

Lossless Audio Codec Comparison
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Introduction

While testing the efficiency of lossy codecs can be quite cumbersome (as results differ for each person), comparing lossless codecs is much easier. As the last well documented and comprehensive test available on the internet has been a few years ago, I thought it would be a good idea to update.

Beside comparing with CD-audio (which is often done to assess codec performance) and spitting out a grand total, this comparison also looks at extremes that occurred during the test and takes a look at 'high-resolution audio' and multichannel/surround audio.

While the comparison was made to update the comparison-page on the FLAC website, it aims to be fair and unbiased. Because of this, you'll probably won't find anything that looks like a conclusion: test results are displayed and analysed, but there is no judgement or choice made. As different people have different demands, there is probably no codec that is 'the best' for everyone anyway.

It is important to understand that nothing in this document is set in stone, codecs are still being tweaked and big surprises are still very well possible, see for example the still recent move of Apple to make ALAC open-source. Besides that, the test material is, while being quite diverse, currently limited to 43 CDs for the CD-audio test, 2 sources for the high-resolution audio test and 1 source for the multichannel test. Because of this, the results should be used with care. Furthermore, this comparison is "only about numbers", comparing speed to compression. Other important stuff, like software/hardware support and development activity are not mentioned at all. For more information on these features, I would like to recommend the HydrogenAudio comparison of lossless codecs [5] and the codec comparison on FLAC's homepage [4].

Chapter 1

Test setup

In earlier versions of this comparison, some codecs were tested through wine and some were run natively. While wine has a minimal overhead, this wasn't really fair. Now all tests are run on a Windows computer, just to make absolutely sure any overhead is equally spread among all codecs. Between the second and third revision, I was able to find the tools necessary to get the same consistent measurements, like a CPU-cycle based timer and a RAMdisk. Because of these tools, the test results are reliable, reproducible and easy to automate.

The machine used is a system built from off-the-shelf components, using a AMD A4-3400 CPU+GPU and 4GB of RAM. Dynamic frequency scaling was disabled for this test (the CPU was fixed to its 2.7GHz limit) and one core was disabled, so only one core is available to the codecs. Timing was done with 'timer32.exe' from the 7-zip benchmark suite, both real time and cpu time were measured but only cpu time has been used in the following analyses. Before the test starts, the WAVE files are copied to a ramdisk (ramfs) to bypass the hard drive entirely.

1.1 Scripting and graphing

The scripting was done in PHP (because I'm familiar with it, not because it's a good choice for this use) and was basically executing encoding and decoding commands within the timeer command and sanitizing this data before it went into the cvs-file. It made sure every encoder would have a fresh copy of the files (in case one encoder would mangle them) in the ramdisk and measured the size of the WAV-files and compressed files to extract a compression ratio.

These cvs-data was ordered by hand and fed into a graph generator, GLE. This resulted in four graphs: two with the familiar 'encoding or decoding speed' versus compression and two which displayed more or less the inverse of the speed versus the compression. The latter two graphs were added because the linear scale used doesn't display the really slow codecs well. Using logarithmic scales was possible as well, but considering those are hard to read for most people this wasn't done. Furthermore, the inverse of encoding speed happens to be CPU-usage, which is a value that is probably easy to relate for most readers.

1.2 Codecs and parameters used

Every known lossless codec that could be easily used with scripts on Windows has been tested. The most notable exception is Real Audio Lossless, as a command line encoders for this format

seems to be unavailable. Considering the parameters, the ones recommended by the developer (or the command-line help of the encoders) were used, with some exceptions, see table 1.1. For example, not all available compression modes of OptimFROG were used, because there are a lot and the codec is pretty slow. Also, after some preliminary tests, it was chosen to drop ALS's -7 mode and OptimFROG's maximumcompression. ALS -7 was simply too slow with little or even negative gain (see figure 1.1) and OptimFROG's -maximumcompression is not advised for daily use, only for benchmark purposes. While this is a benchmark, daily use is the focus of this report.

As you can see¹ in figure 1.1, the encoding of ALS -7 and OptimFROG maximumcompression both took 2.5 times the playing length of the files, which for such a comprehensive test is far too long: together they used half of the running time of the test, while they offer no real benefit. On this CD, ALS -7 is actually even worse than ALS without parameters, but this usually wasn't the case. This is strange, as the comparison I did in May 2009 (with an earlier version of ALS) did show fairly large gains, but with this version it seems those gains were lost.

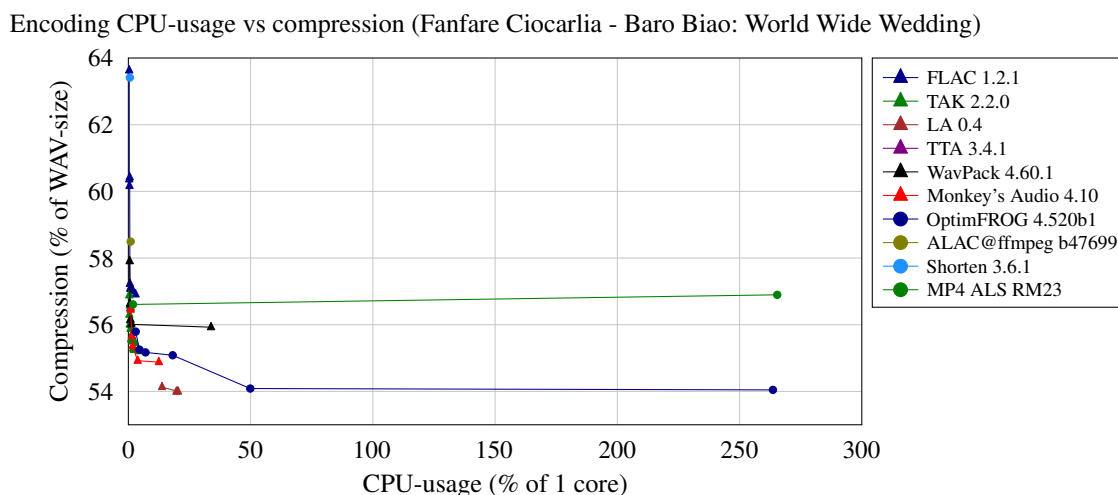


Figure 1.1: Encoding speed as 'calculated CPU-usage' versus compression for 'Fanfare Ciocarlia - Baro Biao: World Wide Wedding'

¹This graph was made for the second revision of this comparison and will not be updated. Because these tests were done on a different machine with a different configuration, the results can't be compared directly to other results. For more information on the used equipment, see revision 2 of this test

| Codec | Parameters used |
|---------------|---|
| FLAC | -0, -1, -2, -3, -4, -5, -6, -7, -8 |
| TAK | -p0, -p0e, -p0m, -p1, -p1e, -p1m, -p2, -p2e, -p2m, -p3, -p3e, -p3m, -p4, -p4e, -p4m |
| LA | [-], -high, -high -noseek |
| TTA | [-] |
| WavPack | -f, [-], -h -x, -hh -x |
| Monkeys Audio | -c1000, -c2000, -c3000, -c4000, -c5000 |
| OptimFROG | -mode fast, -mode normal, -mode high, -mode best, -mode best-new |
| ALAC | [-] |
| Shorten | [-] |
| MP4ALS | [-] |

Table 1.1: Parameters used for each codec

1.3 MD5 checksumming

Checksumming is a safety feature of a few lossless codecs. I tested its impact on encoding and decoding performance², because FLAC has checksumming enabled by default while other codecs (like TAK) have it disabled by default. The results are shown in 1.2 on the following page. It is clearly visible that especially the fast presets suffer a lot from checksumming, up to 25 percent. To make this a fair comparison between the codecs and because checksumming is usually not implemented in playback hardware, FLACs checksumming was disabled.

²These tests were made in the first revision of this comparison and will not be updated, because their use is only to explain why certain choices were made. Because these tests were done on a different machine with a different configuration, the results can't be compared directly to other results. For more information on the used equipment, see revision 1 or 2 of this test

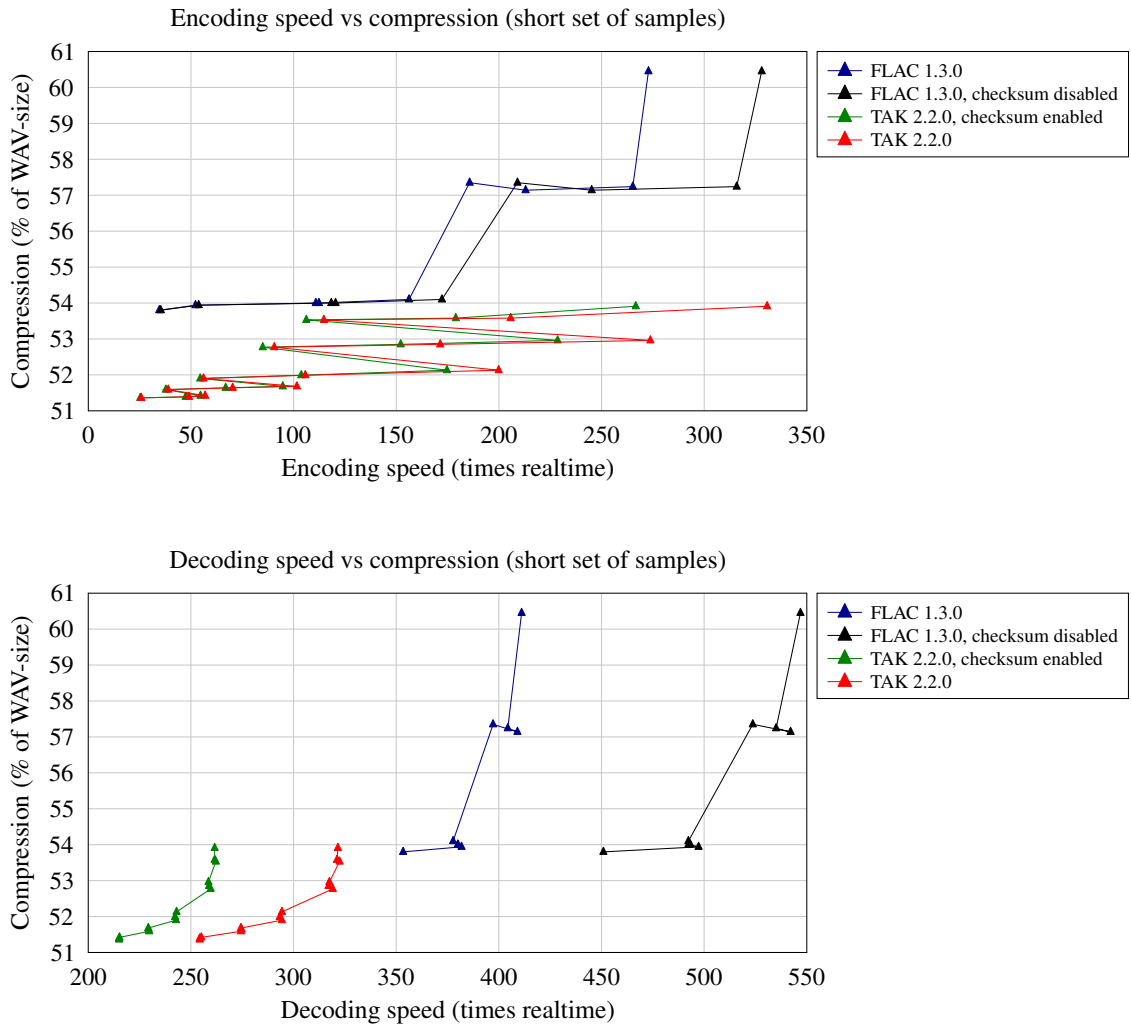


Figure 1.2: Performance of TAK and FLAC with and without checksumming

Chapter 2

CD-audio test

The most important use of lossless codecs nowadays is compressing CD-audio. Because of this, most of this report focuses on CD-audio. First, the performance of all codecs on the whole corpus will be examined. Next, some CDs will be examined separately to comment on particular quirks and weak points of certain codecs.

