HifiVoice
Sharing experiences...

iPod Classic Audio Measurements

[15-09-2007, firmware 1.0.1 update]

Non-technical summary

This web page discusses the Audio Classic 160GB audio performance. I've started this page because of the sonic differences between the iPod Classic, and the iPod Video 5G 60GB. In my opinion the 5G sounded better than its successor 6G. My first impression of the sound quality of the iPod Classic showed quite a difference with the iPod Video. I noticed that the 6G sounds precise, crisp, but lacks 3D image and has an electronic haze to the sound. At first, this might sound like an improvement (crisp, detailed), but when listening more carefully and for longer times, it becomes fatiguing after a while. The 5G sounds less precise, but its timbre contains more harmonic information and sounds less electronic. For me, the 5G is closer to how I experience acoustic music in real life, and for me is the better sounding device overall. This is not to say that the 6G is a terribly bad sounding device! It's just less than the 5G, and sound electronic/acoustical as opposed to acoustical/musical.

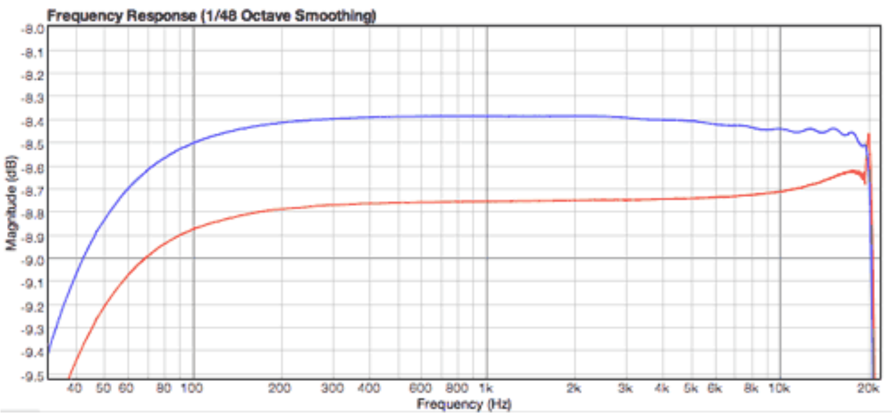
To backup my findings, I've performed some measurements. These measurements show that the iPod Classic uses badly engineered circuitry in its audio chain.

Measurement Setup

I've used Fuzzmeasure to measure the iPods. I've constructed a sound file (aiff, so by-passing the compression algorithms) with a 1 second sweep. I connected my iPod to the line input of my PowerMac, and recorded the playback of the sweep using Quicktime. Then I've imported the resulting file into Fuzzmeasure using the Field Recording option, and get an impulse response as a result. From that impulse response, the analysis has been done. Please keep in mind that this measurement setup is not a professional measurement setup, so in absolute sense the measurements might deviate from reality. However, for comparison purposes these measurements are valid, as the measurement context is exactly the same for both devices.

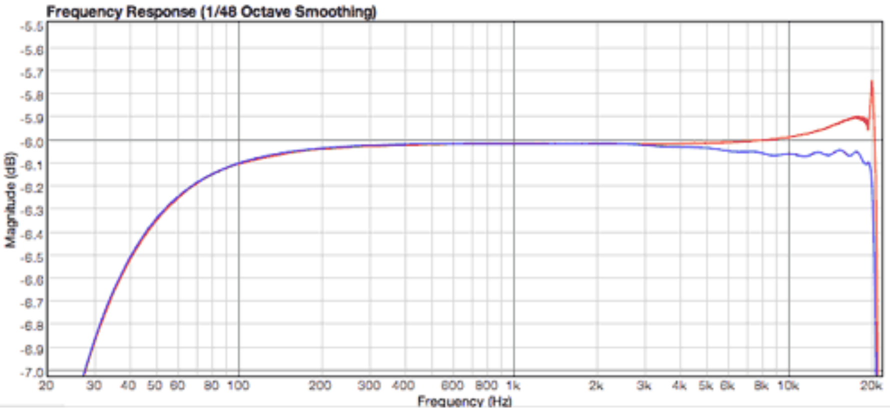
iPod Classic 6G firmware 1.0.0

The following figure shows the frequency response measurements of the 5G and 6G line outputs (Classic 6G Red, Video 5G Blue), measured via the docking station.

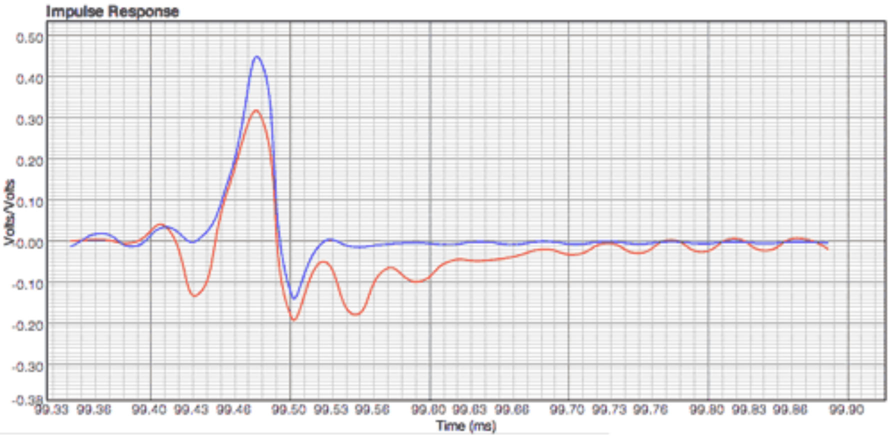


- It is obvious that there is an uplift of about 0.1-0.2dB in treble for the iPod Classic, whereas the iPod Video 5G has a small attenuation in treble. Although 0.1dB in a might seem a small difference, one should notice that a relative uplift of 0.1dB over a wide range (3 octaves, from 6kHz - 20kHz) is audible. It is common practice in the audio field that a slight attenuation of treble is beneficial for the perceived performance, and rising treble is associated with a less harmonic/analytical/metallic timbre. The peak at 20kHz is probably a numerical issue (it disappears when I extend the measurement from 20kHz to 22kHz).
- Overall, the 5G has a 0.5dB higher output, which is strange regarding the fact that one would expect the line output to be standardized.

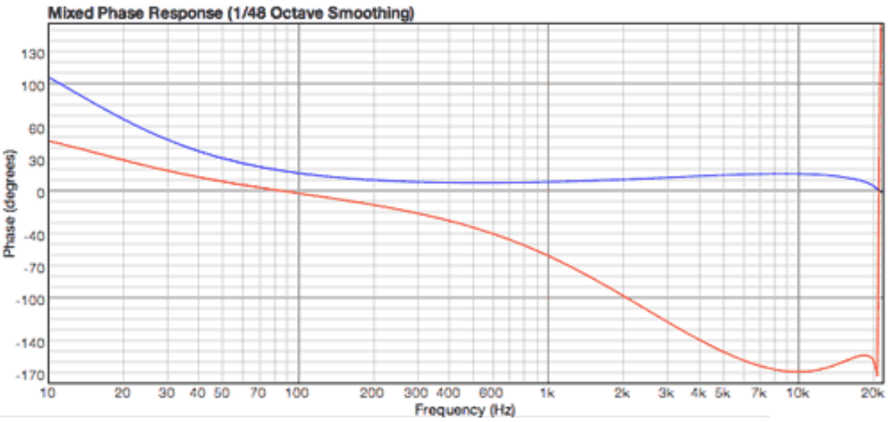
The headphone output yields similar results as shown by the following figure, but the differences in volume are larger because my Classic is EU volume limited, and uncap software is not available yet. I've aligned volume as good as possible, but for reference purposes I've aligned both curves at 1kHz by shifting the curves vertically.



