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Mono: Stereo: Multi


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Distortion is a powerful tool used by mixengineers to enhance the presentation of audio through manipulation of an existing sound. Distortion can take on many forms, with common distortion tools either emulating an existing hardware tools or providing new interfaces for the enhancement of audio, adding new material to manipulate the energy delivery of a chosen sound. This enhancement has the potential to not only draw attention of the listener to particular components of a sound, but also changes the fundamental delivery energy of that sound.

As mix practice has moved into the Digital Audio Workstation (DAW) environment, plugin developers have increasingly moved to emulating classic hardware, with ever more accurate representation of the signal paths of the target processing tools. Recent developments in plugin design have seen the provision of user control for the manipulation of the distortion component of the processing in a channel strip or console input channel, with opportunities to either reduce the impact of distortion or indeed to simulate circuit drive to a higher level than would have been possible in the analogue circuit without increases of gain. In addition to the provision of emulations of classic hardware, there have been developments in channel strip designs that do not offer direct emulation of a particular hardware unit, instead choosing to offer flexible direct control over parameters such as distortion, providing drive controls and the ability to focus the distortion, commonly on either even or odd low order harmonics.

This paper will explore usage of distortion in the contemporary DAW environment, focusing on the musical impact of low order harmonic distortion as applied in music mixing using a range of audio processing tools. The selected audio plugins are taken from a range of manufacturers, demonstrating both emulations of existing hardware and tools designed specifically for use in the DAW environment. The selection of plugins made does not represent
endorsement or quality judgment on the tools themselves, rather offering a representative case study of low order harmonic distortion in mixing. Selection of tools is derived from mix and production process, exploring processing utilized in the traditional analogue chain and now emulated in the digital domain. Digital only tools developed for use in the DAW have also been chosen for exploration. Through technical measurement, listening analysis, and audio examples various low order distortion approaches will be explored in relation to the manipulation of performance gesture and energy in music mixing.

Audio Files

The link provided includes a folder of audio examples giving musical context to the measurements undertaken through this paper https://www.dropbox.com/sh/l4x0t3i6uzmigfc/AADGBnvIND9OYaBP4MuJbo3Ea?dl=0.

Exciting Stuff

Distortion is commonly used in music mixing to manipulate the perception of a particular sound or sounds, with the properties of various processing tools known to engineers and sought out for their particular sonic affordances (Clarke, 2005). The sonic impact of various large format consoles is “instantly recognizable” to experienced engineers (Massy, 2016), with specific sounds sought after for their association with existing records. Massy goes on to describe the process of “creaming the mic pres”, driving classic microphone preamps into desirable distortion that is pleasing to the listener. By driving the mic pre a sense of excitement is added to the sound, due to combinations of reduction in crest factor (ratio of peak to RMS level) through natural volume compression and the addition of harmonically related material. Case (2007) also refers to the excitement afforded by distortion, stating that

When a device is overloaded, something exciting must be happening. Someone is misbehaving. Rules are being bent or broken. Distortion in rock and roll is as natural as salsa in Mexican food. It is the caffeine of music (Case, 2007, p.97)

During recording and mixing it is common to drive the input circuitry of tools to add excitement to an audio signal. Contemporary tools allow increased range of distortion, with for example the Brainworx console series of plugins allowing greater depth of distortion from the same input signal through a variable increase in total harmonic distortion (THD). The impact
of maximum THD is shown in figure 1, with the addition of third harmonic material to the sine wave being processed by the Console E emulation.

![Figure 1. Additional distortion from maximum THD addition.](image)

It is also however clear that the impact of driving the mic input of a console results in a very different distortion profile to that achieved through re-amping via a guitar amplifier or high distortion tube interface such as a Thermionic Culture Culture Vulture. Low order harmonics are “dramatically less audible” (Whitlock, 2015, p.378) with significantly different affordances to higher order harmonics.