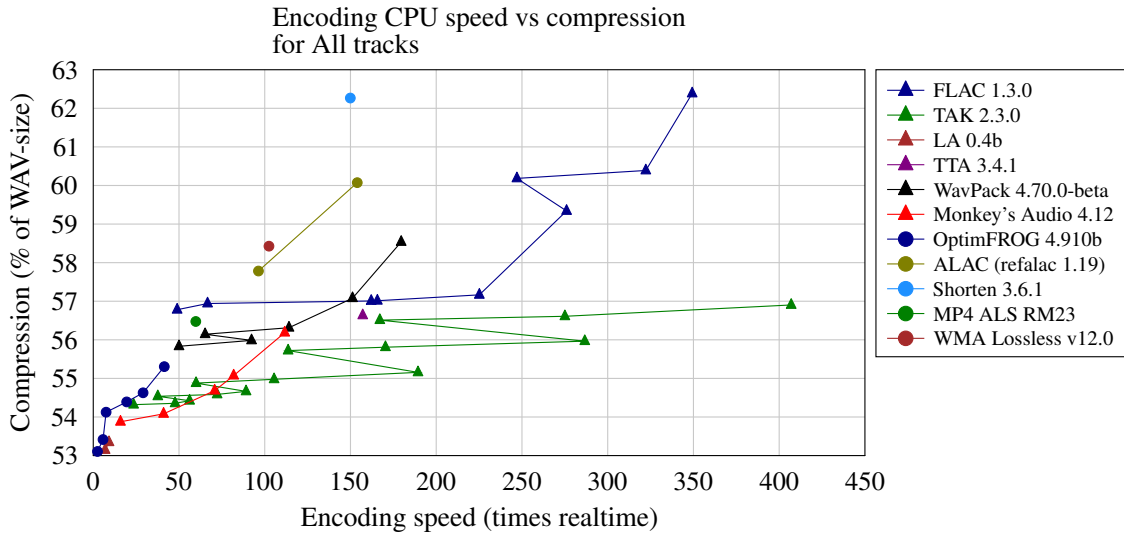
2.1 CD's used

The CD's used in this test are listed in table A.1 on page 28, because the list became too long to include here. Besides the title of the disc, there is a very general indication of the kind of music it is, should represent or what special significance it has, in case the performer is unfamiliar to you. These CD's should encompass a wide range of music and therefore give balanced results, with the weak spots of each codec exposed equally. For more information, see appendix A.

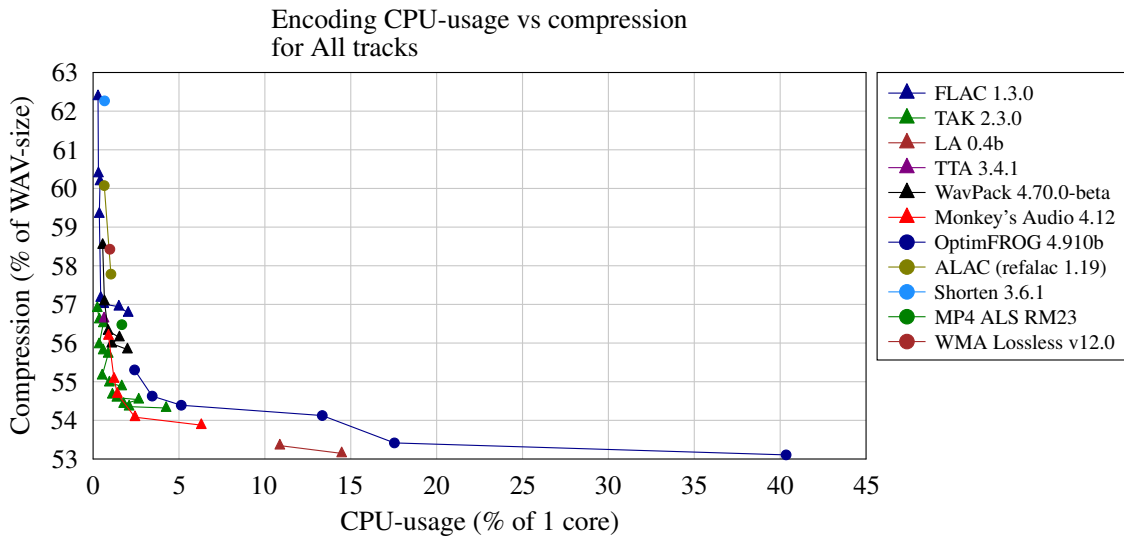
Quite some effort was put into choosing and balancing the list of CDs, with a lot of help from [3]. In particular, Tom Beck, developer of the TAK codec, pointed out that mastering can make a real difference in codec performance, and therefore the test should encompass as much different 'mastering techniques as possible'.

2.2 Results all CD's together

The results following are from all the CDs mentioned above averaged. This was done by averaging the CD results, not those of the individual tracks. This is done because otherwise CDs with more tracks would influence the results more than CDs with only a few tracks.

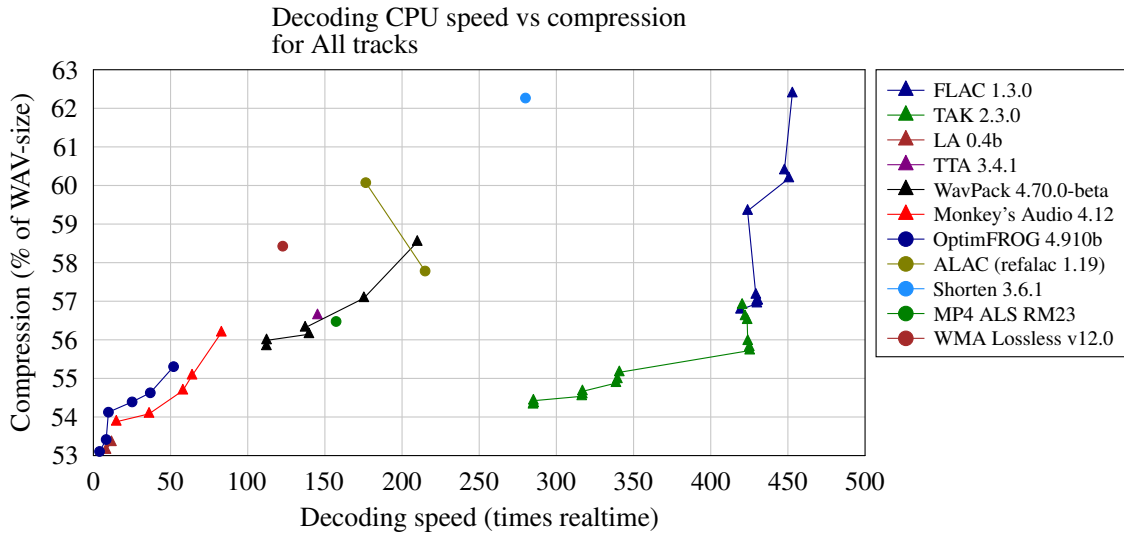


(a) Displayed the usual way

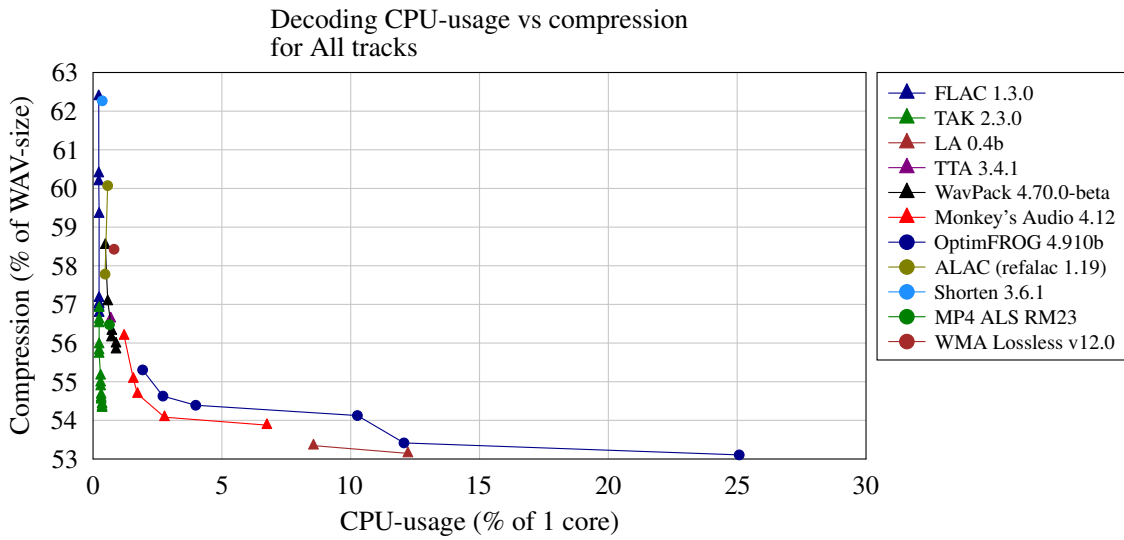


(b) Displayed as realtime CPU-usage

Figure 2.1: Encoding codec performance of all CD's averaged



(a) Displayed the usual way



(b) Displayed as realtime CPU-usage

Figure 2.2: Decoding codec performance of all CD's averaged

2.3 Interesting quirks

While testing different CD's to obtain a balanced total, the results of the individual CD's were plotted as well to look for certain peculiarities, both to report and to assess the validity of the test. If the results of most CD's look similar and any strange behaviour is explainable, one could say the test is more or less valid because it converges. Apart from ALAC –fast, FLAC setting -0 and -3 and Shorten fluctuating a lot (because of lacking stereo decorrelation), there was only one case in which non-standard behaviour was observed, which will be discussed next. Furthermore, some observations will be discussed.

2.3.1 Mono encoded as stereo (Dan Browns Angels and Demons)

The biggest difference with the all-round test is the audio book. The tested material contains a lot of silence, is pure mono (encoded as stereo as CDs don't have a mono-mode) and features only one voice. The encoding and decoding performance is displayed in figure 2.3.

