

Types of Audio Distortion

To get the most enjoyment from our music collections, we need to get the least distortion from our audio systems. Distortion is not just an important subject for audio, it is THE subject. It is often not well understood, too limited in scope, and rarely covers all the various forms of distortion effecting sound reproduction. In some cases, it's conveniently ignored. After searching the internet for a comprehensive list of the various forms of audio distortion, I came up with next to nothing. Very surprising for a topic that is fodder for endless argument and disagreement among audiophiles. How can we begin to get the max from our music without a solid understanding of the obstacles standing in the way of achieving realistic sound?

Small digression:

<https://www.stereophile.com/interviews/850/index.html>

Audio, Precision, & Measurement: Richard Cabot

Richard Cabot: I certainly believe that if something can be reliably heard—if the person really is hearing it—you can measure it if you know what to measure. But **I would not swear that I could, with a simple set of measurements, automatically measure the right things. I would try to do a broad spectrum of measurements. There are a lot of measurements that we haven't figured out how to make yet. We aren't really measuring the right things.**

...I have no doubt that measurements will be found in the future that we don't know how to do today. I'm sure they will be found.

<https://www.diyaudio.com/community/threads/sound-quality-vs-measurements.200865/post-2856456>

After 10 years of debating the correlation between measurements and sound quality, here is the final verdict:

jan.didden

... it will always be possible engineering wise to build a 'better' amp and I expect that other measurements may be required to proof that one amp is better than another, but **I have no specific answer as to which measurements this might be.**

A similar confession from Bob Cordell:

<https://www.diyaudio.com/community/threads/stereophile-january-2008-pages-13-and-15.115513/post-1404393>

Bob Cordell

I'm saying that **it is often tough to measure those things that are at work in a relevant way to make the sound better or worse or just different.**

Nevertheless, you can still meet radio amateurs and audio developers who are firmly convinced that THD measured at a frequency of 1 kHz (at best, at a frequency of 20 kHz) in steady state is enough to assess the quality (as a standard Audioprecision device does)

End of digression

Since I never found a single source outlining the various forms of audio distortion, this page is aimed at filling the need with a concise summary. It doesn't go into great detail. For depth, see the links to references below. Some of the links contain technical jargon and

mathematical equations. Not to worry, the bulk of it is straight forward. You can easily pull out the essential information necessary for understanding the concepts without fully grasping the math.

It is very important to keep in mind that all distortion is not equal. Different forms have varying audibility levels and therefore some get in the way of the music much more than others. This is a complex subject in which too little knowledge, gaps of knowledge, or placing too much emphasis on a single part taken out of context can cause wild misunderstanding and misleading interpretation. With this in mind, let's start with a basic definition.

Distortion is any change in the content of an electrical signal or the shape of a sound wave during its transmission. It could also be described as information either lost or added relative to the original signal. Audio distortion can be placed in two broad categories.

- Type 1 – linear, altered amplitude content.
- Type 2 – nonlinear, added frequency content.

Type 1 is also known as frequency response, which involves both amplitude (changes in the volume) and phase errors. These distortions can be corrected with signal processing.

Type 2, in its most common form, is harmonic distortion (added frequencies). Type 2 can not be corrected after the fact. Each of these types can be subdivided into more specific forms.

Note. Such distortions are sometimes introduced deliberately, for example, in the form of pre-distortions when recording records or magnetic recording. True, these distortions are not always completely eliminated by the inverse transformation.

Linear Distortion (Type 1)

When all audible frequencies are transferred at the same level, a system is called linear. If specific frequencies are output at different levels, the system is distorting. With a little experience this can be detected by ear if it exceeds ± 2 dB, and sometimes less depending on the bandwidth of the deviation. Linear distortion is more easily perceived as the deviation spreads across a wider band of frequencies. The narrower the bandwidth and amplitude range of linear distortion the better. Over the entire audible spectrum less than ± 1.5 dB is desirable. More than that is like watching TV with dark and light spots in the picture or an off-color cast.