**Adding Odd Harmonics - Transformers**

The channel strips of the classic consoles all offer specific harmonic enhancement in their analogue circuitry. Recognized recording consoles include those manufactured by Neve and API, each of which has differing sonic characteristics desirable for particular approaches to record making. The transformers in the audio circuits are a significant contributor to audio performance, with an impact on both the harmonic content added to the signal and in envelope shaping in response to transient material in the musical content. The transformer in the audio circuit performs a range of functions, being used in signal balancing and noise rejection and as a gain-providing element. As level increases, transformers also exhibit increasing frequency specific phase shift and non-linearities in distortion, making them dynamic devices that can effectively be ‘dialed in’ through the end user driving signal into the transformer to match the specific sonic requirements of a record. The harmonic impact of a transformer is defined by the materials found within the transformer core, the size of the transformer, and the nature of the transformer windings (Whitlock, 2015). The bigger the transformer is, the deeper the low frequency response and the higher the level of signal that can be handled by the transformer before saturation takes place (Winer, 2012). It is worth noting however, that increase in inductance in larger transformers does compromise high frequency response, making larger transformers unsuitable for audio usage. Selection and design of audio transformers has historically been undertaken with the aim of providing the optimal frequency
response and amplification characteristics at a given impedance. The harmonic content that is now craved by engineers was an unfortunate by-product of the available technology at the time. It is interesting that modern designs have often embraced active integrated operational amplifier (opamp) technology to improve linear behavior and minimize distortion and noise beyond the measured performance offered by the audio transformer. Despite the improved measured performance of an opamp based circuit, the technical flaws of older transformer designs are still incredibly desirable from a musical perspective.

Distortion found in audio transformers is predominantly third order in nature, resulting in for example new material at 300Hz added to an input signal at 100Hz. The percentage of Nickel in an audio transformer directly correlates to the level of distortion provided by the core, with higher percentage of Nickel resulting in a less distorted output. Three common core materials are 84% Nickel, 49% Nickel and M6 steel, with increasing distortion as the Nickel content reduces and the highest distortion provided by the M6 Steel core (Whitlock, 2015, p378). The lower the frequency hitting the transformer the higher the distortion that is added by the transformer, with the high nickel content transformers exhibiting negligible harmonic distortion above 50Hz. The cutoff frequency continues to rise as the percentage of nickel in the core drops, however, all core materials exhibit lower distortion as frequency increases. Shadow Hills Industries offer variable transformer control to the end user, with the Gamma preamp for example offering Nickel or Steel settings, as well as a transformerless discrete option to help shape the musical impact.

One desirable characteristic of audio transformers is the resistance to intermodulation distortion. Intermodulation distortion is both musically undesirable and easily heard, and as such, much effort is made in the design stage to minimize intermodulation distortion. As discussed, transformers exhibit third harmonic distortion, with very little measured intermodulation distortion. Whitlock (2015) provides an example of the performance of a Jensen audio transformer in comparison to an amplifier circuit with a similar distortion profile;

The Jensen JT-10KB-D line input transformer has a THD of about 0.03% for a +26dBu input at 60Hz. But, at an equivalent level, its SMPTE IM distortion is only about 0.01% or about a tenth of what it would be for an amplifier having the same THD. (Whitlock, 2015, p.379)

The lack of undesirable intermodulation distortion with the musically pleasing third harmonic enhancement makes transformers an important aspect for consideration in the musical application of distortion.
Comparative Measurement Methodology
In order to begin the process of comparing the musical impact of distortion from transformers, two emulations of the input transformers from a vintage Neve and an API console have been explored. Kush Audio has developed a hybrid mic preamp solution; with a 500 series preamp working in concert with the Omega transformer plugin to replicate the harmonic enhancement provided by either a Neve or API input circuit. It is important to note that the impact of the channel processing and mix bus in the consoles is not replicated in this process, with the plugin simply replicating the transformer itself. In order to demonstrate the harmonic impact of the emulated transformer a 100Hz sine wave is passed through the input, with the output measured to compare. Figure 2 shows the initial measurement with the plugin bypassed, resulting in a pure 100Hz sine wave at the output.

Figure 2. Sine Wave Measurement

Figure 3 shows the same 100Hz input signal, but this time run through the Omega A API transformer emulation.
Figure 3. API Transformer

The measurement shows significant presence of the third harmonic, with some additional fifth harmonic content present. As well as these odd harmonics, there is also some presence of second harmonic distortion present in the signal. By contrast when measured the Omega N plugin, emulating a Neve input transformer, figure 4 demonstrates a pure third harmonic distortion at a lower relative intensity to that found in the API transformer.