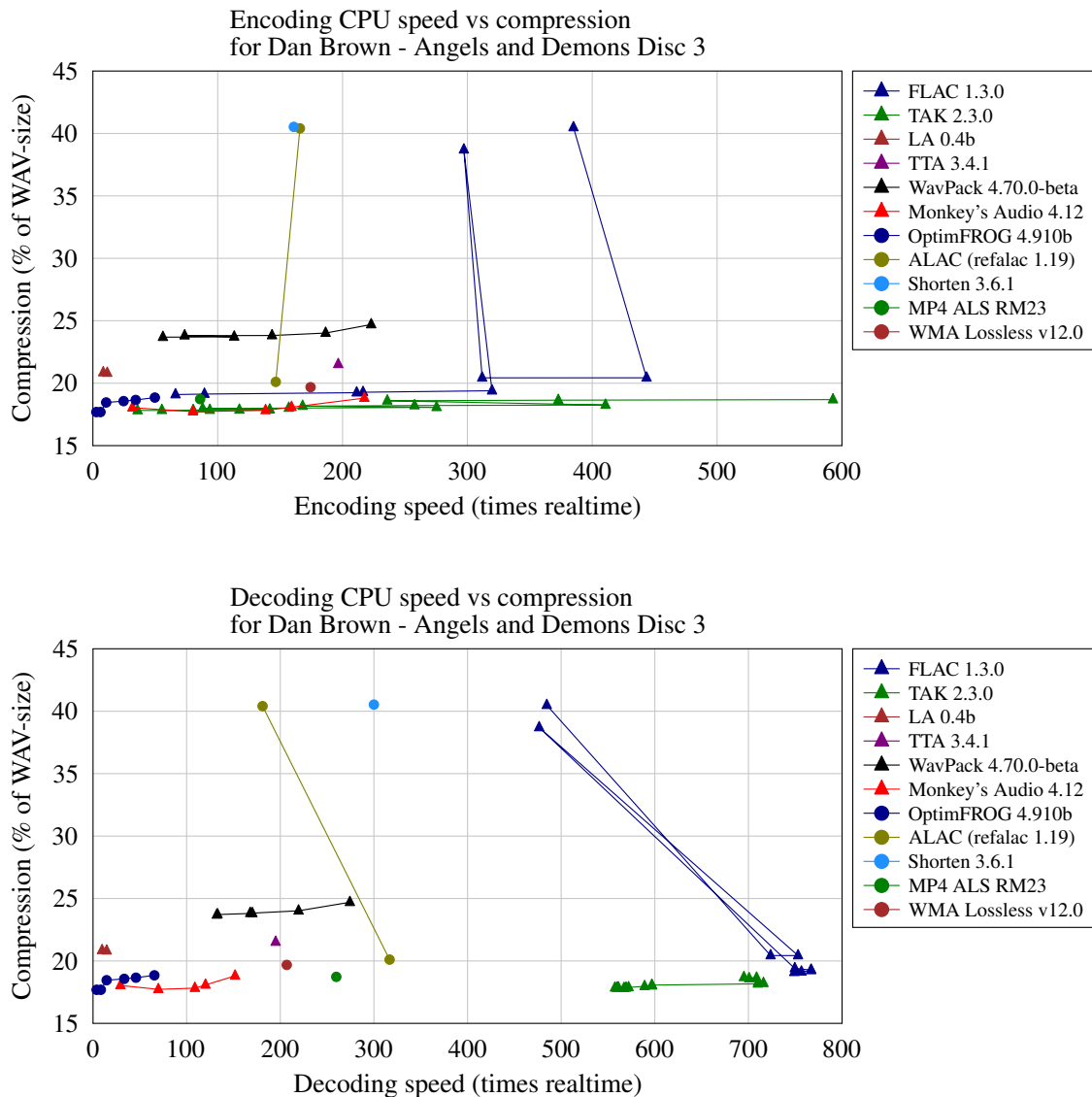


Figure 2.3: Codec performance for the audiobook Angels & Demons

The most obvious features are the behaviour of FLAC, ALAC and the bad performance of WavPack, Shorten and LA. FLAC's behaviour is because at modes -0 and -3 (which are the two peaks visible) no stereo decorrelation is done. All other modes have some form of stereo decorrelation, which obviously helps as this is pure mono: it halves the size of the files here. This is probably also true for refalac's -fast mode. WavPacks bad performance is a known 'bug'. Newer encoders have an option -optimize-mono, but it has to be set manually as it might break compatibility with older decoders. Shorten has no stereo decorrelation at all and LA seems to suffer from the same bug as WavPack does.

When looking for best compression, OptimFROG has a very small lead. Its -bestnew mode has the best compression (17.727%) while Monkey's Audio -c4000 (extra high) compresses only little less (17.733%). It is strange, but Monkey's Audio insane mode (which is slower than the extra high mode) gets only 18.0%. TAK and FLAC both perform very well considering their speed. A last remark is that LZMA2 (7-zip's compression mode), while not displayed in the graph, does very well considering it is not an audio codec, it scores 30% compression and outperforms ALAC fast, FLAC -0, -3 and Shorten here.

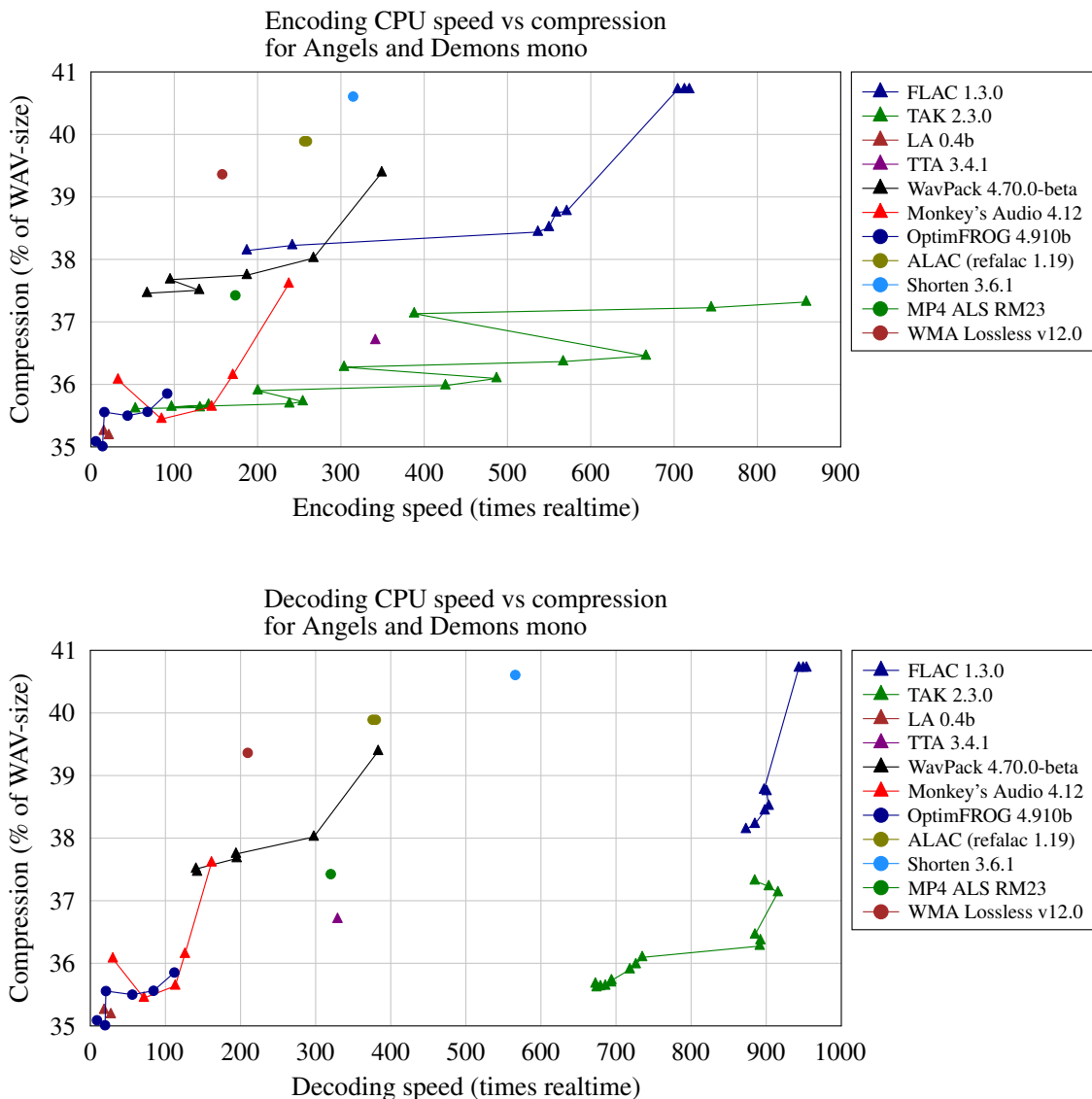


Figure 2.4: Codec performance for the audiobook mixed to mono

To find out which part of the performance of the codecs was due to the file being mono and

which was due to the file containing lots of silence and only one voice, I decided to rerun the test with the files mixed to mono. This mono mixing was done with SoX using "remix 1" as a filter. So no mixing, I just took the first (left) channel to form the mono-channel.

The results are displayed in figure 2.4 on the previous page. The results for this test are more like the overall result, with the performance of LA and WavPack back on par and shorten (which seems to have no stereo decorrelation at all) benefits the most. The strange behaviour of Monkey's Audio stays, however. The most striking difference between the stereo original and the mono mix is that FLAC and the lower TAK and WavPack levels have halved their encoding time: apparently, stereo decorrelation takes a lot of time. In FLAC, stereo correlation is more or less 'brute-force', so that fits the picture very well.

2.3.2 Compressibility

While the results of these tests show that codecs perform similar on very different material (in other words, no codec is very good at a certain kind of music while not at others), some kinds of music seem to have more room for 'improvement'. For example, when looking at Yann Tiersen - Le Fabuleux Destin d'Amélie Poulain (see figure 2.5), OptimFROG bestnew preset delivers a file 9.3% smaller than its fast preset. Likewise Monkey's Audio gets a 8.8% smaller file when comparing the fast with the insane preset and TAK improves 9.8%. However, when looking at System of a Down - Mezmerize (see figure 2.6), OptimFROG gets 2.5% extra out, Monkey's audio 2.6% and TAK 3.9%.

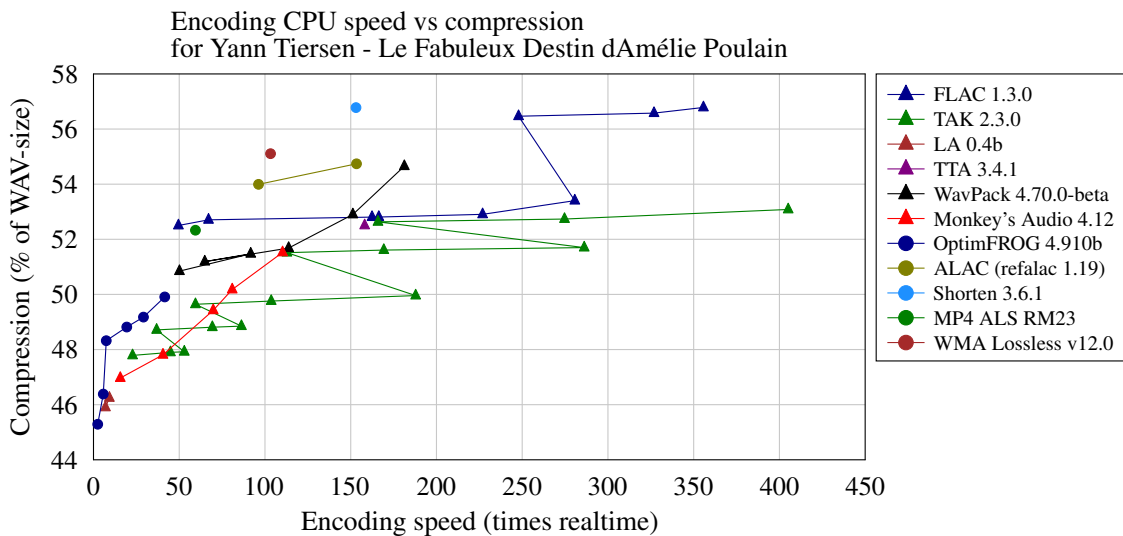


Figure 2.5: Compression versus encoding speed for Le Fabuleux Destin d'Amélie Poulain

So it seems the 'law of diminishing returns' is different for each CD, but it seems to match well between different codecs. It is easily seen in the graphs, as the y-axis for the Mezmerize album run from 67% to 78% of the original file size, a difference of 14%, while for the other CD this is a difference of 24%. For most CDs the difference wasn't this large or small (these were two carefully selected extremes) but it is related to music genre: metal has usually less improvement while quiet, clean music has large improvements.