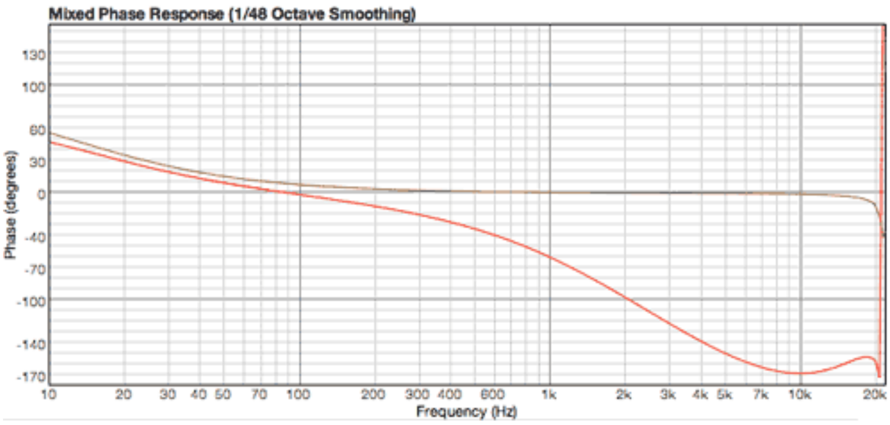
Because the line output and the headphone output yield similar results, and can conclude that the response characteristics are determined by the Codec or power supply, and less by the analog output circuitry. As the frequency response measurements might explain a certain electronic haze/zizz in the sound, it certainly can't explain the lack of 3D image. Therefore I've also looked at the timing behavior, which is reflected in the phase curve and impulse response. The following graph shows the impulse response of the 5G (blue) and the 6G (red).



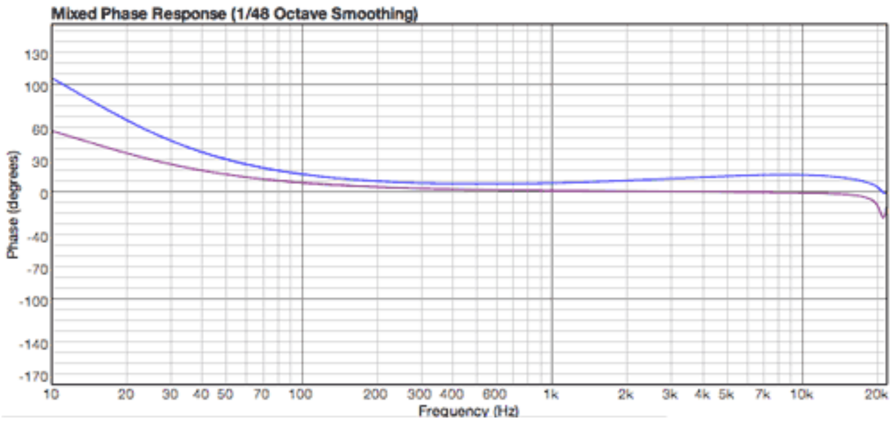
The impulse response of the 5G looks almost perfect, with only a small ripple. The impulse response of the 6G shows misalignment of frequency components; it takes a while before it settles compared to the 5G. This misalignment is reflected by the group delay, which van be deducted from the steepness of the phase response curves. The following figure shows the phase response of the 5G and 6G (due to the measurement grid I can't completely align the phase response).



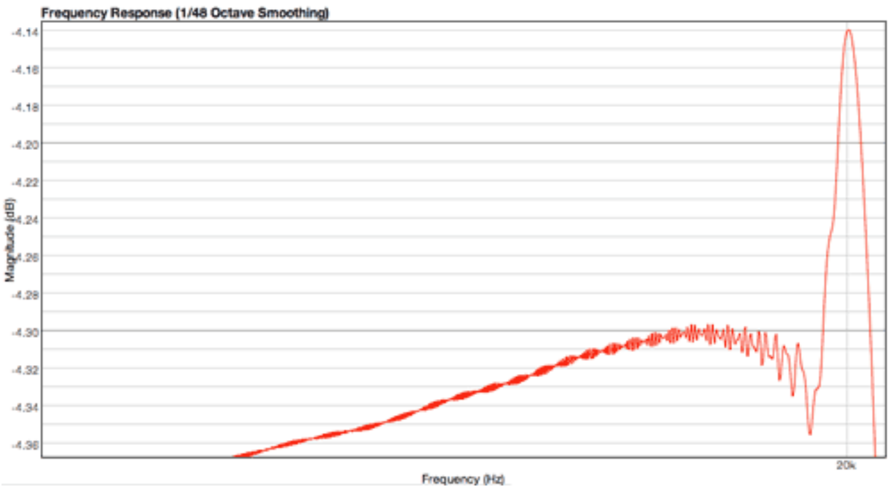
One can see a rather flat phase response for the 5G due to the fact that most of the phase response is flat. At lower frequencies the group delay is larger, and therefore bass with lag mid and treble a bit. For the 6G the group delay of the bass, low-mid, mid and treble regions are different, because the steepness of the phase curve is different in those regions. This might explain why the new iPod Classic lacks sonic spatial information. The phase response is non-linear, as it deviates from a calculated minimum phase curve (brown) with the measured phase:

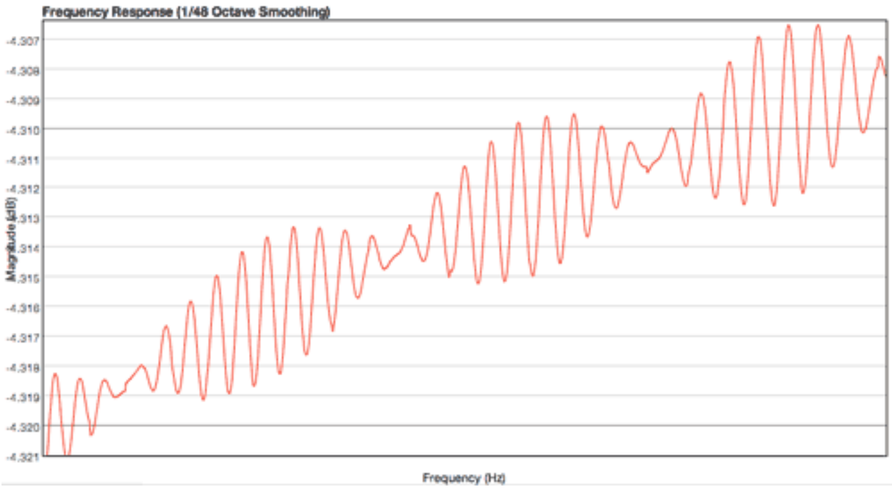


The minimum phase behavior of the 5G looks very good in comparison:

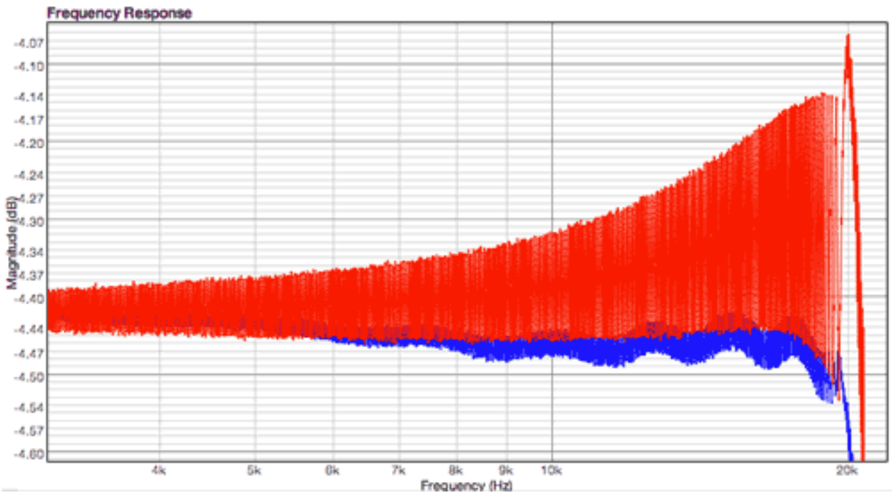


The impulse response of the Classic shows a strong 22.1kHz modulation component, obviously some crosstalk effect. Zooming in into the frequency curves clearly shows that the modulation folds back to the whole freq. domain, and hints at a bad designed noise shaper in a DA-convertor, bad power supply rejection or signal processing (I hope the last, as that can be fixed with firmware).

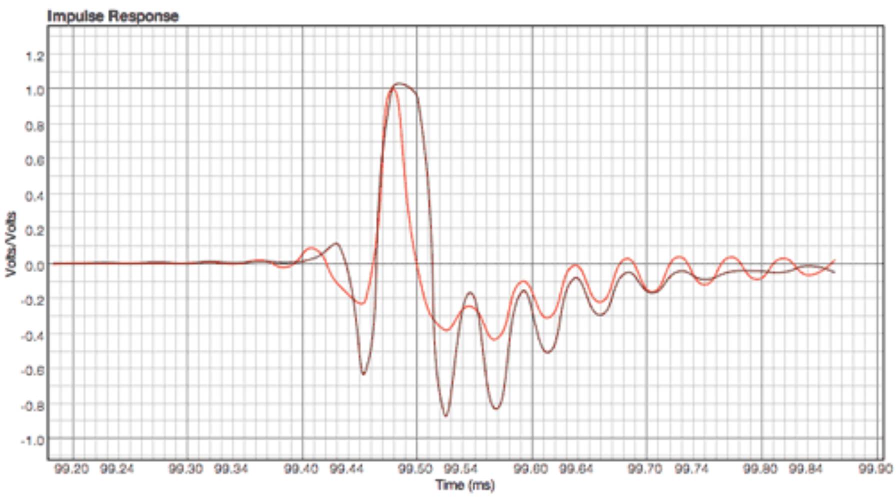




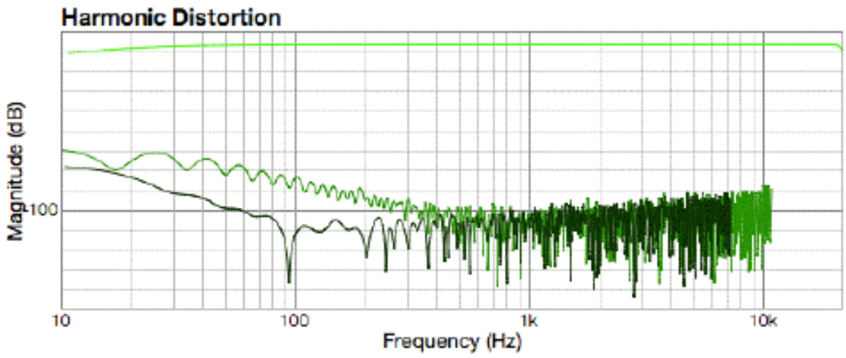
At 1/48th octave smoothing of the curves, there is no sign of such a modulation for the 5G at all. The 6G shows a comb due to the smoothing. With no curve smoothing applied, things start looking worse for both, but especially for the 6G :



I've cross-checked the measurement setup by directly measuring the output of my PowerMacG5, and it shows no trace of intermodulation products at all, so it is definitely part of the iPods. The 22kHz modulation signal is a constant. I've measured the iPod Classic using two volume settings (full - red, and half - brown), and as one can see, the contribution of the 22kHz component increases with lower playback volume. This hints at a the use of a poor noise-shaping technique (bad dithering, DC at the input?) in combination with a sigma-delta convertor and/or a PWM-based amplifier.



Christopher (the author of the Fuzzmeasure program) was so kind to create a harmonic distortion figure out of the measurements (darker lines are higher harmonics), which looks pretty OK:



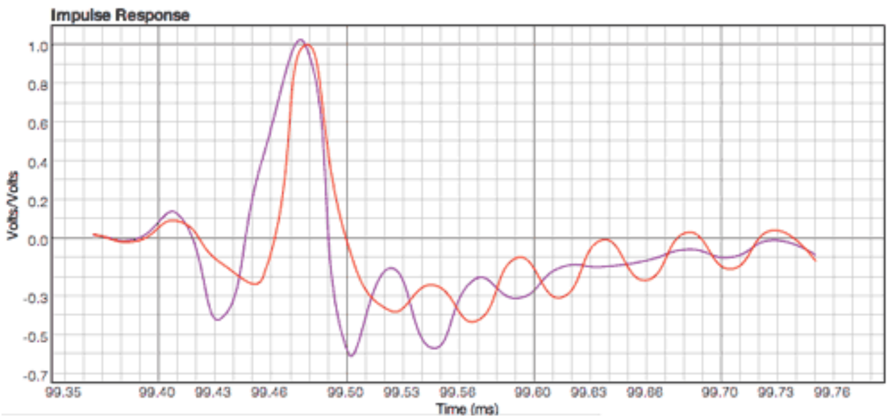
The measurement observations of the 6G are:
- A slight uplift in treble.
- A group delay that depends on frequency.
- A strong modulation with 22.1k, causing intermodulation distortion.

