Electrical Signal Analysis of Audio Latency Functions of Murideo 8K Seven Generator

September 18, 2023
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1 Contents

2 Purpose

This document assesses the accuracy of audio latency measurements reported by the Murideo 8K Seven Generator (M8SG) and provides recommendations to correct any inaccuracies found. This assessment is performed at the electrical level using analog signal (spectral) analysis on the frequency and time domain, and other electrical measurement approaches on the time domain.

3 Introduction

3.1 Importance of Accurate Sink Device AV Sync Error Measurements

In almost all consumer electrics review cases, audio latency is relevant to audio/video synchronization (AV sync) and calculation of AV sync error. AV sync error is detectable when it exceeds +45 ms (audio leading video) or -125 ms (video leading audio).[1]

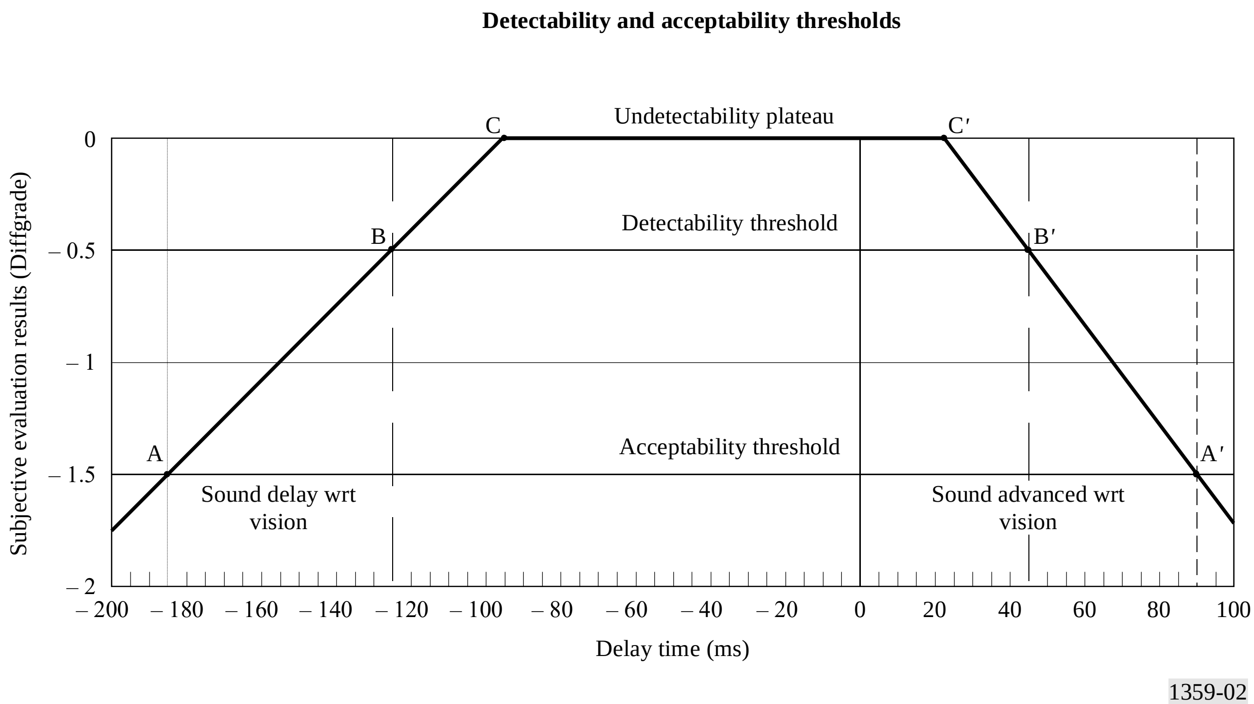


Figure 1 Detectability and acceptability of AV sync error. Source: Recommendation BT.1359-1

At face value, this research may suggest that a sink device, such as a TV, soundbar, or combination thereof, must fall within these thresholds; however, this interpretation is flawed because source content, which contributes to overall AV sync error, can be expected to have an AV sync error within the limits of +25 ms to -100 ms.[2] In some cases, source content may contain a detectable or unacceptable level of AV sync error, as defied by Rec. ITU-R BT.1359-1 (Figure 1), because there is no strict regulation of content production.

In addition to the AV sync error inherent to source content, it is also common for source devices, such as media players, game consoles, or computers, to introduce additional and variable AV sync error. For

[1] Rec. ITU-R BT.1359-1, Appendix 1, point 3
[2] Rec. ITU-R BT.1359-1, Recommendations, point 3

example, the author has measured at least a 26 ms variance in AV sync error from the Netflix app on a 4K Apple TV. This measurement was performed by repeatedly restarting the playback of the Netflix AV sync video and measuring the AV sync error using the Harkwood Sync-One2. This test was prompted by another user of the Harkwood Sync-One2 who contacted the author about a problem that they were experiencing on their home media player setup.

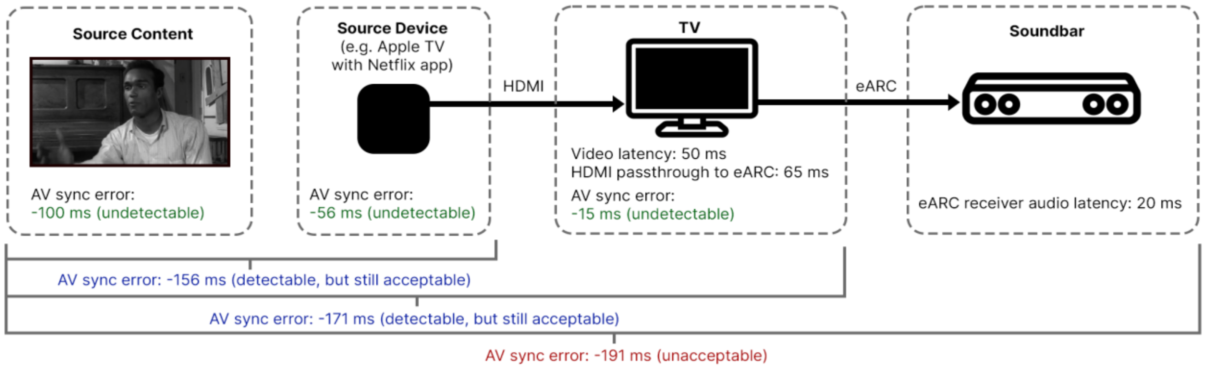


Figure 2 Example of an AV setup with an unacceptable AV sync error with video leading audio.[3]

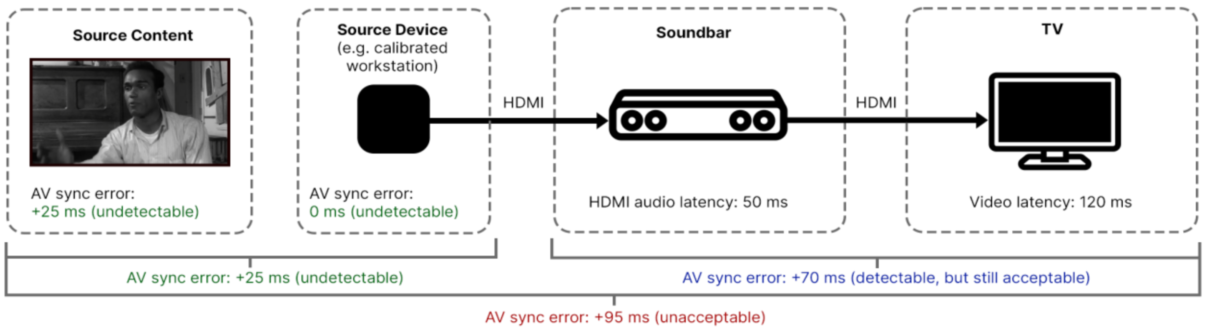


Figure 3 Example of an AV setup with an unacceptable AV sync error with audio leading video.

With such high levels of AV sync error inherent to source content and source devices, it becomes extremely important for sink devices and sink device configurations to have an AV sync error very close to 0 ms; Only a small difference in sink device AV sync error, either positive or negative, can cause the presented audio and video to transition from the undetectable range to the detectable range or from the detectable range to the unacceptable range.

3.2 Importance of Accurate Sink Device Audio and Video Latency Measurements

Accurately measuring audio latency and video latency is required to correctly measure the AV sync error that is specific to sink device(s) because it is difficult to guarantee a perfectly synchronized audio/video signal from an HDMI source device. Inaccuracy in either of these latency measurements will result in an incorrect AV sync error calculation. AV sync error is calculated by subtracting audio latency from video latency.

[3] *This -56 ms AV sync error example of the Apple TV with Netflix app is representative of tests performed by the author using the Harkwood Sync-One2 on a home theatre setup with matching sink device audio and video latency.*

Accurate video latency measurements are relatively easy for an end-user to derive from input lag measurements reported on consumer electronics review websites.[4] It should be expected that any reported audio latency measurements will be used by end-users, alongside of these video latency measurements, when shopping to determine the AV sync error of a combination of AV equipment. Additionally, review websites may choose to report video latency measurements in the future, to allow users to more easily pair audio and video equipment with matching audio and video latency.

For example, when shopping for an AV receiver the author used input lag measurements reported on RTINGS.com to determine the video latency of their TV in game mode. Next, multiple AV receivers were purchased and the audio latency of each was measured. The AV receiver with the closest audio latency to the video latency of the TV was selected. A consumer electronics review website can assist in this process by providing accurate audio and video latency measurements.

[4] AV Latency.com: Leo Bodnar Video Signal Lag Tester - Measuring HDMI Video Latency https://avlatency.com/measuring-latency/video-latency/leo-bodnar-video-signal-lag-tester/

4 Summary of Results

Audio latency measurements of the Marantz NR1711 AV receiver were taken at the electrical level and using the M8SG. By comparing these results, a measurement error was discovered in PCM audio latency reported by the M8SG. This error was not present in Dolby-encoded audio formats when using HDMI ARC. It was not feasible to measure Dolby-encoded audio formats at the electrical level when using HDMI audio or HDMI eARC.

Audio Latency Type	**Audio Format**	**Possible Error in Electrical Measurement (+/- ms)**	**Electrical Measurement (rounded ms)**	**Murideo 8K Measurement (ms)**	**Difference (ms)**
HDMI Audio Latency (TMDS)	PCM-48kHz-2.0ch	< 1	6	25	**-19**
HDMI Audio Latency (TMDS)	PCM-48kHz-5.1ch	< 1	6	25	**-19**
HDMI Audio Latency (TMDS)	Dolby Digital-48kHz-2.0ch	Unable to measure*		85	
HDMI Audio Latency (TMDS)	Dolby Digital Plus-48kHz-2.0ch	Unable to measure*		48	
HDMI Audio Latency (TMDS)	Dolby Digital Plus-48kHz-Atmos	Unable to measure*		86	
HDMI Audio Latency (TMDS)	Dolby MAT (PCM)-48kHz-Atmos	Unable to measure*		66	
HDMI ARC Receiver Latency	PCM-48kHz-2.0ch	< 1	5	11	**-6**
HDMI ARC Receiver Latency	PCM-48kHz-5.1ch	< 1	5	11	**-6**
HDMI ARC Receiver Latency	Dolby Digital-48kHz-2.0ch	2.6	71	71	**0**
HDMI ARC Receiver Latency	Dolby Digital Plus-48kHz-2.0ch	3.7	44	45	**-1**
HDMI ARC Receiver Latency	Dolby Digital Plus-48kHz-Atmos	3.9	80	83	**-3**
HDMI eARC Receiver Latency	PCM-48kHz-2.0ch	< 1	5	6	**-1**
HDMI eARC Receiver Latency	PCM-48kHz-5.1ch	< 1	5	6	**-1**
HDMI eARC Receiver Latency	Dolby Digital-48kHz-2.0ch	Unable to measure*		66	
HDMI eARC Receiver Latency	Dolby Digital Plus-48kHz-2.0ch	Unable to measure*		43	
HDMI eARC Receiver Latency	Dolby Digital Plus-48kHz-Atmos	Unable to measure*		82	
HDMI eARC Receiver Latency	Dolby MAT (PCM)-48kHz-Atmos	Unable to measure*		61	

Figure 4 Audio latency measurement results, comparing electrical measurements with M8SG measurements.
** See section "Dolby Audio over TMDS Encoded HDMI Audio and HDMI eARC" for details regarding why these could not be measured.*

Detailed results can be found in the "Murideo 8K Seven Generator Audio Latency Analysis.xlsx" supplementary spreadsheet file. Additional information on the measurement methods used to produce these results is provided in "Section 5 Murideo 8K Seven Generator Audio Latency Measurements" onward.

4.1 Recommendation

Until a fix for the error in PCM audio latency measurements is provided via a firmware update, it should be corrected using the following formula:

PCM HDMI Audio Latency: **Subtract 19 ms from M8SG measurement.**
PCM HDMI ARC Receiver Audio Latency: **Subtract 6 ms from M8SG measurement.**
PCM HDMI eARC Receiver Audio Latency: **Subtract 1 ms from M8SG measurement.**
Dolby Audio Latency: **No adjustment of measurements required.**

5 Murideo 8K Seven Generator Audio Latency Measurements

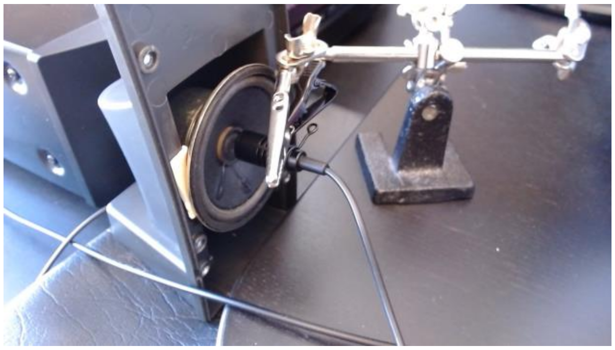


Figure 5 Microphone placement during M8SG measurements.

