Quality, Clarity, and Competitive On-Air Processing: Understanding Clipper Induced Intermod Distortion!

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Quite often I'm asked if there will ever be the ultimate audio processor, or if the limits in this unique combination of art and science will ever be reached? My answer has been, and continues to be: "No, it will not!" Personally, I'm always playing around with some processing idea. Not a week passes by, when one of the Team-Omnia crew, or myself, aren't burning the midnight oil over some concept, either to raise the bar of signal processing, or investigating some new frontier.

As long as there are new fresh innovative thoughts about this stuff, and we continue to find platforms to bring ideas to life, processing innovation will continue. It's no different than the personal computer. No sooner do you purchase the latest whiz-bang PC, then that same company releases the *next bigger faster* machine. Frustrating, I know! Processing is no different! Just as your latest laptop PC is an investment to improve your workload efficiency, your next processor will be an investment, yet again, to improve on the dial.

This paper is written as a "state of the audio processing union" message. Much has transpired over the last few years in processor design, along with the mediums that need these *black boxes*. As of this writing, broadcasting requires specialized processing for conventional FM/AM, HD Radio/DAB, Satellite, Streaming, and DTV. As new technologies emerge, the *TO DO* list continues to grow.

Can You Hear Me Now?

To quote an obnoxious cellphone ad, "*Can you hear me now?…Good!*" Present generation on-air audio processors are capable of being competitively loud. It's a safe bet that in most markets, where modulation levels are close to the same, the loudness difference among the dial-dominators is within 0.5dB of oneanother. Most audio professionals will debate that you cannot hear the level difference of a 0.5dB. Well we need to remember that moderate to dense broadcast processing yields significant RMS signal levels. Since the human is a very good RMS detector, it will easily recognize a 0.5dB difference, when moderate to dense audio levels are present. With moderate processing, a level difference of 0.5dB is perceptible between competing radio stations.

Loud audio processing exists today. This has been achieved using algorithms that reduce, or mask, harmonic distortion so the ear will accept more distortion than it's actually hearing. That's the premise behind most processors. As competition rises among broadcasters, so does the amount of processing employed. As the amount of processing increases, other forms of distortion creep in. Aside from harmonic distortion (THD), there are two other types of distortion that must be dealt with: aliasing and Intermodulation Distortion (IMD). Omnia was the first to tackle the digital aliasing problem, yet it still seems to be a challenge for others, but the nemesis that now plagues competitive processing is IMD.

Intermodulation distortion (IMD) has a distinctive sound. Whereas harmonic distortion (THD) sounds like a broken component, IMD is that *packed up, bizzy, rattling, warbled,* texture that appears with dense/heavy processing. It can be created a few different ways. The easiest is when time constants in a dynamic section, like a compressor or limiter, are set too fast. The resulting *pumping*, *bizzy*, and *smashed* quality, that's heard, in the intermod. This problem is fixable via adjustment to the timing networks, usually the release time, or a design that can mask IM distortion. Modern processors have these functions.

