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An Investigation Into The Sonic Signature Of Three Classic Dynamic Range Compressors

Mr. Austin Moore[1], Dr. Rupert Till[2], and Dr. Jonathan P Wakefield[3]

[1] School of Computing and Engineering, University of Huddersfield, Huddersfield, UK
a.p.moore@hud.ac.uk

[2] Department of Music and Drama, University of Huddersfield, Huddersfield, UK
r.till@hud.ac.uk

[3] School of Computing and Engineering, University of Huddersfield, Huddersfield, UK
j.p.wakefield@hud.ac.uk

ABSTRACT

Dynamic range compression (DRC) is a much-used process in music production. Traditionally the process was implemented in order to control the dynamic range of program material to minimize the potential of overloading recording devices. However, over time DRC became a process that was applied more as a creative effect and less as a preventative measure. In a professional recording environment it is not uncommon for engineers to have access to several different types of DRC unit, each with their own purportedly unique sonic signature. This paper investigates the differences between three popular vintage dynamic range compressors by conducting a number of measurements on the devices. The compressors were tested using: THD measurements, tone bursts and objective analysis of music-based material using spectrum analysis and audio feature extraction.

1. INTRODUCTION

In popular music production it is common for a dynamic range compressor (DRC) to be selected for its sonic signature and the non-linearity it imparts onto program material. A qualitative study, carried out as part of a larger research project by the first author, uncovered that music producers are more interested in the colouration effect of DRC on audio material than dynamic range control. Furthermore professionals choose specific types of DRC unit when a given audio source needs to be compressed.

The research presented in this paper begins by investigating the core differences between the most popular types of compressor with a focus on pertinent aspects of their design that affect non-linearity and shape the compressors sonic signature. In particular this investigation looks into the designs of the: Teletronix

LA2A, Fairchild 670 and UREI 1176. These units all utilize different forms of gain reduction and have many unique traits to their designs. The main focus of this investigation evaluates how different designs affect the behavior of the compressors and assesses the nature of the sonic signature they impart onto music based program material. The term sonic signature refers to colouration and non-linearity imparted on program material [1] that can affect the timbre of audio material [2].

2. DRC DESIGNS

The Teletronix LA2A is often referred to as an opto-based compressor because it makes use of an electroluminescent panel and a photoresistor to control compression. The photoresistor in the circuit has its resistance changed by the light that is generated by the electroluminescent panel; in simple terms, more light creates more resistance, and thus more compression. The input signal is passed through a transformer and then into a gain reduction section where the signal is driven into some 12AX7 and 12BH7 valves before being sent to an output transformer.

Two particularly interesting aspects of the LA2A are related to the photoresistor it makes use of that is called the T4 cell. Firstly this cell exhibits program dependent timing responses that vary depending upon the nature of the program material and the level of the audio overshoot. This results in transient material having a fast release and steady state material having a comparatively slower release time. Secondly, as the cell ages over time it's time constant behavior can change and many older cells begin to exhibit ripple modulation of the amplitude during compression activity [3]

Many engineers state that the non-linear colouration, or warmth, associated with the LA2A comes in part from its valve-based circuit [4], which adds to the effect of the optical components. This design is commonly used as a vocal compressor with non-linearity adding flattering character to the timbre of the voice, along with dynamic control.

The Fairchild 660 and 670 compressor design makes use of the variable mu form of gain reduction. This method works by sending the voltage through a number of 6386 valves. As the voltage increases beyond a certain point the flow of electrons between the grid and the gate of the valve are restricted and attenuated thus creating gain reduction. The use of 6386 valves is important to the design and other commonly used valves, such as the popular 12AX7, will not allow for the necessary gain reduction behavior.

In the Fairchild the gain reduction occurs directly within the audio path rather than being sent out to a separate gain reduction block. The original reason for this design approach was to minimize distortion but the Fairchild is not totally free from non-linearity and will in fact impart non-linear colouration when driven into heavy gain reduction. This non-linear colouration is an often-quoted reason for selecting the Fairchild to process audio material [5]. The Fairchild is capable of very fast attack times ranging from 200-800 microseconds and this makes it a suitable choice for fast and aggressive compression techniques. The Fairchild compressor is commonly applied to a range of sources but its fast attack times and valve colouration make it particularly useful with sources featuring short transients thus it is often used on summed drum groups and individual drum room microphone recordings as a source of non-linear colouration to change the timbre of program material [6].