Figure 4. Neve Transformer

Though it is difficult to calibrate these plugins, it is clear that at this level of drive the characteristic of the API transformer features a higher level of harmonic complexity to the pure third harmonic demonstrated in the Neve. Increasing drive on the Neve (figure 5) sees pure odd harmonic distortion,
with third and fifth harmonic present, and each harmonic reducing in intensity. Driving the API (figure 6) sees predominantly odd harmonic distortion, but with some second and fourth harmonic present at a low level. The distribution of energy in the harmonics is also very different in the API, with the fifth, seventh and ninth harmonic all contributing significant energy relative to the fundamental.

Figure 5. Neve Drive

Figure 6. API Drive
Even Harmonics

As demonstrated, transformers are commonly associated with low order odd harmonic distortion, with higher order distortion only manifesting as the core begins to saturate. Other magnetic sources such as tape exhibit similar harmonic characteristics, with a well-maintained tape machine exhibiting low levels of third harmonic content that increase as signal is driven into the tape. Tubes offer a different distortion profile to transformers and tape, with a predominant association with second harmonic distortion. Figure 7 demonstrates the warm tube setting from the Fabfilter Saturn plugin, with a measured response showing dominant second harmonic and very low levels of third harmonic distortion.

![Figure 7. Emulated Tube Distortion](image)

As the drive level is increased, the warm tube profile sees an increase in second harmonic distortion, before then showing odd and even harmonics as the drive moves towards maximum, showing the increased harmonic complexity associated with high levels of drive into tube circuitry.

Contemporary plugin design has seen manufacturers embracing manipulation over odd and even harmonics distortion. One such example of this is in the Waves Scheps Omni channel (Figure 8), which provides variable odd or even distortion. Both odd and even exhibit similar behavior, with the odd harmonic adding increasing third harmonic distortion in the first half of the drive range, and then adding fifth when driving beyond fifty percent. The even mode simply swaps the third and fifth harmonic for second and fourth harmonic distortion. Unlike the tube and transformer distortion devices measured, the Omni Channel does not offer high order saturation at the highest drive levels, instead adding wither fifth or sixth harmonics depending on the selected mode.
Another example of a channel distortion tool that offers variation between second and third harmonic is the SSL X-Saturator. Figure 9 shows the range of controls, with the option to blend between second and third harmonic distortion. When set to second harmonic, there is still some measured third harmonic content, with higher order distortion also prevalent when the drive and depth controls are increased. The X-Saturator also features a unique shape control, allowing a choice between hard and smooth edged distortion.

![Waves Scheps Omni Channel Interface](image)

**Figure 8. Waves Scheps Omni Channel Interface**

There are a number of tools available from a range of manufacturers that offer similar low order odd and/or even harmonic enhancement, as found in classic console strips. Having identified the nature of this distortion it is important to evaluate the impact of this distortion on the musical delivery of sounds in a mix.

**How Does It Sound? Drawing the Sonic Cartoon**

Zagorski-Thomas (2014, 2016) proposes the concept of the sonic cartoon, which provides a useful method for considering the impact of distortion on a
musical event. In the example cited by Zagorski-Thomas, a guiro scrape is used to increase the sense of angst in the Britney Spears vocal performance, manipulating the listener’s interpretation. Distortion is another tool available to engineers to manipulate the listener’s interpretation of performance, giving the ability to manipulate the perceived gesture in the performance of the sound. Distortion is one of a number of tools that allow engineers to manipulate the perception of the original recorded sound (Bourbon & Zagorski-Thomas, 2016), resulting in a sense of increased impact, heaviness, energy and effort subject to the source and the nature of distortion employed. As an analytical tool sonic cartoons provides a useful framework for the study of the affordances of distortion in a mixing context.

