Audio Engineering Society

Convention Paper 5694

Presented at the 113th Convention

2002 October 5–8 Los Angeles, California, USA

Power Supply Regulation in Audio Power Amplifiers

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ABSTRACT

Audio power amplifiers have typically been supplied power by the simplest possible means, usually an offline supply with no line or load regulation, most commonly based on a line frequency transformer. Even modern amplifiers utilizing switchmode power supplies are usually designed without line or load regulation. The exception has been made for high-end audiophile amplifiers. The pros and cons of a regulated power supply are investigated.

BACKGROUND

A typical power supply in an audio power amplifier is shown in Fig. 1. The AC line is passed through a transformer and rectified. More recent offerings have been in the form of Fig. 2, where the AC line is rectified first, then converted to high frequency AC with semiconductor switches, passed through a transformer and rectified.

Neither of these configurations offers line regulation, which is the ability of a power supply to maintain a constant output voltage with variation in the AC line. The output voltages of these circuits are a function of the AC line voltage, shown in Fig. 3.

Also lacking in both configurations is load regulation, which is the ability of a power supply to maintain a constant output voltage when load power draw is varied. The output voltages of these circuits are a function of the load power drawn, shown in Fig. 4.

A switching power supply with line and load regulation is configured as Fig. 2, but with additional control circuitry. It has substantially constant output voltage over a range of line and load conditions.

This paper explores the audio amplifier performance differences in these approaches.

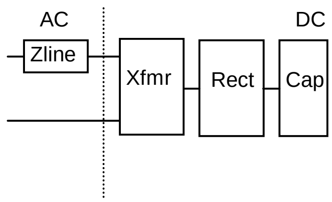


Fig. 1. Unregulated Line Frequency Supply.

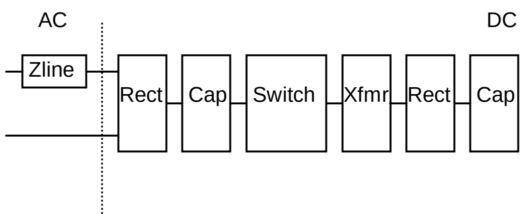


Fig. 2. Unregulated Switching Power Supply.

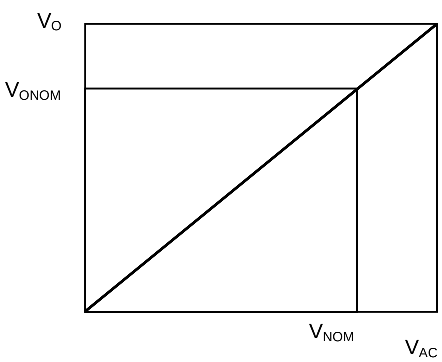


Fig. 3. Unregulated Supply
Output Voltage vs Line Voltage.

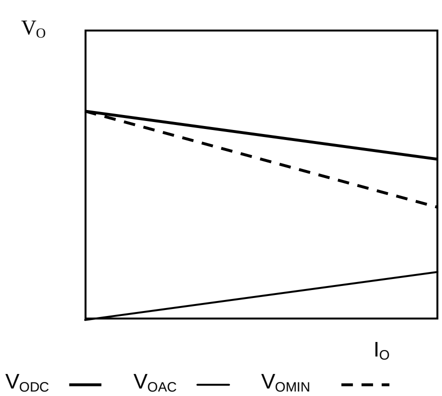


Fig. 4. Unregulated Supply
Output Voltage vs Load Current.

DESIGN CONSIDERATIONS

High Line Limitation

When designing a power amplifier with an unregulated supply, the rail voltage at 15% high line must be chosen so that no amplifier components are beyond their operating limits. If the limiting factor in the design is the voltage rating of these components, then nominal power output will be limited to what can be achieved by operating at about 15% under their ratings.

For example, an ideal amplifier operating with 63V rails can deliver 1000W into 2 ohms, shown in Fig. 5. If the 63V occurs at 15% high line, then the amplifier will operate from 55V rails at nominal line, and put out only 750W. The square law relationship between supply voltage and output power means a small line voltage drop has a pronounced effect on output power. The 750W power at nominal line assumes nominal line voltage is maintained at the power supply input, as could be done with an autoformer.