The Urei 1176 makes use of a Field Effect Transistor (FET) in its gain reduction circuit and consequently is commonly referred to as a FET compressor. The FET works as a voltage dependent resistor whose resistance is altered by a control voltage applied to its gate. The FET creates gain reduction in the circuit by shunting the audio signal to ground once it exceeds the threshold point. Time constants are implemented by means of resistors and capacitors that are placed in between some of the diodes and the gate of the FET. This allows alteration of the speed of the gain reduction, with attack times that can range between 20 to 800 microseconds and release times between 50 milliseconds to 1.1 seconds. In practical use the actual range of the attack time is very limited and this has led many recording engineers to suggest that the attack time ranges from simply fast to faster [7]

A key element of the sonic signature of the 1176 is related to increasingly non-linear behavior when multiple compression ratio buttons are simultaneously depressed. When used in this way the unit functions outside of it's designed working conditions with the bias point of the FET shifting well outside of calibration. This results in significant amounts of distortion and characteristic timing law activity that is commonly referred to by audio engineers as pumping. These types of distortion and temporal modulation effects are popular in use amongst engineers when working with audio material that consists of summed drum kits and drum room mic sources [8]

A fourth type of DRC is the VCA (voltage controlled amplifier) compressor, typified by the Dbx160. This design is characterised by achieving dynamic control while maintaining audio transparency. This paper will not focus on VCA compression, exploring instead opto, valve and FET designs, each of which impart a more individual sonic signature.

3. TESTING THE SONIC SIGNATURE USING TONES

To investigate the sonic signature of these three DRCs a series of measurements were made on hardware units at Snap Studios in London UK. Audio material was sent to the units directly (meaning not routed through the mixing console in the studio) using Prism ADA8 converters at 44.1kHz 24bit resolution. Results of the test tone based measurements are presented first followed by tests using complex program material.

3.1. THD Measurements

To investigate the nature of distortion generated by the DRCs, Total Harmonic Distortion (THD) measurements were made on the units. The DRCs were fed a 1kHz sine wave of 3 different amplitudes and the units were set to not compress the signal thus these measurements tested only for differences in non-linearity as a function of the input level. The DRCs were sent a signal at: 0dBu, +9dBu and +16dBu. The hotter, higher gain input signals were used as it was found that many engineers would drive the input of these units for colouration and non-linear sonic signatures often with the compression not engaged [9], [10] and [11].

The results from the three input levels can be seen in Table 1 and the THD plots for the +16dBu tones are shown in Figure 1 on the next page.

As can be seen in Table 1 the LA2A exhibits higher levels of THD than the other two compressors under this test. The Fairchild and 1176 function similarly with the 0dBu and +9dBu tones but the 1176 begins to impart higher levels of non-linearity than the Fairchild when driven with the +16dBu input. As previously mentioned it was found in the literature that the DRCs tested in this paper were sometimes used by engineers with no compression to impart colouration onto audio material.

Compressor	**0dBu**	**+9dBu**	**+16dBu**
1176	0.01	0.06	0.25
Fairchild	0.01	0.04	0.08
LA2A	0.20	0.50	0.90

Table 1. *THD % for the compressors at three inputs*

However, the results here show that the LA2A is the only unit to consistently produce non—linearity for all of the input levels tested that exceeds the often quoted 0.1% of THD that is required for distortion to be audible in test tones [12]. Furthermore it is the only unit to exhibit the 0.7% of THD that is required for distortion to be audible in music based material [13] albeit only when the LA2A was driven with the +16dBu input signal. It is worth keeping in mind that more recent studies [14] have disputed these figures and suggested that lower amounts of THD may be perceivable under certain conditions. The effect of this non-linearity in subjective listening tests is an area that requires further investigation and the authors intend to explore this in future work.