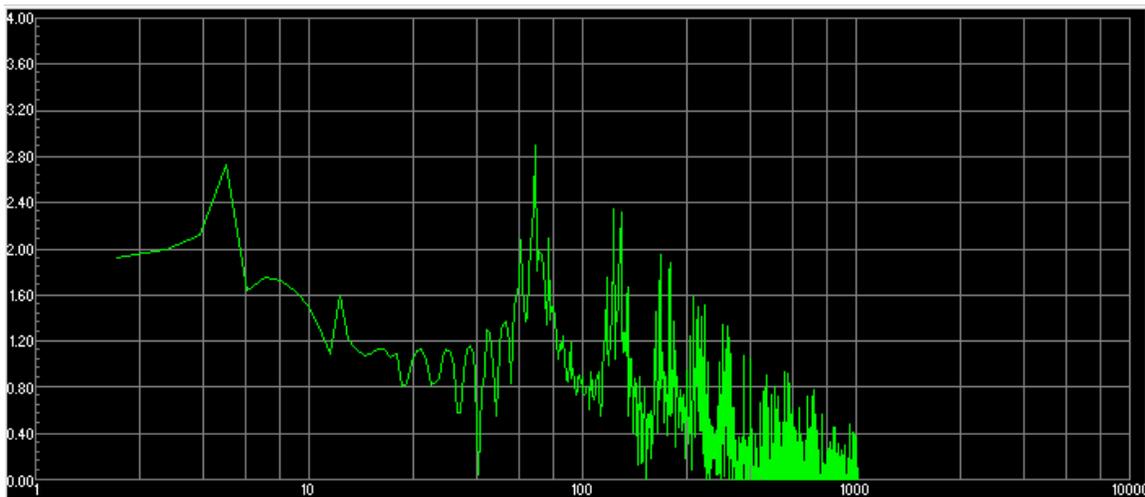## Clipper Induced IMD Explained

Another form of IMD that is very annoying is the effect created when moderately heavy clipping is used. In this case, lower frequencies that reach the clipper threshold, will force all other higher frequency signals, that are present, into the clipper as well. Even if these other signals are below the threshold of clipping, they have been modulated in and out of the clipper process. A good example is sustained audio content that contains a vocalist and bass instrument. As the bass signal reaches the clipper threshold, it will push the vocal range in and out of clipping, even if the vocal is below the threshold of clipping. This results in the vocal sounding *warbled,* as if the singer is underwater. The obvious fix to this would be a reduction in the clipper, but then competitive loudness is lost. Reducing bass, via equalization, might eliminate the problem, but then bass detail is lost.

Spectral analysis is an easy method for viewing harmonic content. Following are spectrographs that will illustrate a twin-tone situation that is used for observing IMD. The first graphic is of the fundamental frequencies of 50Hz and 1kHz. Notice that they are harmonically clean.
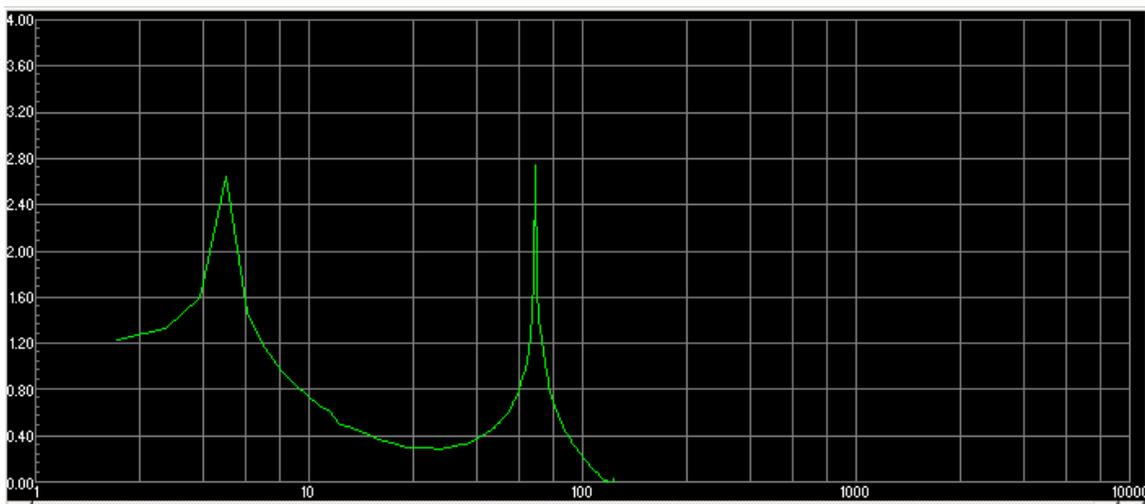

50Hz & 1kHz Fundamental Frequencies With No Clipping

Raising the level of the signals to engage a clipper function by 6dB, the following is a spectral analysis of intermod products that are created.

