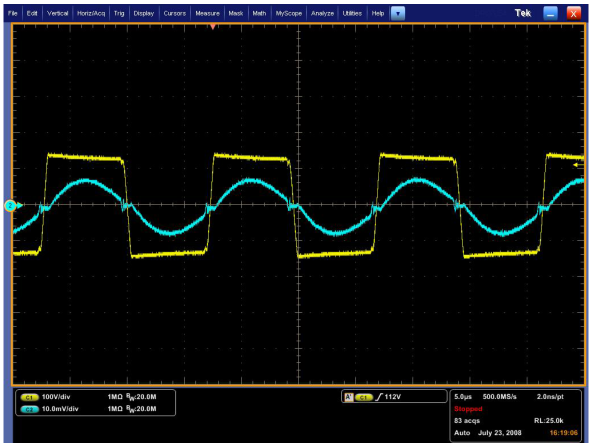
The amplifiers are also carefully designed to suppress internal vibration within the amplifier that could have a negative impact on sound quality. The top surface of the heatsink is reinforced to reduce vibration to the power transistors that are located on top of it. The heatsink itself is fastened to the chassis side panels at numerous strategic points with special insulators that are designed to absorb vibration and chassis resonance that interfere with optimum reproduction.

2.2. Full resonance switching power supply

The power supply plays a crucial role in the quality of any amplifier. Full resonance switching power supplies found on TXn, Tn and PC1N series amplifiers processes two types of switching; Zero Voltage Switching and Zero Current Switching. Full resonance power supplies provide voltage and current waveforms with natural curves, significantly reducing harmonic components from switching noise. Typical switch mode power supplies employ what is typically called "hard switching," which induces more noise into the DC output and gives square waveforms rich in high frequency harmonics, requiring an additional filter to remove them. "Soft switching" as seen in full resonance switching on the other hand, produces natural waveforms that are desirable for music playback.



[Fig.11] Current and voltage of a typical competitor power supply. Visibly much higher noise content can be observed (circled in red). Voltage waveform shown in yellow, and current waveform shown in blue.



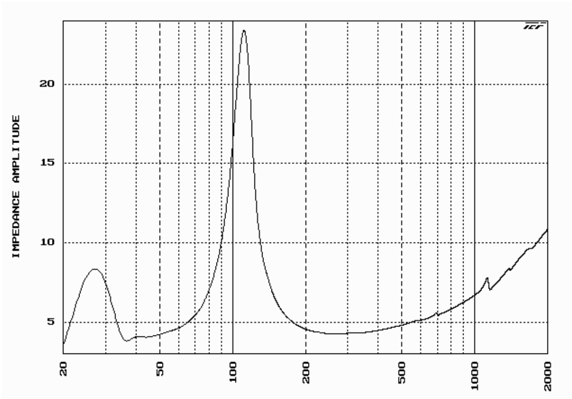
[Fig.12] Yamaha's Full-resonance switching power supply. Smooth, natural waveforms with minimum switching noise. Voltage waveform shown in yellow, and current waveform shown in blue.

3. Behavior of the amplifier under heavy load condition

3.1. Importance of stable 2 ohm load capability

Tn and TXn series were developed with the concept of stable operation under 2 ohm load. We do not necessarily suggest power amplifiers to be configured for a 2 ohm load setup. However, we recognize that stability under extreme low impedance is very important for professional use power amplifiers. For example, in the use of dual subwoofers, woofer units with nominal impedance of about 6 to 8 ohms are typically connected in parallel, giving the amplifier a load of 3 to 4 ohms. Line array speakers are also often connected in parallel, requiring stability at lower impedance. The actual impedance curve of a speaker unit is complex and its load varies greatly depending on frequency. A loudspeaker's lowest actual impedance is usually lower than its nominal impedance. Because of this impedance curve, an operator may unknowingly put extreme stress to the amplifier with a source that repeatedly hits the frequencies most demanding (lower impedance) for the loudspeakers. Because an amplifier is put under extremely demanding conditions at times, it is important that there is enough headroom to keep the amplifier from clipping.

When an amplifier clips, its output signal is distorted and a rectangular waveform is observed. A rectangular wave contains very high frequency and this causes voice coils of the loudspeakers to burn out. Clipping of the output signal, which may potentially destroy speaker units in the system, must be prevented in a professional audio system. An amplifier's ability to maintain stable operation at lower impedance is essential as an amplifier is more likely to clip under lower impedance.