To measure audio latency with the M8SG, its mic was placed in front of a speaker connected to the right speaker output of the AV receiver. The AV receiver was connected to either the HDMI port of the M8SG to measure HDMI audio latency and HDMI ARC/eARC receiver audio latency. Ten measurements were recorded, averaged, and rounded for each audio format and latency type.

To measure 5.1 PCM audio latency, the audio output was changed to 5.1 channel output in the Audio Generator function before performing PCM latency measurements.

For HDMI audio measurements, multiple video refresh rates and resolutions were measured, which demonstrated that the audio latency of this AV receiver was not dependent on video timing.

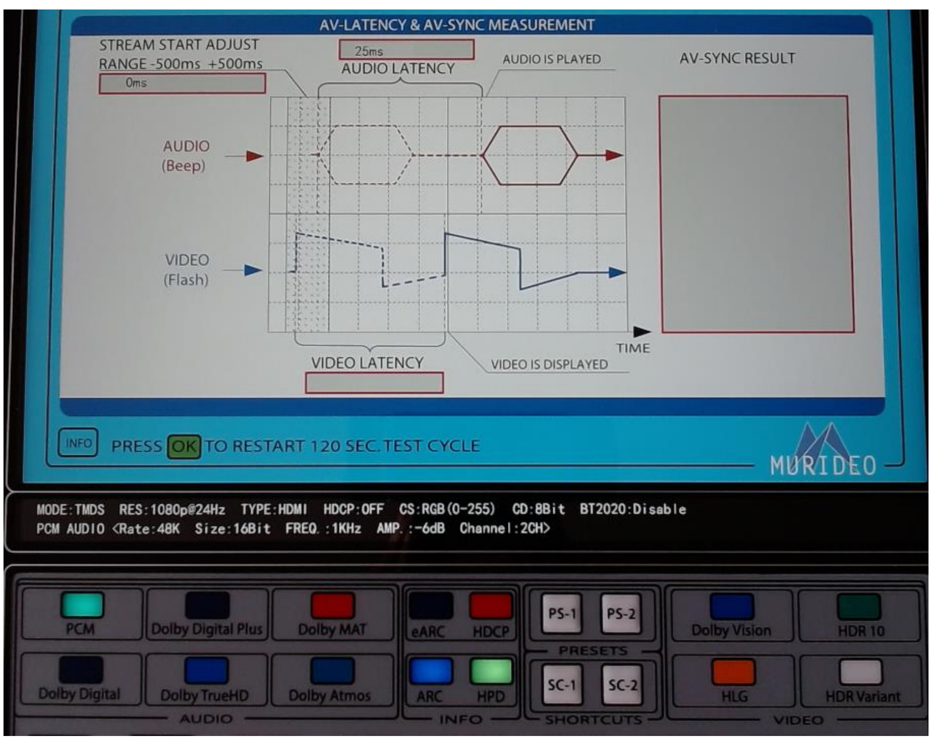


Figure 6 PCM HDMI audio latency measurement from the M8SG.

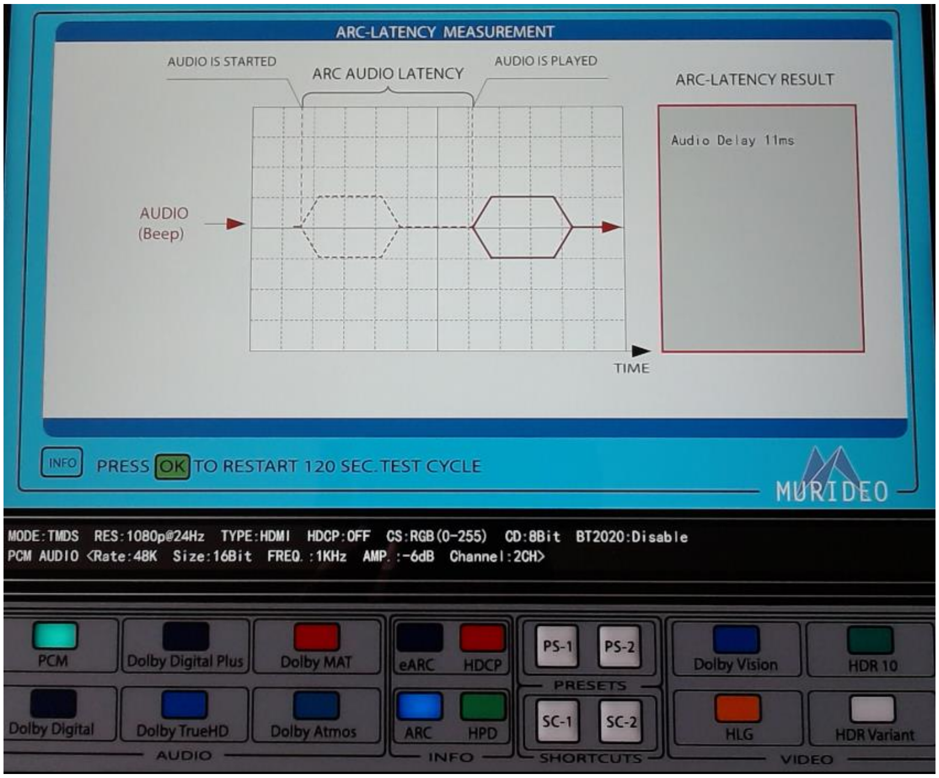


Figure 7 PCM HDMI ARC latency measurement from the M8SG.

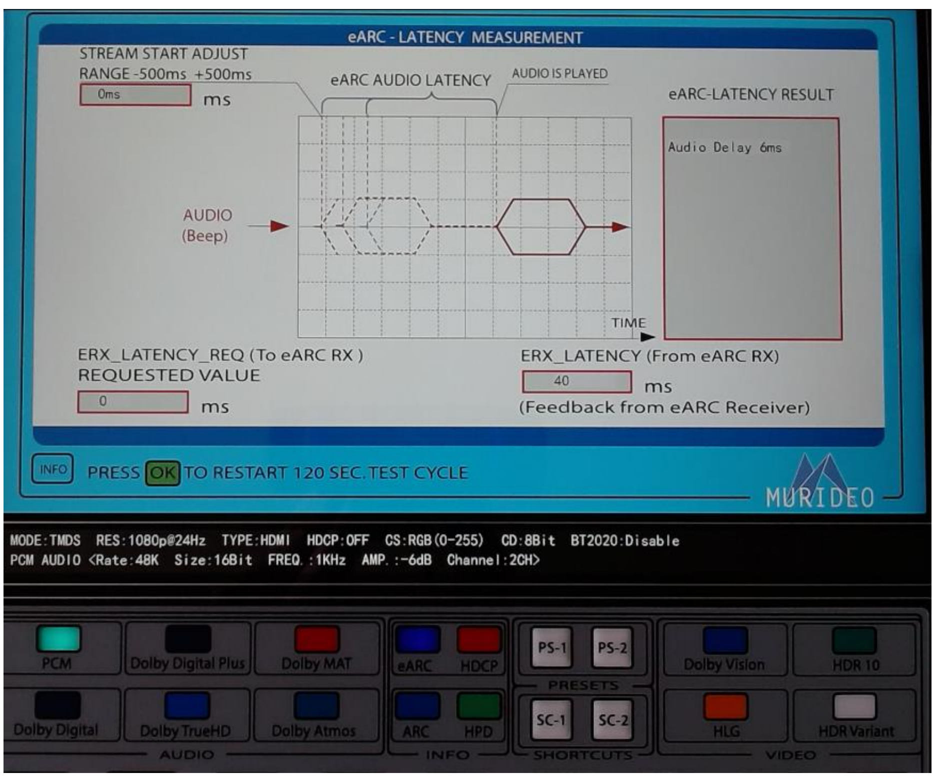


Figure 8 PCM HDMI eARC latency measurement from the M8SG.

6 Audio Latency Measurements at the Electrical Level

Audio latency measurements were performed at the electrical level by comparing HDMI electrical signals to the electrical signal produced by the AV receiver at the speaker connection. A direct electrical connection to the speaker output was used, instead of a mic, to ensure consistent and accurate results.

To verify these electrical measurements could be directly compared to the measurements taken by the M8SG, the audio latency introduced by the speaker and air gap needed to be measured. This measurement was performed by placing a Shure SM58 dynamic microphone at the same distance from the speaker as the M8SG microphone was during the M8SG measurements.

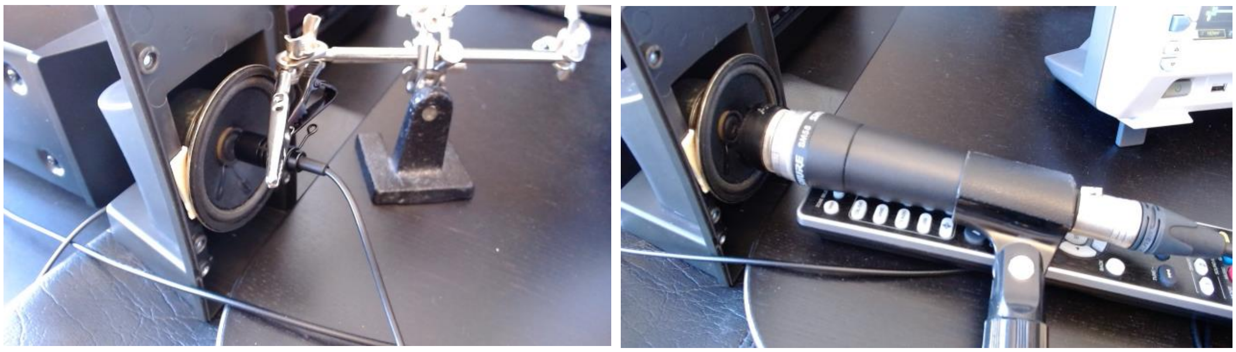


Figure 9 Left: Microphone placement during M8SG measurements. Right: Dynamic microphone placement.

The electrical signal from the dynamic microphone was compared to the electrical signal from the speaker output connection of the AV receiver. This delay was measured to be 0.0036 ms.

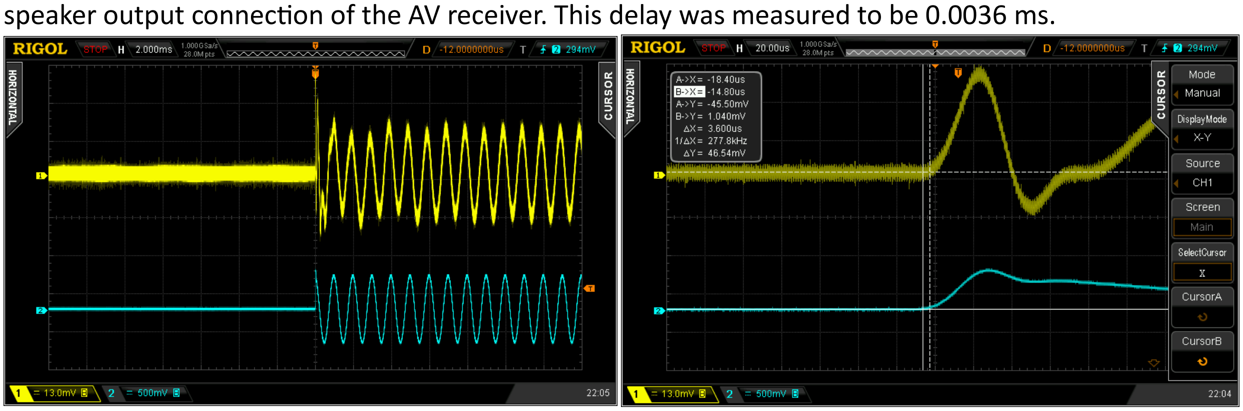


Figure 10 Channel 1 (yellow): Dynamic microphone electrical signal. Channel 2 (cyan): AV receiver speaker output with direct electrical connection.

A delay this small is insignificant and demonstrates that a direct electrical connection to the AV receiver could be compared to the microphone-based measurements produced by the M8SG.

6.1 Electrical Measurements: PCM HDMI Audio Latency

HDMI audio electrical measurements were performed by measuring the electrical signal of the TMDS Data 2 positive pin. The technique used is described in Appendix 1: TMDS HDMI Audio Latency Measurement Method.

It was not possible to use the M8SG as a signal generator for this test because it did not allow for strict control of the video and audio signal with PCM audio, which is needed for this measurement technique. Instead, a Windows 11 PC with an NVIDIA graphics device was used to generate the HDMI signal. This HDMI signal matched the video and audio timing produced by the M8SG.[5] Additional resolutions and refresh rates were measured to demonstrate that the audio latency of this AV receiver was not dependent on video timing.

