MP3 Compression Artefacts as Creative Material

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Abstract

This creative research project is concerned with exploring the production and properties of MP3 data compression artefacts and effects, categorising them in a taxonomy, and arranging those artefacts for the creation of musical works.

The thesis consists of music and text. The music is arranged into a portfolio of six compositions and four interludes that explore the creative potential of compression artefacts. The text provides artistic contexts, perceptual coding concepts, the methodology used for creating artefacts, a taxonomy of compression artefacts, techniques used for arranging the music, and commentaries on the pieces of music themselves.

Artefacts have been produced by encoding noise colours and transient signals with MP3 codecs set to low bitrates and low sample rates. Signals have been run through the encode-decode cycle multiple times, a process called cascading, in order to amplify properties further and make them easier to analyse and compose with.

A taxonomy has been organised, acting as a repository for primary and secondary research, and to act as a guide for re/creating artefacts, whether that be for creative means or otherwise. The taxonomy gives names of artefacts, descriptions of them, and explanations as to how they are created.

Artefacts act as the raw material for composing music, and using arrangement and processing techniques inspired by a variety of electronic and mid-century composers, works have been constructed in an electroacoustic style. Arrangement and processing techniques include – but are not limited to – clusters, streams, time-stretching, and pitch-shifting.

The use of compression artefacts as the sonic material in these musical works places the project within an artistic practice that uses breakages and failure as the aesthetic focus of a work. The project explores the limitations of compression technologies, and approaches

media and formats that are normally considered as a means of transmitting or archiving sound as a means of generating it too.

Lay Summary

This creative research project is concerned with investigating audible side-effects that are often present in MP3s, and using those sounds to make pieces of music.

The project investigates the characteristics of these sounds and how they are created by intentionally producing these audible side-effects with very low-quality MP3s. These side-effects have then been categorised making them easier to recognise and recreate.

The project explores how these sounds can be used musically, by creating compositions with them. Music has been made using practices inspired by composers whose work is concerned with similar ideas and sounds as this project. Therefore, the work belongs to an artistic practice in which musical vocabularies are created using technological noise.

Declaration

I declare that this thesis has been composed solely by myself and that none of the material in this submission has been submitted for any other degree or other qualification.

Jim Reeve-Baker 21/12/2022

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Finally, I must thank my family and particularly my parents, Linda and Denis Reeve-Baker, for their ever-ready and unwavering support.

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https://drive.google.com/drive/folders/1p38ErtVqSM5hjtoyuKC7AnB20s90aLt8?usp=sharing

Folder *s1896562-01-portfolio* includes the portfolio of compositions that make up the musical part of this submission.

The folder includes:

1 Pluck Red Violet.wav

2 First Interlude Violet.wav

3 Pink Blue.wav

4 Second Interlude White and Blue.wav

5 Blue Red.wav

6 Red White Blue Violet.wav

7 Third Interlude White Pink and Violet.wav

8 White Pink.wav

9 Fourth Interlude Red and Violet.wav

10 Red White Blue Pink.wav

Folder *s1896562-02-audio examples* includes audio examples that are referenced within the text.

This folder includes:

Audio Example 3.1 Violet Noice.wav

Audio Example 3.2 Blue Noise.wav

Audio Example 3.3 White Noise.wav

Audio Example 3.4 Pink Noise.wav

Audio Example 3.5 Red Noise.wav

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Audio Example 3.17 White Noise 16 8 Comp.wav

Chapter 1 Introduction

In the form of both text and a portfolio of music, this practice-based research project contributes to an artistic practice of expanding musical vocabularies using the sounds of technological interruption and failure. Specifically, it explores the role of the MP3 format as not only a transmitter or archiver of sound but a generator of it too. This is done musically in the form of six pieces of music and four interludes, which exhibit various artefacts arranged using specific techniques that demonstrate and magnify their properties, while also acting indicatively of the compression processes and methodology that created them.

The music belongs to and contributes towards the continuation of a tradition in contemporary art music which uses forms of media noise as its compositional material. By exploring the limits of compression technologies', interruptions, failures, and unintended sounds that occur within a signal, are evoked.