Bandwidth Distortion (Type 1)

Bandwidth distortion is another aspect of amplitude distortion. It's about how much of the audible spectrum the system is able to produce. Although a reasonably flat response may be produced in the middle of the spectrum, if the high or low end falls off by more than 3 dB, those frequencies are no longer in balance and therefore not part of the *useful* bandwidth. A truncated bandwidth is as distorted as a lumpy one. Published specs often show bandwidth without specifying the tolerance. Consider those specs meaningless. Some specifications differentiate between the bandwidth, total frequency range of the system; and the frequency response, that portion of the bandwidth defined by the -3 dB roll off points of the low and high end frequencies. Specs often fail to mention that linear deviations *between* those points sometimes exceed ± 3 dB.

Possibly important are the frequencies we can't hear. On the low end is the infrasonic. This is felt as vibration which adds to the total experience of music. At the other end of the spectrum is the ultrasonic. Many instruments produce harmonics beyond hearing range, some large amounts. One study has suggested that there may be some perception of ultrasonic frequencies, however, the importance of reproducing them has not been well established. On top of this, reproducing the infra and ultrasonic extremes is an extreme challenge. Most

recordings don't have the content anyway. How far are we willing to go to create a virtual reality? Perhaps it's best to set the audible spectrum as the practical limit.

Harmonic Distortion (Type 2)

Harmonic distortion (HD) comes in two forms, symmetrical (odd order) and asymmetrical (even order). Harmonic distortion is the addition of related frequencies, e.g., whole number multiples of the fundamental. Given a fundamental tone of 250 Hz (approximately middle C on the piano), the 2nd through 5th harmonics would be 500, 750, 1000, 1250 Hz. Lower order harmonics, the 2nd, 3rd & 4th, are less audible as distortion because they are more consonant, closer in pitch and more easily masked by the fundamental. Low order harmonics may be tolerated at surprisingly high levels, 3-5%. (Tolerable, but not inaudible. 3rd is audible at 1%.) Higher order harmonics become audible at lower levels. Very high order harmonics, 7, 9th and higher, are audible at very low levels, tenths of a percent.

Intermodulation Distortion (Type 2)

Intermodulation (IM) is the interaction of two or more frequencies. This interaction creates new frequencies that are the sum and difference of the reference tones, e.g., 100 & 1000 Hz, may produce sidebands of 1100 and 900. Intermodulation adds non related, highly dissonant frequencies that are far more objectionable than harmonic distortion, and audible at levels lower than any other nonlinear distortion. Music is made up of many simultaneous frequencies making IM distortion a major concern. It is consistently agreed that IM is more detrimental than other forms of nonlinear distortion.

Dynamic Distortion (Type 1)

There is more to amplitude distortion than absolute linearity. There is the amplitude from the softest to the loudest levels, the dynamic range. These contrasts are an important part of music. Strong spikes, usually from percussion instruments, give live music impact. Soft passages make the loud more impressive. Unfortunately, many recordings have had the highs and lows of the dynamics compressed into a narrower range and/or the transients chopped off by limiters (sometimes it's done more subtly by gain riding). Some pop recordings have been highly compressed. There's nothing we can do about it, except try to avoid compressed recordings (good luck). At home, we need to concern ourselves with the playback system's contribution. Thermal compression by the drivers or inadequate power or power handling will steal the dynamic life out of music. **Without the full dynamic contrasts and unclipped transient spikes the music will have lost the quality of live sound.**

Temporal Distortion (Type 1 & 2)

Temporal distortion comes in numerous forms. Two related forms are phase angle shift and group delay. Group delay is time lag that varies by frequency. Group delay is not the same as phase distortion, but it results in phase shift. Phase distortion may or may not have a time delay, yet in the end the effects are similar. Group delay and phase distortion can arise from mechanical or electrical sources. Everything, without exception, starting with the recording process, produces some time/phase angle distortion. Fortunately, both are inaudible with music programming even in relatively high amounts. Over 1440° (more than four full cycles) of phase shift has been determined inaudible, and this is more than double the amount any typical audio system causes. This bears repeating : phase angle distortion is **inaudible**. See the links on phase angle distortion in the references below.

