Objective Analysis and Perceptual Evaluation of LA-2A Compressors and Vocal Recordings

Austin Moore
(a.p.moore@hud.ac.uk)

University of Huddersfield, Huddersfield, UK

The LA-2A compressor is a popular optical dynamic range compressor and is much used in popular music productions, particularly as a vocal compressor. There are many claims about sonic differences between different LA-2A versions, but most of these are anecdotal with no empirical evidence to back them up. This paper explores the objective differences between six hardware LA-2A compressors, three vintage Teletronix units, and three Universal Audio Reissues. Firstly, it conducts a series of measurements on six compressors, using frequency response sweeps, total harmonic distortion measurements and tone burst to explore their attack and release characteristics. The results showed subtle differences, particularly around THD, and attack and release. Subsequently, an ABX listen test was conducted with 17 trained listeners to explore the audibility of these differences. The test comprised comparing three songs where the vocal tracks had been compressed using the two most dissimilar LA-2As. The results showed a mixture of significant and non-significant results, suggesting that discrimination is context-dependent and difficult to discern in typical music productions.

0 INTRODUCTION

The LA-2A compressor, despite being originally developed as a broadcast limiter in 1965 [1], is a much used compressor in music production. It is particularly popular as vocal compressor, a role where it is well renowned [2, 3]. Since its original release it has seen many revisions, reissues, clones and software emulations [4] and continues to be enduringly popular despite being sixty years old. It is referred to as an opto-based compressor because it makes use of an electroluminescent panel that shines a light on a photo resistor to change its resistance. The component used to achieve gain reduction in the LA-2A is called the T4 cell and has unique qualities not achievable with similar photo resistors; this plays an integral role in LA-2A's sonic signature [5].

As with many pieces of musical hardware, debate exists regarding the sonic differences in LA-2As, especially regarding vintage and reissue units and purported examples that are 'special' and 'better' than the norm [6, **?**]. These claims are highly anecdotal, disseminated through informal channels and compounded further by marketing claims from developers, suggesting that their unit sounds better than the others, or that they have based their design or emulation on a 'golden' unit [7]. Consequently, the LA-2A has been elevated to mythical status, and one could argue it has been fetishized within contemporary music production communities [8].

Given this context, the present study is based around two core aims:

- To analyze six LA-2A compressors from three professional recording studios in the UK by conducting objective measurements and statistically analyzing the resulting data to explore any differences in their sound quality
- To conduct an ABX listening experiment to further explore these differences and specifically assess if these differences are audible to the listener.

The outcomes of this study aims to benefit three key groups:

- **Music producers** seeking efficiency through informed equipment choices without second-guessing subtle differences. The results might influence decisions around gear acquisition [9] and the speed of decisions during the production process.
- **Educators** needing evidence-based material for teaching production practices while helping students avoid excessive focus on minor sonic details.
- **Developers** requiring technical insights to create accurate software emulations that preserve each unit's distinctive characteristics.

1 LA2A Compressor Operating Principles

1.1 Topology Overview

The LA-2A is an optical compressor, made up of of a transformer-balanced signal path employing Class-A valve gain stages in conjunction with a passive electro-optical attenuator. A conceptual block diagram of this topology is shown in Figure 1.

An audio signal enters via a high-impedance input transformer and is first amplified by a 12AX7 valve stage. A split of the amplified signal is simultaneously routed to a sidechain path, where a secondary amplifier (also a 12AX7 valve) increases the level to drive an optical gain control element—the T4 cell. The control signal modulates the brightness of a tungsten lamp inside the T4 cell, which in turn alters the resistance of two cadmium sulfide (CdS) photoresistors located in the main signal path; this forms a passive voltage divider, applying compression as a function of the input signal's amplitude. After attenuation, the signal is re-amplified by a 12AX7 recovery stage, buffered by a 12BH7 cathode follower, and sent through a transformer-balanced output.

1.2 The T4 Optical Cell: Principle and Characteristics

The T4 cell is the electro-optical component that translates sidechain amplitude into dynamic gain reduction. A conceptual diagram of this internal process is shown in Figure 2. It consists of a sealed, light-tight enclosure containing a tungsten filament lamp and a pair of CdS photoresistors. As the sidechain amplifier responds to increases in input signal amplitude, it drives more current into the lamp, causing it to glow brighter. This increased light exposure reduces the resistance of the CdS cells, which modulates the gain applied to the main audio signal. The T4 cell operates entirely via optical coupling and there is no electrical link between the sidechain and the signal path. The lamp's thermal inertia causes it to respond gradually to signal changes, while the CdS cells exhibit a memory effect based on light exposure history. These characteristics produce the LA-2A's signature attack and release curves, which are not fixed but emerge from the physical properties of the optical components.

2 Related Literature

Dynamic range compression in music production has received some attention in academic research. Several studies have explored dynamic range compression, specifically limiting, and its impact on the perceived sound quality during mastering. This exploration considers this phenomena from the consumers perspective [10, 11, 12] but also from the mastering engineers perspective [13].

Previous studies have also explored typical dynamic range compressor topologies from different lenses. These lenses range from the development of software implementations [14, 15] to investigations into how different compressor designs may impact the sonic signature of music productions [16]. Other work has explored dynamic range compression in terms of listener perception and semantics to better understand how we listen to and make sense of dynamic range compression. This includes an exploration of the factors influencing subjective preference judgments in compression [17], which investigated the role of long-term memory and sound quality attributes in listener preference for compression.