The THD plots in Figure 1 reveal that the Fairchild has some interesting sideband artefacts clustering around the test tone. These sideband artefacts are spaced either side of the 1kHz tone in 50Hz increments and closer inspection of the audio revealed some 50Hz hum which leads the authors to conclude that these sidebands may indeed be sum and difference components that relate to the hum frequency and test tone frequency. The other two DRCs do not exhibit this type of non-linearity and instead produce more archetypal harmonic distortion components. The LA2A has a fairly typical exponential drop in level of the harmonic artefacts and has some higher order components that extend further up the frequency range than the Fairchild. It is it also noteworthy that the 1176 produced a much more pronounced third order harmonic than the other two units and that it generates stronger odd order harmonics. Additionally the Fairchild has a unique response in that it generates strong second and third harmonics that are similar in amplitude to one another.

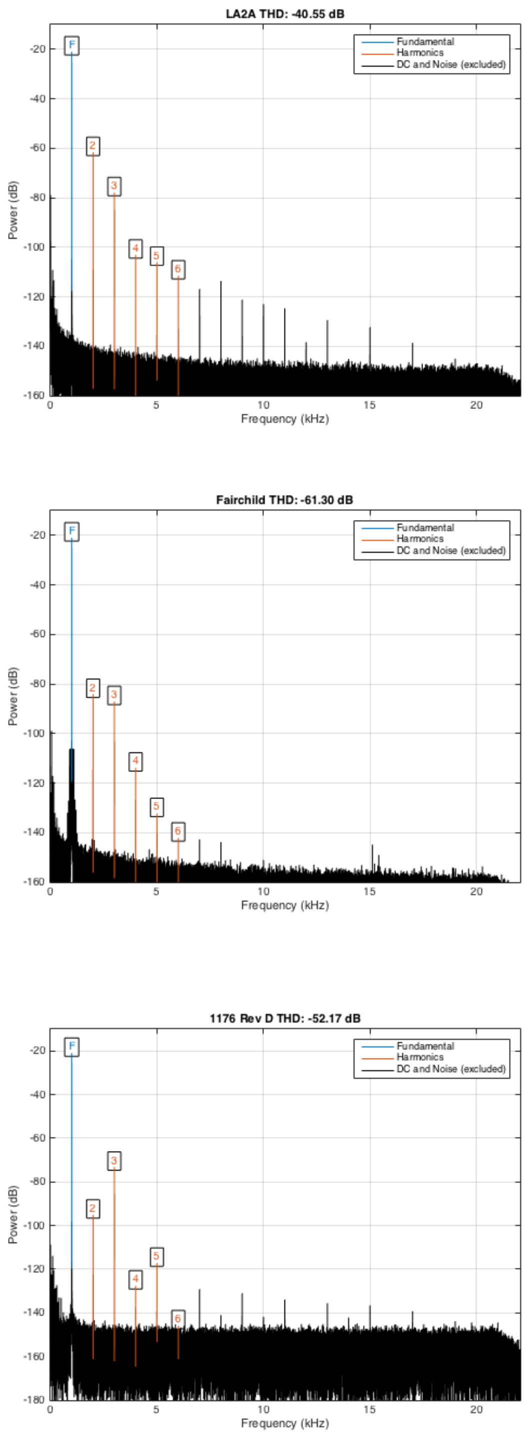

Figure 1. *+16dBu THD plots for the three compressors: LA2A is on top, Fairchild in the middle and 1176 on the bottom.*

3.2. THD Measurements During Compression

The DRCs were also measured for THD during gain reduction activity and also during the release period. This measurement was made by sending the compressors the sine burst test tone shown in Figure 2 and adjusting each compressor to provide -8dB of gain reduction on the DRC units VU meter during compression. The tone consisted of low-level portions of 0dBu either side of an overshoot portion (the middle block in the figure) of 12dBu. This test was based on the method described by Meltzer [15]. The input levels and gain reduction amounts were set to mimic real world working levels within a typical popular music production scenario. The time constants for the 1176 (attack at 3 and release at 7) and Fairchild (position 1) were set according to values used by record producers for general rock vocal compression [16] and [17]. It should be noted that the LA2A has no control over time constants.

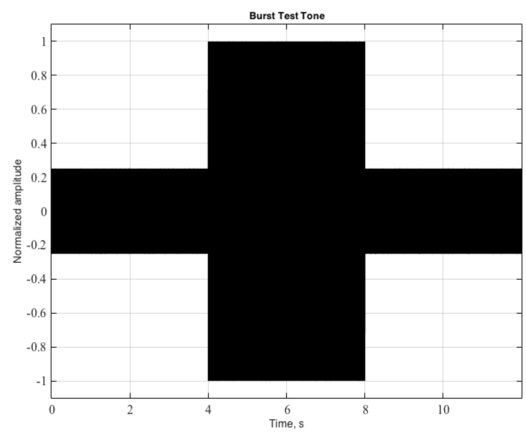

Figure 2. *Tone burst signal*

The results can be seen in Table 2 below and in the plots in Figure 3 on the next page. The table includes two frequencies while the plots only have the 1kHz tone.