50Hz & 1kHz Fundamental Frequencies With Clipper Induced IMD Products

The intermod products are the added *spurs* that are paired up around each of the harmonics of the 1kHz fundamental. This same condition occurs even if *both* frequencies are at or below the threshold of clipping. The summed peak value of the two signals, if they are in phase, will cross the clipper threshold and intermod products are generated. These are the signals that cause the annoyances from dense clipping.
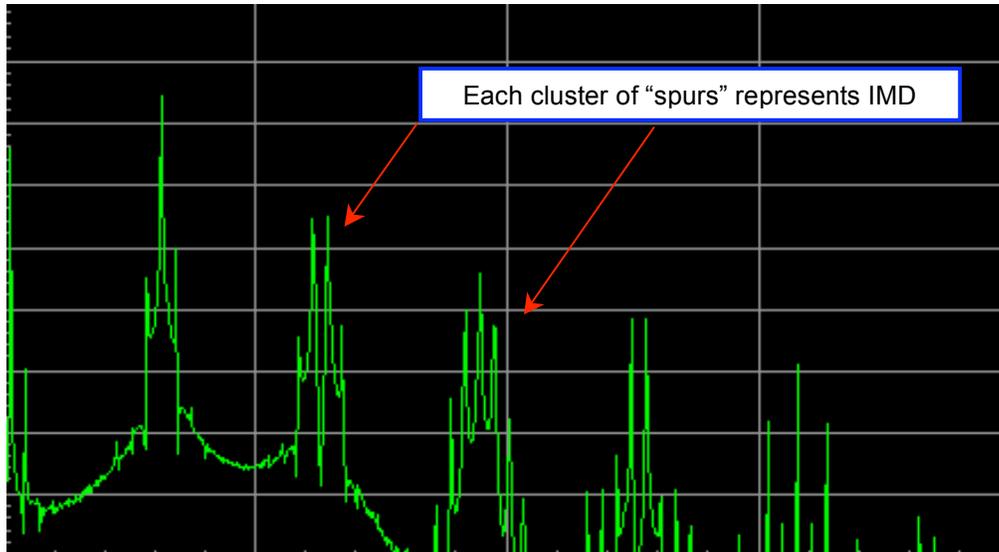
Modestly speaking, we are our own worst critics when it comes to audio. Since the question we're asked most often, is "How can Omnia achieve more?" We sat down, and tried to do just that. Taking the time to challenge ourselves, we observed that after really cranking on the processing, the signal was definitely loud, moderately low in perceived harmonic distortion, but the level of intermod was definitely apparent. In fairness, we observed this with all other processors we tested. (We try to be an equal opportunity offender!)

Reducing clipper induced intermod distortion is easier said than done. Research has shown a few attempts at it, but most of these are dynamics processor sections that are wrapped around a clipper function. They will work some of the time and on some material, but they fail to consistently reduce intermod on a broad range of content. Modifying the clipper to behave as a look-ahead limiter doesn't do the trick either. All of the harmonic distortion is replaced with added intermod content, thereby creating even more *bizziness* to the audio.

Transmission System Contributions

Before embarking on a new *doo-dad*, it's worth examining a few other transmission system elements that are obstacles for an audio processor. The biggest challenge is the management of emphasis networks. Both FM and AM employ them to improve SNR and/or overcome receiver limitations. Preemphasis used in broadcasting establishes a +3dB breakpoint at 2.2kHz and boost will escalate at either 50μs or 75μs, depending upon location about the globe. Even though a multiband limiter is used to manage the emphasis boost, there will remain spectral level uncertainties along the emphasis curve, although they will be radically reduced. As frequency and level rise, their clipper threshold is reduced by a like amount. This makes the upper vocal range much more sensitive to clipping, even if only by a few dB, as compared to the low and mid frequency range. Here is where trouble begins. Upper midrange and presence frequencies are pushed into clipping by large lower frequencies and IMD develops.

