Euphonium Timbre:

A Spectral Analysis of Different Mouthpiece Materials

by

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ABSTRACT

This document explores and utilizes the Digital Audio Workstations (DAW) Audacity and SPEAR (Sinusoidal Partial Editing Analysis and Resynthesis) to create a visual representation of euphonium timbre consisting of complex harmonic structures. Using one mouthpiece model, the Schilke 51 D, this research explores what effect the mouthpiece material has on the amplification of these harmonic structures. Through four exercises geared at different and specific qualities of euphonium sound, this study aims to find the best mouthpiece material for the ideal euphonium sound.

ACKNOWLEDGEMENTS

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Thank you to all my past teachers who have pushed me to continue school. It has been a bumpy and winding road but their encouragement to better myself not only as a musician, but as a person has helped me to be where I am today.

I also owe a great deal of thanks to my family and friends. Their continued support of my dream has never failed, and I am forever grateful. From attending recitals to purchasing plane tickets, I would not be where I am today without my circle.

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TABLE OF CONTENTS

LIST OF TABLES

LIST OF FIGURES

Figure Page

1. INTRODUCTION

Purpose of Project

The purpose of this document is to provide an in-depth understanding of timbre production on the euphonium using spectral analysis while utilizing Audacity and Spear software. By experimenting with mouthpieces constructed of different materials whose dimensions match the Schilke 51D, this study focuses on the harmonics that are produced when playing the euphonium with the intent of discovering the best representation of consistent euphonium timbre. By using Audacity to record and Spear to analyze, a catalog describing the harmonics generated by different mouthpiece materials is created. The mouthpiece materials included are stainless-steel, plastic, gold, and silver-plated.

Need of the Study

While searching for information about what sound the euphonium should produce, there is conflicting data. According to a list written by Briggs (1965), the euphonium, "is similar to the tuba but smaller in size and is used more in brass bands than orchestras."[1] This is problematic in that it discounts the unique timbre of the euphonium, describing it as a derivation of the tuba. Composers often resort to scoring the euphonium an octave higher than the tuba in supporting lines/roles but according to Bevan (1978), "it is folly to put the euphonium on an unimportant note in a chord or give

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[1] G. A. Briggs, *Musical Instruments and Audio.* (Idle, Bradford, Yorkshire: Wharfedale Wireless Works, 1965), 78.

it a disjointed harmonic line. Its tone is so compelling that the arranger's error becomes compulsive listening."[2] By analyzing the behavior of the partials produced by the euphonium with different mouthpiece materials, euphonium players can better understand what mouthpiece material is needed to produce a specific euphonium timbre. Currently there is no spectral analysis of the euphonium.

Limitations of the Study

Two software are used to collect data. The inclusion of other software packages might yield a broader scope of results. With new Digital Audio Workstations (DAW's) being created all the time, future studies may yield more information. Another limitation might be inconsistencies of room temperature at the time of recording. According to Rossing (1990), "The velocity of sound increases about 0.6 m/s for each degree Celsius, so the pitch of a wind instrument rises about 3 cents (3/100 of a semitone) per degree of temperature (the slight lowering of pitch due to expansion in length is negligible)."[3] Also, this study focused on a single instrument and mouthpiece type.

[2] Clifford Bevan, *The Tuba Family*. (New York, Charles Scribner's Sons, 1978), 91.
[3] Thomas D. Rossing, *The Science of Sound*. (Reading, Mass: Addison-Wesley Pub. Co., 1990), 135.

2. BACKGROUND AND CONTEXT

A Brief History of Euphonium Origins and Development

There are multiple claims to who invented the euphonium, but the most consistent name is Ferdinand Sommer of Weimar. Anthony Baines (1993) states, "This name (English 'Euphonium') is said to have been invented by a German musician, Konzertmeister Sommer, in 1843 for his own species of ophicleide-conversion which, after improvement in Vienna, he exhibited across Europe as far as London."[4] While Sommer may have invented the euphonium, the modern euphonium's roots lie with the earliest low brass ancestor, the serpent. The wooden serpent was used back as far as the late Renaissance period and was reportedly difficult to play. Reasons why include holding a centered pitch and a round tone were not practical with six small tone holes that often were of varying size depending on the maker. Building off the serpent's role as the lowest pitched member of the wind band was the bass ophicleide, which according to O'Conner (2007) is, "a bassoon-shaped, keyed brass instrument popular during the first half of the nineteenth century."[5] While the euphonium is not a direct descendent of the ophicleide, it is very similar in the sound, but the euphonium does not have trouble in the upper register of playing. There are many other variations of the modern euphonium that, while essential to the development of the modern euphonium, only find their place among brass bands since the wind band already has most of the brass family incorporated into it.

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[4] Anthony Baines, *Brass Instruments: Their History and Development*. (New York: Dover Publications, Inc, 1993), 258.

[5] Lloyd E.Bone, Eric Paull, and R. Winston Morris, *Guide to the euphonium repertoire the euphonium source book*. (Bloomington: Indiana University Press, 2007), 1.

The euphonium was created to utilize the new valve technology of the early nineteenth century, around 1818. The Périnet valve, which is the most-used valve in brass instruments today, is named after Francois Périnet. The inventor from Paris first displayed his work in 1838 and patented it in 1839. According to the National Music Museum (2009), "The piston is held at rest by a spring, which is placed either on top (top-sprung) or below (bottom-sprung) the piston. The Périnet valve is now the standard for trumpets in most countries (except Germany and Austria), and is often simply called the 'piston valve'."[6] This invention was instrumental in the development of not only the euphonium, but all piston brass instruments as we know them today.

Knowing the origins of the euphonium is essential to understanding why the euphonium was built. There was a need in ensembles for a low-pitched instrument that could play and project the bass solo lines of the wind band literature. Some physical aspects of the modern euphonium, according to O'Conner (2007) include, "nine feet in length with the fundamental pitch of Bb."[7] This type of design is very similar to the original plans by Adolphe Sax to reach the fundamental Bb pitch. The length of the tubing is then compressed together to make the instrument available to hold upright with a slight lean to the right as the mouthpiece protrudes around the left side of the instrument's bell. There are many different types of euphonium that have been constructed during the early years of the instrument's life. The modern euphonium we

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[6] National Music Museum, *Elements of Brass Instrument Construction: Périnet Valves*. (The University of South Dakota, 2009).

[7] Lloyd E.Bone, Eric Paull, and R. Winston Morris, *Guide to the euphonium repertoire the euphonium source book.* (Bloomington: Indiana University Press, 2007), 1.

know today looks like early experiments with the new valve system, but very important additions have been attached to the early blueprints. Examples included are stated by O'Conner (2007) as, "The introduction of the larger, fully tapered bores through the valves, the expansion of bell diameters, and adjustments to the original fourth-valve compensations system."[8] These adjustments have helped the instrument to assume its role as the tenor soloist of the wind band.

The use of the fourth-valve compensation system is important to performers of the euphonium that play with ensembles as it greatly affects tuning. The fourth valve can be located in-line with the three valves up top or positioned so that the left hand can cross over the front of the euphonium and press the fourth valve situated at an angle to accommodate the left hand. With the valve on the opposite side, it makes holding the euphonium easier thus, allowing for more soloists to stand during performances. One problem with the independent fourth valve played by the left hand is the coordination it takes to perform fluidly. The fourth valve acts as the equivalent of pressing down the 1st and 3rd valves to help with low register playing being more in tune, but it is just a valve. The compensating valve reroutes the air through a different set of tubing for the other three valves, lengthening the euphonium. This is important because according to Werden (1996), "To lower a brass instrument ½ step, its length must be increased by 6%."[9] The compensating system helps with intonation and the ability to play chromatically between

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[8] Lloyd E.Bone, Eric Paull, and R. Winston Morris, *Guide to the euphonium repertoire the euphonium source book.* (Bloomington: Indiana University Press, 2007), 15.
[9] Dave Werden, (www.dwerden.com, 1996)

the first and second partials. The inline fourth valve simply adds more tubing to the existing valve combination.

Below is a diagram of the euphonium compensating system. Notice the independent fourth valve that would be used by the player's left hand index finger.

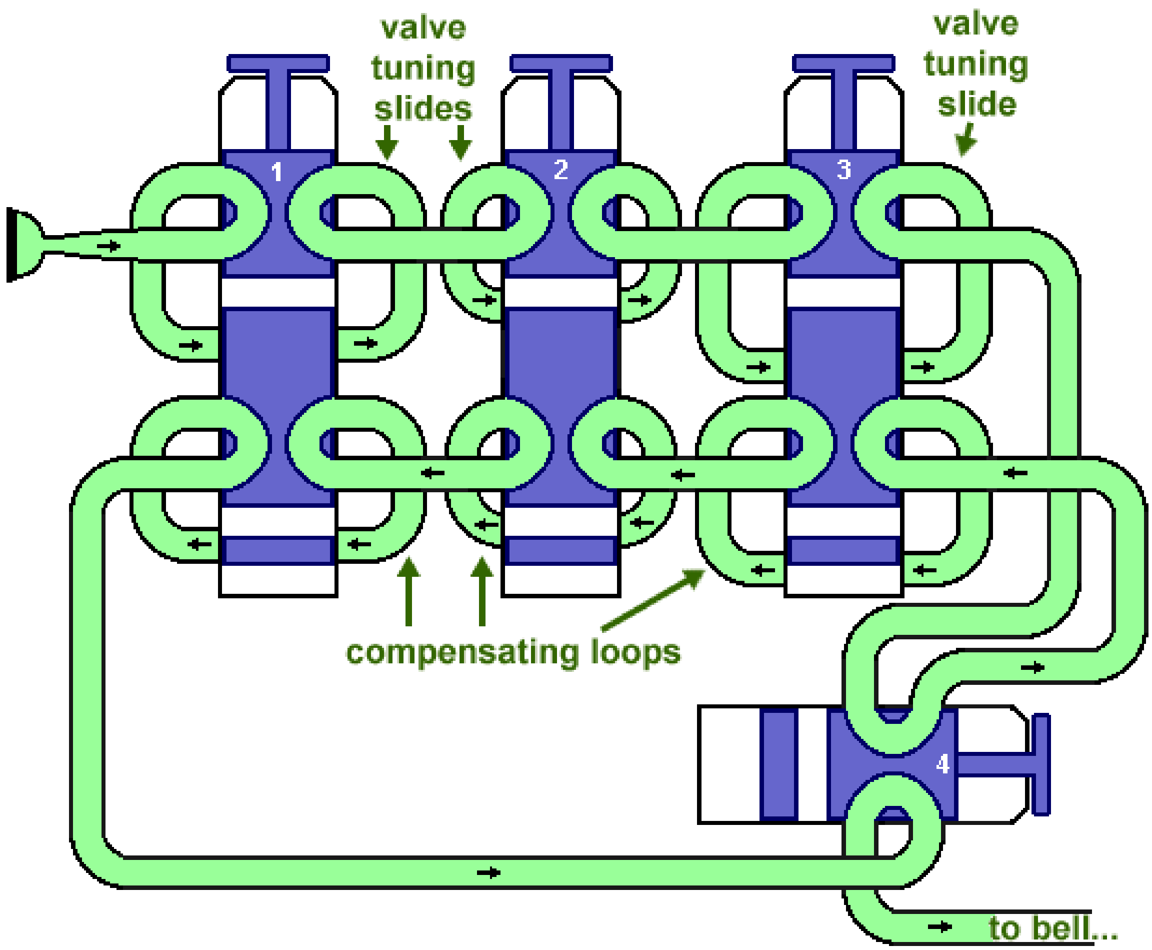

Figure 1. Compensating System Diagram[10]

[10] Dave Werden, (www.dwerden.com, 1996)

What is Timbre?

Before delving into spectral analysis, we need to define timbre. According to the Acoustical Society of America (2020) timbre is, "That multidimensional attribute of auditory sensation which enables a listener to judge that two non-identical sounds, similarly presented and having the same loudness, pitch, spatial location, and duration, are dissimilar. Timbre is related to sound quality, often specified by qualitative adjectives (e.g., bright or dull). Annotation: The timbre of a sound is strongly influenced by its time-varying characteristics, particularly during the initial portion (attack), and is also influenced by its ongoing spectral and temporal characteristics. Timbre is an essential element in the identification of the source of a sound (e.g., particular musical instrument[s]) and the manner of sound production."[11] After one listening, the ability to discern these two tone colors apart is very easy, if an initial attack is present, or some form of sound decay. It becomes harder to separate tone color the closer the instruments are in range and build (for example, euphonium and tuba), since they could be playing in the same frequency range. The attack and decay help identify the timbre of these instruments. This information clarifies why the euphonium is often compared to the tuba sound. A second term to discuss is tone. Another relevant term is tone, which can be defined as, "(a) Sound wave capable of exciting an auditory sensation having pitch. (b) Sound sensation having pitch."[12]

[11] Acoustical Society of America, (https://asastandards.org, 2020)
[12] Ibid.

Harmonics, Overtones and Partials

It is very common to mistake or use these words interchangeably. When discussing harmonics, the Acoustic Society of America (2020) says they are a "Sinusoidal quantity having a frequency which is an integral multiple of the fundamental frequency."[13] When researching the definition of harmonic, there was mention of overtone but has since been discontinued to reduce ambiguity. The term fundamental frequency refers to the lowest natural frequency of a given sound. The Acoustic Society of America (2020) also define partial as a "Sinusoidal component of a complex tone"[14] Sinusoidal referring to the sound wave having the form of a sine curve, discussed below. A complex tone is a set of sine waves built of different frequencies.

In the case of talking about partials and more specifically the overtone series, there is more than one way to interpret the partials. When discussing partials in this document, the fundamental is not included in the numbering. The figure below[15] shows the fundamental of Bb as the first partial with the octave Bb above as the second partial. For this analysis, we will interpret the fundamental (Fund) as F^0 with the octave Bb above the fundamental as the first partial. This will be important when discussing the analysis, specifically sixth partial, or Ab.

[13] Ibid.
[14] Ibid.
[15] David Grasmick, (www.cpp.edu/~dmgrasmick/mu330/acoustics.html)

For this analysis:

F^0 1^{st} 2^{nd} 3^{rd} 4^{th} 5^{th} 6^{th} 7^{th} 8^{th} 9^{th} 10^{th} 11^{th}

Figure 2. Overtone Series

What are Sound Waves?

The last thing to cover before the analysis is discussed is what are sound waves? As mentioned above, sinusoidal waves are sound waves having the sine curve. Here is an image of different types of waves from Gabino Alonso (2017):[16]

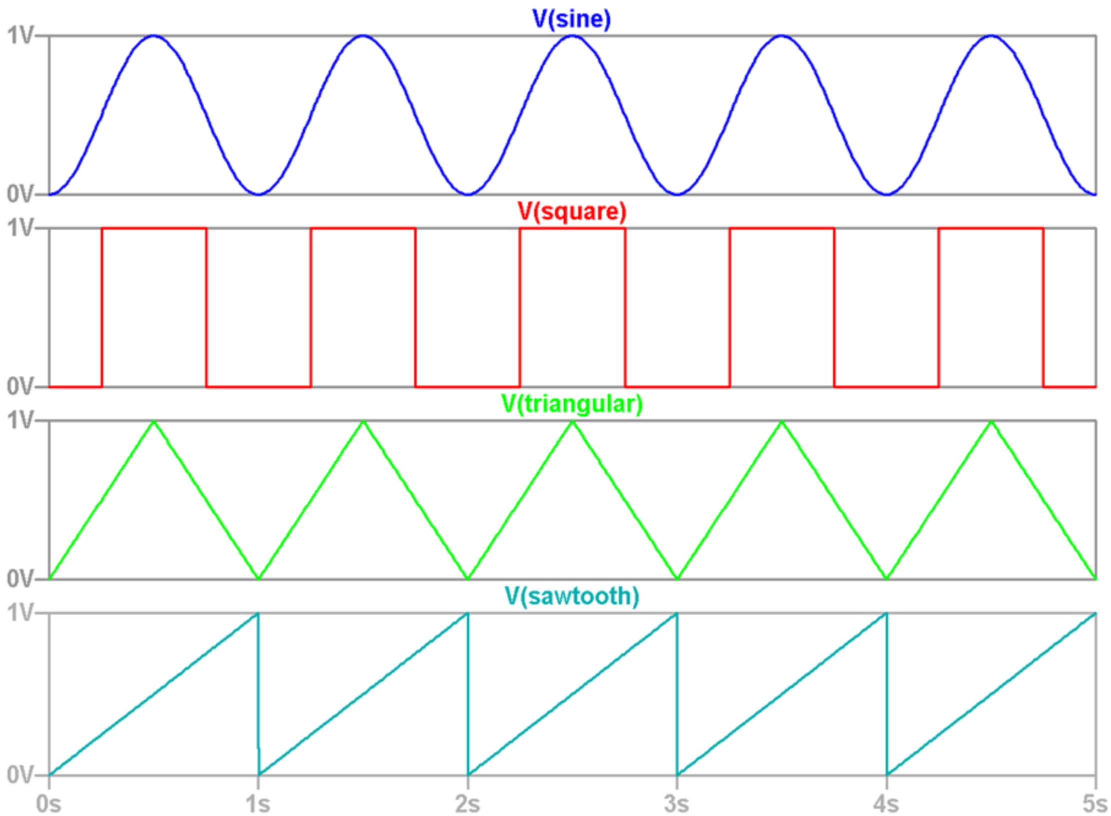

Figure 3. Sine, Square, Triangular & Sawtooth Waveform Shapes

The sine waves are a sinusoidal waveform and are smooth and have a periodic oscillation. The development of a complex wave form consists of overlapping in the pattern shown. A square wave is not sinusoidal and alternates between fixed maximum and minimum displacements instantaneously. They develop by starting as a sine wave but

[16] Gabino Alonso, (https://www.analog.com/en/technical-articles, 2017)

quickly assume the square position with the size of the sine waves decreasing into the square. The triangle waves are also not sinusoidal, contain only odd harmonics and start as sine waves but assume the triangle position. The last wave is the sawtooth wave, which is also not sinusoidal and resembles a saw. Often referred to as a "ramp waveform", this wave contains both even and odd harmonics. For this paper we will be discussing longitudinal sine waves in air. According to Rossing (1990), "Longitudinal means that the back-and-forth motion of air is in the direction of travel of the sound wave (as compared to waves on a rope, in which the back-and-forth motion is perpendicular to the direction of wave travel). As the wave travels through air, the air pressure changes by a slight amount, and it is this slight change in pressure that allows our ears (or a microphone) to detect the sound."[17] As we progress into this paper, this information about sound waves will be essential to understanding the analysis figures and explanations.

[17] Thomas D. Rossing, *The Science of Sound*. (Reading, Mass: Addison-Wesley Pub. Co., 1990), 4.

Definition of Terms

- Audacity – an easy-to-use, multi-track audio editor and recorder for Windows, macOS, GNU/Linux and other operating systems.
- Compensating System – reroutes the air through a different set of tubing for the other three valves, instead of adding more tubing to the existing valve combination. Lengthens the euphonium for better intonation as well as lower pitches.
- Euphonium – a brass instrument consisting of nine feet in length with the fundamental pitch of Bb, and typically fitted with a compensating system.
- Harmonics – Sinusoidal quantity having a frequency which is an integral multiple of the fundamental frequency.
- Overtones – Has frequently been used in place of harmonic. Discontinued term to reduce ambiguity in the numbering of the components of a complex tone.
- Partials – Sinusoidal component of a complex tone.
- Périnet valve – a valve held at rest by a spring, which is placed either on top (top-sprung) or below (bottom-sprung) the piston.
- Spear – Sinusoidal Partial Editing Analysis and Resynthesis for macOS, MacOS 9 and Windows.

- Spectrum[18] – Description, for a function of time, of the resolution of a signal into components, each of different frequency and (usually) different amplitude and phase.
- Timbre – Multidimensional attribute of auditory sensation which enables a listener to judge that two non-identical sounds, similarly presented and having the same loudness, pitch, spatial location, and duration, are dissimilar.
- Tone – Sound wave capable of exciting an auditory sensation having pitch.

[18] Acoustical Society of America, (https://asastandards.org, 2020)

3. ACQUIRING MATERIALS FOR RESEARCH

Instrument (Willson 2900)

Figure 4. Picture of a Willson 2900[19]

The euphonium used in this research is the Willson 2900. One of the most common euphoniums among professionals, this euphonium has become a standard of many military bands. Many winners of competitive auditions have used the 2900 and

[19] The Horn Guys, (Willson 2900 & 2950 Euphoniums, 2021)

swear by its core sound and ease of playability. The company from Switzerland has this list of specifications for the 2900 on their website:[20]

Willson 2900TA Specifications:

- Pitch: Bb
- Bore: 15.0 / 16.8mm (0.590" / 0.661")
- Weight: 4.5kg / 9.9 lbs
- Bell diameter: 290mm / 11.41"
- 4 stainless steel valves with valve springs underneath
- 3 water keys
- Convenient hand rest
- Yellow brass bell
- Nylon valve guides
- Finish: lacquered or silver plated
- Water catcher
- Option: main tuning slide trigger* Included in this analysis

[20] Willson, (willson-euphonium-2900ta-0, 2021)

Computer Softwares

Audacity was used for the recording process, version 2.4.2 of Audacity recording and editing software was used[21] Wave form audio files (.wav) were created by recording sounds through a condenser microphone (TONOR BM 700 XLR) via Audacity. The .wav files were then imported into Spear, which produces a standard format called SDIF (Sound Description Interchange Format); this is helpful with the visualization of the sound waves and consequently with the spectral analysis used in this paper. Spear aids in harmonic and partial tracking, which is helpful to understand the different timbral characteristics of different mouthpieces.

[21] Audacity® software is copyright © 1999-2021 Audacity Team.
The name Audacity® is a registered trademark.

Microphone

Microphone: TONOR BM 700 XLR Condenser[22]

Figure 5. TONOR BM 700 XLR Condenser

[22] SoundinOut, soundinout.com/tonor-bm-700-review/#Specifications

Specifications of the XLR from SoundinOut[23]

TONOR BM-700 XLR Condenser Microphone comes with Φ16 Pressure Gradient Transducer element. It also has a frequency response of 20 Hz-20 kHz and comes with a sensitivity of 38dB±2dB (0dB=1V/Pa al 1 kHz).

The microphone's output impedance is the 150Ω±30% (al 1 kHz) and has a load impedance is ≥1000Ω. Also, it comes with an equivalent noise level of 16dBA. The MAX.SPL of the microphone is 130 dB (al 1kHz≤1% T.HD). The S/N Ratio is 78dB.

Moreover, it comes with an electrical current of 3mA. The overall weight of the TONOR BM-700 XLR Condenser Microphone is 346g and comes with a Φ46 x 150mm body dimension.

The microphone was mounted and suspended on a desk to restrict vibrations, as well as a pop filter to cancel out background noise.

[23] SoundinOut, soundinout.com/tonor-bm-700-review/#Specifications

USB Audio Interface: Focusrite Scarlett 2i2

Figure 6. Picture of a Focusrite Scarlett 2i2

Specifications of the Focusrite Scarlett 2i2 from focusrite.com[24]

Supported sample rates include 44.1kHz, 48kHz, 88.2kHz, 96kHz, 176.4kHz, 192kHz. The microphone inputs have a frequency response of 20Hz - 20kHz ± 0.1dB. The dynamic range is 111dB (A-weighted). The THD+N is <0.0012% with a noise EIN of -128dBu (A-weighted). The maximum input level is 9dBu (at minimum gain) with a gain range of 56dB. The impedance is 3kΩ. For the line inputs, the frequency response is 20Hz - 20kHz ± 0.1dB. The dynamic range is 110.5dB (A-weighted). The THD+N is

[24] Focusrite, www.focusrite.com/en/usb-audio-interface/scarlett/scarlett-2i2

<0.002%. A maximum input level of 22dBu (at minimum gain) with a gain range of 56dB. The impedance is 60kΩ. The instrument inputs have a frequency response of 20Hz - 20kHz ± 0.1dB. the dynamic range is 110dB (A-weighted). The THD+N is <0.03%. The maximum input level is 12.5dBu (at minimum gain) with a gain range of 56dB. The impedance is 1.5MΩ. The line/monitor outputs have a dynamic range (line outputs) of 108dB. The THD+N is <0.002%. The maximum output level (0 dBFS) is 15.5dBu. The impedance is 430Ω. The headphone outputs have a dynamic range of 104dB (A-weighted). The THD+N is <0.002%. The maximum output level is 7dBu. The impedance is <1Ω.

Schilke 51 D Specifications

Below are specifications from Schilke's website[25]

- 25.55 mm rim/1.005 inches
- J (.277″) throat
- E = European shank

Acoustic Space

The acoustic space used to record is a 10 ½ ft by 10 ½ ft room. There were a few rugs in the room to improve the sound reflections/deflections and the euphonium bell was projected towards the microphone at a distance of one foot with a pop filter.

[25] Schilke, www.schilkemusic.com/products/mouthpieces/trombone-euphonium/

Mouthpiece Lineup and Initial Thoughts

Below is a list of the different mouthpieces, based on Schilke's 51 D, in the order they were recorded:

Stainless-Steel

Figure 7. Stainless Steel 51 D from KELLY Mouthpieces[26]

[26] KELLY Mouthpieces, www.kellymouthpieces.com/stainlesssteel/index.asp

Plastic

Figure 8. Plastic (Lexan material) 51 D from KELLY Mouthpieces[27]

[27] KELLY Mouthpieces, www.kellymouthpieces.com/stainlesssteel/index.asp

Gold

Figure 9. Gold 51 D from Schilke[28]

[28] Hickeys Music Center, www.hickeys.com/music/brass/tuba_and_euphonium/accessories/euphonium_mouthpieces/products/sku036336-schilke-51d1-euphonium-mouthpiece-european-shankgold.php.

Silver-Plated

Figure 10. Silver-Plated 51 D from Schilke[29]

[29] Hickeys Music Center, www.hickeys.com/music/brass/tuba_and_euphonium/accessories/euphonium_mouthpieces/products/sku031775-schilke-51d1-euphonium-mouthpiece-european-shank.php.

Potential Performance Issues and Suggestions

After the initial test of range and agility on each mouthpiece, the ability to discern them from one another was largely due to seeing and feeling each mouthpiece. Each mouthpiece had a very distinct feel, but this information was left out of the analysis to be fair to each. A few areas that had issues when recording was the ability to perform the exercises well enough on each different mouthpiece material to have adequate data.

4. RECORDING SOUND SAMPLES IN AUDACITY

Since the Audacity tracks were in audio format, it was difficult to present the recordings in this paper. Instead, each exercise that was performed and recorded on each mouthpiece is shown and then analyzed in Chapter 5. The process of recording for each mouthpiece is below:

Process of Recording Mouthpiece Materials (Exercises and Length)

Warm-Up

To begin the procedure, long tones were recorded on each mouthpiece. This was to get a feel of the rim pressure needed to perform on each specific mouthpiece, while acclimating myself to the tuning tendencies. A slight articulation was used to separate the notes. This was used as a warm-up exercise and was not recorded.

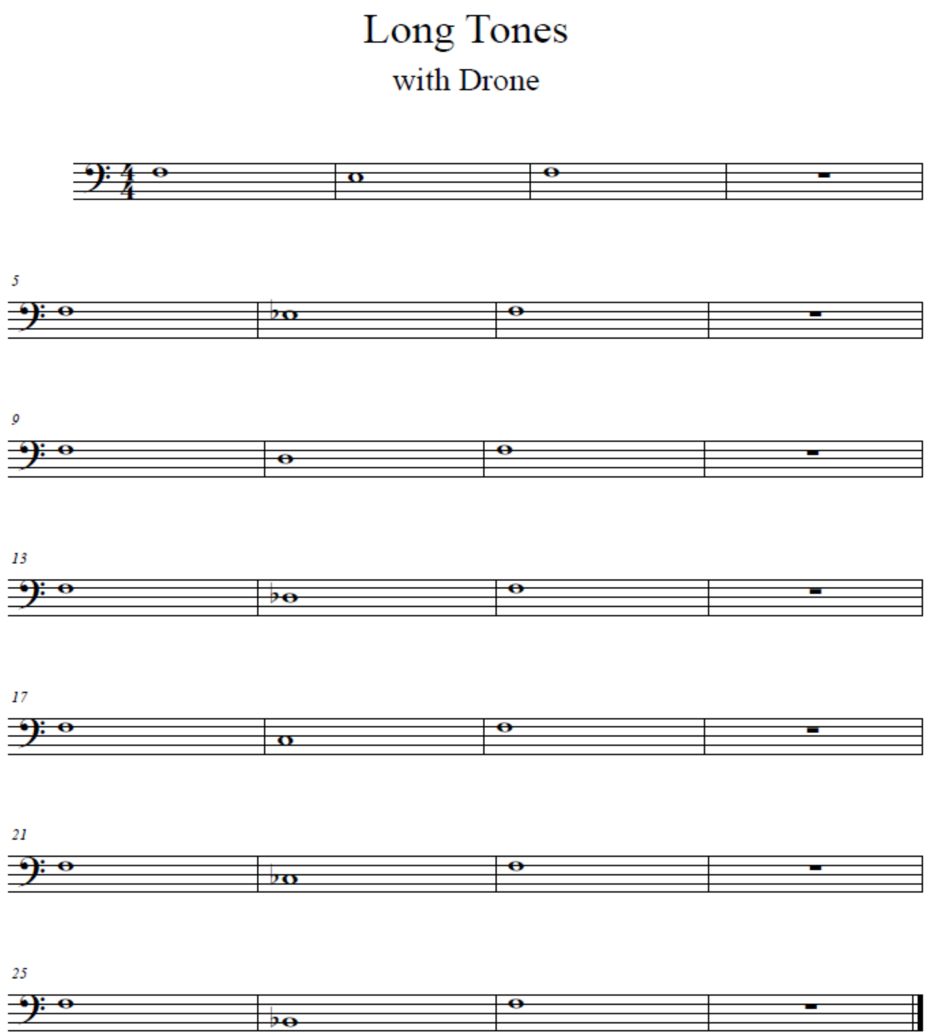

Figure 11. Long Tones with Drone

The second exercise used for the warm-up was Smooth Air Movement from The Brass Gym[30] by Sam Pilafian and Patrick Sheridan. The focus here was to keep a constant air stream to support each mouthpiece, since the designs of the Schilke 51 D differ slightly.

[30] Samuel Pilafian and Patrick Sheridan, *The Brass Gym*. (Focus On Music, 2008), 19.

Figure 12. Smooth Air Movement with Drone[31]

[31] Samuel Pilafian and Patrick Sheridan, The Brass Gym. (Focus On Music, 2008), 19.

After the warm-up was completed, the focus of the study transitioned to three areas of concentration; Arpeggios that focused on the high register of each mouthpiece along with the upper harmonics; Descending *BEAUTIFUL SOUNDS* exercise from Brass Gym[32] focused on the lower register of each mouthpiece along with the lower harmonics, and two different sets of long tones, one with a crescendo and one with a decrescendo, focusing on a loud dynamic range (*ff*) and a soft dynamic range (*pp*). Each exercise focused on a specific set of harmonics from the lowest fundamental pitch possible on the euphonium to create a dense harmonic structure.

For the recording process, single tracks were made for each line of music. Examples: arpeggios measure 1 through 4 on a single track, *BEAUTIFUL SOUNDS* measure 1 through 3, long tones measure 1 and 2. All exercises were recorded on one mouthpiece before moving to the next mouthpiece, to ensure consistency across the sound quality and acoustic environment. The recording level of the microphone was set on the audio interface and was consistent across all tracks.

[32] Samuel Pilafian and Patrick Sheridan, *The Brass Gym*. (Focus On Music, 2008), 31-33.

Arpeggios

Figure 13. Arpeggios

The intent of the Arpeggios was the creation of a strong fundamental chordal structure before sustaining the highest harmonic possible. During the recording it became apparent that the minor arpeggio whole notes were consistently denser with harmonics due to the extended time of the recording. The analysis therefore utilized the minor arpeggio whole note. The Arpeggios data is graphed and cataloged in the Appendix of this document. Stainless-Steel pg. 47, Plastic pg. 79, Gold pg. 111, Silver-Plated pg, 143.

Figure 14. Descending *BEAUTIFUL SOUNDS*[33]

[33] Samuel Pilafian and Patrick Sheridan, *The Brass Gym*. (Focus On Music, 2008), 31-33.

The intent of the Descending *BEAUTIFUL SOUNDS* was the creation of a complex harmonic structure by including not only the major third and major fifth, but a major second, major seventh, and a major sixth. By creating this harmonically dense line and reinforcing the fundamental, the result was more low harmonics visible in the analysis. The Descending *BEAUTIFUL SOUNDS* data is graphed and cataloged in the Appendix of this document. Stainless-Steel pg. 55, Plastic pg. 87, Gold pg. 119, Silver-Plated pg, 151.

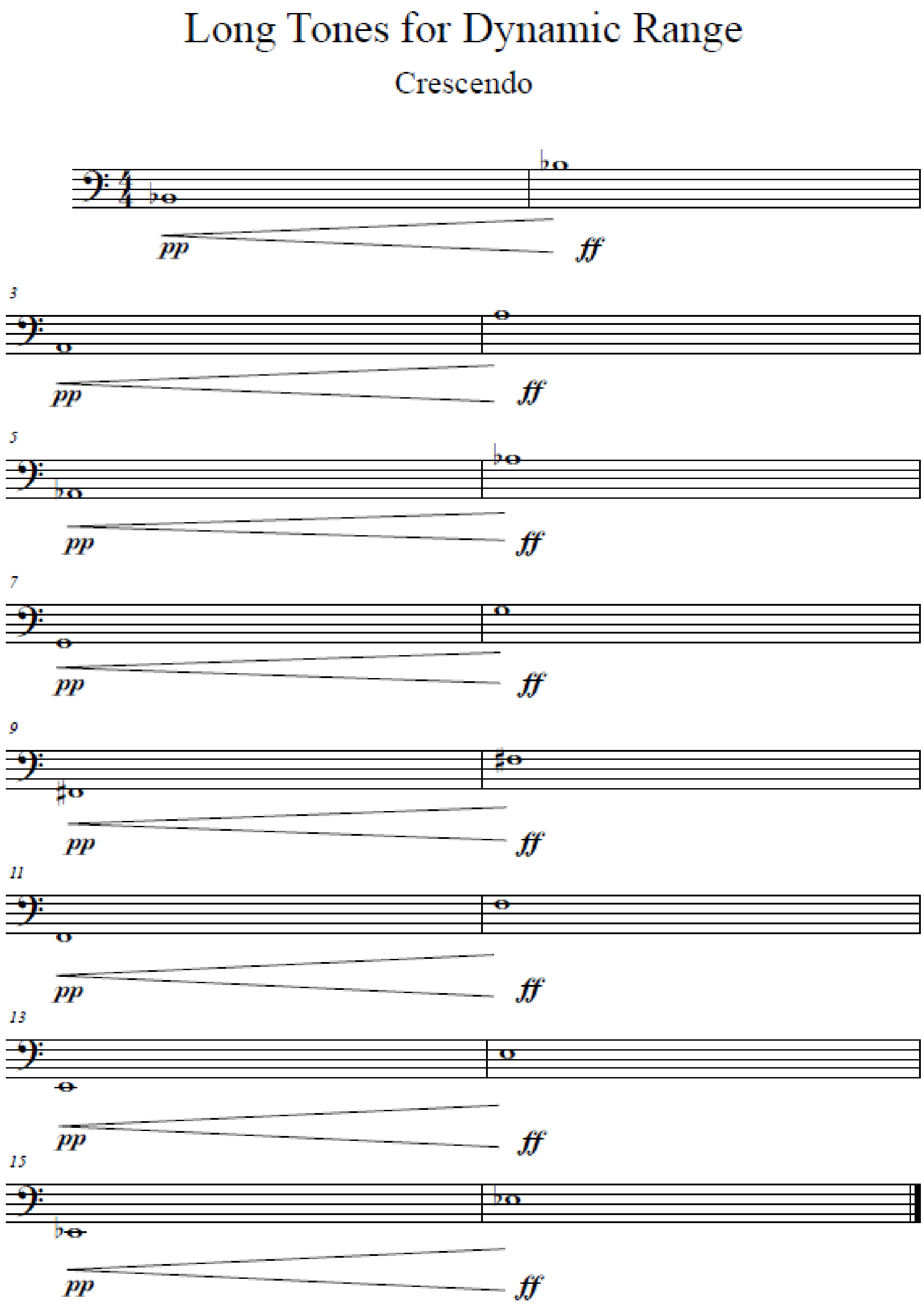

Figure 15. Long Tones for Dynamic Range, Crescendo

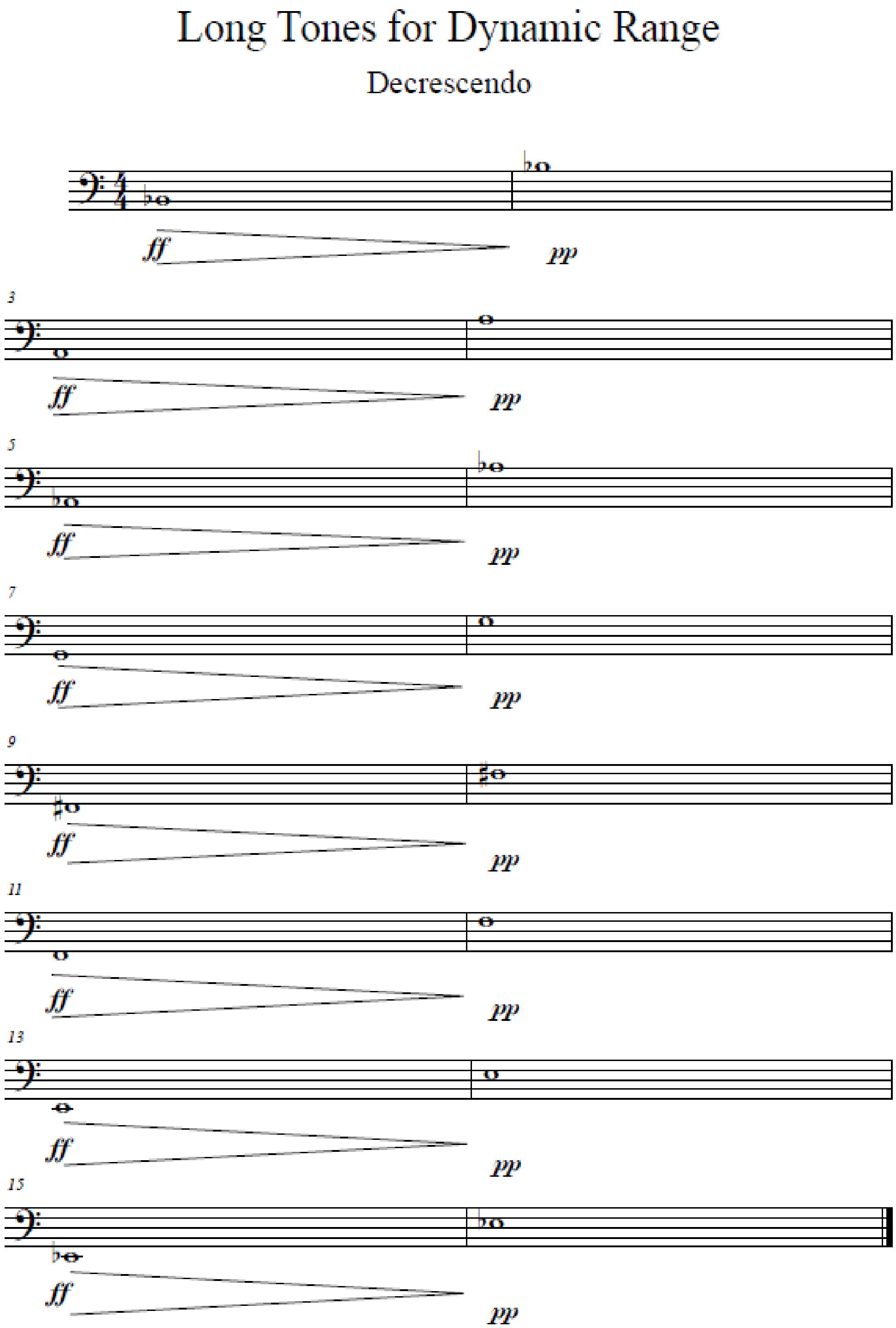

Figure 16: Long Tones for Dynamic Range, Decrescendo

The intent of the Long Tones for Dynamic Range, Crescendo and Decrescendo was to test the dynamic range of each mouthpiece. By performing a crescendo for one measure from *pp* to a full measure of sustain at *ff*, it was possible to determine whether the ascending octave jump would display any harmonics effectively. By performing a decrescendo for one measure from *ff* to a full measure of sustain at *pp*, it was possible to see if the descending octave jump would display the harmonics above the fundamental. The Long Tones for Dynamic Range, Crescendo data is graphed and cataloged in the Appendix of this document. Stainless-Steel pg. 63, Plastic pg. 95, Gold pg. 127, Silver-Plated pg. 159. The Long Tones for Dynamic Range, Decrescendo data is graphed and cataloged in the Appendix of this document. Stainless-Steel pg. 71, Plastic pg. 103, Gold pg. 135, Silver-Plated pg. 167.

Performance Issues and Suggestions

Issues that arose during the recording process were player fatigue from day to day. By having to repeat the process until a great recording was caught, the process of recording was very precise. Due to this, a mouthpiece recording for a specific exercise would last longer than one day. Another issue that was easily fixed was the automatic volume compression on the microphone. After changing the setting on the audio interface, this was no longer an issue. The recordings used for the analysis are those that I felt best represented the individual mouthpiece. The last issue that arose was making sure that the dynamic ranges had little effect on intonation, as it resulted in fewer harmonics being produced. To aid this, a tuner was used as a reference for each individual mouthpiece.

5. RESEARCH USING SPEAR

The main purpose of this study was to find the number of harmonics present for each mouthpiece. For the analysis, each individual track was checked for three things: The number of complete harmonics present, the highest complete harmonic (SPEAR shows harmonics as darker lines), and the highest partial captured. To find the number of complete harmonics present in each track the lowest harmonic that registered was selected with the cursor, the edit dropdown menu was utilized, and the select harmonics option was enabled. This highlighted the harmonics present in red. To find the highest complete harmonic, the graph was minimized until the highest and darkest harmonic present was found, the cursor hovered over the harmonic and the cursor reader was used to find exact measurements. To find the highest partial, or incomplete harmonic, the graph was minimized until the sound waves stopped registering. The notes that were focused from the exercises above were always the last sustained notes. After the creation of a harmonic structure, the last note had the best results. A complete list of each track's Number of Complete Harmonics, Highest Complete Harmonic, and Highest Partial in Hz as well as a graph is included in the appendix of this paper.

Mouthpiece Observations

Below is each mouthpiece's total number of harmonics for each exercise. A ranking was given from 1-4 with 1 having the most harmonics produced and 4 having the least harmonics produced. The average harmonics was configured from the total number of harmonics divided by the number of each exercise (8) for an average for each exercise.

Stainless-Steel Analysis

Overall Rank: 2 of 4

Table 1. Stainless-Steel Analysis

Exercise Name	**Total Number of Harmonics**	**Average Number of Harmonics**	**Rank Across All Mouthpieces**
Arpeggios	102	12.75	1
Descending *BEAUTIFUL SOUNDS*	280	35	4
Long Tones for Dynamic Range, Crescendo	173	21.625	1
Long Tones for Dynamic Range, Decrescendo	55	6.875	4

For this mouthpiece there was an overall inconsistent harmonic structure as can be seen from the ranking going between 1 and 4. When playing into the upper register and with a louder dynamic, the charting was very easy to read and dense as can be seen in the Arpeggios exercise and Long Tones for Dynamic Range, Crescendo. While analyzing the Arpeggios and Long Tones for Dynamic Range, Crescendo, the Highest Complete Harmonic was almost always in the sixth partial of the euphonium. The sixth partial is particularly difficult to play on the euphonium, so this mouthpiece helps with this problem. During the Descending *BEAUTIFUL SOUNDS* exercise, the Highest Partial in Hz was consistently an odd number, which when compared to the other mouthpieces, was not normally seen. In contrast to this, the Long Tones for Dynamic Range, Decrescendo exercise showed that the Highest Partial in Hz had more whole numbers.