Figure 9. SSL X Saturator

In considering drums the impact of low order distortion is most obvious in the perception of the gesture of hitting the drum. When distortion is engaged using the Waves Omni Channel there is a clear sense of the drum being hit harder, with increased drive leading to a more dramatic sense of the drum being hit. The impact is less dramatic than that provided by the transformer emulation tools, with the additional transient shaping and increased compression created by the processing also creating the sense of effort associated with distortion and compression. There is however a clear sense of change in
impact, with the distorted versions offering a much greater sense of conviction in the hit of the drums. There are 3 sets of audio files provided as drum examples, with microphone output processed only with the distortion section of the Waves Omni channel. Both odd and even distortion afford a sense of increased impact and punch, but with changes in the nature of that impact and the staging of the drums depending on the distortion setting.

The even harmonic distortion gives a much stronger sense of the drum being hit hard, with a strong feeling of solidity and drive. The kick drum in particular feels tighter and drier, with the lower midrange in the snare feeling considerably more solid. The presentation of the overheads is also significantly manipulated, with a real sense of detail in the stick hitting the cymbals and an overall more coherent presentation of the image of the drums. The sense of a single drum kit, rather than a collection of drums that is provided by this distortion processing is significant, creating a very different picture of the drummer and the performance to the listener.

When exploring the balance of the example featuring odd harmonic distortion there is again a sense of increased impact. Compared to that of the second harmonic distortion example however, there is a very different sense of groove. Whilst the second harmonic provides a real sense of hard hitting and coherent drive, there is a sense of lift in the third harmonic example, creating a sense of lightness and bounce. There is an increased sense of air around the cymbals, and overall a greater sense of the space that the drums exist in. The second harmonic distortion example has a greater sense of focus, whilst the third offers coherency but through air and bounce. Placed in context with a track the impact of the distortion changes again, showing the importance of evaluating distortion in context when undertaking a mix. If we were to compare a different drummer playing a different part, we would see a different result again- the aim here is not to create a typology for distortion, but merely to recognize that the impact of distortion is to change the perceived presentation of the element being distorted. The decision to provide a more focused driven sound, or a lighter more open groove is entirely dependent on the context of the recording, with choices made through the production and mixing process in response to a musical language.

A similar impact can be heard when working with orchestral sample parts. When engaging the SSL X-Saturator plugin on programmed strings, it is possible to manipulate the playing gesture, increasing the sense of the bow dragging on the string. Adding depth creates a sense of friction, bringing out detail and a sense of reality in the performance audible in sample. By moving from second to third harmonic it is possible to move the focus, with the second harmonic creating a sense of richness and warmth, and the third harmonic offering a sense of edge and friction. Again the appropriate choice is entirely dependent on the context- in this case the composer was keen to add intensity and a sense of aggression, which was supported by the choice to embrace third harmonic distortion on the string sections. The brass parts also
received third harmonic distortion with significant drive, adding not only a sense of the instrument being played harder, but also allowing the instrument to cut through the mix.

**Distortion and Masking**

In addition to manipulating the performance gesture, distortion can also be a powerful tool in managing the impact of frequency masking on the mix. As the harmonic content is enhanced, separation between elements can also be enhanced, with harmonic content clearly identified as belonging to a particular element. In an example of this, after hearing a saturated piano part in a recent mix, the client asked what had happened to the bass? The bass line had clearly become more pronounced, with detail in the bass line significantly enhanced. This improvement in bass detail and perceived increase in performance solidity came solely from distortion of the piano line, which also moved from sounding insecure to sounding resolute. When exploring these tools it is important to always work in context, as the harmonic interaction of elements in a mix are only understood when all elements are exposed. It is also important to work in context as low order, low energy harmonic distortion is considerably subtler than higher order harmonics, and can often only be heard in context. A vocal with light distortion in a mix may see emotional enhancement that matches the requirements of the song, but in isolation may be difficult to detect.