Apple seems to have changed the Codec from Wolfson to Cirrus Logic, and this seems to be a bad choice. There is no reason why a Codec should not be minimum phase and exhibit strong modulation components.

iPod Classic 6G firmware 1.0.1

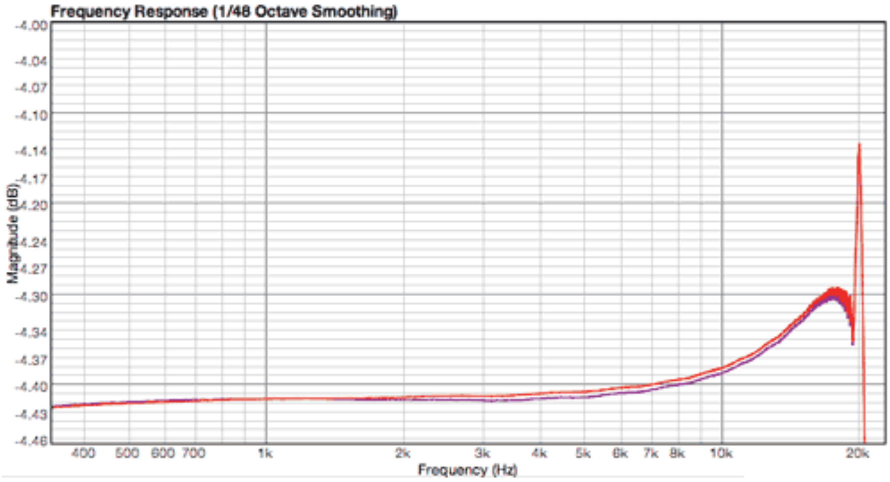
In about one week after the announcement, Apple issued a firmware update. It hints at bug fixes, probably related to the album art bugs reported. The sonic differences between the 5G and 6G_v1.0.1 still remain large (the 6G sounding thin and metallic), and are in the same order of magnitude as with the v1.0.0 firmware version of the 6G. I don't think anything has been done about.

The impulse response differences (6G_v1.0.1 red, 6G_v1.0.0 purple) look as follows:



Though it looks like there are difference, there are hardly any. The measurement grid is about 0.02ms (44.1kHz sample frequency, whereas the drawing grid is about 0.01ms (100kHz). This means that there is only one measurement sample per 2 grid steps available, and the impulse response is interpolated between those samples. As I have to press record on the computer, and start the iPod by hand, there is always a difference in the starting delay. I remove this delay by hand as much as possible, but the sample deviations remain.

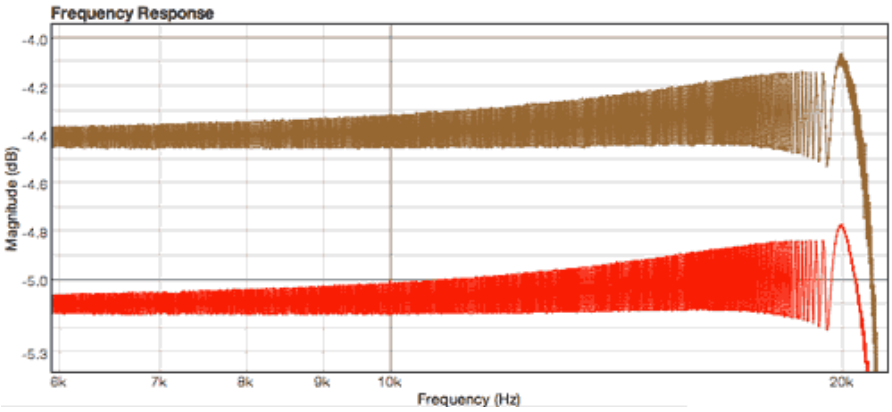
The fact that there are no audible and measurable differences is supported by the frequency and phase curves, that show no relevant differences (an example of the frequency response shown below):



Conclusion, no audio improvements in this firmware version.

iPod Classic 6G firmware 1.0.2

With respect to audio, there are no changes to report (iPod 6G v 1.0.2 red, curves displaced for comparison).

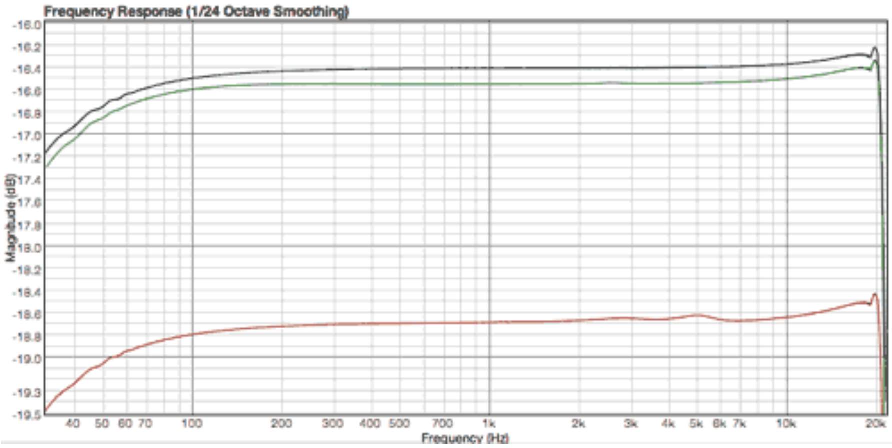


Sensitivity to headphones

I've bought a splitter, so that I could also measure the iPod headphone output under the load of a headphone.

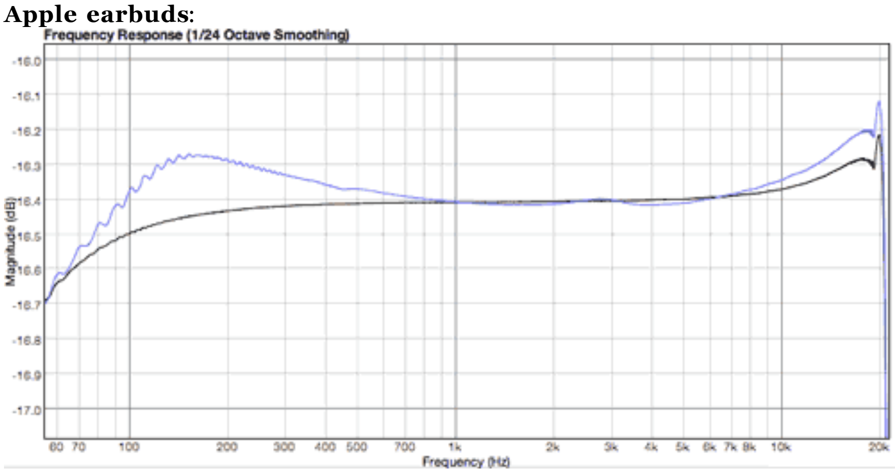
Technical Intermezzo: Before I jump into the resulting measurement, first a little bit about the technical backgrounds, as these measurements can be easy to misinterpret (something that has happened with the previous measurements on the forums as well). Each voltage amplifier (hence also the one in the iPod has a "source impedance". Ideally, the source impedance of an amplifier is zero Ohms, so that if an amplifier generates some voltage, the current is fully determined by the resistance of the headphone Rh (according to Ohm's Law I = V / Rh). As headphones do not have a constant impedance over their frequency range, this implies that the amplifier will need to generate more current at places where the headphone impedance is lower. In case the source impedance is low, and if the amplifier is capable of providing all current needed (depending on the design of the power source), an amplifier will be pretty insensitive to the load provided. In my previous measurements, I've used my PowerMac G5 and the M-Audio Mobile Pre to perform measurements. The inputs of the measurement devices have typically a high input impedance, and hence hardly put a load on the iPod. When the headphone impedance shows a strong deviation w.r.t. the source impedance, the headphone will see large deviations in voltage as well. Suppose that we have 1V, an source impedance of 99 Ohm, and a headphone impedance of 1 Ohm (which is crazy) , then only 10mV of the 1V is left for the headphone! As voltage and acoustic output are coupled (speakers are voltage controlled devices), the effect of half the voltage will be half of the output. Hence, it is important to have a constant voltage curve over the whole frequency spectrum.