Another contributor is the *Gibbs Phenomena* of the 15kHz low pass filter. In simple layman's terms, this is what creates the overshoot characteristics of a low pass filter, when a square wave is passed through it. Under ideal conditions, such as a phase linear filter, overshoots are kept to a minimum of 1.09, or 9%, of the original peak level. Additionally, the upper 1/3 of the filter's spectrum will be subject to this effect due to the removal of any third harmonic from any square wave that has a fundamental at 1/3 the low pass

filter's range or above. As the third harmonic is removed, the square wave changes to a sine wave. Following is an illustration of the *Gibbs Phenomena*.
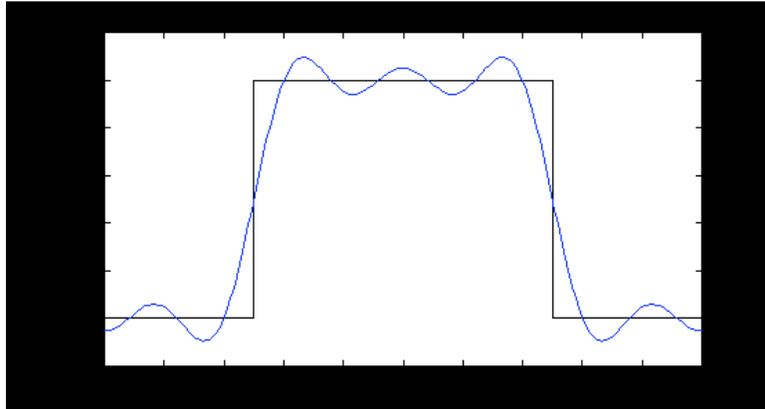
Gibbs Phenomena

Now consider the 15kHz audio spectrum for FM-Stereo broadcasting. The *Gibbs Effect* will consume just about all of the preemphasis curve as the effect will kick in at 5kHz, which is 1/3 the cutoff frequency. Preemphasis increases gain significantly within the upper third (5kHz – 15kHz) of the filter's passband, in what can be called the *Gibbs Region*. This yields high levels of clipper activity producing significant density along with severe overshoot content. **Note**: This is reset to 10kHz for those AM broadcasters using NRSC response, and even narrower for those whom choose to use 5kHz.

Properly designed audio processors employ methodologies to eliminate overshoots caused by *Gibbs Phenomena*. A subsequent clipper is not viable after the low pass filter as recreates harmonic spectra that the low pass filter removed. Any processing system that relies on this type of tech is poorly designed as it yields additional distortion due to the cascading clipper sections.

Of concern is the signal range between DC – 5kHz, especially the range between 1kHz and 5kHz where fundamental frequencies for vocals, and string instruments reside. Also, based upon the Fletcher-Munson curve, it is the area of maximum hearing sensitivity. Note that the breakpoint of preemphasis occurs smack dab in the middle of this 1kHz – 5kHz range, thus making clipper induced IMD that much easier to perceive.

What transpires as IMD is a summation of preemphasis, effects from *Gibbs Phenomena*, and where human hearing is most sensitive. Throw in some moderately aggressive processing in front of the clipper, and trouble arises.

Out Of The Box Thinking…LoIMD Clipper!

In giving this scenario deeper thought, the ultimate objective would be a clipper that had enough brainwave activity to understand they type of signal content *and* density that was applied. Allow the clipper to truncate peaks that exist in a specified dimension, but also know when to adapt so that sustained signals do not intermod among other spectra. An algorithm of this nature allows the clipper to retain power and impact, yet reduce or eliminate IMD from moderate to aggressive levels of clipping. The overall effect would be retained loudness and *punch*, but more importantly restoring clarity to the signal.

This is not the same as reducing the drive to the clipper like a dynamic section would do, or modifying a multiband limiter to manipulate the frequency domain. There is a difference. A dynamics processor will modify the overall RMS/Average level, and affects loudness consistency. Additionally, the timing of the dynamics section is not fast enough to adjust levels to eliminate IMD imperceptibly. If adjustment is

performed in the frequency domain using multiband limitng, the spectrum is modified to a point where holes in tonality are heard. Intermod is reduced, but at the same time, processing consistency is eliminated.