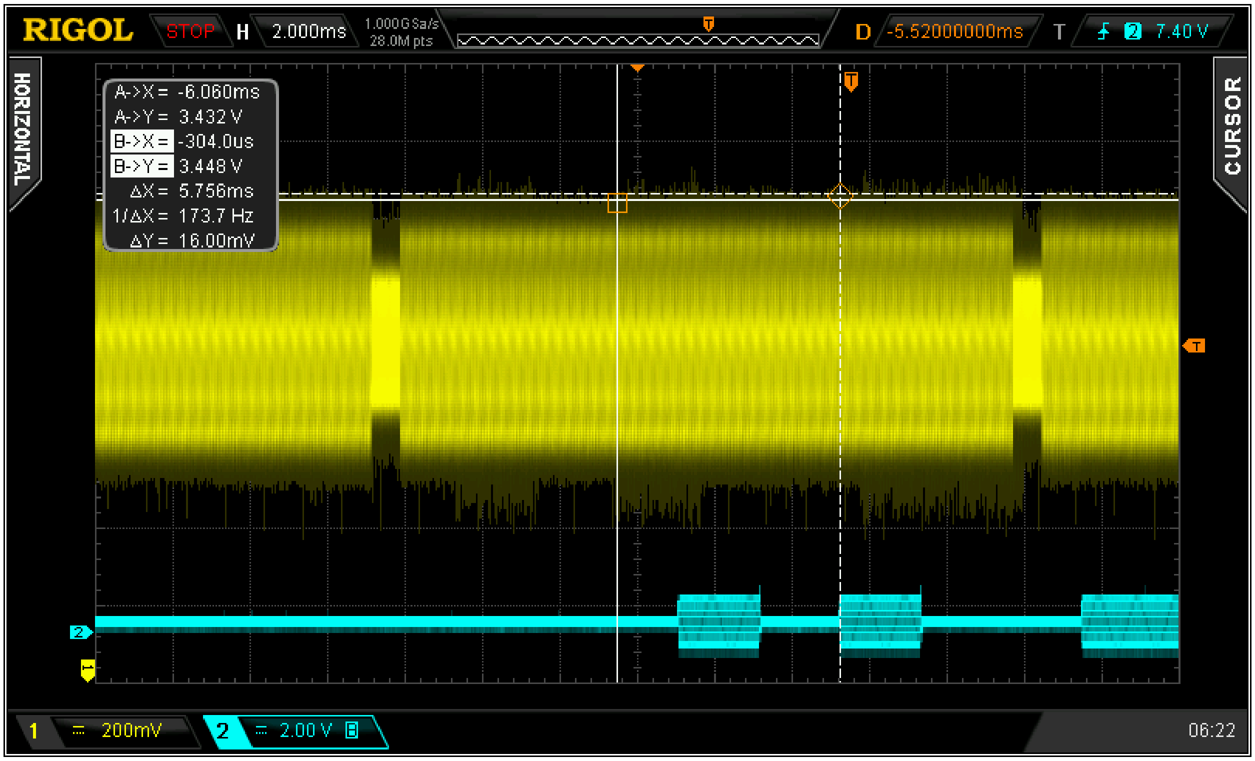


Figure 11 Two channel HDMI audio latency measurement of 5.756 ms. Channel 1 (yellow): HDMI TMDS Data 2 pin. Channel 2 (cyan): AV receiver speaker output.

[5] See the "HDMI Analysis" supplementary text files for a comparison of the HDMI signal produced by the NVIDIA graphics device and M8SG.

Figure 12 Surround (5.1) HDMI audio latency measurement of 5.901 ms. Channel 1 (yellow): HDMI TMDS Data 2 pin. Channel 2 (cyan): AV receiver speaker output.

6.2 Electrical Measurements: PCM HDMI ARC Receiver Latency

PCM HDMI ARC electrical measurements were performed by analyzing the electrical signal of HDMI pin 14. The HDMI ARC signal was the audio latency test pattern of the M8SG.

The change in PCM audio data was clearly visible in the HDMI ARC electrical signal:

Figure 13 Top: 2 channel PCM M8SG ARC output configuration. Bottom: Channel 1 (yellow): HDMI pin 14. Channel 2 (cyan): AV receiver speaker output.

Figure 14 Top: 5.1 channel PCM M8SG ARC output configuration. Bottom: Channel 1 (yellow): HDMI TMDS Data 2 pin. Channel 2 (cyan): AV receiver speaker output.

6.3 Electrical Measurements: Dolby HDMI ARC Receiver Latency

Dolby-encoded HDMI ARC electrical measurements were performed by analyzing the electrical signal of HDMI pin 14. Two HDMI ARC signals were used for measurements:

1) The audio latency test pattern of the M8SG.
2) A custom Dolby-encoded test file provided by RTINGS.com that was played through the M8SG "My Stream" feature.

The Dolby encoded audio stream is sent over ARC in data packets sent every 32 ms. The audio latency of the AV receiver is most accurately described as the time between the end of the first data packet containing the audio tone and audio output of the tone by the AV receiver. If the audio tone was aligned to the beginning of the data packet's audio stream, an accurate audio latency measurement could be made with this simple approach. If the audio tone was aligned to the end of the data packet's audio stream, the audio latency measurement would be 32 ms higher than it should be.

The audio latency test pattern used by the M8SG appeared to have 4 fixed alignments of the audio tone within these data packets, so only 4 measurement values could be obtained with this pattern. The custom Dolby-encoded test file has a wider variety of audio tone alignments within these data packets, which increased confidence in the accuracy of final audio latency measurements. Because a 32 ms spread of results was expected, the possible error in these measurements could be calculated by simply subtracting the spread of results from 32 ms. This possible error was recorded in the results summary.

Audio packets could be identified as having audio tone data or not by visually inspecting the electrical signal capture from HDMI pin 14.

6.3.1 Dolby Digital-48kHz-2.0ch

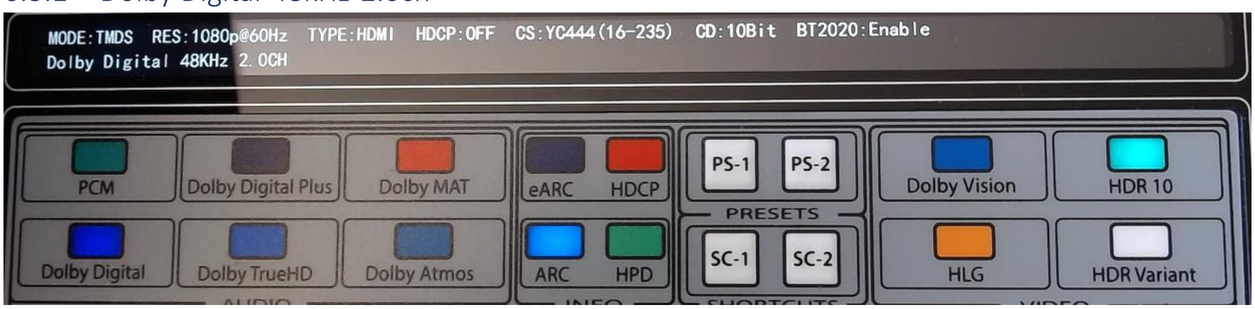


Figure 15 Dolby Digital over HDMI ARC, M8SG audio latency test pattern.

Figure 16 Dolby Digital over HDMI ARC, M8SG "My Stream" custom Dolby Digital AC3 playback on the M8SG.

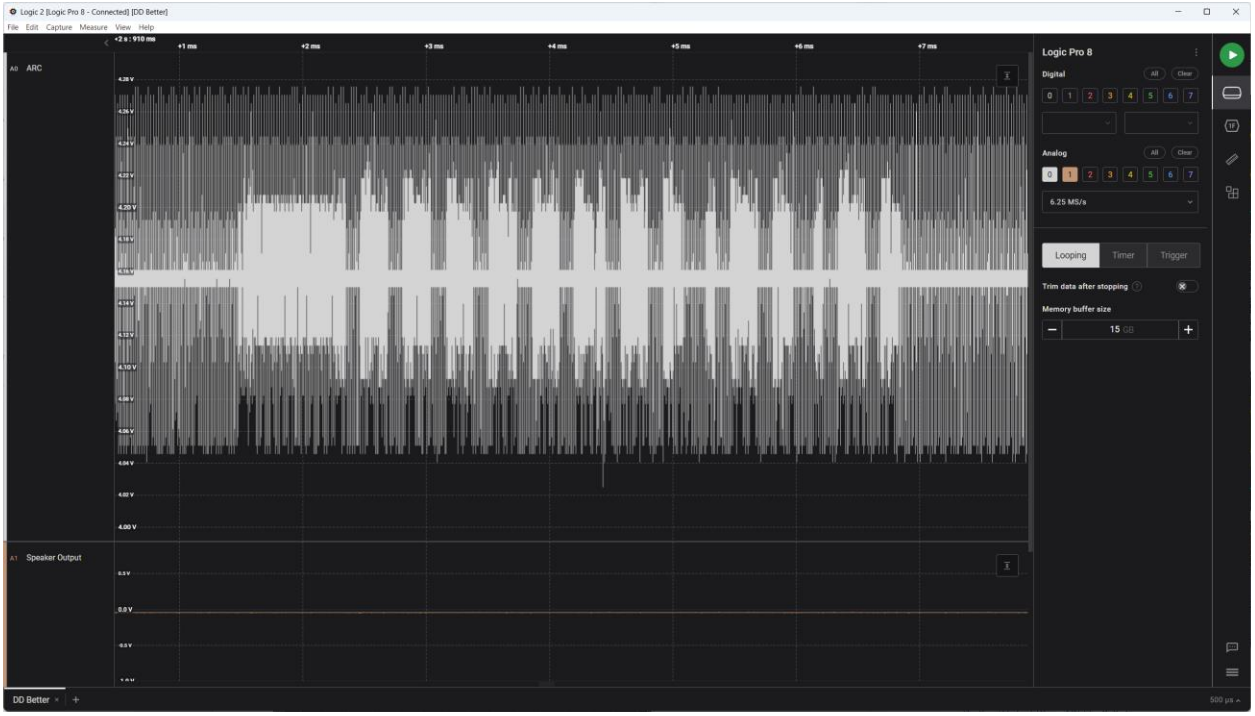


Figure 17 Dolby Digital over HDMI ARC data packet with no audio data.

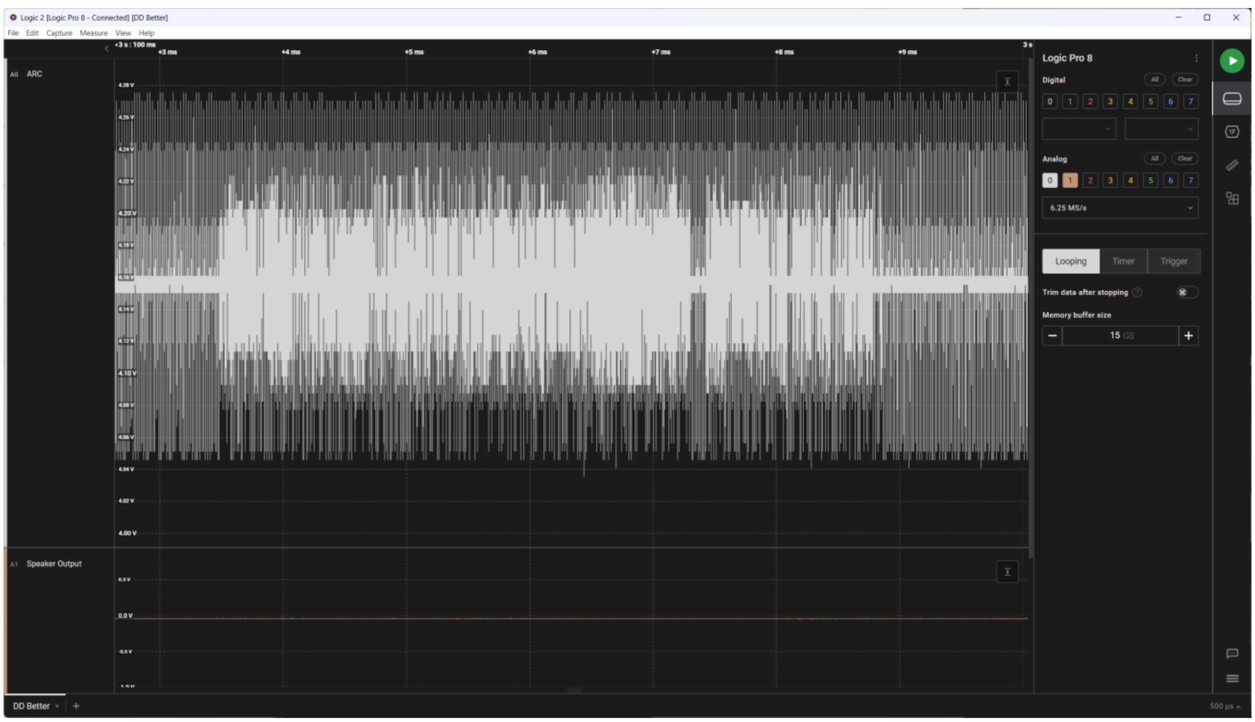


Figure 18 Dolby Digital over HDMI ARC data packet with audio data. Exactly two of these always precede the speaker output in the M8SG audio latency pattern.