**Distorting the Delivery- Envelope Manipulation**

As well as providing harmonic coloration, transformers can also distort the envelope of musical material, particularly when transients are processed. Audio transformers are inherently slower to react to an input signal (Whitlock, 2015 p.380), resulting in the rounding of edges of a square wave when presented into the transformer subject to the way the transformer is integrated into the circuit. Improper damping of the transformer can see audible ringing in the transformer, with a network of resistors used to customize the response of the transformer to audio transients. The result of this is that transients take longer to pass through the transformer, rounding the transient in addition to adding the discussed harmonic distortion. On a drum this can be seen as being similar to comparing a contemporary bearing edge with a vintage leading edge. The vintage drum has a softer edge, creating a longer contact time with the drumhead and passing the signal less quickly in to the drum than the modern cut drum edge. In a modern drum the transfer into the shell is faster, with less damping effect on the drumhead through the transfer of energy. This increased transfer time creates a sense of increased impact time, which from a hitting and sonic cartoon perspective could be described as a punch to the stomach rather than a slap to the face. Both approaches
increase the sense of being hit, but with a significantly different gestural impact.

As level sent into the transformer increases, the core moves towards a point of saturation, with a resultant increase in distortion and average level. Combined with the rounding of transients, the impact of transformer distortion moves beyond simple harmonic enhancement. As the core cannot cope with increased level the peak output level increases at a slower rate than the input level, creating a decrease in the ratio of average level and peak level. This natural compression results in a changed envelope, and also a change in the overall spectrum with the core saturation leading to frequency-specific dynamic changes subject to the musical material, and the nature of the transformer. In addition to this we also see significant phase shift present in some transformers- the Neve transformer for example showing 40 - 60 degrees of phase shift above 10kHz. These characteristics come together to create a multi-faceted distortion, which can significantly impact on the perceived contribution of the processed sound to the overall musical presentation.

Compressors and Distortion

Compressors are another audio processing device that add distortion to signals, and as with transformers tend to offer frequency-dependent distortion with a more aggressive distortion profile often encountered when compressing low frequency with a fast attack time. It is also the case that many hardware compressors offer two stages of distortion, the first being in the audio path of the compressor regardless of the presence of compression, and the second being the distortion added by the gain reduction cell. Figure 10 shows a Universal Audio 1176 LN Revision E audio path distortion response, with figure 11 showing the same compressor in the act of compression. It is clear that the distortion added by this device is entirely dependent on the amplitude of the signal arriving at the sidechain.

By setting the point of onset of compression it is possible to dynamically manipulate a performance, with the louder sections receiving the combina-
tion of level change and harmonic enhancement. The harmonic profile of compression varies from compressor to compressor, with the Teletronix LA-2A performance presented in figures 12 and 13.

![Out of Compression](image1.png) ![In Compression](image2.png)

**Figure 12. Out of Compression**  **Figure 13. In Compression**

The above figures show that the LA-2A has prominent second harmonic distortion in the audio path, with third and fifth harmonic added during compression. The end result of the presented distortion and compression profiles is a sense of hair and air in the compression action of the 1176, with increasing aggression at higher ratios and with greater gain reduction. As a semantic descriptor hair is perhaps a controversial term, however the sense of detail and growl added to a vocal supports the use of this terminology. Faster attack enhances the sense of hair, with a genuine sense of air added as release times are decreased. The compressor is also fast enough to add significant low-end distortion, acting as a pseudo fuzz box on a bass guitar if set aggressively. The LA-2A by comparison has a sense of warmth in the audio path, but with a sense of openness, lightness and detail added during compression, adding a smooth yet open sound to a vocal and adding a sense of detail in the impact between the stick and the cymbal on a pair of overhead microphones. It is clear that low order harmonic distortion in a compressor plays a huge part in the manipulation of performance energy and gesture, in concert with attack and release characteristics to give engineers a multi-faceted tool for the manipulation of perceived performance.

**From Light To Heavy Distortion- Changing The Role Of Distortion**

The focus of this paper has been on low order harmonic distortion used at a relatively low level to manipulate the perceived performance energy of a musical sound. As channel strips are driven in level, considerably higher distortion can be exhibited. Figure 14 demonstrates the Waves NLS Nevo channel, emulating a Neve 5116 channel input section. As has been demonstrated in previous Neve consoles, the distortion is mainly third harmonic in nature with similar sonic impact to that experienced with the other Neve
channel. Figure 15 is the same Neve channel, but running through the mic pre emulation, adding significant gain and distortion.