Note. The statement about the inaudibility of phase distortions is highly doubtful. Most likely, they measured something wrong (or wrong), hence the diagnosis was incorrectly made ... Temporal distortions are associated with vector errors that depend on the signal propagation time (time Propagation Delay) which can be measured using the Hafler SWDT test. The effectiveness of this test was proved in practice by Bob Carver. If we go further, it is not difficult to measure all types of distortions at the design stage. To do this, it is enough to subtract the output signal from the input signal normalized to the output and delayed by a

time tPD at the testing frequency. This can be done most clearly on a burst with a frequency of 10 kHz or on a triangular signal of the same frequency.

Another type of temporal distortion is resonance. This one is critical. Let's call it time dilation because it stretches the signal out for a longer duration than in the recording, in other words, lengthening the decay, or ringing. Stored energy that is not dissipated as heat is reradiated as unwanted sound. Drivers with poor damping and cabinets that don't completely absorb or block the internal vibrations of the enclosure radiate delayed acoustic energy into the room. This is a major contributor to the perception of, "It doesn't sound live; it sounds like speakers." It is measured by the cumulative spectral decay, CSD.

Note. At resonance, not only distortions in the time domain occur, but also amplitude distortions in the frequency response

Note on CSD : Measurements show strong correlations between amplitude, CSD, and harmonic distortion. Higher amplitude response at specific frequencies will usually presage higher resonance/longer CSD at those same frequencies, which in turn will presage higher levels of harmonic distortion. The reverse is also likely. If you look at a distortion chart that has a peak in a certain range, it will probably indicate a peak in frequency response and lengthened CSD in the same range. At very low frequencies the correlations partially break down. They continue to show a strong parallel between resonance and harmonic distortion, but not amplitude. The low end amplitude may fall off rapidly while the HD and CSD increase rapidly.

Group delay, phase shift, and resonance distortions also come into play when sound waves are altered or redirected *after* the transducer, under the control of the electrical signal, has produced them. Resonant cavities and various means of controlling dispersion result in alteration of the waveform. It's best to let the transducer disperse the sound without interference.

Analog magnetic tape and LPs are subject to their own set of temporal distortions, speed, wow, and flutter, not applicable to digital. When the playback speed varies from the recording speed it causes a change of pitch and tempo. Wow is a slowly wavering deviation from the proper speed, and flutter is a fast wavering. Wow & flutter are usually well controlled and mostly inaudible. Turntables need to be periodically checked to assure they are turning at exactly 33.33 RPM.

Noise Distortion (Type 2)

Noise is any addition of non specific, unrelated, and often broad spectrum frequencies, e.g., electrical noise, tape hiss, vinyl surface noise. Sometimes it is frequency specific in the form of 60 or 50 cycle hum and its harmonics. Good electronics add minuscule, yet slightly audible amounts. Grounding problems can add large amounts. Digital forms of noise include aliasing, jitter, and quantization noise. Digital forms are well understood and normally kept to extremely low levels, typically below the noise floor of the electronics.

Acoustic Distortion (Type 1 & 2)

Room acoustics as distortion? Certainly, it can be regarded as added new and amplitude modulated frequency content not in the original recording. It could almost be compared to noise. An anechoic chamber is the only way to eliminate this distortion, but most claim that listening in an anechoic chamber or very heavily damped room is not good.

(Headphone/earphone listening is another option for eliminating AD, yet not without its own set of issues.) It is best to have rooms that are neither too lively, nor too dead. But no matter how the acoustics of the room are behaving, the reverberant field passively created by the room won't sound natural unless all of the acoustic energy radiated into the room by the speakers is balanced. It's advisable for the reflections to be moderately absorbed and/or diffused and also slightly delayed before they reach the listener. Delay gives the ear/brain

time to distinguish the direct sound from the reflected sound. It may also be important to keep the direct to reflected ratio at 1:1 or greater, however, this is difficult to do in practice.