Investigation of the clipping mechanism used in Omnia processors reveals that the conditions to create IMD are present in the same signal used to eliminate processing induced aliasing distortion. Through further analysis of this, IMD symptoms are monitored. Then, the gathered information is used to modify the clipper algorithm to reduce, and under many conditions, totally eliminate IMD.

This lead to the new *LoIMD Clipper* design that suppresses IMD when moderate to heavy clipping is used. End result: Preservation of clarity and detail in the audio, even with aggressive processing! Much easier said then done, but the diversity delay requirement for HD Radio gave reason to rethink audio processing in a different dimension. It makes sense to put this time to use for *real work* and not just static delay. Intellectual property protection does not allow further disclosure about *LoIMD*, but the following spectrographs reveal performance capabilities. For the purposes of discussion, 100Hz and 5kHz are used.

The first illustration is during initial impact of all frequencies on the clipper. High levels of IMD are easily observed with sideband pairs around each of the 5kHz harmonics. This is what occurs in a clipper design, even when it contains distortion-canceling methods, as that pertains to harmonic distortion.
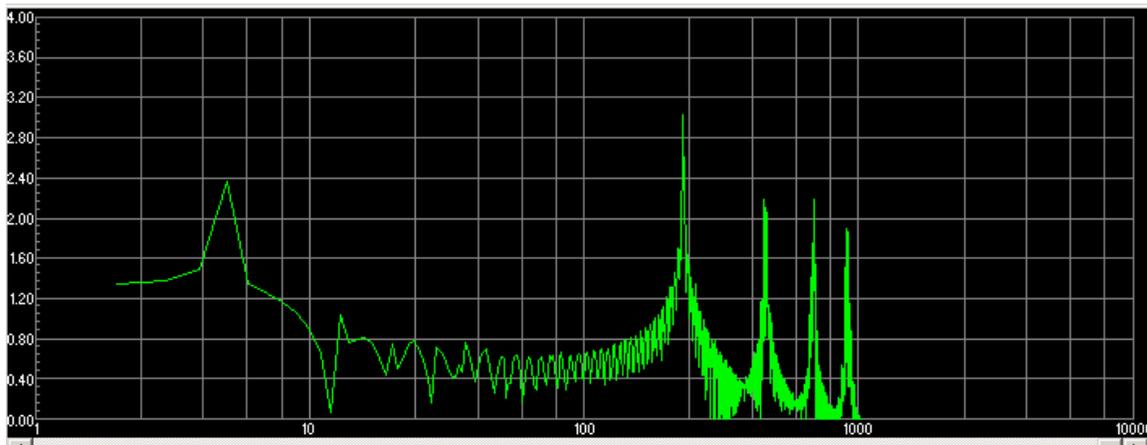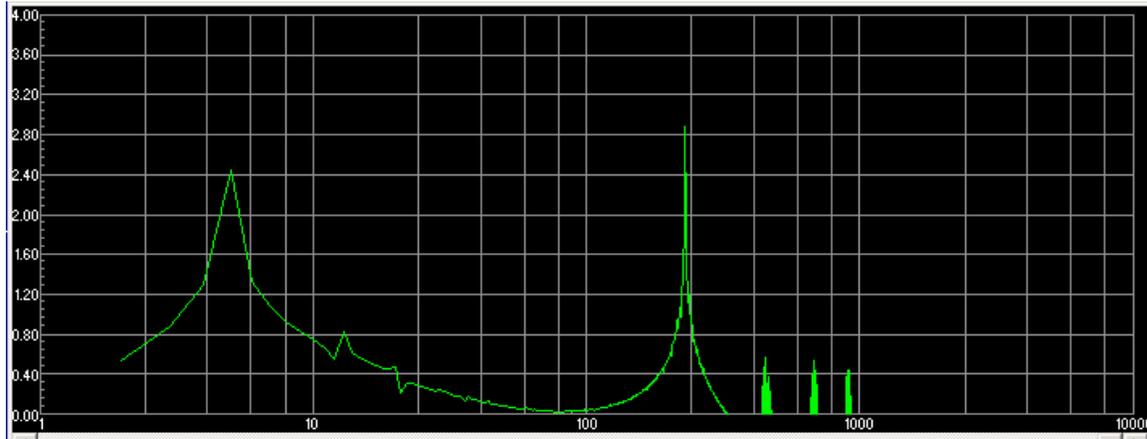

