An Easy way to Correlate distortion with Sound Quality using FFT slope

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1. Introduction

This article is an update to my THD weighting article in Linear Audio Volume 4 [1]. In that article a weighting filter was used to amplify the higher frequency harmonics relative to the ones close to the fundamental so the THD reading after the filter becomes a far better indicator of sound quality than straight THD readings without this filter.

This updated paper covers a simpler approach that I have been routinely using in simulations. It is easy to use and does not require any extra hardware.

My updated approach

My new approach allows you to look at an FFT plot of harmonics from distortion in an amplifier and decide how useful it is as an indicator of sound quality. You need an FFT plot of the distortion spectra for the first 5 or 10 harmonics when running near full rated power. I used 330Hz with a PC sound card.

Then you simply to place a ruler on the harmonics and find a reasonable fit through the peaks of the first few harmonics. Then slide the ruler to the vertical axis to read the x-axis to get the slope from the change in dB (Y-axis) divided by change in number of decades of frequency (I usually use one decade). It's that easy.

The next step is to look at the fundamental and the 2nd (or 3rd) harmonic to see if these harmonics are already below the audible level. See **Fig. 1** below for the limits for audibility [2,3]. With a 50Hz or 100Hz fundamental its 2nd harmonic is not audible below about 1% and about 0.3% for 3rd.

When the 2nd (or 3rd) harmonic are below audibility AND the harmonics slope is faster than -50dB per decade then you know the higher harmonics cannot be heard above the lower harmonics. This is because our hearing is about +50dB decade more sensitive to the higher harmonics than the lower ones.

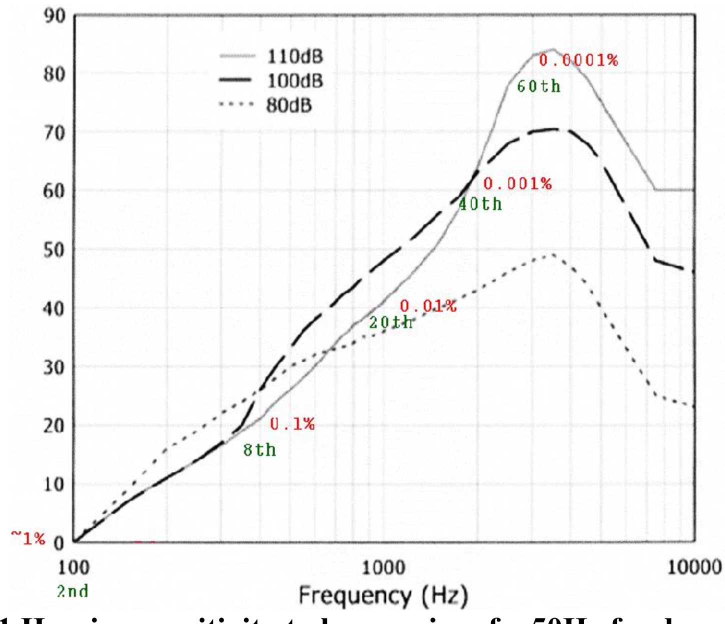


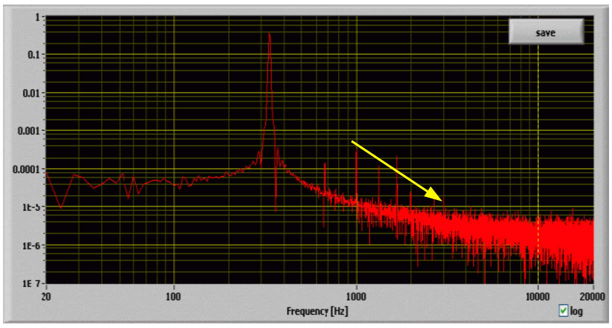
Fig. 1 Hearing sensitivity to harmonics of a 50Hz fundamental.
Courtesy Linear Audio Vol.4 Fig 2 with data from [2].

If you find the slope is less than about -40dB per decade then you know the higher harmonics may play a part in whether this distortion is audible. Even if the 2nd (or 3rd) harmonics are not audible it may be that the higher harmonics can be heard.

According to the data for Fig.1, the most extreme example is the 60th harmonic of 50Hz to 100Hz fundamental which is just audible at a level of about 1ppm (0.0001% or -120dB) [footnote[1]]. For harmonics around the 20th you can hear them at around 0.01% (or -80dB).

Demonstrating amplifier harmonic rolloff

The Cube-law Class-A amplifier harmonic spectrum [4] is shown below at 50 watts and 300Hz. The harmonics roll-off at about -80dB per decade.



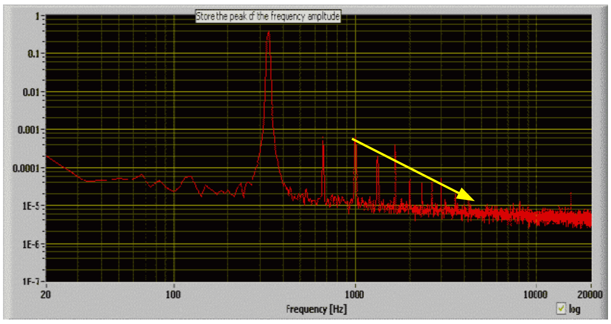


Figure 2[L]. Cube-law Class-A harmonic distortion spectra at 50W.
Fig 3[R] Cube-law Class-AB_{50} at 50W with half the idle current gives increased high-order harmonics and a rolloff lower slope. Note: Y-axis is ratio not % so '0.001' is '0.1%'.