(II) **UPDATE 21-01-10** : It appears there are dissenting opinions about anechoic listening. The logic is solid. It makes me reconsider the importance of the room and that a more damped, absorbent room may be better. But the more one understands room acoustics, the more one realizes the near impossibility of doing it effectively.

Deliberate Distortion (Type S)

Distortion is not always avoided. Sometimes it's added deliberately by musicians to alter the sound of their instruments, or by engineers to modify their recordings. Numerous kinds of analog and digital signal processors are used to create distortion that musicians willing exploit for novel, interesting effects. On the production side of music, this is good. On the other hand, for the reproduction of music, distortion is the bane of high fidelity. Every step of the recording and playback process adds its share. In the end, the sound reaching our ears has a substantial accumulation of all types of distortion. Kept at a minimum, we can achieve some relatively realistic results. Yet many audiophiles aren't satisfied with minimal distortion on the reproduction side. Some have a strong preference for adding small amounts of just the right forms. A little extra low order harmonic distortion produces a pleasant fullness and depth that has an easy-on-the-ears quality. The attractiveness of this effect clearly explains the renewed interest in vinyl and vacuum tubes. Both add moderate amounts of *the right stuff* of distortion. (Plus some resonance and IM along with low order harmonics.) Not too little, not too much, just enough to add some warmth and smooth out the hard edges inherent in the sound of live acoustic instruments and human voices. The stark reality of neutral, clean, analytical, precise digital sound is not for them. I see the controversy between analog and digital similar to the bickering, back in the 1980s, over the merits of Ektachrome and Fujichrome (color slide film). Most photographers preferred Fuji for its wonderfully rich, saturated colors—its colors were hyper-real. Purists stuck with Kodak Ektachrome for its accuracy, color fidelity and realism. Ultimately, Fuji won and Kodak introduced new high saturation films to compete. Digital is for purists—analog for idealists.

Mental Distortion (Type F)

This is a very curious type of distortion. It's audible only when the music is off—exactly when we're least likely to be listening for it. It's an all too common form of distortion perpetuated by deceitful companies that feed on credulity and naïveté. They purport to make amazing products which are based on obscure, unprovable science, gross omissions of relevant facts, and their own twisted theories that are barely plausible to anyone who has graduated high school, and make absolutely no sense to anyone with a degree in a hard science. Their white papers and websites are so outrageously full of bewildering gibberish it's hard not to snicker, giggle, chuckle and finally conclude that they've got to be parodies. Yeah, they are funny, but there is a not so funny flip side. These scam operations are laughing right back in your face, harder and louder. How do you know when you've run across one of these cheats? It's easy. If it gets you asking yourself, "Is this for real?" You know. That twinge of doubt in your gut is telling you. (The goofy names of these companies and their products are another clue.) Their rambling sales pitches are all about hooking your curiosity, raising your hopes, using promises as bait, and baffling you with *mental distortion* just before reeling in your money.

Stay focussed and you'll soon learn to easily recognize and avoid this hideous form of distortion.

The more I learn, the more I realize the importance of supporting the content of this site. Links are added frequently. More can be found on other pages.

Links to the references for this page :

Start with a good [Audio Glossary](#).

A link to information about [Testing Procedures and Specifications](#).

Covers HD and negative feedback in amplifiers : [Distortion & Feedback](#)

Brüel & Kjær : [Audio Distortion Measurements](#)

Amplifier distortions : [Valves vs Transistors](#) & [Harmonic & Intermodulation Distortion](#).& [Output Impedance](#)

A four part series on the properties of hearing and its correlation with distortion : [Human Hearing - Part 1](#) and [Distortion Audibility - Part 3](#)

More on thresholds of [Distortion Audibility](#)

In addition : [Phase angle distortion audibility](#)

Waveforms & Harmonics : [All About Circuits, Spectrum Analysis](#)

Two links about ultrasonics : [Ultrasonic Harmonic Content of Musical Instruments](#).& [Promastering.com/pages/techtalk](#)

An electrical engineer on LP/CD distortion : [... orders of magnitude lower](#)

More on LPs and related links : [The Skinny on Vinyl](#)

Some like it distorted : [Analogue Warmth](#)

A decade old article from an industry insider : [High Density Audio Formats](#)

Bits about jitter & aliasing : [Oversampling vs Upsampling : Differences Explained](#)

Often ignored : [Audio Compression : The Silent Distortion](#).