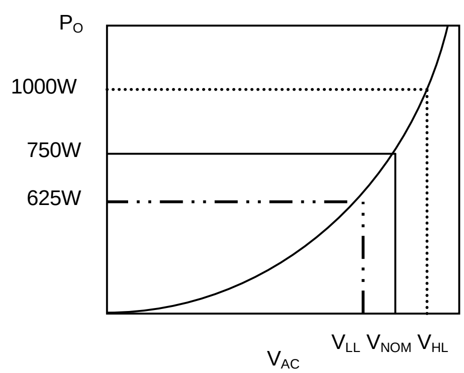


Fig. 5 Unregulated Supply P_O vs V_{AC}

Low Line Performance

When run from the unassisted AC line, the source impedance of the line, Zline in Fig. 1, will cause the output voltage to sag even lower. Zline will vary with location, but a high powered amplifier can easily sag the line voltage 10%. Even if one piece of unrelated high power equipment drags the AC line voltage down, all amplifiers on that circuit will see the same decreased line voltage. This means that a nominal 750W amplifier may see rails of only 50V in a real world application, with output power limited to 625W, down from our 1000W limit by one-third

Overexcursion

The peak available output in this example varies from 625W to 1000W. When specifying a loudspeaker to run from this amplifier the driver excursion limits must be considered. The high line limit of 1000W can be reached on a transient basis, and will cause driver overexcursion if not accounted for.

Power vs Load Impedance

An ideal amplifier running from regulated rails has the characteristic of doubling output power when load impedance is halved, as shown in Fig. 6. So an ideal amplifier rated at 250W / 8 ohms would give 500W / 4 ohms and 1000W / 2 ohms. An unregulated amplifier could be designed in several ways. It could be limited at 8 ohms due to voltage constraints, and would start at 250W / 8 ohms, but power would not double with a halving of load impedance. A typical product delivers 350W /4 ohms, and 500W / 2 ohms, shown as Unregulated Supply 1 in Fig. 6. So in comparison to the regulated amplifier, the unregulated amplifier has less power at 2 ohms for a given 8 ohm power.

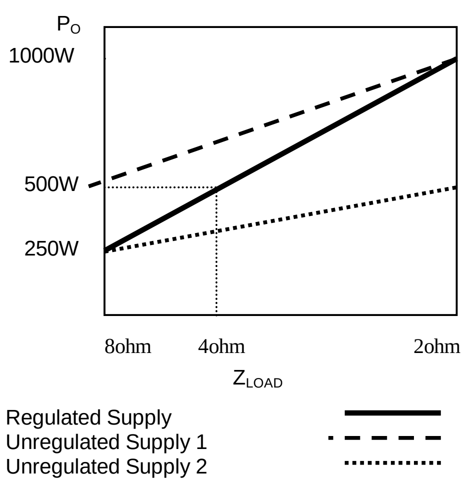


Fig. 6. Output Power vs Load Impedance

Another design approach could have the unregulated amplifier match the 1000W 2 ohm power rating of the regulated amplifier, which would typically achieve give 750W / 4 ohms, and 500W / 2 ohms. So in this comparison the unregulated amplifier, shown as Unregulated Supply 2 in Fig. 6, has more 8 ohm power for a given 2 ohm power.

A third unregulated design could match the 4 ohm power of the regulated amplifier, with 2 ohm power falling below the regulated rating, and 8 ohm power rising above the regulated rating.

SMALL SIGNAL CONSIDERATIONS

Generally, the effects of regulation should not come into play at low signal levels.

The possibility exists that an amplifier driven at high power can cause enough AC components in the power supply rails to affect the gain stages of the amplifier if they are not designed to safeguard against this. An example would be where a differential pair used in the front end has its current source configured as a high value resistor tied to one of the rails. In this case, supply ripple would actually modulate the loop gain of the amplifier, affecting stability and clip recovery characteristics.

Another possibility is that one channel of a stereo amplifier could be driven at high power, modulating the rails of a second channel driven lightly. In this case, we are relying on the power supply rejection ratio of the power amplifier to keep the ripple out of the signal output. Fortunately, PSRR is very good at low frequencies for any well designed amplifier, so this effect should be minimal.

LARGE SIGNAL CONSIDERATIONS

Most of the difference seen when using regulation occurs at high power, at or near clipping. When heavily loaded the unregulated supply has line frequency related components as well as output frequency related components. These are visible at clipping in the envelope modulation of the output. Since the line frequency related components are not harmonically related to the audio signal, the spectrum at clipping will contain components that are not harmonically related.

Fig. 7 shows the audio output of an amplifier driven with a 200mS duration 100Hz tone burst, running from an unregulated 60Hz supply. There are several effects immediately visible.

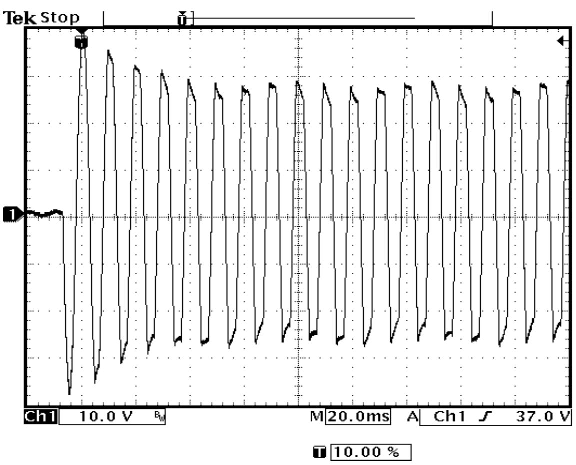


Fig. 7. Unregulated Supply Burst Output Waveform.