Furthermore, there was the creation of a lexicon for compression [18], which used category analysis to code 51 reviews of analogue compressors and identified key terms used to describe analogue compression. The perceived differences in compression ballistic settings was explored in the literature [19], with results showing that the attack parameter influences perceived style more than the release parameter, and that this is more evident in Jazz and Rock styles compared to EDM or Hip-Hop. Additionally, a Delphi method study that used discourse analysis, online content analysis and a survey with professional mastering engineers explored the descriptor ”glue” and how it pertains to compression [20]. A study highlighting the influence of compression on the perception of temporal placement in music [21] argues that dynamic range processing, particularly sidechain compression, significantly impacts how listeners perceive the timing and groove of music, especially in EDM. Finally, an investigation into the perceived effect of compressor attack and release times on the perceived style of music [22] employed a listening experiment where participants rated the appropriateness of varying attack and release settings applied to different musical styles and selected descriptive tags for the perceived sound.

Despite limited studies on the LA-2A compressor and optical compression, a few stand out in their detailed examination. A recent study explored how to model the behavior of optical compressors [23]. As part of the study, the authors investigated the sonic characteristics of the LA-2A and the Tubetech CL1B, which is a more modern but similarly popular optical compressor in music production. They noted that one of the main challenges in modeling was around capturing the optical compressors time variant characteristics. Other work has looked at optical compression within the context of hardware design and investigated the nuances of electro-luminescent optical cells in the development of hardware optical compressors [24]. The findings uncovered that the timing behavior of optical compressors could differ depending upon the type of panel used in the compressors design. Finally, another study [25] explicitly used the LA-2A, as well as an 1176 and Fairchild compressor, to explore the variances between three vintage hardware units. This study showed with audio measurements that the LA-2A was the most colored unit with significant non-linearity during compression and release compared to the Fairchild and 1176

Although the reviewed literature highlights both the subjective and technical dimensions of dynamic range compression, few studies have systematically quantified interunit variation in widely used analogue compressors. This study addresses that gap through controlled objective testing of six LA-2A units.

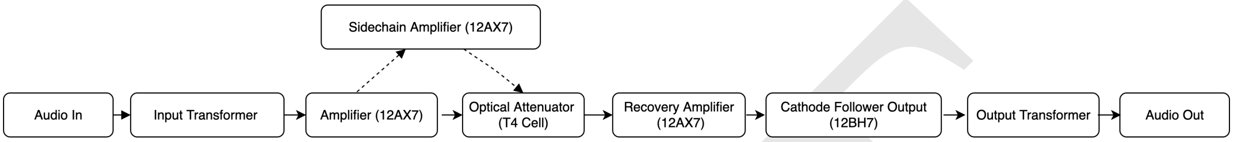

Fig. 1: Block diagram of the LA-2A signal path, showing the core gain stages and optical control loop.

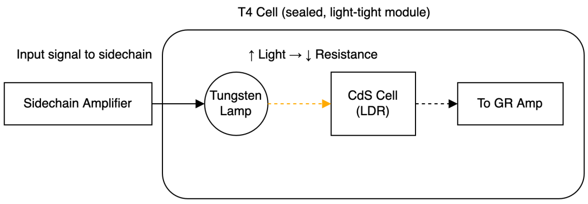

Fig. 2: Conceptual diagram of the T4 electro-optical gain reduction cell.

3 Objective Testing

The following sections discuss how the objective testing stage was conducted, focusing initially on how signals were processed and captured and then presenting and discussing the results. The purpose of this exploration, is to explore the differences in the tested units when using conventional test measurements.

3.1 Test Signals Generation and Capture Methods

The objective performance of the LA-2A compressor was evaluated initially using test signals via the following procedures:

1. **Test Setup:** Objective testing involved six LA-2A compressors (three vintage, three reissues) using a Metric Halo 2882 interface at 96kHz/24bit for playback and capture. Burst and test tone signals were processed with Avid Pro Tools, with frequency response sweeps analyzed via Fuzzmeasure, using system calibration to EBU R68 (-18 dBFS = +4 dBu) standards. No external 600-ohm termination was applied during testing. All LA-2A units were interfaced directly with the Metric Halo 2882, which presents a high input impedance (> 10 kΩ). This reflects common modern studio conditions and was applied consistently across all measurements to ensure comparability.
2. **Frequency Response:** Frequency response was assessed with a 20Hz–20kHz sine sweep using Fuzzmeasure, with gain reduction inactive by setting the Peak Reduction control fully counter-clockwise.
3. **THD Measurements:** THD was assessed using five test tones (1kHz to 63Hz) by inputting +4dBu signals to achieve 6dB gain reduction. To ensure accurate and consistent gain reduction measurements digital test meters were used to monitor input and output signals; this approach avoided the inconsistencies of the VU meters. The captured audio was analyzed in MATLAB, calculating THD as the root-sum-square of the 2nd to 6th harmonics; 2nd and 3rd harmonic levels were also compared. A Hann window minimized spectral leakage.
4. **Timing Response:** Timing response was evaluated using a 1kHz tone burst consisting of two -18 dBFS sections flanking a -6 dBFS section, played via Pro Tools. Handheld digital meters were used here to monitor input and output levels to assess gain reduction. Further program dependency testing is planned for future studies.
   Prior to each tone burst measurement, the signal was run through the unit several times to allow the T4 cell to thermally stabilise. This pre-conditioning ensured that the lamp and photoresistor reached a consistent operating state, minimising variation in the cell's dynamic response due to thermal lag. The actual measurement was then captured on a single pass, following this brief warm-up. This approach reflects a compromise between repeatability and realism, as the LA-2A's electro-optical gain control is inherently sensitive to temperature and recent signal history. Averaging across multiple burst captures may provide further insight into the thermal non-linearity of the T4 cell and could be explored in subsequent studies.