A short video on [Audio Compression](#).

Link to a short article about [Dispersion & Directivity](#).

Rarely do I find a forum thread useful or informative, yet the following has an interesting discussion about room acoustics : [Diffusion vs Absorption](#)

For more about rooms see : [Omnidirectional Loudspeakers](#)

And in case you're wondering : [What's with the Tube Hype?](#)

Is the world really [Analog or Digital?](#)

back to the [Knowledge Base](#) page

on to the [3 Keys to Superior Loudspeakers](#) page

Deafened by MP3s

Before I go blaming MP3s for ruining ears, it needs to be pointed out that the problem really started long before MP3 compression, or digital for that matter. The opportunity to listen to unamplified music is nearly nonexistent today. The only exception is classical music. You can't even go to a small club featuring a jazz trio or an intimate coffeehouse with a folk singer/guitarist and not be blasted with amplification—and not good amplification, but distorted, out-of-balance amplification. It's no wonder that few people, other than musicians and a small percentage of classical concert goers, truly know the real sound of human voices and musical instruments. Even for the concert listener, few have had the experience of hearing a violin, a singer, an oboe, a cymbal, or any instrument close up in an ordinary room without any large hall reverberation.

When the phonograph was a novelty, demonstrations of it were compared to live musicians. The unaccustomed ears at the time were so amazed by the magic of reproduced sound that many people had a hard time distinguishing the live musician from the recording. Inconceivable by today's standards, but a revealing example of how previously learned experience has a powerful effect on perception. You can see where this is headed.

All the poorly, overly amplified sound, all the low-fidelity earphones and compressed digital files have trained our ears to be accustomed to a high degree of distortion and a low degree of fidelity. Add to this the fact that most of us live in noisy urban environments that inadvertently conspire to cause us to turn up the volume evermore in compensation. Commercial concerns further compound the problem by bombarding us with thundering low frequency effects, escalating volumes, and deliberately overwhelming us with unnaturally exaggerated levels that over saturate our already sorely overloaded senses.

Consequently, the problem isn't MP3s, they serve a purpose; or amplification, we need it for countless uses, but rather, it's the abuse of them that has numbed the senses and diminished the ability to discriminate the false from the real. Can there be any doubt why so many people actually seek out distortion or gradually impair their hearing with subpar audio? Even those who claim to be audiophiles aren't always satisfied with the lowest possible distortion. They don't like analytical reality, claiming it's "too hi-fi." Fidelity is out of their comfort zone. They are so used to the artificial that the real doesn't sound natural to them.

There is no solution to this, except perhaps to open our mouths and vote with our wallets. Let the venue know that you don't appreciate being deluged with deafening sound. Let them know that distortion isn't pretty. And let them know you aren't going to patronize their establishment unless it's corrected.

For the time being I am finished with "live" music, even classical concerts. Either it's badly amplified, amplified for no good reason, or (and this is another subject) the concert hall is riddled with rude, noisy, inconsiderate audience members. For the cost of a single average ticket I can buy three or four recordings, sometimes more. I can listen to the music at my leisure, in the comfort of my home, at the volume I please, as many times as I want, on a high quality system that's properly balanced. A personal, at my command, in-home concert. Now that's worth a king's ransom.

Ears may be getting used to the inferior quality of compressed music files, but the inferior 8-track tape didn't completely ruin the Boomers' ears. What about today, [Are There Any Young Audiophiles?](#)

And some fun listening tests :

[MP3 320 kbps vs 128 kbps](#) (On this single short sample I found it difficult to hear a distinction, but not impossible, and I was using merely good quality earphones.)