Comp	125Hz In Comp	125Hz In Release	1kHz In Comp	1kHz In Release
1176	0.40	0.27	0.07	0.01
Fairchild	0.56	0.35	0.07	0.03
LA2A	2.13	1.18	2.64	2.38

Table 2. *THD % during compression and release*

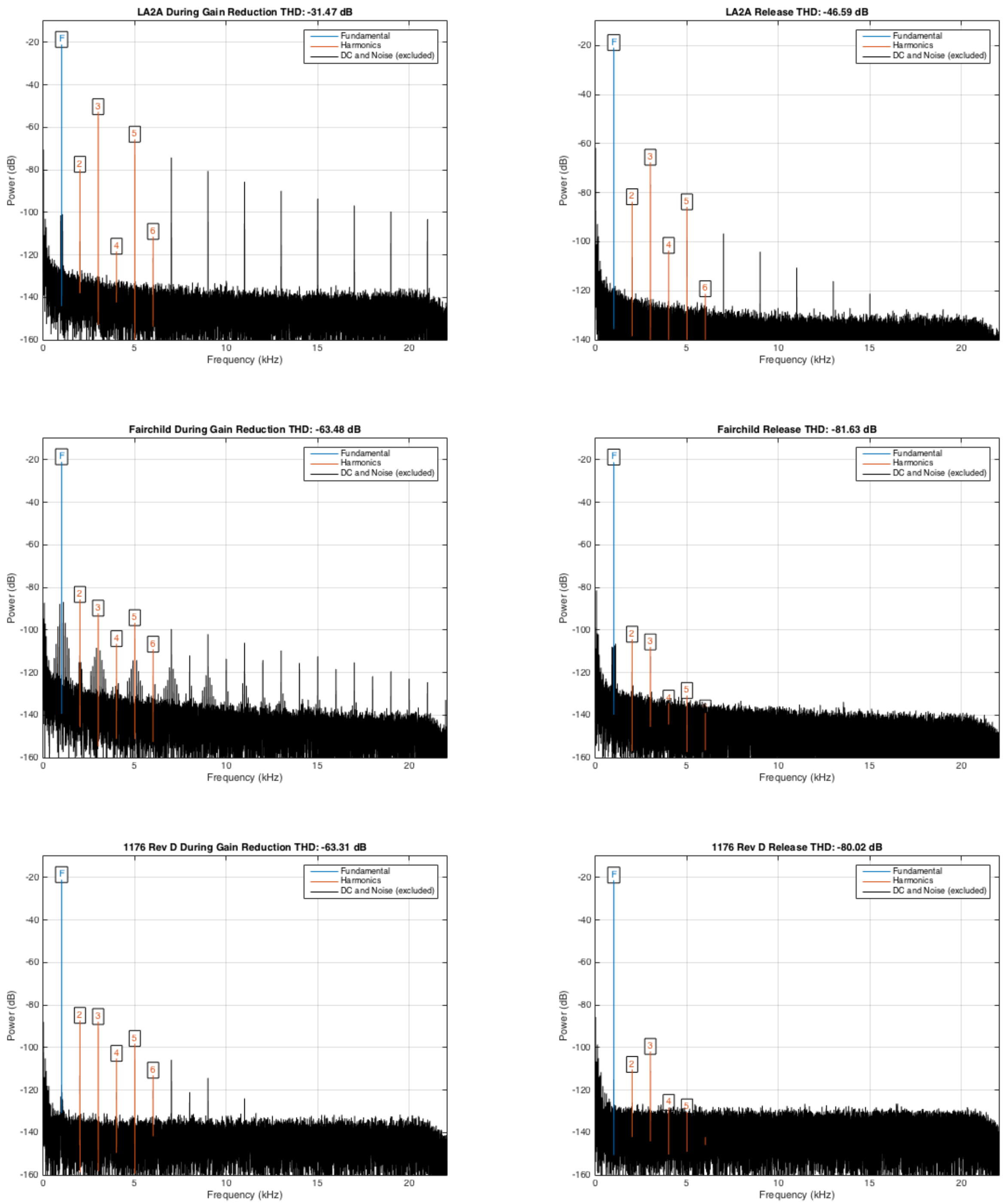

Figure 3. *The three compressors during gain reduction on the left and release on the right. The LA2A is on top, Fairchild in the middle and 1176 on the bottom.*