This difference might be explained by instrumentation. In metal music, the sound is usually saturated with overdriven guitars and is usually percussion-heavy. The extensive use of cymbals

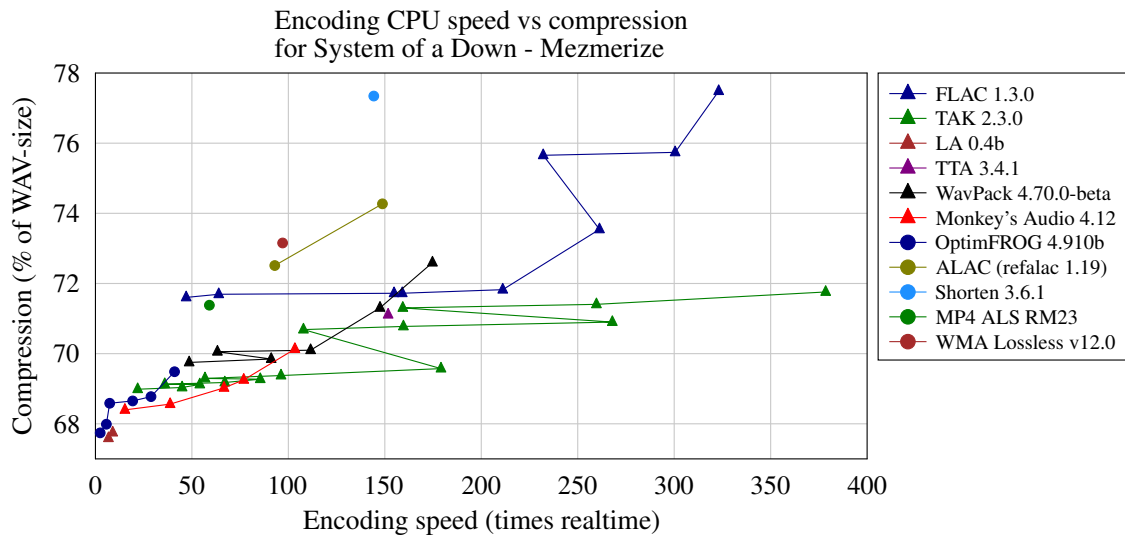


Figure 2.6: Compression versus encoding speed for Mezmerize

for example, might influence the compressibility, as the sound of a cymbal is usually characterized as 'colored noise'. As is known, codecs perform very bad on noise-like input, because of the high entropy. As lossless codecs try to find correlation in the input as much as possible, one might conclude that this kind of music (with very present noise-like sound like cymbals) has little input to filter and a lot of residual to store. The codecs can't find more correlation as more resources (CPU, RAM etc.) are allocated to compress.

The music from *Le Fabuleux Destin d'Amélie Poulain* is characterized by simple instrumentation, usually solo or small ensembles. This is more easily compressed (because there is less noise-like content) but there are more 'similarities' to find and filter too, so besides getting smaller files with all codecs, compression benefits more from deeper searches.

So, when looking at the averaged results, one should take into account that different kinds of music can bring quite different results. While it seems codecs take roughly the same spot in whatever ranking you might make with different CDs, the improvements between better-compressing codecs and slower presets might be different on different kinds of music. If you want to look at this feature in detail, I'd suggest you take a look at the raw results that should accompany this report.

2.4 Convergence of the results

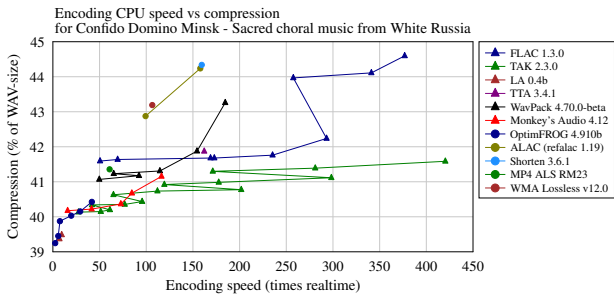
One of the most important questions regarding any results of this test would be whether the results are truly 'average' and whether they represent all different kinds of CD-audio out there. As pointed out in section 2.3, this is not the case: some codecs perform better than usual at certain CD's. However, most results seem fairly similar while being obtained from very different material.

From comparing results and trying to draw conclusions on the convergence of the results, one can observe differences regarding the reliability of certain codecs. For example, when one takes a look at figure 2.3 on page 11, certain codecs (FLAC -3 and Monkeys Audio -insane) generate larger files while being slower: choosing a higher 'mode' will not always result in better results.

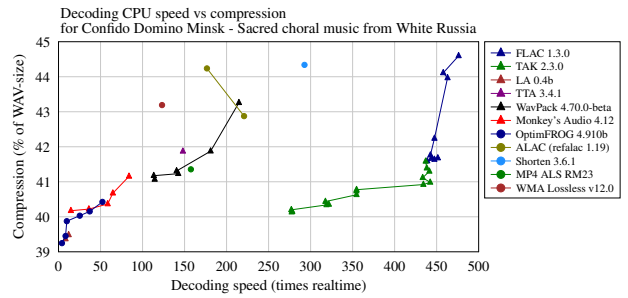
In figure 2.7 on page 16 the encoding and decoding performance of all codecs are graphed for

four very different kinds of music: a capella choral, metal, soul and jazz. While the average compression achieved and speed differs, codecs all perform similar for different kinds of music: LA and OptimFROG take turns in achieving the best compression while both being pretty slow, FLAC is always the fastest decoding, Shorten performs at FLAC -0 but slower, Monkey's Audio ranges from OptimFROGs –best to WavPacks default setting (but being slower than the latter), TAK is almost always the best performer when trading off compression to encoding speed etc.

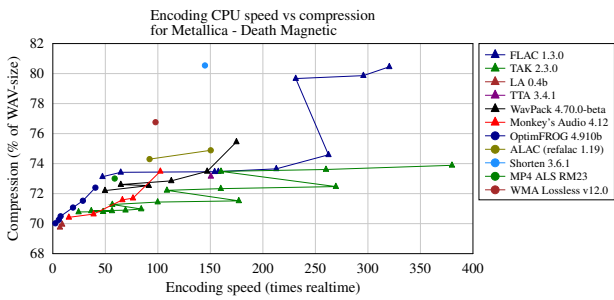
The 'typical' position of each codec works for very different kinds of music and is never much better or worse when compared to the average of all CD's, except perhaps FLAC -0 through FLAC -3 and Shorten.



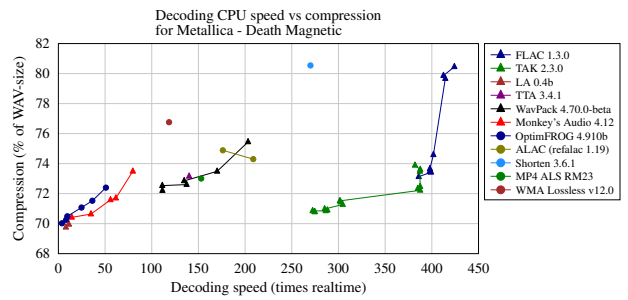
(a) Encoding choral music



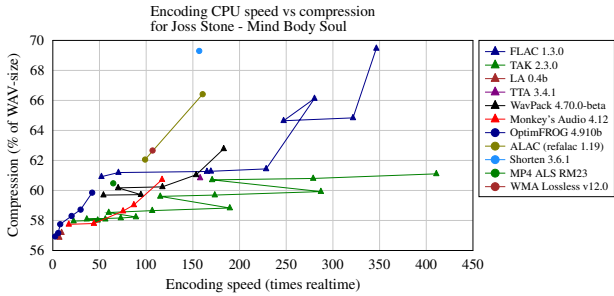
(b) Decoding choral music



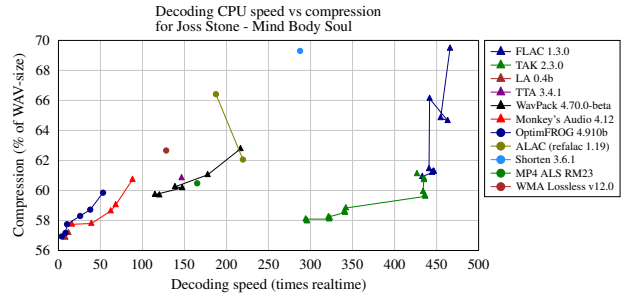
(c) Encoding metal



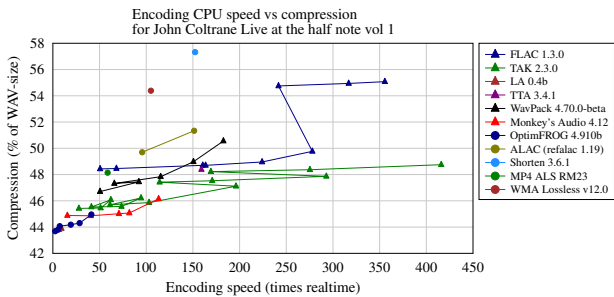
(d) Decoding metal



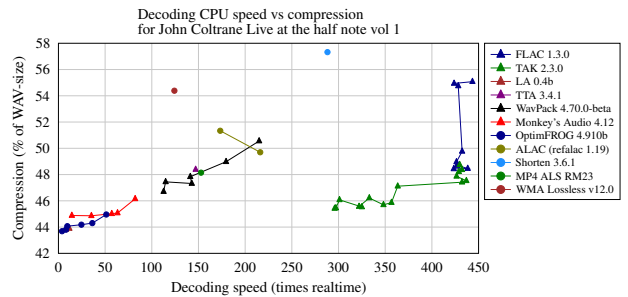
(e) Encoding soul



(f) Decoding soul



(g) Encoding jazz



(h) Decoding jazz

Figure 2.7: Codec performance for various music genres

Chapter 3

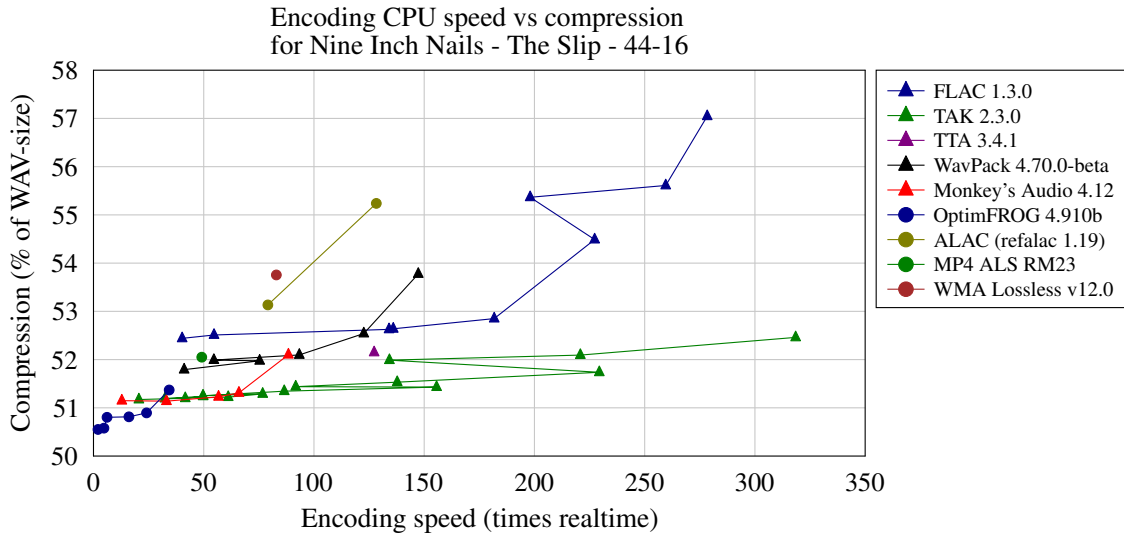
High-resolution audio

While the use for 'high resolution' (i.e. a high sample rate or high bit depth) is open to discussion, lossless codecs are used to pack this kind of material, so it should be tested as well. Two codecs do not participate in this test: both LA and Shorten do not handle these sample rates/bit depths at all.