What distinguishes this work from that of many of the other artists and composers who belong to this tradition (some of whom are described in section 2.4), is that the artefacts created by the compression process are caused by a specific interaction between the MP3 and the audio recorded onto it. The creation of compression artefacts relates specifically to the audio being encoded and decoded, contrasting with analogue and other digital media.

For example, the noise on an analogue medium, such as tape hiss or vinyl crackle, can be created arbitrarily on the surface of the medium, and the digital glitching of a CD player is caused during the decoding process of a CD. These noises occur regardless of whether audio has been recorded onto the format or not.

The work of Christian Marclay and Maria Chavez explore the relationships between the media and its physical environment through the creation of scratches on the surface of the record, and not in relation to the audio record onto the disc. The hiss and disintegration of the tape in William Basinski's *The Disintegration Loops* was caused by the physical characteristics of the tape changing over time, rather than the sound recorded onto it.

Tone's exposure of CD playback artefacts, again, would have been created irrespective of the audio recorded onto the disk.

Compression artefacts, however, are indicative of a set of interactions between the perceptual coding processes and the audio being encoded. Therefore, the work presented here not only explores the limitations of a piece of technology but also the dynamic relationship between the audio and the format, in turn dismantling the 'hierarchal relationship' (Thompson 2017, 43) between audio and medium through a feed-backing relationship whereby the signal and the medium affect one another.

The project therefore contributes to the development of this musical practice insofar that it provides new ways with which to explore the active relationship between audio and media in contemporary communications technologies, while also expanding the musical vocabulary of 21st century electronic music.

Primary research was key in the creation of the music. By undertaking experiments, artefacts' causes and properties could be rigorously explored. This, in combination with secondary research by engineering projects, has resulted in the development of a reproducible methodology for creating artefacts and a taxonomy of them. The development of a methodology and taxonomy has been intended to act as a foundation for future creative practitioners who also want to recreate artefacts. The taxonomy described in this thesis does this by using technical, qualitative, and figurative language in the description of artefact properties, while the methodology gives a clear guide for how to create specific artefacts.

The taxonomy also contributes sub-artefacts, and explores in greater detail effects that have been recognised but under-explored. Sub-artefacts include *birdie* variants, such as *flightless birdies* and *high-flying birdies*, and artefacts that have been less represented in research include *amplitude variations* and *delays*. The depth and breadth of the taxonomy draws on not just primary research but also by bringing together existing secondary research from different sources. It includes information from academic papers focused on mitigation and overviews of artefacts from academic and popular journals.

The project, therefore, creates connections between discourses and practices from engineering and artistic spheres, and, by doing so, presents opportunities for new perspectives to develop. This builds on and contributes towards artistic and research-oriented approaches that use processes from engineering spheres as the means with which to create or organise musical material.

As such, this practice-based research project thesis consists of two major elements: a series of musical works and this text.

This text begins by giving an artistic context to the work, describing similar projects that are also concerned with the incorporation of technological interruptions and noises into their musical vocabularies for similar reasons as this project. It then outlines the causes of MP3 compression artefacts, describing the processes involved in perceptual coding and giving the specific methodology used in this research to create artefacts. Lastly, the text describes how the music was composed using processing and arrangement techniques from influential composers and musicians. This text also includes commentaries for the music, which act as in-depth analyses of each work, describing how artefacts are used in specific ways to achieve the goals of the project. The musical part of this research consists of six pieces of music ranging in length between 5’50 and 11’32 and four short interludes, the pieces are discussed in detail in the commentaries though are also referred to throughout the text.

This introduction chapter will explain the motivations behind the project, the objectives it seeks to achieve, and contributions it has provided. It also gives an overview of the text’s structure, an explanation of appendices, and the titles of pieces in the portfolio.

1.1 New Material, Arrangements, and Music

The opening sentence in the introduction to Henry Cowell’s *New Musical Resources* is ‘contemporary music makes almost universal use of materials formerly considered unusable’ (Cowell 1996, ix). This book, first published in 1930, sets out in various ways the techniques in practice by composers in the early to mid 20th century that allowed them to explore new methods and materials for creating music. These practices gained traction as the century developed with composers incorporating chance, noise, non-musical sounds, and extended techniques into their compositions at both the art and popular levels of music making (Collis 2008, 32).