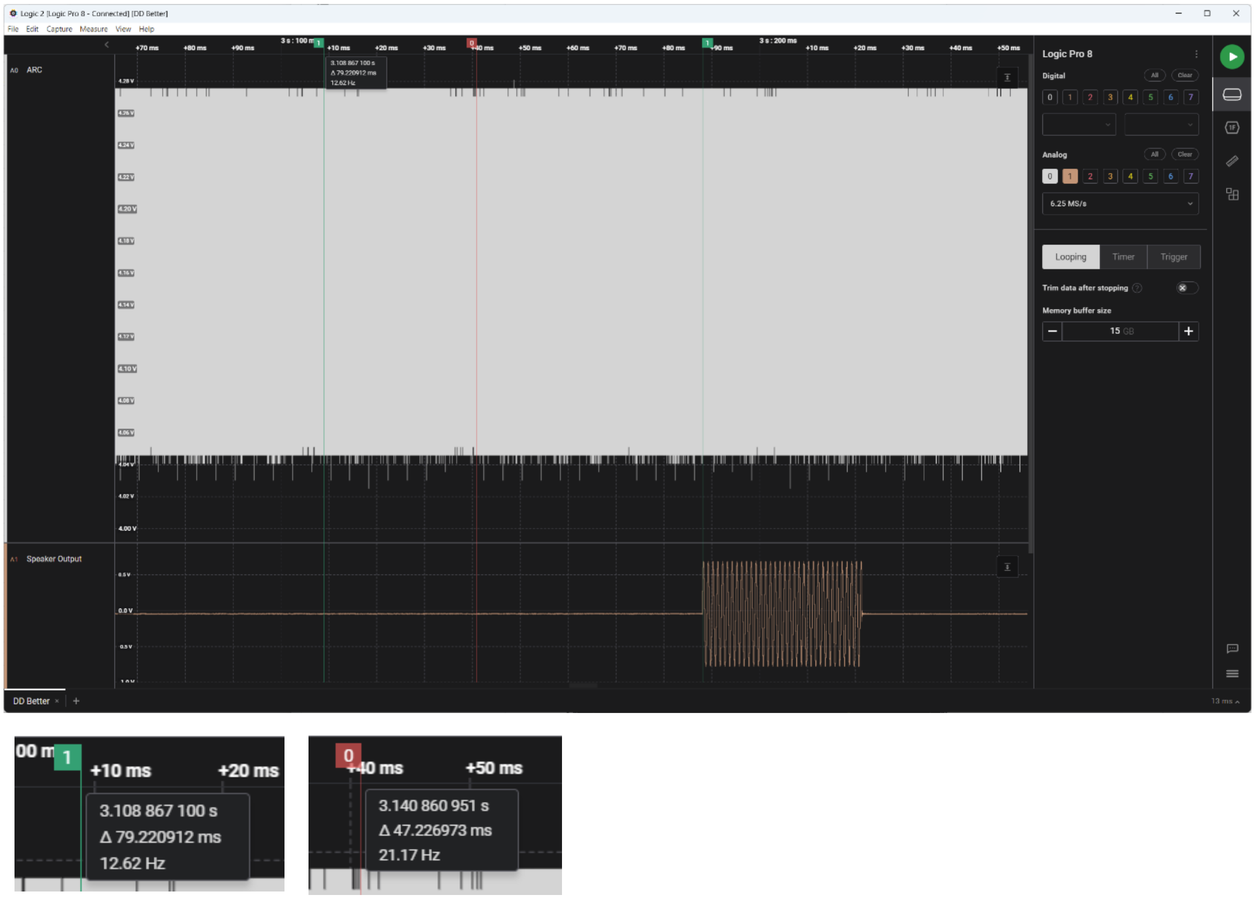


Figure 19 Marker pair 1 (green): The time between the end of the first audio packet with audio data and the rendered audio tone. Marker pair 2 (red): The time between the end of the second audio packet with audio data and the rendered audio tone.

6.3.2 Dolby Digital Plus-48kHz-2.0ch

Figure 20 Dolby Digital Plus over HDMI ARC, M8SG audio latency test pattern.

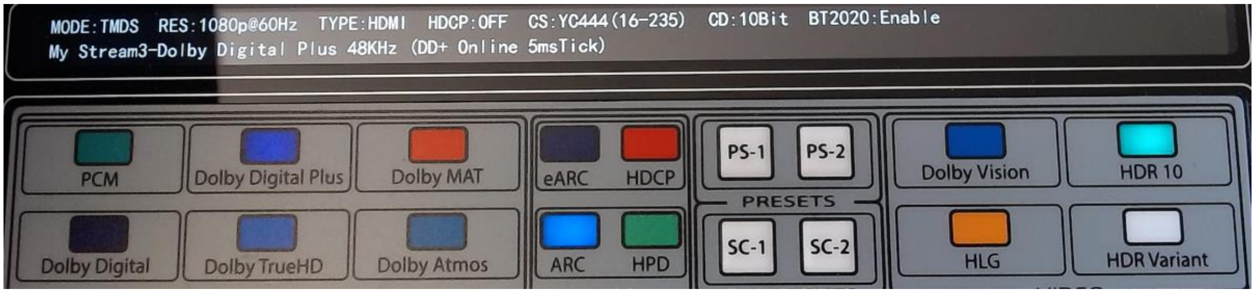


Figure 21 Dolby Digital Plus over HDMI ARC, M8SG "My Stream" custom Dolby Digital Plus E-AC3 playback on the M8SG.

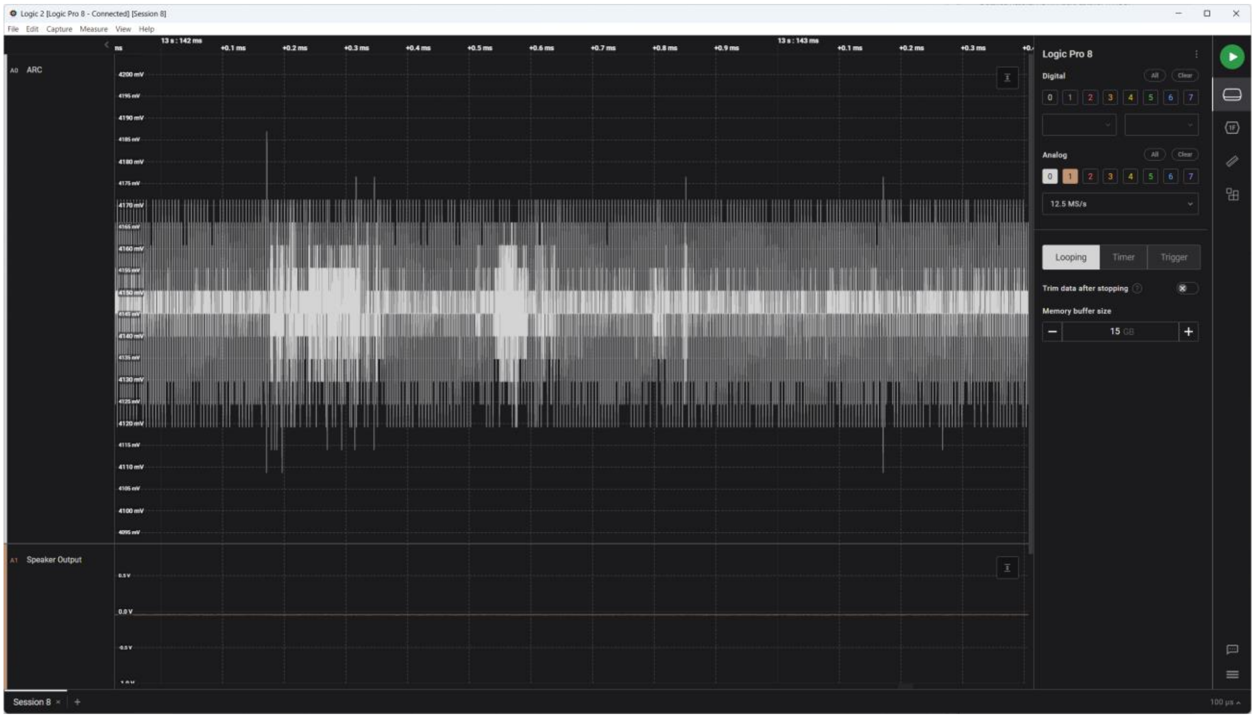


Figure 22 Dolby Digital Plus over HDMI ARC data packet with no audio data.

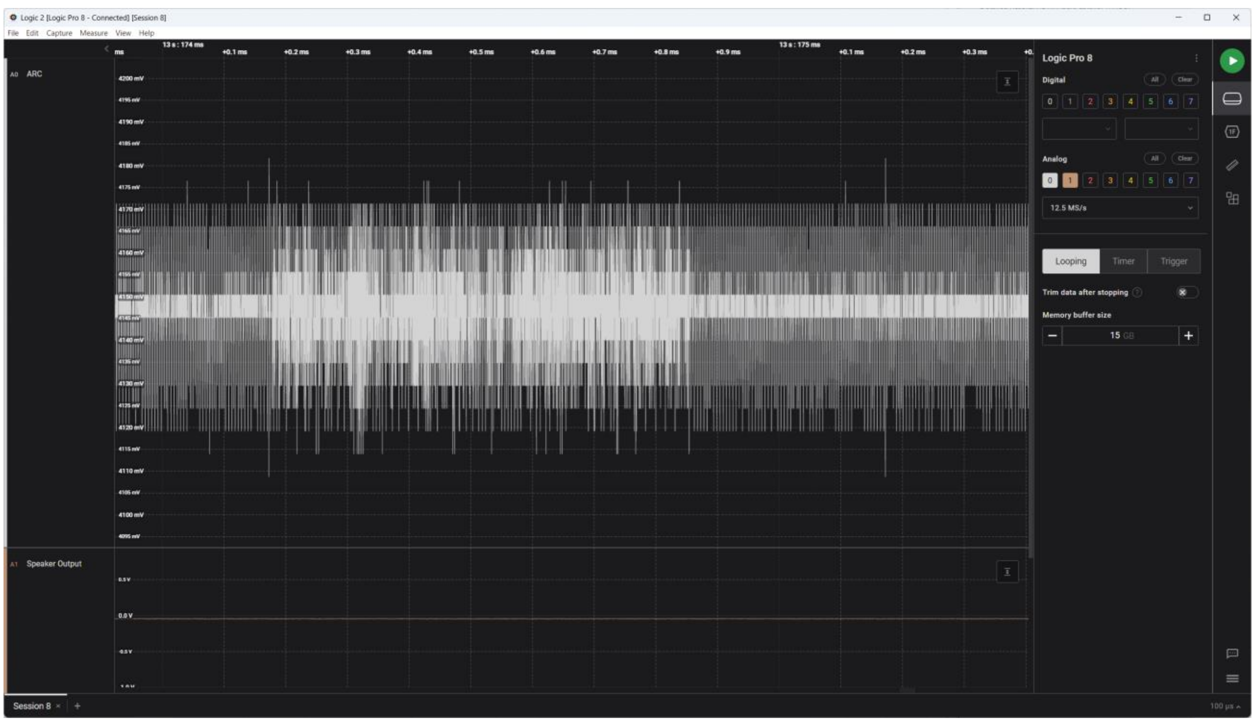


Figure 23 Dolby Digital Plus over HDMI ARC data packet with audio data. Exactly two of these always precede the speaker output in the M8SG audio latency pattern.

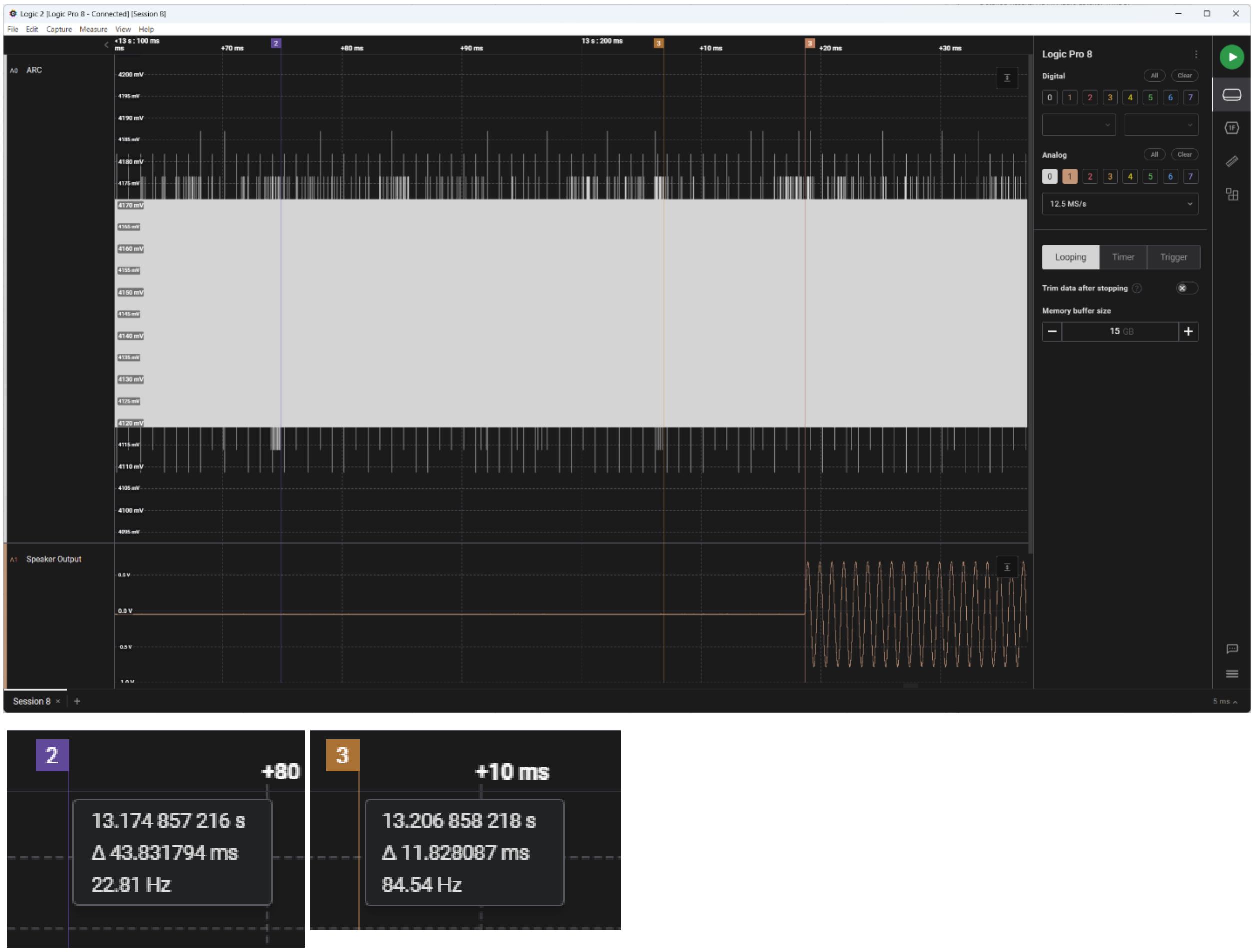


Figure 24 Marker pair 2 (purple): The time between the end of the first audio packet with audio data and the rendered audio tone. Marker pair 3 (orange): The time between the end of the second audio packet with audio data and the rendered audio tone.