Figure 14. Neve Line Drive

Figure 15. Neve Mic Drive

The higher order harmonic distortion present in the mic drive option results in a very different sonic impact to the lower order harmonics discussed in this paper. The NLS Nevo on a vocal creates a sense of midrange weight and air, effectively creating a sound with more conviction in the performance and an increased sense of quality and luxury in the vocal chain. On engaging the mic mode, the vocal is instantly transformed, sounding over-
driven and buzzy. Rather than creating a sense of quality and expense, the vocal chain instead sounds broken, with the vocal breaking up in the distortion. There is a sense of heightened emotion in the delivery after the aggressive distortion, but not in a way that could be used in the context of the chosen song to support a musical direction.

When placed on a parallel processing path, the high order distortion pictured in Figure 15 creates a sense of energy and heightened emotion in the delivery. The breakup in signal is particularly noticeable on louder words, adding impact and a sense of theatre to the vocal delivery. There is a significant increase in density of the sound, creating a vocal that dominates the center of the image and adds a sense of weight to the lyrics of the song. The impact on the lyric is particularly interesting, with the song feeling less like the artist is reflecting on ‘how to fix a broken heart’, and instead asking the listener directly. This transition from an internalized thought process to an externalized question posed to the listener represents a subtle change sonically, but a significant and indeed powerful change from the perspective of performance and communication. As the level of the parallel distortion is increased, the more prominent aggressive distortion creates a sense of fire and emotion in the vocal delivery, but with the distracting presence of high order harmonics detracting from the emotion of the song. Utilizing the pentode tube emulation of Soundtoys Decapitator (Figure 16) still provides the feeling of fire and emotion in the vocal, but with a pleasing less edgy quality that retains musicality despite high levels of drive.

![Figure 16. Soundtoys Decapitator Pentode](image-url)
When drums are added to the same distortion parallel the sense of intensity increases across the mix, with a sense of desperation in the vocals supported by the now significantly distorted drums. The distortion parallel brings the drums and vocals together, adding both drive and depth, as well as a sense of vintage tone to the overall presentation. Significant parallel distortion of vocals, and indeed other elements is a technique that is explored by a number of top mix engineers, with mix engineers such as Tom Elmhirst regularly creating a sense of emotional energy and depth in vocals, drums and keyboards through what would be traditionally considered as over distortion. One example of this can be heard in Elmhirst’s mix of ‘Hello’ (2015), where the distorted vocal can be heard with the main vocal, adding emotional weight to core lyrics and enhancing performance. As the song moves into the chorus the distortion becomes more prominent, which both heightens the emotional impact of the vocal and also creates a sense of size as the distortion interacts with the space and the vocal layering and delay processing. As the drums are exposed through the track the presence of distortion also adds to the sense of delivery and grand energy. As the filtering on the drum opens through the final chorus the distortion on the drums is further exposed, adding a sense of the entire track calling out to the listener. Distortion is an essential tool employed in this mix in order to manipulate performance energy, emotion and gesture communicated to the listener, enhancing the iconic sound of Adele and the associated staging of the record.

Conclusions - Distortion In Modern Workflow

The DAW has provided engineers with an environment where distortion can be used in a variety of ways to enhance the performance energy perceived by the listener. From low-level harmonic distortion, adding a sense of size and weight to delivery through to heavy distortion creating a sense of aggression or destruction, distortion plays an important role in manipulating the performance gesture and emotion. It is important to note however that the prevalence of distortion in contemporary mixing practice does not come without its cost. As the loudness wars have seen a reduction in perceived loudness, mixes have increased in distortion as a by-product of reduced crest factor and significant limiting. Modern DAW gain staging requirements see practically infinite headroom within the DAW, with the only consequence of heavily clipped channels being the requirement to turn down the master fader before bouncing the track. The high order distortion in many contemporary mixes is also brought out in the mastering process, leading to brighter and more abrasive mixes that lead to the listener reaching to turn down rather than turning up the music.
Further Study

Whilst this paper has focused on low order distortion on channels, there is potential for continued research into higher order distortion and its use in contemporary mix practice. The impact of high order distortion, and low order distortion of high frequencies also provides a subject for further consideration, particularly with the identified trend for brighter more aggressive mixes. The next area for the continuation of this research is in the study of distortion on mix busses, and in mastering.

Bibliography


Discography