Selecting a Power Supply for Multi-Channel DDX® Amplifiers

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Abstract

Audio amplifiers are intended to provide a varying power level to a transducer or speaker such that it faithfully recreates the original analog recording or digital transcription of an original sound source at our ears. Over the years, abuse in power output claims for audio amplifiers caused regulatory agencies to step in and create standards for testing. Most power rating standards resolve to just some preconditioning (warm-up) time at significantly less than full rated power followed by a 5 minute (or more) operation at the claimed continuous rated power. As a result, consumers can now compare advertising claims for amplifier output power on a somewhat uniform basis. This paper will give insight on how to design a power supply for an audio amplifier such that it will meet those claims without the supply becoming too costly. It will also discuss the trade-offs.

Introduction

Output power claims for audio amplifiers are tightly controlled by most governmental regulatory agencies. Power supplies must be able to deliver power to the amplifier stages such that the product performance meets these regulatory requirements.

Currently, most regulatory agencies accept that a warm-up or pre-conditioning period at 1/8 of the "continuous power" rating followed by a short term (at least 5 minutes) at "continuous rated power output" is a sufficient test of an amplifier's capability. They generally feel that 1/8 power is a fair indicator of the average music content of your "typical" CD. The duration of the warm-up period varies with the specifying agency.

Specification	Pre-conditioning (warm-up)		Time at "Continuous Rated Power"
	Power	Time	
DIN EN 61305-3	None	None	600 Seconds
EIA/CEA-490-A	1/8 power	½ hour	5 minutes (Note 1)
FTC 16 CFR Part 432	1/8 power	1 hour	5 minutes (Note 2)

Note 1: Each channel is tested individually, while all other channels run at 1/8 power.
Note 2: All channels in same frequency range test at full power. Subwoofer tests separately.

Table 1. Various Test Methods for Audio Amplifiers

This, however, does not represent all CDs. To double-check what "typical" and "worst case" are, we drove both channels of a stereo DDX® amplifier from a digital CD player at full power (unity gain with no clipping or compression) into two "8-Ω" speakers. Various music CDs were chosen, ranging from classical to heavy metal and played through from start to finish.

Using a FLUKE 89-IV TRUE RMS MULTIMETER, the "average RMS" power was integrated over the total playing time of each CD. Most rock and heavy metal CDs ranged around 20% of the continuous power rating, while classical CDs varied widely from very little power up to higher levels than rock CDs, depending on the composer and the level at which they were recorded. The worst case RMS power found was on a "Mega-Bass" CD. The average power measured over the length of this entire CD was about 40% of the "continuous power" rating for the amplifier. To properly play this "worst case" CD at full power for one-hour, you would need a power supply that can deliver 40% of its maximum power on an RMS basis.

Choosing the Design Configuration

One almost never needs 40% power on a "continuous" basis. Most consumers run their systems at well below the maximum with only occasional use at or near full power. This difference between maximum available power and typical usage is expressed in the power rating systems of the various regulatory agencies. A power supply can be designed in different ways depending on the needs of the intended market place:

Full RMS Power Supply (Full Power Requirement).

Here the power supply has components that fully meet all the power requirements and the heatsink(s) are appropriate to support the total dissipated power on a continuous basis. This power supply can deliver full power all the time. This approach, which is expensive, would be used in only the most demanding high quality DDX® amplifiers as used in professional, studio or laboratory audio amplifiers.

Medium Power Supply (1/3 Continuous Power Requirement).

Previous versions of the FTC and EIA specifications required this power supply level. In this power supply, the semiconductors and components are rated to take the full output current for several minutes, but the heat-sink's thermal capacitance limits the time duration. The power supply heatsink is sized to sustain 1/3 output power continuously (RMS) but has enough thermal mass and components are robust enough to keep the power supply from overheating long enough to meet the "5 minutes at full power" requirement. After meeting the test requirements this power supply will continue to function properly if returned to 1/3 power level. This approach still performs well, with minimal clipping or compression, but is more expensive than the minimum regulatory agency requirements.

Cost Efficient Power Supply (1/8 Continuous Power Requirement).

Current versions of the FTC and EIA specifications allow for this kind of a supply. In this design the components can carry the peak currents for a limited time. The heatsink may be undersized in area but has sufficient thermal mass (1/8 inch or greater aluminum thickness) to keep the semiconductor temperatures below the specified thermal limits for the duration of the test period. Continued usage following the test period could result in a power supply failure if thermal protection is not implemented in the design.

