CLEANER…Yet Still Loud!

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ABSTRACT

Audio processing for conventional broadcast transmission (FM and AM) has reached extreme levels. Various methods available today are capable of creating LOUD competitive signals, but at the expense of perceptible quality. What causes this, and what can be done…again…to raise the bar?

Through critical listening, extensive research, and evaluation of processing methods, it has been determined the single most annoying quotient is due to intermodulation distortion (IMD) induced by aggressive functions within the processing system. The algorithms are pushed to the limits, and beyond.

Through discussion, and sonic demonstration, the problem is illustrated. More importantly, a new method for competitive audio processing is revealed which eliminates the challenges suffered by current methods. Audio demonstrations are used to provide A/B comparisons of the present and new method.

Additionally, it will be discussed how this method can be used for other processing applications in addition to conventional FM and AM broadcasting.

ON-AIR ANABOLIC STEROIDS

Audio processing is no different today, than athletes who takes performance enhancing drugs to get an extra edge! "I want to pump you up," as the old Saturday Night Live skit proclaimed! A scan across the dial in most markets, around the world, yield radio stations transmitting *DC modulation* as their means to be the loudest-proudest on the air. Some even subscribe to the notion of "more loudness than allowed by law!"

Not to be outdone, the music industry has adopted the same radio mindset producing ***L-O-U-D*** CDs that are so heavily processed, they sound as if they're on-the-air, before *being* on-the-air! To say we live in a dynamically processed world is an understatement!

Being loud is not the problem. "If it's too loud, you're too old" does apply! The problem is the unfriendly annoying artefacts generated by current processing practices employed by broadcasters and the music industry. The combination of hyper-compressed content and "I gotta be louder than the other guy" on-air processing, results in audio lacking definition, and quality, while containing many annoyances. It would be easy to say, just back down the processing and all will be OK, except reality, and the psychology of broadcasters believe differently. We will always have loud radio stations, as long as programming philosophy remains, as it has, since Mike Dorrough fathered multiband processing!

The challenge now is how do we put quality back into on-air audio; yet retain the competitive loudness level broadcasters demand? The challenge seems simple: Research to find the cause, then whip up a new solution. In reality, the research was extremely exciting, and the solution has been two plus years of effort. This presentation highlights the journey of this work.

FINDING THE ACHILLES HEEL

The path to find the next frontier in processing began with a simple, but somewhat frightening, exercise: Careful and extremely critical listening of the status quo. As a developer it requires leaving your own ego at the door, and be prepared to face some harsh realities. Suffice it to say, this author was about to embark upon a humbling experience.

Having been around the block a few times with respect to loud competitive processing, our own system was setup to simulate any one of a number of well-known major market radio stations. Hot Rockin' Flame Throwin' applies! Benchmarking was done using stock processing, and cranked up presets, as well as processors from other manufacturers. The choice of programming content was made up of recent recordings, as well as many time-tested segments used over the past twenty-plus years for processing development.

The Pain…

Modern music mastering practices generate content that is noticeably rich in deep bass, presence, and treble. When processed aggressively, especially for FM-Stereo, the resulting audio appears synthetic in tonality and quality. Treble frequencies appear overly bright, and sometimes harsh, even with additional application of dynamic high frequency processing. Bass sounds tight and defined, but depending upon the processor's spectral limiting system, it can also sound distorted.

Listening to current music, with aggressive processing, yields a distinct annoyance, the appearance of a *sizzling* or *frying* sound to midrange, presence, and treble spectra. This was noticeable on all the processors used for evaluation. Reducing the final limiting, or clipping, helped ease the pain. This indicated the problem is harmonic related to the clipping process. Significant reduction of clipping removed the annoyance, but the loss of loudness was on the order of 6dB or more. Not suitable for the needs of competitive audio.

Was this the age-old issue of too much bass forcing the rest of the spectrum into the limiter? This is known as bass induced intermod. At first, it would seem so, but the test segments did not have any bass content, and the *frying* was still present. Was it in the original source, and the processor was magnifying it via multiband dynamics control? Careful evaluation of the source audio revealed the answer to be no! Seems a new gremlin hath arrived!!