100Hz & 5kHz Fundamental: Initial Clipper Impact

As density to the clipper increases, the algorithm begins to modify clipper behavior and IMD products start to reduce.
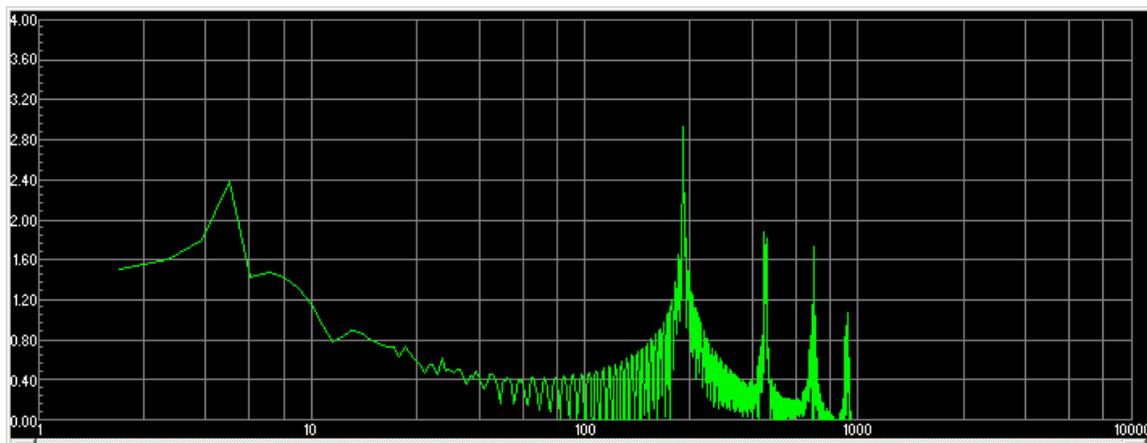
*100Hz & 5kHz Fundamental: Elapsed Clipper Action*

After prolonged clipping activity, approximately 3ms, further behavior modification of the clipper has greatly reduced IMD.
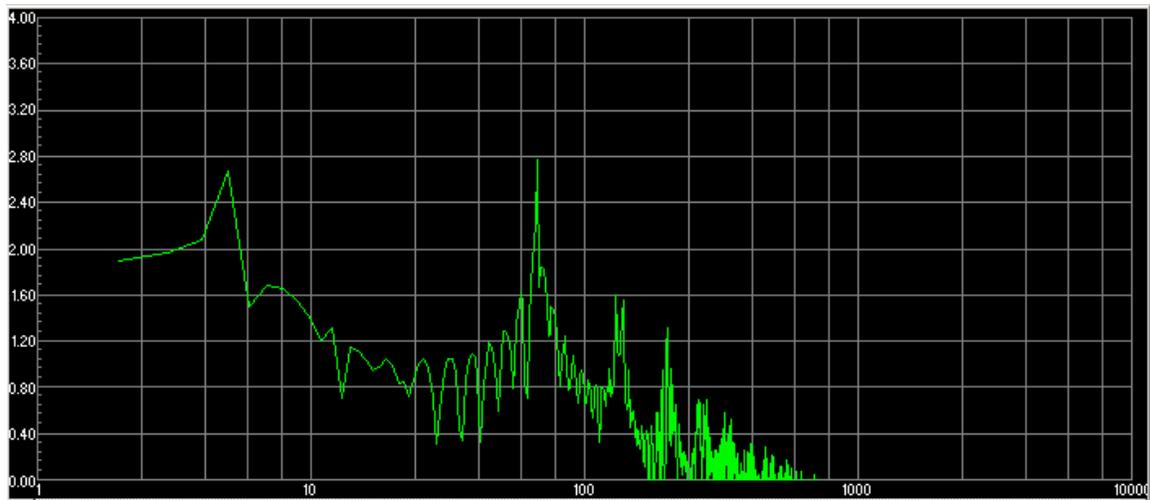