OK, now for the measurements themselves. The black curve in any of the measurements is the "unloaded" curve (which means > 47kOhm, so hardly w.r.t. the source impedance of the iPod). The following graph shows the curves for my Sennheiser HD650 and Creative EP-630. The Sennheiser HD-650 has a fairly high impedance (above 300 Ohms), whereas the Creative EP-630 has a fairly low impedance (18 Ohm). The attenuation is about 2.3dB, which corresponds to a source impedance of the iPod Classic of about 13 Ohm (which is rather high). This will imply that in case the impedance of the headphone is low, the curve will follow the impedance curve of the headphone, and the acoustic output will be less than normal.

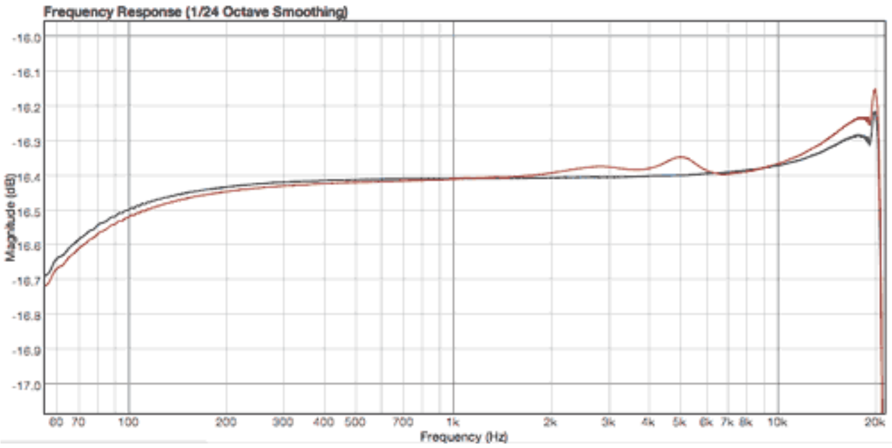


Although the measured curve of the Creative is lower, it doesn't mean the acoustic volume is lower as well. This fully depend on the efficiency of the headphone, and in this case the Creative is much more sensitive than the Sennheiser, and hence will play louder. This makes comparing those curves on absolute scale worthless, and therefore I've normalized all curves at 1kHz from this point on. Furthermore, and uplift in a curve doesn't mean that a headphone will sound louder in that range than another headphone, as it will depend on the acoustics response curve as well. The only thing it says is how the headphone will sound different on the iPod compared to the same headphone connected to an idealistic amplifier with a very low source impedance. I.e., it shows the characteristics on the iPod Classic 6G added to the ideal headphone response. The measurements are in alphabetic order of some headphones that I have easy access to:

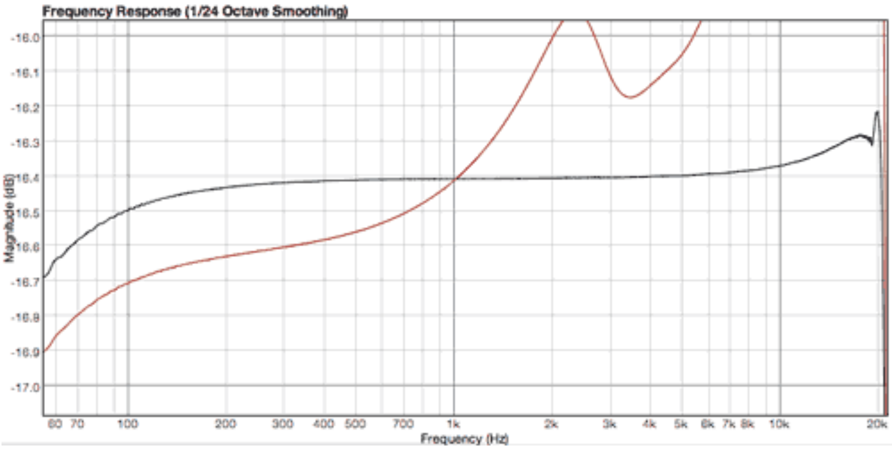
Apple earbuds:



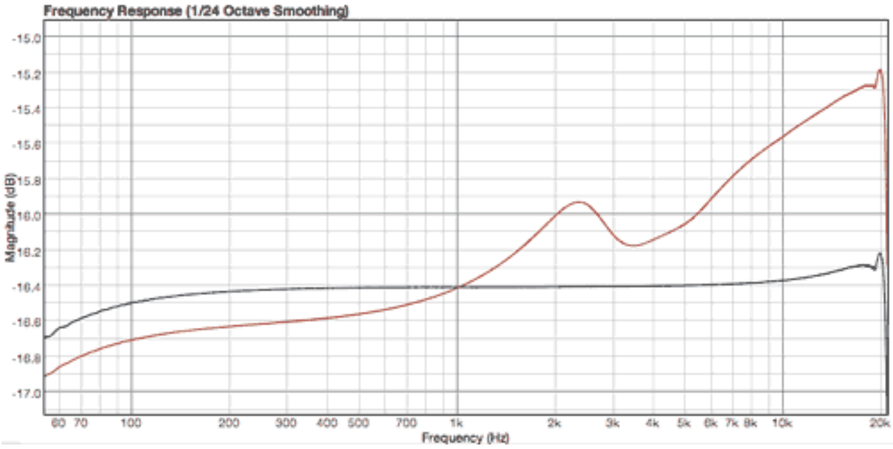
Creative EP-630:



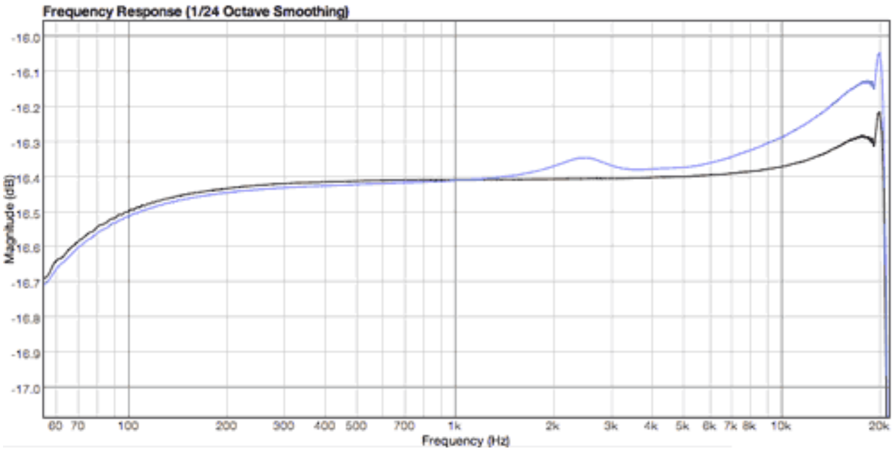
Etymotics ER-4P:



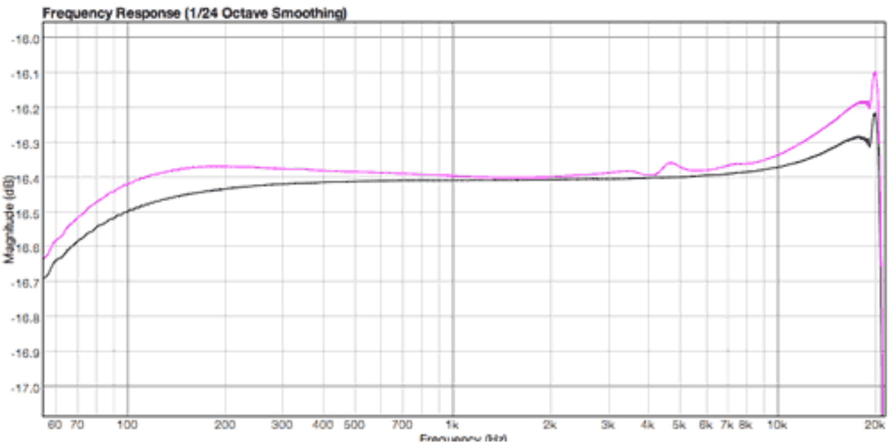
and scaled:



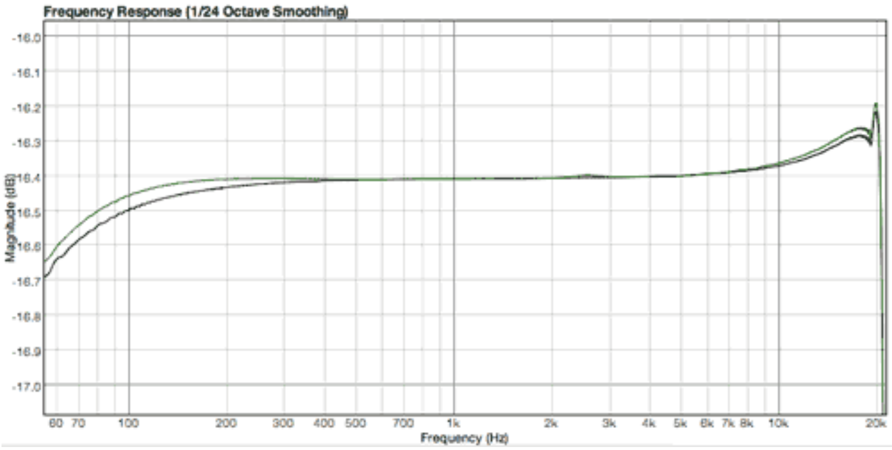
Etymotics ER-4S:



Sennheiser HD497:



Sennheiser HD650:



As for most headphones, I think the results are slightly audible, but not signifcant, with the exception of the Etymotics ER-4P, which shows a tremendous uplift, but when changed into a ER-4S with the convertor cable (basically adding 100 Ohms) becomes better (but unusable soft with an EU-volume limited iPod, grrrrrrrr). Another observation is that due to the rising impedance of most headphones (because of their inductive nature), the treble gets more uplift. My Macbook shows similar measurements, so also a high output impedance. I've double checked by measuring with my M-Audio Mobile Pre, which show similar results. Unfortunately, my iPod Video 5G has been sold, so I couldn't repeat the measurements with the Video.

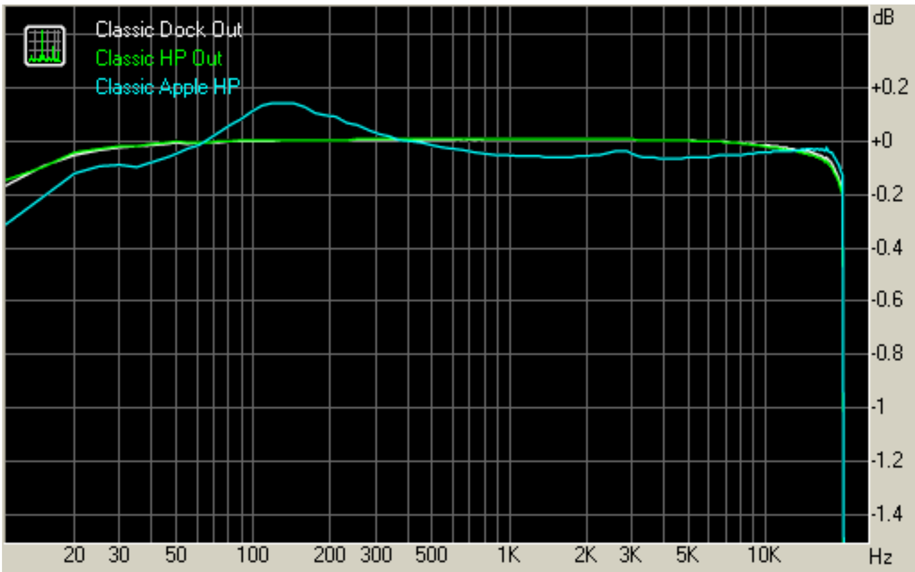
What can we conclude from all of this? Basically the iPod behaves electrically very linear over whole its frequency range. If the impedance of the headphone doesn't drop too low, or has significant deviations, I don't expect too much issues. The treble in each case is a bit emphasized, so the uplift in treble is magnified a bit. This might hint at the reason why devices with a slightly attenuating curve have the tendency of sounding more natural, as this compensates for the inductive behavior of the speaker units.

Other people's measurements

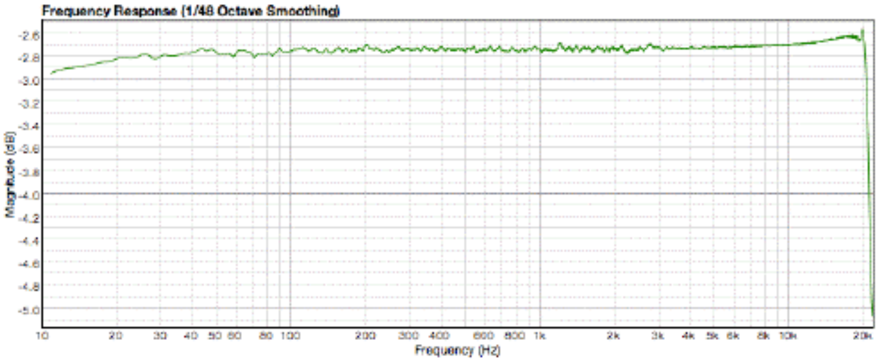
Some other measurements are posted on the web. Here are the ones I know of.