6.3.3 Dolby Digital Plus-48kHz-Atmos

Dolby Digital Plus Atmos was measured using the same method as Dolby Digital and Dolby Digital Plus audio formats. Unfortunately, the M8SG did not recognize the "My Stream" Atmos-encoded file as a Dolby Atmos audio format, but measurement results between the M8SG and the "My Stream" file were extremely consistent. Like the other two Dolby-encoded audio formats, the "My Stream" file did not end up contributing to the final audio latency value, but simply demonstrated a higher spread of measurement values due to a different packet alignment, thus reducing possible error.

Figure 25 Dolby Digital Plus Atmos over HDMI ARC, M8SG audio latency test pattern.

Figure 26 Dolby Digital Plus Atmos over HDMI ARC, M8SG "My Stream" custom Dolby Digital AC3 playback on the M8SG.

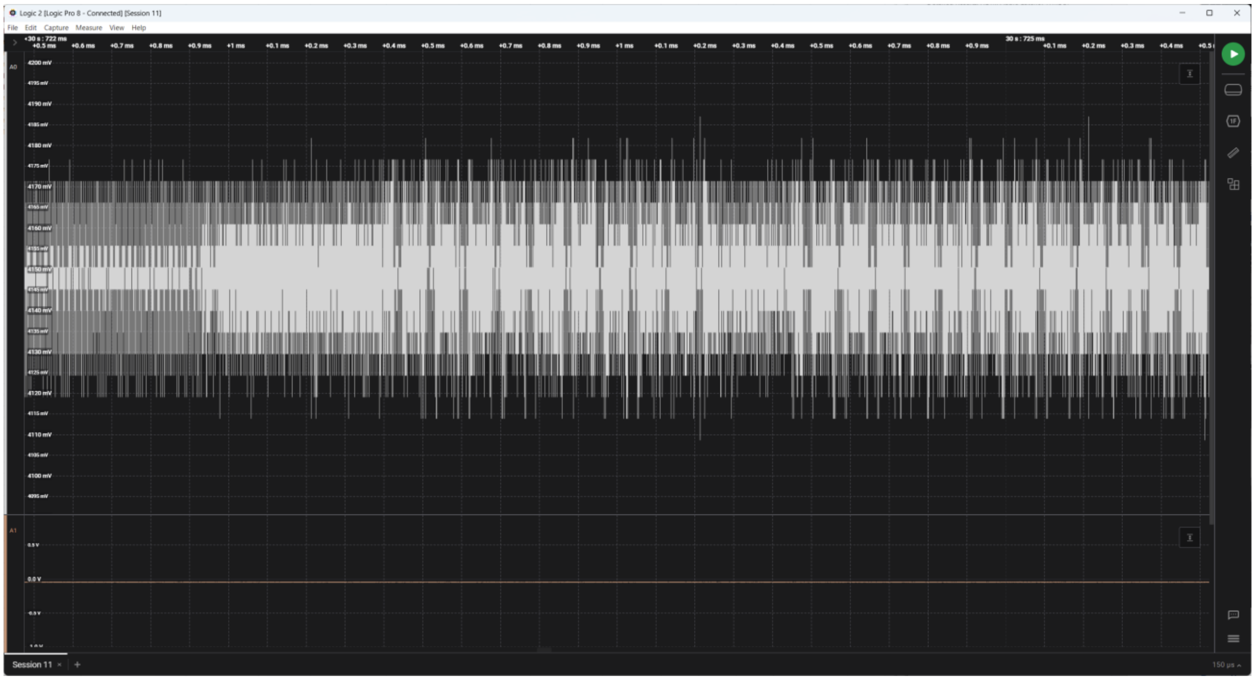


Figure 27 Dolby Digital Plus Atmos over HDMI ARC data packet with no audio data.

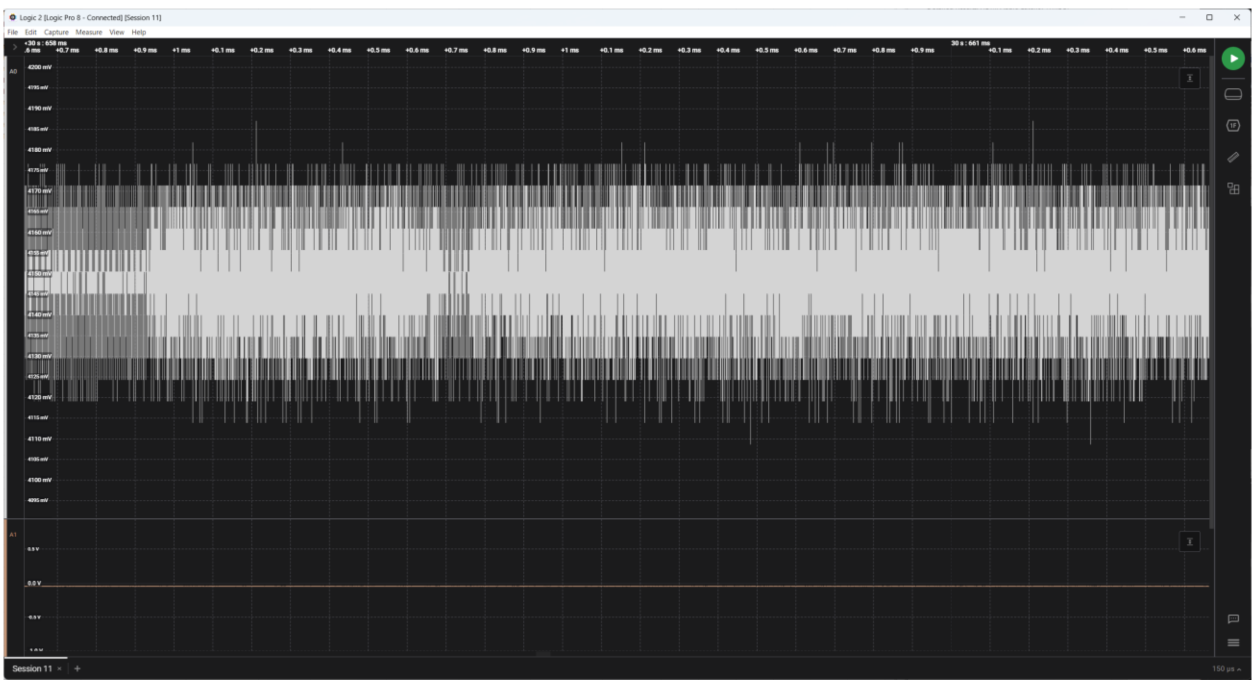


Figure 28 Dolby Digital Plus Atmos over HDMI ARC data packet with audio data. Exactly two of these always precede the speaker output in the M8SG audio latency pattern.

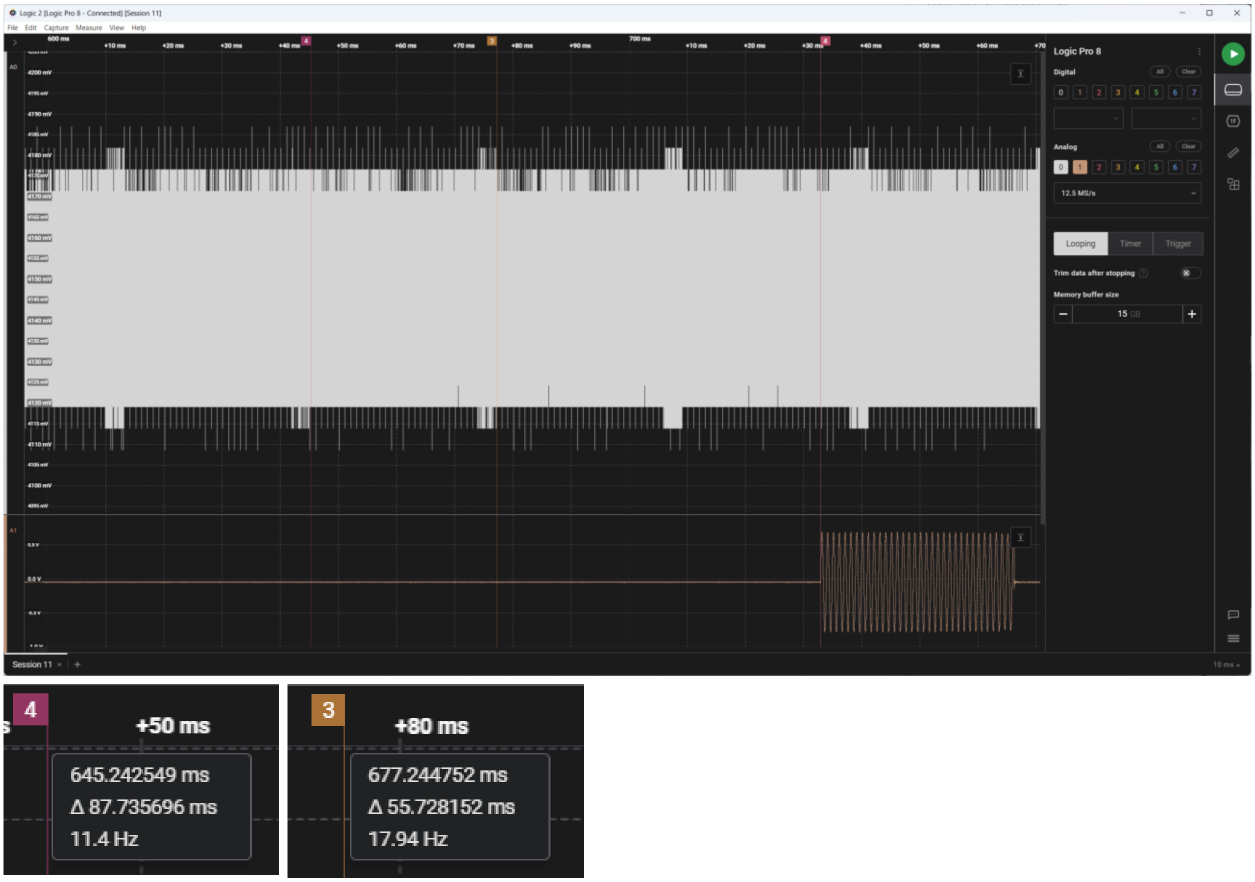


Figure 29 Marker pair 4 (Red): The time between the end of the first audio packet with audio data and the rendered audio tone. Marker pair 3 (orange): The time between the end of the second audio packet with audio data and the rendered audio tone.

6.4 Electrical Measurements: PCM HDMI eARC Receiver Latency

PCM HDMI eARC electrical measurements were performed by analyzing the electrical signal of HDMI pin 14. The HDMI eARC signal was the audio latency test pattern of the M8SG.

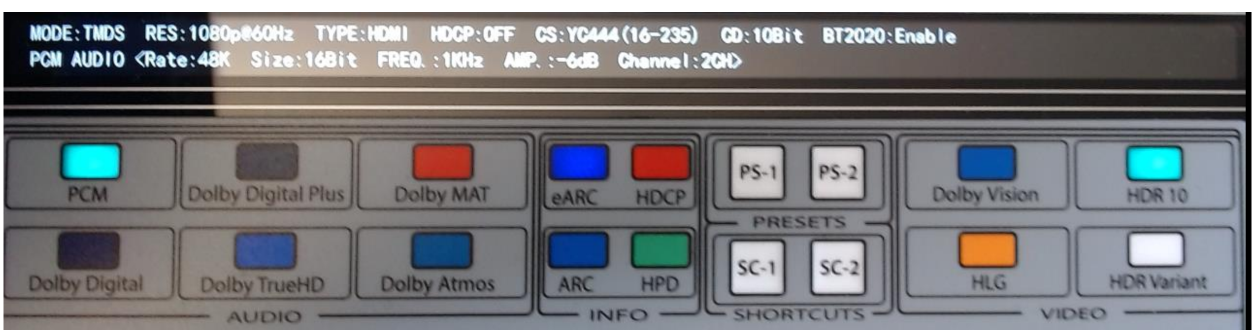


Figure 30 2 channel PCM M8SG eARC output configuration.