100Hz & 5kHz Fundamental: Reduced IMD Products

These illustrations are based upon the sustained signal conditions as described earlier between bass and midrange/presence content. No longer will lower frequencies cause midrange signals to warble. Instead, midrange content is held at, or just under, the main clipper threshold, and clarity is restored. When content contains wider dynamics, the algorithm allows the clipper to operate more historically. If observing the dynamic audio signal on a scope, less squaring of the waveform is observed, even during moderate levels of clipping. This further improves transient detail on short duration peaks.

Remember the earlier spectrograph depicting IMD among 50Hz and 1kHz? Well, here are the *before* and *after* pictures once this new algorithm is applied.
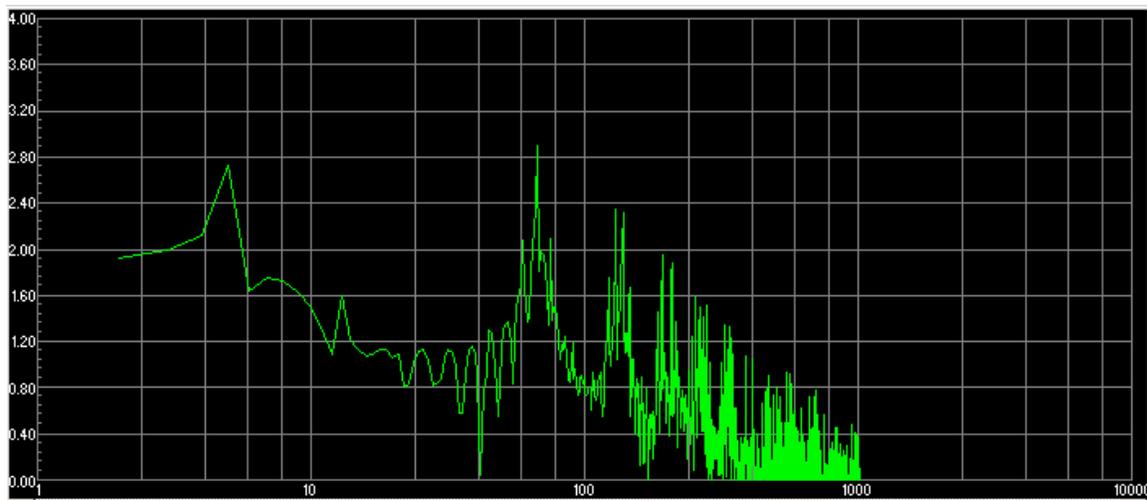
50Hz & 1kHz Fundamental Frequencies With Clipper Induced IMD Products

50Hz & 1kHz Fundamental Frequencies With Reduced IMD Products

Summation…

In this age of *bigger, better,* and who's *louder,* broadcasters need to realize that their audience now has many more choices of what to listen to. If they choose to process for the sake of loudness at all costs, the results might find listeners migrating to better sounding alternatives. It's vitally important to remain competitive sounding with respect to other stations on the dial, but it's just as crucial, if not even more so, to offer quality along with the competitive loudness quotient. For this to happen, processor design must raise the bar, yet again, with fresh innovation that yields clarity, quality, and competitive loudness.

For further information regarding this new clipper design, please contact Customer Support at Omnia Audio (216) 241-7225 or www.omniaaudio.com.