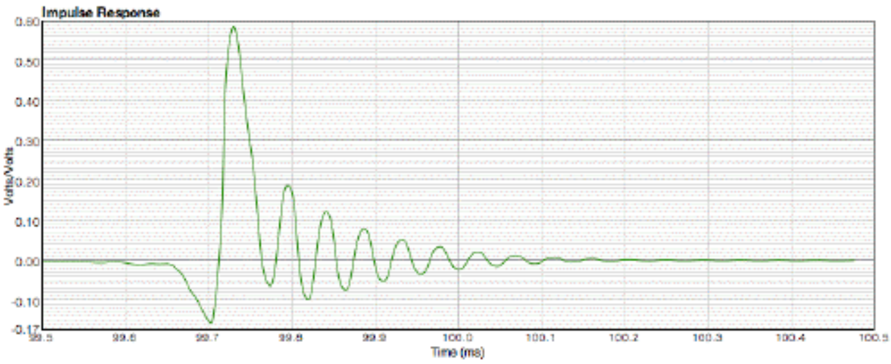
Helder (German version here) shows a better behaviour of the iPod 6G headphone output when loaded compared to the 5G (which is audible indeed). It shows the decrease of treble for the 5.5G (they measure -0.5dB as opposed to my -0.1dB). Please note that the level of averaging, windowing, etc. might affect the measurements and shapes of the curve.

Miguel pointed me to his own measurements, with yet another different curve shapes. Again, much will depend on the settings of the way the FFT is performed, the sound card used etc. Miguel also posts comparisons with the 3G, 4G and Nano 1G, with and without headphone load.

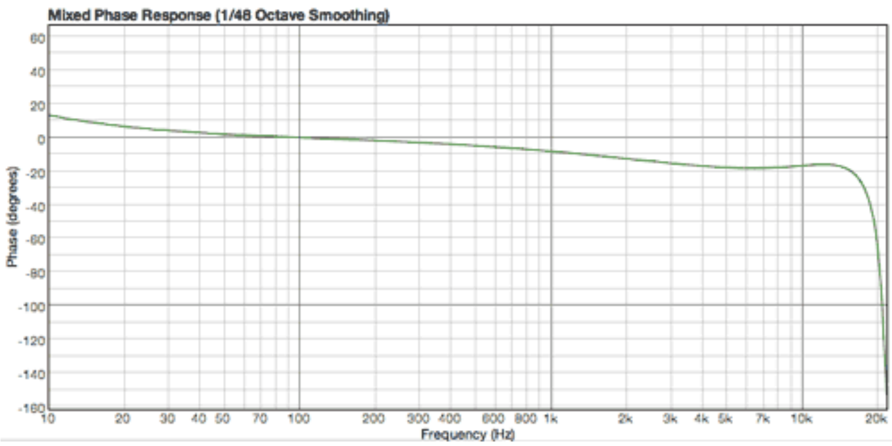


[Mirumu](#) (Matt) shows similar measurements, probably recorded at another level, with less drop in bass (using an M-Audio instead of a the PowerMac G5 inputs), showing the same uplift and the 22kHz modulation signal.



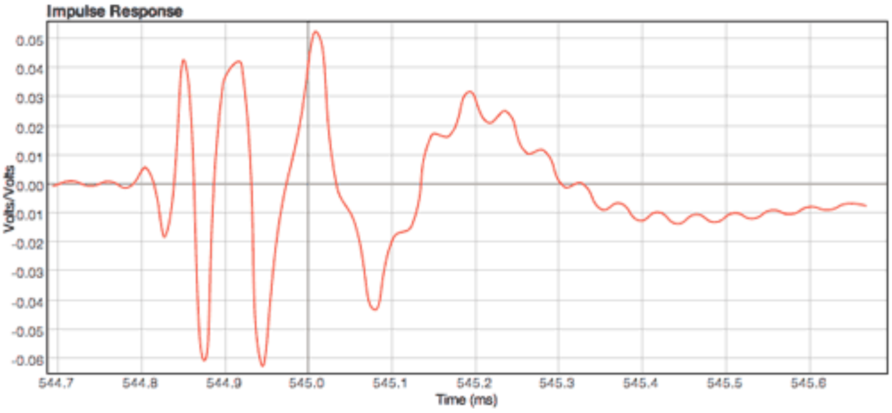


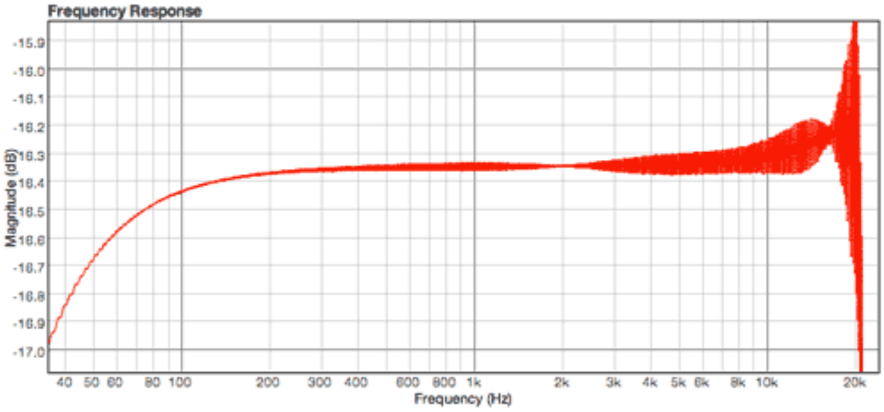
I've asked Matt the measurements, so that I could compare them with my own. Due to the fact that the start of the measurement window over the impulse response can be positioned in a better way, the phase response looks more flay, but is essentially the same.