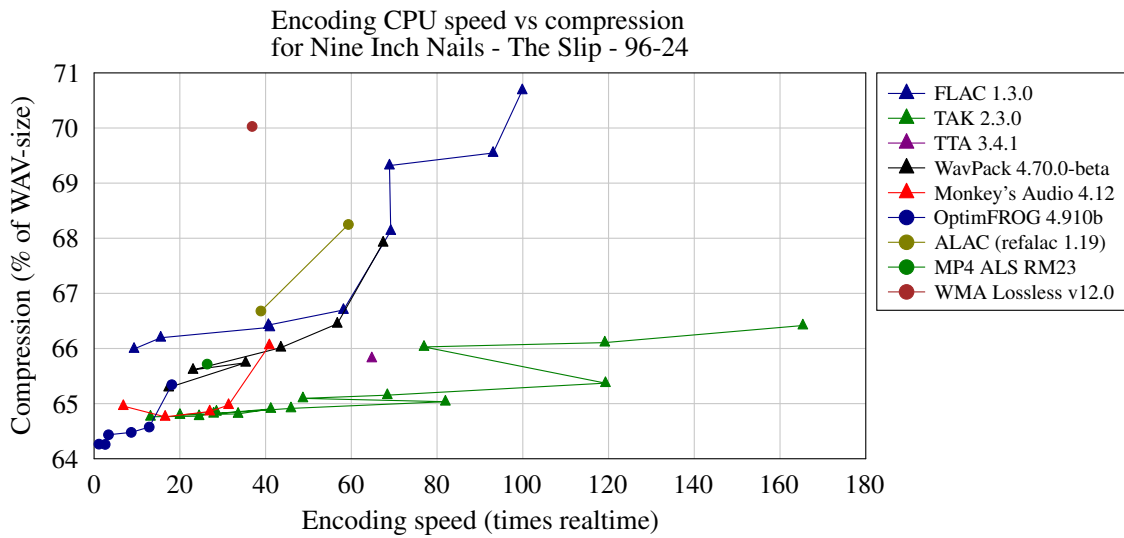
3.1 Nine Inch Nails' The Slip

The Slip was made available free of charge from the website of NIN, releasing both 44kHz/16-bit FLAC-files as well as 96kHz/24-bit files.

The results are shown in figure 3.1 and 3.2. Nothing spectacular: all codecs perform similar when compared to the CD-audio, only FLAC seems to perform worse, being much slower than usual in both encoding and decoding and compressing a little less. Monkey's Audio -insane (or -c5000) preset misbehaves here, just like with the Dan Brown audiobook test and the next test in this chapter, it is slower and compresses less than -c4000.

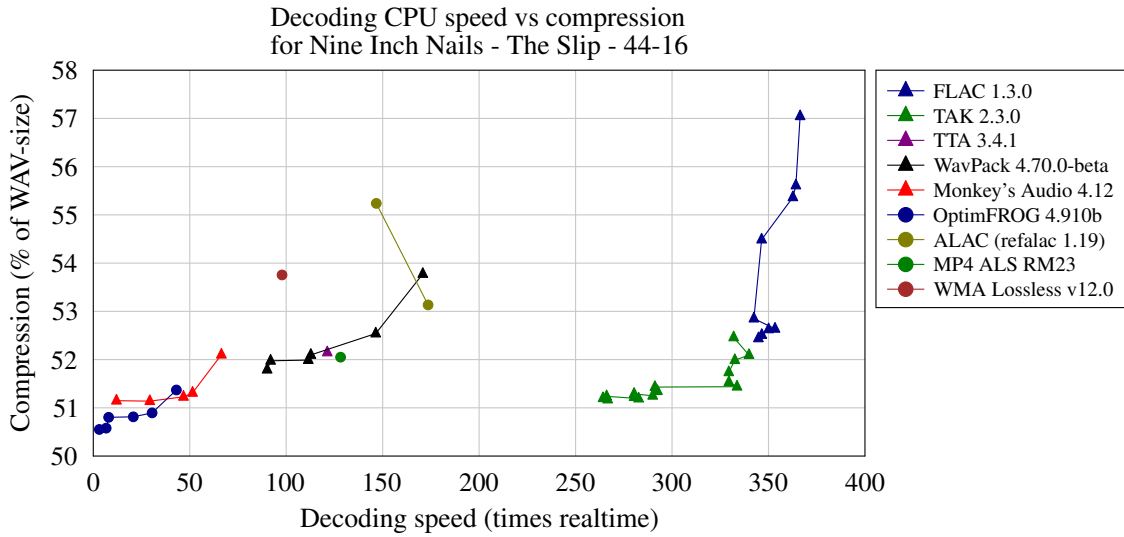


(a) Sample with 44/16

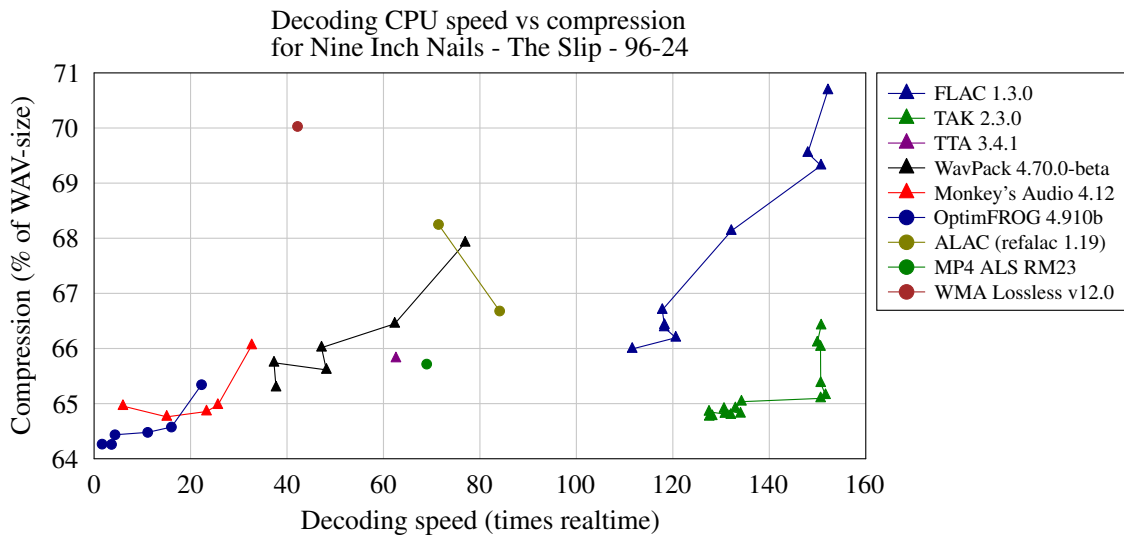


(b) Sample with 96/24

Figure 3.1: Encoding performance



(a) Sample with 44/16



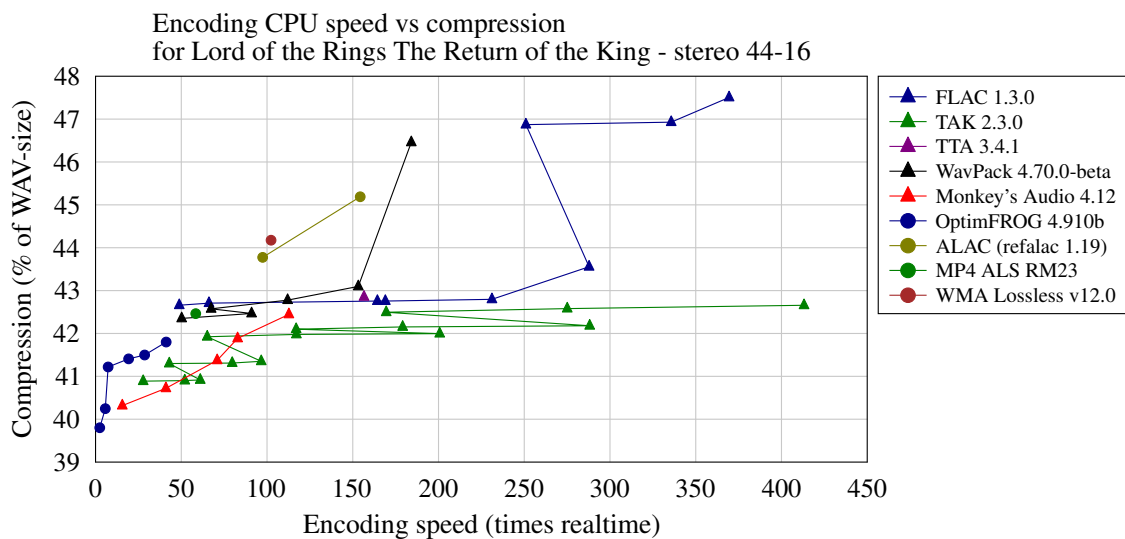
(b) Sample with 96/24

Figure 3.2: Decoding performance

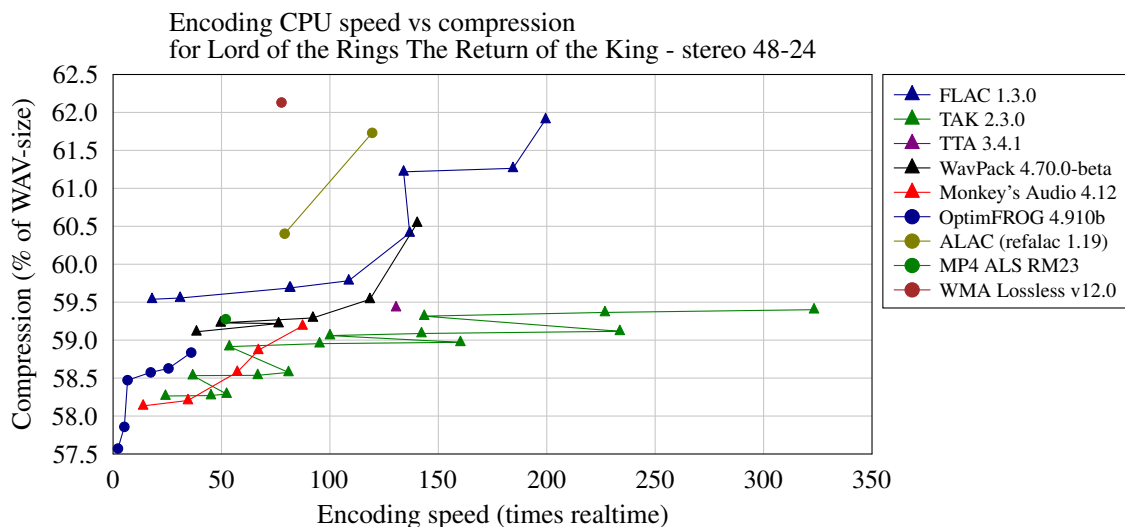
3.2 Howard Shore's soundtrack for The Lord of the Rings: The Return of the King

The complete recordings of the soundtrack for The Return of the King features an DVD-A along with the 4 audio CDs. This disc was used in the following test. While I first tried another DVD-A from the same trilogy, this disc had some features that made it unsuitable for this comparison, see section 3.3 on the matter. The results are shown in figure 3.3 and 3.4.

The results are very similar to those obtained with NIN's The Slip in section 3.1. Interesting to note it that the differences between different codecs and compression modes are even smaller, similar to the discussion in section 2.3.2, moving to 24-bit adds a lot of incompressible noise to the input.