Level discrimination (Each gets progressively closer.)

Pitch discrimination (Musicians will not find this difficult.)

— *Sidetrack B* —

1982 : The End of HiFi

It's positively amazing. In the pre-digital era, while I was in high school, I got interested in HiFi. After finishing with college, everyday life demands took precedence. I listened to lots of music, but the equipment side was eclipsed for over twenty years. It wasn't until 2003, when a new large screen rear projection TV was set up and the need for a new sound system to go along with it, that my interest in audio was seriously reignited. For years I had been blissfully unaware of the goings on in the land of audiophilia with one prescient exception. I recall having had a discussion, in the early 90s, with someone who severely bashed CDs and digital. At the time, I was astonished and puzzled. It was my only clue to what was happening in high-end audio, but not knowing any better, I thought the basher was some sort of bizarre weirdo.

Little was it suspected that the introduction of digital audio in 1982 would spoil everything. It raised the bar and lower it at the same time. It raised the bar of signal-to-noise ratio. It raised the bar for dynamic range. It lower the bar for distortion. It eliminated wow & flutter, rumble, pops, surface noise, and numerous other annoyances and inconveniences of LP playback. And to top it off, while raising the quality bar above the state-of-the-art analog reproduction of the period, it lower the bar of accessibility. It opened the world of high fidelity to nearly everyone across the globe. Within a few years after CDs came out the cost dropped to mass market levels. Audio no longer needed the heavy duty dedication of time and attention, or prodigiously deep pockets to achieve surprisingly high quality sound.

No doubt, this came as a major blow to the HiFi industry. It was also a major assault on the sensibilities of audiophiles. How could something this cheap, easy, and convenient out do the current best? How could the industry survive without having some kind of exclusivity on high fidelity?

For the diehards, there was hope. Early digital audio had a few unforeseen glitches that the critical listeners of the era claimed to hear. Digital wasn't going to sweep away analog—not overnight—not without a fight.

And the fight rages on, and on, and on, . . .

In a relatively short time the jitter and aliasing issues of early digital were taken to task. But it was too little, too late. Schrödinger's cat was out of the box. There was no way self respecting audiophiles were going to let go of its tail. The golden ears of the day exposed those early faults before the faults were even known to exist (or so they claimed). Although improvements were made, the problems were not completely eliminated. To this day the high-end audio industry and analog aficionados hold on to traditional technologies. There is no substitute for the graceful wiggle-room analog and tubes allow. This tolerance is in direct contrast to the brick walls of disaster inherent in digital and solid state. The Venusian beauty of analog cannot be duplicated by the unyielding Martian lockstep of digital. Top this off with the pedestrian ubiquity of digital audio and you have a ripe recipe for wrangling. Something as commonplace as CDs, as low cost and simple to use as digital certainly couldn't be superior. As we charge into the second decade of the 21st century, be reminded once again of the problems with digital and transistors. They still exist, and Hope still exists for some new, yet

unknown defect(s) to be uncovered that will ultimately vindicate analog and show once more the inferiority of digital audio.

Well, it's been almost thirty years since its introduction. Digital continues to dodge the bullet and demonstrate otherwise. Science and technology, siding with digital, demonstrate otherwise. And even my tin ears keep telling me otherwise. But, Hope springs eternal. For the time being, analog needs the uncertainty principle to sustain its life.

Will the arguments ever stop going 'round and 'round about this dippy dispute? Not anytime soon, but there really isn't anything to fight over. There is no war between digital and analog, vacuum tubes and transistors, CDs and LPs. There's nothing to win or lose. There's nothing to defend or condemn. There is no uncertainty. We've opened the box; the cat is dead.

Long live the cat.

[A brief interview with J. Gordon Holt](#)

[Peter W. Mitchel chuckles](#)

[Audio Vanity](#)

(||) [Audio Home](#)

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