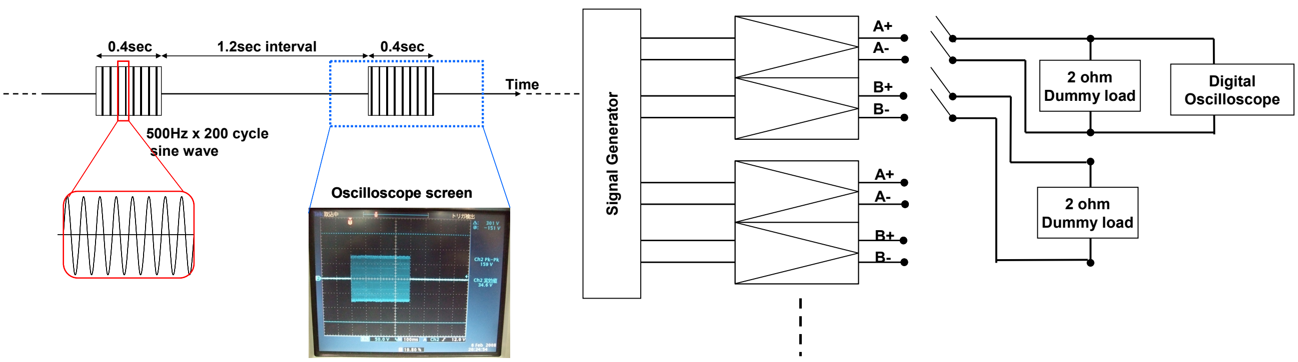


[Fig.13] A typical impedance curve of a bass reflex woofer. The nominal impedance is 4 ohms but the lowest impedance is below 4 ohms.

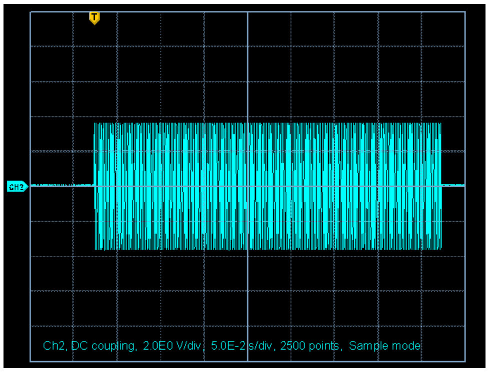
3.2. Comparison of amplifiers at lower impedance situations

Below are oscilloscope measurements to visualize differences in behaviors of some of the better known power amplifiers available today. The test signal is sine wave (200 cycles of 500 Hz = 0.4 sec) followed by 1.2 seconds of interval (no signal). This frequency can be found in many typical program materials, and an interval was set because continuous playback of sine waves is not realistic in actual sound reinforcement applications.

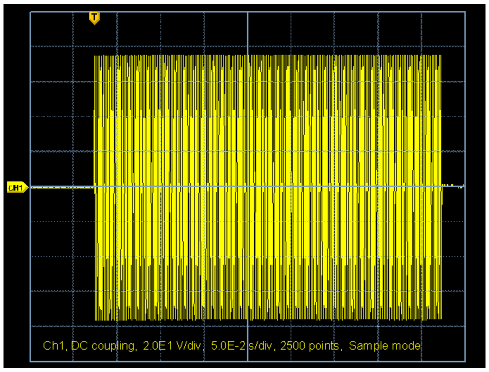
This is a comparison of various power amplifiers in the market, all of which are rated from 2500W to 3000W at 2 ohms. Voltage gain and input levels have been carefully measured and adjusted for a fair comparison.



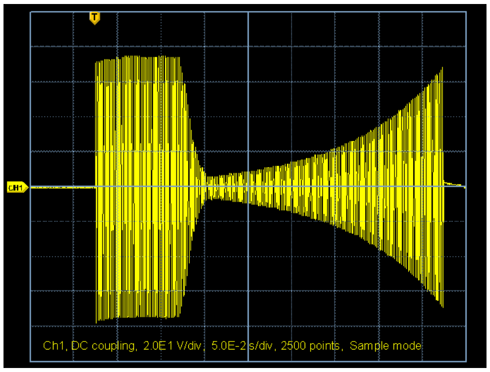
[Fig.14] Set up overview



[Fig.15] The input signal. The same waveform with a higher amplitude is desired for the output signal of the amplifier.

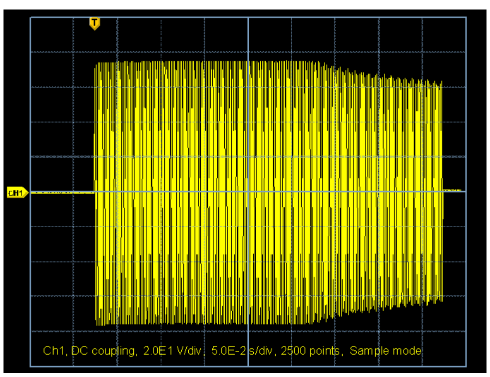


[Fig.16] Output of Yamaha's T5n amplifier (2500W @ 2ohms). Output signal is very true to the input signal.