As can be seen in Table 2 the LA2A imparts significantly more non-linearity during both compression and release activity than the other two units under this test. Both the Fairchild and the 1176 have the same THD figure of 0.07% during compression for 1kHz but clean up during the release portion. The LA2A on the other hand continues to impart high THD results during the release period and this compressor is on the whole the most coloured unit of the three tested in this experiment.

Looking at the plots in Figure 2 uncovers more sideband artefacts in the Fairchild. As can be seen, the side bands now not only cluster around the test tone but also around the non-linear components. This is especially clear during compression. The 1176 plot shows some similar non-linear components to the Fairchild but without the sidebands.

The Fairchild and the 1176 are significantly more non-linear with the 125Hz tone and this is the case during both compression and release activity. The LA2A on the other hand is slightly cleaner with the lower frequency test tone. The faster time constants of the Fairchild and 1176 are presumed to be responsible for this additional distortion. Low frequency artefacts of this kind are often employed by music producers for colouration and effects [18]

3.3. Testing The Timing Response With Burst Tones

The timing response of the DRCs was tested using the previously described burst tone and making use of the same attack and release times. As seen in Figure 4 the LA2A has the slowest response of the three units with a slower attack and release. The unit appears to have a "multistage" attack response with 63% of the gain reduction occurring over the first 125 milliseconds and all attenuation applied over approximately 1100 milliseconds. There are also some noticeable ripples in the plots that are most likely as a result of some T4 cell ripple modulation. The Fairchild has the most aggressive attack time under this test, quickly attenuating the overshoot. There is a spike of 1 millisecond at the overshoot and a slight amount of attenuation of the signal that lasts 30 milliseconds before the Fairchild has fully compressed the overshoot. It should be noted that this attenuation is not visible on the plot in Figure 4 due to the small size of the image.

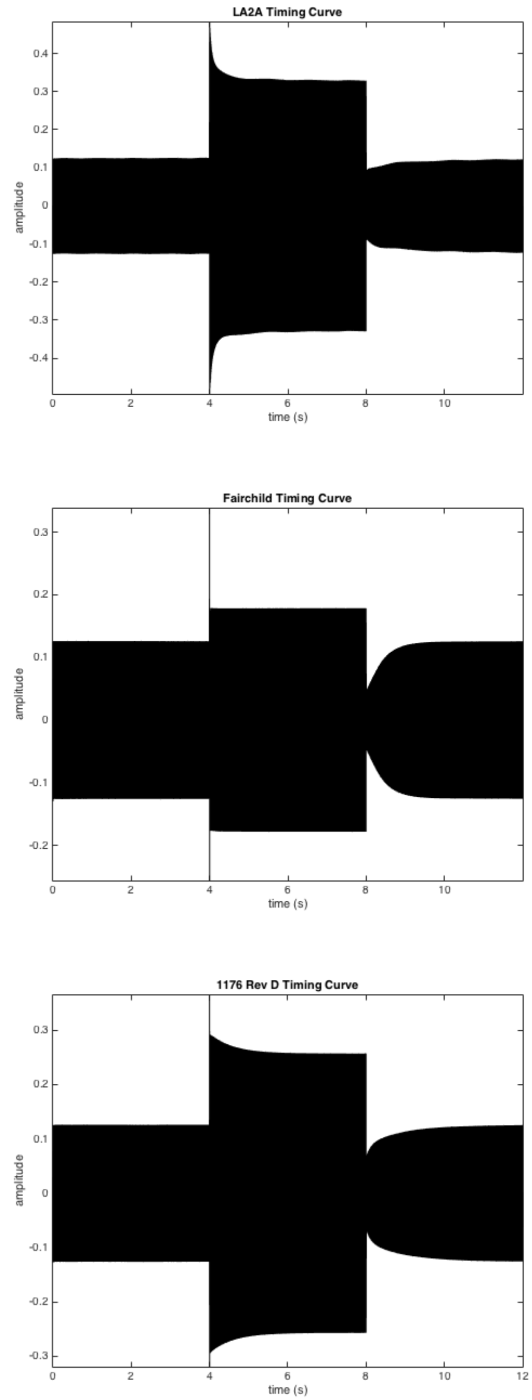

Figure 4. *Timing response comparison of the three compressors with a vocal setting. The LA2A is on top, Fairchild in the middle and 1176 on the bottom.*