By example, this is easily heard in the song "*Because Of You*" by *Kelly Clarkson*. The opening of the selection is a piano solo, and the vocalist begins to hum along with the piano, a few seconds later. Present day audio processors, setup aggressively, cause the humming in the vocal to sound as if bacon is being fried! Prior statement not intended for humour, by the way. This was/is a high rotation song on CHR (Contemporary Hit Radio) formatted radio stations. Since most of those require aggressive processing, this test case, replicates the real world. This example is just one of many that illustrate the challenges in current processing technique.

The Investigation…

Since the afore-mentioned *bacon frying* annoyance was affected by the action of the clipping function, a probe into that algorithm was in order. Most final limiting/ clipping systems in modern audio processors employ some form of proprietary means to control perceived distortion. The methods for these vary. While open for subjective discussion, the end result is still the same, absolute peak control is performed, and a minimal level of harmonic distortion is *acceptable* within a specified operating range. Basically, some form of masking method is used to hide the most annoying clipping side effects from the ear. Although, it appears now, we've pushed these methods to the point where modern recordings generate distortion annoyances when aggressive processing is used.

For the processing novice, a clipper – by design – will generate harmonics of the fundamental audio frequency. Using a sinewave for an example, if the upper and lower peaks of the waveform are chopped off - clipped, harmonics are born out of the *clippings*, and show up within the spectrum space as harmonic multiples of the original frequency. An example frequency of 1 kHz, with 3 dB of clipping, generates odd-order harmonics at 3kHz, 5kHz, 7kHz, etc, out to infinity. *Figures 1 – 2* illustrate examples of this.

Note: Broadcast audio processors bandlimit frequency spectra within a specified range, for their respective transmission paths. FM-Stereo bandwidth is 15kHz, and AM is between 4.5kHz and 10kHz, depending on the worldly location. As such, clipping harmonics are limited via non-overshooting filtering methods in order to properly maintain operating legal bandwidth.

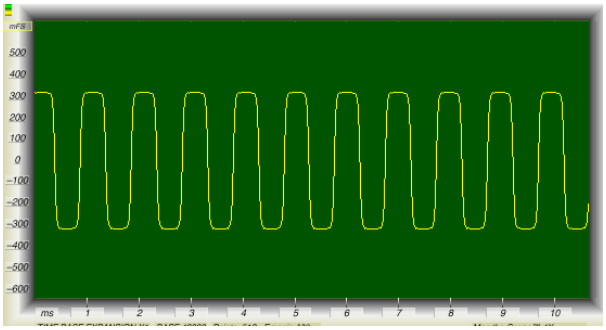

Figure-1, 1kHz Square Wave

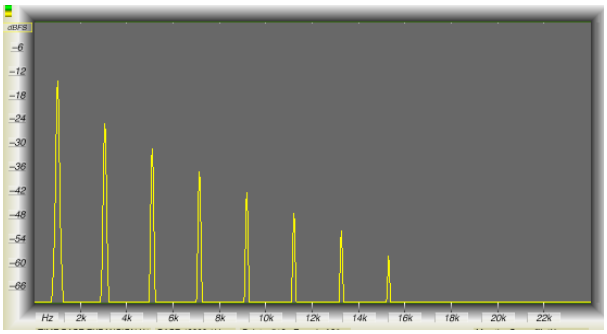

Figure-2, 1kHz Square Wave Spectra

The challenging problems stated here are not based upon clipping functions of singular frequencies. Modern clipping methods, with distortion management, reduce clipping side effects over a preset range, and only up to a specified level. It appears modern recording techniques ether overload the present distortion mechanisms, or they cannot process this content aggressively without generating this *frying/sizzling-like* distortion. Since this problem

exhibits itself with full range linear recordings, data reduced content (mp3 audio files) is even more distorted. This question becomes, where's the rub?

What happens when additional spectra is added?