Design considerations

In the U.S., a quick look at chain stores that sell audio equipment reveals what is most common - virtually every system uses a "cost efficient" power supply. For that reason this paper will focus on that kind of supply. Everything discussed for this supply could also apply to either of the higher capability power supply types as well.

Switching power supply inductors must be able to handle the peak current without saturating because inductor saturation causes excessive current to flow in the regulation transistors, which can very quickly cause a failure.

Power supply output capacitors must be of a low impedance type to minimize heat losses due to high frequency AC current flowing through the ESR of the capacitor. In addition, this provides a low output source impedance when looking back from the amplifier. This impedance acts in series with the amplifier's own output impedance and affects the amplifier's overall damping.

The power supply must incorporate current limiting to protect against short circuits. If the amplifier is driven such that current limiting engages, the following effects may be noticed:

- As the power supply voltage sags due to current limit, the audio output becomes compressed. AC ripple voltage from the AC line filter capacitor may pass through to the power bridge, which may result in amplitude modulation distortion in the audio output.
- If a multi-tap power supply is used to generate the ±12 V, 5 V, 3.3V, 2.5V, etc. for the front end components, they could sag in proportion to the main audio output voltage. This could cause tuner and/or motor drive problems. It is recommended to design a single output supply capable of providing peak audio power plus enough extra to drive a secondary post-regulator that can provide auxiliary power for the front end system components. This provides an additional benefit in that it establishes a minimum load for the power supply when the power stage is not drawing any power.

Design Procedure

Calculate the Required Power Supply Voltage

The required power supply output voltage (V_{DC}) to be applied to the power bridge can be calculated from the following equation:

$$V_{DC} = \frac{(Z_{PCB\_TRACES} + Z_{FETS} + Z_{INDUCTORS} + Z_{SPEAKER})}{Z_{SPEAKER}} * \frac{\sqrt{2 * P_{RMS} * Z_{SPEAKER}}}{d} \qquad \textit{Eq. 1}$$

Where:

Z_{PCB_TRACES} = Total impedance of all PC board traces in series with speaker loads. This value should be held to less than 0.05 Ω total.

Z_{FETS} = Total DC resistance of two MOSFETS in series.
NOTE: The $R_{DS\text{-}ON}$ of a MOSFET increases to 150% of its data sheet resistance when the junction temperature reaches 150ºC.

$Z_{INDUCTORS}$ = Effective DC resistance of both output filter inductors after accounting for hysteresis losses, high frequency "skin effect" and shift in copper resistance due to heating.

$Z_{SPEAKER}$ = Speakers are usually specified as "8 Ω". You should use the actual measured DC resistance which is usually much lower, typically 50% to 80% of the "specified" impedance. Include the DC resistance of leads connecting the amplifier terminals to the speaker here as well.

P_{RMS} = Required RMS output power.

d = Maximum achievable PWM duty cycle (d = 0.9375 for the DDX-2060 and DDX-2100 power devices)

Calculate the Power Requirements

A power amplifier made from a DDX-2100 or DDX-2060 power device will have an overall full-power efficiency greater than 89% when operated at 25ºC into one 8 Ω speaker per bridge or into one 4 Ω speaker with two bridges connected in parallel. This efficiency figure includes the losses in the filter components, i.e., the hysteresis, eddy current and resistive losses in the filter inductors. The following equation can be used to calculate the total power the supply must deliver to produce a required audio power output level: Engineers must perform their own efficiency calculations if they design their own output filter.

$$P_{SUPPLY} = \frac{P_{AUDIO}}{h_{AMP}} + P_{FRONT\_END} \qquad \textit{Eq. 2}$$

where:

P_{SUPPLY} = Total power provided by the power supply.

P_{AUDIO} = Audio power to the speaker.

η_{AMP} = Efficiency of the Power Amplifier.

P_{FRONT_END} = Power for tuners, drives, etc.

The overall power stage efficiency drops to 86% when the power bridge is heated to 150ºC (the maximum allowable junction temperature of the device.) The reduction in efficiency at elevated temperatures is due in part to the change in the MOSFET's $R_{ds\text{-}on}$ and in part to the increase in the filter inductor's copper resistance.

Design Example

Let's look at a typical 5.1 channel system, composed of five 50-watt satellites and one 100-watt subwoofer for a total output power of 350 watts.