To confirm the baseline performance of the measurement setup, the Metric Halo 2882 interface was looped back from output to input, bypassing any LA-2A units. The resulting frequency response was flat within ±0.5 dB from 20 Hz to 20 kHz, and the residual total harmonic distortion (THD) measured approximately 0.003% at 1 kHz with a +4 dBu input level. These figures represent the system's inherent resolution and noise floor, ensuring that the measurements of the six LA-2A units reflect actual device characteristics rather than limitations of the test setup.

The six compressors are referred to as LA-2A1–6. Units 1, 3, and 5 are modern Universal Audio reissues, while units 2, 4, and 6 are original Teletronix units.

3.2 Results and Discussion

3.2.1 Frequency Response

The frequency response of the six compressors was explored within 30 Hz to 15 kHz to match the frequency response discussed in the compressor's manual; it states a tolerance of +/- 0.1 dB across this range.

Rather than displaying a frequency response plot, Table 1 ranks the compressors from the smallest to the largest variance in dB within this frequency range. As can be noted, none of the units conform precisely to the manual's specification of +/- 0.1 dB variance. LA-2A2 shows the least amount of variance, while LA-2A5 shows the greatest variance. However it is worth noting that for all the com-

Table 1: Frequency Response Variance for LA-2A Compressors 30 Hz to 15 kHz. The highest value in each row is marked with an asterisk (*)

Compressor	**Min dB**	**Max dB**	**Variance**	**Primary Colouration Range**	**Primary Colouration (dB)**
LA-2A2	-0.501	0.000	0.501	Below 30 Hz	-2.21 dB
LA-2A3	-0.503	0.000	0.503	Below 30 Hz	-2.45 dB
LA-2A6	-0.709	-0.004	0.705	Below 30 Hz	-2.31 dB
LA-2A4	-1.142	0.000	1.142	Above 14 kHz	-5.18 dB
LA-2A1	-1.249	0.000	1.249	Above 14 kHz	-5.48 dB
LA-2A5	-2.282	-0.947	1.335*	Below 30 Hz	-3.50 dB

pressors, the primary colouration rage is either below 30Hz or above 14kHz. Thus, this deviation in frequency response is unlikely to be audible in most cases and will be program dependent.

These variations are likely due to minor differences in transformer performance, especially in the output stage. Small deviations in winding characteristics or core material between units—particularly between older and newer models—can result in slight shifts in bandwidth and phase response. The valve amplification stages themselves are not expected to contribute significantly to this behaviour, given their inherently wide frequency response when operated linearly.

3.2.2 THD

Table 2 shows significant THD variation among units, with values from 0.9% to 4.2% at 1kHz. As can be seen, third harmonic distortion (typically 10–20 dB higher than second harmonic, per Table 2), is dominant and will be a contributing factor in the non-linear colouration of these compressors. It is important to remember that these measured THD values were captured during gain reduction, which explains why they are significantly higher than the nominal manufacturer specifications (typically $< 0.5\%$), measured under baseline signal level conditions rather than during compression. However, the measurements made for the current study are commensurate with measurements made previously by the author [25] and align with user measurements reported in pro audio technical forums [26], which confirm THD during compression ranges from approximately 0.5% up to over 4% depending on the specific unit and conditions.

One should also consider that while lower percentages are indicative of better audio system performance, professional music producers actively seek out non-linearity in their music production devices. With this in mind, it is likely that these THD levels are responsible for the colour that professional music producers desire and will play a role in the preference some have for what they consider 'golden units'.

While all active stages in the LA-2A contribute to the overall signal behaviour, the primary contributor to total harmonic distortion during gain reduction is likely the T4 electro-optical attenuator. The nonlinear relationship between lamp brightness and photocell resistance, combined with the dynamic behaviour of the tungsten filament and cadmium sulfide (CdS) cell, introduces time-varying distortion components that are particularly prominent during attack and release transitions. In addition, both the input and output transformers are known to introduce subtle harmonic coloration, especially under asymmetric loading or saturation at high levels. Conversely, the Class A valve stages (typically 12AX7 and 12BH7) are generally operated near their most linear region in this topology and are therefore unlikely to be the dominant source of distortion. Overall, the observed THD values reflect a complex interplay of these factors, but the dynamic response of the T4 cell remains the most plausible source of the elevated harmonic content observed during active compression.

3.2.3 Tone Bursts Analysis Method

To quantify the dynamic response times of each compressor, a custom MATLAB function was employed to analyze the output signal $y(t)$ resulting from the tone burst signal described in 3.1. The analysis focused on determining the time required for the output signal's envelope to stabilize after the abrupt input level changes corresponding to the attack and release phases.

A peak-hold envelope $y_{\text{env}}(t)$ was extracted from $y(t)$ using a 2 ms moving maximum window (`envelopeWindowTime_ms`), and its rate of change was approximated by the first-order difference, $y'_{\text{env}}(t)$. The start times of the attack ($t_{\text{attack\_start}}$) and release ($t_{\text{release\_start}}$) phases were automatically detected using $y'_{\text{env}}(t)$ and estimates of the signal levels (guided by `quietLevel_dBFS`, `peakLevel_dBFS`, `expectedGR_dB`).