The release curve of the Fairchild is gentler than its attack but quicker than the LA2A and without any of the modulation during the compression stages.

Like the Fairchild, the 1176 has a 1 millisecond spike where the signal overshoots the threshold but then takes 5 milliseconds to reach 63% of its steady state level. As with the other two compressors tested the 1176 has a release stage that is gentler than the attack

4. TESTING THE SONIC SIGNATURE USING COMPLEX PROGRAM MATERIAL

The DRCs were also tested using a number of music-based signals. These were processed through the DRCs again using the same time constant settings. The material was processed to make use of light, medium and heavy amounts of gain reduction by matching the amount of gain reduction on each devices VU meter, While this method did not mean that all the DRCs had exactly the same amount of gain reduction it was decided to be appropriate as it mimicked real work working conditions during typical production sessions. It was found that under light and moderate amounts of gain reduction all the DRCs performed very similarly. It was not until the audio was processed with heavier amounts of gain reduction that more noticeable differences manifested in the audio. The following section will briefly look at the results from the vocal based program material under heavy gain reduction. A more thorough analysis will be included in future work. The audio used was from a professional tracking session by producer Joe Baressi of the band Zico Chain and full permission to use the audio in this research was kindly given by the band.

The audio extract was analyzed using a mixture of spectrum analysis (using a Hann window with an FFT size of 2048 and an overlap of 75%), critical listening and extraction of a number of audio features using Matlab and MIRToolbox [19]. Long Term Audio Spectrum (LTAS) measurements were plotted with a Matlab function [20] using 1/16th octave smoothing. A Filterbank in MIRToolbox consisting of octave-scaled second order elliptical filters was used to generate sub bands of the audio to investigate the effect on the DRC in different regions of the audio spectrum.

Figure 6 shows the LTAS for the audio extract and Figure 7 shows time domain and spectrogram plots for the compressed and uncompressed signals. Table 3 shows the results for the extracted audio features and Table 4 features spectral flux data extracted from the 200-400Hz sub band.

Comp	Roll Off	Spectral Centroid	Brightness	Low Energy
Fairchild	10361	4970	0.604	0.411
LA2A	10410	4943	0.588	0.375
1176	10253	4826	0.586	0.415
No Comp	10095	4584	0.550	0.532

Table 3. *Audio Features for the uncompressed and compressed material.*

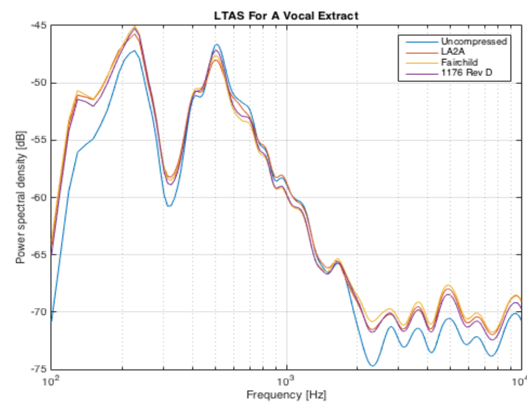

Figure 6. *LTAS for the uncompressed and compressed material. The plot shows 100Hz to 10kHz*

Compressor	Spec Flux Mean	Spec Flux Std
Fairchild	6.84	7.81
LA2A	7.20	8.75
1176 Rev D	6.84	8.18
No Comp	6.79	9.22