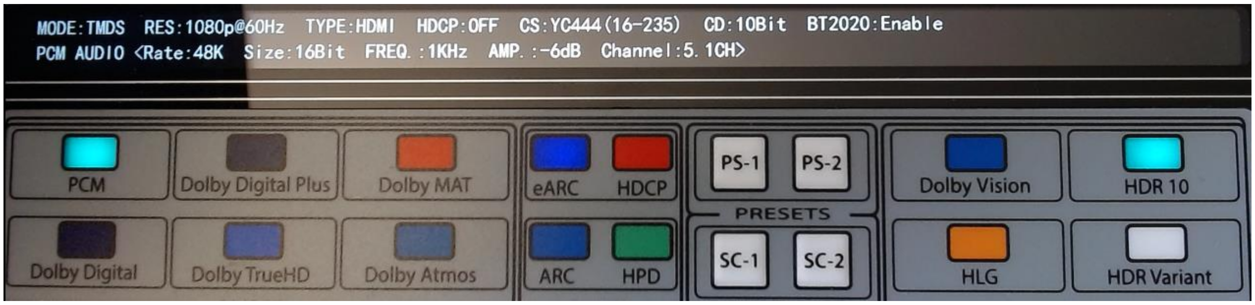


Figure 31 5.1 channel PCM M8SG eARC output configuration.

The change in PCM audio data was visible in the HDMI ARC electrical signal:

Figure 32 Marker 0 (red): Start of 2 channel PCM audio tone data in an eARC data stream.

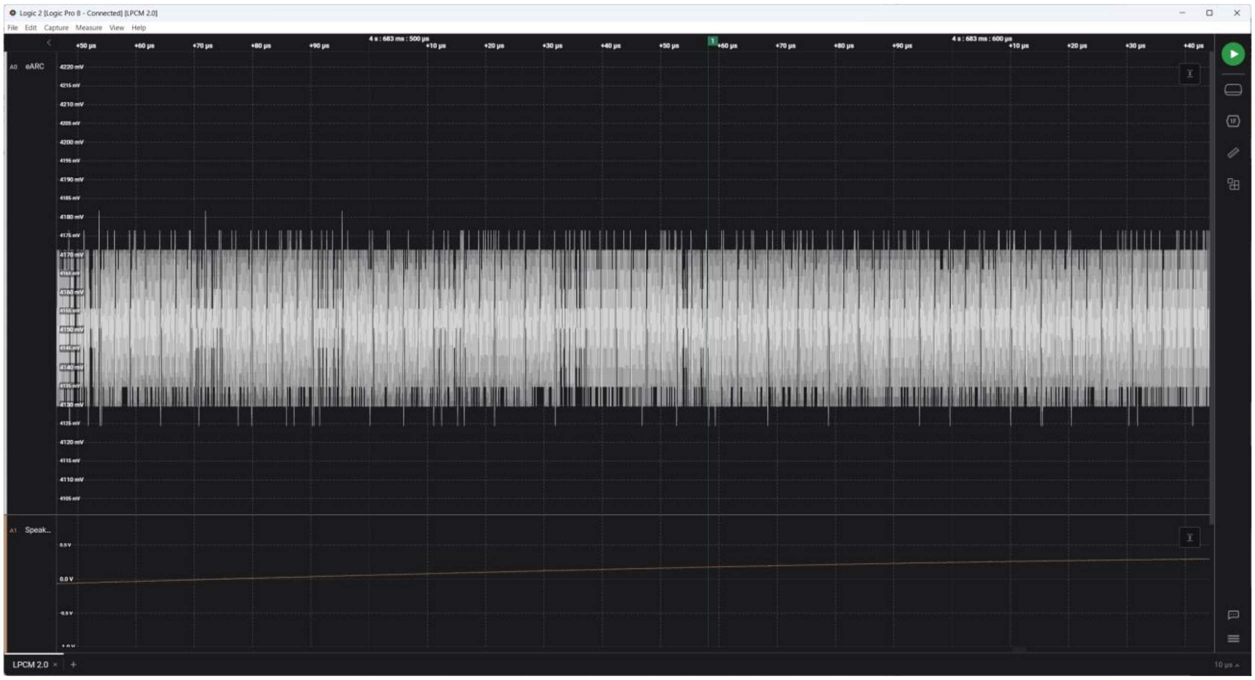


Figure 33 Marker 1 (green): End of 2 channel PCM audio tone data in an eARC data stream.

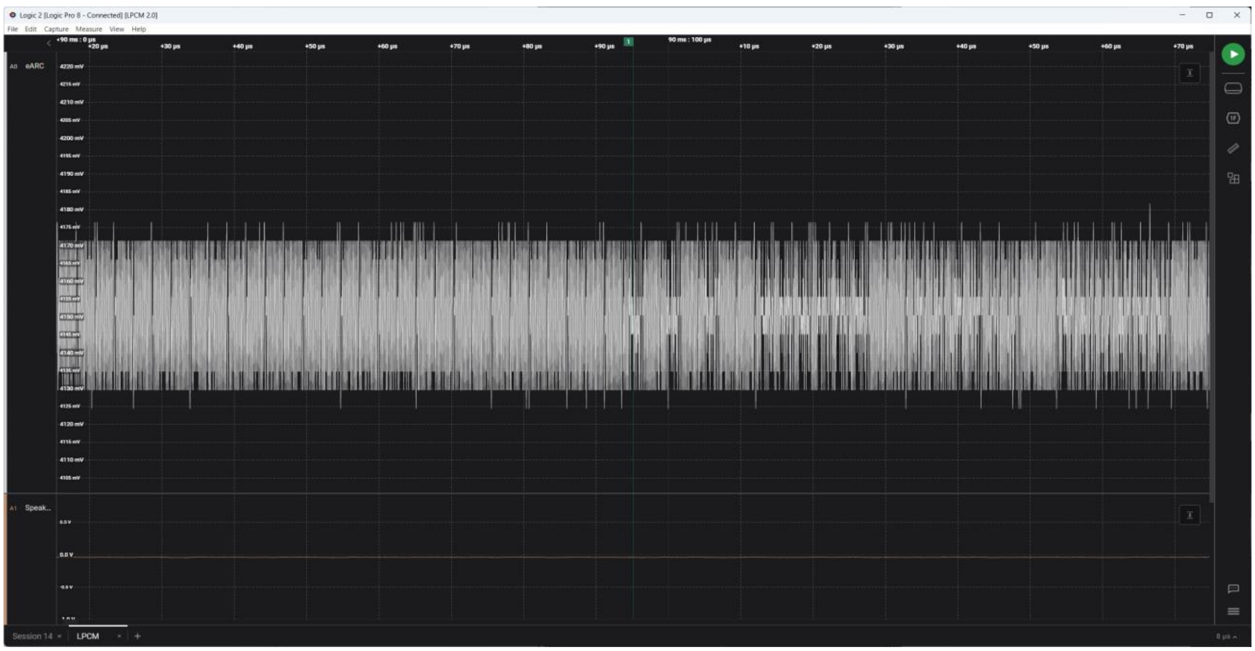


Figure 34 Marker 1 (green): Start of 5.1 channel PCM audio tone data in an eARC data stream. This appeared similar to the 2 channel PCM data stream.

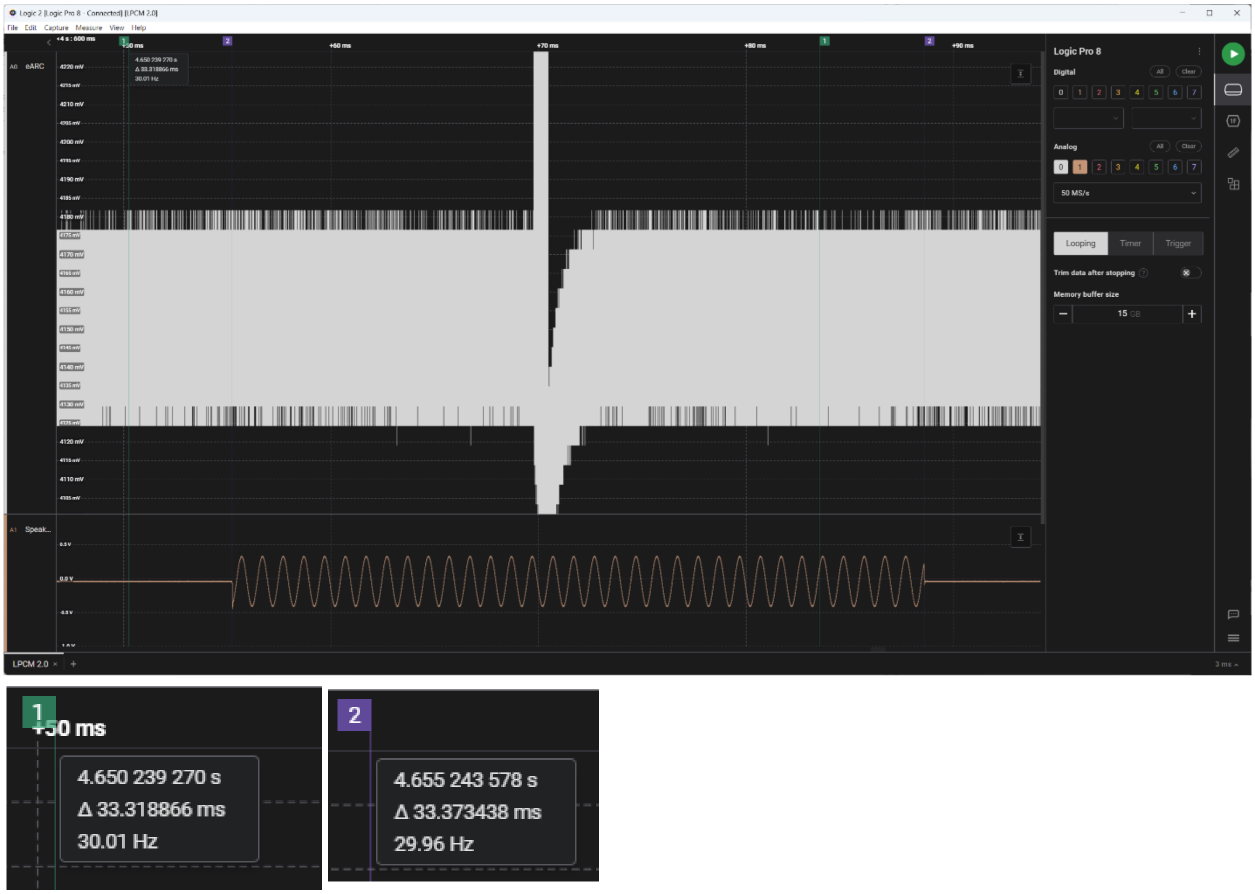


Figure 35 Marker 1 (green): Duration of digital audio data. Marker 2 (purple): Duration of rendered audio. The duration of the eARC audio data was equal to the duration of the audio tone of the M8SG latency test pattern, demonstrating the digital audio data was correctly identified. This was the case for both 2 channel and 5.1 channel audio streams.

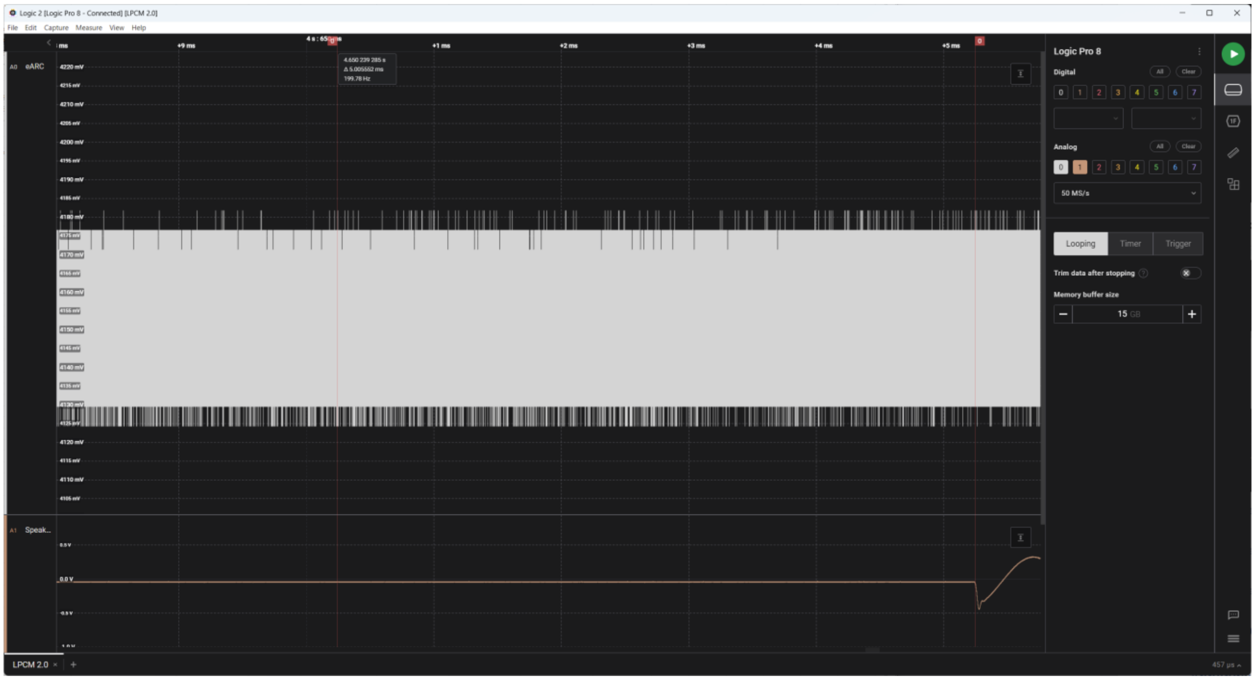


Figure 36 Marker pair 0 (red): Time between the start of the 2 channel digital audio stream and the start of the rendered audio tone.