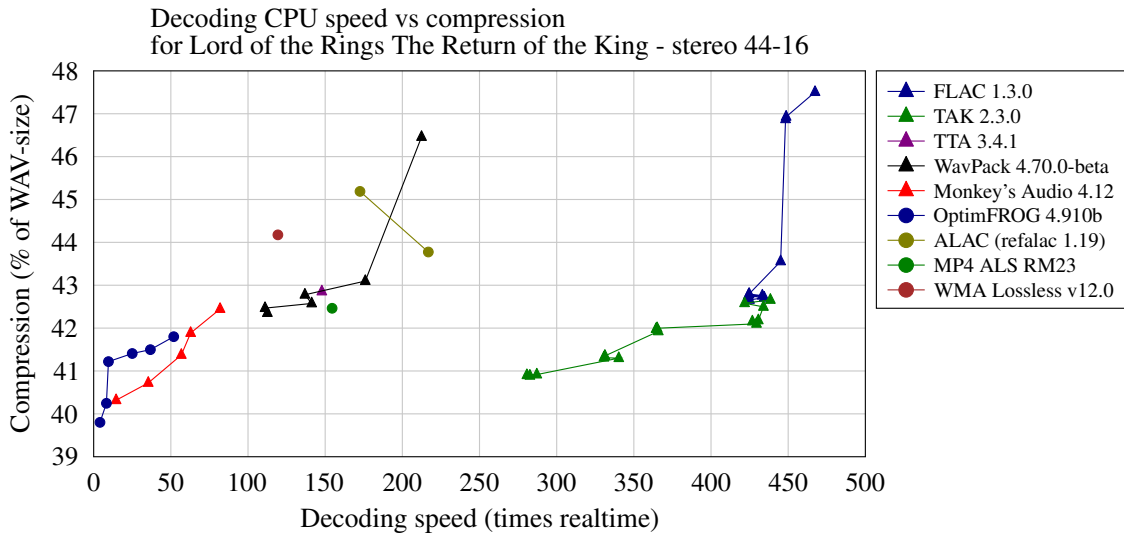


(a) Sample with 44/16

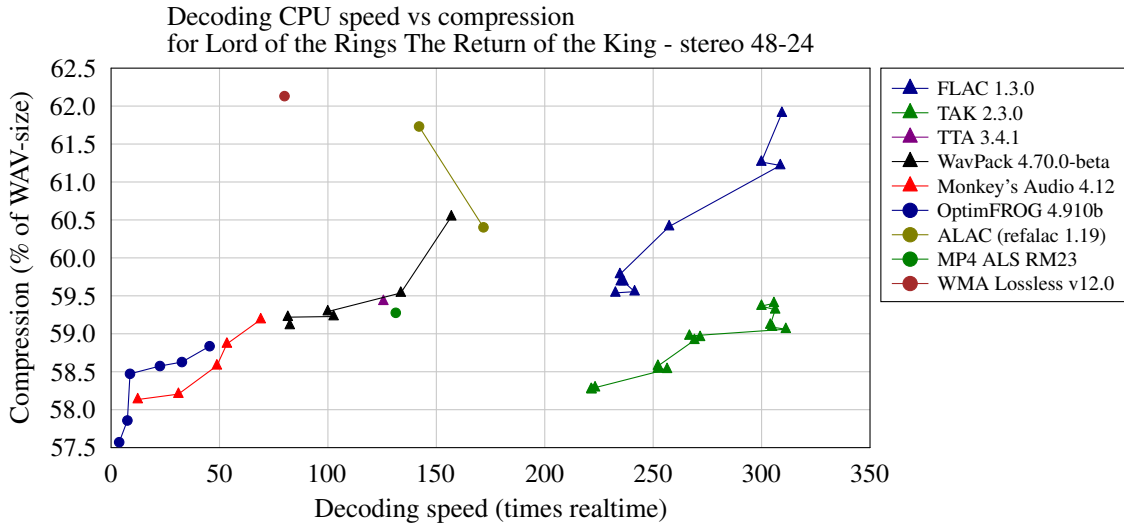


(b) Sample with 48/24

Figure 3.3: Encoding performance



(a) Sample with 44/16

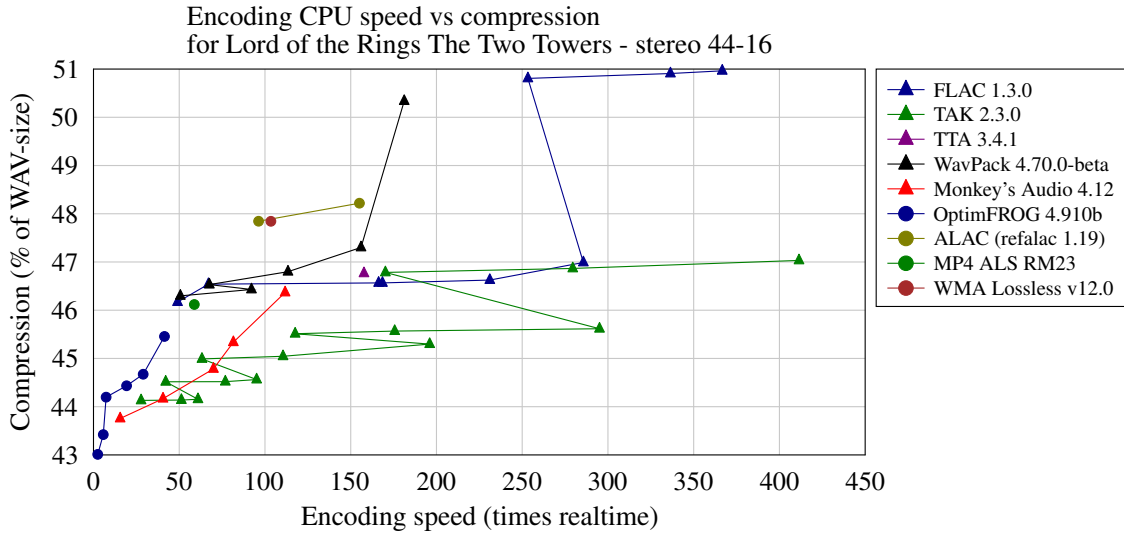


(b) Sample with 48/24

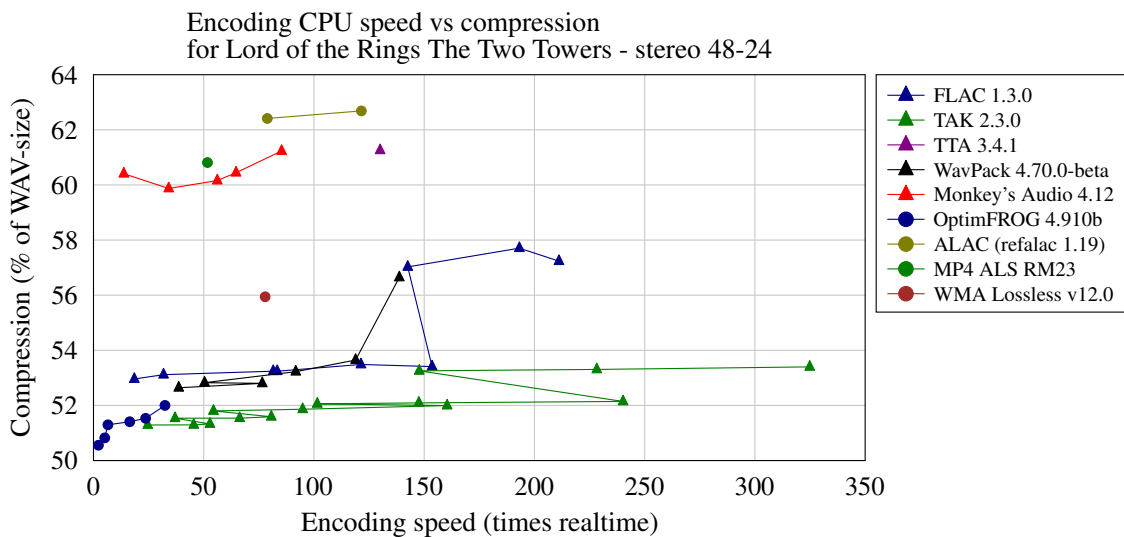
Figure 3.4: Decoding performance

3.3 Wasted bits

When testing the complete recordings of The Lord of the Rings: The Two Towers soundtrack, some rather strange results were obtained, shown in figure 3.5 and 3.6. After looking at the analyse-files generated by the official FLAC decoder, it became clear that something called 'wasted bits' was responsible for this behaviour.



(a) Sample with 44/16

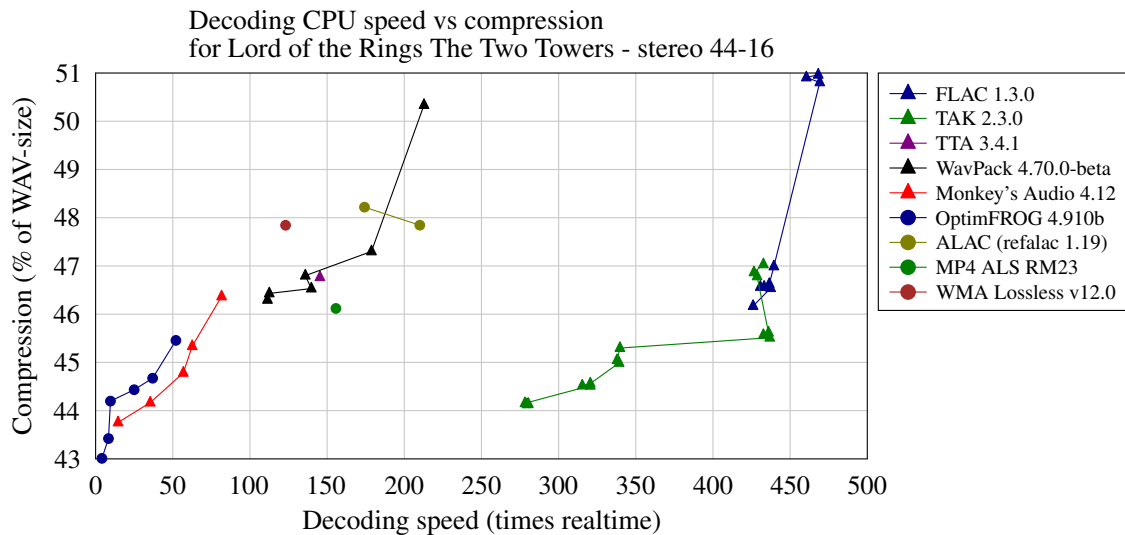


(b) Sample with 48/24 (2 wasted bits)

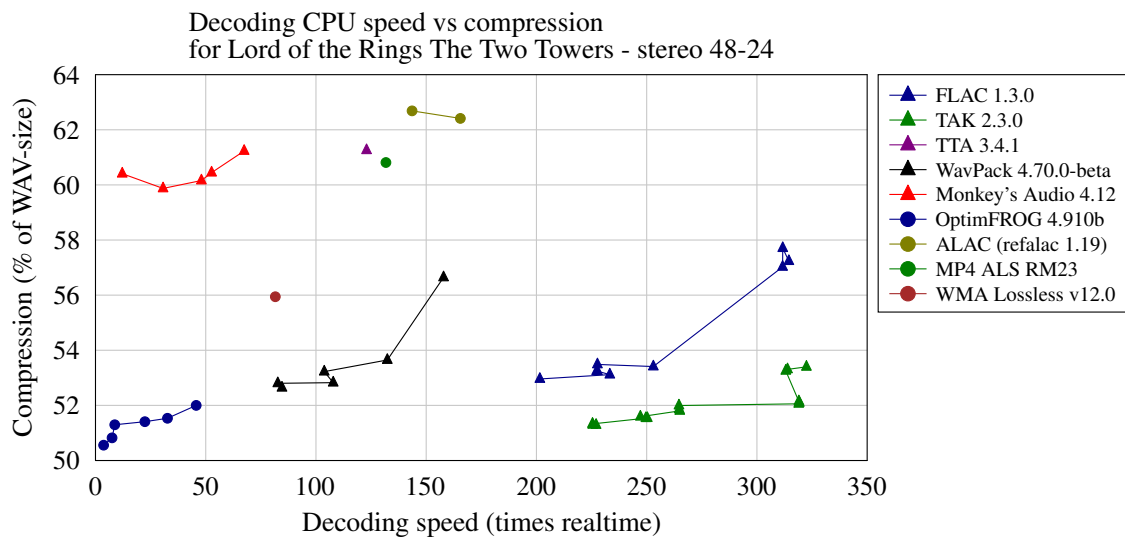
Figure 3.5: Encoding performance

The first thing that stands out when looking at these results is that the results seem to form two groups: one group (consisting of FLAC, WavPack, TAK and OptimFROG) that does pretty well on these samples and one group (Monkeys Audio, ALAC, TTA and MP4ALS) that fall short. This is because the latter group of codecs do not search for so called wasted bits. This 2 wasted bits mean that, while the files are packed in a 24-bit file, the data actually is 22-bit only and the two least significant bits are always zero. ALS can perform better, but a switch (-l) has to be used on encoding.