Calculate the Power Supply Voltage

The $R_{ds\text{-}on}$ of each of the MOSFETS in either the DDX-2100 or the DDX-2060 is 0.25 Ω per MOSFET. This would mean that the total series "hot" resistance of the MOSFET pairs in a bridge is:

$$Z_{FETS} = 2 * 0.25\Omega * 1.5 = 0.75\ \Omega \text{ at } 150^{o}\text{C.}$$

According to Equation 1, providing 50 watts RMS to an ideal 8 Ω speaker requires about 33.4 V_{DC} input to the power bridge to account for series resistance losses:

$$V_{DC} = \frac{(0.05 + 0.75 + 0.05 + 8)}{8} * \frac{\sqrt{2 * 50 * 8}}{0.9375} = 33.4\ V_{DC}$$

using just the inductor's DC resistance or approximately 34 V_{DC} when we factor in the inductor's hysteresis losses.

NOTE: The DDX-2060 is rated at 30 V_{DC} max.

Calculate the Power Requirements

The power required for front end components such as tape drives, CD/DVD drives, digital readouts, microprocessors, tuners, etc. are also part of the power supply's minimum load. Since these elements can draw as much as 10-30 watts they add to the power supply's minimum load. Lets look at the calculations for a typical DVD player. With zero audio output the power supply has to deliver:

$$P_{PS\,\min} = (\frac{0w}{.89} + 22.5w) = 22.5w$$

One eighth of the total continuous power rating of 350 watts is about 44 watts. Factoring in power stage efficiency, the power supply has to deliver about 50 watts to the output stage. Since the drives and front-end components could draw another 22.5 watts:

$$P_{PS\,mid} = (\frac{44w}{.89} + 22.5w) = 72w$$

When you use five full range speakers plus a subwoofer, at full 350 watts "total continuous power" it would appear that the power supply might have to deliver:

$$P_{PS\,\max} = (\frac{350w}{.86} + 22.5w) = 430w \text{ peak.}$$

In reality, due to the crossover between the satellites and the subwoofer, the calculation is somewhat different. Regulatory agencies typically specify that you must test at 1 kHz. The subwoofer will provide negligible output power at 1 kHz, so only the five satellites will draw power during this test. This substantially lowers the requirements:

$$P_{PS\max} = (\frac{250w}{.86} + 22.5w) = 313w \text{ peak.}$$

Due to the steady state front-end requirements, the ratio of power supply output power required for maximum output vs. that required at “1/8 power output” would be a little over 4.5 to 1 instead of the 8 to 1 ratio we expected.

Power Supply for a Typical DVD Player

With a DDX® ® amplifier the power stage draws anywhere from Zero power to full output power. A switching power supply doesn’t like to operate any of its outputs at zero output power. The regulation between full power and no power will include the change in forward drop of the rectifier diodes. For this reason, we recommend that you provide a single output Primary Power Supply, (an off-line, 34 volt output switcher at 313 total watts peak output power). You can use this to drive a secondary post-regulator to provide the front-end power requirements. A typical DVD player might have the following power supply requirements:

Primary Power Supply

Volts	**Amps**	**Power**	**Description**
+34 VDC	8.5 A Max	290 W Max	Input Power to Audio Output Stages
+34 VDC	0.66 A	22.5 W Avg.	Input Power to Post-Regulator (includes losses)
Total Power	9.2 A	313W Max	Max Power Output from Primary Power Supply

Post-Regulator Power Supply

Volts	**Amps**	**Power**	**Comments**
+ 5 VDC	2.1 A	10.5 W	This output also provides power to LDO regulators for the 3.3 and 2.5 V_{DC} outputs
+12 VDC	600 mA	7.2 W	Motor drives, op-amps, etc.
-12 VDC	100 mA	1.2 W	Op-amps, etc.
-26 VDC	50 mA	1.3 W	Bias voltage for display
Total Power	- - -	20.2 W	Total power at output of regulators

For this example we see that the power supply needs to provide about 313 watts during the required testing time of a “full power” test. At normal operation, however, it provides less than 72 watts.

Conclusions

Meeting current regulatory requirements for audio amplifiers at a maximum available audio output power rating, a working power supply has to provide a ratio of maximum power to average power that is broader than other types of devices. This "peak" power has to be delivered for a reasonably long time in order to meet the specifications, but experience shows that if used with satellite-subwoofer systems that separate the frequency ranges into different speaker groups, the supply rating can be considerably reduced below the sum output power of all channels. The time it takes a heatsink to raise its temperature (thermal time constant) helps us to operate at this condition for a reasonable period of time and within acceptable operating temperatures.