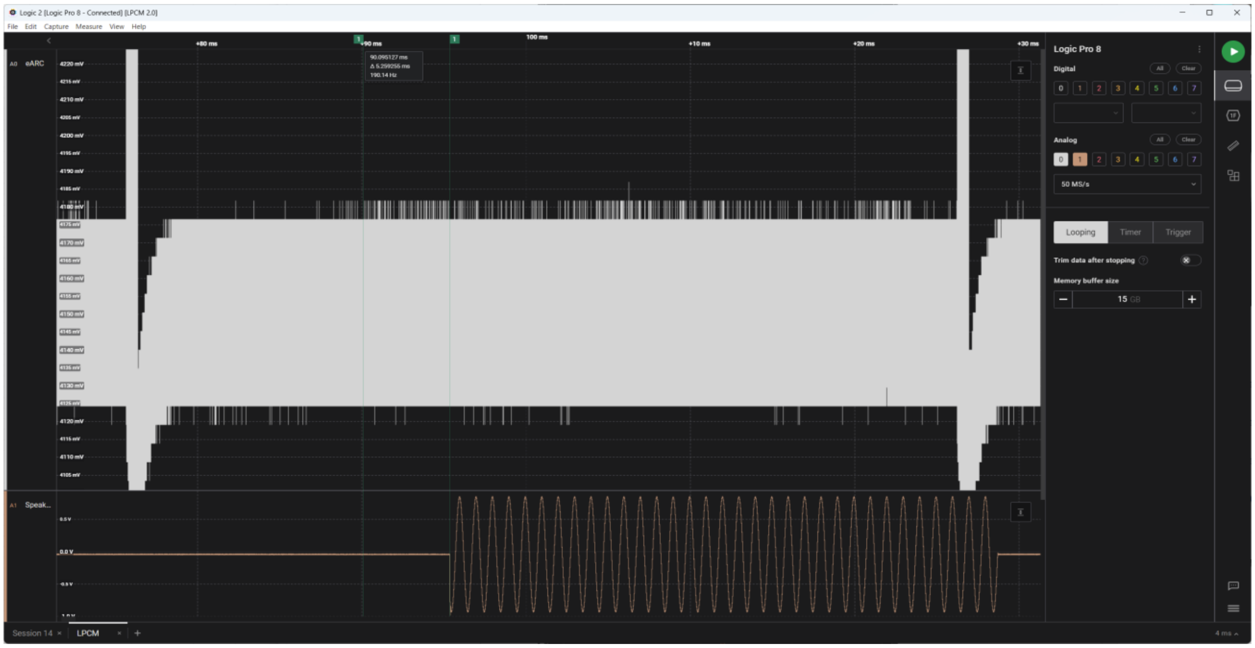


Figure 37 Marker pair 1 (green): Time between the start of the 5.1 channel digital audio stream and the start of the rendered audio tone.

6.5 Dolby Audio over TMDS Encoded HDMI Audio and HDMI eARC

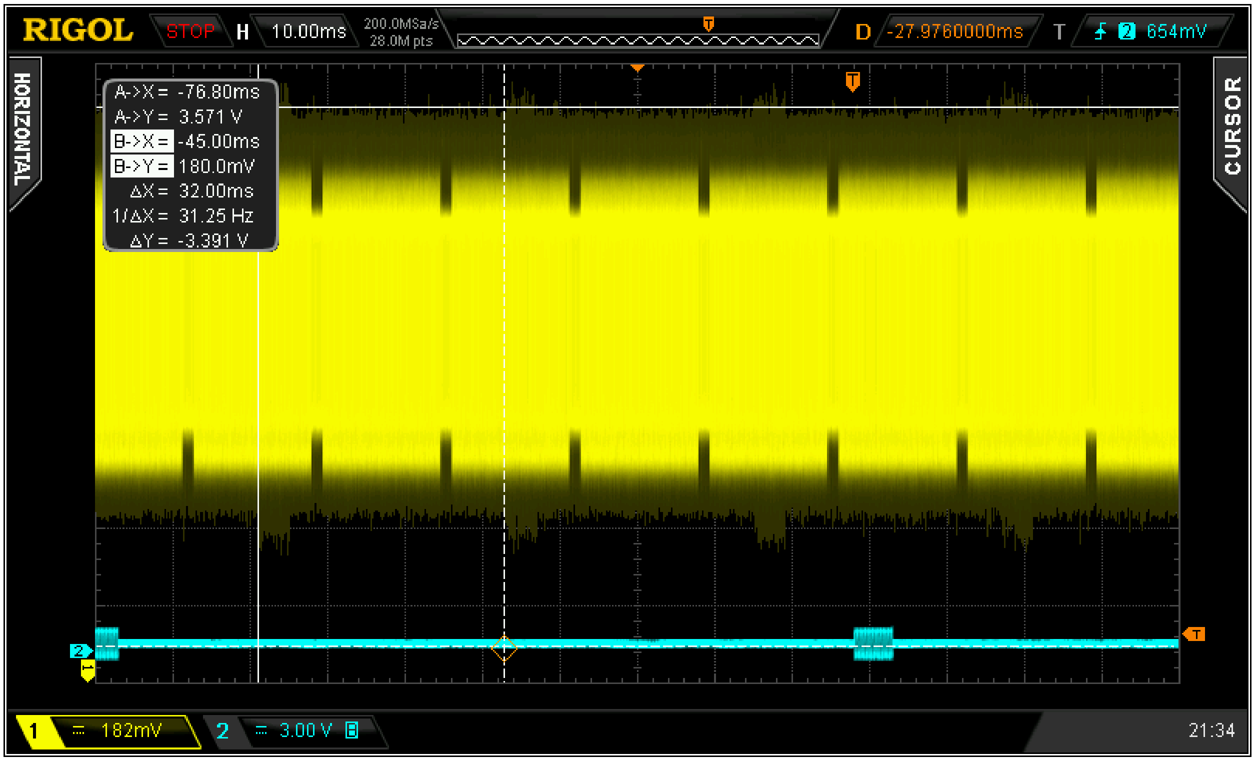


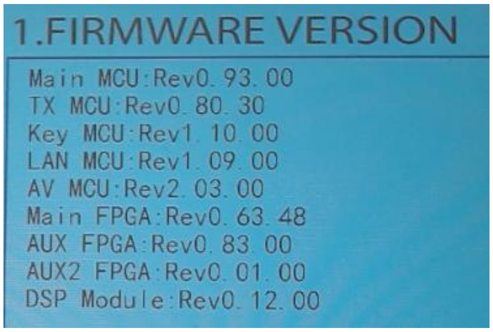
Figure 38 Dolby Digital AC3 audio over TMDS HDMI audio. Audio packets are sent every 32 ms.

Unlike ARC audio, HDMI audio and HDMI eARC audio use TMDS encoding. While it was possible to visualize the Dolby-encoded audio packets that are transmitted every 32 ms under TMDS encoding, it was not feasible to determine which packets contain different audio data than the others. This meant that audio latency of Dolby encoded audio over TMDS HDMI audio and eARC audio could not be measured.

7 Equipment

The following equipment was used:

Murideo 8K Seven Generator



Rigol DS2302A, 2 Ch, 300 Mhz, 2 GSa/sec

Saleae Logic Pro 8

Marantz NR1711 AV Receiver

Shure SM58 dynamic microphone

Kramer 861 HDMI Analyzer

NVIDIA 980 Ti (Windows 11 PC)

Appendix 1: TMDS HDMI Audio Latency Measurement Method

In TMDS HDMI audio, audio packets are contained in data islands within the video signal's horizontal and vertical blanking regions. The bandwidth of an HDMI signal is very high, so it requires very expensive and very specialized equipment to perform bit-perfect capture of a TMDS data pair.

But we don't need to fully decode an HDMI signal to understand when audio data has changed. Instead, we can measure audio latency through manipulation of the source audio and video and spectral analysis of a bandwidth limited analog representation of the HMDI signal. In short, the colour of the video lines are manipulated to result in what appears to a low bandwidth oscilloscope as high frequency with high attenuation. Conversely, the audio tone is manipulated to appear as low frequency with low attenuation. This allows us to visualize the change in audio data as a change in amplitude on the low bandwidth oscilloscope's voltage axis.

We start by connecting a 300 MHz oscilloscope via a simple 10x probe to the positive TMDS Data2 pin of the HMDI signal. Because we are depending on attenuation of higher frequencies of the analog representation of the HDMI electrical signal, it's actually helpful to have a couple of full-length HDMI cables involved. Here I'm using two 6 foot HDMI cables with a cable breakout that I made. Inductance is added and the signal quality degrades, but that's actually helpful for this bandwidth limited approach. In fact, it's important that the analog electrical signal entering the oscilloscope does not have a high quality digital signal because we want a high attenuation of higher frequency signals.

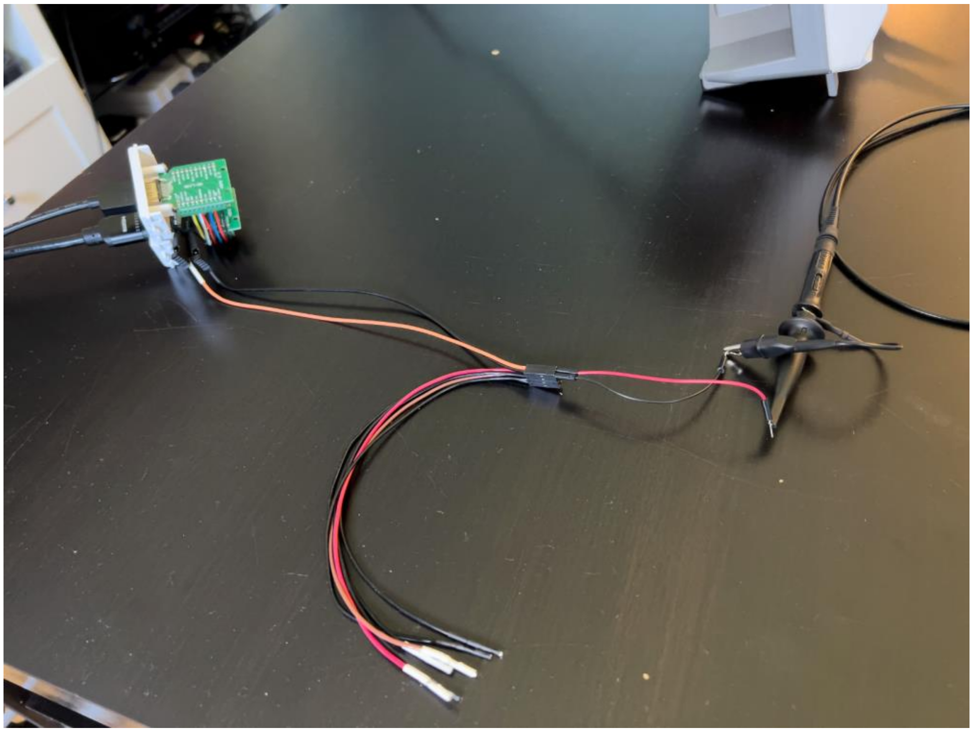


Figure 39 Connecting an HDMI cable to an oscilloscope in a way that allows additional inductance.