Table 4. *Spectral flux of the vocal extracts from sub band 200-400Hz*

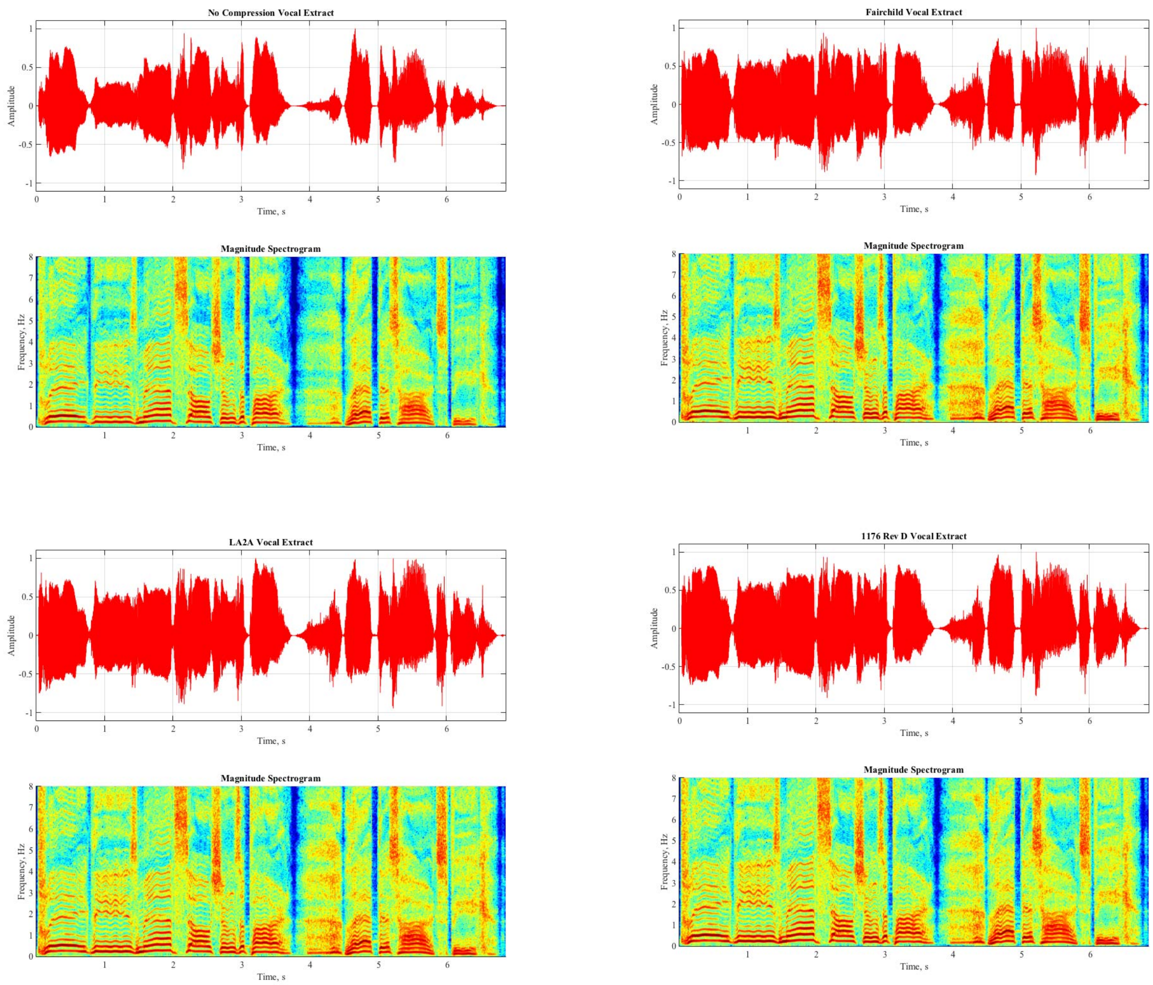

Figure 7. *Time domain and spectrogram plots for the uncompressed and compressed material*

In terms of the spectral content there has been an overall increase in intensity during the plosives and the breaths in the vocal performance. There is a slight amount of attenuation at the top end of the spectrogram in all the compressed plots, perhaps as a result of the compressor attenuating the signal after short bursts such as plosives and sibilants in the vocal part. This attenuation in the higher end does not noticeably affect the perceptual characteristics of the uncompressed and compressed signal thus the changes observed in the spectrogram are at most subtle. Of the three units the LA2A has a slightly fuller body to the sound quality that is consistent with the comparatively higher spectral flux figures for this compressor in Table 4. Alluri and Toiviainen have found that spectral flux in lower bands of the audio spectrum can correlate with a perceptual sense of fullness [21]. The non-linearity observed in Table 2 and Figure 3 also plays a role in this perceived sense of fullness, with the non-linearity fusing with the original program material to alter its timbre.