Stabilization was defined relative to the global maximum absolute derivative, denoted as $D_{\max} = \max|y'_{\text{env}}(t)|$. Specific stabilization thresholds were calculated using different sensitivity factors for each phase. The attack threshold, θ_{attack}, was determined using a factor $f_{\text{attack}} = 0.01$ (`attackStabilizationThresholdFactor`) as

$$\theta_{\text{attack}} = f_{\text{attack}} \times D_{\max}, \quad (1)$$

while the release threshold, θ_{release}, used a stricter factor $f_{\text{release}} = 0.001$ (`releaseStabilizationThresholdFactor`), given by

$$\theta_{\text{release}} = f_{\text{release}} \times D_{\max}. \quad (2)$$

Table 2: THD Measurements for Six LA-2A Units. Frequencies in Hz, Harmonics in dBc relative to fundamental, THD calculated as Total Harmonic Distortion percentage.

Unit ID	**Metric**	**63 Hz**	**125 Hz**	**250 Hz**	**500 Hz**	**1000 Hz**
	2nd Harm (dBc)	-47.25	-50.22	-50.86	-51.51	-51.47
LA-2A-1	3rd Harm (dBc)	-31.68	-32.24	-32.50	-32.53	-32.46
	THD (%)	2.71	2.52	2.45	2.44	2.46
	2nd Harm (dBc)	-63.59	-66.20	-69.14	-76.03	-71.79
LA-2A-2	3rd Harm (dBc)	-30.63	-29.84	-29.23	-28.59	-27.89
	THD (%)	3.07	3.35	3.61	3.89	4.22
	2nd Harm (dBc)	-59.44	-71.05	-67.54	-72.09	-74.82
LA-2A-3	3rd Harm (dBc)	-32.07	-33.72	-35.16	-34.60	-33.83
	THD (%)	2.58	2.09	1.81	1.94	2.12
	2nd Harm (dBc)	-81.24	-56.67	-57.32	-58.00	-57.98
LA-2A-4	3rd Harm (dBc)	-61.86	-37.48	-37.53	-37.45	-37.42
	THD (%)	0.08	1.37	1.37	1.38	1.39
	2nd Harm (dBc)	-71.29	-65.40	-64.04	-64.01	-64.15
LA-2A-5	3rd Harm (dBc)	-33.95	-35.06	-34.98	-34.09	-33.22
	THD (%)	2.06	1.80	1.83	2.04	2.26
	2nd Harm (dBc)	-55.42	-67.42	-61.97	-58.19	-56.79
LA-2A-6	3rd Harm (dBc)	-39.61	-41.84	-42.65	-41.79	-40.77
	THD (%)	1.08	0.81	0.75	0.84	0.94

The Attack Stabilization Time ($T_{\text{stab\_attack}}$) was then measured from $t_{\text{attack\_start}}$ until the time $t_{\text{stable\_attack}}$ where $|y'_{\text{env}}(t)|$ remained below the threshold defined in Eq. (1) for a minimum duration $T_{\min} = 10$ ms (`minStableTime_ms`). Similarly, the Release Stabilization Time ($T_{\text{stab\_release}}$) was measured from $t_{\text{release\_start}}$ until $t_{\text{stable\_release}}$ where $|y'_{\text{env}}(t)|$ remained below the threshold from Eq. (2) for the same minimum duration $T_{\min}$.

Variations in attack and release time across units are most likely due to differences in the individual T4 cells, particularly in how each unit's lamp and photoresistors respond to changes in signal. Aging, prior usage, and temperature all influence this behaviour, and as no fixed time constants define the LA-2A's envelope, such variation is expected.

3.2.4 Tone Bursts Results and Discussion

Looking at Table 3 shows there is variation in the attack and release times between the six units, with the attack times ranging between 33 to 81 milliseconds with a mean 52.83 (SD=18.46) milliseconds and release times from 449 to 1,670 milliseconds with a mean 916.5 (SD=426.98) milliseconds. As can be noted, there is more variation within the release compared with the attack, which is comparatively more consistent.

As a point of comparison, a previous study [24] measured the attack and release times of various optical cells and found the attack ranged from 65 to 500 milliseconds and release times from 30 to 1600 milliseconds. There are clearly some differences here, but regardless, both the previous and the present study show there can be considerable variation in the attack and release times of optical compressors. These differences can be because of many factors, including aging components, servicing and general manufacturing differences. In a practical sense, these differences will impact the sound of a compressor and how it reacts to signals, particularly how it shapes the transient and envelope of program material.

4 Component Variartion and Measured Differences

Due to the professional studio environment in which the units were tested, no physical inspection or disassembly was possible. Internal component identification would have required partial deconstruction, which was not appropriate for vintage studio-owned equipment of high value. This constraint reflects common real-world conditions in audio research, where hardware under test is operational and in service rather than lab-isolated.

While the exact serial numbers and manufacturing dates of the tested units were not recorded, the general production era of each unit was confirmed through consultation with studio staff and owners. In the absence of direct internal inspection, reference was made to three key sources of technical documentation: the 1966 Teletronix service manual [27], the 1979 UREI service manual [28], and the Universal Audio reissue documentation [5]. These materials reflect well-documented design trends across a range of relevant production eras.