When additional audio is added to a fundamental, lots of fun activity occurs! Sum and difference frequencies are created, along with another component known as *intermodulation, or IMD* for short. Simply stated, this is where one signal will ride alongside, on top of, or modulate another. Sometimes this is done for specific effect. Music synthesizers use various intermodulating functions to create desired sounds.

In an audio processor, the dynamic action of compressors and limiters are examples of modulators, as they generate a level controlling signal to change the gain of the audio. The level controlling signal and audio is routed to a multiplier function, and the audio is *multiplied* by the controlling signal. Through this action, the level is dynamically adjusted. This is an example of intermodulation, as the audio is modulated by the control function. When the control signal starts to operate too fast, it generates a controlling rate with an additional frequency, of its own. This operating frequency will possess additional harmonics, and those get factored (multiplied) into the audio during the multiplication stage. The resultant contains the level adjusted audio along with harmonics from the controlling signal that were *intermodulated* into the final product. This is what happens when the control signal operates overly aggressive, and the sonic quality becomes fuzzy, dull, and lifeless. We refer to this as dynamic intermodulation distortion.

With the above example in mind, let's consider what happens within a clipper, when multiple audio signals are present and clipping is applied. A clipper, in reality, is a zero-attack/zero-release time limiter operating with a ratio of infinity-to-one. When multiple frequencies are present, and clipping is active, the lower fundamental frequency will push the higher fundamental frequency into, and out of, the clipper at the rate of the lower frequency. This is known as *clipper induced IMD*. An easy example of this would be music with deep defined bass, and a solo guitar or vocal. When clipping is active, the guitar or vocal will *warble* at the rate of the bass frequency due to the action of the bass signal pushing the guitar/vocal signal in and out of the clipper. Some audio processors employ bass processing techniques to reduce, and in some cases, remove this annoyance. On account of this, IMD components are amplified in level and spectra. Even modern distortion cancelling clippers - or whatever other marketing name given to them - generate IMD.

Up until now, it's been an accepted notion that clipper induced IMD was a by-product of deep bass and enhanced midrange/presence/treble content. When studying the example of the Kelly Clarkson track, it became evident the problem was related to clipper induced IMD, except the example does not possess any bass spectrum of any significance.

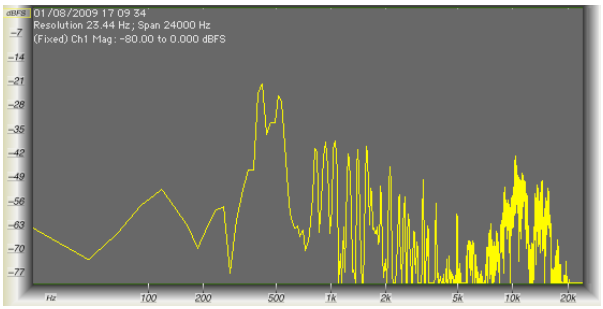

Figure-3, Kelly Clarkson Segment

Notice in *Figure-3*, a segment taken from the Kelly Clarkson track, the dominance of signal centered at 500Hz, and the range between 10kHz – 15kHz. Wonder what happens if some IMD tests were run on present clipping systems?

Under The Microscope…

Performing an IMD test on a clipping system is quite easy. Two audio frequencies are mixed together, then passed through the system under test, and the output is observed on a scope and spectrum analyzer. In this instance, the clipping systems all employed the required 15kHz low pass filtering and zero-overshoot control mechanisms found in broadcast processors.

For the test, 100Hz was inserted at a level, which generated 3dB of clipping. A high frequency component was mixed in at the same level, and 75µs preemphasis was applied. The tests were run over the range of 5kHz up through 15kHz, while 100Hz was used as a constant low frequency source. *Figures 4 – 8* are the results of the tests.