Of course one could wonder why this exists, material which is 'only' 22-bit while it is advertised



(a) Sample with 44/16



(b) Sample with 48/24 (2 wasted bits)

Figure 3.6: Decoding performance

as being 24-bit. In this case, the material was packed on the DVD-A with a lossless codec which is called MLP (Meridian Lossless Packaging) which is a proprietary format. (Just as a side note: It's compression was 59.3%) MLP is among the codecs that benefits from wasted bits as well, so this way it was possible to fit the audio on one disc, with 8GB of 8.5GB filled, without these wasted bits the disc would have been too small. It actually is listed as an 'feature' by its creators, but is not often seen on commercial discs apparently. For more information, you can search for 'LossyWAV', which is an application that makes use of the wasted bit system.

So, in the rare case you come across a disc which is compressed with MLP and is packed-as-24bit-but-actually-isnt-24bit, half of the tested codecs might not be able to handle this very well.

Chapter 4

Multichannel audio

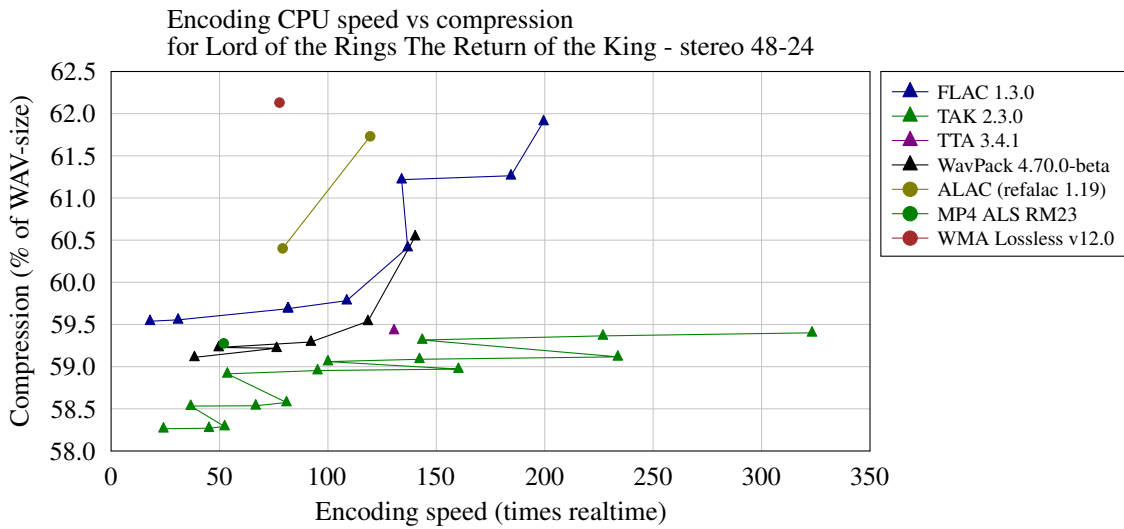
While surround sound is usually paired with a movie and not often sold 'just audio', it might become an interesting topic in the future. Since the introduction of stereo sound, people have been talking about 'more than 2 channels', and while sales of surround-sound music never really took off it has some really interesting advantages over stereo.

Because it never really took off, codecs usually focus on mono and stereo sound. For example, FLAC has a few tricks to use the similarity of stereo channels to get some more compression, but there is no such decorrelation for multichannel audio. Other codecs, like Monkey's Audio, OptimFROG and shorten have no support for multichannel audio at all.

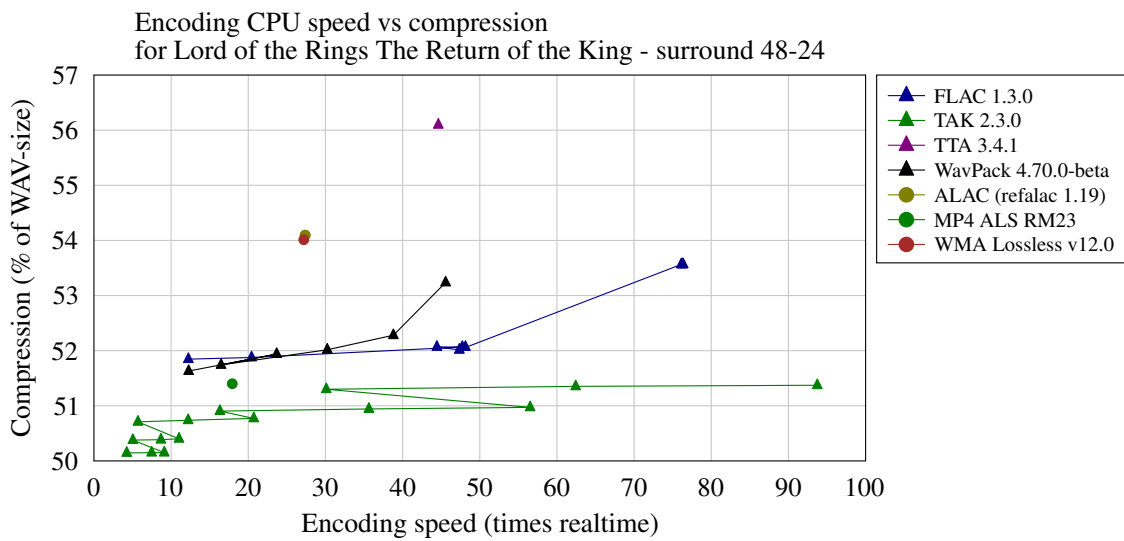
4.1 Howard Shore's soundtrack for *The Lord of the Rings: The Return of the King*

The complete recordings of *The Lord of the Rings* (*The Two Towers*) soundtrack feature the usual 44.1kHz/16-bit stereo sound on CD, but also pack an Audio-DVD with the same music in 48kHz/24-bit stereo sound and 48kHz/24-bit surround sound. As this and the same package for the *Two Towers* discussed in section 3.3 are the only 2 sources of lossless multichannel audio I have, this is the only material used for comparison. Only the first 8 tracks are tested because of size constraints on the ramdisk.

The results for these tests are shown in 4.1 and 4.2. It seems that, like the comparison between 16-bit and 24-bit audio, the number of channels does not seem to matter much. The only strange thing is that TTA performs pretty bad compared to its usual performance. This is strange because being able to encode multichannel-audio (up to 65536 channels) is one of its selling points on the TTA-website. FLAC is performing better than usual, but the difference is only small so mastering (or the way of down-mixing to stereo) could be a reason for this, this is no reason to believe that FLAC performs better than usual on all multichannel material.

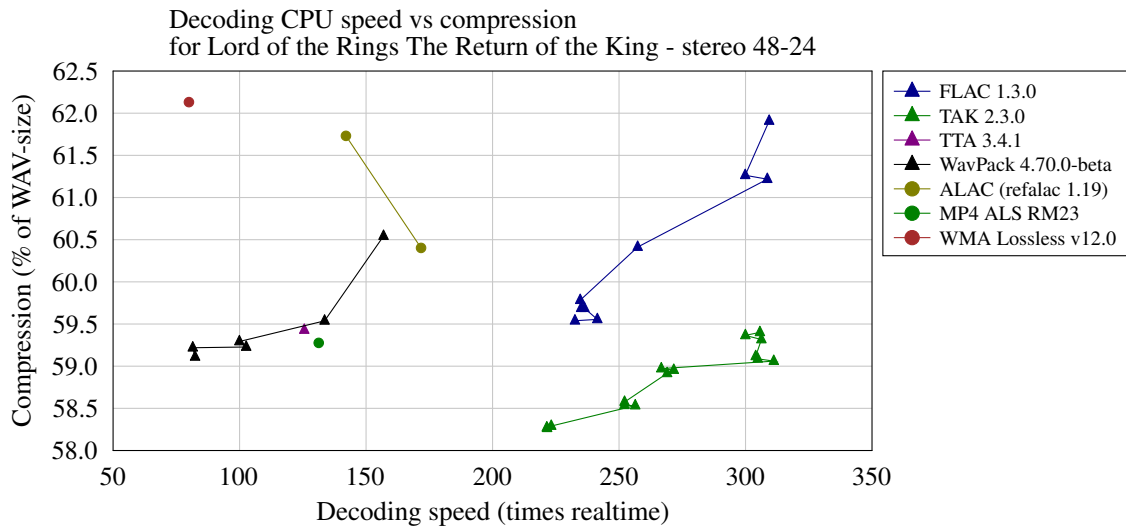


(a) Sample with 48/24 stereo

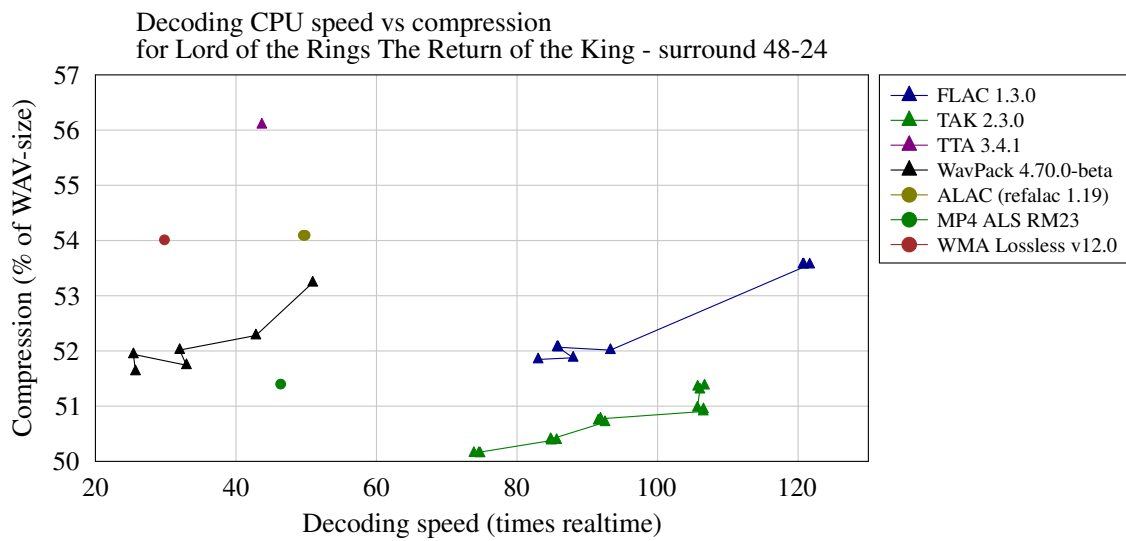


(b) Sample with 48/24 surround

Figure 4.1: Encoding performance



(a) Sample with 48/24 stereo



(b) Sample with 48/24 surround

Figure 4.2: Decoding performance

Appendix A

Motivation for choosing these CDs

The validity of this test is for a large part dependent on the audio material used. It was chosen to pick full CDs instead of single tracks because single tracks might exhibit a single strong 'characteristic' which could influence the test. We want to capture the influence of a certain genre, not that of a peculiarity of a track. However, we might still capture the 'sound' of a certain album (for example the way it was mixed or mastered), but this is not reasonably avoided, as one would have to test an awful lot of CDs.