Table 4 presents typical component differences between 1970s-era Teletronix LA-2A units and current Universal

Table 3: **Summary of Attack and Release Stabilization across the LA-2A Units.**

Comp	Attack to Stabilization (ms)	Release to Stabilization (ms)
LA-2A 1	51	1670
LA-2A 2	70	1121
LA-2A 3	33	740
LA-2A 4	81	1030
LA-2A 5	40	449
LA-2A 6	42	491

Audio reissues, providing useful context for interpreting the objective measurement results.

Although these general component distinctions are informative from both historical and technical perspectives, they did not correspond to any clear performance stratification in this study. Objective measurements revealed subtle unit-to-unit variation, but these differences did not consistently align with vintage or modern production status. As will be discussed in Section 5.3, a clustering analysis based on vocal audio features revealed no consistent grouping by production era,which reinforces the idea that unit-level variation outweighs vintage/reissue status. Individual unit variation—shaped by component tolerances, servicing history, and the complex interplay of optical and analog subsystems—is arguably more influential than any single era-specific design choice. Valve selection may also contribute to this variability: although all units employed the same nominal valve types (e.g., 12AX7, 12BH7, 6AQ5), differences in manufacturer, age, and wear characteristics likely introduce small but measurable performance differences. However, the specific impact of individual valve brand, age, or condition was not isolated or quantitatively assessed within the scope of this study. Taken together, these variations may help explain the enduring appeal of so-called "golden units," whose distinct sonic traits cannot be easily attributed to production era or any single component in isolation.

5 Vocal Signal Signal Analysis

While test tones can be useful in assessing a compressors behavior and highlighting the differences between units, the use of musical signals can reveal much more meaningful results about its sonic character. The following sections detail how vocal recordings were processed through the LA-2A compressors and presents the results and discussion from the analysis of the objective measurements. Vocal recordings were used in this study as literature, previously stated in this study [3], has shown this compressor is very commonly used for vocal compression. Furthermore, a short exploration of online reviews for the Universal Audio software version of the LA-2A showed that the word 'vocal' was used 143 times, almost 3 times more than the next most commonly named instrumental source, bass, which was mentioned 49 times.

5.1 Vocal Signal Capture Method

Compressor behavior with dynamic musical material was evaluated using vocal tracks from the multi-tracks from three songs sourced from a online music production training service [29] and processed through the six LA-2A units (using the test setup described previously). Each vocal track was processed at three target average gain reduction (GR) levels: -3 dB, -6 dB, and -12 dB, chosen to explore the compressor's behavior across a range from subtle to more pronounced. These gain reduction amounts will be referred to as low, medium and high for the rest of the study.

Software metering with Pro Tools plugins (Peak, RMS, LUFS) was used to ensure consistent gain reduction across units. Input gain was adjusted for each compressor until the LUFS difference between pre- and post-compression matched target levels (-3, -6, -12 dB) over two-bar phrases. The calibrated audio was then recorded into Pro Tools.

5.2 Audio Features Extraction

Audio features were extracted from the processed vocal tracks using MIRToolbox in MATLAB [30] for objective comparison between the six compressors. Ten features were extracted: spectral centroid, brightness, spectral flux, roughness, low energy, zero crossing rate (ZCR), roll-off, attack time, spectral spread, and kurtosis and these features were chosen to quantify relevant spectral, temporal, textural, and energy characteristics. Features were computed for each of the three songs across the three gain reduction (GR) levels for all six compressors.

5.3 Principal Component Analysis

Principal Component Analysis (PCA) was applied to the extracted audio feature dataset across three songs. The primary goals were dimensionality reduction, visualization of relationships between different compressor settings (unit and GR level), and informing the selection of representative stimuli for subsequent perceptual listening tests by identifying key variance patterns.

5.3.1 Objective Analysis: Clustering Results

K-means clustering was applied to the standardized feature data to explore objective similarities between compressor instances. Table 5 presents the results for both k=3 and k=6 cluster solutions.

Table 4: Typical Component Differences Between 1970s-era LA-2A Units and Modern UA Reissues

Component	**1970s-era Units**	**Modern UA Reissues**
Input Transformer	UTC A-10 (as per original schematic)	Custom Cinemag or UA-spec remake
Output Transformer	UTC A-24 (as per original schematic)	Cinemag/UA custom equivalents
Amplifier valves	12AX7, 12BH7, 6AQ5 (brands varied)	12AX7, 12BH7, 6AQ5; modern production, typically Russian or Chinese manufacture
T4 Cell	Original T4B units with aged CdS response	UA-manufactured T4B; newer CdS elements with tighter tolerances
Power Supply Rectifier	6X4 valve rectifier	Solid-state rectification or modern 6X4 valve variant
Passive Components	Carbon composition resistors; paper and oil capacitors	Metal film resistors; electrolytic and film capacitors
Chassis/Build	Turret board construction with point-to-point wiring	PCB-based with modern layout and internal shielding

Table 5: **Clusters and corresponding compressor settings identified through K-means clustering.**