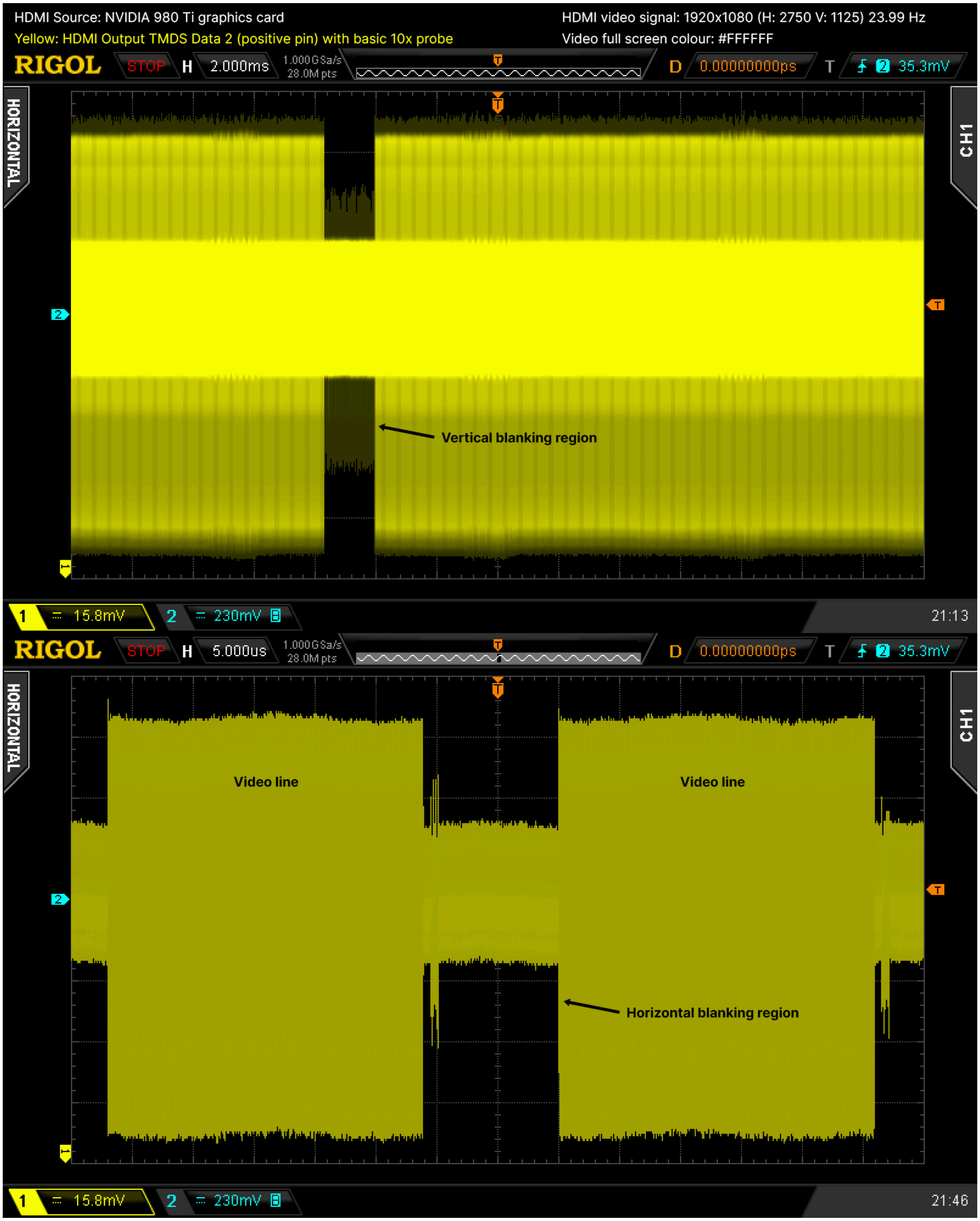


Figure 40 Top: Zoomed-out view showing vertical blanking region. Bottom: Zoomed-in view showing horizontal blanking region.

We can see the horizontal blanking regions, and it's possible we're even looking at the data island that hosts the audio packets, but it's very hard to see from the zoomed-out view of the signal where a change in these audio packets might happen. The next step is to increase the analog frequency of this electrical signal during the video lines, which will increase the signal attenuation and decrease the visual size of the video lines on the oscilloscope's view.

This might sound difficult, but it's as simple as opening Photoshop and making a full screen colour appear on the display. Then gradually change the brightness, one step at a time to find a colour that results in a high frequency TMDS signal during the video lines. For these specific signal parameters (1080p 24 Hz), I found that #545454 was best at attenuating the video lines by increasing their analog electrical frequency:

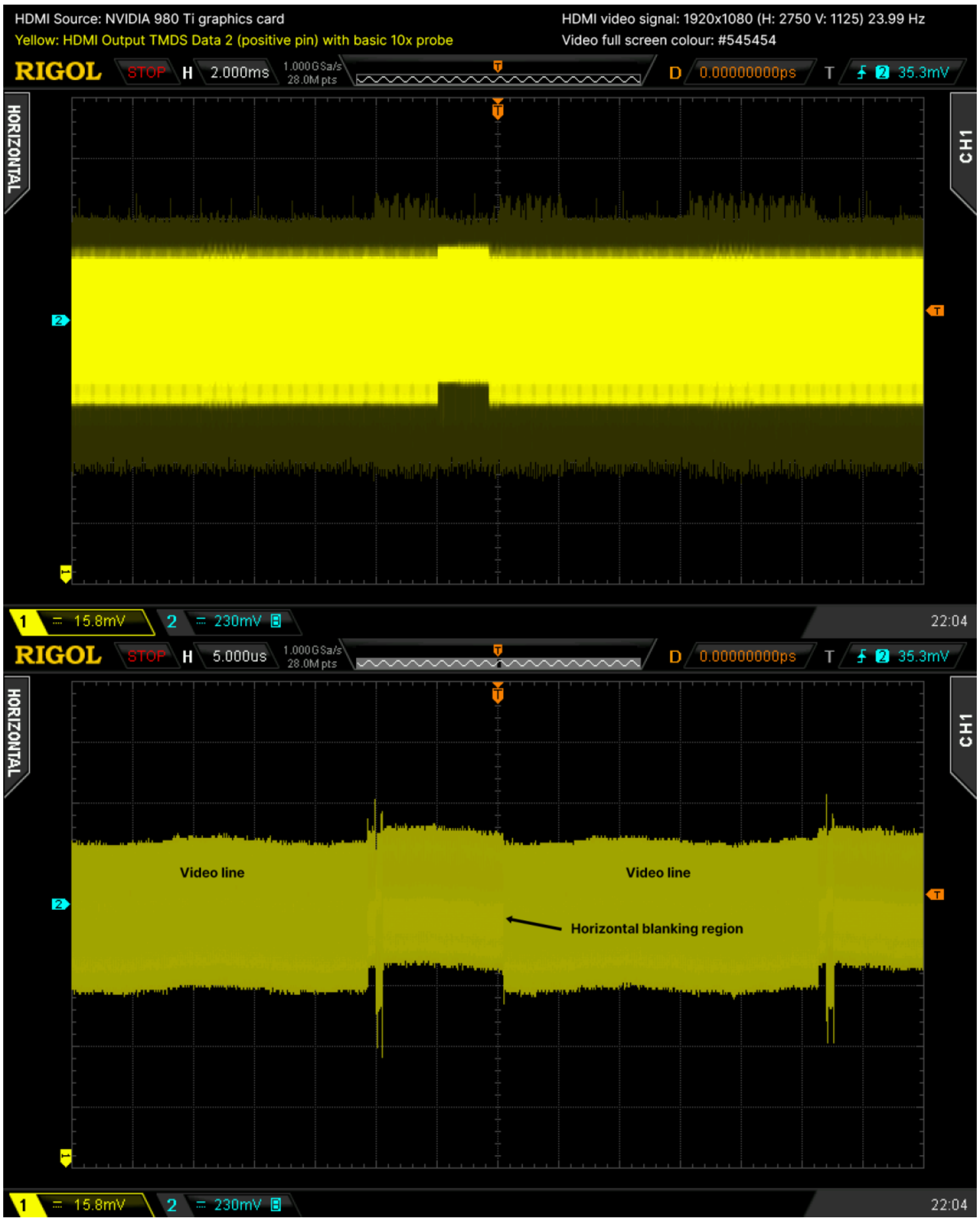
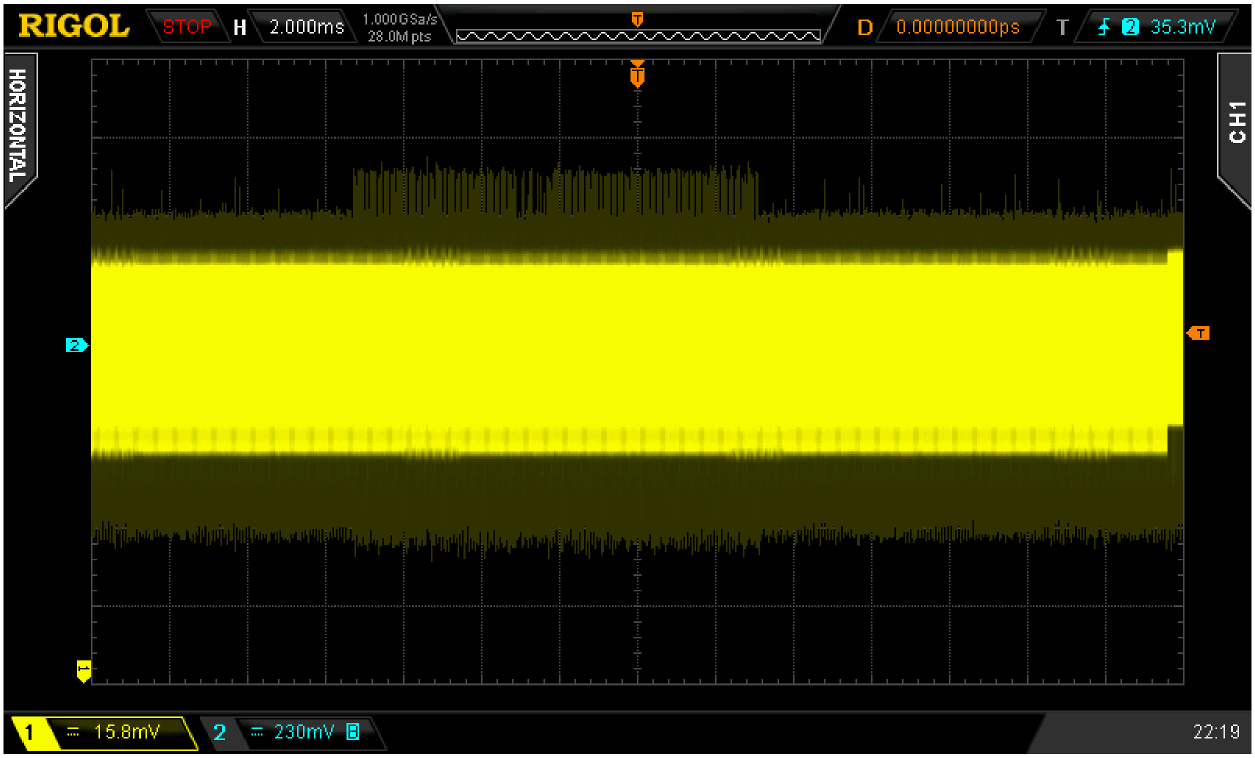
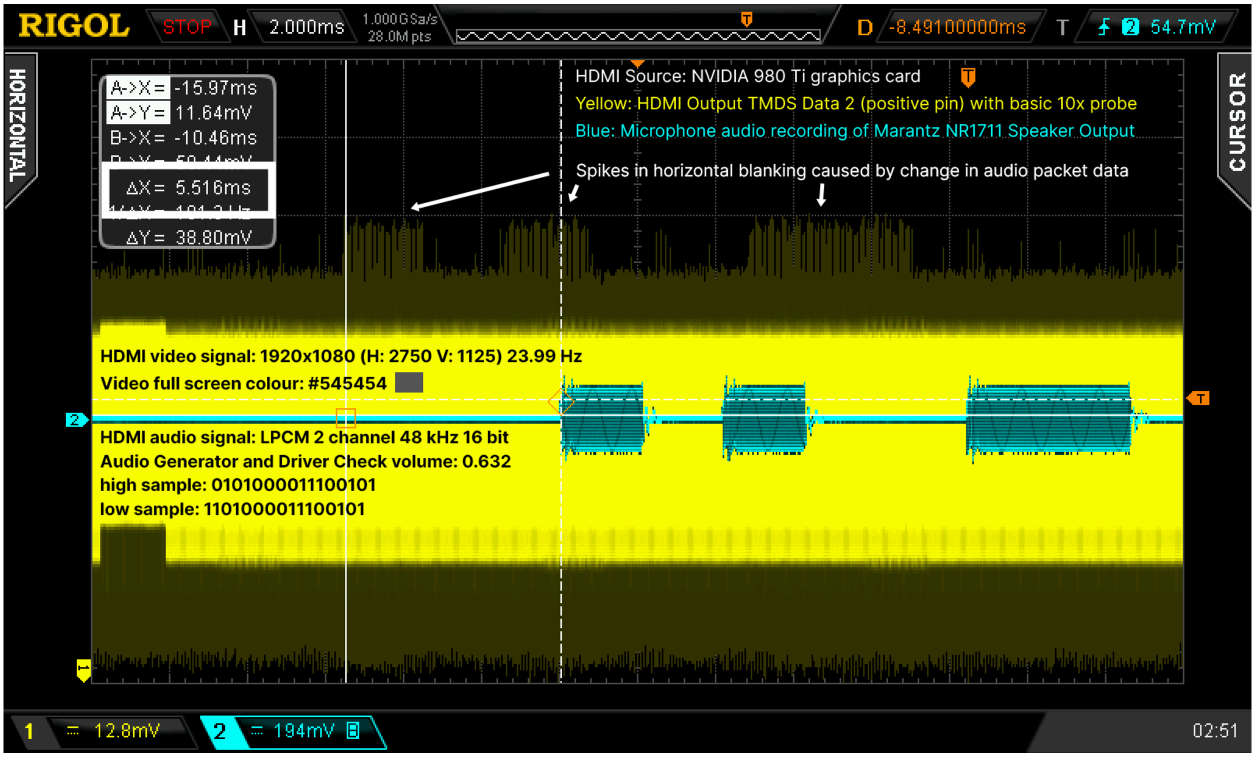


Figure 41 Top: Zoomed-out view showing vertical blanking region. Bottom: Zoomed-in view showing horizontal blanking region.

Now it's much easier to see a change in the horizontal blanking regions when zoomed out. The audio signal is a repeating 100 ms pattern that has unique sample patterns that are easy to visually identify. A change in the volume of the audio output will change the audio packet data and allow us to control the resulting analog frequency. I found a volume level of 0.632 to result in very clear changes in audio packet data due to a low analog frequency that has low attenuation:



Now that our HDMI signal is easy to visually analyze, let's add on an audio recording from an AV receiver to get an accurate audio latency measurement:



This measurement comes in at 5.5 ms between the time the audio data was transmitted over HDMI and when the audio is presented as sound by the AV receiver.

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