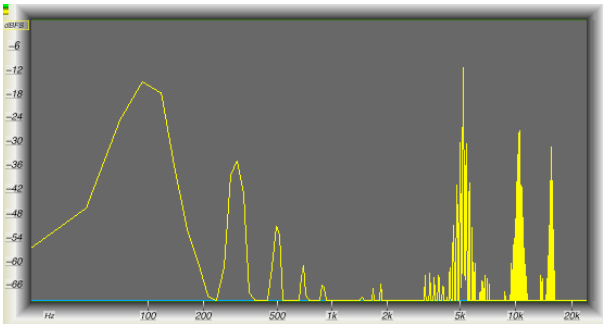

Figure-4, Clipper Induced IMD: 100Hz & 5kHz

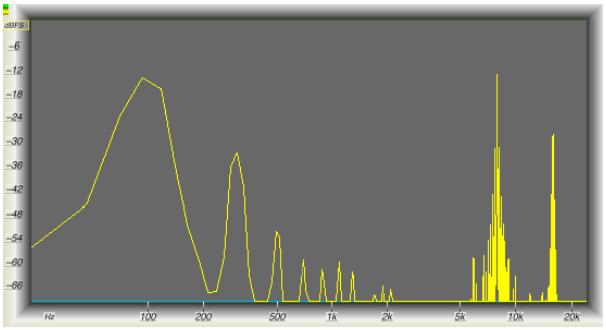

Figure-5, Clipper Induced IMD: 100Hz & 7.5kHz

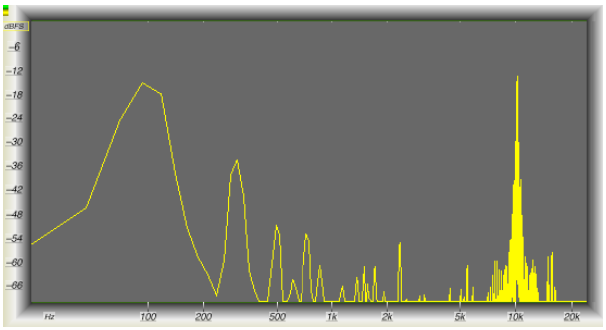

Figure-6, Clipper Induced IMD: 100Hz & 10kHz

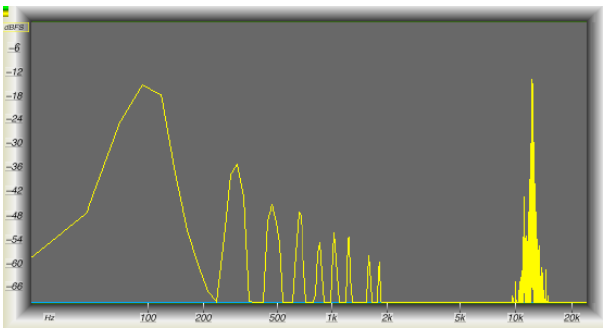

Figure-7, Clipper Induced IMD: 100Hz & 12.5kHz

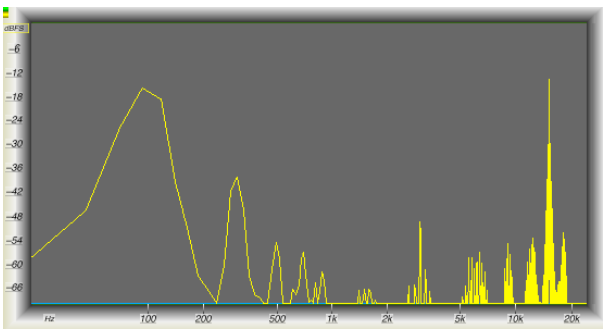

Figure-8, Clipper Induced IMD: 100Hz & 15kHz

Notice as the upper frequency is increased, there is significant difference spectra that falls between the two fundamentals. This is extremely severe at 10kHz, 12kHz, and 15kHz. If you recall the music example, this is very close to the spectral illustration in the Kelly Clarkson track. Houston, we've got a problem, and it's clipper induced IMD!

Clipper Systems, Distortion Cancelling, and Too Many Bands!