See table A.1 for the CDs and some data describing their contents. For more information on the DR measurement, see www.pleasurizemusic.com

Each CD in this list is there for a reason. First of all, for every main genre I could find (with some help of wikipedia [2] and the list of genres for which Grammy-awards are awarded [1]) I tried to add a CD or two. The only genre that is missing that is on the list of Grammy awards is gospel, but this might be added in the future. Besides, one could argue gospel is close to soul music and there is already some 'religious' music in the test. At least one can conclude that drawing a line and getting the list right is not easy.

Not every genre has the same amount of CDs tested, and this is not easily explained: one could argue that certain music genres feature much more diverse kinds of subgenres or that certain (distinct) genres sound much alike technically, and the division is mainly on lyrics. While this all holds true, I would say there is no inherently better way to 'balance' a test, there's no accounting for tastes. Even the very classification of music in genres has spawned numerous discussion.

I did my best to balance the CDs between different genres and give every genre as much credit as it deserves. If you think there's something wrong and the list could be balanced better, please post suggestions at the thread mentioned in the bibliography at [3].

For rock, "**30 Seconds to Mars - This is War**" and "**Rush - Grace under Pressure**" were added. The first is more recent and has seen moderate dynamic range compression, while the second is (despite it being a later remaster) from the '80s and has a lot more dynamic range. They are musically quite different 'spots' of the rock-genre as well. Considering rock, "**Jeff Waynes Musical Version of the War of The Worlds**" might be regarded as rock as well, but this features far more electronic influences and is half audiobook, half music, so it fits no general category at all.

Confido Domino Minsk's Sacred choral music from White Russia is half orchestral plus choir and half a capella choir. It features, as it's name would suggest, mainly religious music and tests the various codecs on their handling of voice-only content.

| Album | Genre | Remarks | DR |
|--|-----------------------------------|-------------|----|
| 30 Seconds to Mars - This Is War | rock | - | 6 |
| Abba - Gold: Greatest Hits (1992) | pop | - | 13 |
| Albert King - Years Gone By | blues | - | 14 |
| Alicia Keys - The Diary of Alicia Keys | R&B, soul | - | 8 |
| Alison Krauss Union Station - New Favorite | country, bluegrass | - | 10 |
| Armik - Rain Dance | flamenco/jazz | - | 15 |
| Café del Mar - Volumen nueve | chill-out | - | 8 |
| Coldplay - Parachutes | pop | - | 8 |
| Confido Domino Minsk - Sacred choral music from White Russia | choral, religious | - | 12 |
| Daft Punk - Alive 2007 | electronic | live | 5 |
| Dan Brown - Angels and Demons | audiobook | - | 16 |
| Enya - Amarantine | new age | - | 8 |
| Fanfara Ciocarlia - Baro Biao: World Wide Wedding | world music, brass | - | 12 |
| Gilberto Santa Rosa - Esencia | salsa | - | 9 |
| Giuseppe Verdi - Messa da Requiem (Berliner Philharmoniker feat. conductor Claudio Abbado) | orchestral, romantic | - | 12 |
| Howard Shore - The Hobbit: An Unexpected Journey | orchestral, OST | - | 10 |
| Iron Maiden - Brave New World | metal | - | 7 |
| James Brown - Love, Power, Peace (Live at the Olympia, Paris, 1971) | funk | live | 12 |
| John Coltrane - Live at the half note, vol. 1 | jazz | live | 11 |
| Joss Stone - Mind, Body & Soul | soul | - | 7 |
| J.S. Bach - Magnificat | orchestral, baroque | - | 13 |
| Koninklijke Militaire Kapel - [no name] | military brass | vinyl rip | 11 |
| Kraftwerk - Autobahn | electronic | - | 13 |
| Lana del Rey - Born to Die | pop | - | 5 |
| Lil Wayne - Tha Carter III | hip hop | - | 7 |
| Martin O'Donnell & Michael Salvatori - Halo: Reach | ambient-ish, OST | - | 11 |
| Metallica - Death Magnetic | metal | - | 3 |
| Michael Bublé - meets madison square garden | pop, jazz | live | 8 |
| Mike Oldfield - Tubular Bells (2000 remaster) | not classifiable | - | 11 |
| 'N Sync - Home for Christmas | pop | - | 8 |
| Nicholas Hooper - Harry Potter and the Order of the Phoenix | soundtrack | - | 12 |
| Peter Tosh - Equal Rights (2011 legacy edition) | reggae | - | 10 |
| Rosenberg Trio - Djangologists | jazz | - | 7 |
| Rush - Grace under Pressure (1997 remaster) | rock | - | 10 |
| System of a Down - Mezmerize | metal | - | 5 |
| Szakcsi - Virágom, virágom | world music | - | 10 |
| Tiësto - In Search of Sunrise 7: Asia | dance | - | 8 |
| The Lumineers - The Lumineers | folk | - | 10 |
| Various - Jeff Waynes Musical Version of The War of the Worlds | radio drama-ish, rock, orchestral | - | 11 |
| Various - Latin Village, CD 1: Salsa | salsa | compilation | 8 |
| Waylon Jennings - Honky Tonk Heroes | country | - | 12 |
| Xzibit - At the Speed of Life | hip hop | - | 10 |
| Yann Tiersen - Le Fabuleux Destin d'Amélie Poulain | minimalism | - | 11 |

Table A.1: CD data

For electronic music, 3 CDs were used: "**Daft Punk - Alive 2007**", "**Kraftwerk - Autobahn**" and "**Tiësto - In Search of Sunrise 7: Asia**". The first is because Daft Punk has been an popular electronic artist for quite some time and this album is quite recent. Kraftwerk's Autobahn was added to counter any recent mastering issues and is as well well known. Tiësto was added because it was the only dance music I have in my collection and seems to fit in this test well: it is quite different from the other two CDs in this category. Daft Punk's CD is a live album.

Dan Browns book Angels and Demons as read by Richard Poe was added to add pure speech to the test as well.

Enya - Amarantine represents New Age music in this test.

Considering world music **Fanfare Ciocarlia - Baro Biao: World Wide Wedding** and **Szakcsi - Virágom, virágom** were added. While they are both European (Romanian and Hungarian to be precise), they are very different and seem to feature two extremes of what one would call world music. Fanfare Ciocarlia can be typed as gypsy music as well and is mainly brass. Szakcsi is very different and features both very serene and stimulating folk music, it consists of variations on children's songs and features no brass instruments at all.

To add some latin (which one could call 'world music' as well of course), two CDs featuring salsa music were added: **Gilberto Santa Rosa - Escencia** and a compilation-CD. The first sounds more like traditional salsa, while the second features more elements of current popular music.

Classical music is represented by **Guissepe Verdi's Requiem** and **Bach's Magnificat**. The first is from the romantic movement and, as is very Verdi, sounds more like an opera than a requiem. Bach was an baroque composer. Both cultural movements are more or less opposing considering size: baroque features a small orchestra and a small choir, while romantic music features large orchestra's and very large choirs. In this respect, these two recordings span different kinds of orchestral music.

Howard Shore's soundtrack for The Hobbit: An Unexpected Journey and **Nicholas Hooper - Harry Potter and the Order of the Phoenix** are orchestral as well, but The Hobbit only features choir in a few tracks and is less brass-heavy than the previous two. The music by Nicholas Hooper uses the orchestra in a much less 'classical' way, with lots of small chamber-music like settings, using extensive panpotting and close-miking and featuring non-orchestral instruments. Furthermore, these were composed in 2011 and 2007 respectively, so they are still relatively fresh.

To add metal to the test **Iron Maiden - Brave New World**, **System of a Down - Mezmerize** and **Metallica - Death Magnetic** were added. System of a Down is quite chaotic and fast, while Iron Maiden is more steady and brutal. Death Magnetic has been extensively criticized for its extremely high dynamic range compression, which explains the very low DR-number of 3.

John Coltrane - Live at the half note vol.1 and **The Rosenberg Trio - Djangologists** were added to represent jazz. Coltrane's CD represents live recorded music as well.

Joss Stone - Mind, Body & Soul and **Alicia Keys - The Diary of Alicia Keys** add soul/R&B to the test.

The vinyl rip of the Koninklijke Militaire Kapel adds some military wind music to the test.

Lana del Rey's Born to Die, **Michael Bublé's live album**, **Coldplay - Parachutes**, **'N Sync - Home for Christmas** and **ABBA - Gold: Greatest Hits** add some pop music

to the test. Picking pop music was hard, as quite a lot of pop music can be classified as rock as well, or poprock for that matter. Lana del Rey's CD is more downtempo, Bubl  is more jazz-like, Coldplay is more rock (pop rock probably), 'N Sync is a classical example of a pop boyband and ABBA adds earlier pop music. The spread of DR reflects that these 5 span quite different masterings: the album Lana Del Rey has seen quite some dynamic range compression while the ABBA CD might be considered a pre-loudness war release.

Lil Wayne - Tha Carter III and **Xzibit - At the speed of life** were added two represent hip hop.

Martin O' Donnell & Michael Salvatori's soundtrack for Halo: Reach is mainly ambient music, and was added to represent it

Mike Oldfield - Tubular Bells was added to add some older popular music as well, while it is not really possible to name a genre this would fit to.

As classic guitar is featured as a solo instrument in quite a lot of music, **Armik - Rain Dance** was added, which is flamenco music. It has a nice high DR too, the highest of all music samples tested.

For funk, a live album by James Brown, **James Brown - Love, Power, Peace (Live at the Olympia, Paris, 1971)** was added. This was recorded in 1971 but it was not released until 1992, on CD.

For some blues, **Albert King - Years Gone By** was added.

Caf  del Mar - Volumen nueve features chill-out music.

For reggae, **Peter Tosh - Equal Rights** was added. The 2011 remaster (legacy edition) was used, but only the 8 tracks that were originally featured on the first release.

For folk music, **The Lumineers - The Lumineers** was added. Note that, while this CD is quite recent, its mastering was done with little dynamic range compression.

Waylon Jennings - Honky Tonk Heroes and **Alison Krauss & Union Station - New Favorite** to account for country music.

Finally, **Yann Tiersen's soundtrack for Am lie** features music with different (but always few) instruments, and is usually regarded minimalism music. It was added to check performance on the 'less popular' instruments featured.

Appendix B

Revision history

- Revision 1 - January 7, 2013 - Initial version
- Revision 2 - March 19, 2013 - Improved graph readability and optimized for screenreading
- Revision 3 - August 10, 2013 - Added Metallica's Death Magnetic, Coldplay's Parachutes, Armik's Rain Dance, the self-titled album of The Lumineers, Peter Tosh's Equal Rights, Alicia Keys' The Diary of Alicia Keys, 'N Sync's Home for Christmas, James Brown's Love, Power, Peace, ABBA - Gold: Greatest Hits, Waylon Jennings - Honky Tonk Heroes, Alison Krauss & Union Station - New Favorite, Café del Mar - Volumen nueve and Nicholas Hooper - Harry Potter and the Order of the Phoenix.

Testing was moved to a different computer running Windows. Newer versions of FLAC, TAK, WavPack and Monkey's Audio. Because of the move to use Windows, a newer (windows-only) release of OptimFROG is tested as well and WMA Lossless is featured in all tests. Real Audio has been dropped because it has no command line encoder/decoder. FLAC's encoding and decoding is now with the undocumented `-no-md5-sum`, see section 1.3 for more information.

Bibliography

- [1] List of Grammy Award categories, http://en.wikipedia.org/wiki/List_of_Grammy_Award_categories
- [2] List of music genres and styles, http://en.wikipedia.org/wiki/Music_genre
- [3] Once more: Time for a new lossless codec comparison?, More comprehensive, more detail, (a thread I started to ask for advice), <http://www.hydrogenaudio.org/forums/index.php?showtopic=94685>
- [4] FLAC - comparison, <http://xiph.org/flac/comparison.html>
- [5] Lossless comparison - HydrogenAudio Knowledgebase, http://wiki.hydrogenaudio.org/index.php?title=Lossless_comparison