As can be seen in Figure 6 all the DRCs have a similar increase in the bottom and top ends of the frequency spectrum and the curve of the LTAS has the compressors grouped very closely suggesting again there are only very small frequency related differences between the units.

The results of extracted audio features reveal a similar picture with few differences between the units. All the DRCs have had the effect of increasing the value for features related to an increase in the top end (spectral centroid and brightness) and have lower low energy values than the uncompressed material with the LA2A having the lowest result for this feature. Lower low energy values mean that more of the frames of audio taken for calculation are higher than the average energy, which results in a low low-energy rating. This can translate perceptually as a more consistent piece of audio in terms of dynamic variations. For comparison the same vocal extract was processed using a parametric EQ in Adobe Audition with the centre frequency fixed a 6kHz and boosted in 1dB increments. This centre frequency was selected as it was deemed to be appropriate for vocal EQ processing to increase the brightness of a voice. Using this method an EQ boost of between 4-6dB was needed to achieve the same change in spectral centroid as the compressed material and a boost of 3-4dB was required to achieve the same change in brightness. Therefore it can be said that this is a significant side effect of the DRC units processing and sonic signature.

To investigate the difference in the envelope of the material compressed through the units, the RMS energy of the audio was extracted and plotted over time. The energy was plotted using a window size of 4096 and a hop size of 1024. The results can be seen in Figure 8 where again the units have many similarities and only some small differences that are typically in the micro dynamics of the signal around the start of phrases. It is particularly interesting to note the similarity of the Fairchild and the 1176. The dynamic range and peak crest factor of the extracts were calculated using a Matlab function and the results revealed the largest difference in both dynamic range and peak crest factor was 1.15dB between the LA2A and 1176. It is thought that this difference is largely due to the LA2As slower attack time. The Fairchild and 1176 generated only slightly different results with the 1176 working more aggressively on the material. However the differences in envelope contour are small and again perceptually all the compressors sound similar in character.

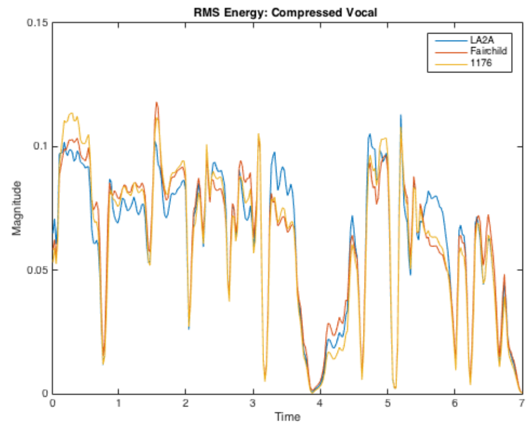

Figure 8. *RMS energy for the three compressors*

5. CONCLUSIONS

The aim of this paper was to investigate the differences in sonic signature between three commonly used DRCs. It was found that each of the units had some differences with regard to distortion artefacts and this was particularly apparent during compression activity. Furthermore it was noted that there was variation in the timing response of the DRCS and this was most noticeable during the attack stage of gain reduction.

When the compressors were tested with complex program material it was noted that all the units had the effect of increasing audio features that pertained to an increase in perceived brightness (spectral centroid and brightness) and a sense of fullness to the sound (spectral flux in the 200-400Hz area of the audio spectrum). The sonic signature of each unit, and their resultant use in specific production circumstances, appears to be formed by audio artefacts that are subtle and difficult to distinguish individually. The units each reduce gain without significantly distorting the audio signal when used with moderate settings. However, when used with higher amounts of input gain, high amounts of gain reduction, or beyond normal operating parameters, a range of more evident (but still audibly subtle) distortions are generated by each unit, offering a sonic signature that is desired by audio producers to add colour to audio material.

6. FURTHER WORK

Further subjective tests are planned making use of a panel of expert listeners to investigate how perceivable the differences are between units when making use of audio material that has been processed with light, moderate and heavy amounts of gain reduction. The study will also aim to catalogue subjective responses regarding each unit's sonic signature and map these responses onto acoustic properties of the sound such as the audio features extracted for this current study.

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