As stated prior, present day clipping systems all employ methods to control distortion. Of interest is each of these use a static method to mask harmonic distortion when clipping is active. As the Kelly Clarkson example clearly illustrates, harmonic distortion is not the concern, as it once was. Intermodulation, due to added presence and high frequency spectra, has overtaken the problem that once was dominated by harmonic distortion. Suffice it to say, all clipping methods must employ some form of harmonic distortion control, or they will not operate sufficiently enough to generate competitive sounding on-air audio. Modern content now requires additional processing means to reduce induced IMD.

Suppressing IMD is significantly more difficult, as the constant difference frequency components are a non-stop moving target, whereas suppressing harmonic distortion can easily be predicted, and controlled through a static filtering system.

Proof of this is demonstrated with an evaluation of present day distortion cancelling systems. All of them employ static filtering to mask distortion components. They vary in range from broadband to 5-6 band, or more, and all of these fail, with aggressive processing. The broadband method suppresses harmonics, and some IMD at specific frequencies. The multiband methods are designed to insert gentle low pass filters after multiband clippers in each audio band. This works, over a narrow range, but falls apart with aggressive levels of clipping. Mutiband clipper/filtering is done in parallel architecture, and each singular band clipper is not able to understand what the others are doing. Therefore, the resulting filtered harmonics of each band interact in unpredictable ways, some of which exaggerate IMD. Adding more bands or steeper filters does not improve or fix the problem!

The Answer Is…

…Not in the number of bands. Anyone who thinks adding more bands of clipping and filtering to the system is wasting DSP cycles, or computer MIPS, along with a lot of marketing rhetoric! The answer lies in understanding the range of frequencies that generate both harmonic and intermodulation distortion, then applying various masking means to suppress both simultaneously, as they are generated. Much easier said than done! It's a combination of breaking down the audio spectrum by octaves and interaction with the Gibbs Phenomenon. Almost explained too much already. Suffice it to say, the prior statement, along with SENSUS technology enables a clipping system that suppresses BOTH harmonic and IMD distortion components, when aggressive processing levels are

required. Additionally, and more importantly, this new clipping method does not employ the use of dynamic compressors or limiters to control depth of clipping, in order to minimize clipping induced IMD. There have been, and remain, a few proponents whom do utilize this method to reduce generated IMD, but it's at the expense of added dynamic intermod which manifests itself as audio pumping, and hole punching.

Proof

Running the same IMD tests, as mentioned earlier, now offer the following results. Compare *figures 9 - 13* to those of *figures 4 - 8* of both the old and new methods.