Cluster	**Compressor/Settings**
3-0	LA-2A 1 Low, LA-2A 1 Med, LA-2A 2 Med, LA-2A 3 Med, LA-2A 4 Low, LA-2A 4 Med, LA-2A 5 Low, LA-2A 5 Med, LA-2A 6 Med, LA-2A 4 High
3-1	LA-2A 1 High, LA-2A 2 High, LA-2A 3 High, LA-2A 5 High, LA-2A 6 High
3-2	LA-2A 2 Low, LA-2A 3 Low, LA-2A 6 Low, No Comp
6-0	LA-2A 1 High, LA-2A 2 High, LA-2A 3 High, LA-2A 5 High, LA-2A 6 High
6-1	LA-2A 2 Low, LA-2A 3 Low, LA-2A 6 Low
6-2	LA-2A 1 Low, LA-2A 4 Low, LA-2A 5 Low
6-3	LA-2A 2 Med, LA-2A 3 Med, LA-2A 6 Med
6-4	LA-2A 1 Med, LA-2A 4 Med, LA-2A 5 Med
6-5	LA-2A 4 High, No Comp

Analyzing the **k=3 solution** first, a broad separation emerges:

- Cluster 3-0 contains all Medium GR settings, Low GR settings for units {1, 4, 5}, and LA-2A 4 High.
- Cluster 3-1 contains High GR settings for units {1, 2, 3, 5, 6}.
- Cluster 3-2 groups the No Comp signal (uncompressed audio used as a control) with Low GR settings of units {2, 3, 6}.

This k=3 result primarily isolates the strong effect of High gain reduction (Cluster 3-1) and differentiates the uncompressed/low GR {2,3,6} combination (Cluster 3-2) from the moderate GR settings, low GR {1,4,5}, and LA-2A 4 High (Cluster 3-0).

The **k=6 solution**, also detailed in Table 5, provides finer granularity, revealing further distinct patterns primarily driven by the gain reduction (GR) setting, alongside clearer unit-specific groupings:

- **Gain Reduction Dominance:** The clustering strongly segregated instances based on the applied GR. High GR settings grouped into Cluster 6-0 (units {1, 2, 3, 5, 6}). Increased gain reduction (12 dB) reduces unit-specific differences by converging dynamic and spectral variations, resulting in more similar outputs across these units. Low GR settings split into Cluster 6-1 (units {2, 3, 6}) and Cluster 6-2 (units {1, 4, 5}), while Medium GR settings split into Cluster 6-3 (units {2, 3, 6}) and Cluster 6-4 (units {1, 4, 5}). The uncompressed signal grouped with LA-2A 4 High in Cluster 6-5.
- **Consistent Unit Groupings:** The consistent separation within both Low GR (Cluster 6-1 vs. 6-2) and Medium GR (Cluster 6-3 vs. 6-4) reveals two distinct objective profiles based on unit groupings: {1, 4, 5} versus {2, 3, 6}. This suggests some objective difference exists between these groups of units under moderate compression levels.
- **LA-2A 4 Behaviour (k=6):** LA-2A 4 aligns with the {1, 4, 5} grouping for Low (Cluster 6-2) and Medium (Cluster 6-4) settings, but its High setting groups with No Comp (Cluster 6-5); this behavior warrants an explanation. While processing audio through the units, the author noted that LA-2A 4 could only achieve a maximum of -9 dB gain reduction. This was unlike other units, which could easily reach the maximum of -12 dB of gain reduction used in this study (although not tested, it is likely they could achieve approximately -40 dB, which would be typical for an LA-2A). As a result of this restricted compression, LA-2A 4, under its high gain

reduction setting, groups closer to uncompressed audio than the other high gain settings.

6 Listening Experiment

A listening test was conducted to ascertain if the differences uncovered during the previous objective investigations could be discerned by the listener. This combination of both objective and subjective assessment affords a deeper exploration of the LA-2A through multiple perspectives.

6.1 Method

An ABX test was implemented to assess the perceptual differences between selected LA-2A units and was chosen for its sensitivity in detecting subtle audio variations. ABX tests have been used in several other audio engineering related studies [31, 12, 32, 33]. To mitigate listener fatigue associated with comparing all 18 unique compressor settings (6 units × 3 GR levels), it was decided to focus the listening experiment on the two most different LA-2A compressors out of the six explored in this study. The two LA-2As for use in the ABX test were selected by quantifying objective differences in the PCA-transformed feature space. Pairwise Euclidean distances $d_{i,j}$ were calculated between all 18 instances (6 units × 3 GR levels) within the principal component space derived from standardized audio features (spectral centroid, brightness, etc., across three songs) using:

$$d_{i,j} = \sqrt{\sum_{k=1}^{n} (x_{i,k} - x_{j,k})^2} \tag{3}$$

where $x_{i,k}$ and $x_{j,k}$ are the k^{th} principal component scores for instances i and j.

Several distance analyses highlighted that LA-2A 3 and LA-2A 4 showed the greatest objective dissimilarity:

– The overall maximum distance between any two instances ($d_{max} \approx 8.600$) occurred between `LA-2A 3 Low` and `LA-2A 4 Low`.
– The maximum distance between fully aggregated unit profiles (averaging over all songs and GR settings per unit) was found between LA-2A 3 and LA-2A 4 ($d_{agg\_max} \approx 8.200$).
– Analysis of maximum pairwise distances *within* each gain reduction (GR) setting revealed:
  ∗ Low GR: Max distance ≈ 8.600 (between LA-2A 3 and LA-2A 4).
  ∗ Medium GR: Max distance ≈ 8.300 (between LA-2A 3 and LA-2A 4).
  ∗ High GR: Max distance ≈ 8.100 (between LA-2A 3 and LA-2A 4).