Plastic Analysis

Overall Rank: 3 of 4

Table 2. Plastic Analysis

Exercise Name	**Total Number of Harmonics**	**Average Number of Harmonics**	**Rank Across All Mouthpieces**
Arpeggios	69	8.625	4
Descending *BEAUTIFUL SOUNDS*	341	42.625	1
Long Tones for Dynamic Range, Crescendo	136	17	4
Long Tones for Dynamic Range, Decrescendo	61	7.625	2

For this mouthpiece there was a gap in harmonic structure between 2000 Hz and 7500 Hz. All exercises showed a consistently present sixth partial on euphonium, especially the Long Tones for Dynamic Range, Crescendo. Like the Stainless-Steel mouthpiece, the sixth partial is particularly difficult to play on the euphonium, so this mouthpiece helps with this problem. The Arpeggios exercise showed a very weak harmonic structure for the upper register resulting in the lowest of all the mouthpieces. During the Descending *BEAUTIFUL SOUNDS* exercise, there was a very full, complex harmonic structure with exact Hz (.000) across the graphs. While performing the Long

Tones for Dynamic Range, Decrescendo, the Highest Complete Harmonic was always a very prominent fourth partial on the euphonium.

Gold Analysis

Overall Rank: 4 of 4

Table 3. Gold Analysis

Exercise Name	**Total Number of Harmonics**	**Average Number of Harmonics**	**Rank Across All Mouthpieces**
Arpeggios	75	9.375	3
Descending *BEAUTIFUL SOUNDS*	303	37.875	3
Long Tones for Dynamic Range, Crescendo	144	18	3
Long Tones for Dynamic Range, Decrescendo	56	7	3

For this mouthpiece there was a gap in harmonic structure between 3300 Hz and 6500 Hz. Throughout all exercises, the Highest Complete Harmonic was always exact (.000). When analyzing the Arpeggios exercise, there was an inconsistent Number of Complete Harmonics. By just descending by a half-step in the exercise resulted in 8 additional or missing harmonics. With the same exercise being performed, this number should not fluctuate just because the pitch changed. During the Descending *BEAUTIFUL SOUNDS* and Long Tones for Dynamic Range, Crescendo, there was an increase in the

Number of Complete Harmonics as the exercise descended chromatically. Also, when manipulating the low end of dynamics with the Long Tones for Dynamic Range, Decrescendo, there was consistently a low Number of Complete Harmonics.

Silver-Plated Analysis

Overall Rank: 1 of 4

Table 4. Silver-Plated Analysis

Exercise Name	**Total Number of Harmonics**	**Average Number of Harmonics**	**Rank Across All Mouthpieces**
Arpeggios	87	10.875	2
Descending *BEAUTIFUL SOUNDS*	323	40.375	2
Long Tones for Dynamic Range, Crescendo	166	20.75	2
Long Tones for Dynamic Range, Decrescendo	62	7.75	1

For this mouthpiece, the Highest Complete Harmonic was consistently even in Hz (.000). While inspecting the Arpeggios exercise, there was a decreasing Number of Complete Harmonics as the exercise descended chromatically. Contrasting to this, the Descending *BEAUTIFUL SOUNDS* and Long Tones for Dynamic Range, Crescendo had an increasing Number of Complete Harmonics as the exercise descended chromatically.

Like the Plastic analysis, the Long Tones for Dynamic Range, Decrescendo had the Highest Complete Harmonic always in the fourth partial on the euphonium.

After looking at the averages, one can see that the mouthpiece to create the most harmonics is Plastic with an average of 42.625, produced during the Descending *BEAUTIFUL SOUNDS* exercise. The mouthpiece to produce the most upper register harmonics using the Arpeggios exercise was Stainless-Steel with an average of 12.75. For the crescendo exercises, it was a lot closer, all within 4 harmonics, but the Stainless-Steel mouthpiece had the most with an average of 21.625. Last is the decrescendo, with an average of 7.75 harmonics produced by the Silver-Plated.

6. CONCLUSION

Combining all the data has shown that the rank of mouthpieces based on the average number of harmonics produced are Silver-Plating 1, Stainless-Steel 2, Plastic 3, and Gold 4. The most consistent of all the mouthpieces was the Silver-Plated. With an average rank of 2 for each exercise, this mouthpiece created the best harmonic structure of all the mouthpiece materials present for the exercises analyzed. While Stainless-Steel and Plastic also had a few exercises where they scored a rank of 1, they were followed up by having two low ranks of 4, giving them an overall low average score. The Gold mouthpiece was consistent with a rank of 3 across the board.

Table 5. Combined Analysis

Mouthpiece Material	**Rank**	**Total Harmonics (All Exercises)**	**Total Average (All Exercises)**
Silver-Plating	1	638	19.9375
Stainless-Steel	2	610	19.0625
Plastic	3	607	18.96875
Gold	4	578	18.0625

With Silver-Plating having the most harmonics consistently produced in all ranges on the euphonium, the author concludes this mouthpiece material to be the best representation of consistent euphonium timbre. There are many ways to interpret an ideal sound, but for this paper, I am equating the presence of strong overtones as the basis for an ideal euphonium sound. After this research has taken place, euphonium players might consider using different mouthpiece materials for different performance situations in order to utilize specific harmonics.

Some questions that this research has presented is whether a performer could utilize different mouthpiece materials for different pieces of music? What if it takes more than one mouthpiece to bring out the best of the euphonium sound?

Possible areas of continued research could be a different mouthpiece model other than the Schilke 51 D. By changing the rim and cup size, one may find a more consistent mouthpiece for the euphonium. Another possible extension of this study would be utilizing multiple players with the same conditions and materials. The data found between different players and the same materials could yield a different outcome. A final area of continued research would be a listener perception study, to determine if a listener can hear a significant difference between mouthpiece materials.

A couple of areas for further study of this research would be to create a mouthpiece that utilizes all the best rankings from each individual mouthpiece. By having the best ranking for each exercise, it could possibly create the most complete mouthpiece for euphonium in terms of harmonics produced.

Another area to change the perceived sound of the euphonium could be to manipulate the acoustic environment. Using more than one microphone or the placement in relation to the sound source could have different results. By having the same research recorded in a performance hall, there could be harmonics produced due to a prolongation of the sound over time, which already showed results as evident in the Arpeggios exercise.

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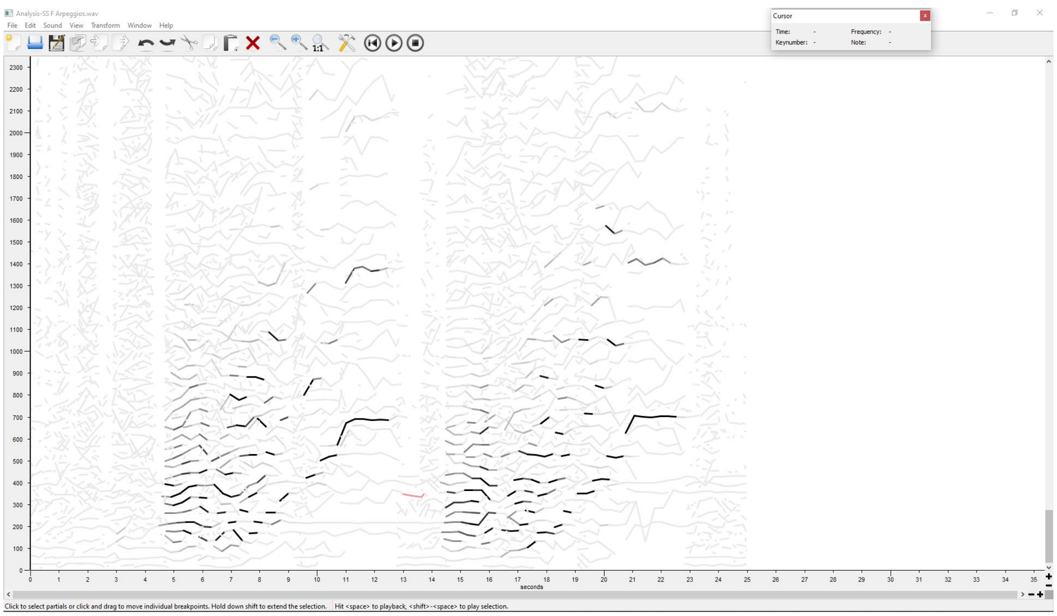
APPENDIX

A. DATA COLLECTED JANUARY 2021 – MARCH 2021

Stainless-Steel Arpeggios

F Arpeggios:

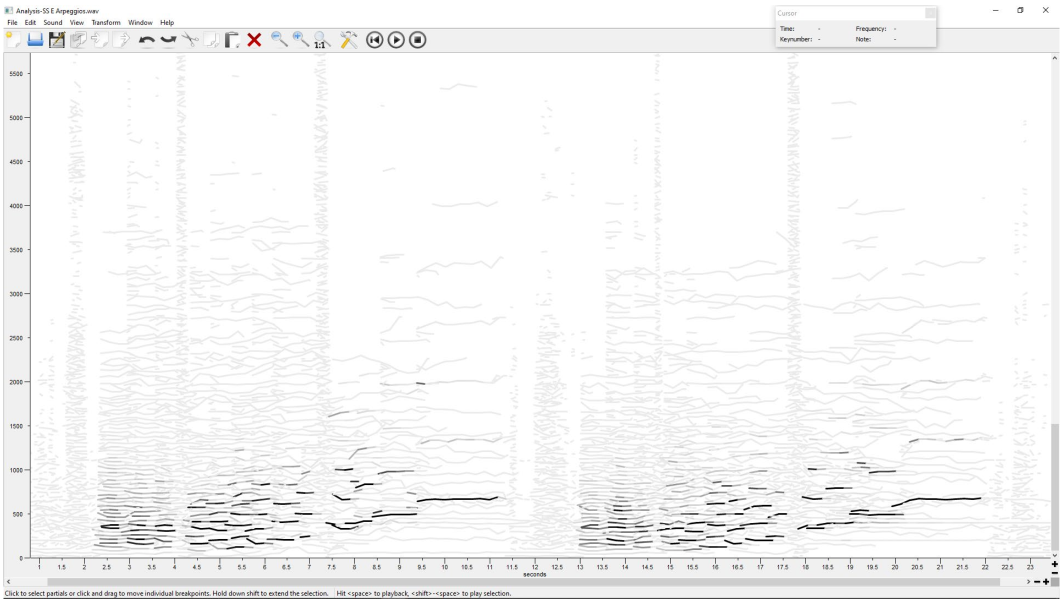


Number of Complete Harmonics – 13

Highest Complete Harmonic – G6, 1572.000 Hz

Highest Partial in Hz – Bb9, 14702.080

E Arpeggios:

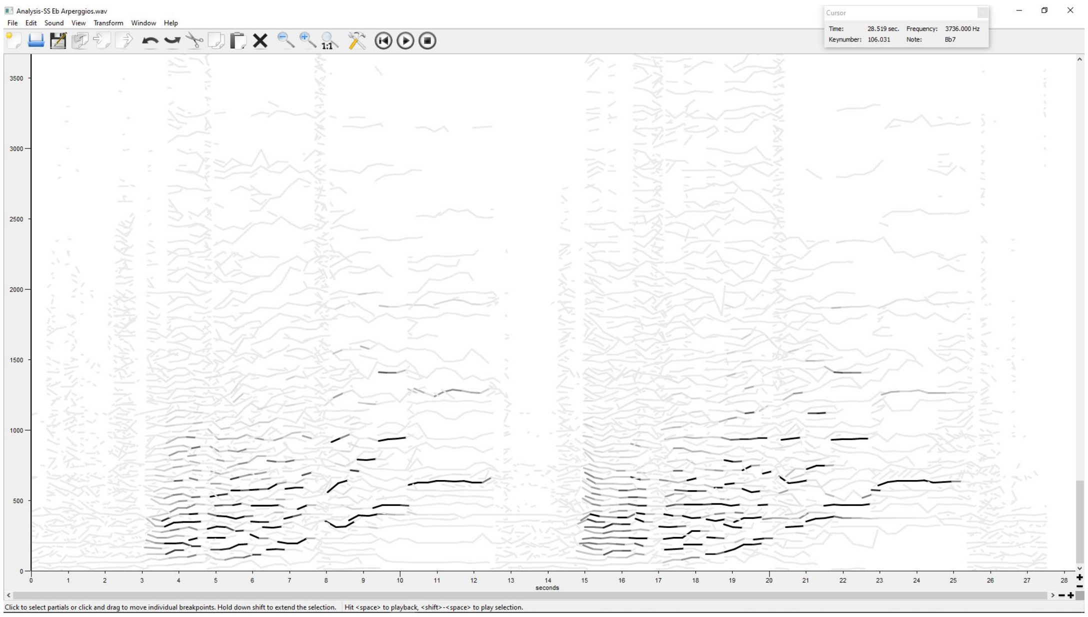


Number of Complete Harmonics – 11

Highest Complete Harmonic – B6, 1987.500 Hz

Highest Partial in Hz – Eb10, 19799.998

Eb Arpeggios:

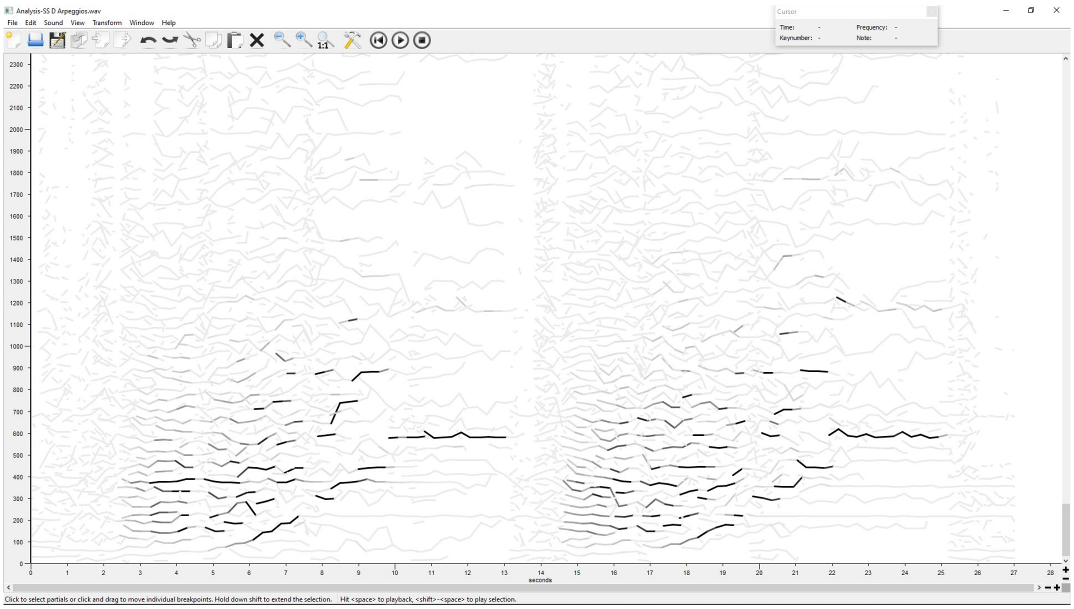


Number of Complete Harmonics – 13

Highest Complete Harmonic – F#6, 1456 Hz

Highest Partial in Hz – F10, 22039.061

D Arpeggios:

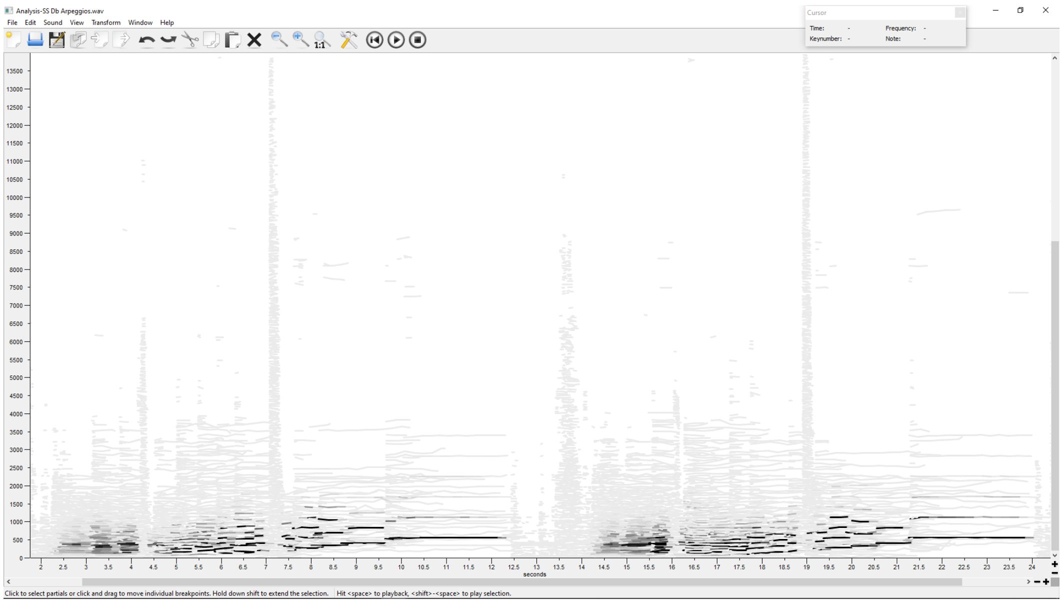


Number of Complete Harmonics – 12

Highest Complete Harmonic – Eb6, 1228 Hz

Highest Partial in Hz – Eb10, 20065.000

Db Arpeggios:

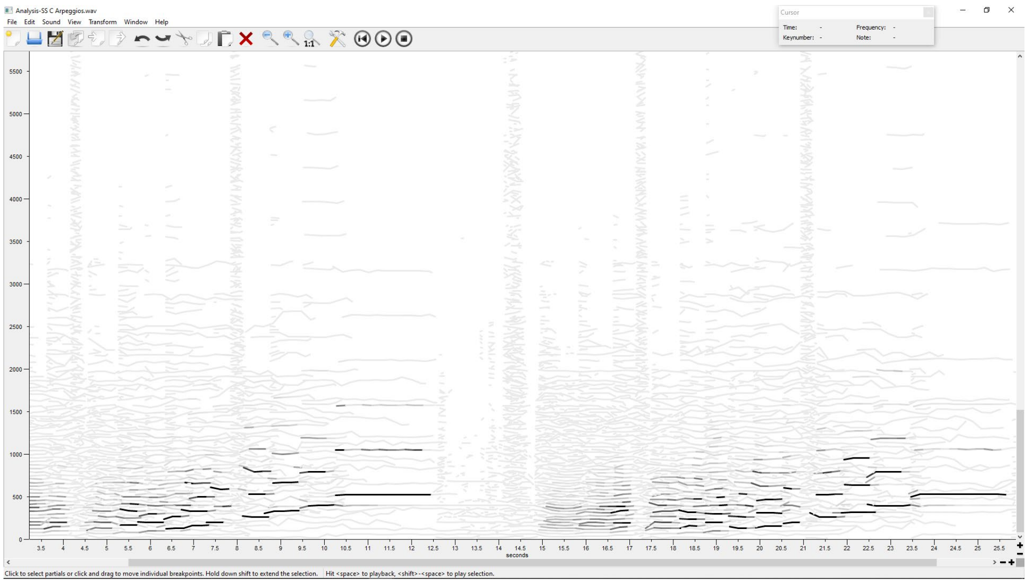


Number of Complete Harmonics – 6

Highest Complete Harmonic – G#6, 1687.500 Hz

Highest Partial in Hz – C#10, 18005.369

C Arpeggios:

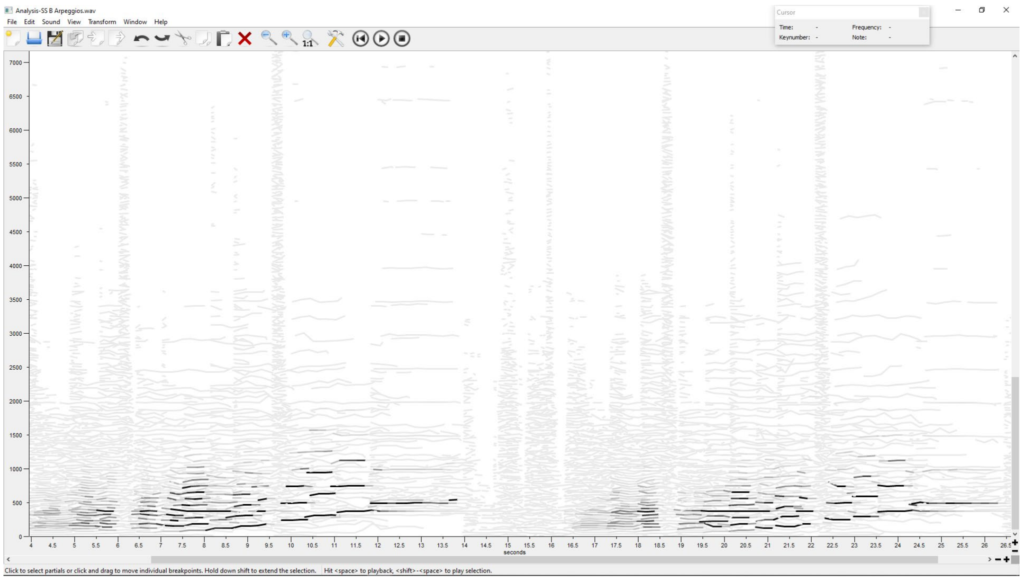


Number of Complete Harmonics – 23

Highest Complete Harmonic – G7, 1575.000 Hz

Highest Partial in Hz – F10, 21806.248

B Arpeggios:

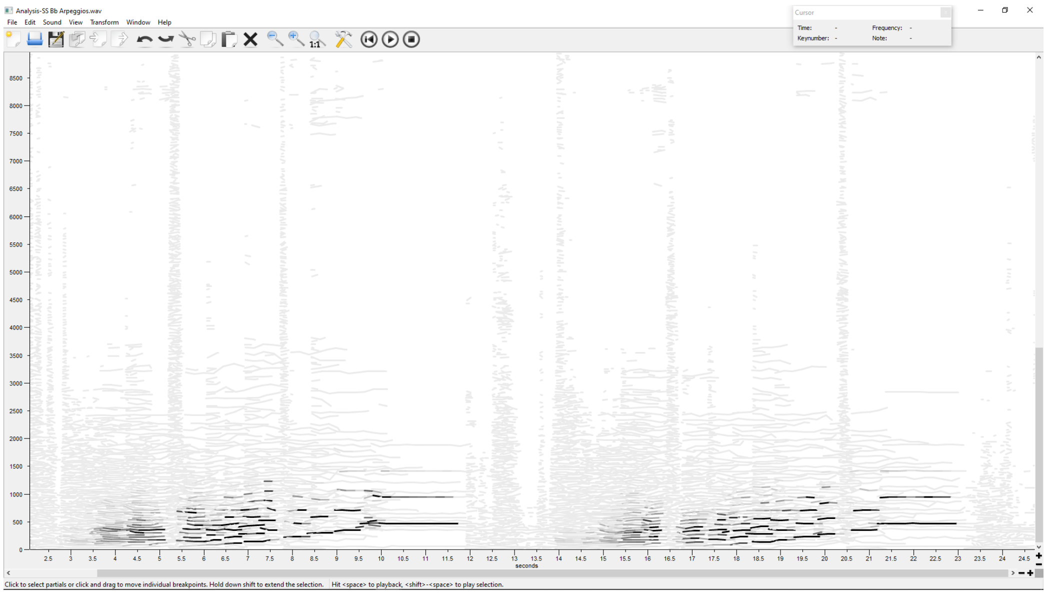


Number of Complete Harmonics – 17

Highest Complete Harmonic – C#6, 1125.000 Hz

Highest Partial in Hz – E10, 21337.889

Bb Arpeggios:

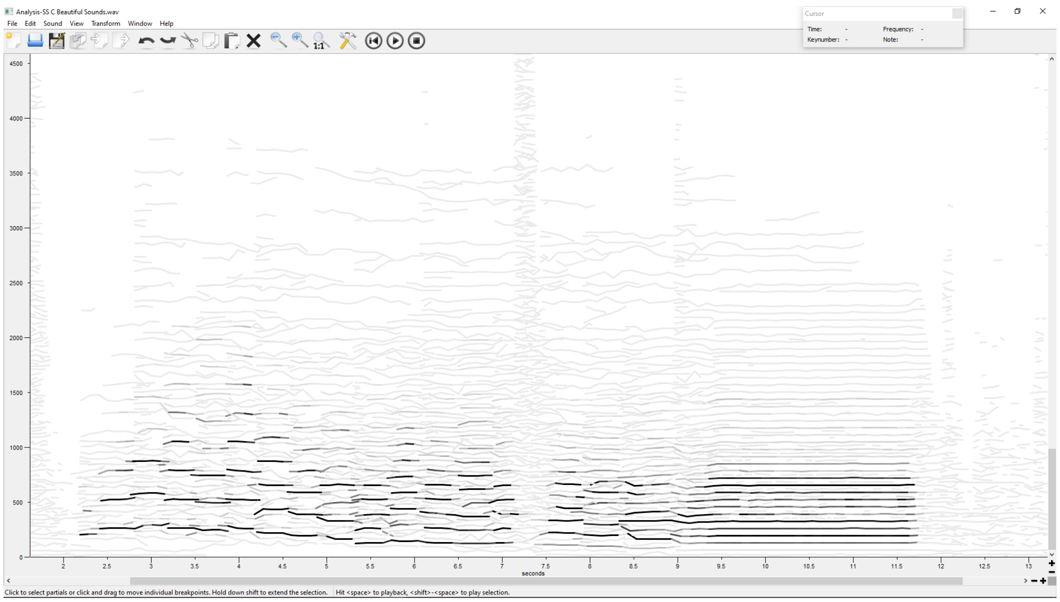


Number of Complete Harmonics – 7

Highest Complete Harmonic – Eb6, 1226.563 Hz

Highest Partial in Hz – B9, 15781.249

C Descending *BEAUTIFUL SOUNDS*:

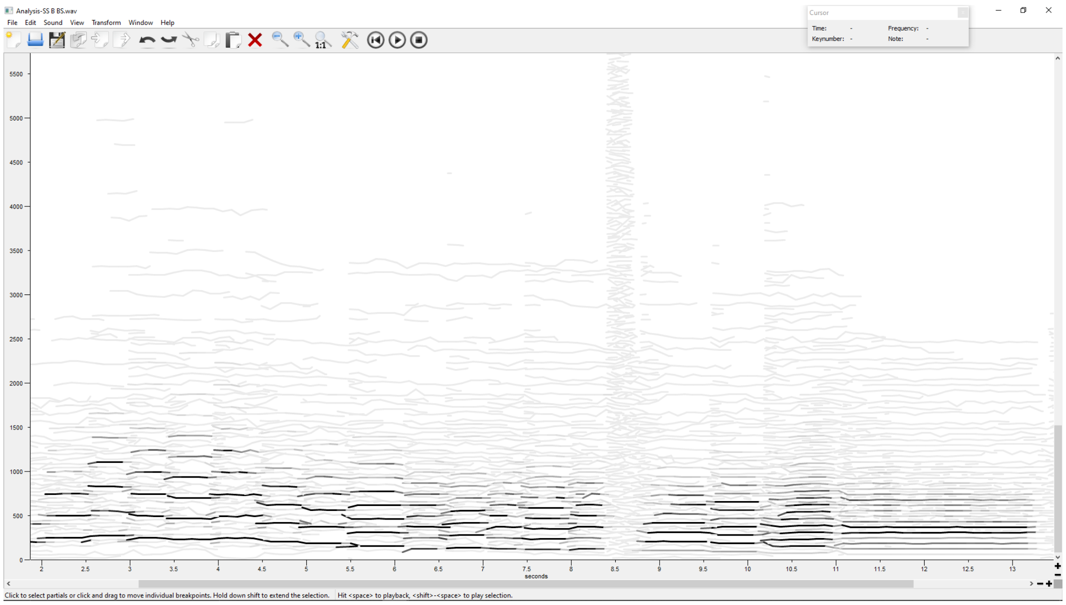


Number of Complete Harmonics – 26

Highest Complete Harmonic – G#5, 850.000 Hz

Highest Partial in Hz – D10, 19256.248

B Descending *BEAUTIFUL SOUNDS*:

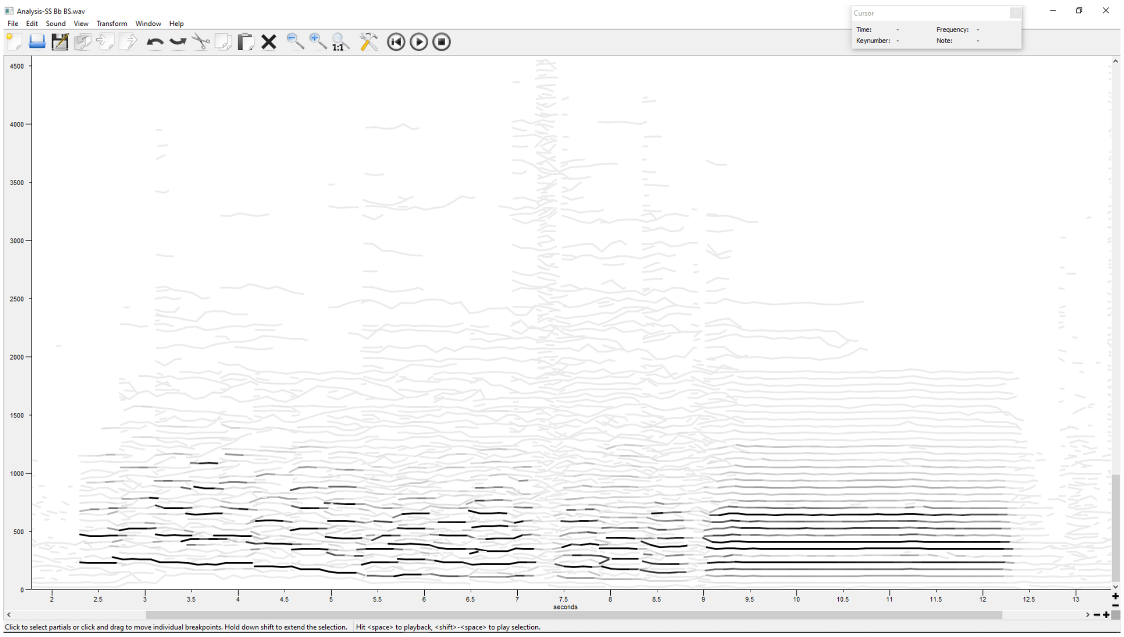


Number of Complete Harmonics – 22

Highest Complete Harmonic – F#5, 750.000 Hz

Highest Partial in Hz – E10, 20578.123

Bb Descending *BEAUTIFUL SOUNDS*:

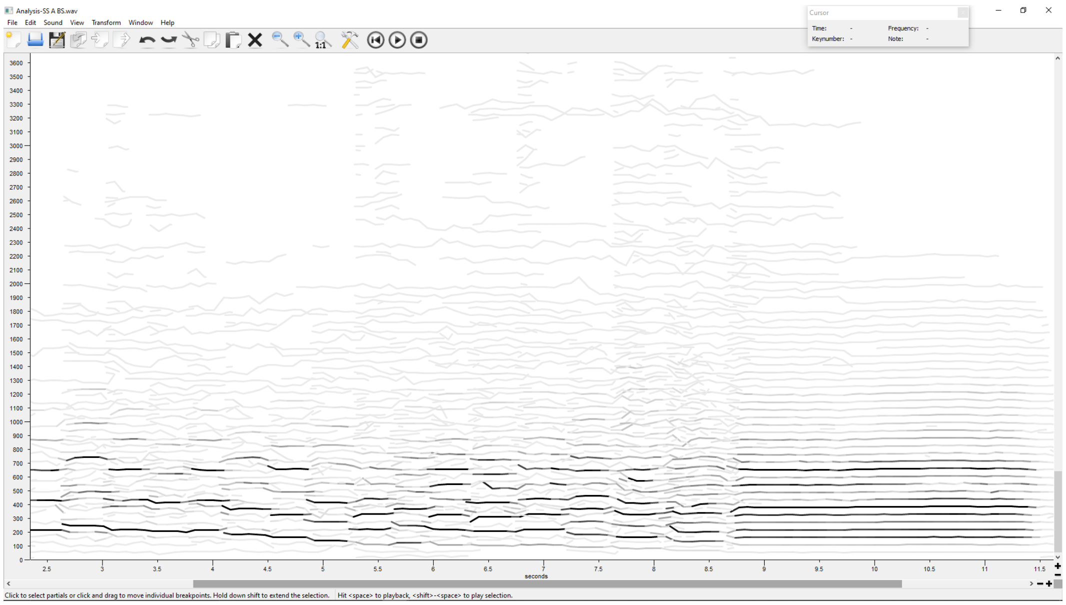


Number of Complete Harmonics – 33

Highest Complete Harmonic – F#5, 720.000 Hz

Highest Partial in Hz – Eb10, 19555.000

A Descending *BEAUTIFUL SOUNDS*:

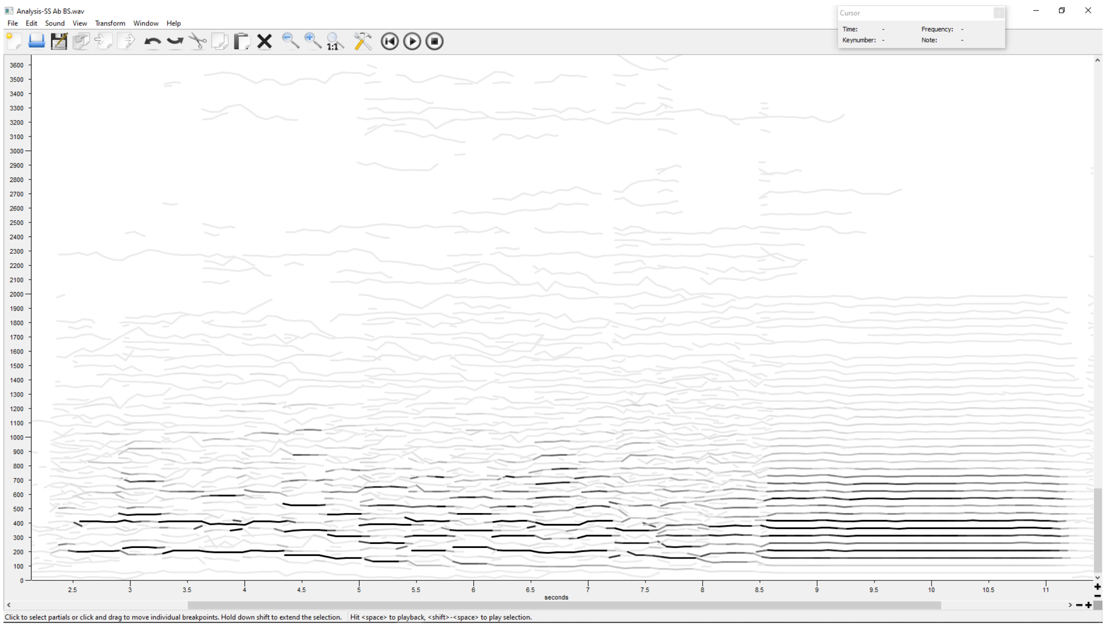


Number of Complete Harmonics – 37

Highest Complete Harmonic – F5, 712.000 Hz

Highest Partial in Hz – C9, 8299.999

Ab Descending *BEAUTIFUL SOUNDS*:

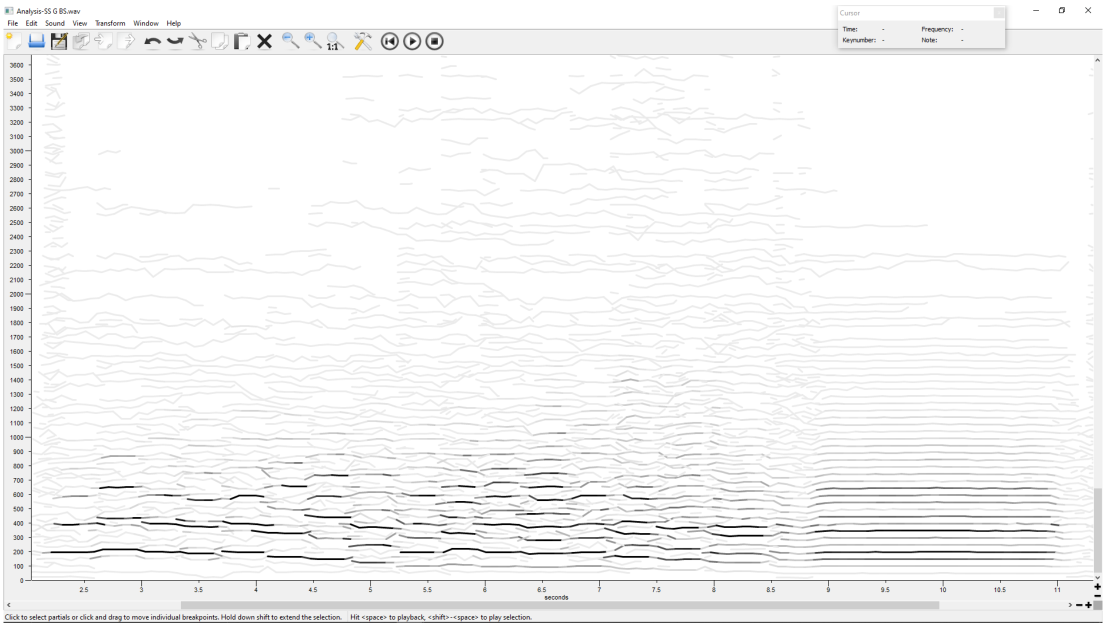


Number of Complete Harmonics – 37

Highest Complete Harmonic – F5, 716.000 Hz

Highest Partial in Hz – C9, 8218.750

G Descending *BEAUTIFUL SOUNDS*:

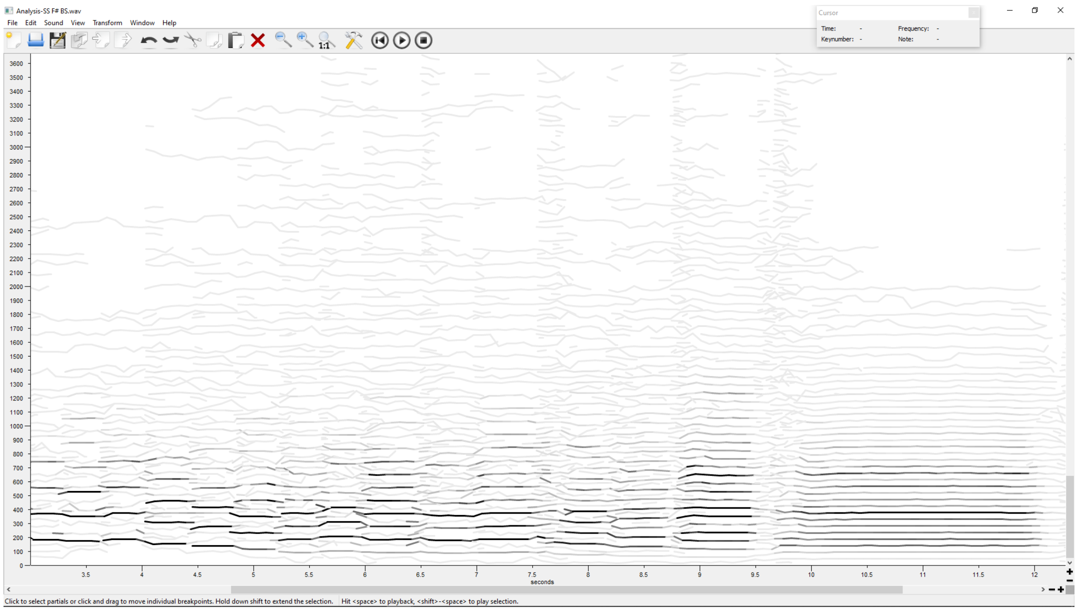


Number of Complete Harmonics – 40

Highest Complete Harmonic – E5, 648.000 Hz

Highest Partial in Hz – G#8, 6543.750

F# Descending *BEAUTIFUL SOUNDS*:

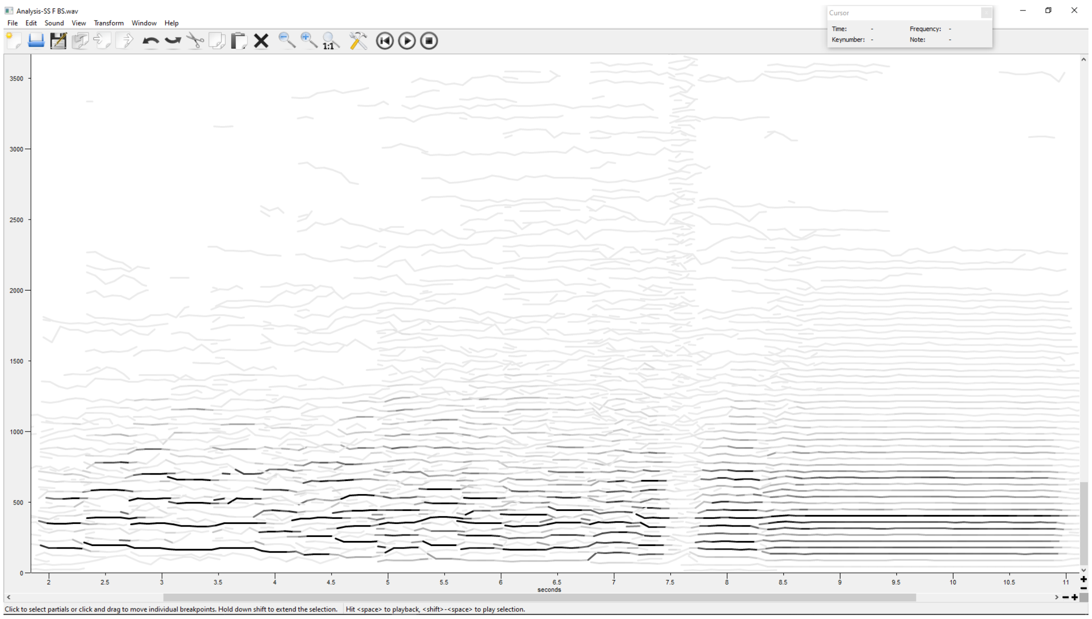


Number of Complete Harmonics – 37

Highest Complete Harmonic – G#5, 852.000 Hz

Highest Partial in Hz – D9, 9174.999

F Descending *BEAUTIFUL SOUNDS*:

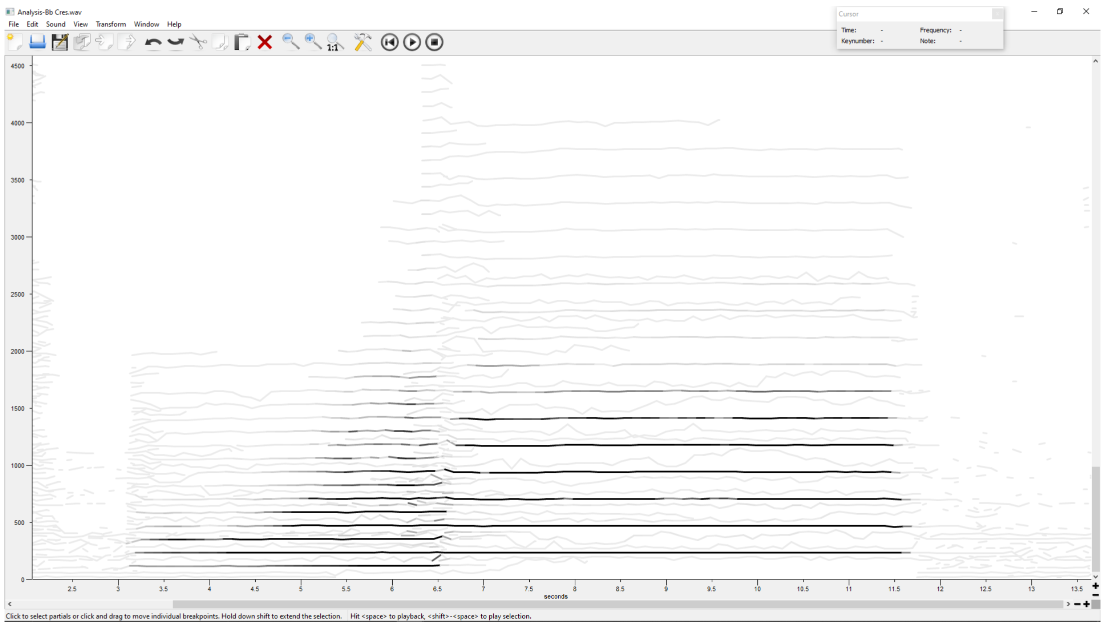


Number of Complete Harmonics – 48

Highest Complete Harmonic – E5, 668.000 Hz

Highest Partial in Hz – B9, 15500.000

Bb Long Tones for Dynamic Range, Crescendo:

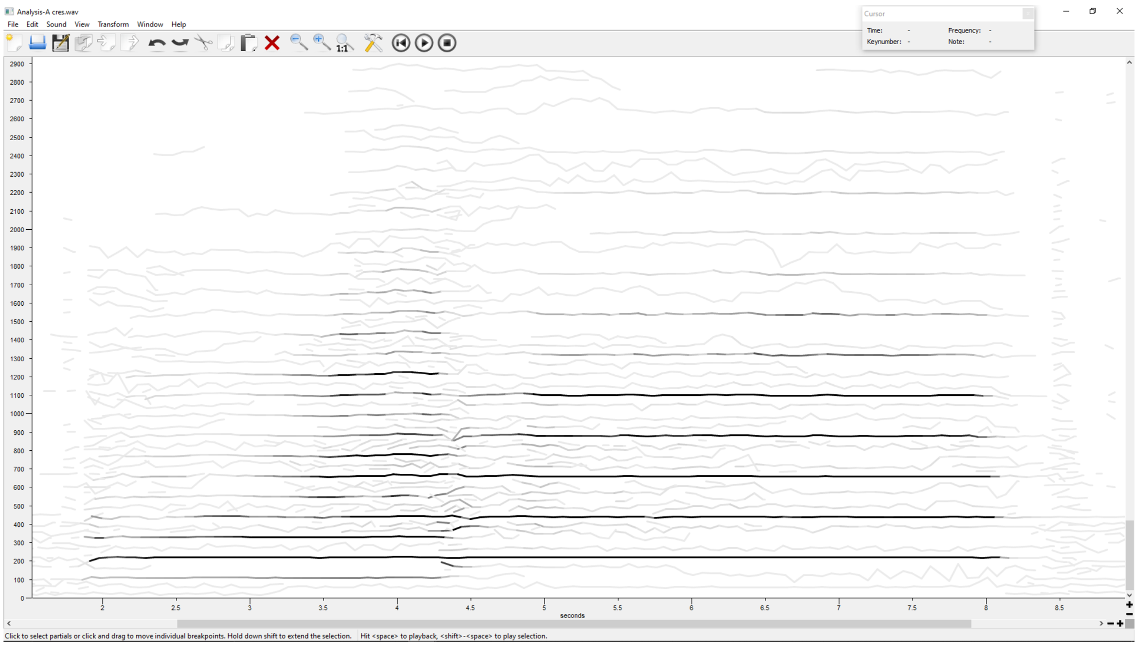


Number of Complete Harmonics – 24

Highest Complete Harmonic – G#6, 1640.625 Hz

Highest Partial in Hz – E9, 10771.483

A Long Tones for Dynamic Range, Crescendo:

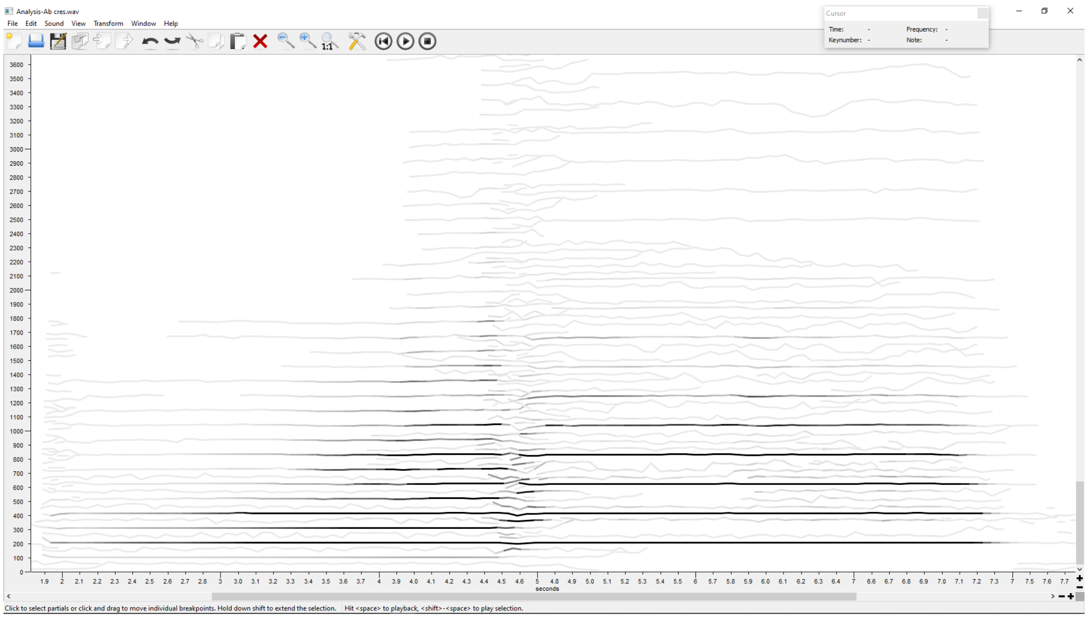


Number of Complete Harmonics – 19

Highest Complete Harmonic – G6, 1539.062 Hz

Highest Partial in Hz – C#9, 8867.188

Ab Long Tones for Dynamic Range, Crescendo:

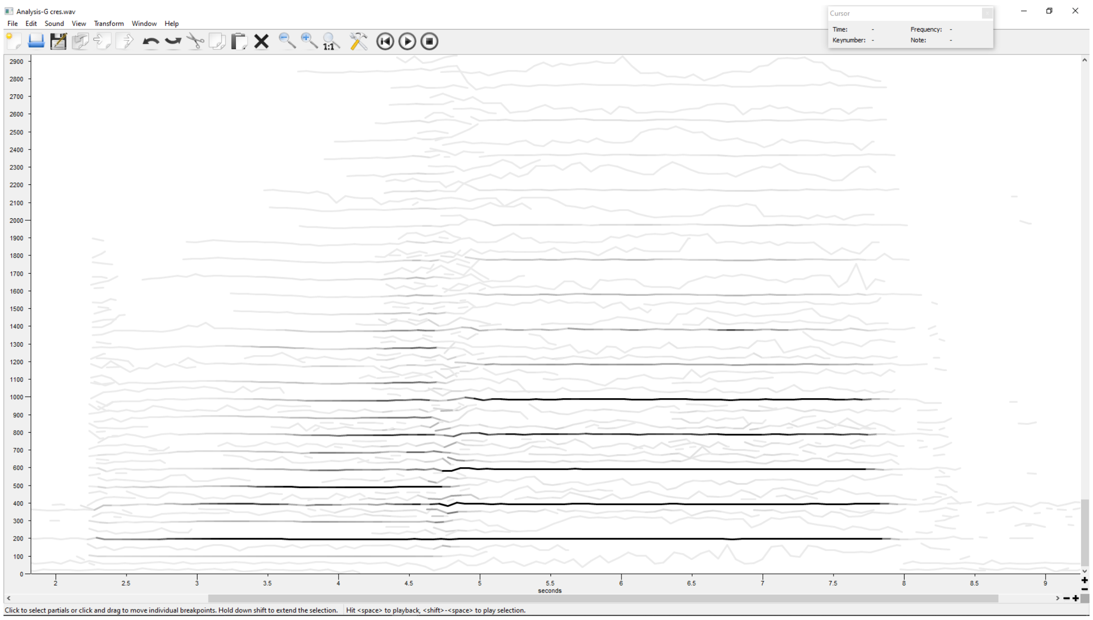


Number of Complete Harmonics – 19

Highest Complete Harmonic – G#6, 1660.000 Hz

Highest Partial in Hz – C#9, 8632.813

G Long Tones for Dynamic Range, Crescendo:

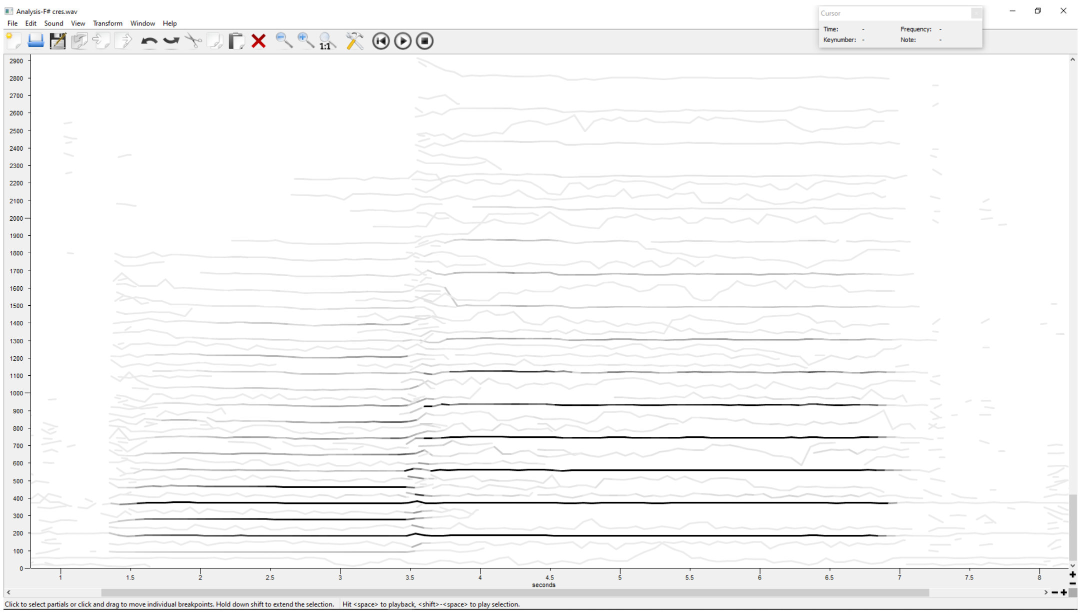


Number of Complete Harmonics – 21

Highest Complete Harmonic – F6, 1380.000 Hz

Highest Partial in Hz – C#8, 4539.063

F# Long Tones for Dynamic Range, Crescendo:

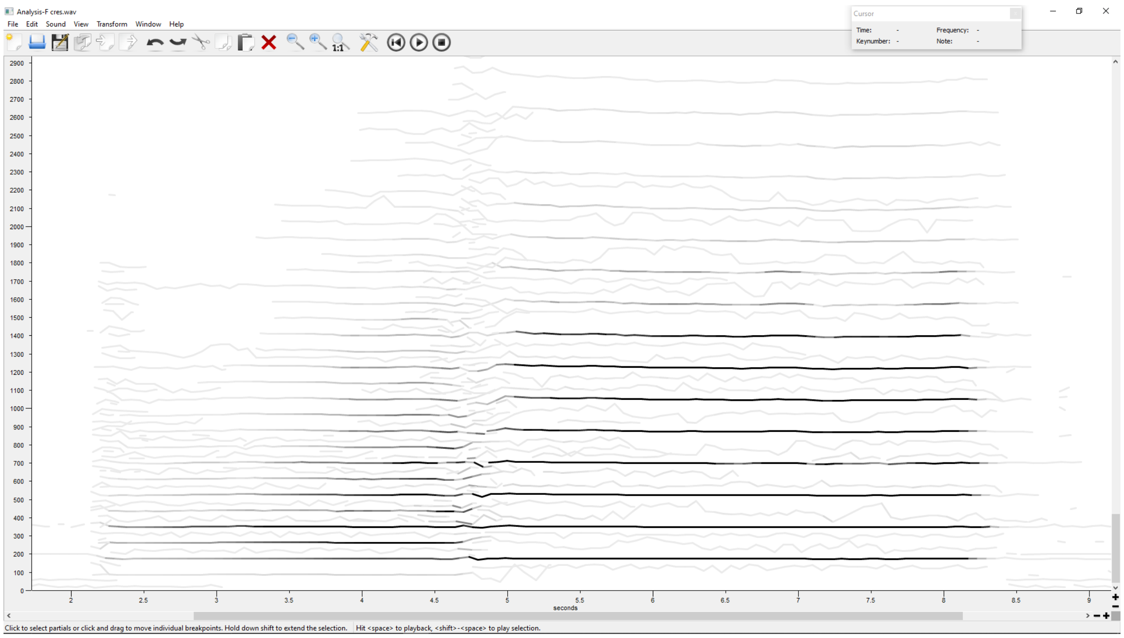


Number of Complete Harmonics – 18

Highest Complete Harmonic – C#6, 1124.000 Hz

Highest Partial in Hz – F#8, 5850.000

F Long Tones for Dynamic Range, Crescendo:

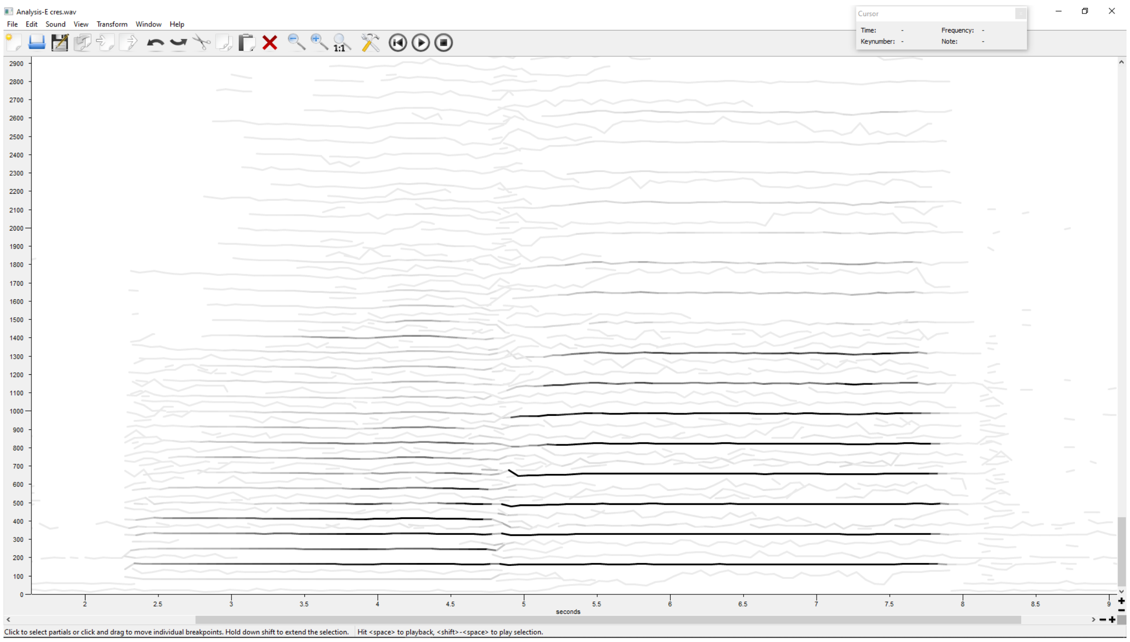


Number of Complete Harmonics – 19

Highest Complete Harmonic – A6, 1756.000 Hz

Highest Partial in Hz – B7, 3920.000

E Long Tones for Dynamic Range, Crescendo:

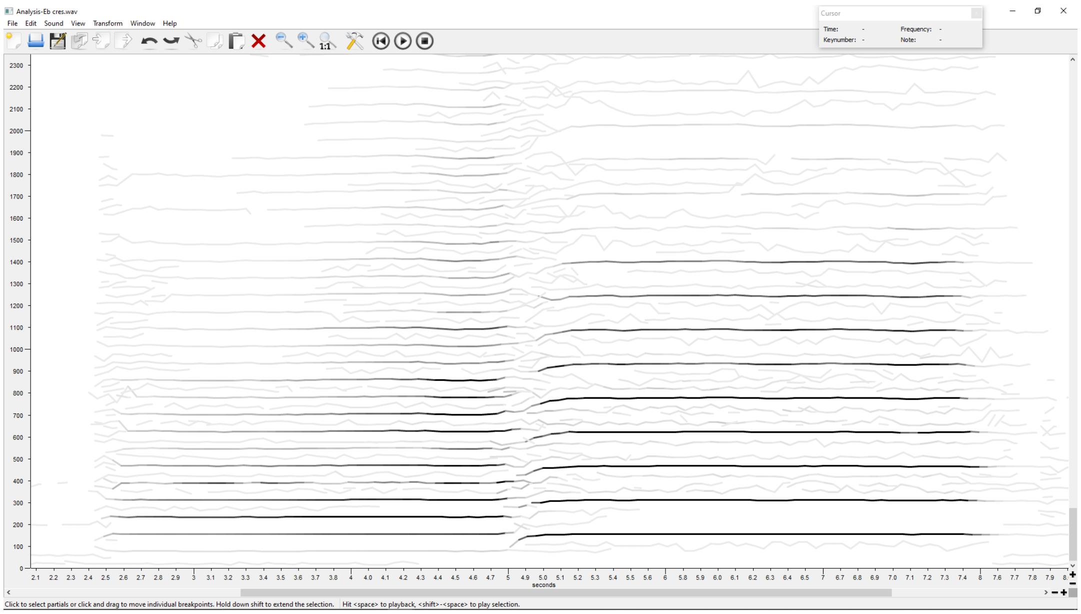


Number of Complete Harmonics – 26

Highest Complete Harmonic – E6, 1312.500 Hz

Highest Partial in Hz – C9, 8406.249

Eb Long Tones for Dynamic Range, Crescendo:

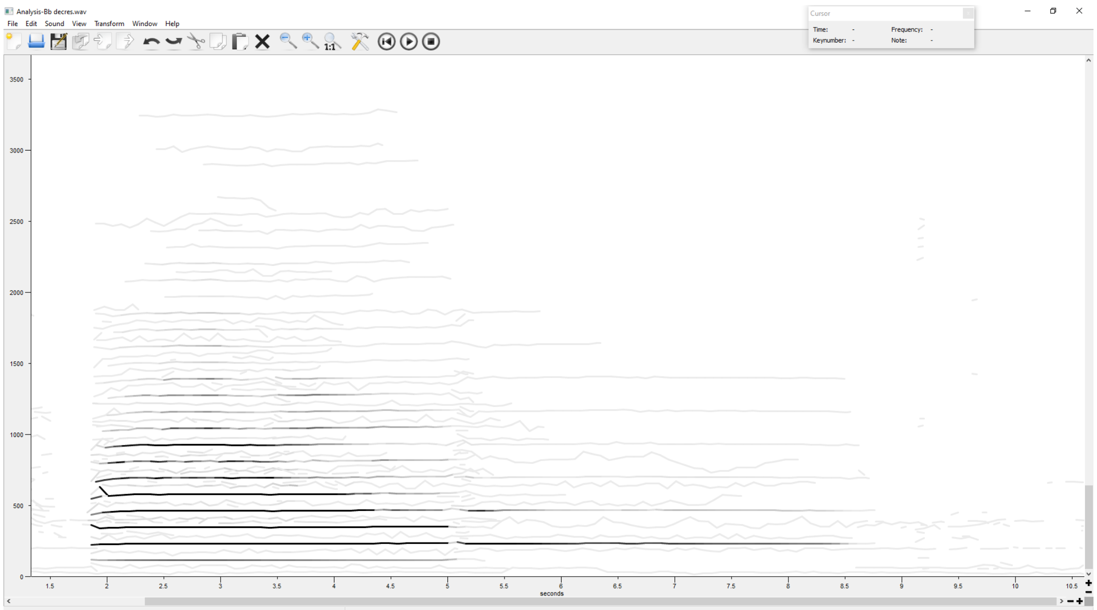


Number of Complete Harmonics – 27

Highest Complete Harmonic – F6, 1400.000 Hz

Highest Partial in Hz – F9, 11462.499

Bb Long Tones for Dynamic Range, Decrescendo:

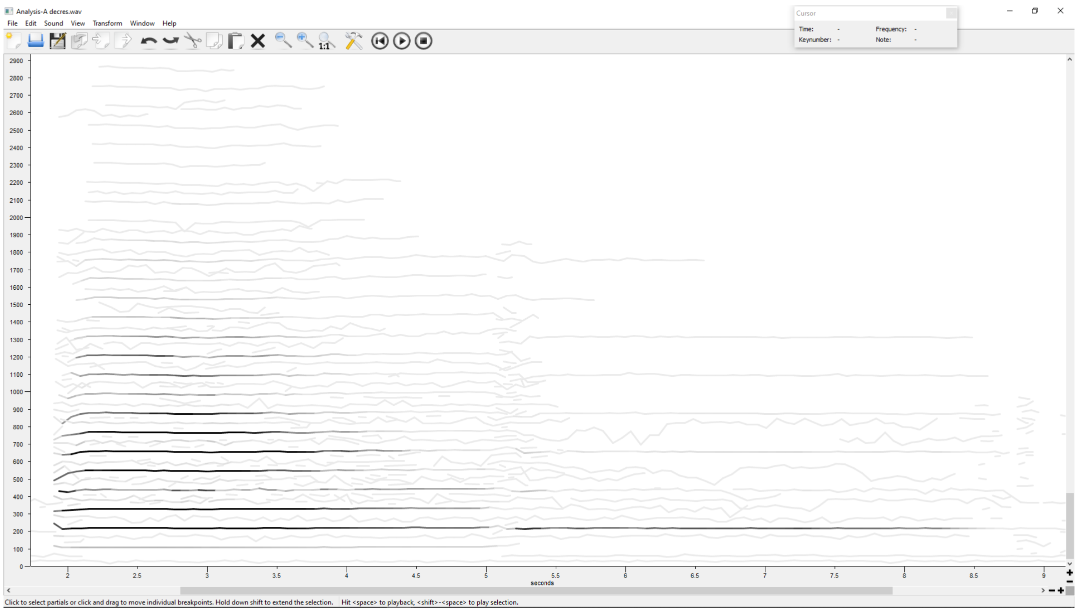


Number of Complete Harmonics – 6

Highest Complete Harmonic – F6, 1400 Hz

Highest Partial in Hz – G#6, 1640.000

A Long Tones for Dynamic Range, Decrescendo:

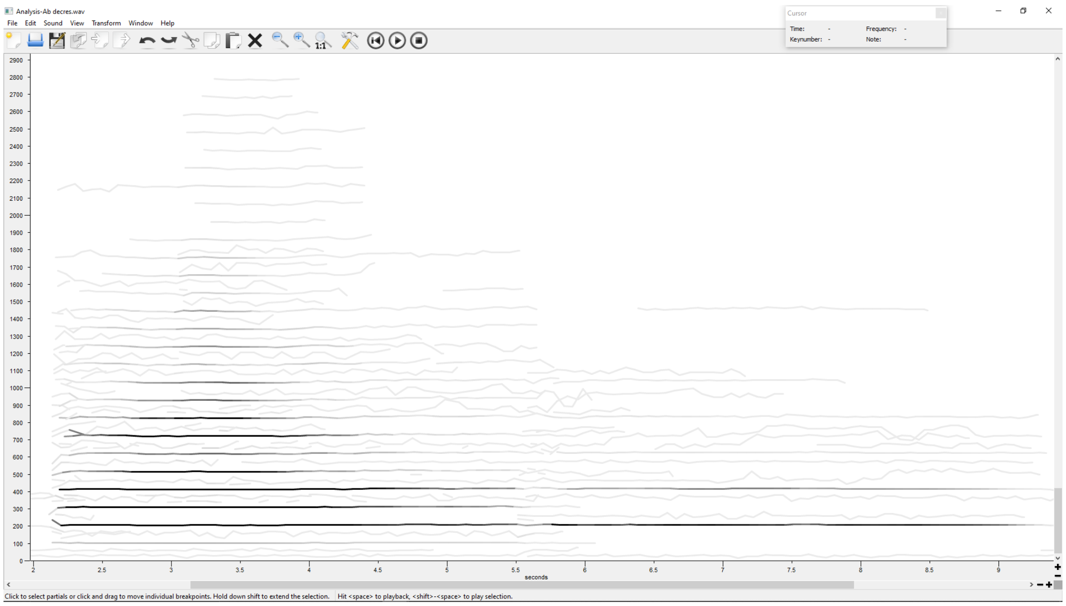


Number of Complete Harmonics – 6

Highest Complete Harmonic – E6, 1320.000 Hz

Highest Partial in Hz – A6, 1756.000

Ab Long Tones for Dynamic Range, Decrescendo:

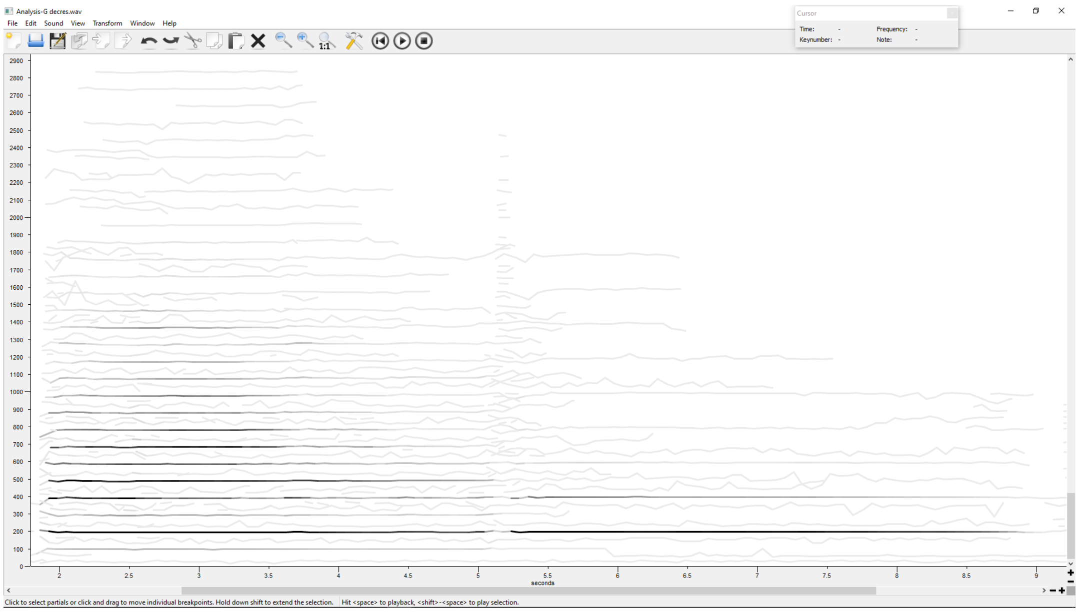


Number of Complete Harmonics – 6

Highest Complete Harmonic – G#4, 420.000 Hz

Highest Partial in Hz – F#6, 1455.000

G Long Tones for Dynamic Range, Decrescendo:

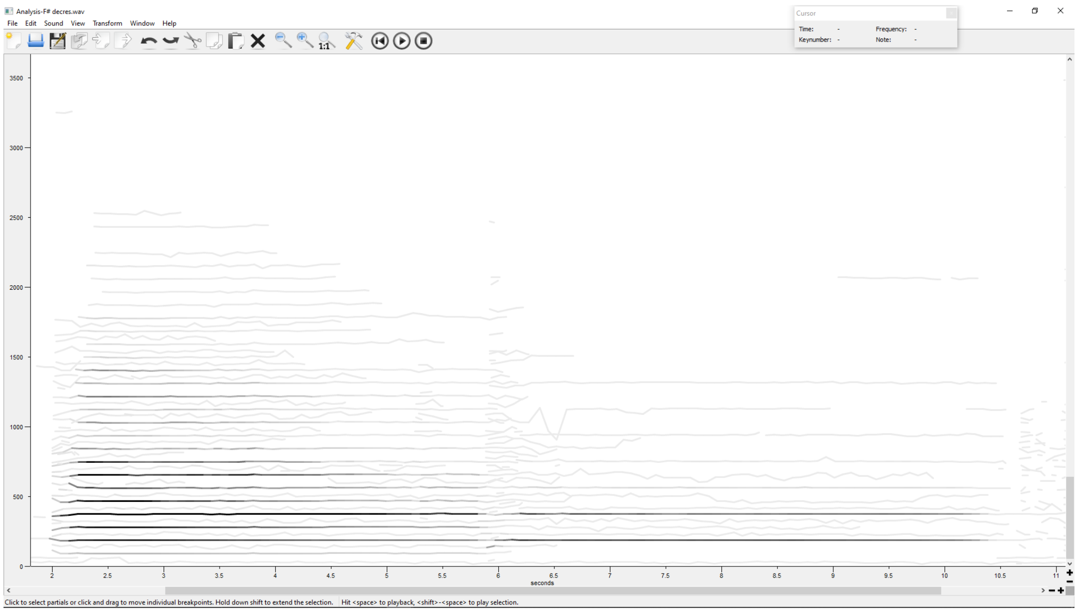


Number of Complete Harmonics – 9

Highest Complete Harmonic – G4, 395.000 Hz

Highest Partial in Hz – A6, 1780.000

F# Long Tones for Dynamic Range, Decrescendo:

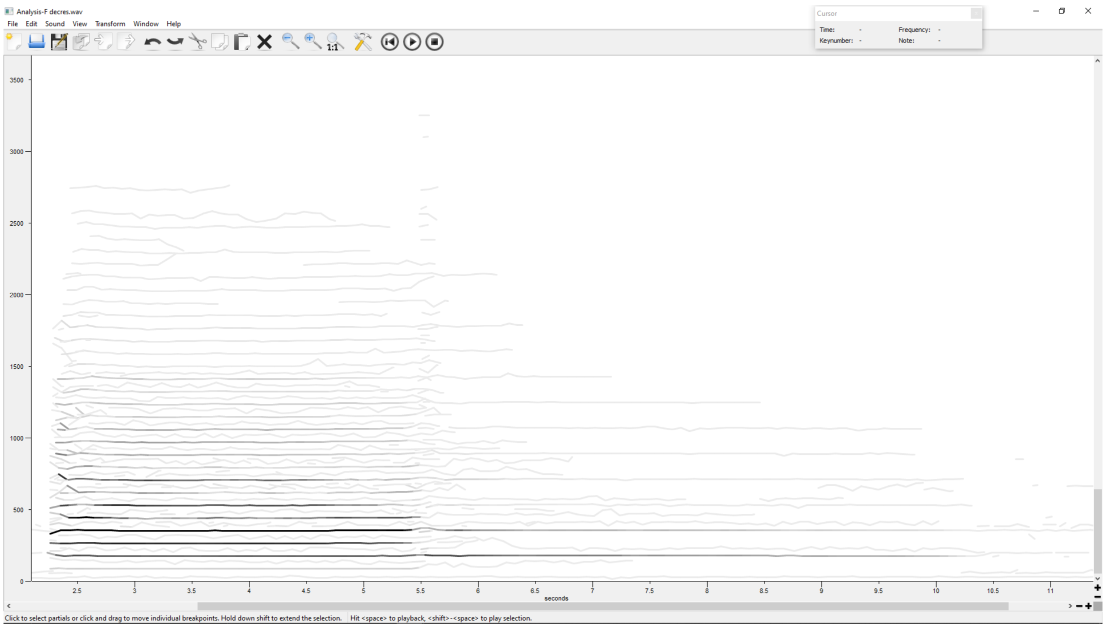


Number of Complete Harmonics – 7

Highest Complete Harmonic – F#4, 375.000 Hz

Highest Partial in Hz – C7, 2070.313

F Long Tones for Dynamic Range, Decrescendo:

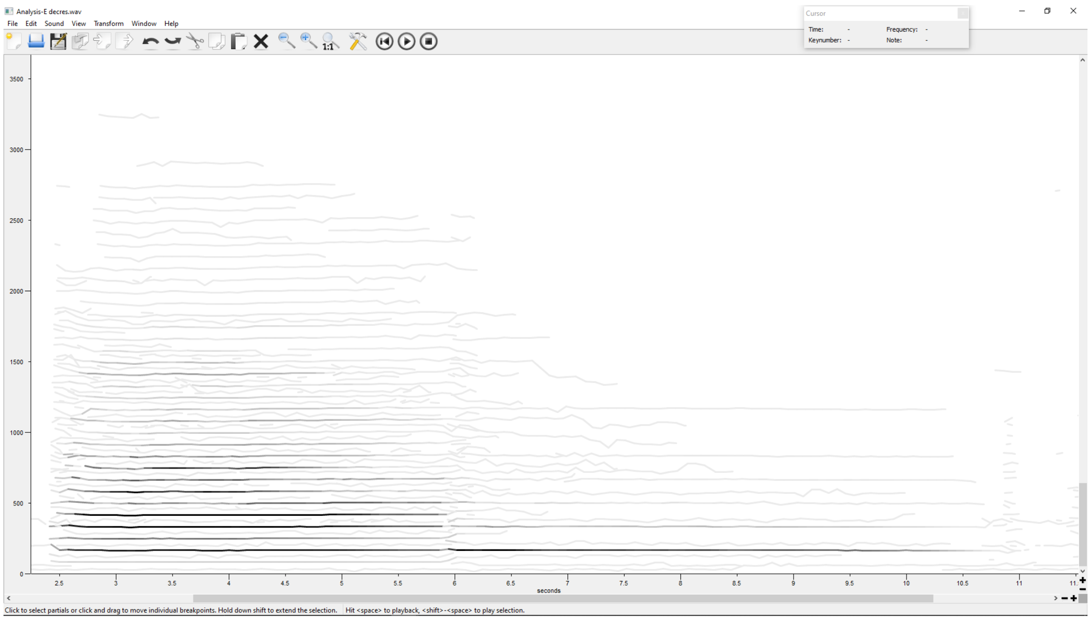


Number of Complete Harmonics – 7

Highest Complete Harmonic – F4, 356.000 Hz

Highest Partial in Hz – A6, 1788.000

E Long Tones for Dynamic Range, Decrescendo:

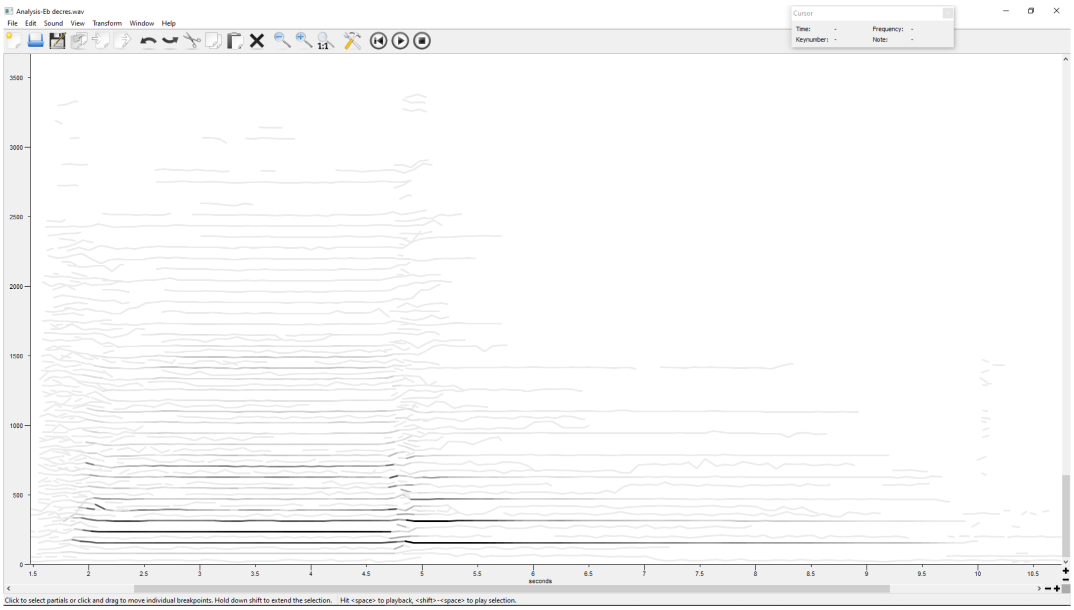


Number of Complete Harmonics – 6

Highest Complete Harmonic – E4, 325.000 Hz

Highest Partial in Hz – E6, 1343.750

Eb Long Tones for Dynamic Range, Decrescendo:



Number of Complete Harmonics – 8

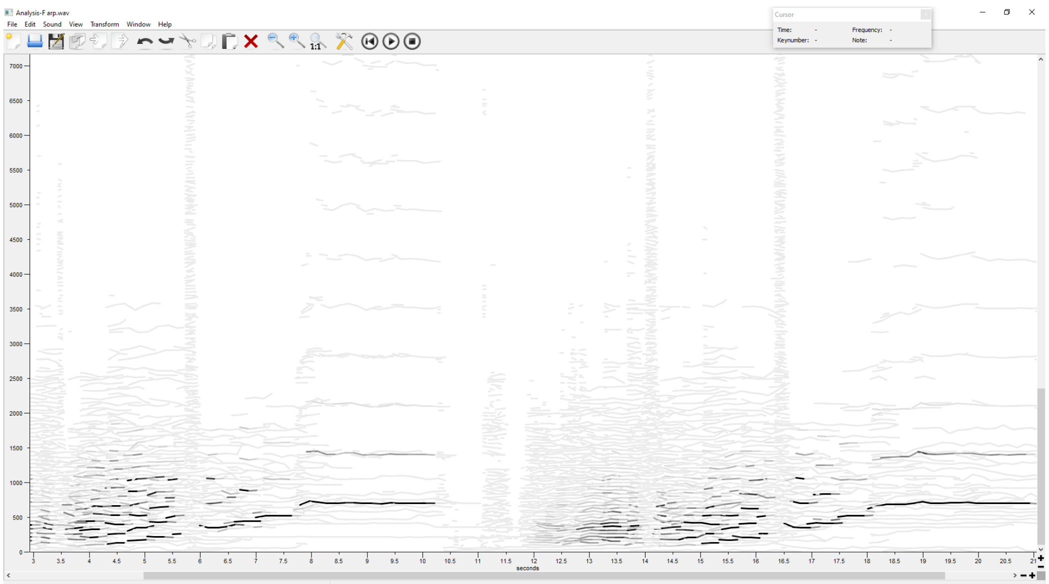
Highest Complete Harmonic – Eb4, 310.000 Hz

Highest Partial in Hz – F6, 1410.000

Plastic Analysis

Plastic Arpeggios

F Arpeggios:

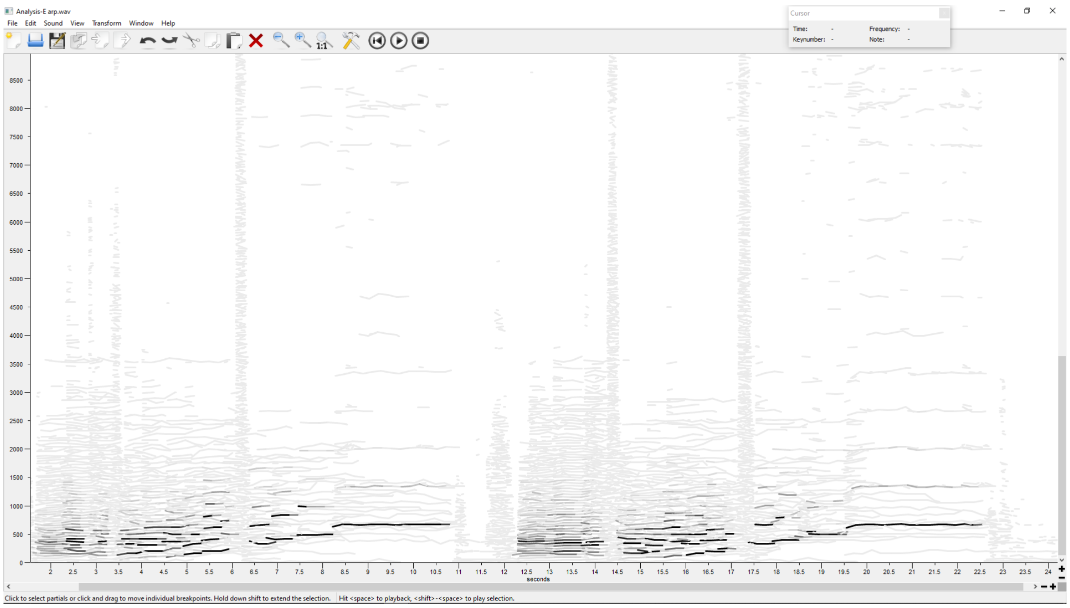


Number of Complete Harmonics – 12

Highest Complete Harmonic – F6, 1406.250 Hz

Highest Partial in Hz – A9, 13804.687

E Arpeggios:

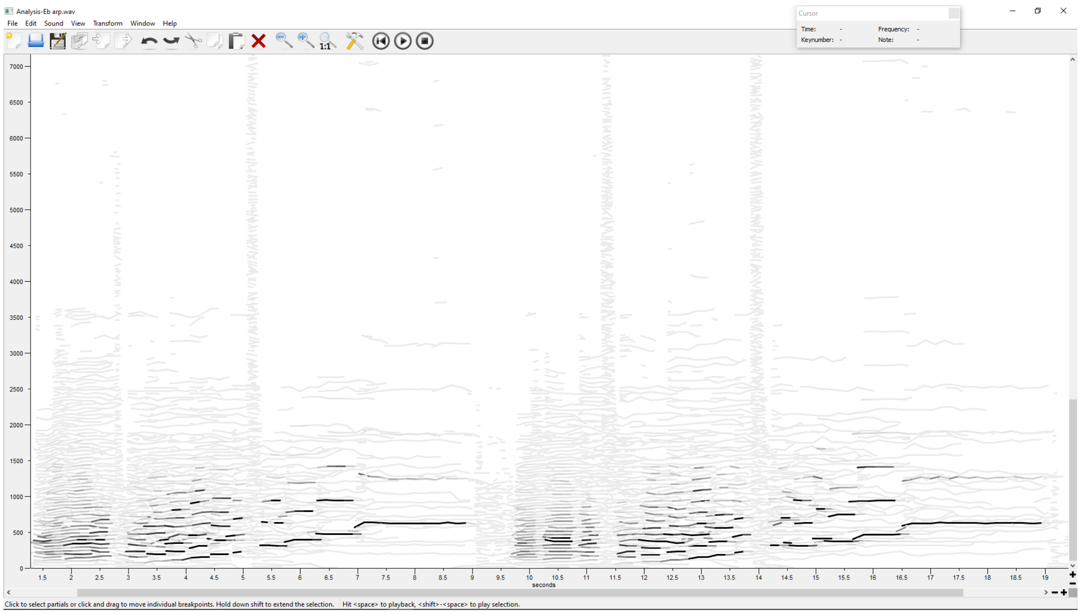


Number of Complete Harmonics – 13

Highest Complete Harmonic – E6, 1335.937 Hz

Highest Partial in Hz – B9, 15439.452

Eb Arpeggios:

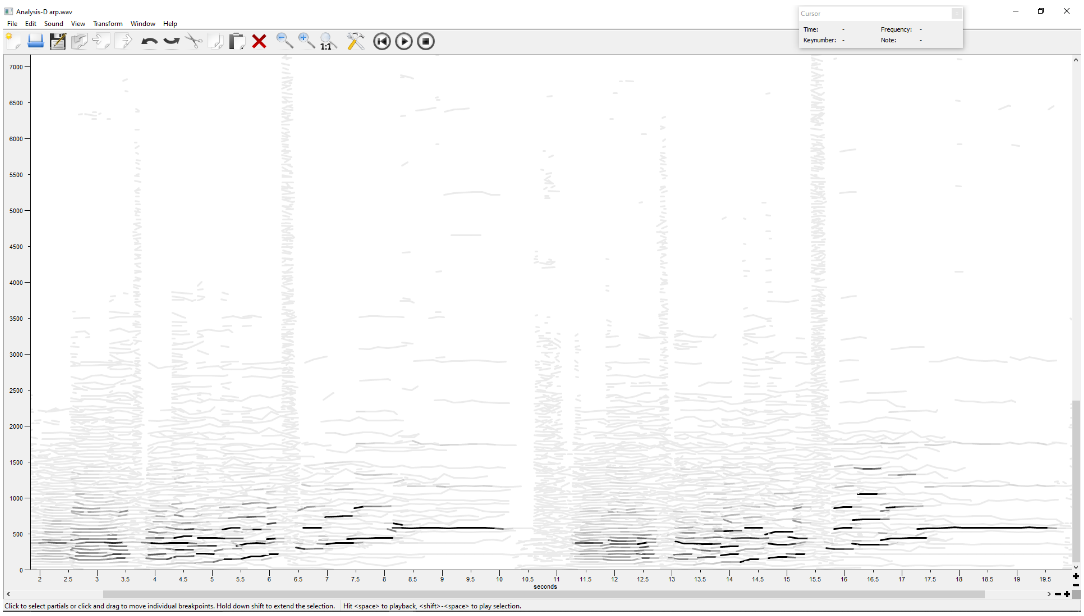


Number of Complete Harmonics – 6

Highest Complete Harmonic – Eb6, 1281.250 Hz

Highest Partial in Hz – A9, 14273.437

D Arpeggios:

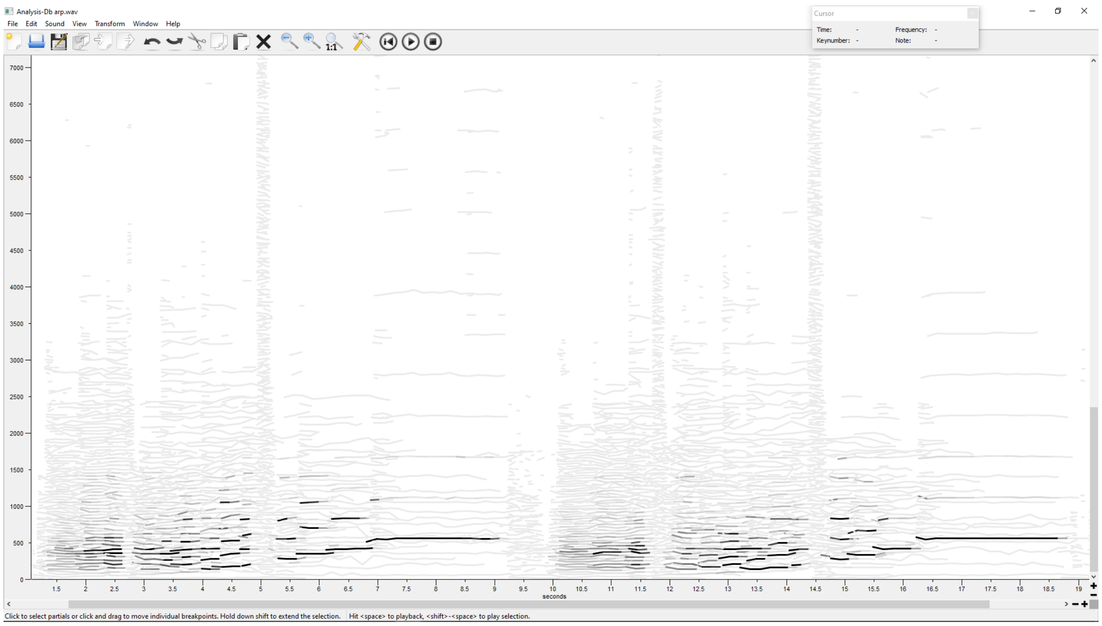


Number of Complete Harmonics – 10

Highest Complete Harmonic – D6, 1168.750 Hz

Highest Partial in Hz – C#10, 17443.748

Db Arpeggios:

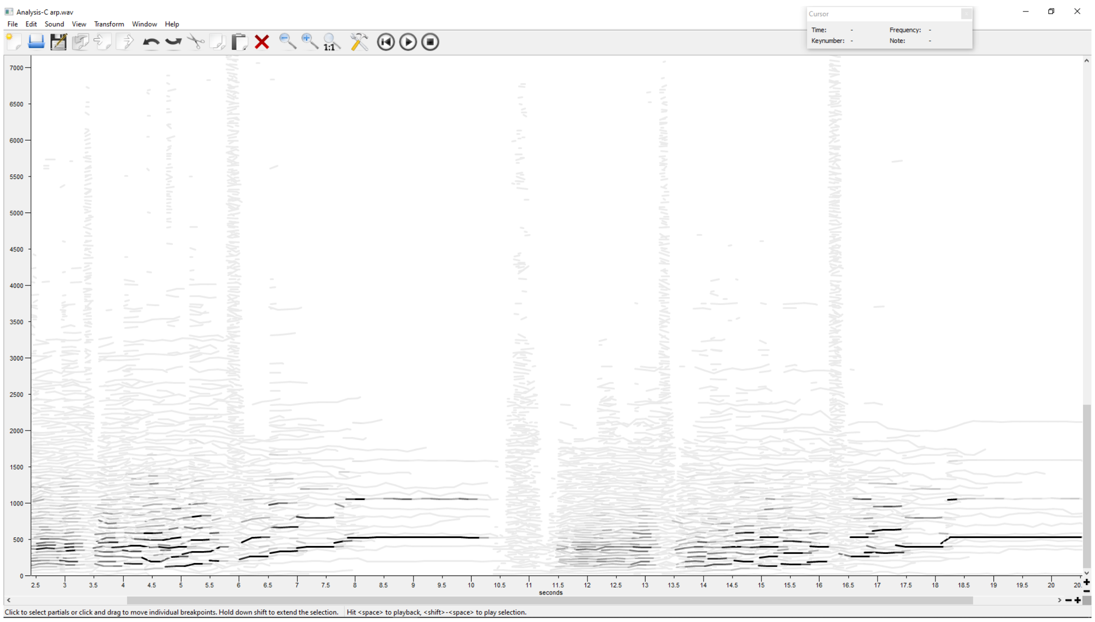


Number of Complete Harmonics – 11

Highest Complete Harmonic – C#6, 1140.625 Hz

Highest Partial in Hz – B9, 15374.999

C Arpeggios:

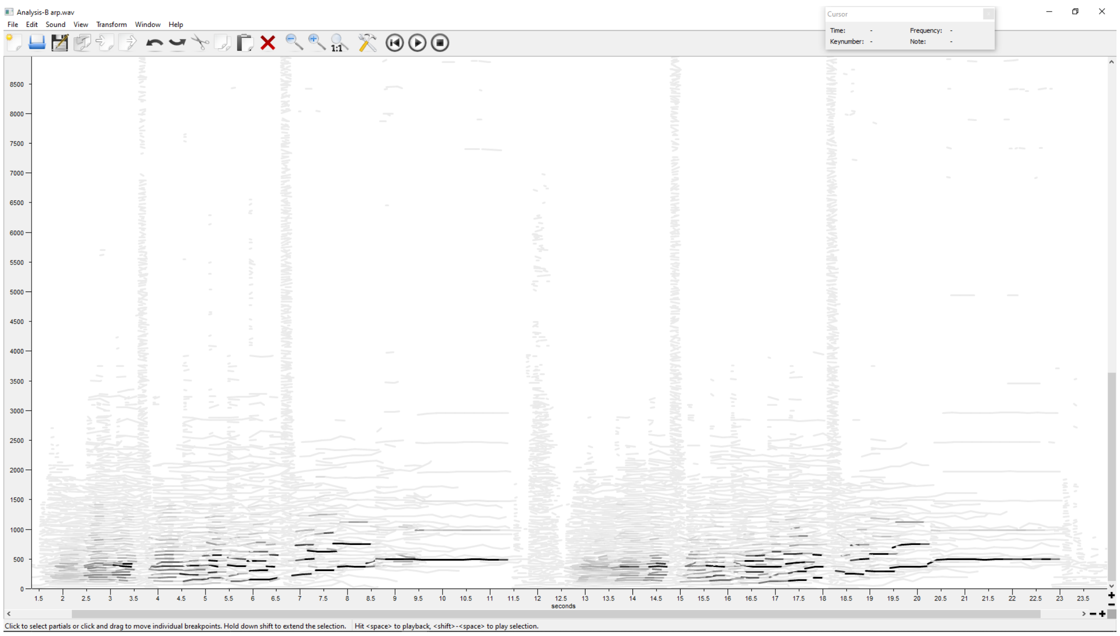


Number of Complete Harmonics – 4

Highest Complete Harmonic – C6, 1046.875 Hz

Highest Partial in Hz – C#10, 17437.500

B Arpeggios:

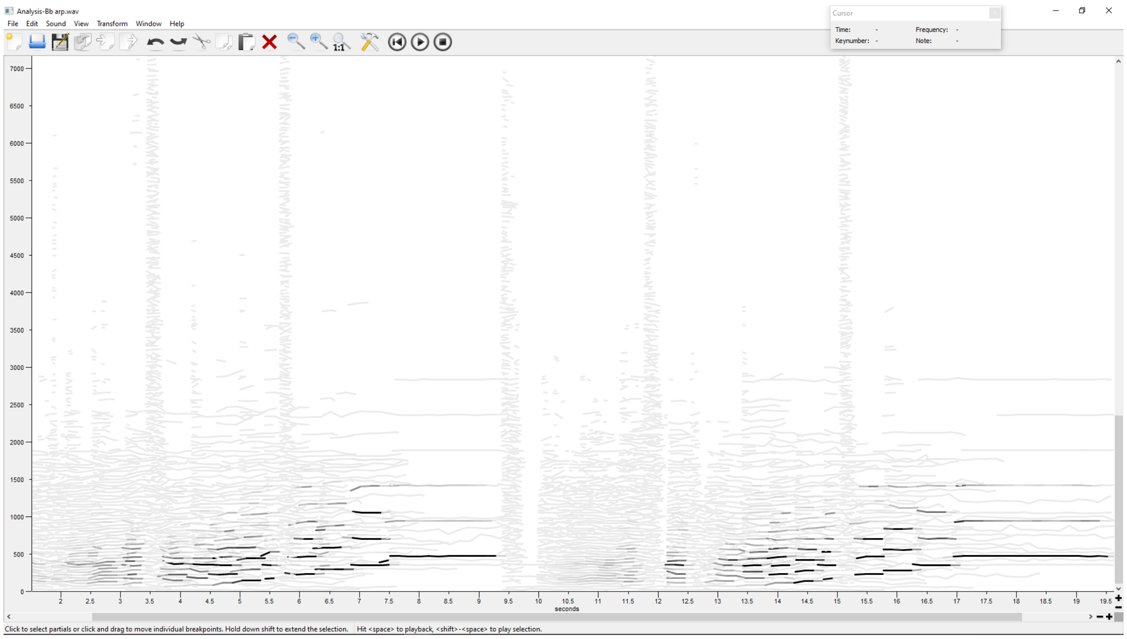


Number of Complete Harmonics – 6

Highest Complete Harmonic – B5, 984.375 Hz

Highest Partial in Hz – D10, 18289.063

Bb Arpeggios:



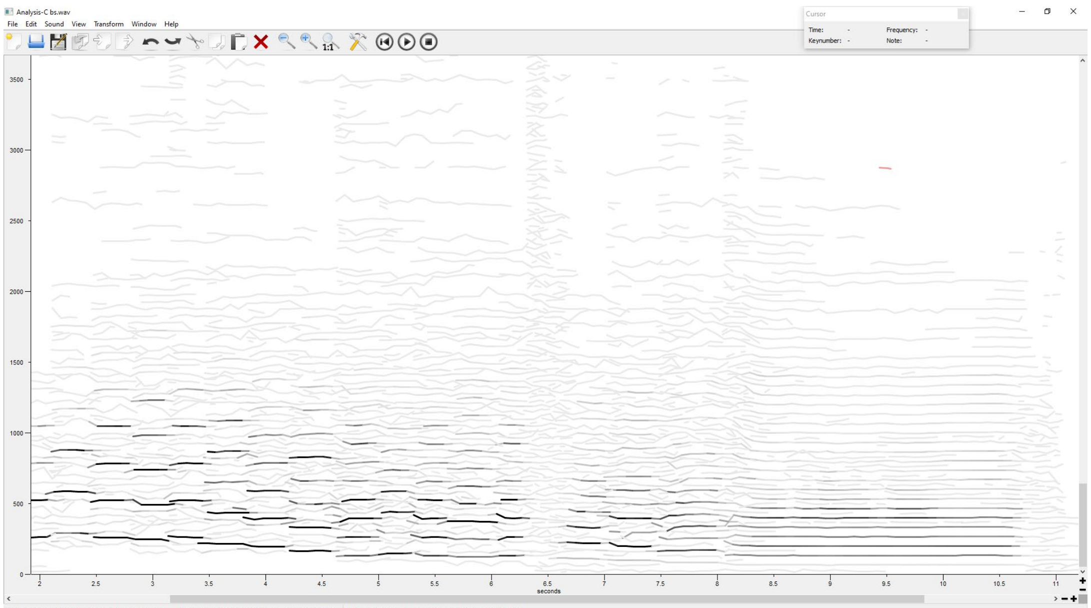
Number of Complete Harmonics – 7

Highest Complete Harmonic – F6, 1412.500 Hz

Highest Partial in Hz – A9, 14304.687

Plastic Descending *BEAUTIFUL SOUNDS*

C Descending *BEAUTIFUL SOUNDS*:

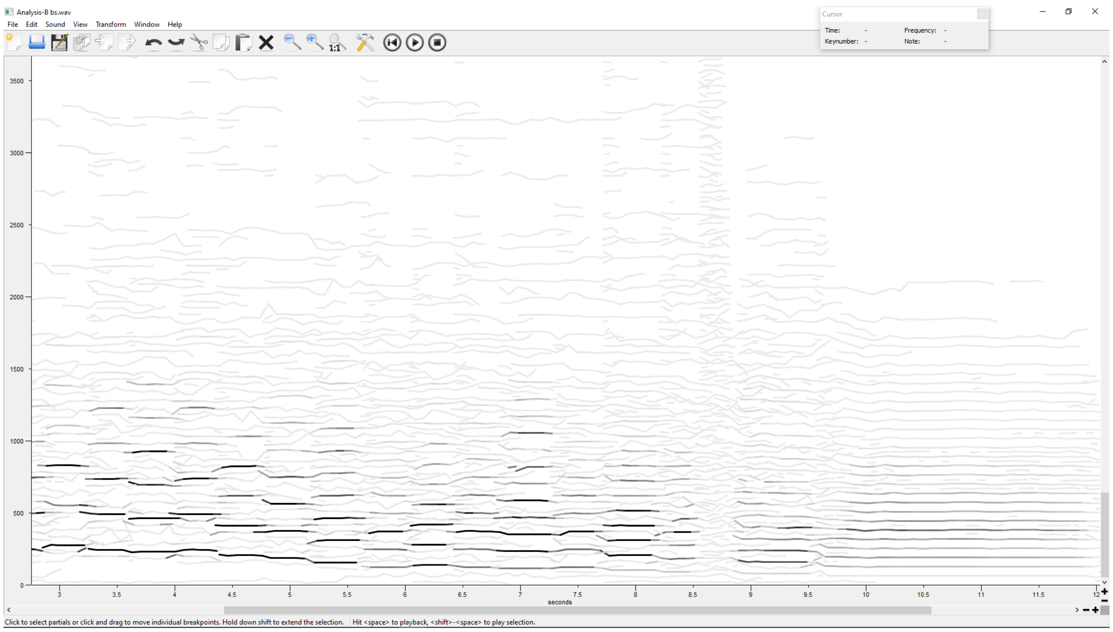


Number of Complete Harmonics – 27

Highest Complete Harmonic – Bb4, 465.000 Hz

Highest Partial in Hz – F7, 2865.000

B Descending *BEAUTIFUL SOUNDS*:

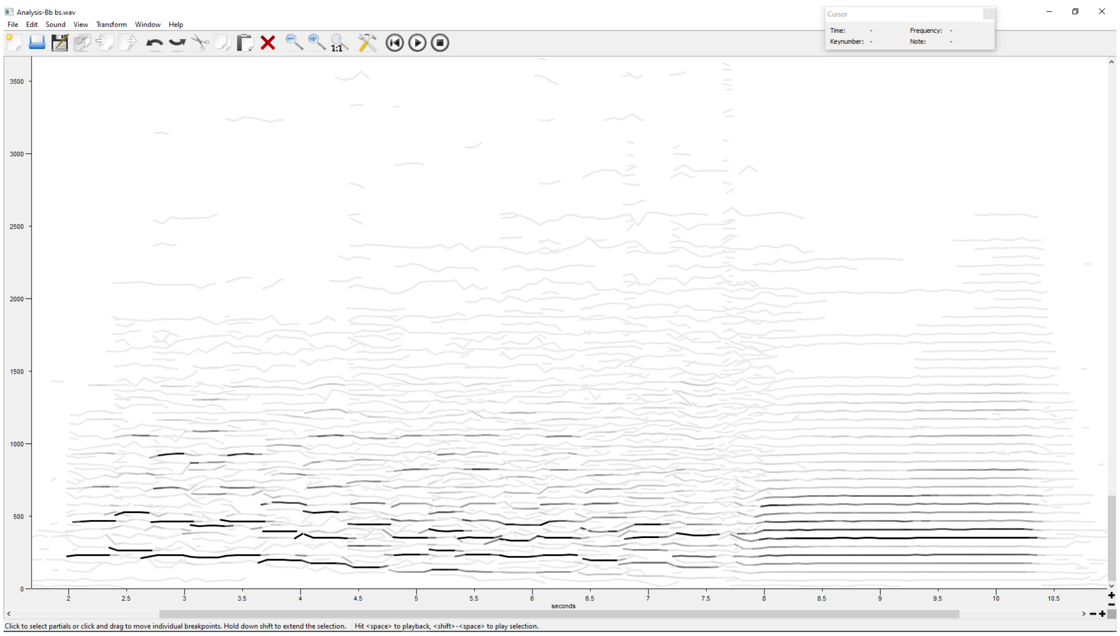


Number of Complete Harmonics – 28

Highest Complete Harmonic – F#4, 380.000

Highest Partial in Hz – C7, 2112.000

Bb Descending *BEAUTIFUL SOUNDS*:

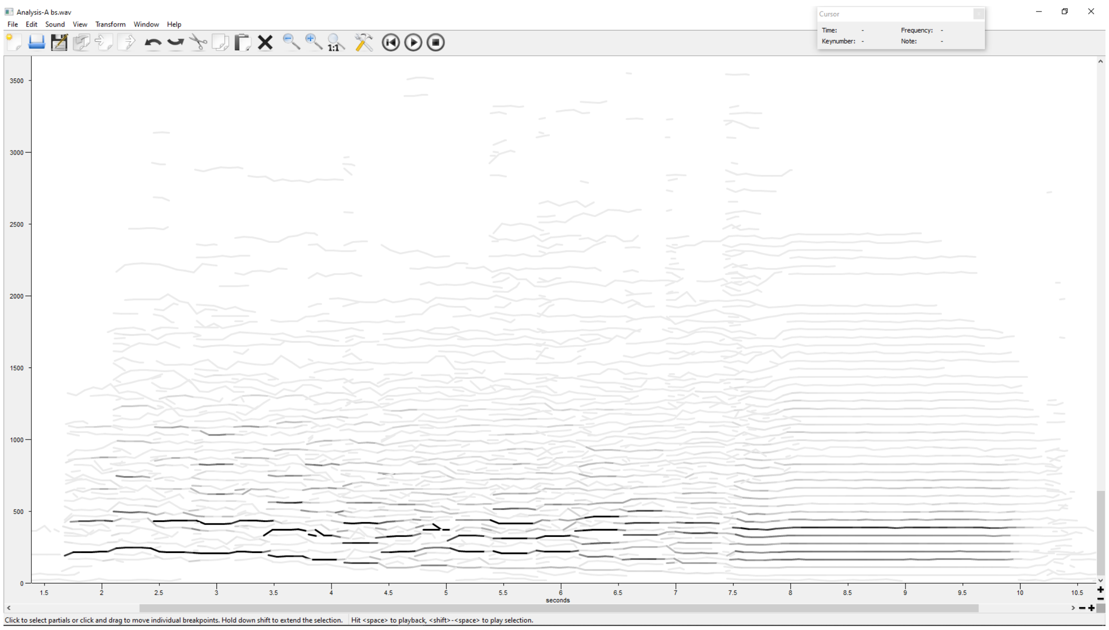


Number of Complete Harmonics – 42

Highest Complete Harmonic – G#5, 8240.000 Hz

Highest Partial in Hz – Bb7, 3744.000

A Descending *BEAUTIFUL SOUNDS*:

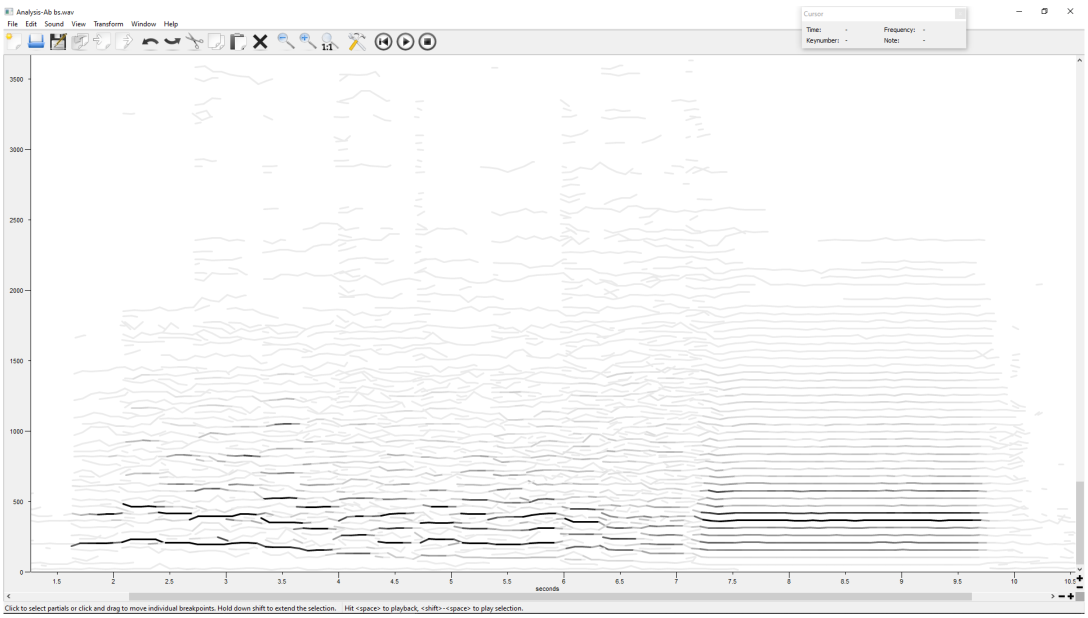


Number of Complete Harmonics – 39

Highest Complete Harmonic – A4, 444.000 Hz

Highest Partial in Hz – Eb7, 2428.000

Ab Descending *BEAUTIFUL SOUNDS*:

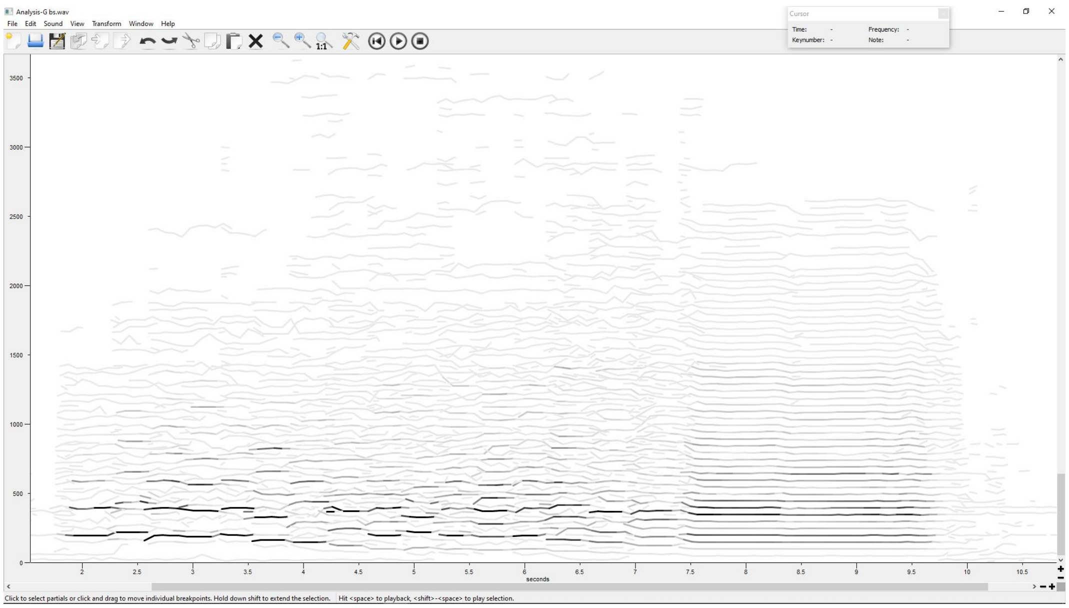


Number of Complete Harmonics – 42

Highest Complete Harmonic – Eb5, 628.000 Hz

Highest Partial in Hz – D7, 2352.000

G Descending *BEAUTIFUL SOUNDS*:

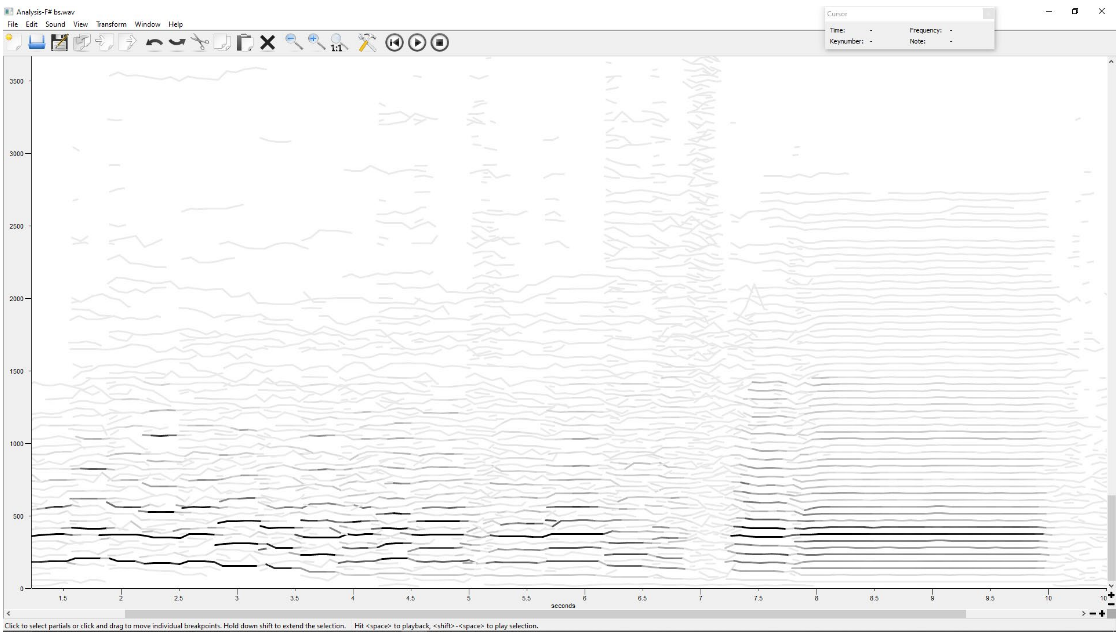


Number of Complete Harmonics – 51

Highest Complete Harmonic – E5, 640.000 Hz

Highest Partial in Hz – E7, 2608.000

F# Descending *BEAUTIFUL SOUNDS*:

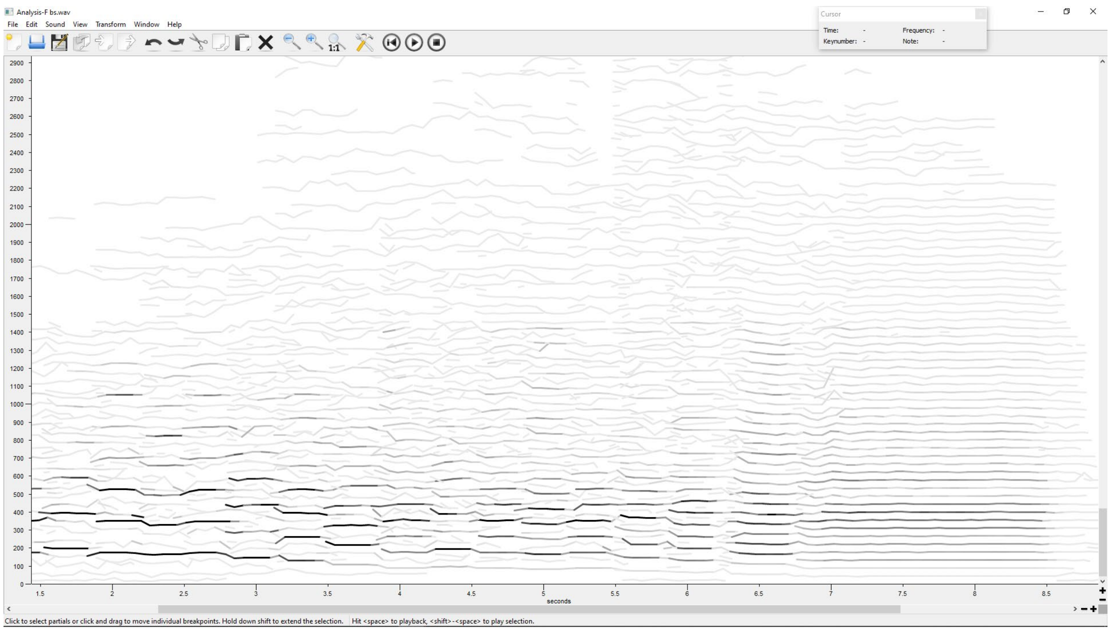


Number of Complete Harmonics – 57

Highest Complete Harmonic – G#4, 425.600 Hz

Highest Partial in Hz – F7, 2720.000

F Descending *BEAUTIFUL SOUNDS*:

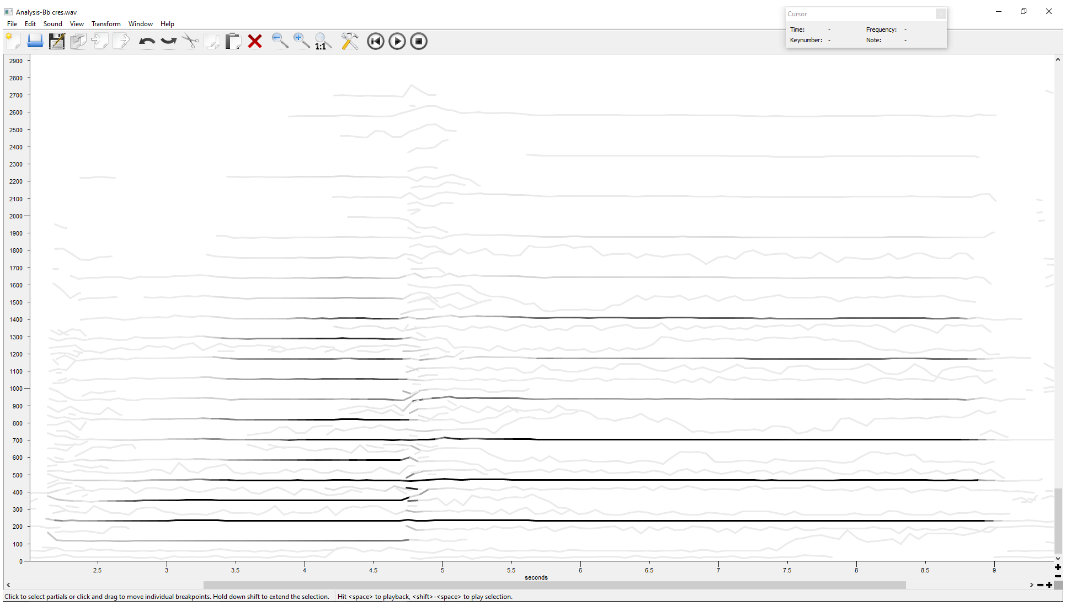


Number of Complete Harmonics – 55

Highest Complete Harmonic – D5, 548.000 Hz

Highest Partial in Hz – E7, 2588.000

Bb Long Tones for Dynamic Range, Crescendo:

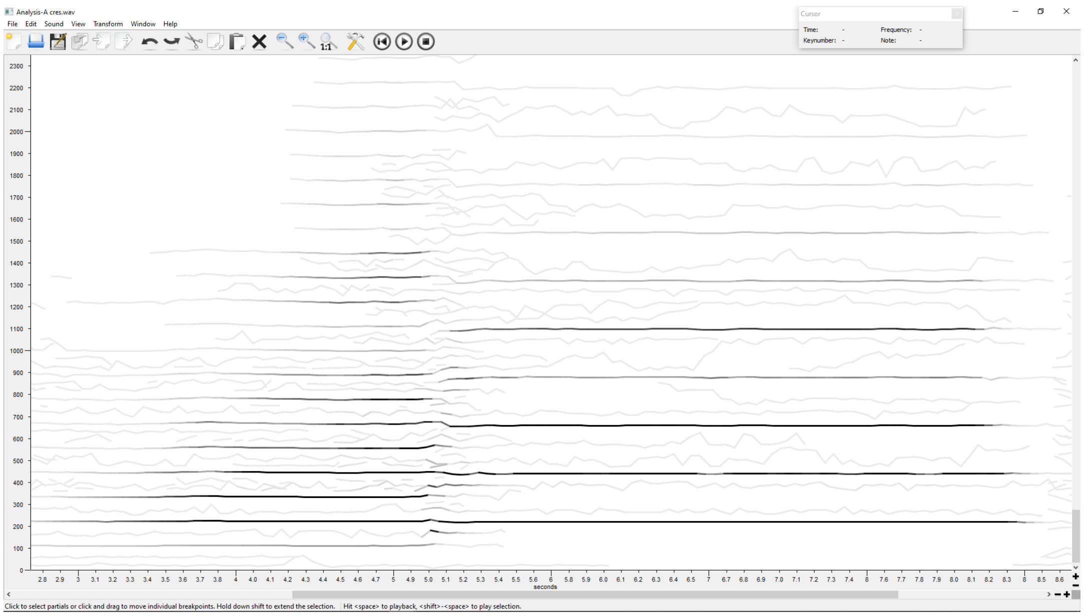


Number of Complete Harmonics – 12

Highest Complete Harmonic – F6, 1400.000 Hz

Highest Partial in Hz – G7, 3050.000

A Long Tones for Dynamic Range, Crescendo:

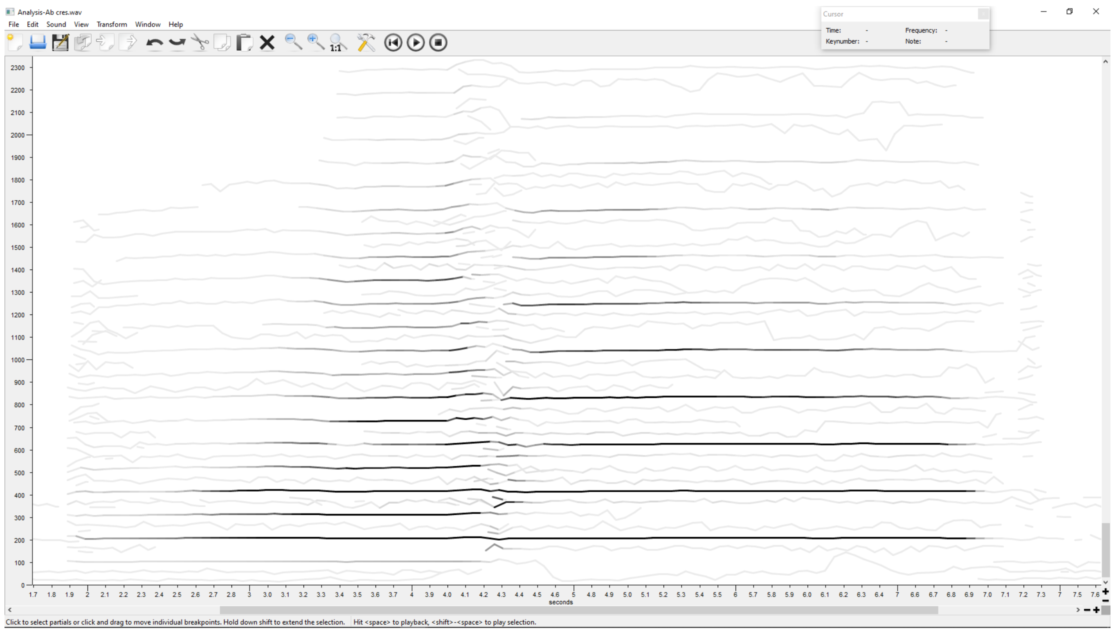


Number of Complete Harmonics – 14

Highest Complete Harmonic – E6, 1312.000 Hz

Highest Partial in Hz – A7, 3516.000

Ab Long Tones for Dynamic Range, Crescendo:

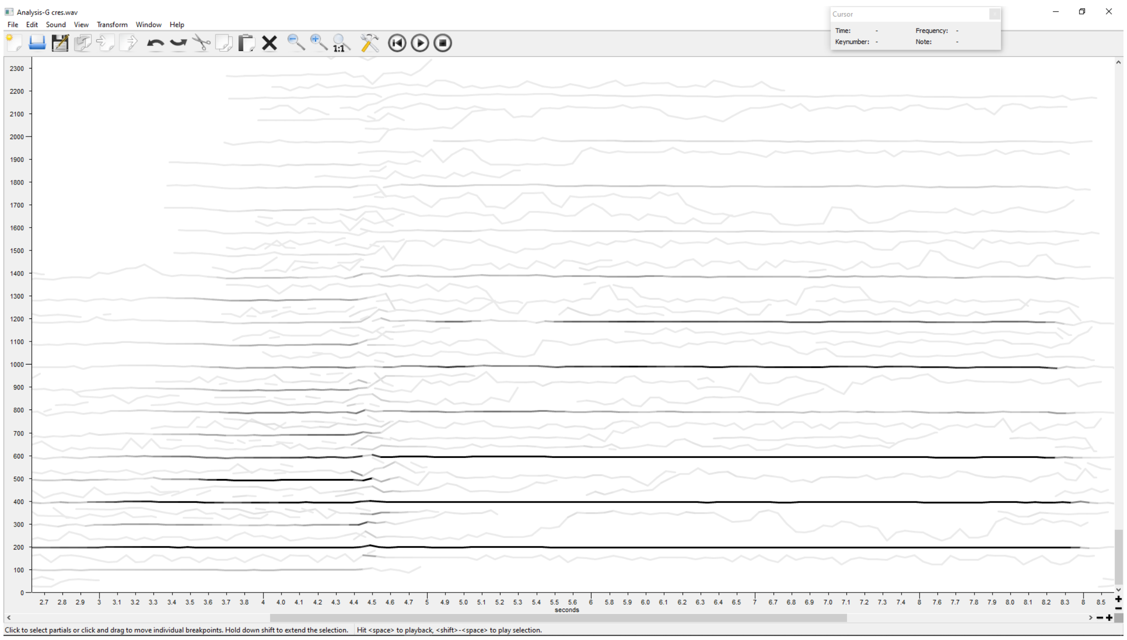


Number of Complete Harmonics – 16

Highest Complete Harmonic – G#6, 1664.000 Hz

Highest Partial in Hz – B7, 3972.000

G Long Tones for Dynamic Range, Crescendo:

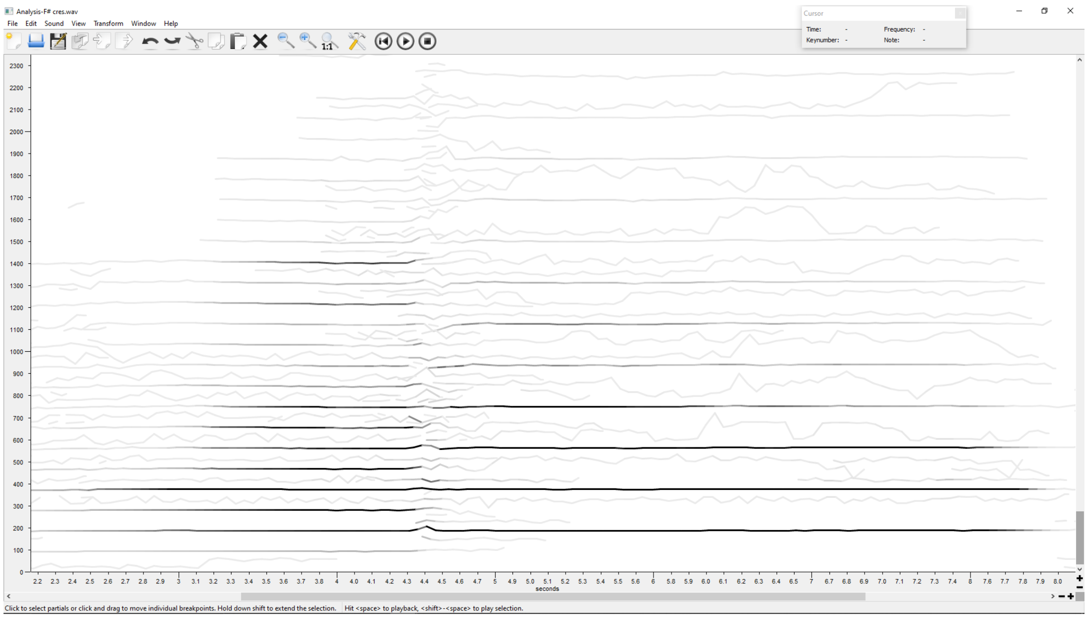


Number of Complete Harmonics – 17

Highest Complete Harmonic – D6, 1188.000 Hz

Highest Partial in Hz – A7, 3560.000

F# Long Tones for Dynamic Range, Crescendo:

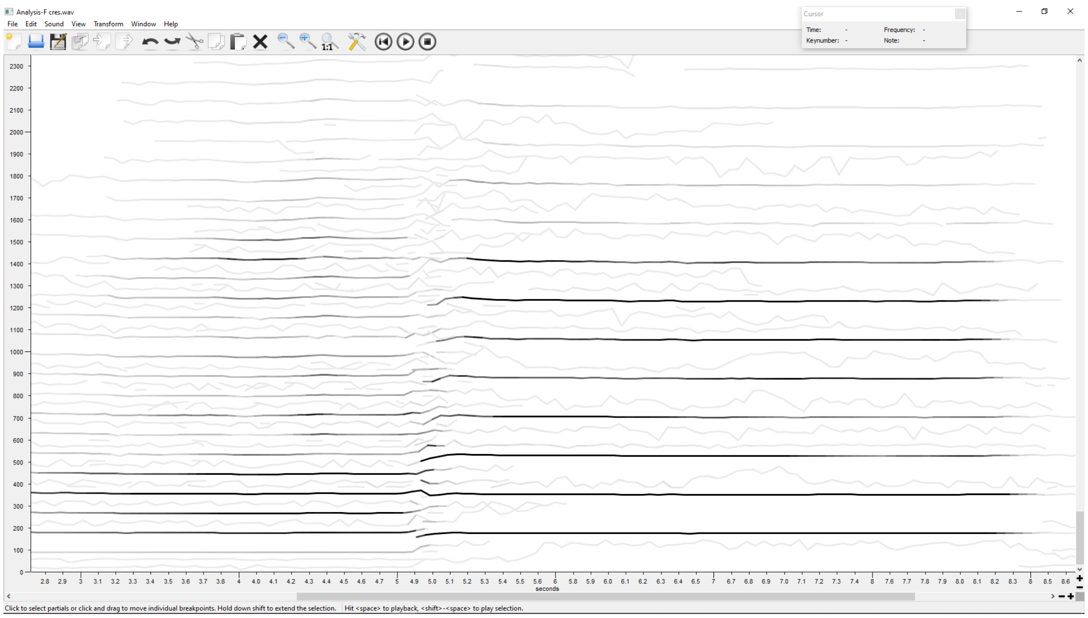


Number of Complete Harmonics – 16

Highest Complete Harmonic – C#6, 1128.000 Hz

Highest Partial in Hz – F#7, 3012.000

F Long Tones for Dynamic Range, Crescendo:

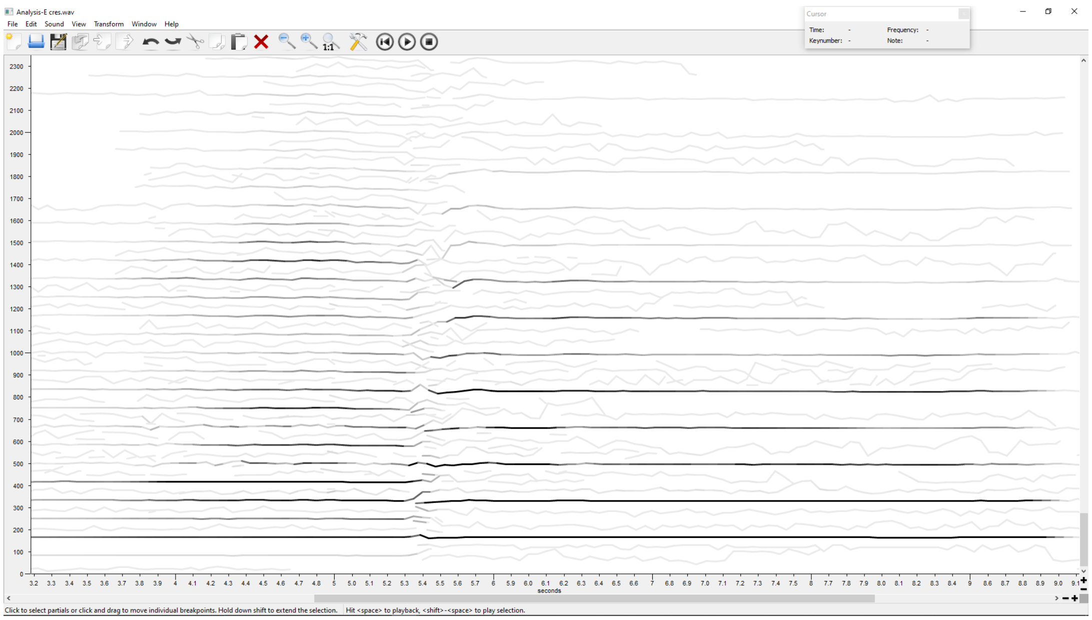


Number of Complete Harmonics – 22

Highest Complete Harmonic – F6, 1408.000 Hz

Highest Partial in Hz – D8, 4744.000

E Long Tones for Dynamic Range, Crescendo:

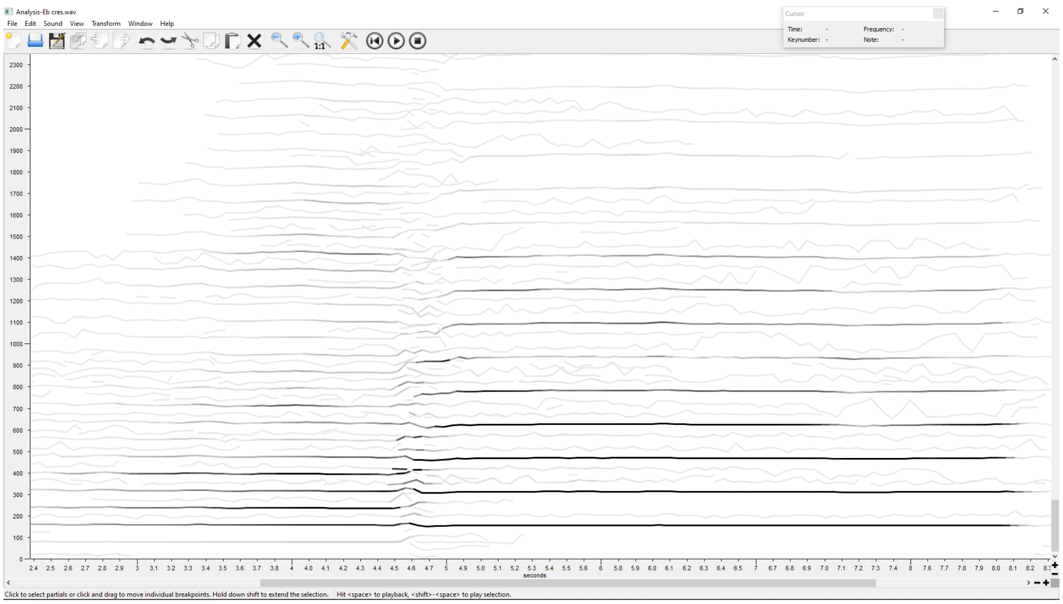


Number of Complete Harmonics – 20

Highest Complete Harmonic – E6, 1324.000 Hz

Highest Partial in Hz – C8, 4300.000

Eb Long Tones for Dynamic Range, Crescendo:



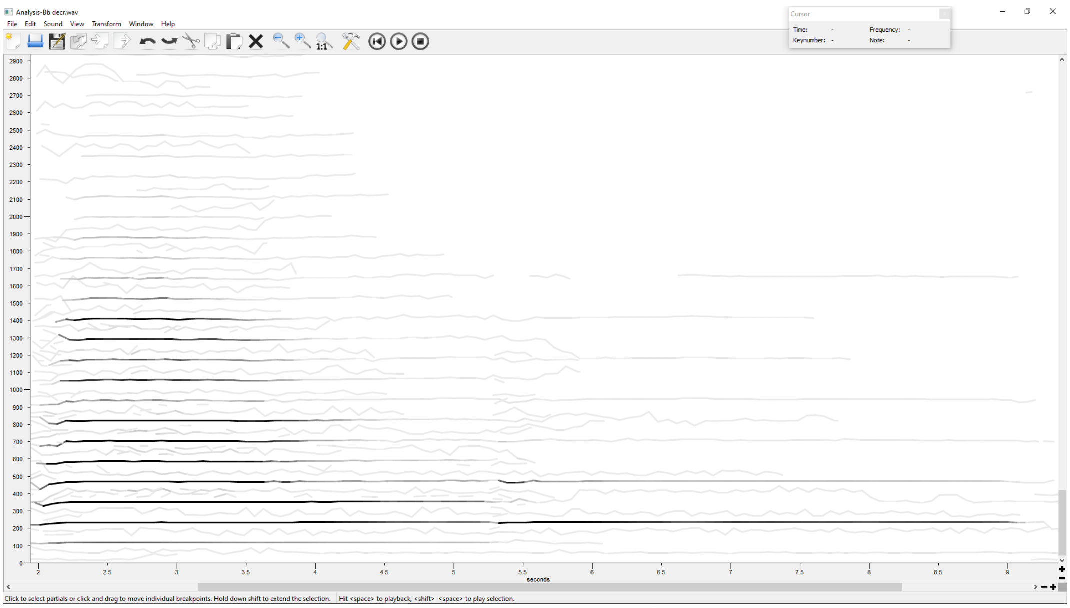
Number of Complete Harmonics – 19

Highest Complete Harmonic – F6, 1404.000 Hz

Highest Partial in Hz – B7, 3744.000

Plastic Long Tones for Dynamic Range, Decrescendo

Bb Long Tones for Dynamic Range, Decrescendo:

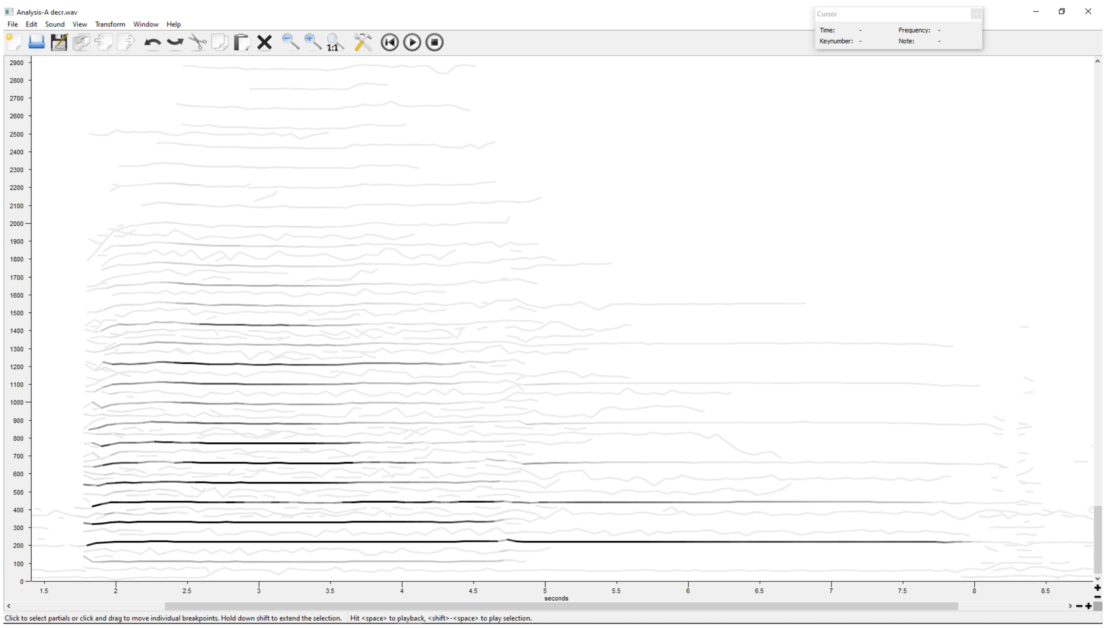


Number of Complete Harmonics – 7

Highest Complete Harmonic – Bb4, 472.000 Hz

Highest Partial in Hz – G#6, 1656.000

A Long Tones for Dynamic Range, Decrescendo:

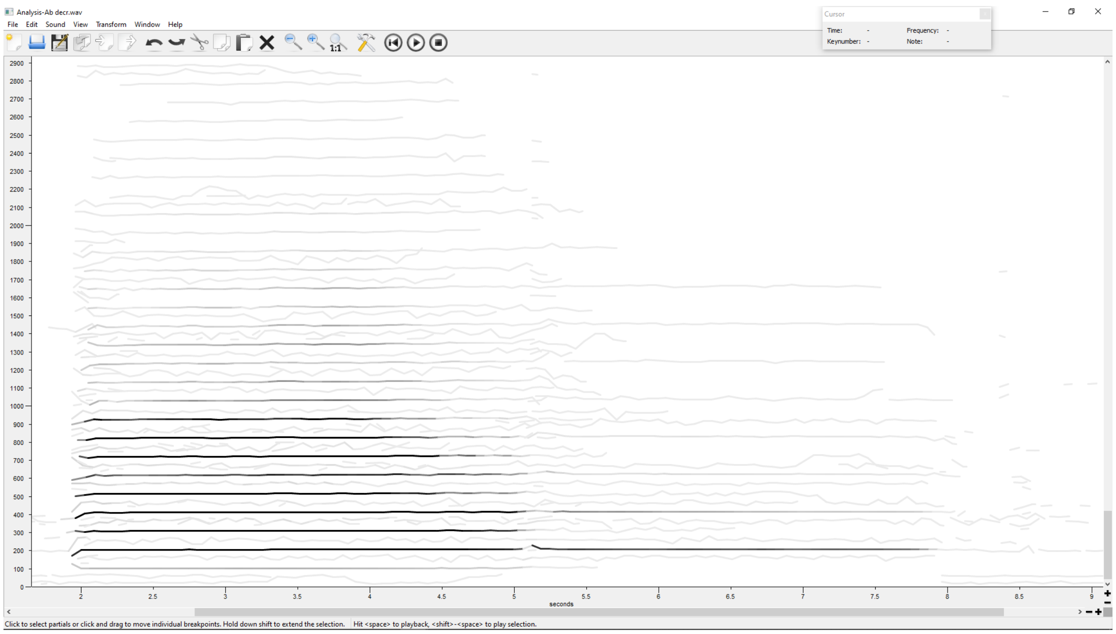


Number of Complete Harmonics – 7

Highest Complete Harmonic – A4, 440.000 Hz

Highest Partial in Hz – G6, 1548.000

Ab Long Tones for Dynamic Range, Decrescendo:

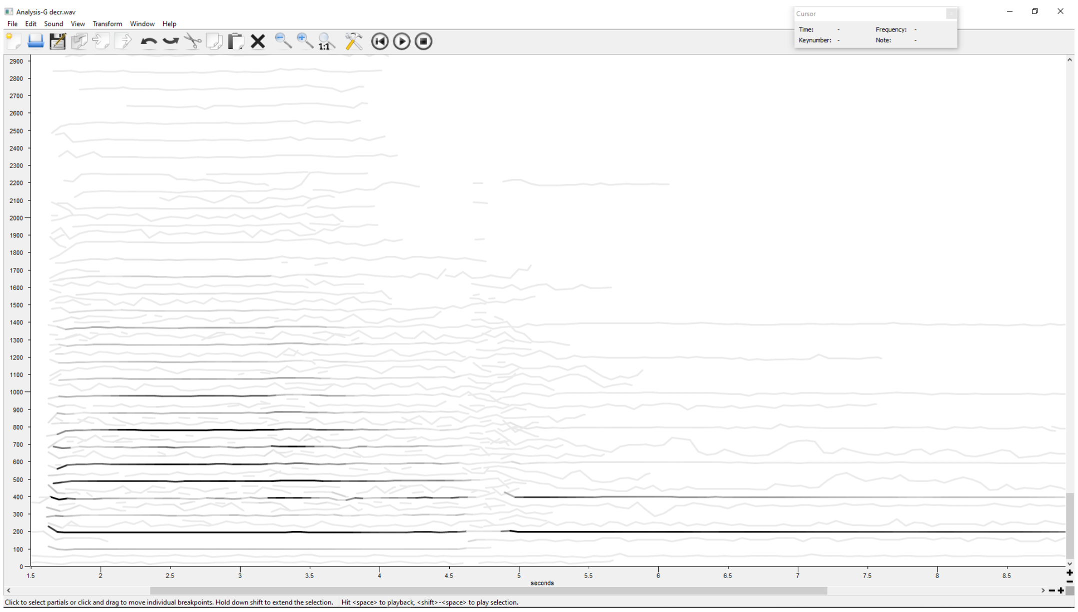


Number of Complete Harmonics – 8

Highest Complete Harmonic – G#4, 416.000 Hz

Highest Partial in Hz – G#6, 1668.000

G Long Tones for Dynamic Range, Decrescendo:

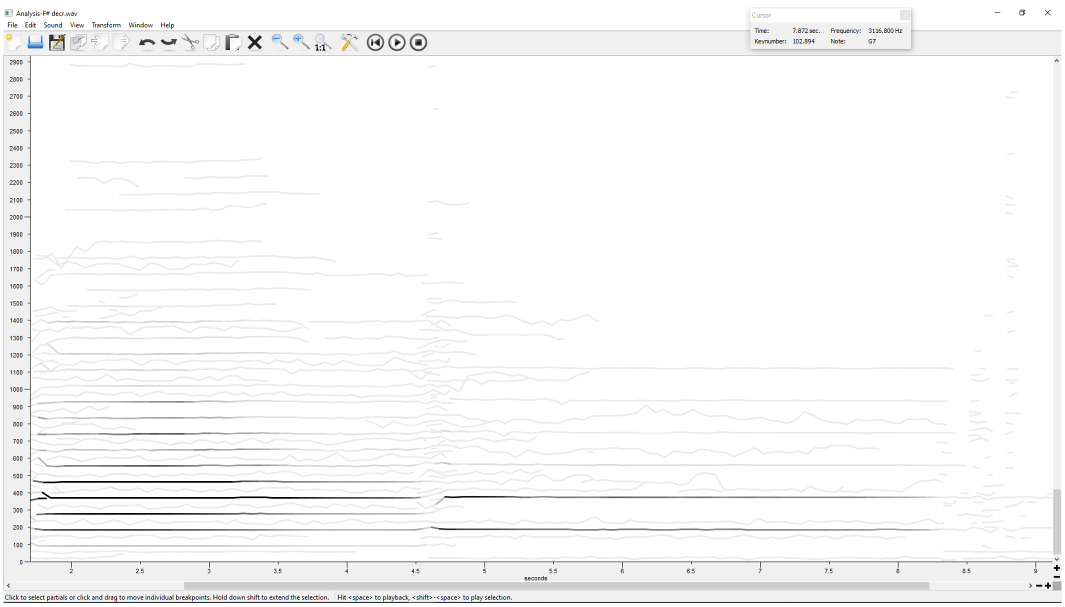


Number of Complete Harmonics – 7

Highest Complete Harmonic – G4, 400.000 Hz

Highest Partial in Hz – F6, 1392.000

F# Long Tones for Dynamic Range, Decrescendo:

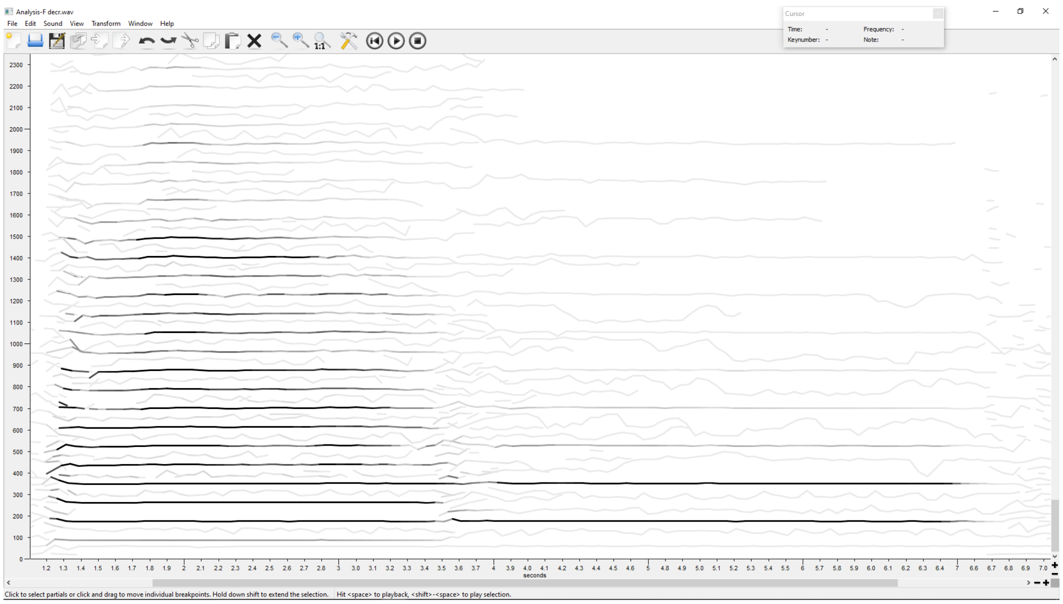


Number of Complete Harmonics – 6

Highest Complete Harmonic – F#4, 372.000 Hz

Highest Partial in Hz – C#6, 1128.000

F Long Tones for Dynamic Range, Decrescendo:

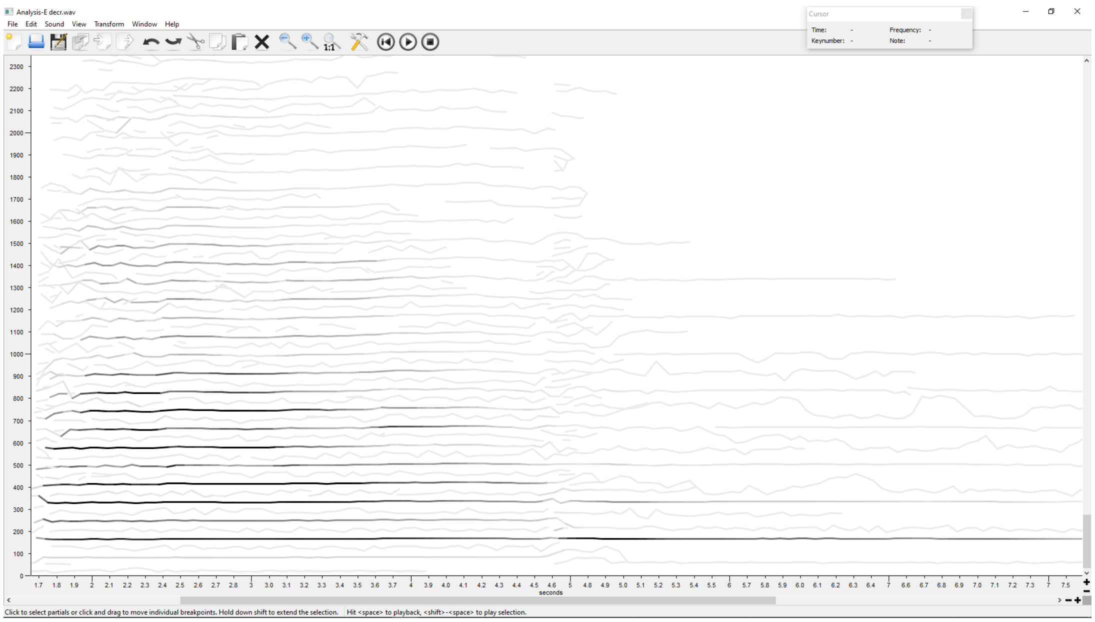


Number of Complete Harmonics – 11

Highest Complete Harmonic – F4, 356.000 Hz

Highest Partial in Hz – B6, 1928.000

E Long Tones for Dynamic Range, Decrescendo:

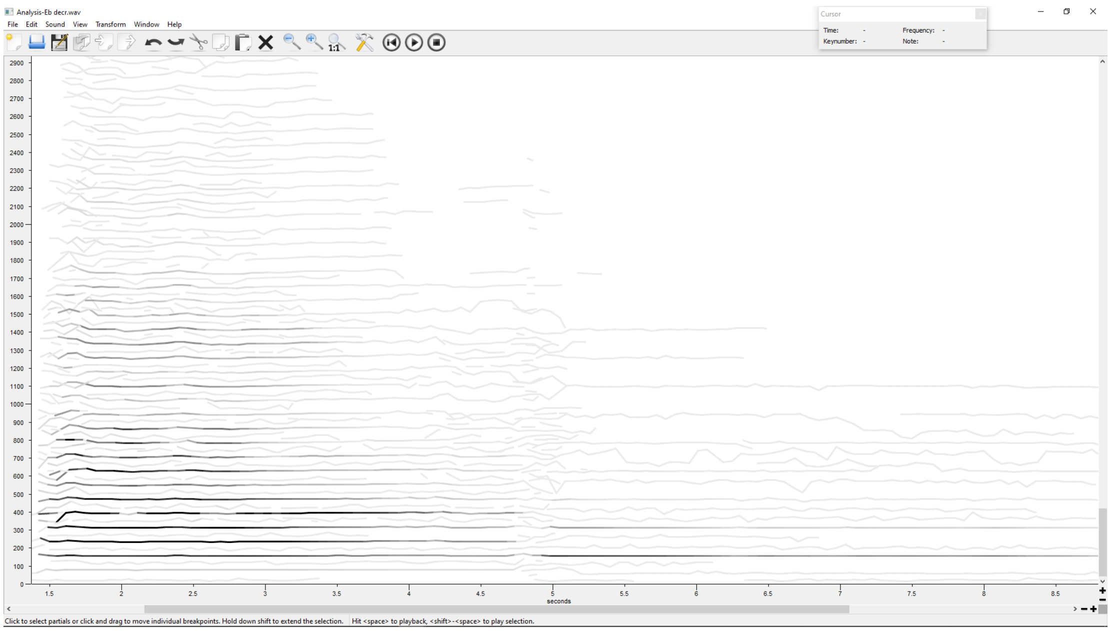


Number of Complete Harmonics – 8

Highest Complete Harmonic – E4, 336.000 Hz

Highest Partial in Hz – E6, 1336.000

Eb Long Tones for Dynamic Range, Decrescendo:



Number of Complete Harmonics – 7

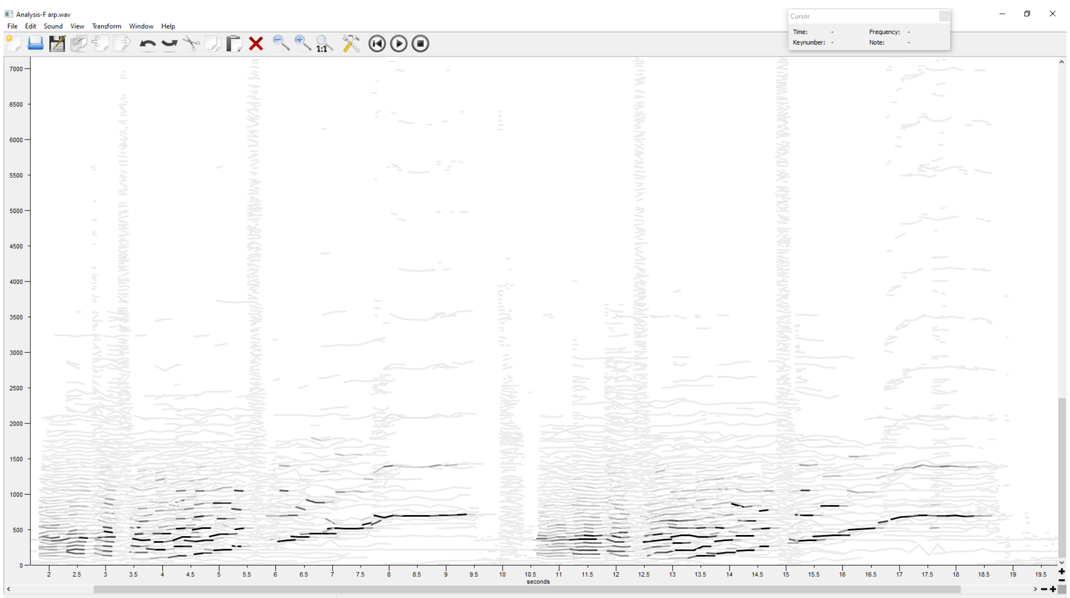
Highest Complete Harmonic – Eb4, 316.000 Hz

Highest Partial in Hz – C#6, 1096.000

Gold Analysis

Gold Arpeggios

F Arpeggios:

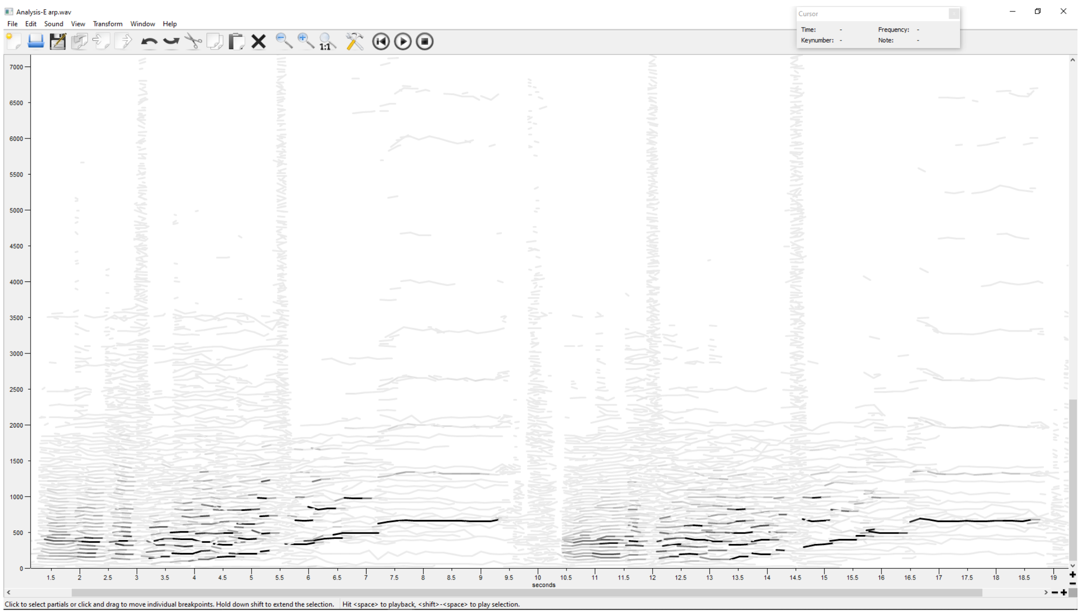


Number of Complete Harmonics – 12

Highest Complete Harmonic – F6, 1405.000 Hz

Highest Partial in Hz – Eb9, 9784.999

E Arpeggios:

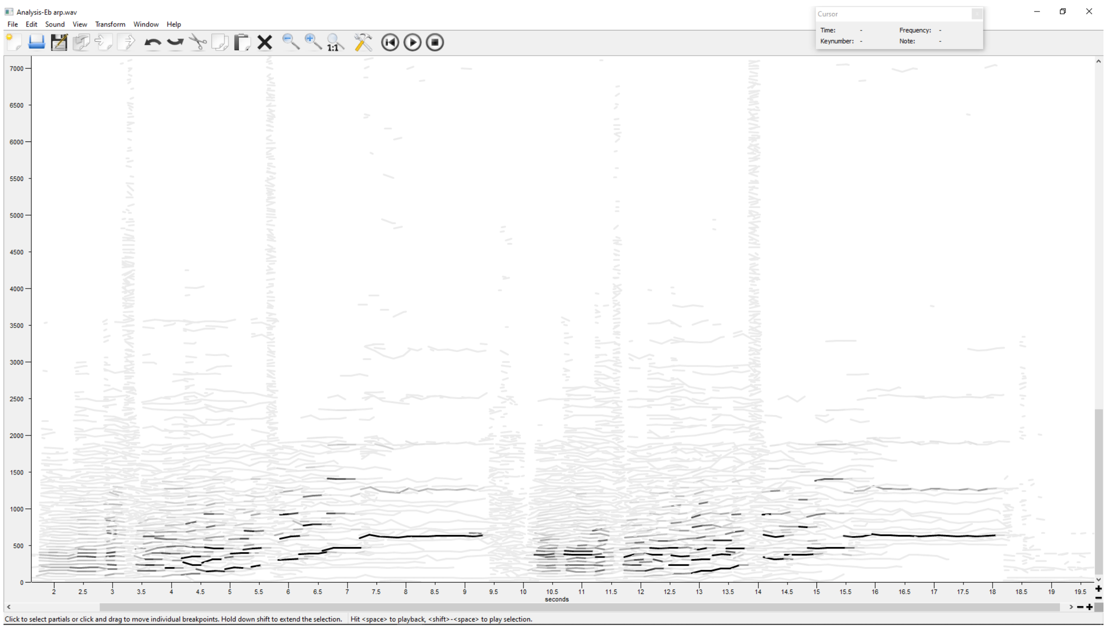


Number of Complete Harmonics – 13

Highest Complete Harmonic – E6, 1318.500 Hz

Highest Partial in Hz – Eb9, 9837.499

Eb Arpeggios:

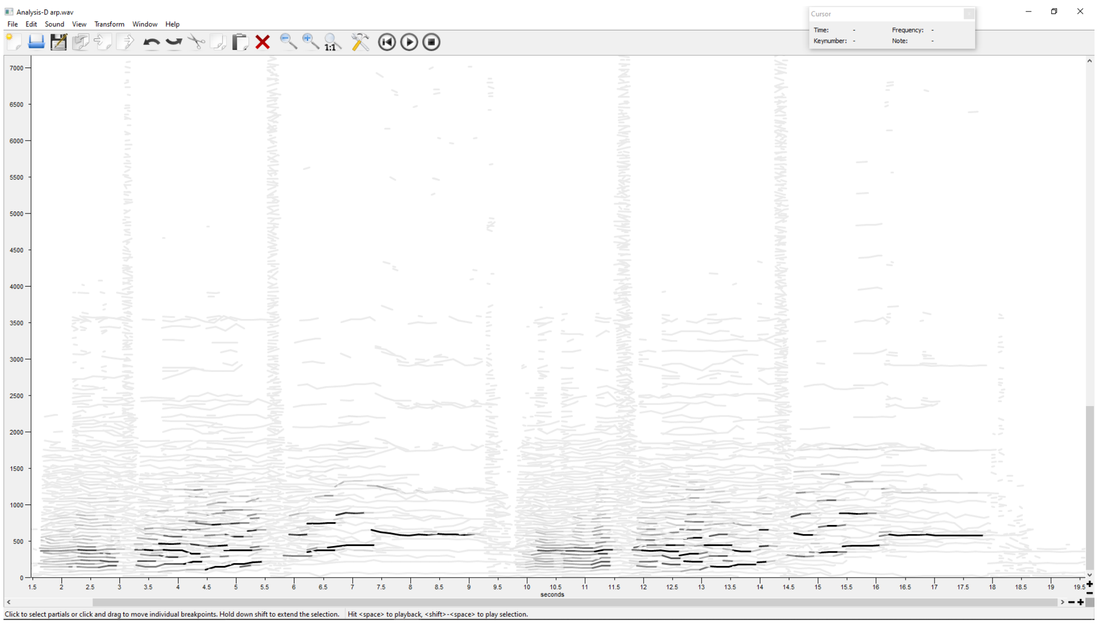


Number of Complete Harmonics – 4

Highest Complete Harmonic – Eb6, 1255.000 Hz

Highest Partial in Hz – Eb9, 9870.000

D Arpeggios:

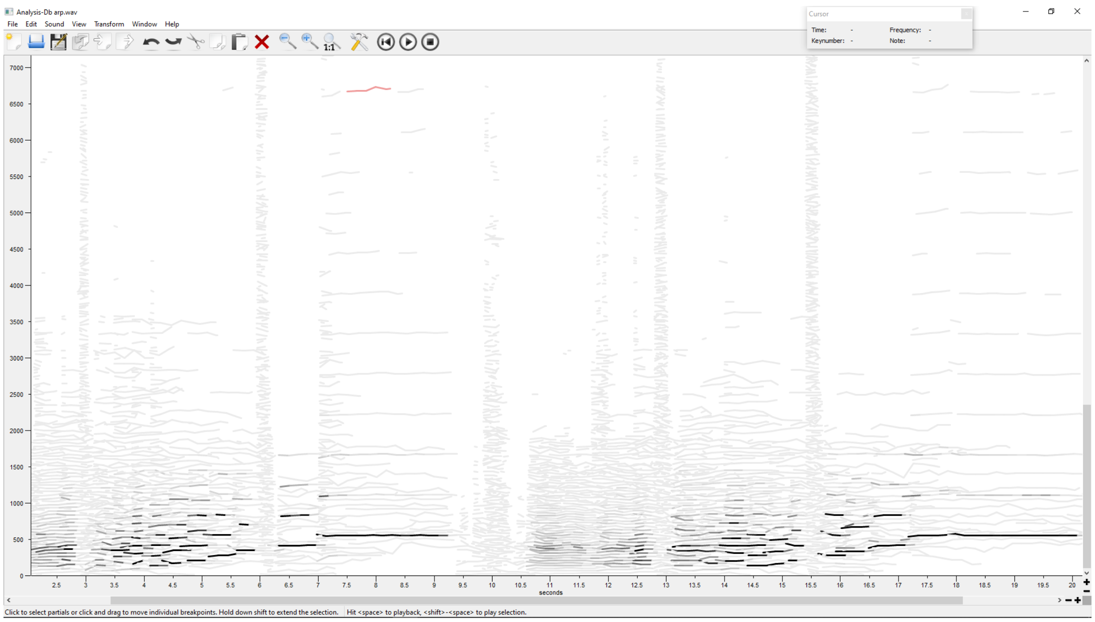


Number of Complete Harmonics – 5

Highest Complete Harmonic – D6, 1162.500 Hz

Highest Partial in Hz – D9, 9249.999

Db Arpeggios:

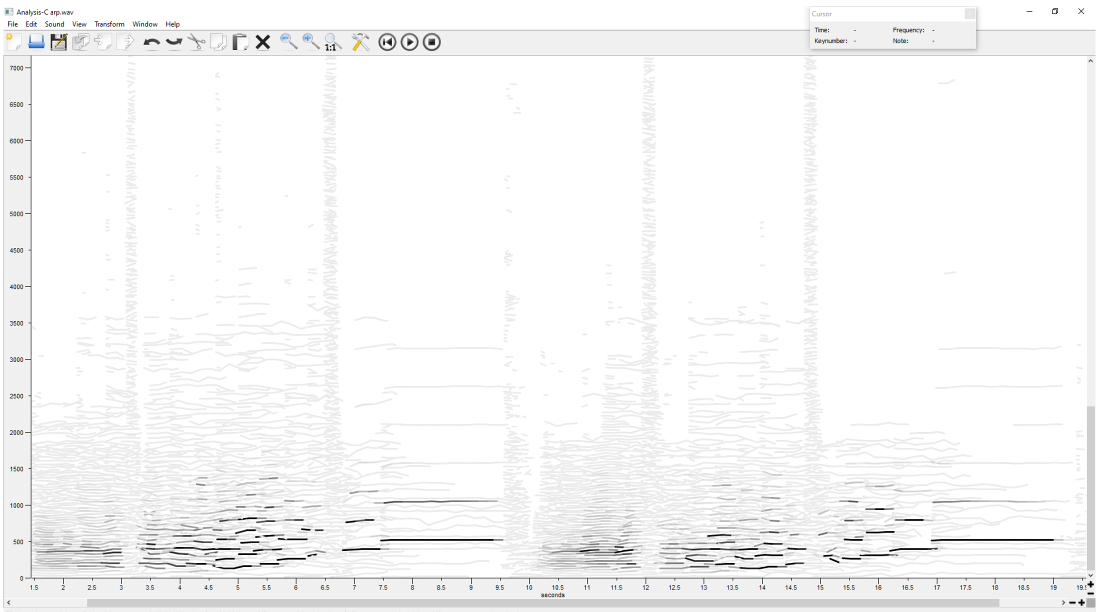


Number of Complete Harmonics – 16

Highest Complete Harmonic – C#6, 1100.000 Hz

Highest Partial in Hz – D9, 9515.000

C Arpeggios:

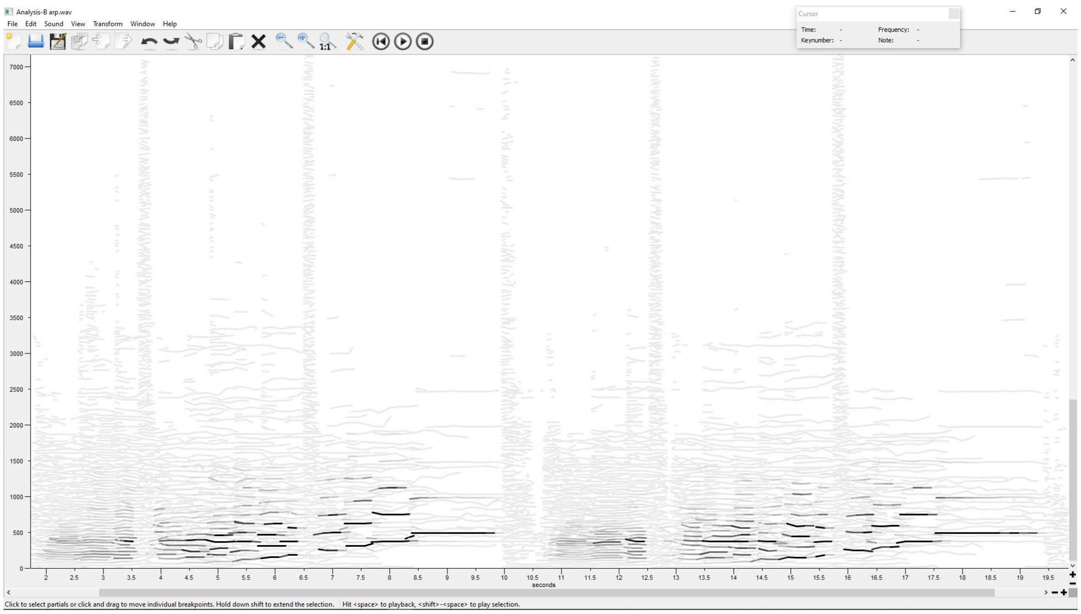


Number of Complete Harmonics – 8

Highest Complete Harmonic – C6, 1056.000 Hz

Highest Partial in Hz – C#9, 8948.000

B Arpeggios:

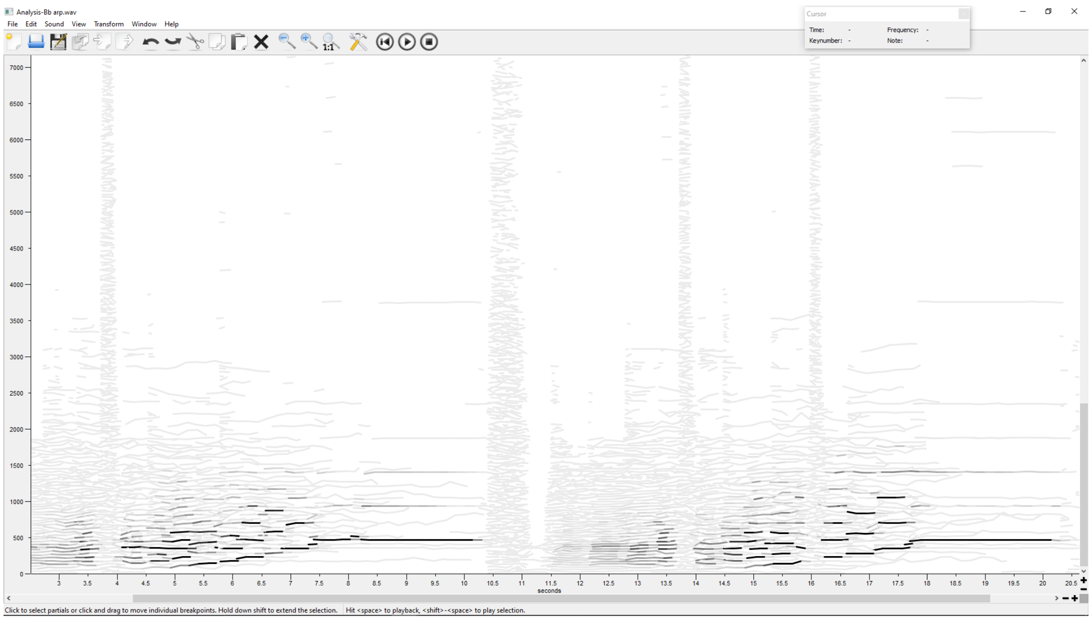


Number of Complete Harmonics – 5

Highest Complete Harmonic – B5, 993.750 Hz

Highest Partial in Hz – C#9, 8918.749

Bb Arpeggios:



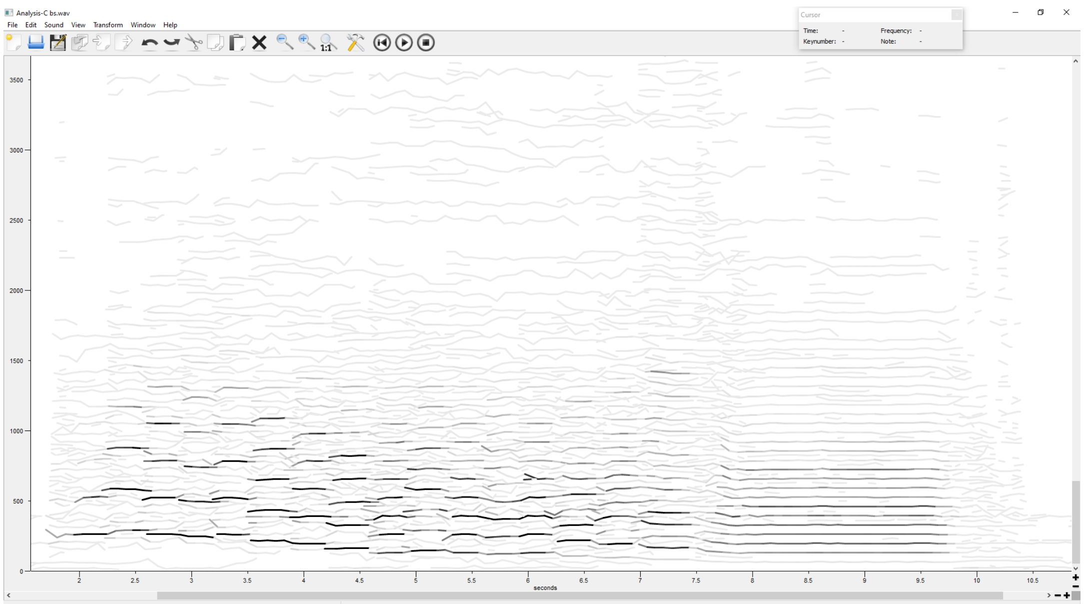
Number of Complete Harmonics – 12

Highest Complete Harmonic – F6, 1400.000 Hz

Highest Partial in Hz – D9, 9399.999

Gold Descending *BEAUTIFUL SOUNDS*

C Descending *BEAUTIFUL SOUNDS*:

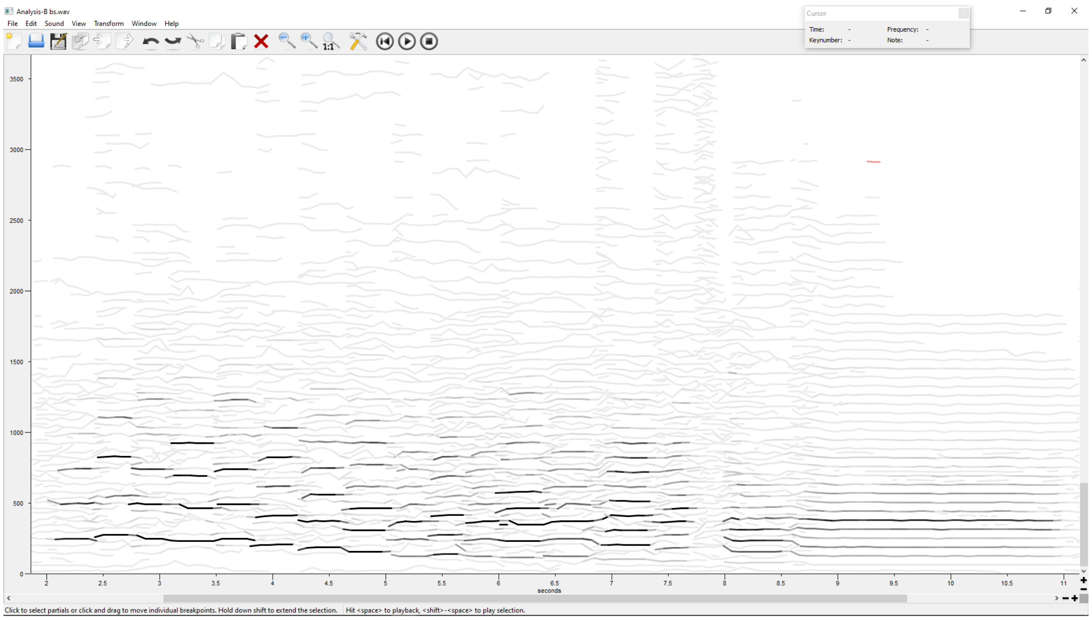


Number of Complete Harmonics – 29

Highest Complete Harmonic – F#5, 720.000 Hz

Highest Partial in Hz – D8, 4808.000

B Descending *BEAUTIFUL SOUNDS*:

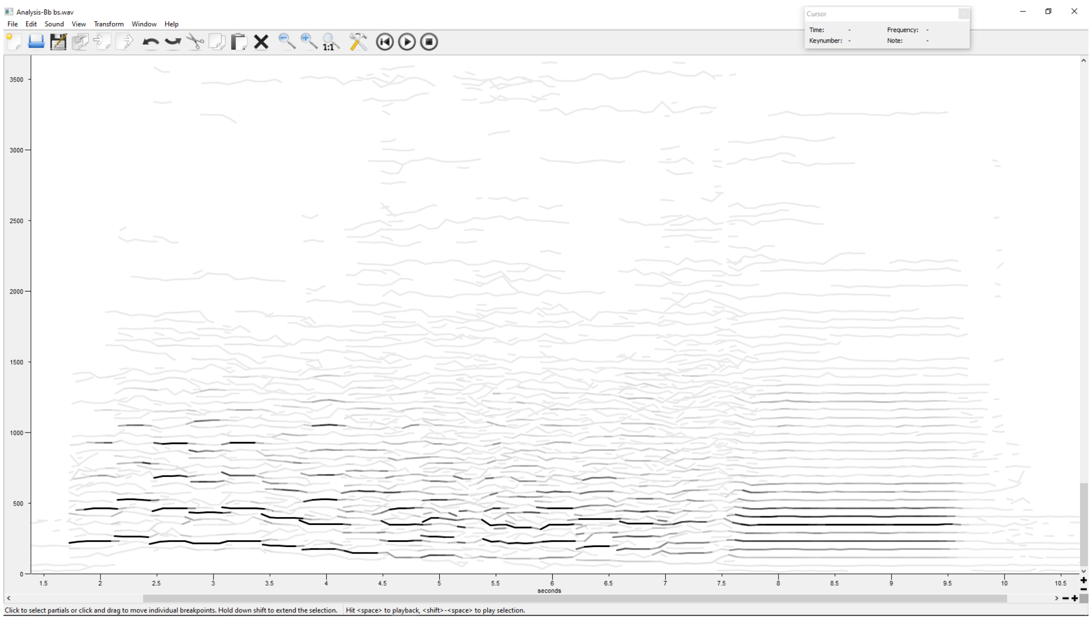


Number of Complete Harmonics – 28

Highest Complete Harmonic – G#5, 820.000 Hz

Highest Partial in Hz – F#7, 2912.000

Bb Descending *BEAUTIFUL SOUNDS*:

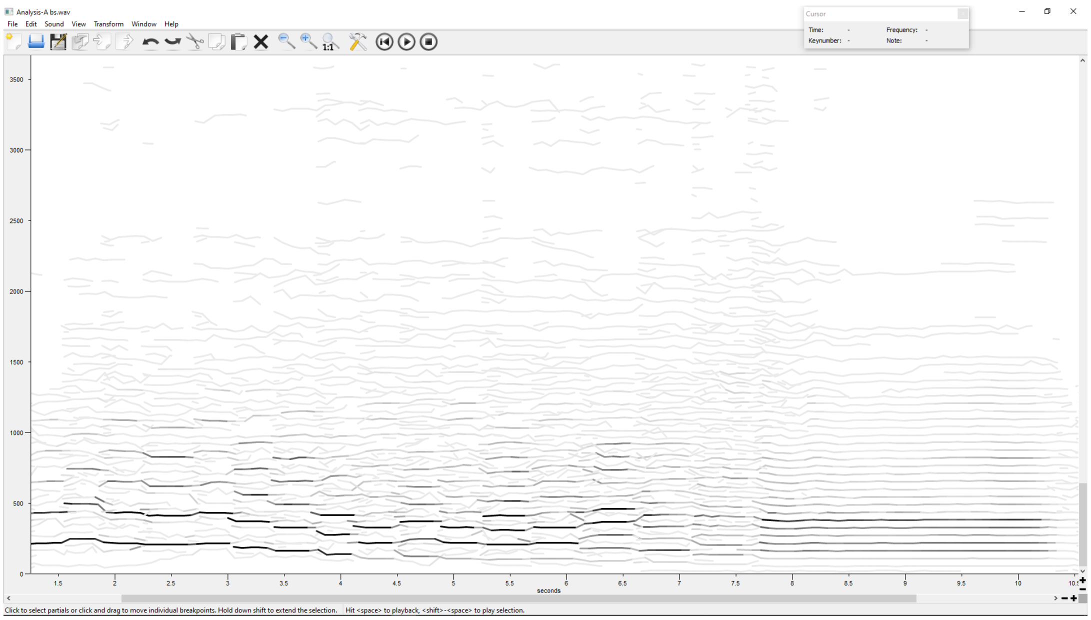


Number of Complete Harmonics – 34

Highest Complete Harmonic – Eb6, 1220.000 Hz

Highest Partial in Hz – G#7, 3264.000

A Descending *BEAUTIFUL SOUNDS*:

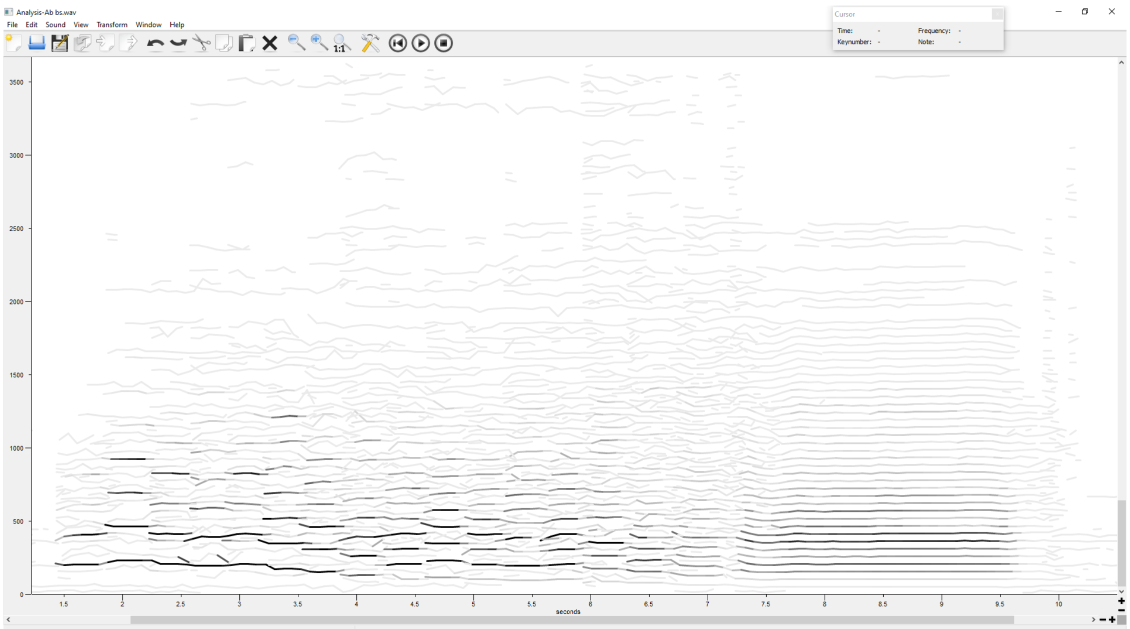


Number of Complete Harmonics – 31

Highest Complete Harmonic – G#5, 816.000 Hz

Highest Partial in Hz – E7, 2624.000

Ab Descending *BEAUTIFUL SOUNDS*:

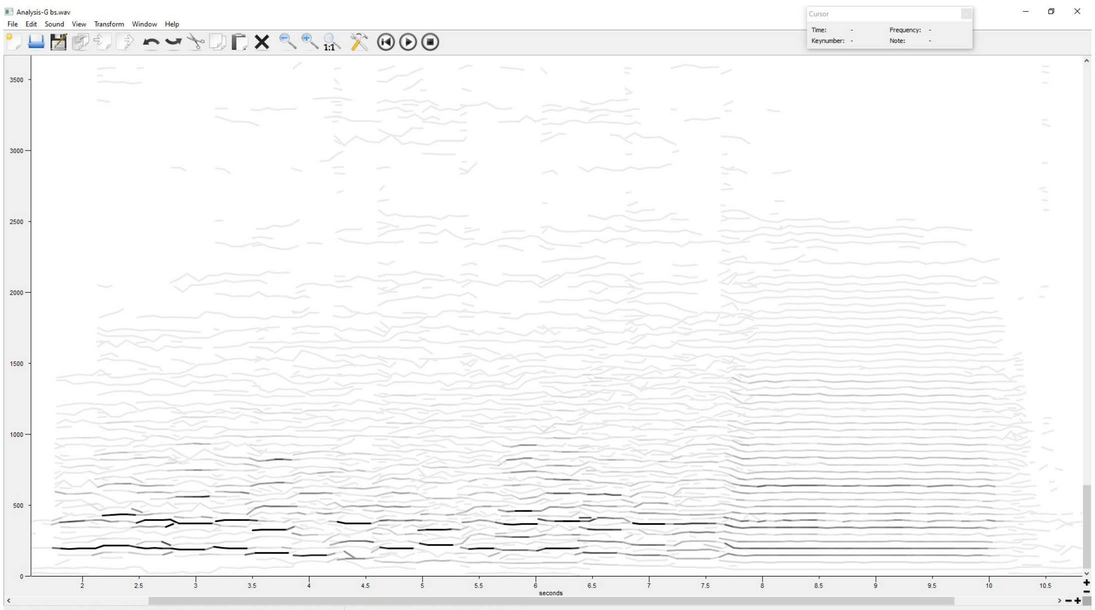


Number of Complete Harmonics – 41

Highest Complete Harmonic – G#5, 836.000 Hz

Highest Partial in Hz – A7, 3536.000

G Descending *BEAUTIFUL SOUNDS*:

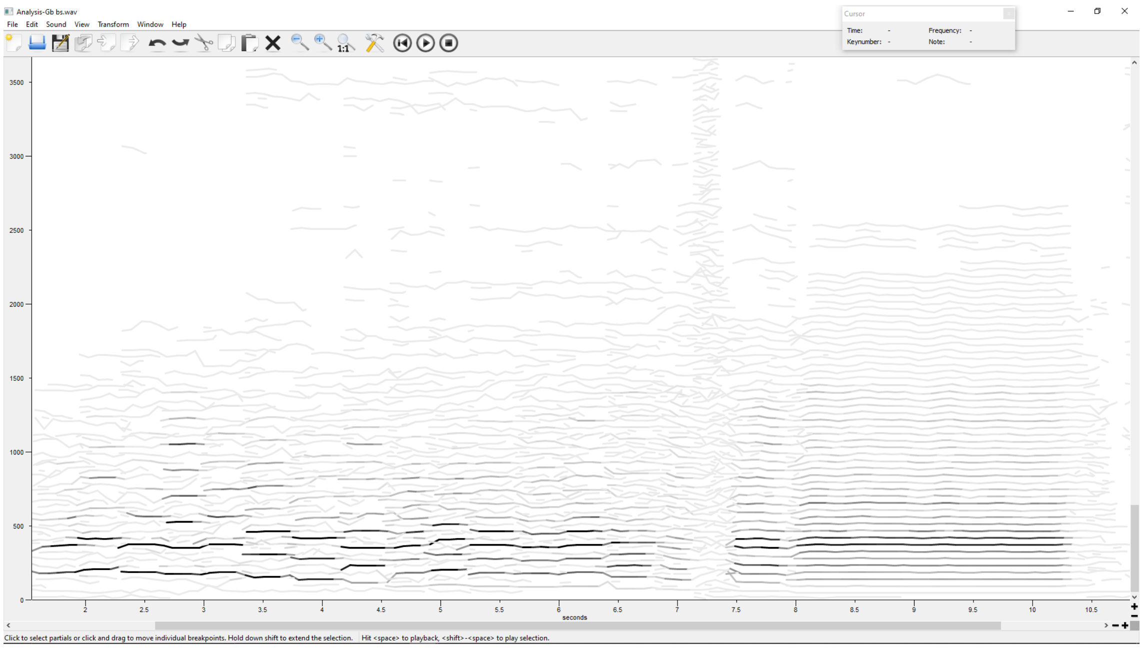


Number of Complete Harmonics – 48

Highest Complete Harmonic – Eb5, 636.000 Hz

Highest Partial in Hz – Eb7, 2460.000

F# Descending *BEAUTIFUL SOUNDS*:

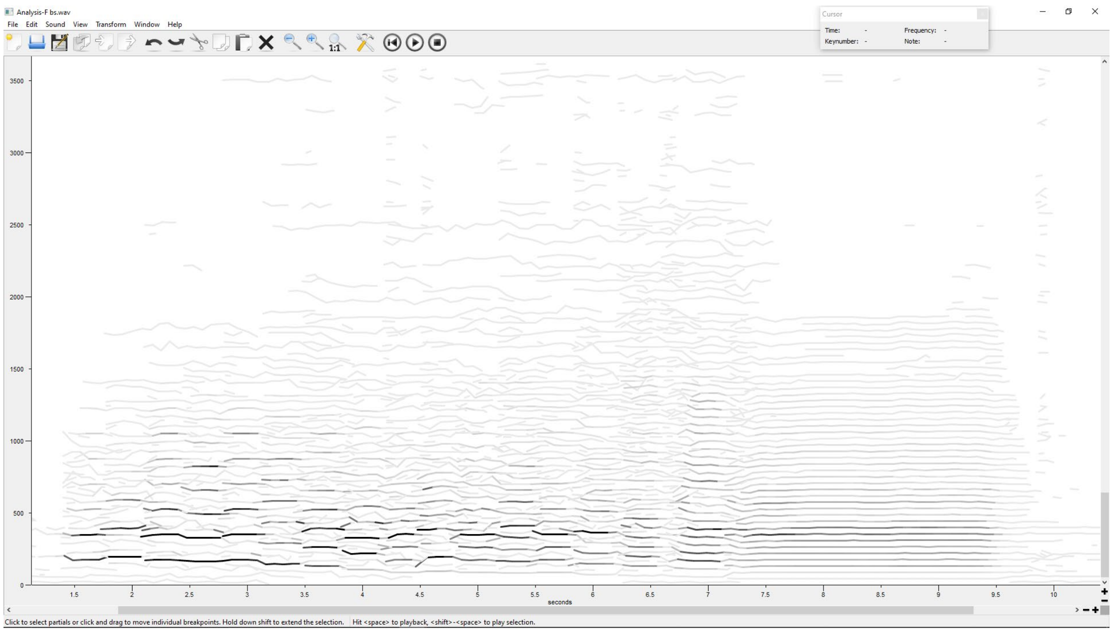


Number of Complete Harmonics – 52

Highest Complete Harmonic – E5, 652.000 Hz

Highest Partial in Hz – E7, 2660.000

F Descending *BEAUTIFUL SOUNDS*:

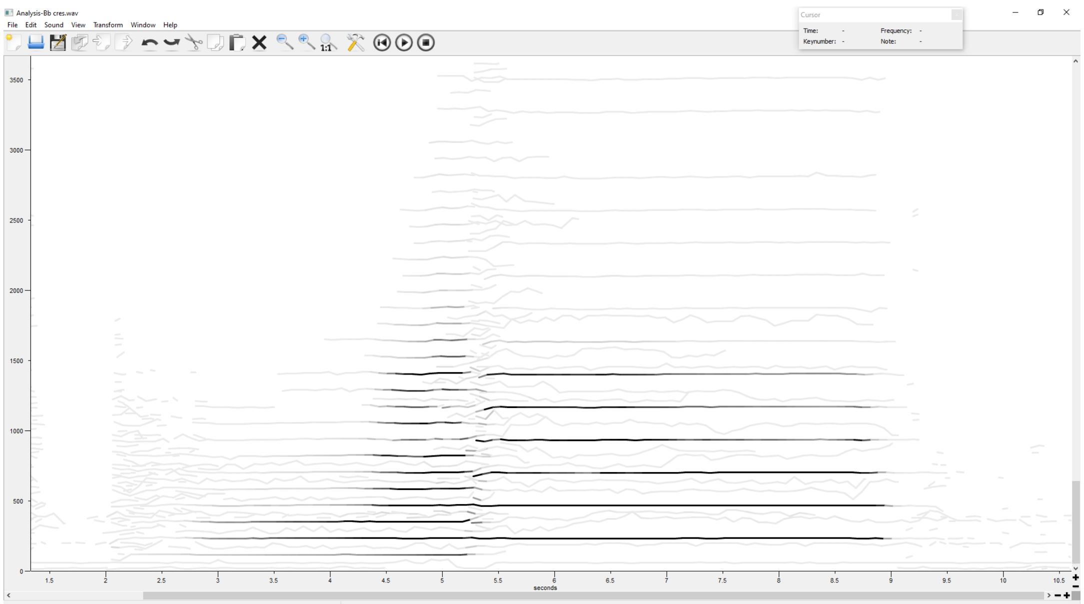


Number of Complete Harmonics – 40

Highest Complete Harmonic – G4, 400.000 Hz

Highest Partial in Hz – Bb6, 1856.000

Bb Long Tones for Dynamic Range, Crescendo:

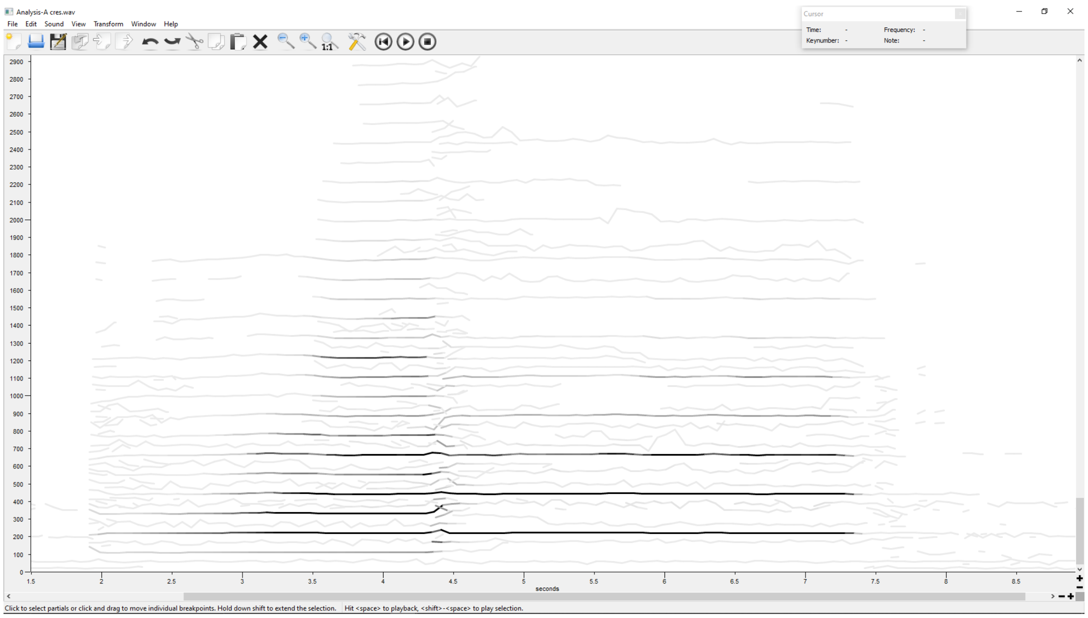


Number of Complete Harmonics – 14

Highest Complete Harmonic – F6, 1400.000 Hz

Highest Partial in Hz – A7, 3515.000

A Long Tones for Dynamic Range, Crescendo:

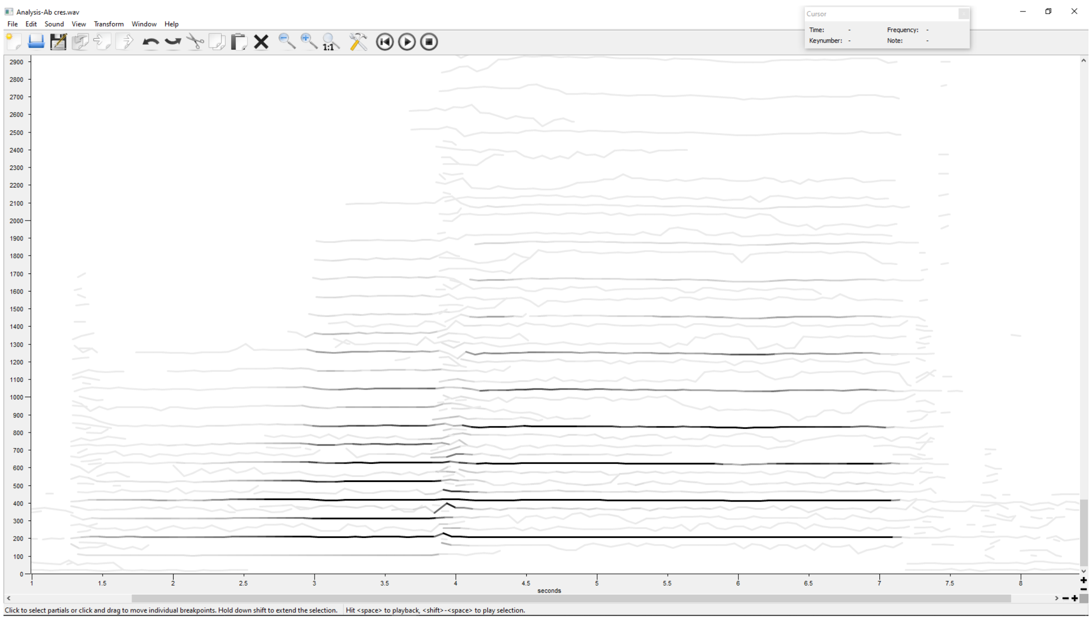


Number of Complete Harmonics – 12

Highest Complete Harmonic – C#6, 1105.000 Hz

Highest Partial in Hz – A7, 3550.000

Ab Long Tones for Dynamic Range, Crescendo:

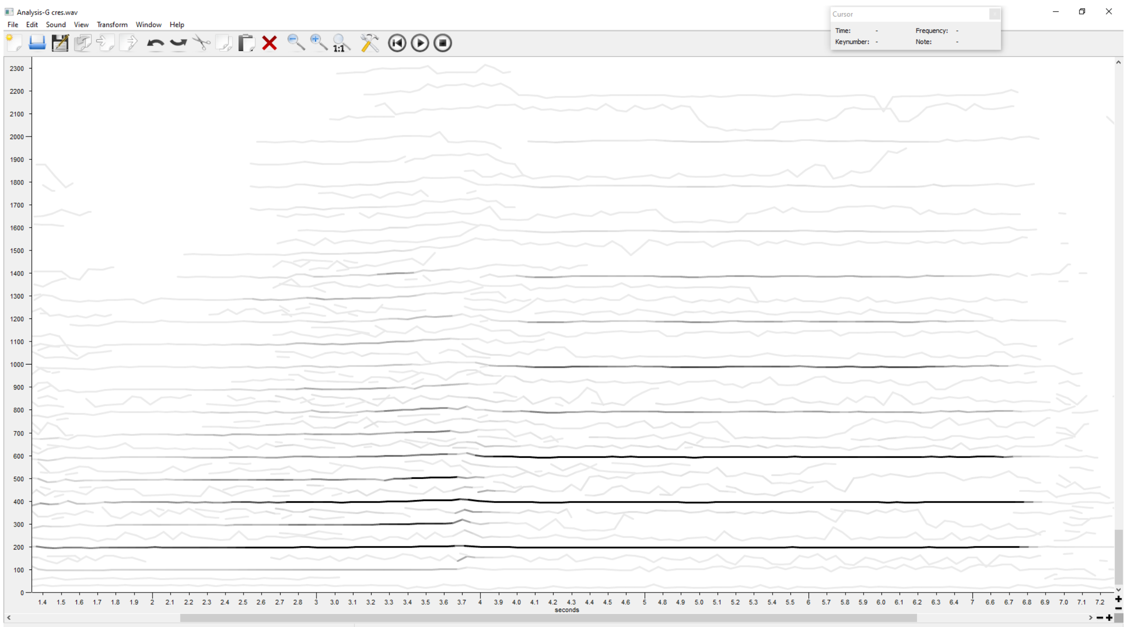


Number of Complete Harmonics – 14

Highest Complete Harmonic – F#6, 1455.000 Hz

Highest Partial in Hz – G7, 3100.000

G Long Tones for Dynamic Range, Crescendo:

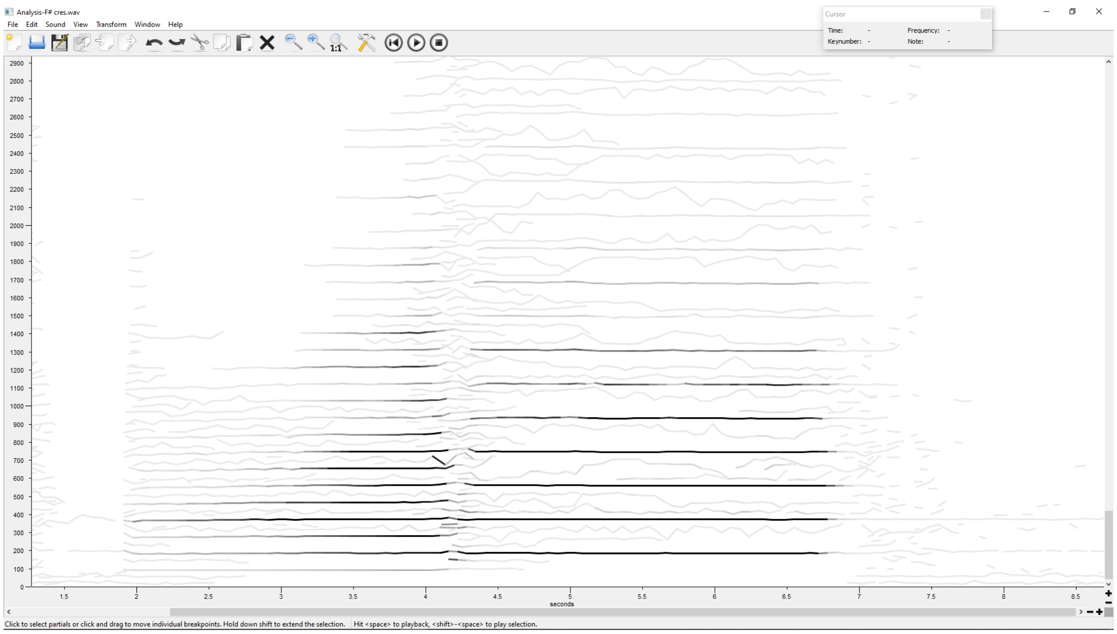


Number of Complete Harmonics – 15

Highest Complete Harmonic – F6, 1380.000 Hz

Highest Partial in Hz – F#7, 2965.000

F# Long Tones for Dynamic Range, Crescendo:

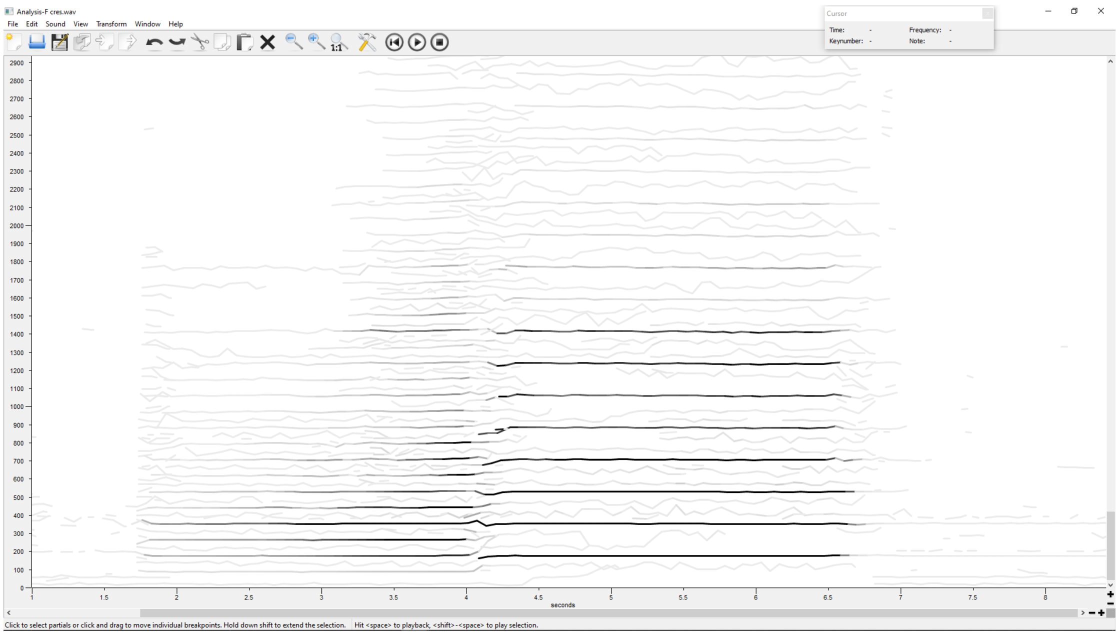


Number of Complete Harmonics – 19

Highest Complete Harmonic – G#6, 1675.000 Hz

Highest Partial in Hz – C8, 4105.000

F Long Tones for Dynamic Range, Crescendo:

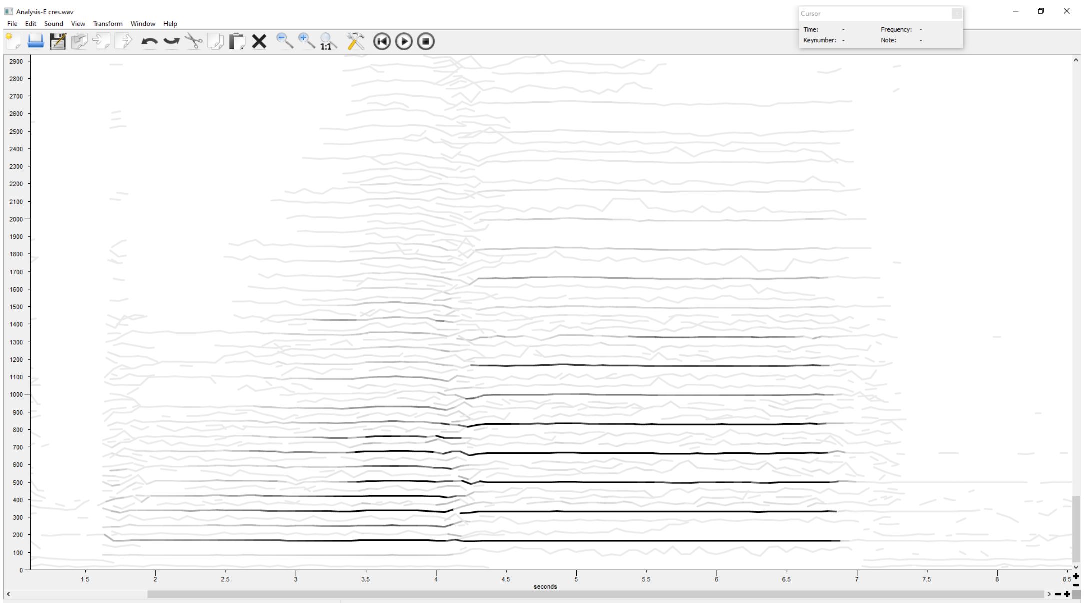


Number of Complete Harmonics – 21

Highest Complete Harmonic – A6, 1765.000 Hz

Highest Partial in Hz – C#8, 4420.000

E Long Tones for Dynamic Range, Crescendo:

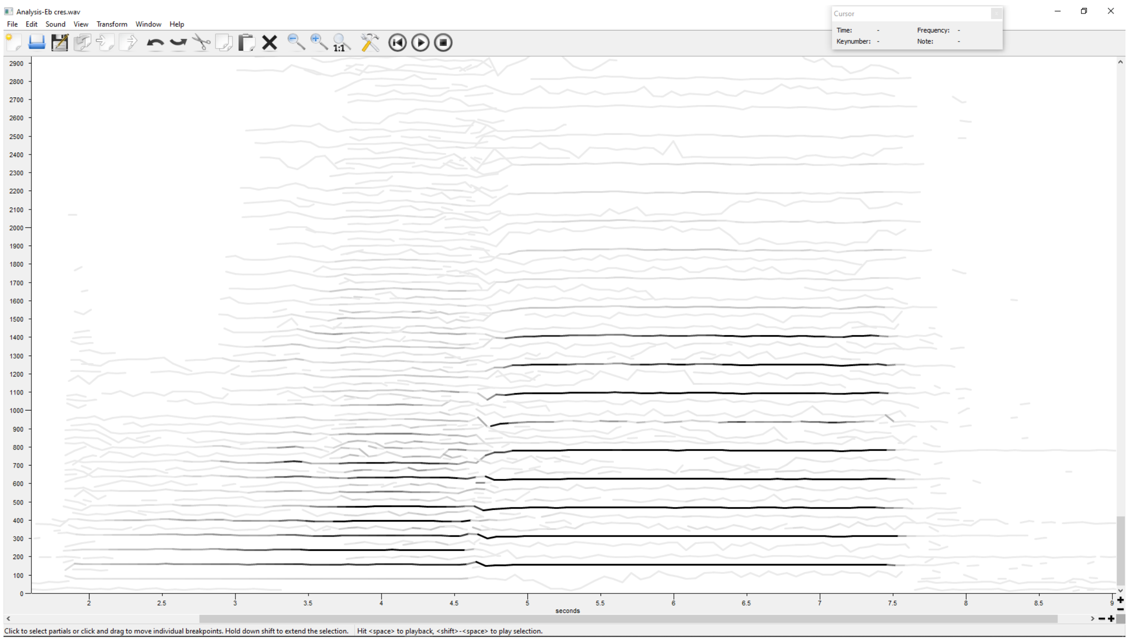


Number of Complete Harmonics – 24

Highest Complete Harmonic – G#, 1655.000 Hz

Highest Partial in Hz – D8, 4810.000

Eb Long Tones for Dynamic Range, Crescendo:



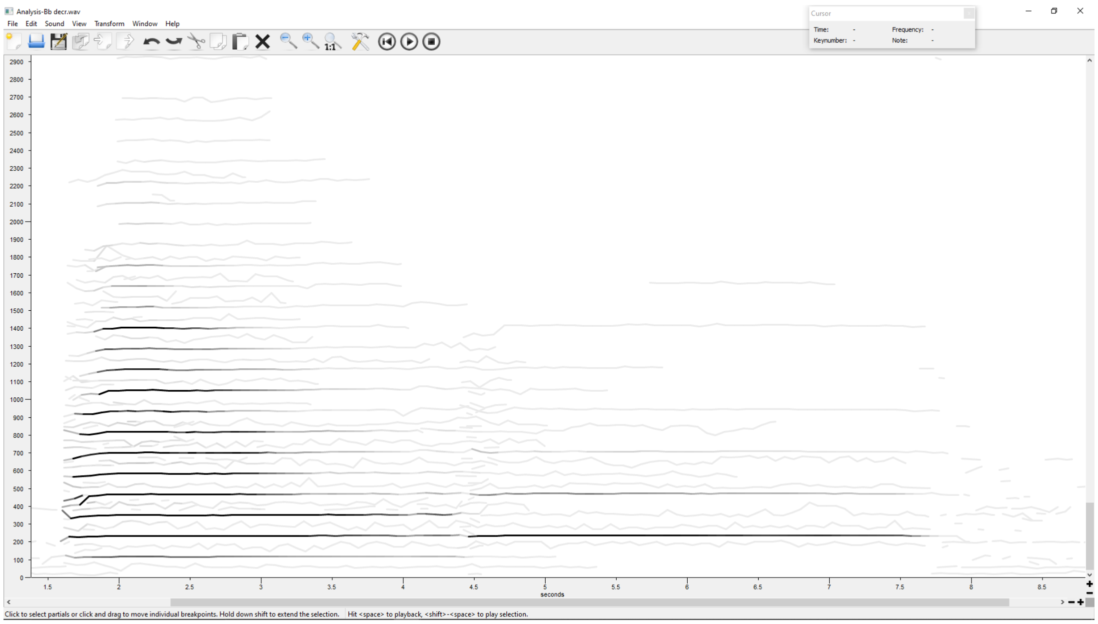
Number of Complete Harmonics – 25

Highest Complete Harmonic – G6, 1560.000 Hz

Highest Partial in Hz – B7, 4065.000

Gold Long Tones for Dynamic Range, Decrescendo

Bb Long Tones for Dynamic Range, Decrescendo:

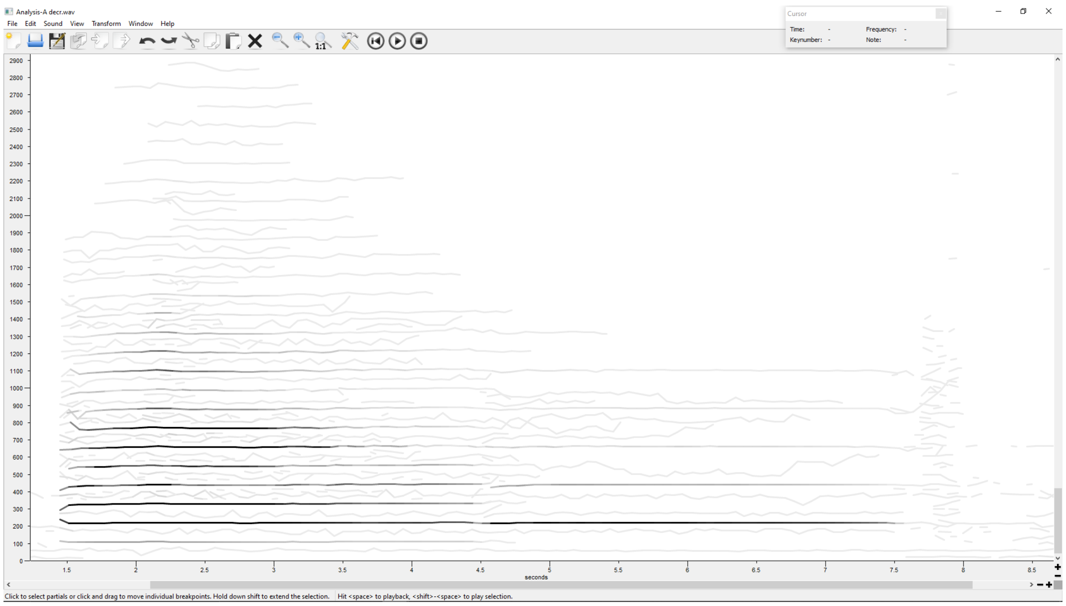


Number of Complete Harmonics – 7

Highest Complete Harmonic – Bb4, 472.000 Hz

Highest Partial in Hz – G#6, 1656.000

A Long Tones for Dynamic Range, Decrescendo:

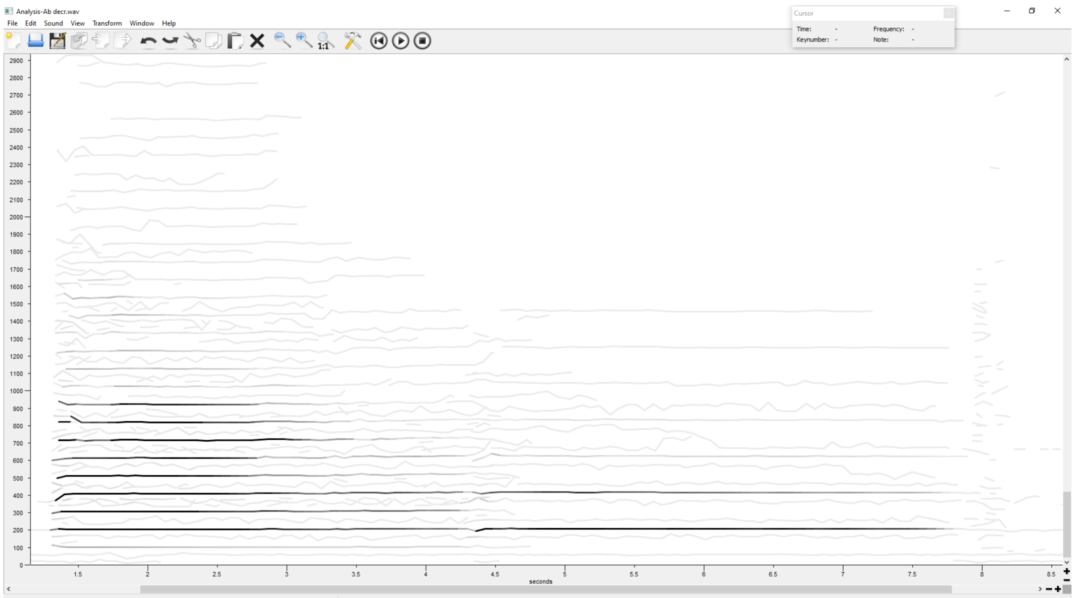


Number of Complete Harmonics – 5

Highest Complete Harmonic – A4, 444.000 Hz

Highest Partial in Hz – C#6, 1100.000

Ab Long Tones for Dynamic Range, Decrescendo:

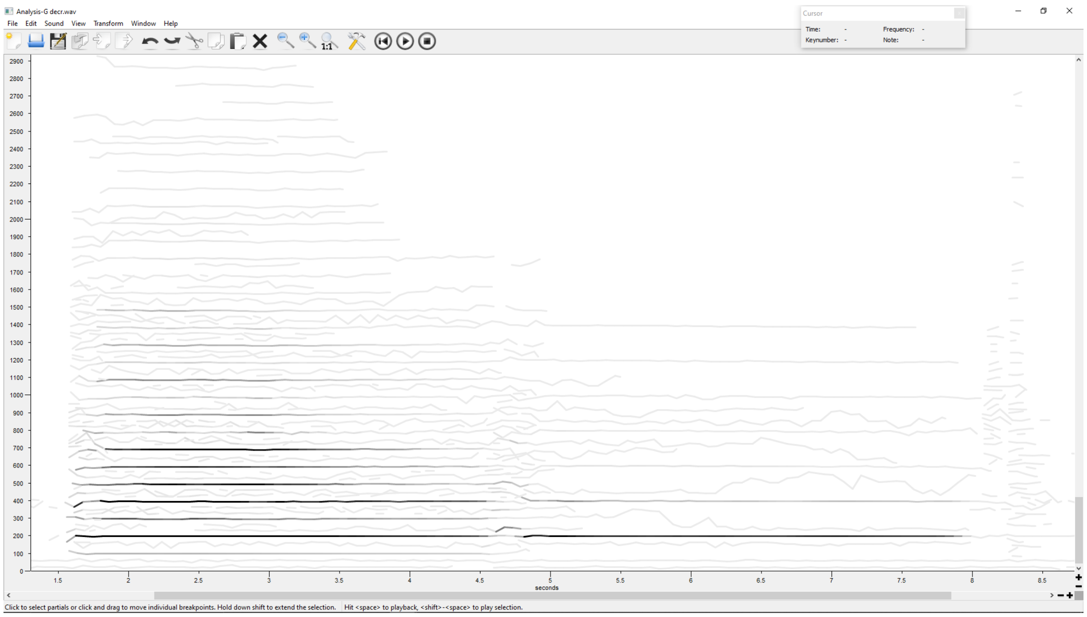


Number of Complete Harmonics – 7

Highest Complete Harmonic – G#4, 416.000 Hz

Highest Partial in Hz – F#6, 1460.000

G Long Tones for Dynamic Range, Decrescendo:

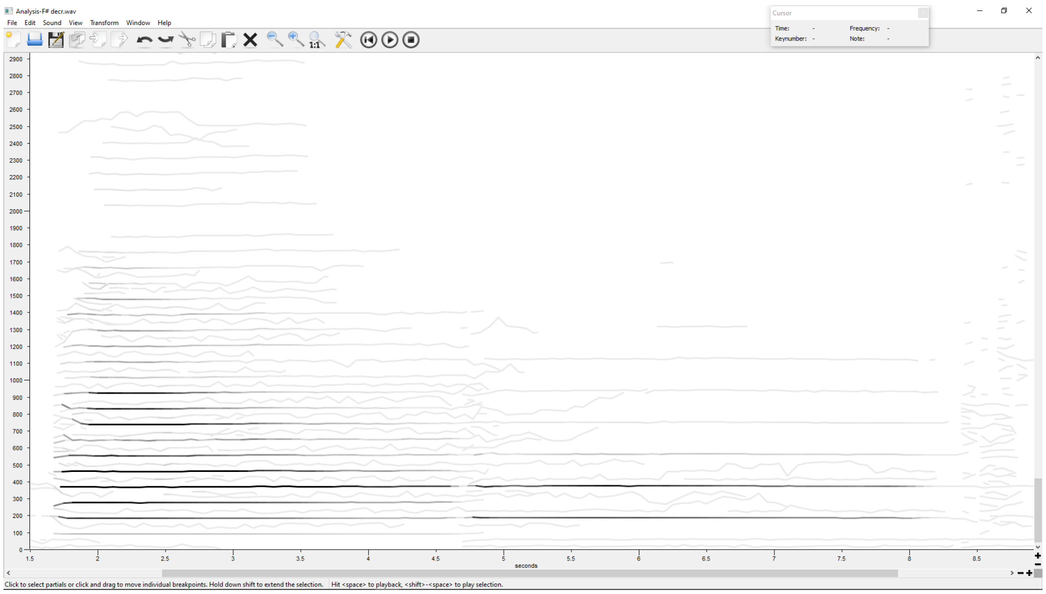


Number of Complete Harmonics – 7

Highest Complete Harmonic – G4, 396.000 Hz

Highest Partial in Hz – F6, 1392.000

F# Long Tones for Dynamic Range, Decrescendo:

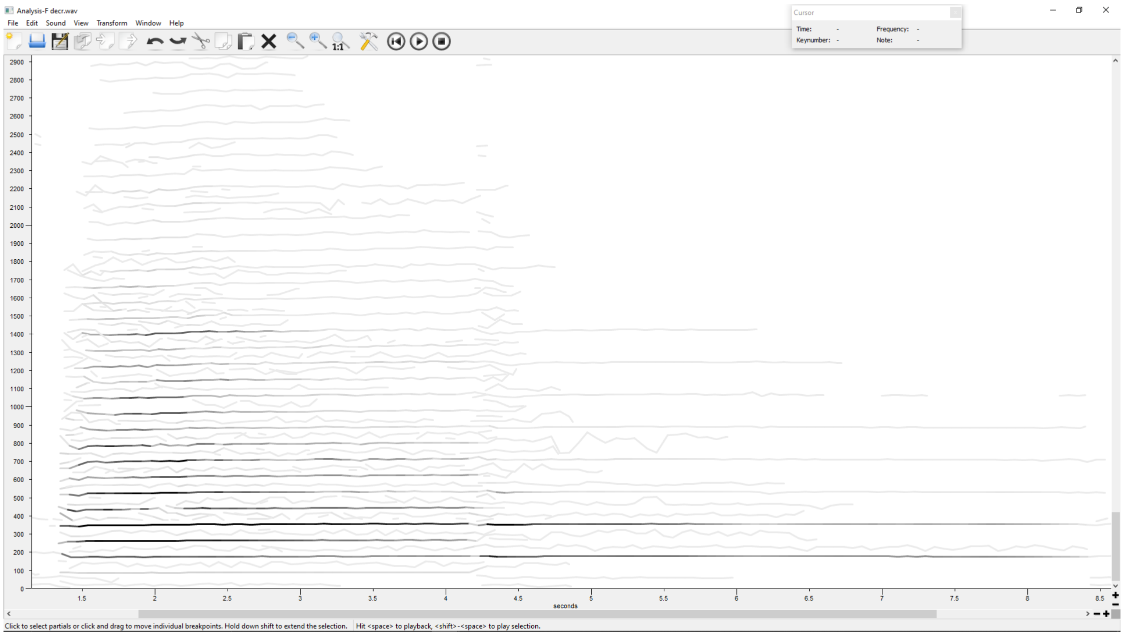


Number of Complete Harmonics – 6

Highest Complete Harmonic – F#4, 372.000 Hz

Highest Partial in Hz – E6, 1316.000

F Long Tones for Dynamic Range, Decrescendo:

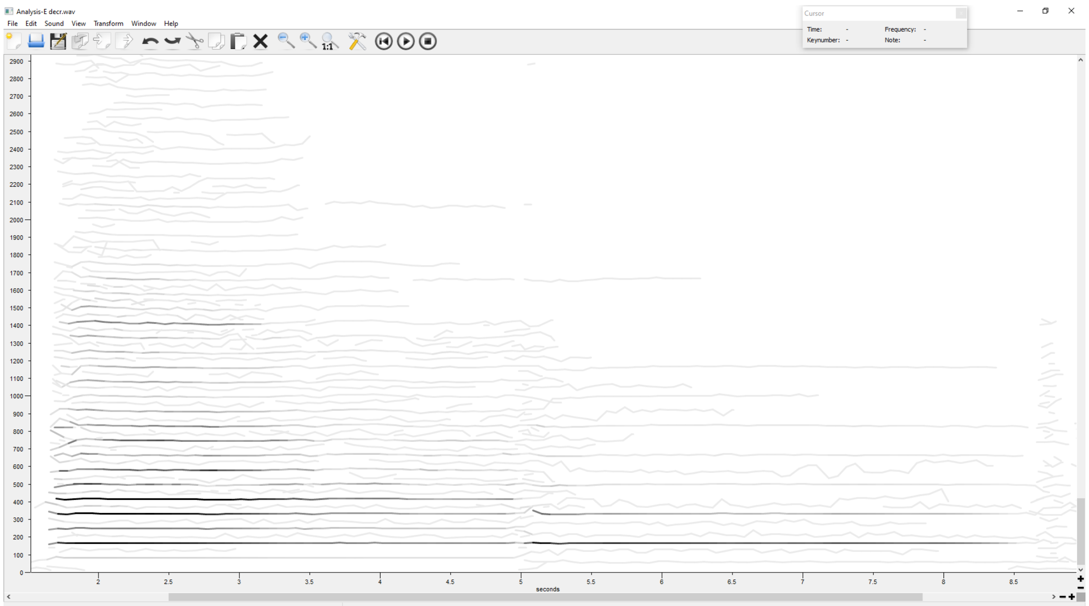


Number of Complete Harmonics – 8

Highest Complete Harmonic – F4, 355.000 Hz

Highest Partial in Hz – F6, 1425.000

E Long Tones for Dynamic Range, Decrescendo:

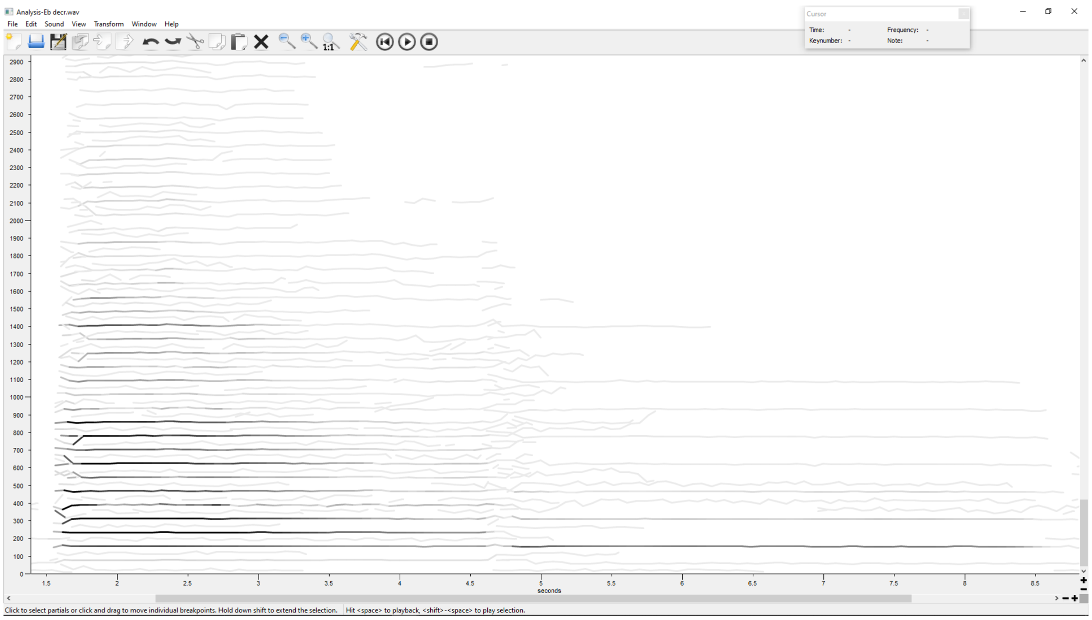


Number of Complete Harmonics – 8

Highest Complete Harmonic – E4, 336.000 Hz

Highest Partial in Hz – D6, 1160.000

Eb Long Tones for Dynamic Range, Decrescendo:



Number of Complete Harmonics – 8

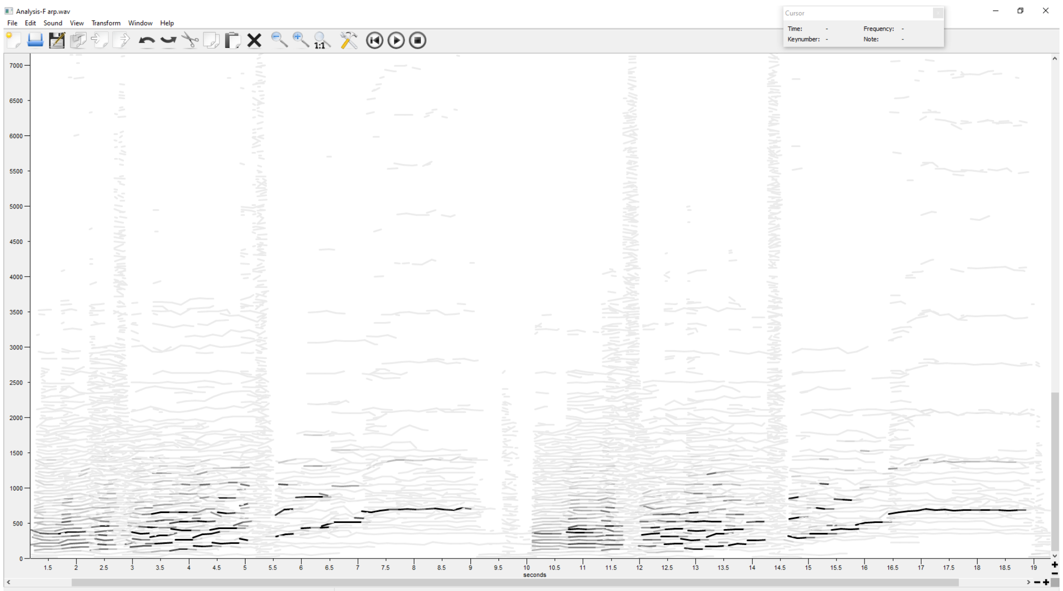
Highest Complete Harmonic – Eb4, 308.000 Hz

Highest Partial in Hz – C#6, 1088.000

Silver-Plated Analysis

Silver-Plated Arpeggios

F Arpeggios:

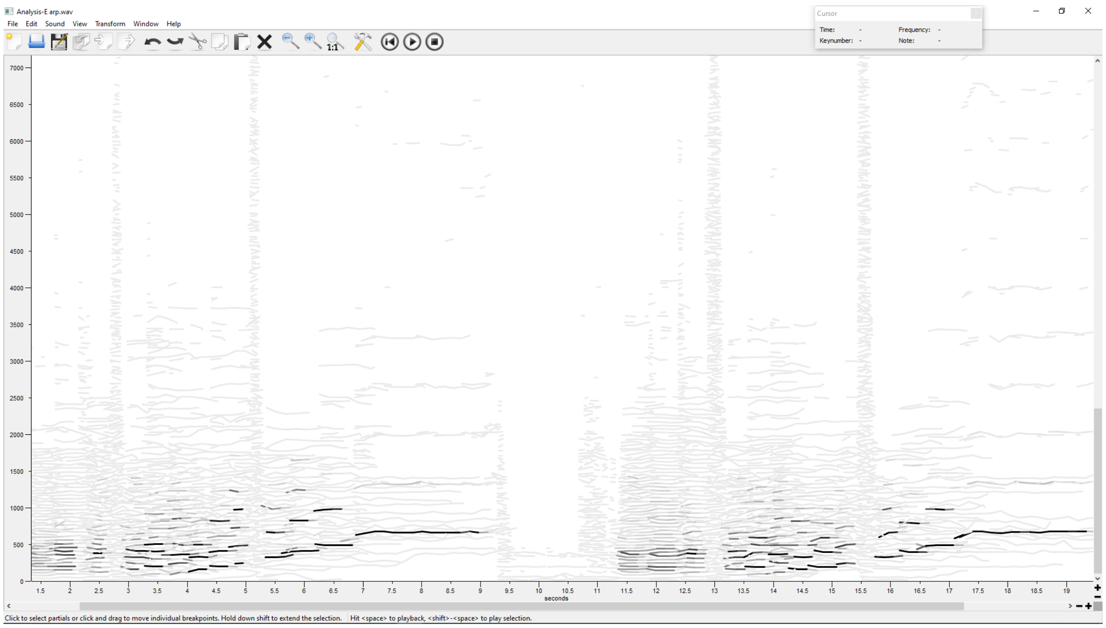


Number of Complete Harmonics – 12

Highest Complete Harmonic – F6, 1375.000 Hz

Highest Partial in Hz – D9, 9659.999

E Arpeggios:

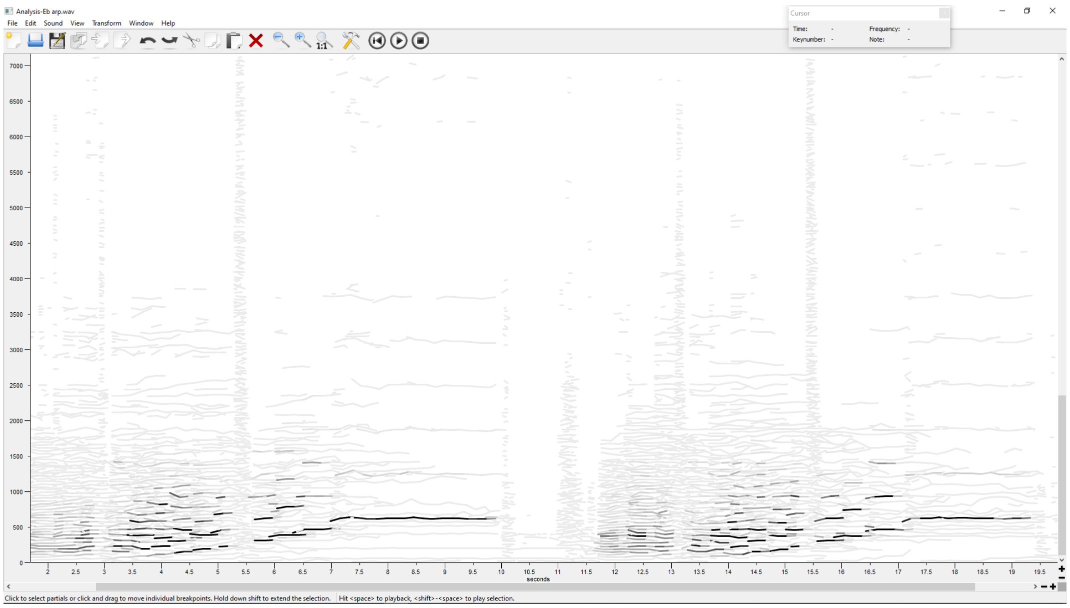


Number of Complete Harmonics – 13

Highest Complete Harmonic – E6, 1331.250 Hz

Highest Partial in Hz – C#9, 8649.999

Eb Arpeggios:

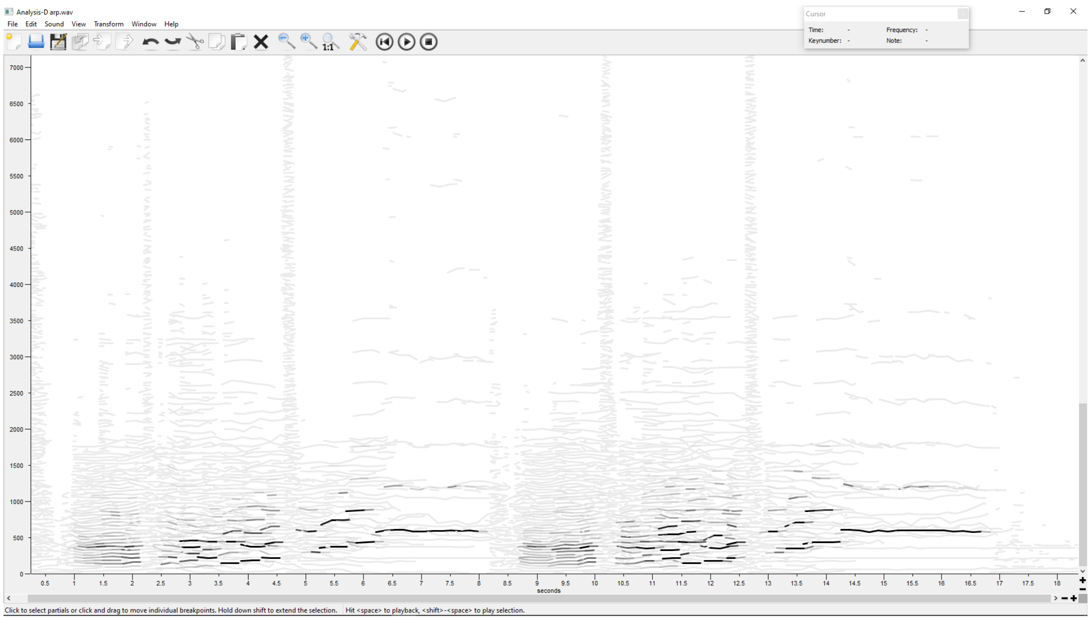


Number of Complete Harmonics – 15

Highest Complete Harmonic – Eb6, 1262.500 Hz

Highest Partial in Hz – D9, 9343.999

D Arpeggios:

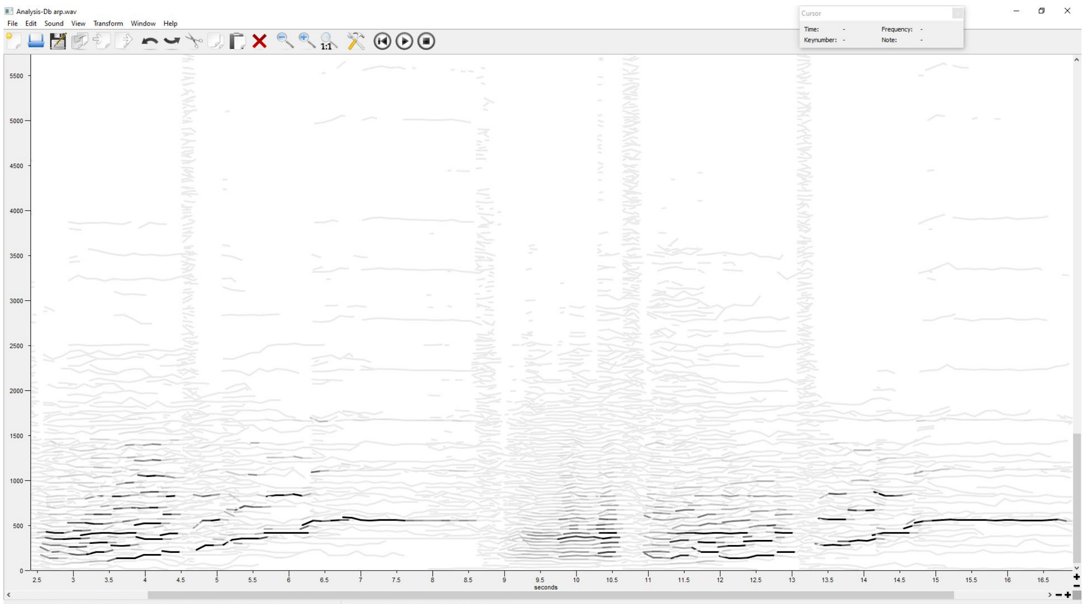


Number of Complete Harmonics – 11

Highest Complete Harmonic – D6, 1162.500 Hz

Highest Partial in Hz – Eb9, 9712.499

Db Arpeggios:

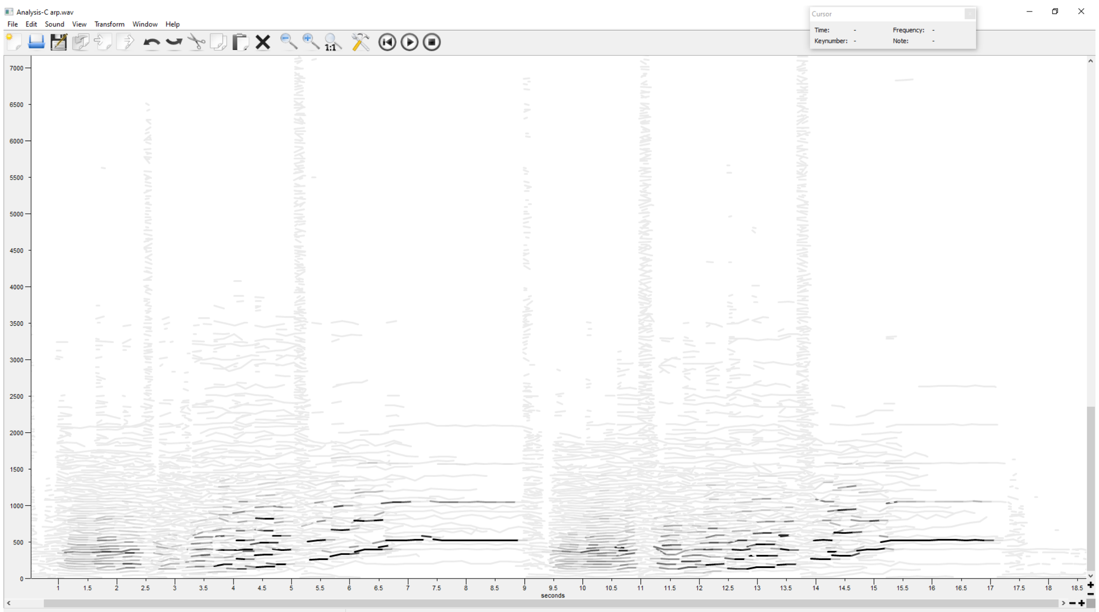


Number of Complete Harmonics – 17

Highest Complete Harmonic – C#6, 1106.250 Hz

Highest Partial in Hz – C#9, 8937.499

C Arpeggios:

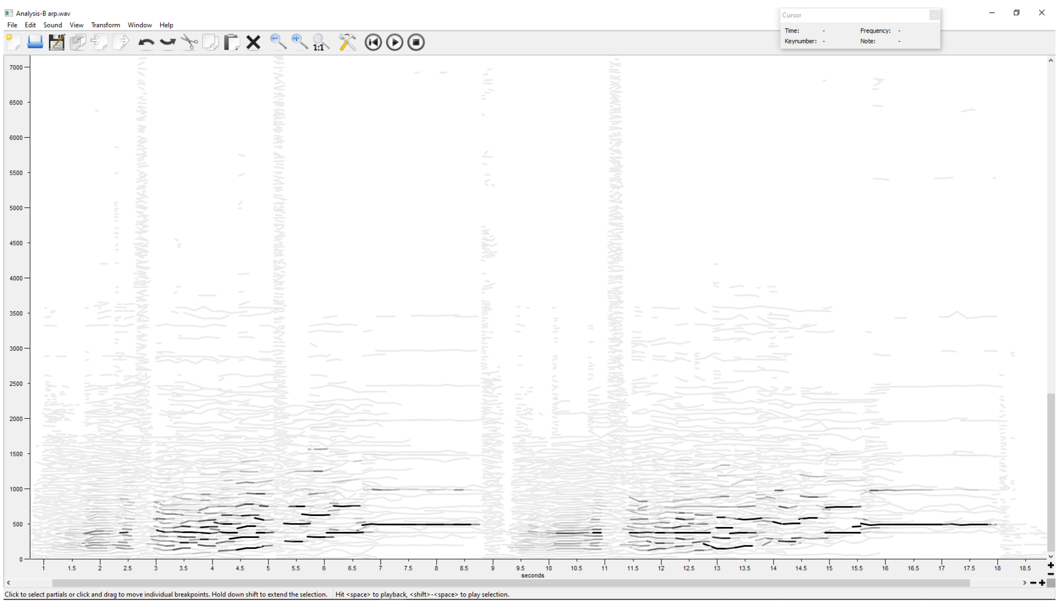


Number of Complete Harmonics – 5

Highest Complete Harmonic – C6, 1050.000 Hz

Highest Partial in Hz – C9, 8462.499

B Arpeggios:

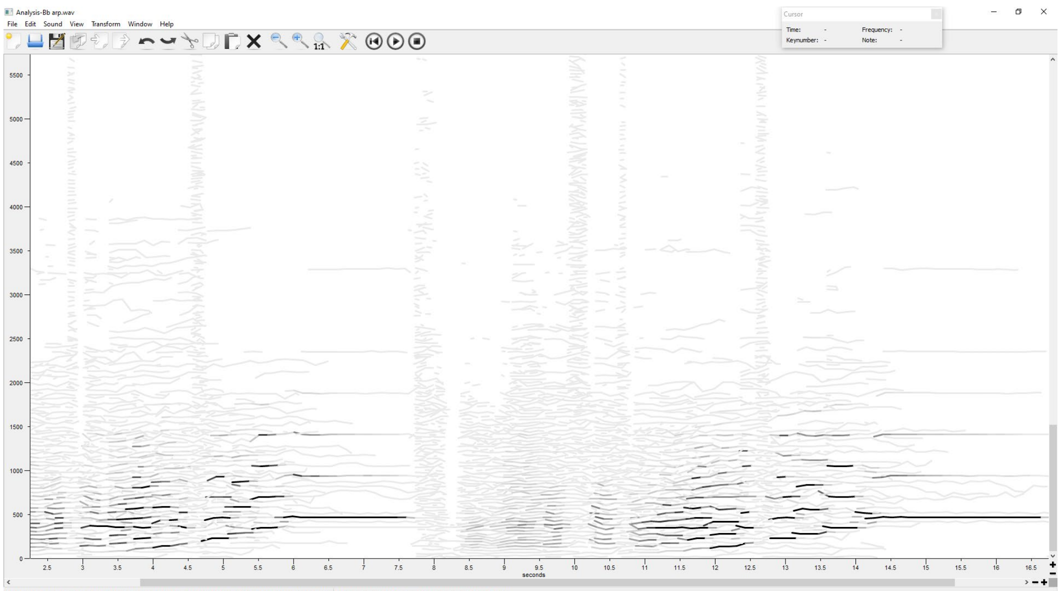


Number of Complete Harmonics – 8

Highest Complete Harmonic – B5, 980.000 Hz

Highest Partial in Hz – C#9, 8835.000

Bb Arpeggios:



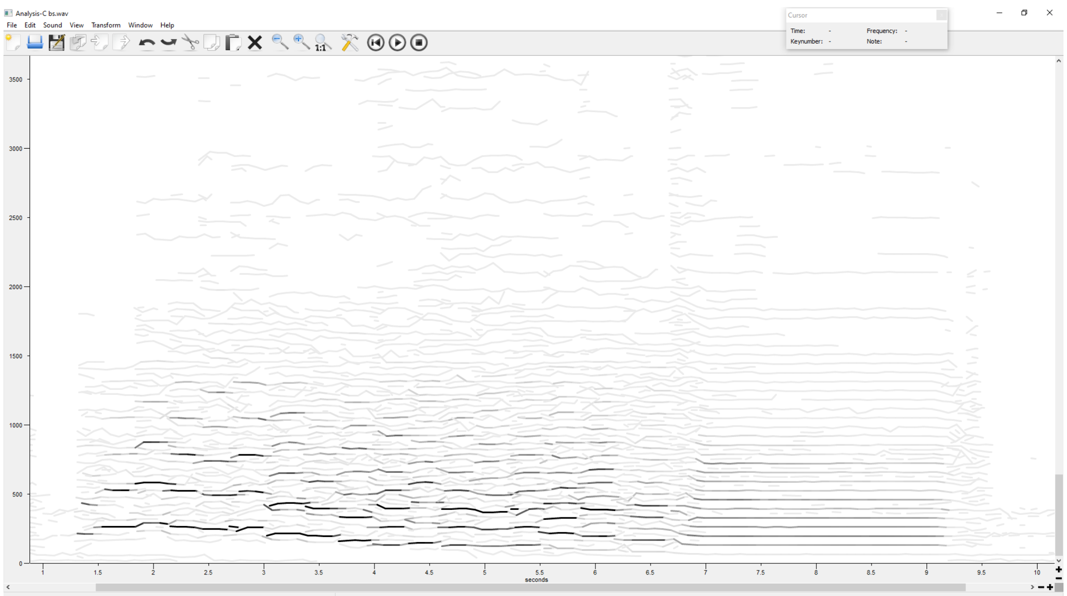
Number of Complete Harmonics – 6

Highest Complete Harmonic – Bb5, 943.750 Hz

Highest Partial in Hz – C#9, 8953.125

Silver-Plated Descending *BEAUTIFUL SOUNDS*

C Descending *BEAUTIFUL SOUNDS*:

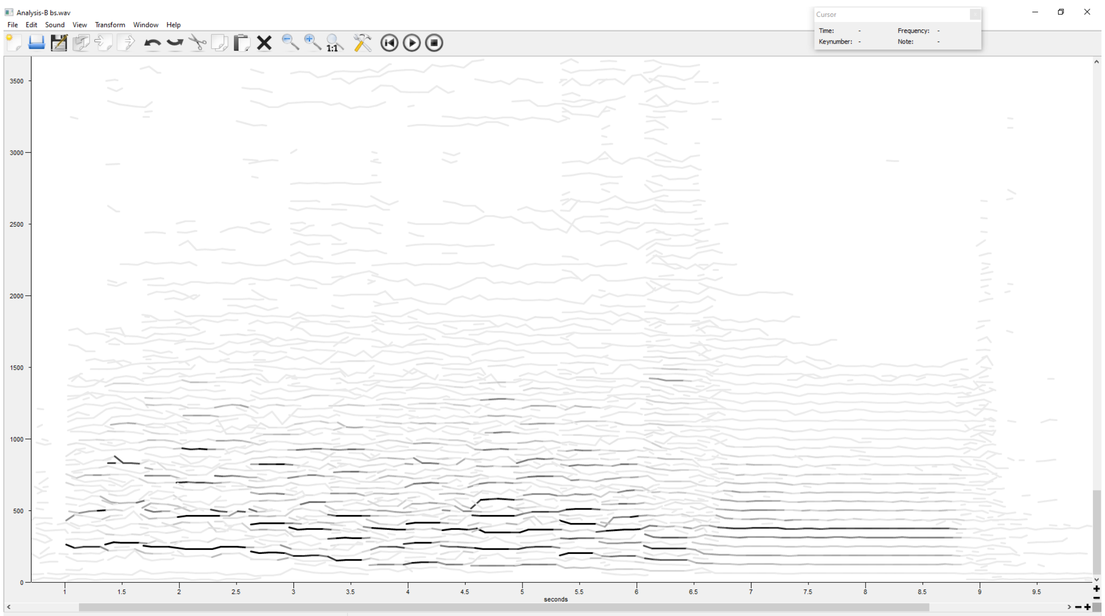


Number of Complete Harmonics – 26

Highest Complete Harmonic – F#5, 723.200 Hz

Highest Partial in Hz – F7, 2828.000

B Descending *BEAUTIFUL SOUNDS*:

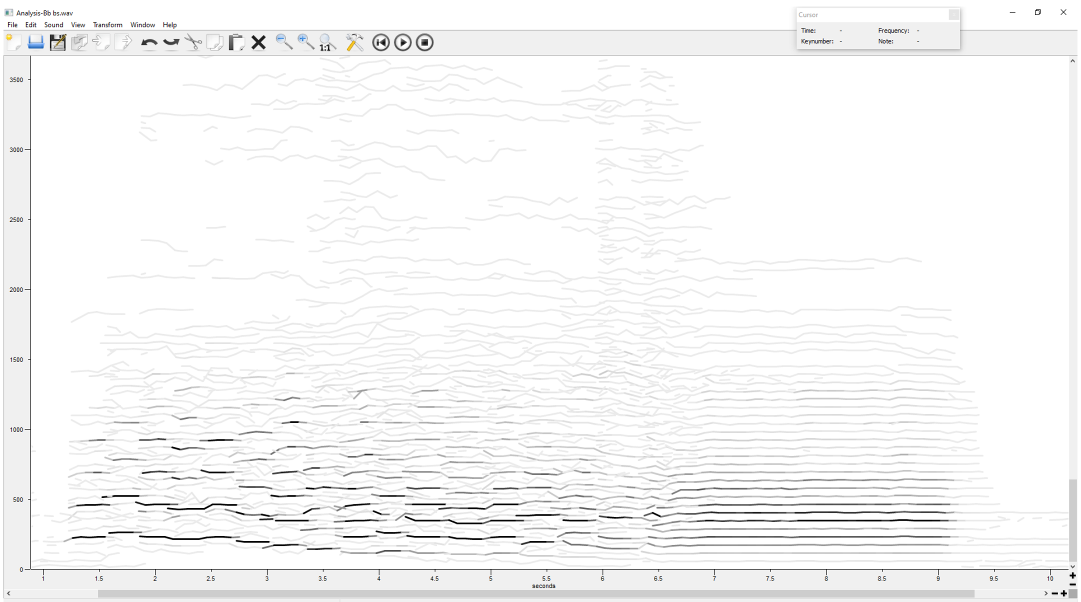


Number of Complete Harmonics – 24

Highest Complete Harmonic – Eb5, 624.000 Hz

Highest Partial in Hz –F#6, 1512.000

Bb Descending *BEAUTIFUL SOUNDS*:

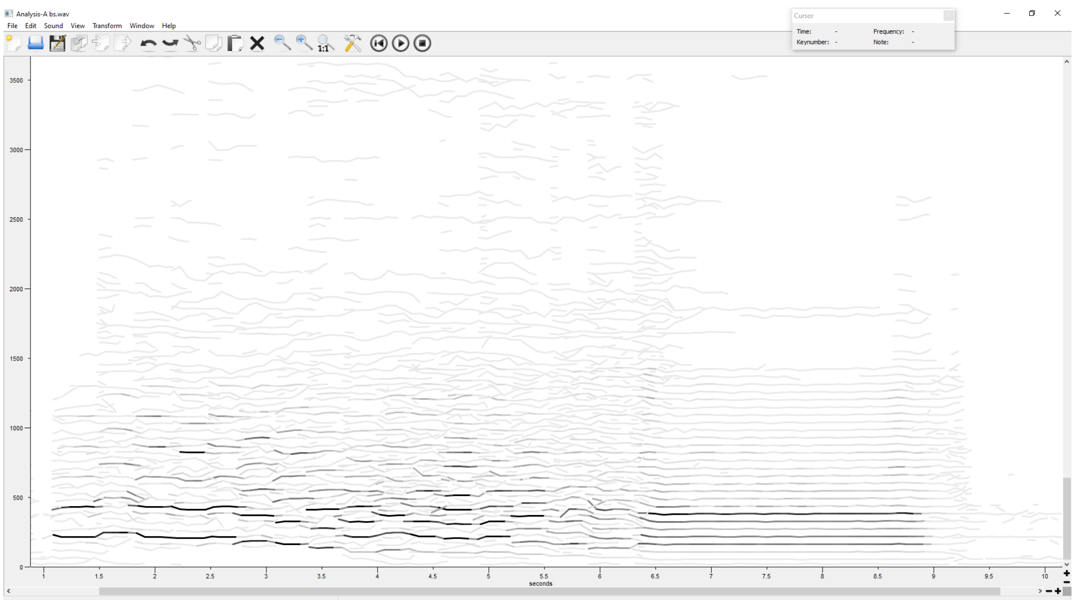


Number of Complete Harmonics – 32

Highest Complete Harmonic – Eb5, 640.000 Hz

Highest Partial in Hz – C#7, 2204.000

A Descending *BEAUTIFUL SOUNDS*:

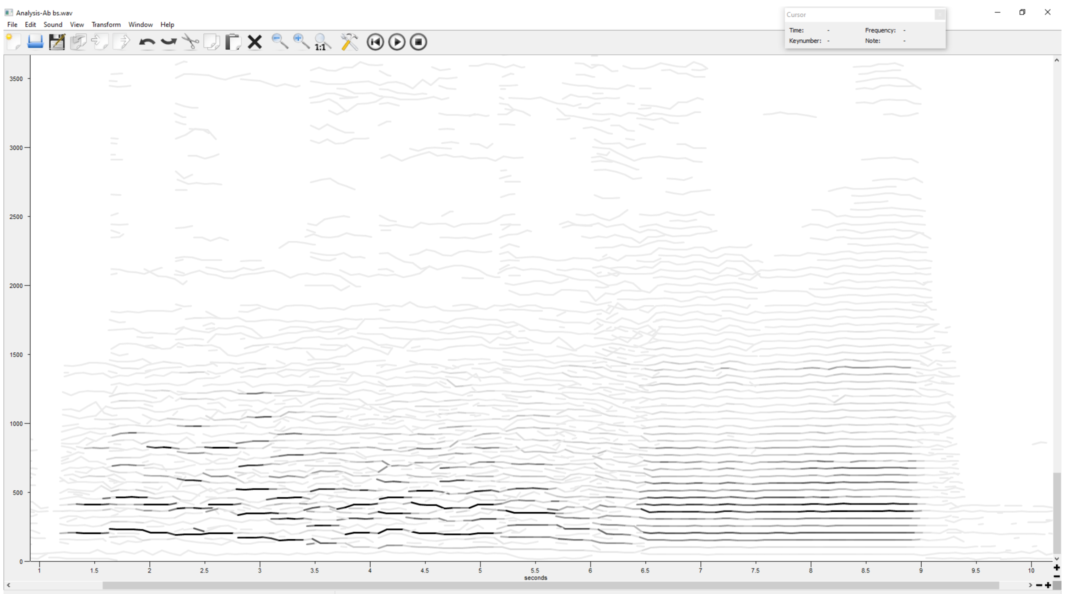


Number of Complete Harmonics – 28

Highest Complete Harmonic – G#5, 824.000 Hz

Highest Partial in Hz – Bb6, 1864.000

Ab Descending *BEAUTIFUL SOUNDS*:

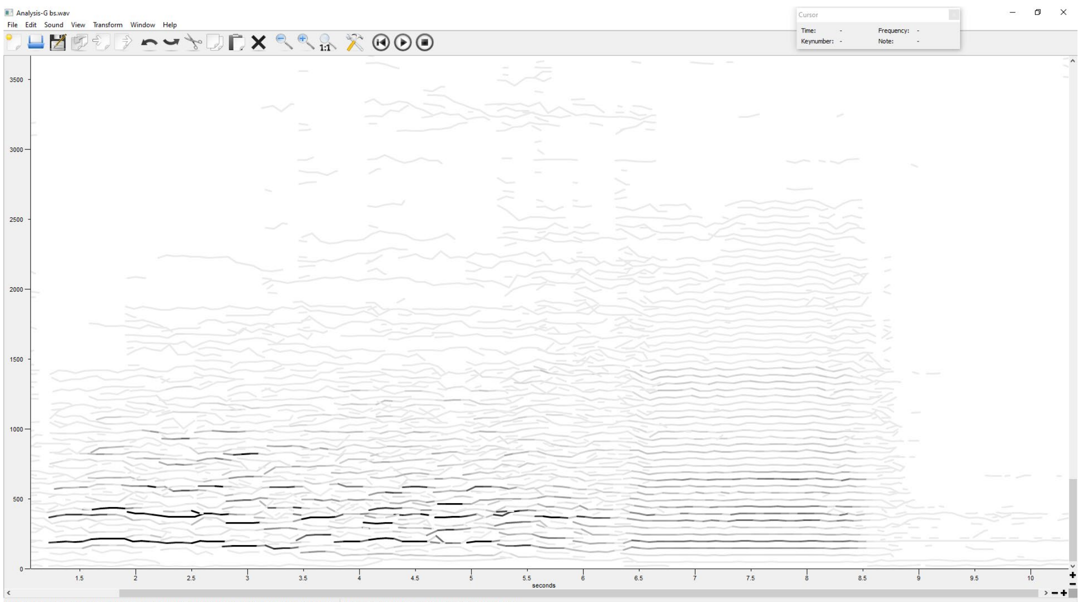


Number of Complete Harmonics – 50

Highest Complete Harmonic – F6, 1404.000 Hz

Highest Partial in Hz – Bb7, 3744.000

G Descending *BEAUTIFUL SOUNDS*:

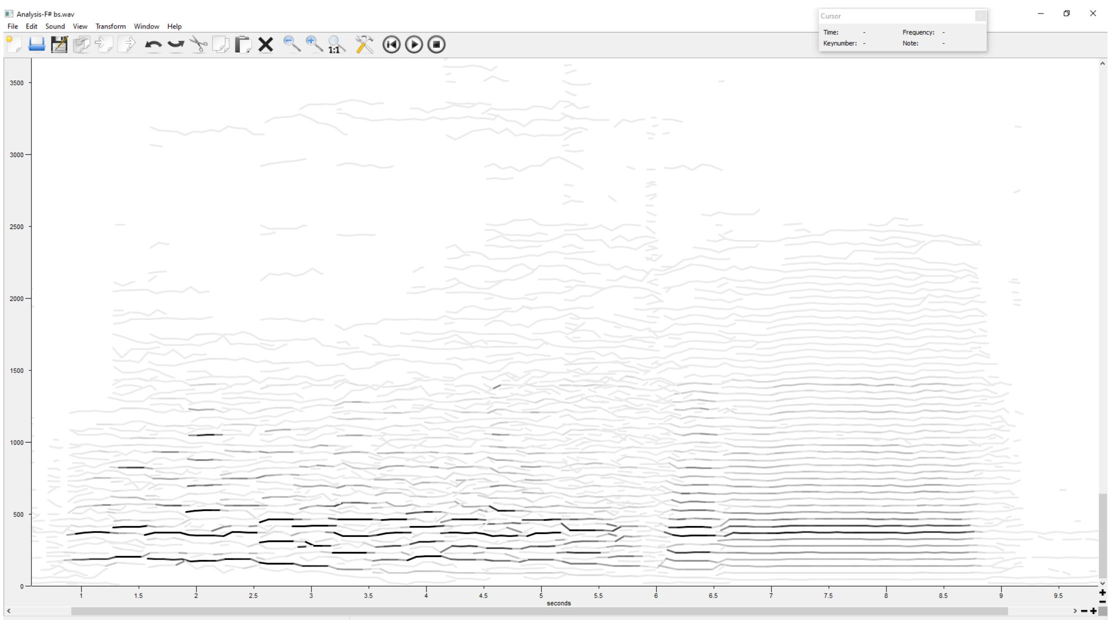


Number of Complete Harmonics – 52

Highest Complete Harmonic – Eb5, 640.000 Hz

Highest Partial in Hz – E7, 2616.000

F# Descending *BEAUTIFUL SOUNDS*:

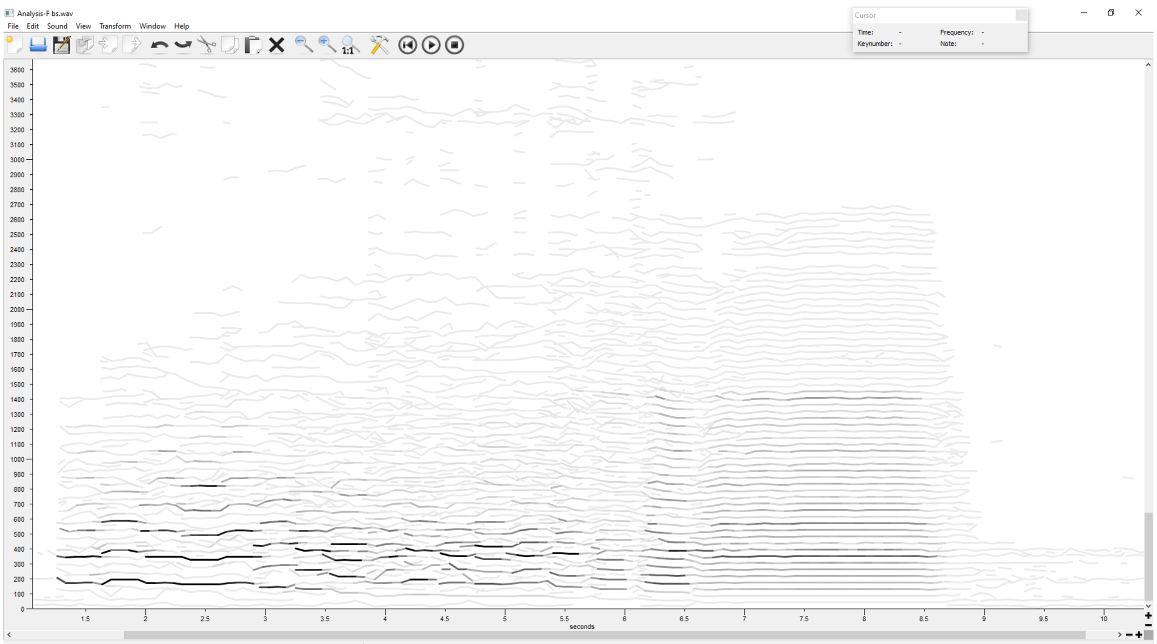


Number of Complete Harmonics – 53

Highest Complete Harmonic – Bb4, 464.000 Hz

Highest Partial in Hz – Eb7, 2476.000

F Descending *BEAUTIFUL SOUNDS*:



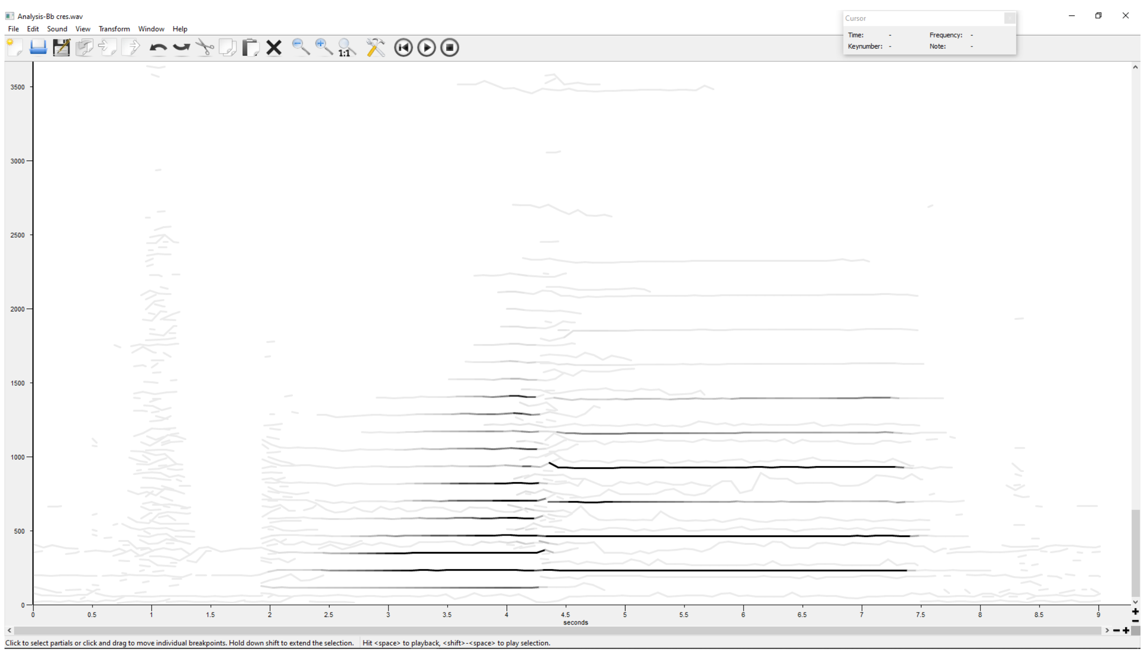
Number of Complete Harmonics – 58

Highest Complete Harmonic – F6, 1416.000 Hz

Highest Partial in Hz – E7, 2644.000

Silver-Plated Long Tones for Dynamic Range, Crescendo

Bb Long Tones for Dynamic Range, Crescendo:

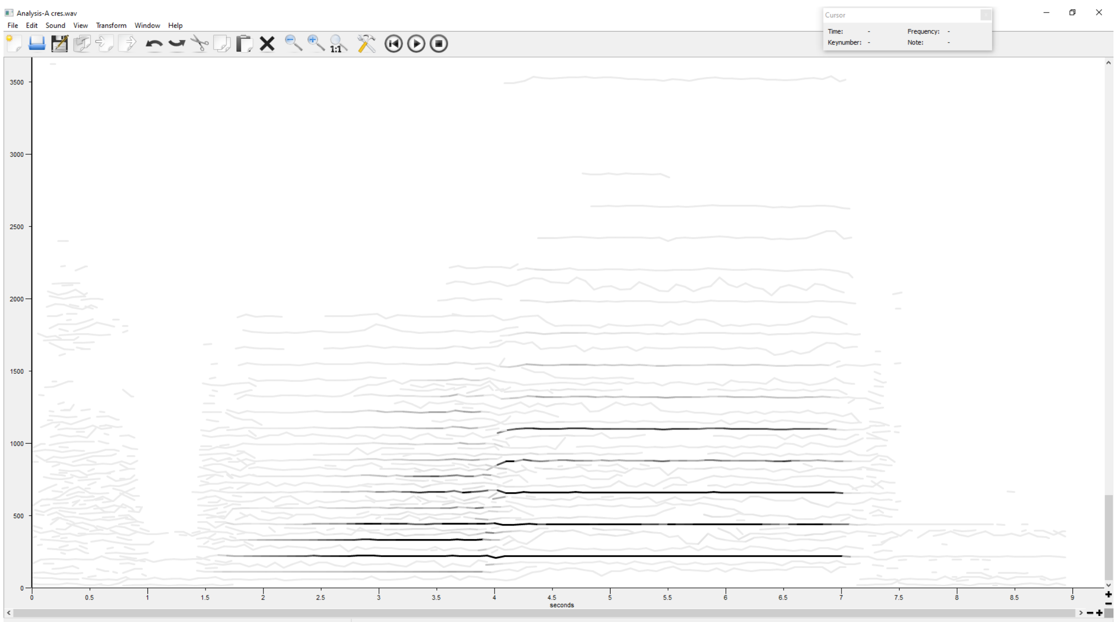


Number of Complete Harmonics – 11

Highest Complete Harmonic – F6, 1400.000 Hz

Highest Partial in Hz – A7, 3480.000

A Long Tones for Dynamic Range, Crescendo:

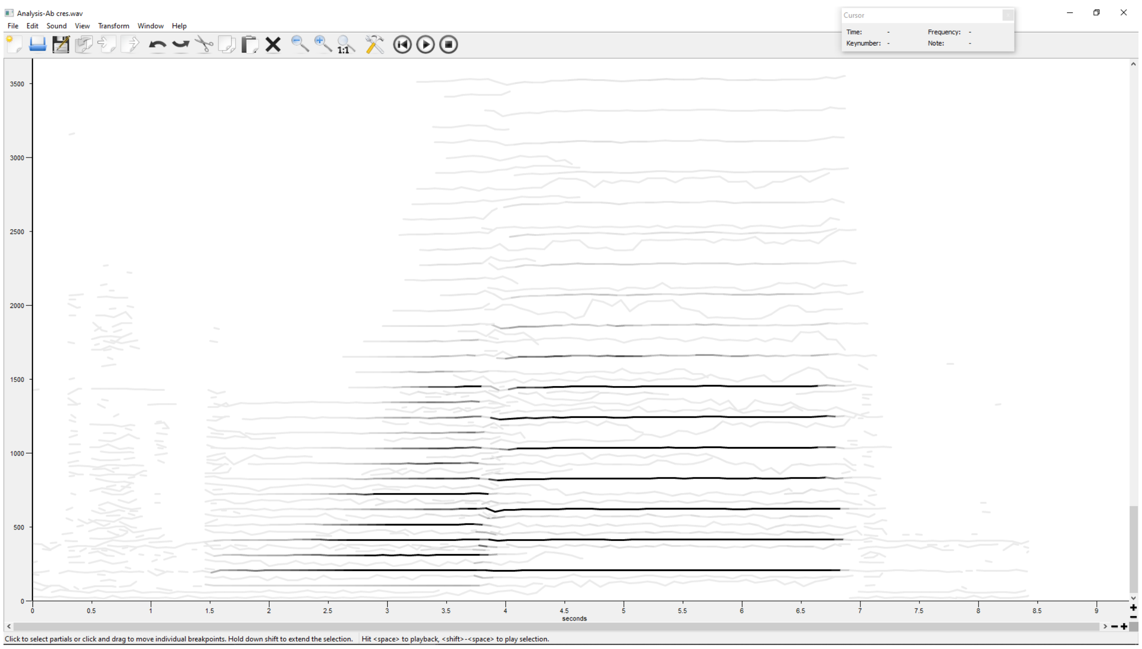


Number of Complete Harmonics – 14

Highest Complete Harmonic – C#6, 1095.000 Hz

Highest Partial in Hz – A7, 3515.000

Ab Long Tones for Dynamic Range, Crescendo:

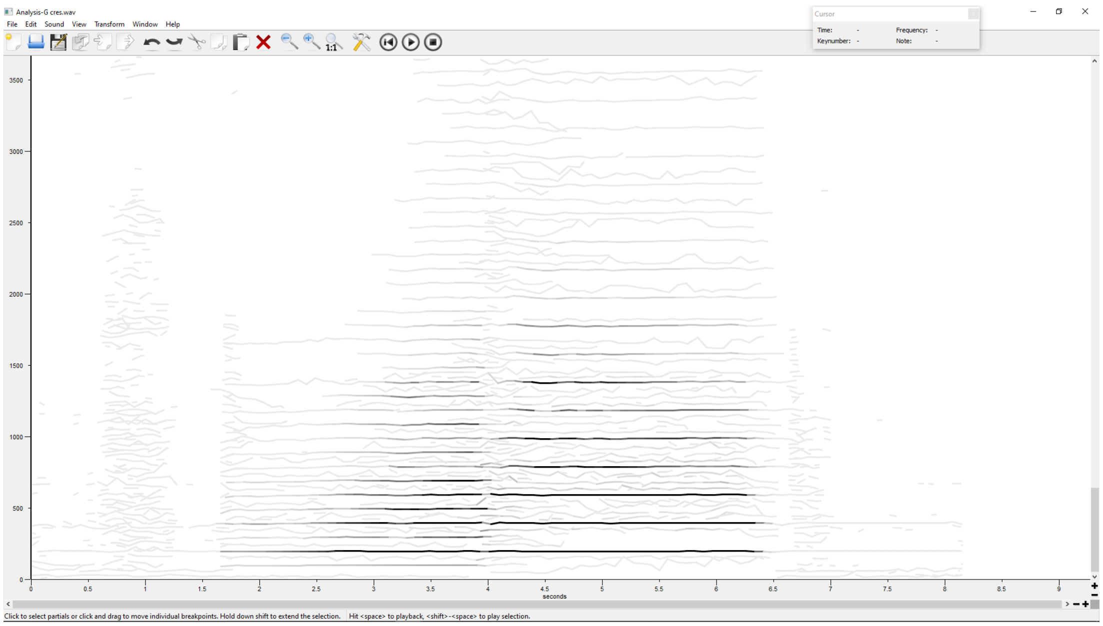


Number of Complete Harmonics – 20

Highest Complete Harmonic – G#6, 1655.000 Hz

Highest Partial in Hz – C#8, 4355.000

G Long Tones for Dynamic Range, Crescendo:

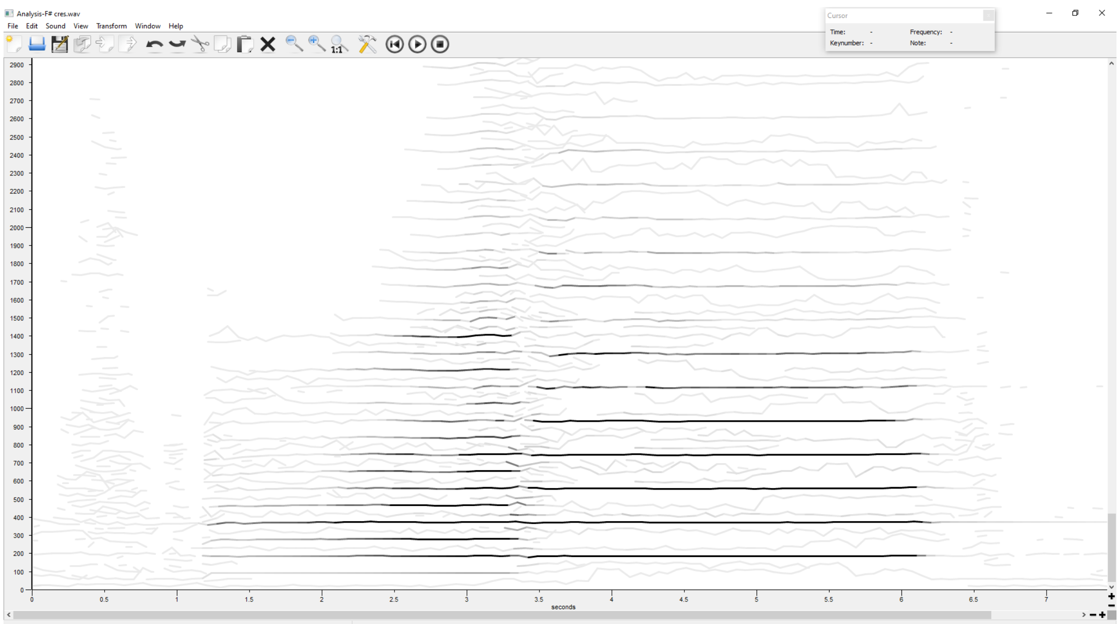


Number of Complete Harmonics – 21

Highest Complete Harmonic – A6, 1775.000 Hz

Highest Partial in Hz – C#8, 4355.000

F# Long Tones for Dynamic Range, Crescendo:

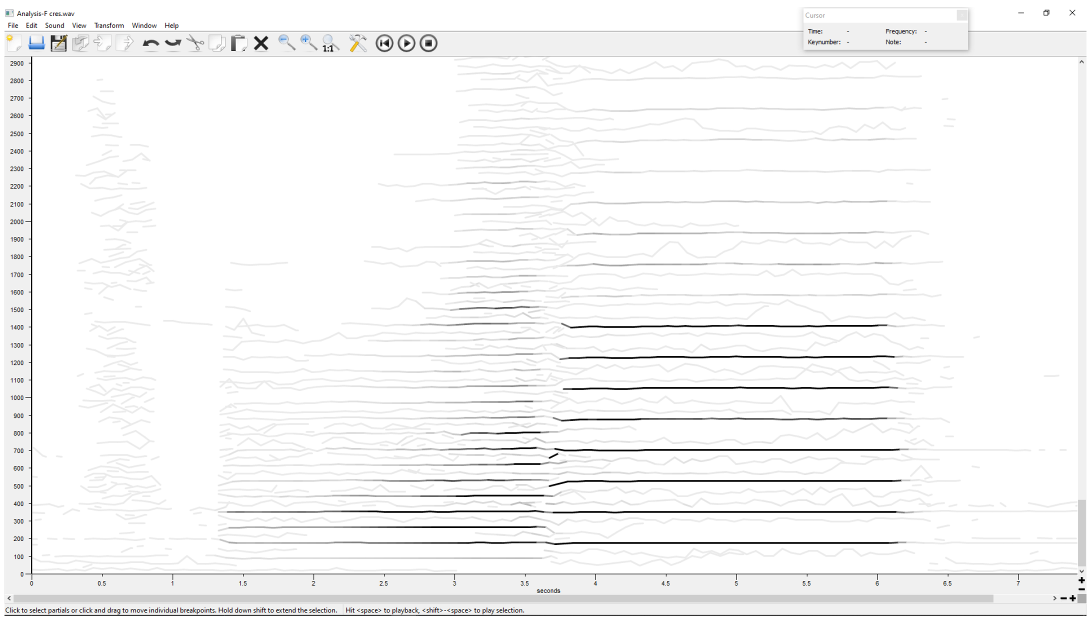


Number of Complete Harmonics – 26

Highest Complete Harmonic – G#6, 1676.000 Hz

Highest Partial in Hz – Eb8, 4840.000

F Long Tones for Dynamic Range, Crescendo:

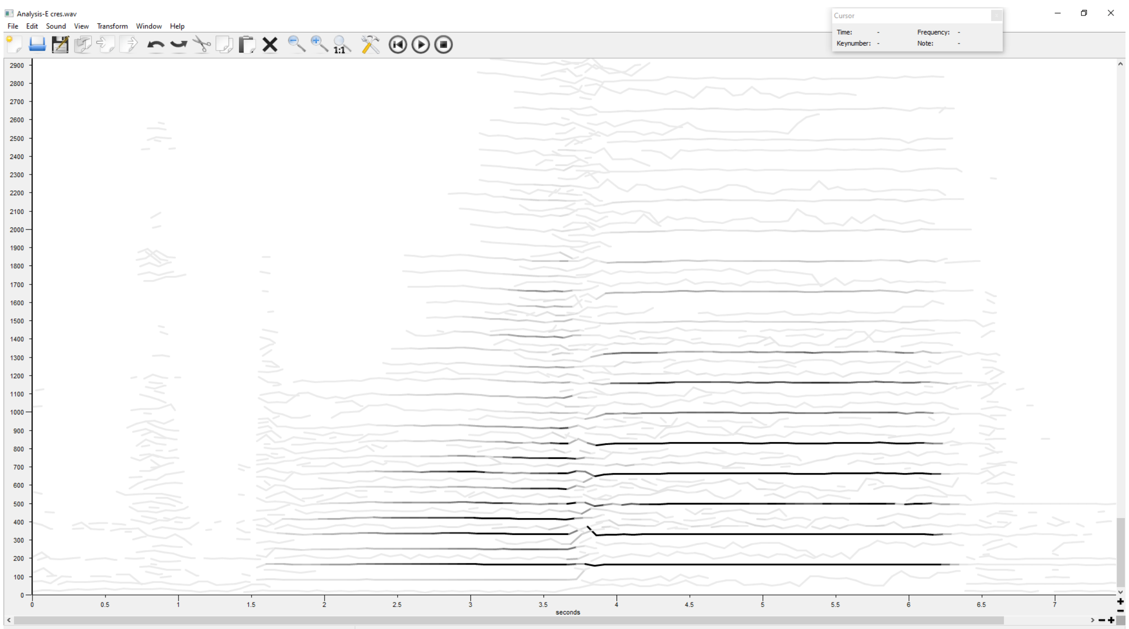


Number of Complete Harmonics – 25

Highest Complete Harmonic – B6, 1932.000 Hz

Highest Partial in Hz – Eb8, 5108.000

E Long Tones for Dynamic Range, Crescendo:

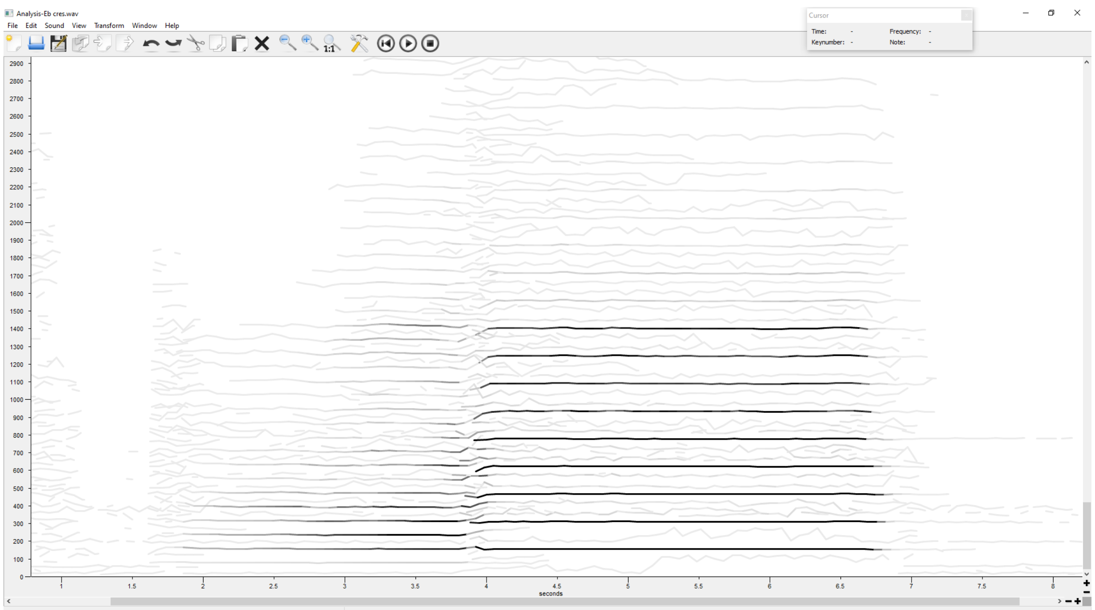


Number of Complete Harmonics – 23

Highest Complete Harmonic – E6, 1328.000 Hz

Highest Partial in Hz – B8, 7812.000

Eb Long Tones for Dynamic Range, Crescendo:



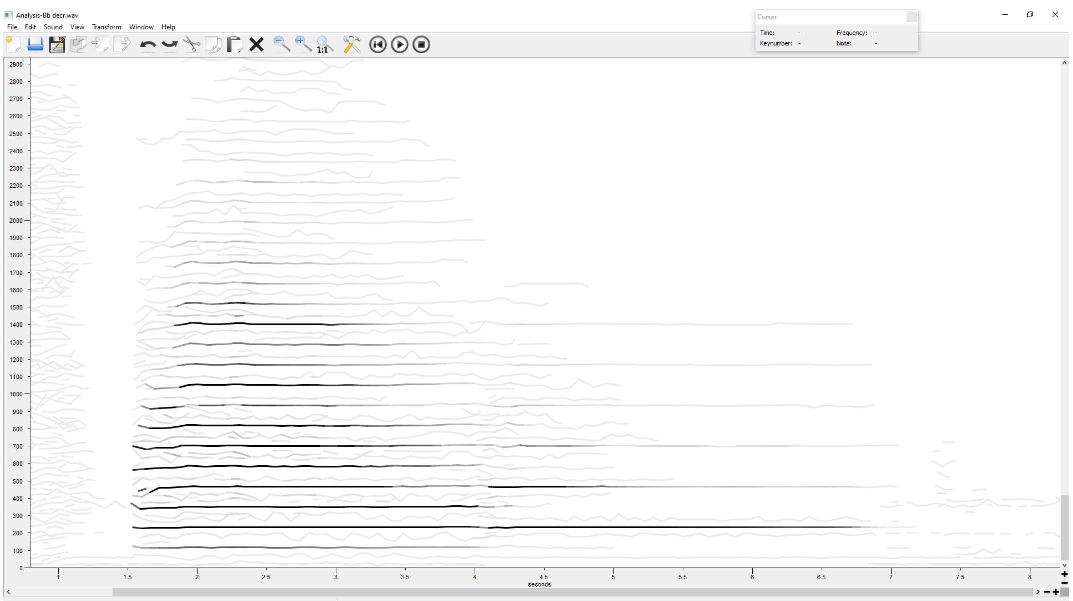
Number of Complete Harmonics – 26

Highest Complete Harmonic – F6, 1400.000 Hz

Highest Partial in Hz – C#8, 4356.000

Silver-Plated Long Tones for Dynamic Range, Decrescendo

Bb Long Tones for Dynamic Range, Decrescendo:

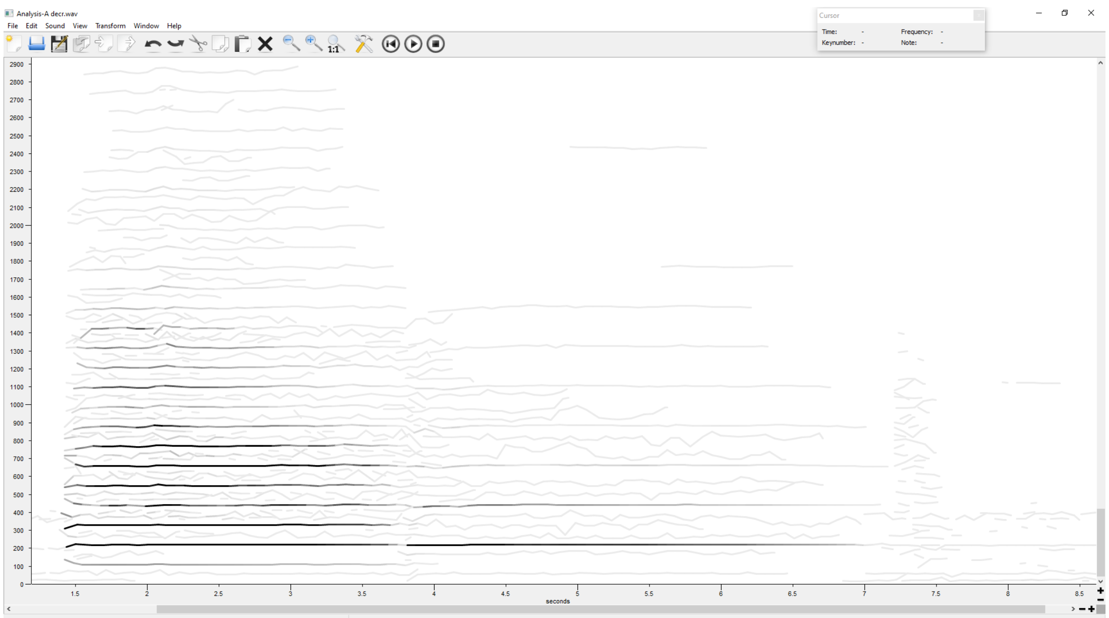


Number of Complete Harmonics – 6

Highest Complete Harmonic – Bb4, 468.000 Hz

Highest Partial in Hz – F6, 1408.000

A Long Tones for Dynamic Range, Decrescendo:

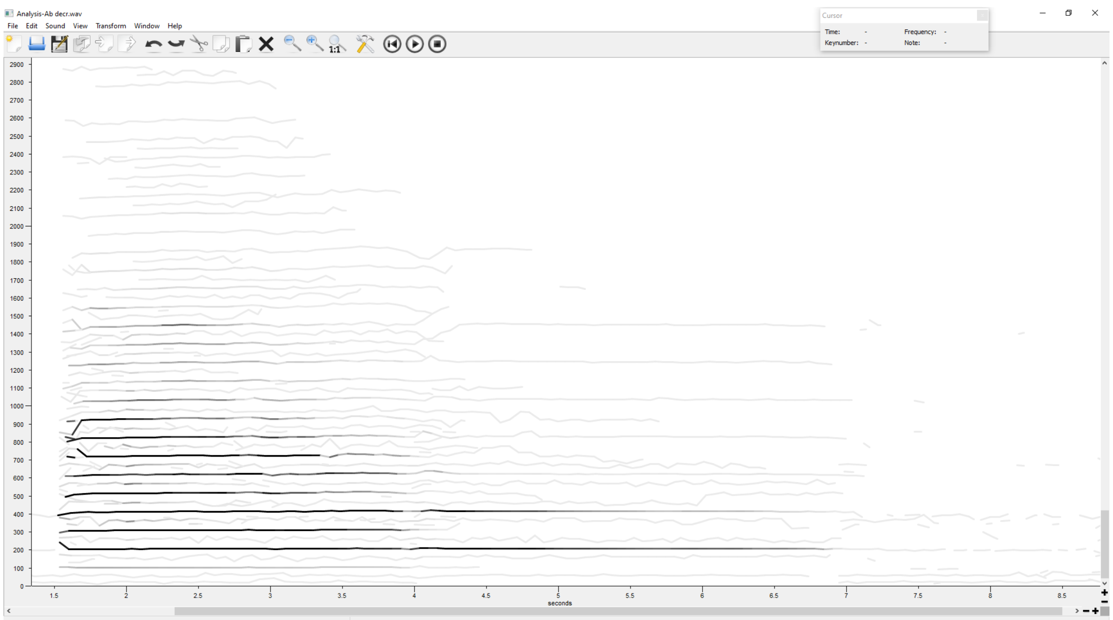


Number of Complete Harmonics – 9

Highest Complete Harmonic – A4, 440.000 Hz

Highest Partial in Hz – Eb7, 2428.000

Ab Long Tones for Dynamic Range, Decrescendo:

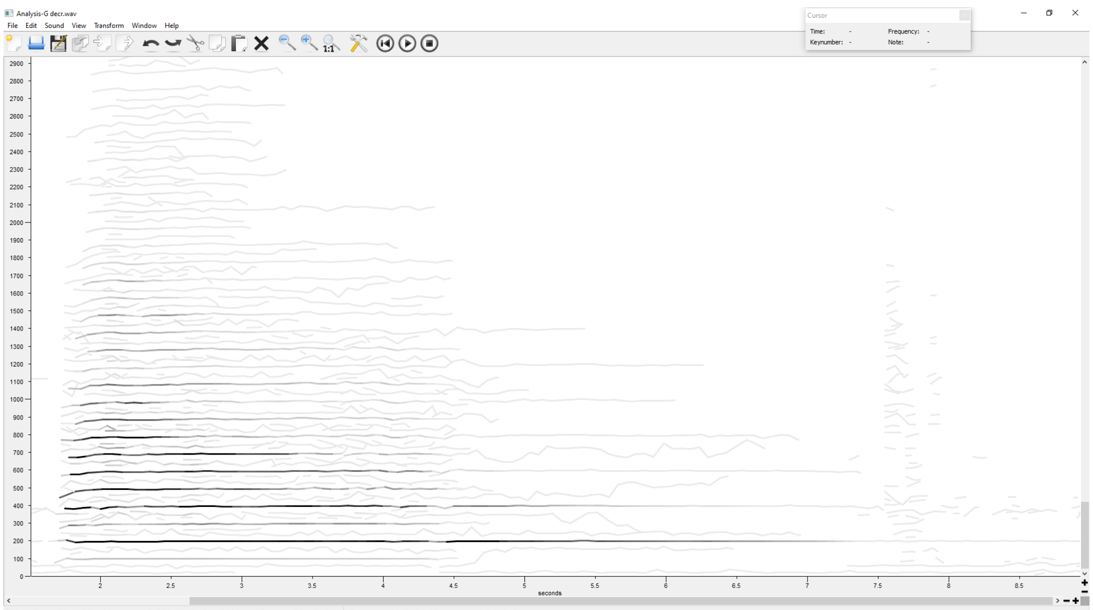


Number of Complete Harmonics – 8

Highest Complete Harmonic – G#4, 416.000 Hz

Highest Partial in Hz – Bb6, 1872.000

G Long Tones for Dynamic Range, Decrescendo:

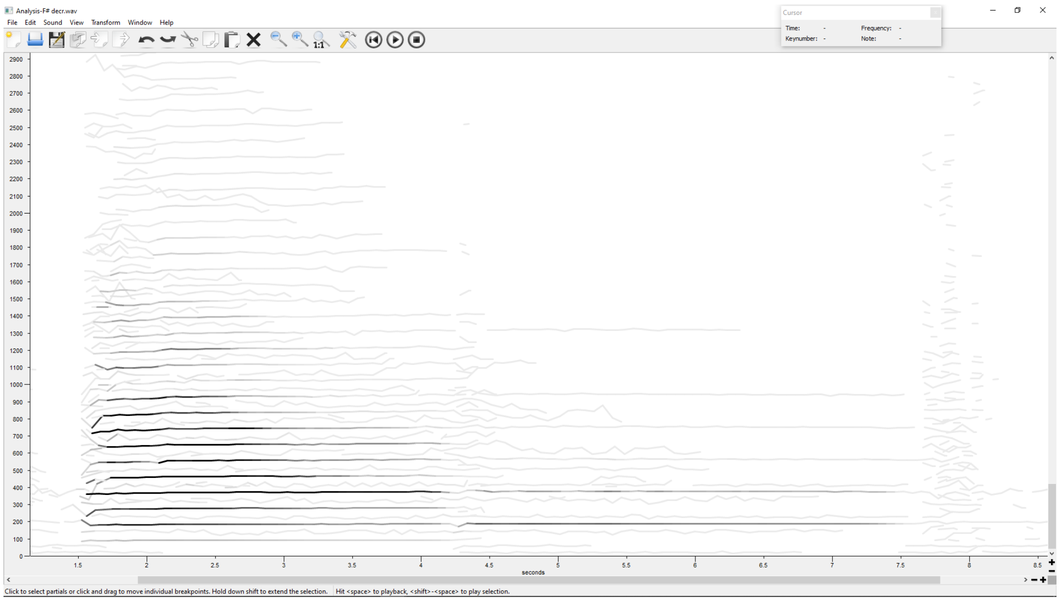


Number of Complete Harmonics – 7

Highest Complete Harmonic – G4, 396.000 Hz

Highest Partial in Hz – F6, 1396.000

F# Long Tones for Dynamic Range, Decrescendo:

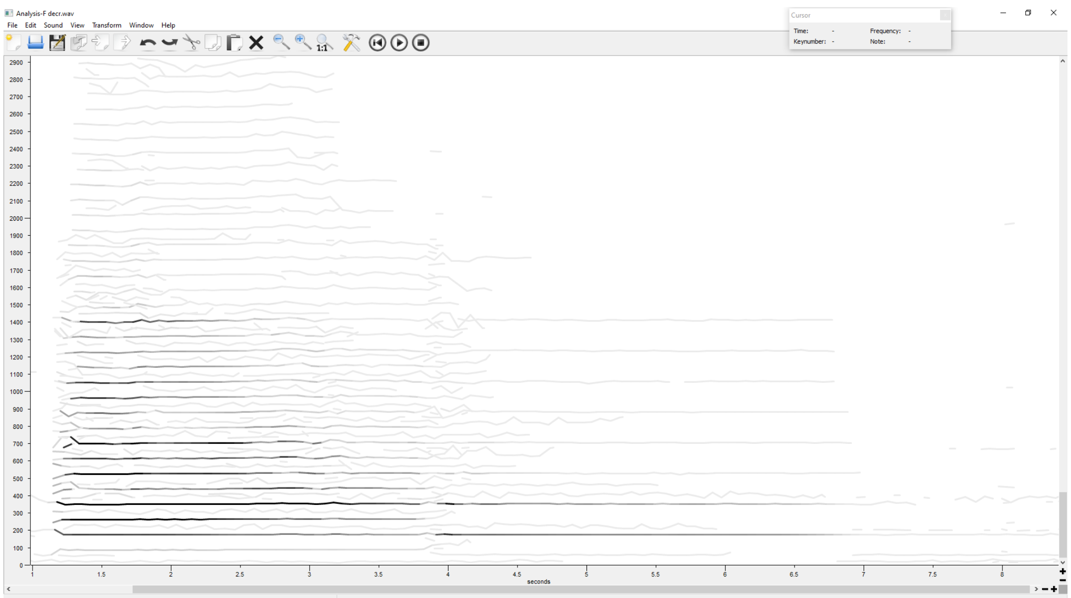


Number of Complete Harmonics – 7

Highest Complete Harmonic – F#4, 372.000 Hz

Highest Partial in Hz – E6, 1320.000

F Long Tones for Dynamic Range, Decrescendo:

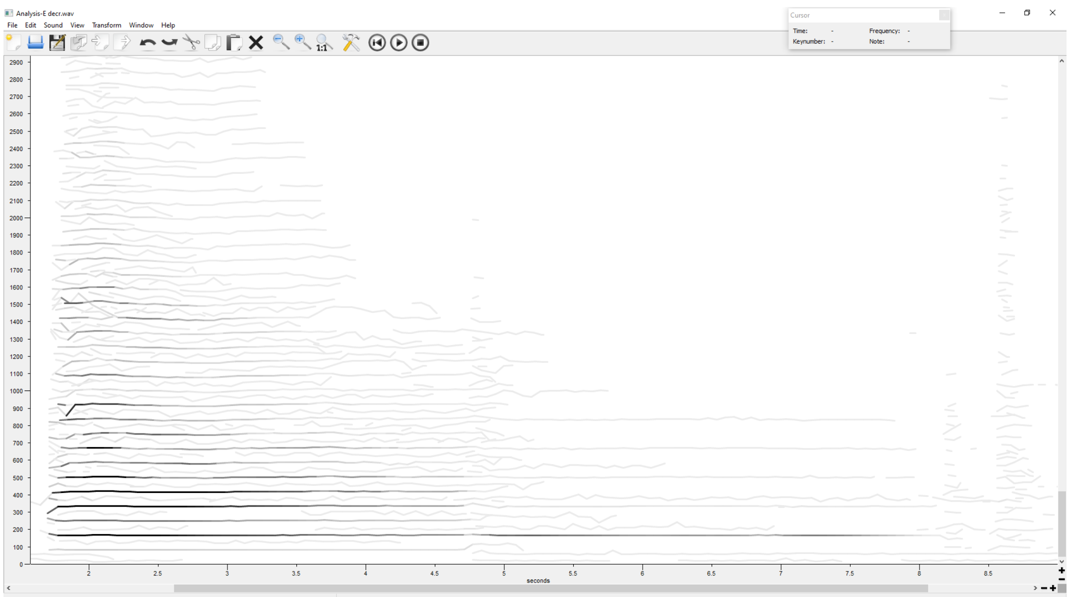


Number of Complete Harmonics – 9

Highest Complete Harmonic – F4, 356.000 Hz

Highest Partial in Hz – A6, 1772.000

E Long Tones for Dynamic Range, Decrescendo:

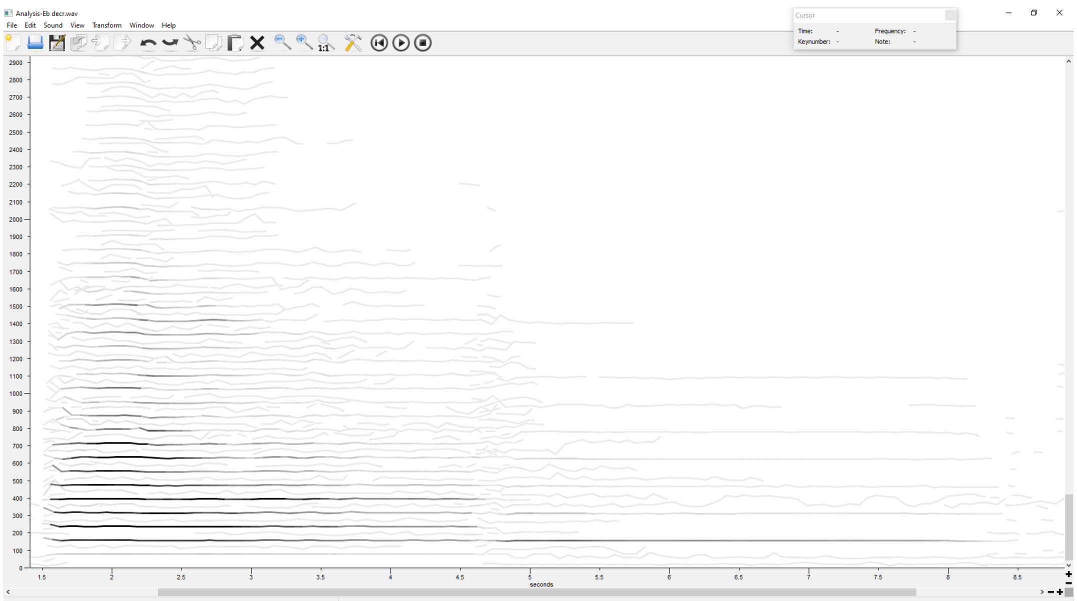


Number of Complete Harmonics – 8

Highest Complete Harmonic – E4, 332.000 Hz

Highest Partial in Hz – E6, 1328.000

Eb Long Tones for Dynamic Range, Decrescendo:



Number of Complete Harmonics – 8

Highest Complete Harmonic – Eb4, 312.000 Hz

Highest Partial in Hz – F6, 1400.000