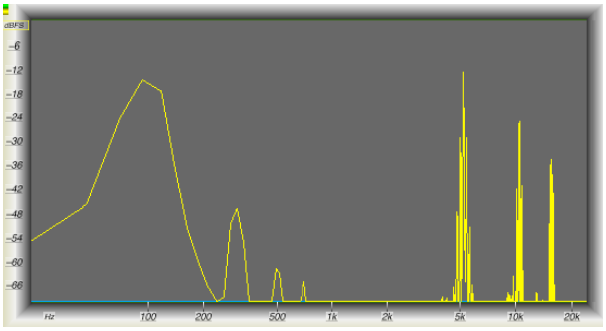

Figure-9, Clipper Induced IMD: 100Hz & 5kHz

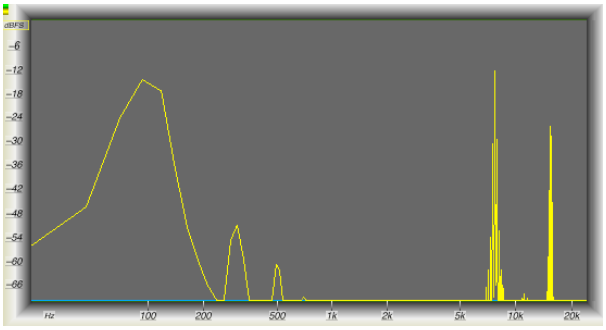

Figure-10, Clipper Induced IMD: 100Hz & 7.5kHz

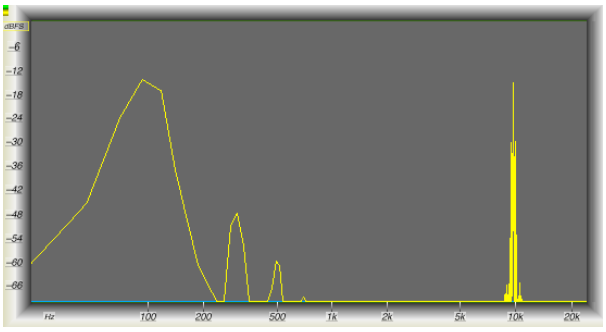

Figure-11, Clipper Induced IMD: 100Hz & 10kHz

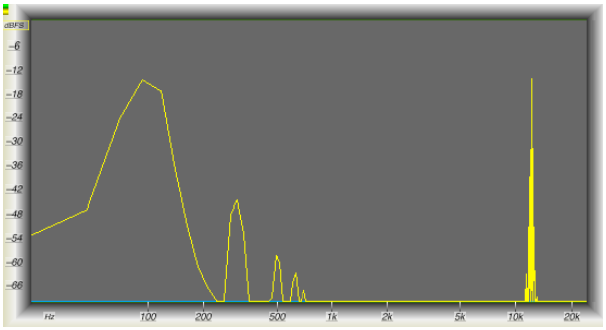

Figure-12, Clipper Induced IMD: 100Hz & 12.5kHz

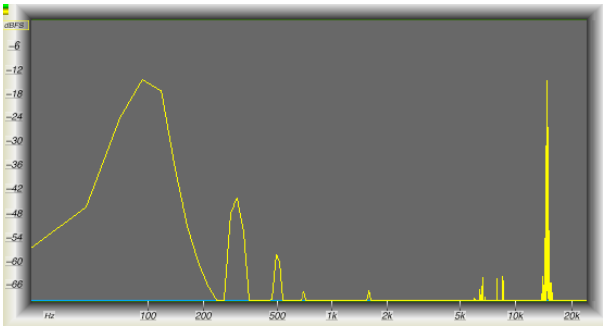

Figure-13, Clipper Induced IMD: 100Hz & 15kHz

Easy to see, for the exact same amount of clipping employed, midrange, presence, and treble IMD is gone! With the new method, Kelly Clarkson's test segment does not possess any of the bacon frying sizzle annoyance as heard prior with all other clipping systems. As a matter of subjective observance, all audio auditioned through this new method, sounds cleaner for the same given level of loudness. Doesn't matter if the content source contains deep-rich bass or not, the audio signal is subjectively cleaner for the same level of loudness!

What Gives?

Just the same as with the recipe for Coca-Cola, this new IMD and THD masking method is locked away in the same vault with the secret ingredients for the famous soft drink! What can be said however, is the answer lies not in the number of clipping bands and filters, but *how* all distortion products are dealt with interactively on an instantaneous basis. Multiband clipping does not take into consideration any interactivity of outlaying spectra. That's where the method eventually fails. The proof is in the audio performance, with critical content.

Where Do We Go From Here?

The never-ending age-old question, if the ever was one. Ten years or so ago, this writer was the first to offer the answer to non-aliasing digital clipping in DSP, along with an improved cleaner final limiting method. At that time, it was said, our imagination was the only limiting factor. Well, it still is. As broadcast and transmission

methods have further evolved over the same period, so has processing. Fortunately, we now have – finally – acquired the needed processing power to delve deeper into critical sonic issues like induced IMD, and offer solutions for that challenge. Moving forward, we're embarking on means where audio processors auto-adjust themselves based upon content, density - or lack there of - in signal content. It's a wide open spaces, and some on this journey have easily out-paced the pack, while others are left pursuing delusions of grandeur.

ACKNOWLEDGEMENTS

This paper is dedicated to the loving memories of Jim Somich, and Mathew Connor. Two passionate, dedicated, driven, and innovative engineers who understood great sounding radio, how to get there, and the advantages of Dial-Dominance!! You both are truly missed.

Rob Dye
Leif Claesson
Tim Carroll
Mike Dorrough
Jim Somich
Matt Connor
Cornelius Gould
Mark Manolio