  Of most importance here is the largest dissimilarity observed within a gain reduction setting occurred at the low gain reduction level across all three songs, specifically between LA-2A 3 and LA-2A 4. Consequently, these two compressors, both working at low gain reduction levels (measured as -3 dB) and presenting the largest objective difference were used in the ABX test.

While the PCA was based only on audio features, the two units used in the ABX test also showed the fastest (LA-2A 3) and slowest attack times (LA-2A 4) in the tone burst tests. It is worth noting that neither of these units had extreme THD or frequency response data, which may suggest that timing behavior, particularly with regard to attack time, may be the most relevant objective measurement pertaining to perceptual differences.

6.2 Listening Experiment Setup

The listening experiment was conducted to evaluate if there were perceptual differences in vocal tracks compressed using the LA-2A3 and LA-2A4 compressors and with a low amount of gain reduction. For three songs, the compressed vocal tracks were mixed into the backing track (the music minus the vocal track), with levels matched to eliminate loudness variations. The mixes were produced by the author who has over 30 years production experience in music production and these mixes were validated by colleagues. Care was taken to ensure the vocals were audible yet balanced and not overly dominant. The songs were all in the pop/rock style, one was a stripped back arrangement with piano, drums, bass and vocal [34] while the remaining two consisted of a typical guitar based rock band, differentiated primarily by the layers of guitars and distortion [35, 36].

The experiment utilized WebMushra [37], a tool for creating web-based listening tests compliant with ITU-R BS.1534 standards [38] Participants were first introduced to the test format through a training page using sine wave test tones, then proceeded to 10 trials of ABX tests for each song. The songs were level-matched to -14 LUFS and listeners were presented with a looped chorus section of each song. The duration of the sections were 17 seconds for Song 1, 14 seconds for Song 2 and 13 seconds for song 3. Listeners could listen to the looped sections as many times as they liked.

Seventeen participants (14 male, 3 female) with formal critical listening training (12 final-year undergraduates, 5 postgraduates in music technology) completed the test using their own high-grade headphones (e.g., Sennheiser HD650, Sennheiser HD600, Beyerdynamic DT 1990 & Audeze LCD2) in quiet environments. While the varied playback systems and locations will have introduced variability, assessing perceptual differences in these more typical listening scenarios provides valuable insights into whether compressor nuances are discernible outside of highly controlled lab conditions. Put simply, this study's focus was practical perceptual significance, not laboratory threshold detection; thus, ecologically valid listening conditions were employed intentionally to reflect real-world relevance.

Table 6: **ABX Test Results with Binomial Significance (=0.05) for Each Song and Combined.**

Song	Number of Trials	Correct Answers	Threshold for 95% Confidence	Above Threshold?
Song 1	170	104	96	Yes
Song 2	170	98	96	Yes
Song 3	170	102	96	Yes
All Songs	510	304	274	Yes

Table 7: **Pooled ABX Test Results Without Participant 17, with Binomial Significance (=0.05).**

Condition	Number of Trials	Correct Answers	Threshold for 95% Confidence	Above Threshold?
Song 1	160	95	91	Yes
Song 2	160	87	91	No
Song 3	160	89	91	No
All Songs	480	271	259	Yes

For the statistical analysis of the collected ABX data, the following hypotheses were tested against a chance performance benchmark:

* **H0 (Null Hypothesis):** Listeners' ability to distinguish between the vocal tracks compressed by the two selected LA-2A units is no better than chance (i.e., 50% correct identification rate).
* **H1 (Alternative Hypothesis):** Listeners' ability to distinguish between the vocal tracks compressed by the two selected LA-2A units is significantly better than chance (i.e., > 50% correct identification rate).

Significance was evaluated using a one-tailed binomial test framework with an alpha level of $\alpha = 0.05$.

6.3 Listening Experiment Results and Discussion

The experiment aimed to ascertain if the objective differences identified in the previous steps, between the selected LA-2A 3 and LA-2A 4 units, were audible to experienced listeners in an ABX test across three different music mixes. To conduct statistical analysis, a binomial probability model [39] was used to compare performance against chance ($p = 0.5$). The threshold for statistical significance (rejecting H_0) was set at a 95% confidence level ($\alpha = 0.05$), applying the binomial distribution to calculate the minimum number of correct identifications needed to confidently refute chance performance based on the number of trials (n).

The Initial pooled results across all 17 participants are shown in Table 6 and indicated statistically significant discrimination for all three songs individually and combined. One-tailed binomial tests showed strong evidence for Song 1 (104/170 correct, $p < 0.001$), Song 3 (102/170, $p < 0.001$), and overall (304/510, $p < 0.001$), with moderate evidence for Song 2 (98/170, $p = 0.012$). Based on this analysis of the initial pooled results, the null hypothesis (H_0) is rejected for all three songs individually and for the combined data, suggesting that, as a group, listeners were able to significantly distinguish between the vocal tracks compressed by the two selected LA-2A units. However, analysis at the group hid considerable variation between the individual participants and an examination of individual listener significance highlighted that only four participants achieved significance across all 30 trials (≥ 20 correct), and per-song significance ($\geq 9/10$ correct) was met by only three participants for Song 1, one participant for Song 2, and two participants for Song 3.

Furthermore, in a short post-experiment discussion with the participants, the highest-performing participant (P17) reported using the interface's looping function for repeated listening that allowed them to focus on specific portions of the audio files. This tactic was used by only this participant, and as such introduced a potential methodological confound that impacted their listening strategy, which may have favorably impacted their ability to discern differences.