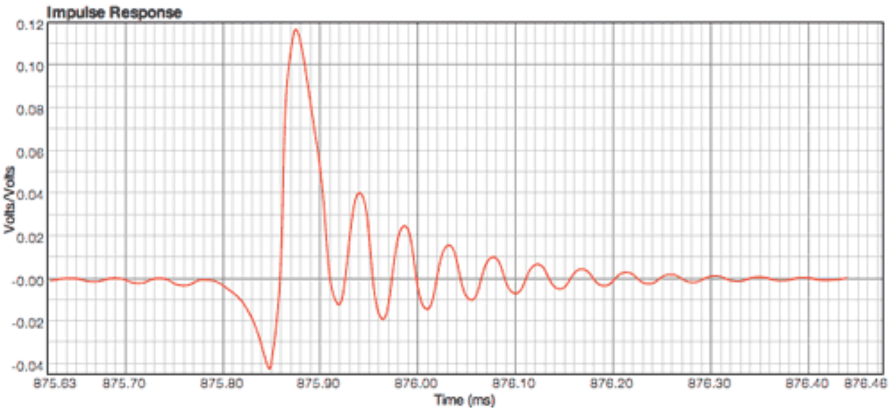
Some unexplainable weird stuff

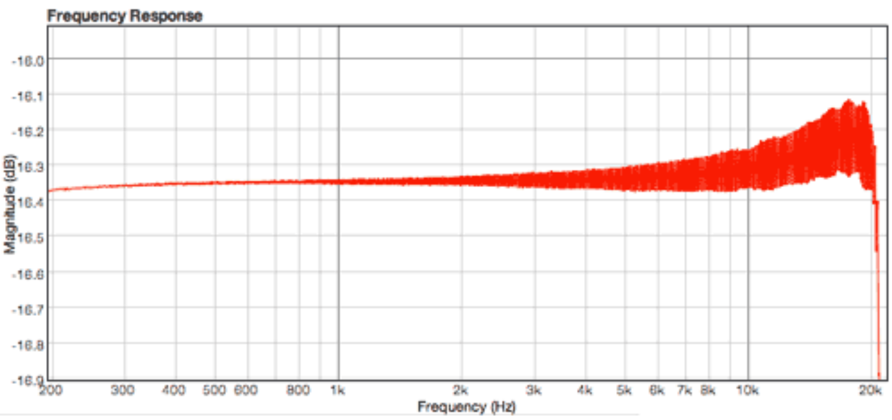
To be able to align the phase measurements, I wanted to obtain more resolution by lengthening the impulse response. I took a 5 second sweep, and I saw some strange impulse response coming out from the 6G.





For comparison, a 0.5s impulse response on the iPod 6G looks as follows (reversed phase).





I double checked whether the measurements setup was flawed by re-doing the measurements a couple of times, take different sample frequencies and frequency ranges, and re-do the exact same measurements by using my MacBook, PowerMac G5, or iPod Nano 2G as a source. The last ones didn't show this behavior at all (their impulse response stayed constant with shorter to longer sweep times). I've contacted the author of Fuzzmeasure (Christopher Liscio), who double checked the validity of the measured data, and couldn't find anything wrong as well. Conclusion, the measurements are valid on themselves.

I have no clue about the reason (clock drift? noise shaping dependent on a window of frequencies? spread spectrum processing?), and doubt whether these measured effects are audible given the long sweep times. They hint at a particular implementation strategy, and again the presence of 22.1kHz intermodulation components. If anybody has an explanation for these type of impulse responses, I would be happy if you could share your thoughts on one the forums.

Links

The fact that the Video and Classic sound so different, can probably be explained by the replacement of the Wolfson chipset with a chipset made by Cirrus (and labeled with Apple).
- Teardown of AppleInsider.
- Teardown of iFixit.
- Barron's observation
- Business Scotman about maximizing margins.
- Head-fi mentions the DAC chip, the Apple 338S0394.

Some more links where people are discussing the iPod sound quality.
- Apple Discussions 1, iPod 160GB - the good and the bad new.
- Apple Discussions 2, Sound quality of the new classic?
- Apple Discussions 3, iPod Software Update 1.0.1 in iTunes now available.
- Apple Discussions 4, Touch's Audio Codec - Same as Classic?
- iLounge, iPod Classic Sound Quality.
- Head-fi 1, iPod Classic... DAC and output stage info from Vinnie of RWA.
- Head-fi 2, READ THIS: Serious flaws in ipod classic.
- Hydrogenaudio, New iPods are out, new ipod are out.
- Engadget, iPod Classic firmware update improves Cover Flow performance.

News:
- iLounge.
- TUAW.
- Arstechnica.
- Techztalk.
- Fuzzmeasure.
- Powerpage.

Conclusions

From these measurements it is obvious that the new audio circuit of the iPod Classic is badly engineered compared to the iPod Video:
- Treble has a slight uplift.
- The group delay is not linear over the frequency range.
- There is significant intermodulation distortion with a 22.1kHz component.

The measurements show a correlation with the things I hear, but from a pure scientific perspective the cause-consequence is not determined by these measurements. The measurements show some flawed behavior of the audio circuitry, which so-far is the only thing that can be concluded without any doubt.

Overall, the 6G overall sound performance is disappointing *to me*, especially considering the well-sounding 5G. Does it mean you shouldn't buy an iPod 6G? The way the change of sound quality is perceived will vary per individual. Therefore I recommend you to judge the 6G individually, and don't let ourself be guided by my opinion, or some measurement graphs.

Call for help

This page is to contribute to the improvement of the iPod product, and not to bash Apple! Let me state that I enjoy the iPod product family, and that I can recommend everybody to buy an iPod for portable music usage

The audible differences between the 5G and 6G are significant, and a firmware correction (most Codecs contain programmable parts) is definitely required to bring back the iPod Classic sound quality to its original levels. In order to convince Apple to prioritize this issue, please provide them feedback (via http://www.apple.com/feedback/ipod.html). For those who are "lazy", I have an example text available: "The new iPod Classic sound is thin, sharp, and misses spatial information compared to previous iPods and competitor products (see http://www.hifivoice.com/audio/ipod/comparison/measurements/measurements.html). Can you improve its sound quality by means of a firmware update?"

Appendix: Debating audibility

In some of the forums, I read people debating the audibility of the measurements shown.

It is true that well-respected books like Psychoacoustics of Fastl and Zwicker mention 1dB as the typical threshold of audibility. But... keep in mind that such a figure is claimed within a very specific context!!! They use modulation techniques applied on two sinusoidal signals or noise signals, which is very relevant in the field of audio encoding. These tests are completely unrelated to a lift of 0.1dB for 30% of the spectrum. In many publications of the Journal of Audio Engineering Society audibility is reported under well-controlled situations (excluding placebo). I can refer to many articles, but that's outside the scope of this web page. I just mention some:

- *Lipshitz and Vanderkooy, "The Great Debate" Subjective Evaluation", JAES Volume 29 Number 7/8 pp. 482-491; July/August 1981.* "Our tests, and those of others, have shown that, differences in level of 0.2 dB over an octave or so can be reliably detected by some listeners. "

- *Lipshitz, Pocock, Vanderkooy" - On the Audibility of Midrange Phase Distortion in Audio Systems", JAES Volume 30 Number 9 pp. 580-595; September 1982.* Report the audibility of phase distortion in well-controlled tests, and with different kinds of source material, including voice and music, where the confidence is reported to be 95%, and where it is reported to be better audible on headphones than on loudspeakers (which also depends on the context, as phase caused by crossover filters determines the polar repsonse, which also is audible, also reported in the JAES by Lee, but that's another subject agai showing that the context of the experiment matters). Their measurements are limited to linear effects.

- *Petri-Larmi, Otala, Lammasniemi, "Psychoacoustic Detection Threshold of Transient Intermodulation Distortion", JAES Volume 28 Number 3 pp. 98-105; March 1980.* Report audibility of intermodulation distortion of 0.03% (under certain conditions). The add to their article "The subjects proved to be very sensitive to distortion in well-known sound sources, suc as choir or piano, whereas pop, for instance, yielded poor sensitivity." and "When the difference increased, various instruments behaved very differently, "high-frequency rattle" being noted in the piano, "hi-fi sound" in the trumpets, "tearing" or "rattl-lng of paper" in the choir, and "lack of precision" in the violins. The sound was now usually described as becoming "brighter" or "more aggressive."