When the idle current is halved giving Class-AB operation at 50W the rolloff rate of the harmonics is reduced to about -40dB per decade. But we want we want harmonics from crossover distortion to roll-off *faster than -50dB/decade* so crossover distortion cannot be heard – and if you do hear distortion then it is only the low-order harmonics which are not so obnoxious and can be tolerated up to significant levels, like 1% for 2nd and 0.3% for 3rd.

This demo shows the THD needs to be reduced more when biasing in the Class-AB mode.

This demo also shows Cube-law Class-A distortion is as benign as Class-A distortion to out ears and can be tolerated up to significant levels like 1% for 2nd and 0.3% for 3rd (gasp!).

… distortion from different OPS modes.

1 Assumptions are the background noise is very very low and the persons hearing is reasonable and not damaged.

Harmonic spectra generated with different output stage modes

My simulations uncovered the following interesting relationship of the harmonic structure of 4 different output stage modes: Class-B, Standard high-bias Class-AB, Square-law Class-AB and Cube-law Class-AB.

I have compared the Fourier analysis of a Square wave to a Triangle wave to a Parabolic wave and Cubic wave. The harmonics for each of these waveforms roll off at -20dB/decade faster than the previous one.

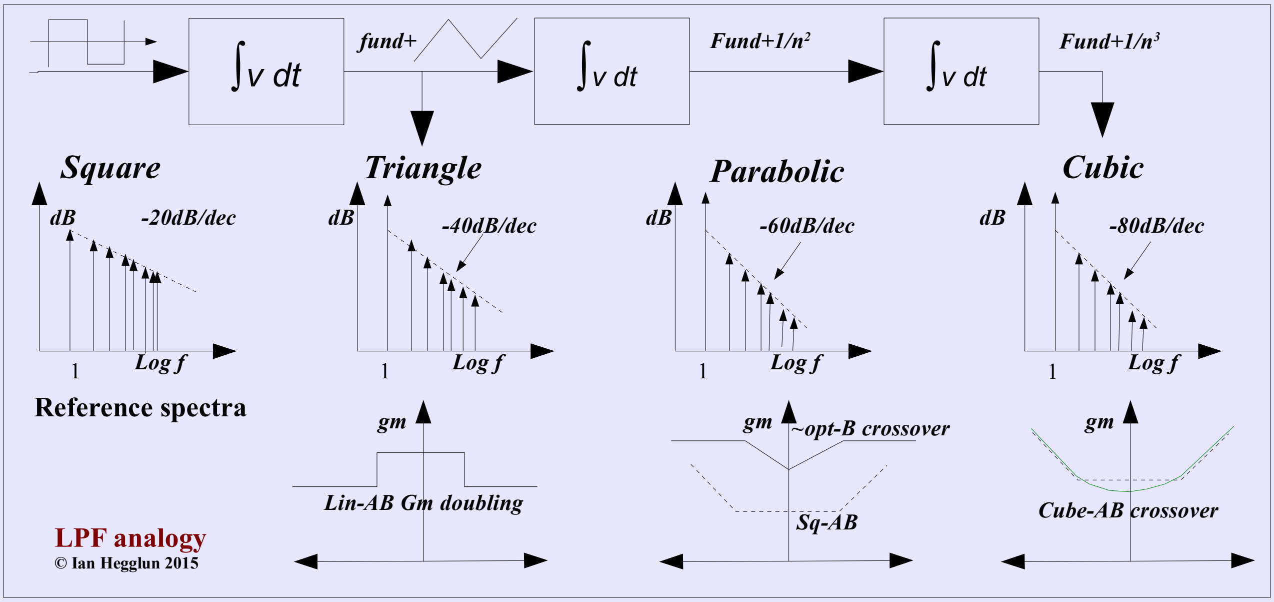


Figure 4. Harmonic spectra for 4 modes for output stages: Gm-doubling, Standard Class-B, and Cube-law Class-AB.

My simulations show roll-off rates as indicated above:
High-bias Class-AB (Gm-doubling) rolls off at -40dB/decade, and
Optimum biased Class-B and Square-law Class-AB rolloff at -60dB per decade. and
Cube-law Class-AB rolloff at -80dB per decade.

We want any harmonics from crossover distortion to roll-off *faster than -50dB/decade* so harmonic distortion from crossover distortion cannot be heard – then our amps can give quite high THD readings[footnote[2]] and it will still sound very good.

References

1. Linear Audio, "Towards a reconciliation of measurements with listening tests", Vol.4 Sep 2012. https://linearaudio.net
2. Louis D. Fielder, E Benjamin, 'Subwoofer performance for accurate reproduction of music', JAES v 36 No. 6, June 1988 p443-456. Figure 10 for the 50Hz threshold plot.
3. Louis D. Fielder, 'Evaluation of Audible Distortion and Noise Produced by Digital Audio Converters', JAES v 35 No.7/8 July 1987 p517-534. See Fig. 1 for auditory bands. See p403 for inadequate 16 bit audio coding, p519 on 24 channels, p521 on noise accumulation and band widths.
4. Linear Audio Vol.8 Fig.8 and Fig 11.

2 Even 0.1% at near full power, which is very high by modern amps!