Thus, to assess the impact of this listening approach, a sensitivity analysis excluding P17 from the group results was performed to observe how it changed the results and this is shown in Table 7. One-tailed binomial tests indicated significant discrimination for Song 1 (95/160 correct, $p = 0.008$) and overall (271/480 correct, $p = 0.004$), but not for Song 2 (87/160 correct, $p = 0.138$) or Song 3 (89/160 correct, $p = 0.074$). Therefore, after excluding the potentially confounded data from participant P17, we reject the null hypothesis (H_0) for Song 1 and the overall data, indicating that listeners could still significantly distinguish the compressors in these contexts. However, for Song 2 and Song 3, we fail to reject the null hypothesis (H_0), suggesting that listeners' performance was not significantly better than chance in distinguishing the compressors for these songs after the exclusion.

This pattern indicates context dependency. The differences between the objectively 'most dissimilar' pair (LA-2A 3 vs 4 at Low GR) were perceptible only in the context of Song 1 [35], which featured the densest musical arrangement. For clarity, in this context, musical density is a combination of spectral fullness, arrangement complexity, and limited dynamic variation. By these measures, Song 1 represented the densest production, featuring a loud rock band with double-tracked wide-panned distorted guitars occupying much of the frequency spectrum, screamed vocals with a limited dynamic variation and a full drum kit emphasizing crash cymbals on the beat to create consistent wash of high-frequency content. In contrast, Song 2 [34] was the sparsest, featuring a staccato bass line doubled with a single-note guitar line, subtle piano chords, vocals performed in the middle register with moderate dynamic variation and drums consisting mainly of bass drum, snare and toms with sparse cymbal accents. Song 3 [36] occupied a middle ground, with moderately distorted guitars, more controlled cymbal use (mainly semi-open hi-hats), and vocals with moderate dynamic variation.

The significant perceptual difference ($p < 0.001$) for Song 1 compared to Songs 2 (p = 0.138) and 3 (p = 0.074) results from a larger spectral centroid difference between LA-2A 3 and LA-2A 4 at low gain reduction (-3 dB), approximately 62 Hz difference for Song 1 versus 7 Hz difference for Song 2 and 57 Hz difference for Song 3. On the other hand, crest factor differences were reasonably small across all songs (0.008 for Song 1, 0.023 for Song 2, 0.026 for Song 3), which indicates that brightness variations in Song 1's denser mix was the primary driver of its discernibility.

7 CONCLUSION

This study adopted a mixed method to investigate the differences between LA-2A units, exploring these differences from both objective and subjective perspectives. The analysis of test tones highlighted some subtle differences between the six LA-2A compressors tested in the study, mainly around total harmonic distortion and attack and release metrics. Objective analysis of vocal tracks compressed with the LA-2As under three increasing amounts of gain reduction revealed some interesting clustering when explored using PCA. Two distinct groupings of LA-2As emerged, suggesting similarities between groups under low (-3dB) and moderate amounts (-6dB) of gain reduction, which converged under heavy gain reduction (-12dB). It was also noted that one particular LA-2A could not compress signals as heavily as the other five units, achieving a maximum gain reduction of -9dB, which resulted in this unit deviating from the five other units in PCA clustering.

This behavior is an interesting example of how in real world use specific limitations of a unit's behavior will play a role in how music producers engage with it during day-to-day use, especially if they have not tested or serviced this unit or do not possess the required skills to do so. It is plausible a unit with this type of behavior could be considered more 'transparent' than another unit, simply because it is not achieving as much gain reduction as its meter might show and one would expect.

The results of the ABX test, which compared the two most dissimilar LA-2A compressors showed that, when results were pooled, the 17 listeners could detect differences between them. However, at the individual level, accuracy was much lower than the pooled results, and one listener had inflated the pooled results by using a listening strategy unique to them (looping of specific sections) that boosted the overall significance of the results. Once this listener (P17) was removed from the results, however, a different picture emerged that showed the remaining listeners' ability to discern differences between the two LA-2As was weakened considerably. However, in both instances, with and without P17, Song 1 ($p < 0.001$) remained detectable at the pooled listener level compared to Song 2 ($p = 0.138$) and Song 3 ($p = 0.074$), suggesting some interplay between discernment and this song's higher spectral centroid. Nonetheless, listeners found the distinctions between units challenging to perceive with consistent accuracy.

Thus, the results of this study bring into question the true scale of the differences between units of the same kind, especially in the context of music mixes. Indeed, it was found that unit-to-unit variations exist, and this could be argued as an expected result, but these differences appear to be context dependent and difficult to distinguish in typical working scenarios. Furthermore, the results here question the anecdotal claims that specific units possess sonic qualities that make them superior to other units, the 'golden unit' idea posited at the start of this article.

Future research could employ more trials, control listening strategies and environments, and use wider musical/compressor sampling. Investigating how musical density and dynamics influence compressor audibility could further clarify these context-dependent effects. While vocals are a common LA-2A application, future studies could explore other sources like drums, where transient sensitivity might amplify unit differences. This work ultimately highlights the necessity of empirical subjective testing alongside objective analysis when evaluating audio tools and anecdotal production claims, emphasizing that production decisions should rely on verifiable data rather than untested assumptions. Finally, while this study focused on the LA-2A compressor, its methodological framework can be used for other studies to broaden the debate around unit-to-unit variations in music production devices and the claims made around their perception.

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