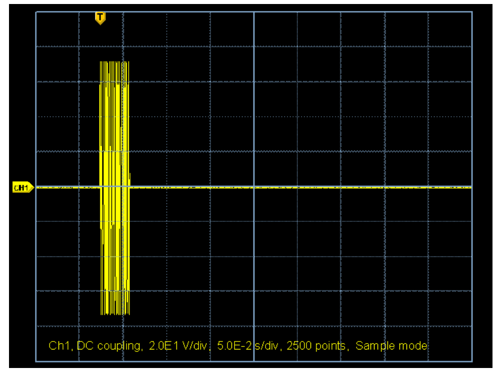
[Fig.17] Output signal of an amplifier, "Competitor A". (2500W @ 2ohms)

The oscilloscope measurement on Fig. 17 shows strong compression-like behavior on its output signal. The output signal shows no resemblance of the input sine wave. This behavior was not seen when the amplifier was driven only on one channel, but quickly became unstable when driven on both channels. We believe this to be result of overstressing of the one power supply that supplies power for both channels.



[Fig.18] An oscilloscope measurement of amplifier model "Competitor B". (2900w @ 2 ohms)

Fig.18 shows that Competitor B, rated 400 watts higher than the T5n at two ohms, seems to start out well but quickly loses power and its output voltage drops. This behavior was observed when the amplifier was driven on both channels.



[Fig.19] "Competitor C" - Rated at 3300W into two ohms, this amplifier muted quickly after its limiter kicked in. (3300W@ 2 ohms)

Fig.19 shows the output signal of amplifier model, "Competitor C". Though this amplifier is rated at 3300W into two ohms and specified to have the highest power of all the amplifiers in this comparison, the oscilloscope trace shows contradicting results. Its limiter kicked in, drastically dropping output voltage. Though not apparent on one still image of the measurement, it took a few seconds for the output voltage to recover, only to have the limiter activated once again shortly afterwards. This behavior repeated for the entire duration of this test.

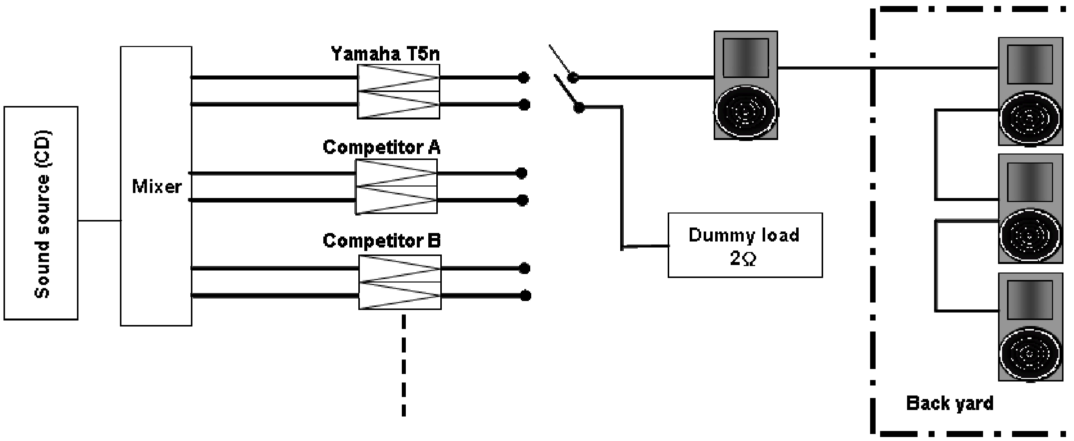
These results show that different amplifiers behave differently under low impedance operation. The results of the comparison also prove that actual performance of an amplifier cannot always be predicted from its catalog specifications. Because there are no industry standards for amplifier specifications, paper comparison of figures such as output power is not very practical.

3.3. Explanation of results of listening test using music source

We conducted the above experiment using a music source. To replicate a more realistic setup, we replaced the dummy load on one channel with four loudspeakers connected in parallel. To reduce interference between the four loudspeakers and also to reduce stress on our ears, we verified our results from one reference loudspeaker; the remaining three loudspeakers were placed in a remote location.

The results of this listening test were basically reproductions of the oscilloscope measurements. The kick drums on "Competitor A" were heavily distorted, extremely harsh on the ears and harmful to the loudspeakers as well. Its playback level fluctuated after the kick drum, as was observed in the oscilloscope measurement.

Competitor B's output was considerably distorted when louder notes were repeated. The amplifier's limiter kicked in on "Competitor C" after the kick drum beat. The amplifier muted for a few seconds before returning. This limiter may protect the amplifier from damage, but this behavior is unacceptable in a live situation. Yamaha's T5n showed positive results in this test. The T5n showed minimal limiting and had the most headroom among the competitors. The amplifier's output did show slight distortion when levels were high, but the playback remained musical and had the best performance in this comparison.



[Fig.20] Listening test set up

YAMAHA CORPORATION

P.O.BOX 1, Hamamatsu, Japan

http://www.yamahaproaudio.com