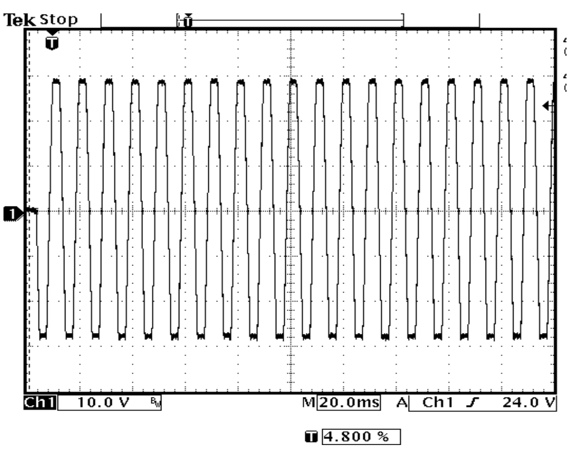


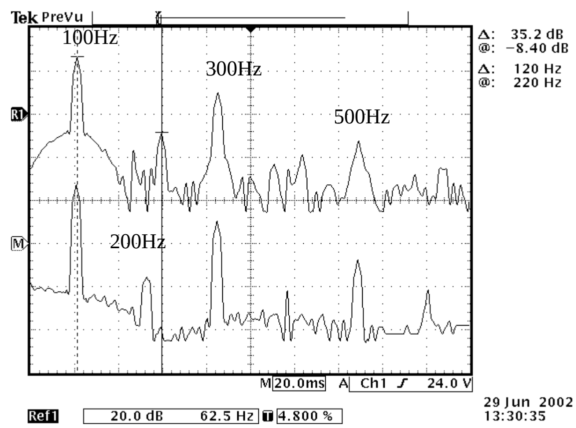
Fig. 8. Regulated Supply Burst Output Waveform.

The first effect seen is the high peak power available for the first cycle compared to the much lower steady state power. This is the transient headroom or dynamic headroom, which could be seen as a benefit if the program material had short peaks of this duration. With bursts of significant duration this effect is of minor relevance, though.

The second salient feature of the output is the envelope modulation occurring at the beat frequency of 20Hz. This causes the clipped waveform to contain this beat frequency component, which is not harmonically related to the 100Hz fundamental.

The third feature noted is the inconsistency in slopes of the clipped sinewave half cycle peaks, slope being dependent on position in the envelope. We see a 5:1 range of slopes.

Fig. 8 shows the audio output of an amplifier driven with a 200mS duration 100Hz tone burst, running from a regulated switching power supply. We see that the clipped peaks all have a uniform horizontal slope, with the first peak the same as all subsequent peaks.



Unregulated: Top
Regulated: Bottom

Fig. 9. Spectrum of Unregulated and Regulated Burst Outputs.

Fig. 9 shows the spectrum of the signals from Fig. 7 and Fig. 8. There are quite a few differences, predictable by inspection of the waveforms. There are many components present that are not harmonically related to the fundamental in the unregulated case. The heterodyned waveform of the unregulated case shows sidebands on the fundamental and harmonics, as well as altogether new peaks when compared to the regulated case.

The magnitudes of these components are not negligible, as shown below with magnitudes relative to the fundamental. The magnitude of the sidebands of the fundamental measured at 80Hz and 120Hz are only down 35dB, as is the 220Hz component. Note there is 200Hz present in the regulated amplifier due to clipping asymmetry, while the unregulated amplifier has significant components at 180Hz and 220Hz.

20Hz	–35 dB
80Hz	–35dB
120Hz	–38dB
180Hz	–43dB
220Hz	–35dB

Table 1. Magnitudes of Selected Unregulated Supply Frequency Components.

The audible effect of this should be apparent to even the untrained ear in a listening test, manifesting itself as a level dependent modulated hum and buzz. In the case where the signal frequency harmonics are close to the line frequency harmonics, the effect may sound like a slightly out of tune string.

Subjective listening tests of amplifiers with similar specs can show audible differences at high power; the above effect will vary significantly from one design to the next, and this may explain some of the difference between amplifiers.

Since this occurs only at clip the effect can be eliminated entirely by sizing the amplifier such that it never clips.

Conclusions

Line and load regulation in power supplies for audio power amplifiers has been reviewed. Some design limitations have been shown. Small signal effects have been dismissed as negligible, but large signal effects have been shown to be significant. The envelope modulation of the output has been shown to give rise to significant components that are not harmonically related to the fundamental. The possibility that this effect is audible and partly responsible for perceived sonic differences between amplifiers has been acknowledged; further empirical work may verify this.