This project also belongs to this tradition by harnessing the artefacts of compressed audio and using them as the material for composing with. In doing this, this project contributes these sounds to a growing palette of musical materials, while also exploring the sonic properties of this material and their means of production (Demers 2010, 43), with the artefacts referring back to their means of production.

What follows then is the question of how to use these sounds to create music, or as Denis Smalley puts it, ‘how to cut an aesthetic path and discover a stability in a wide-open sound world’ (Smalley 1997, 107).

As new sonic material has increased, so new arrangement techniques and, in turn, new styles of music have also developed. This project draws on the conventions of *electroacoustic music*, described by Smalley as opening ‘access to all sounds, a bewildering sonic array ranging from the real to the surreal and beyond’ (Smalley 1997, 107), *glitch music* (Cascone 2000, 15), *microsound* (Roads 2001), and the works of various mid-20th century composers. These styles of music have been looked to as sources of influence due to the material and conceptual similarities between the sounds of those styles of music and the artefacts used in this research.

By linking the aesthetics of failure and noise with the characteristics of electroacoustic music, this project also seeks to challenge the electroacoustic convention of using sound material whose properties do not include the unintended characteristics of the processing technologies. This is a concept described by Denis Smalley as *technological listening*, stating ‘ideally the technology should be transparent, or at least the music needs to be composed in such a way that the qualities of its invention override any tendency to listen primarily in a technological manner’ (Smalley 1997, 109).

Instead, this project intentionally uses sound material that is not transparent, allowing the technologically affected sounds to not only be heard, but recognised as being compression artefacts, and therefore source-bonding the project's sonic material to the process of perceptual coding.

Therefore, these arrangement practices, which are discussed in detail throughout chapter 4, help form to develop out of the properties of the material itself, while also helping to highlight and amplify artefacts' properties.

This project draws on arrangement techniques from the styles of music described above, allowing for greater variety in the work and portfolio, and in turn, hopefully contributing to the stylistic development of contemporary music too.

1.2 Why the MP3

The choice to focus on compressed audio came about when listening to compressed complex signals, such as protesting crowds recorded and transmitted digitally and uploaded to streaming websites or used in news broadcasts, creating sonic artefacts. I found these artefacts appealing due to their unpredictability, which in turn created a sense of novelty and tension. The MP3 codec has been used as the means with which to create artefacts in this project for three key reasons, its ubiquity, its ease of use, and its economic accessibility.

Ubiquity – Streaming and Research

By 2019, the year this research project was started, streaming accounted for 'three quarters (74.4%) of Album Equivalent Sales (AES), the metric used by the industry to collectively measure music streaming and purchasing' (BPI 2020). The year 2019 also marked the first time 100 billion streams across audio streaming services had been surpassed in a single year. Therefore, it is clear that compressed audio is, as of now, a ubiquitous medium in music distribution and consumption, in turn making its properties and the causes of those properties a relevant topic for exploring.

An effect of the medium's ubiquity has been an increase in research by audio engineers who seek to better understand or mitigate the medium's artefacts. Prior research into the properties of audio compression often cited MP3s as the common example of a format that these characteristics belong to. As is shown in section 3.3.4, there is a great deal of research from an engineering perspective on compression artefacts which has acted as a foundation upon which primary research could be conducted. The primary research in this project consists of the deliberate production of compression artefacts using the methodology described in section 3.4 and the creation of a taxonomy described in detail in section 3.5.

The move from considering compressed audio generally to specifically looking at the MP3 was due to its ease of use, an important factor when developing the methodology.

Ease of Use

In addition to its ubiquity, the MP3 codec is easy to use. When using an MP3 codec, there are clear and consistent variable parameters, which can be easily understood. Below is a screenshot of the interface for the iTunes MP3 Encoder, it can be seen how the variables can be changed in detail, allowing for a variety of different bitrates, sample rates, and mono or stereo encoding choices to be made.

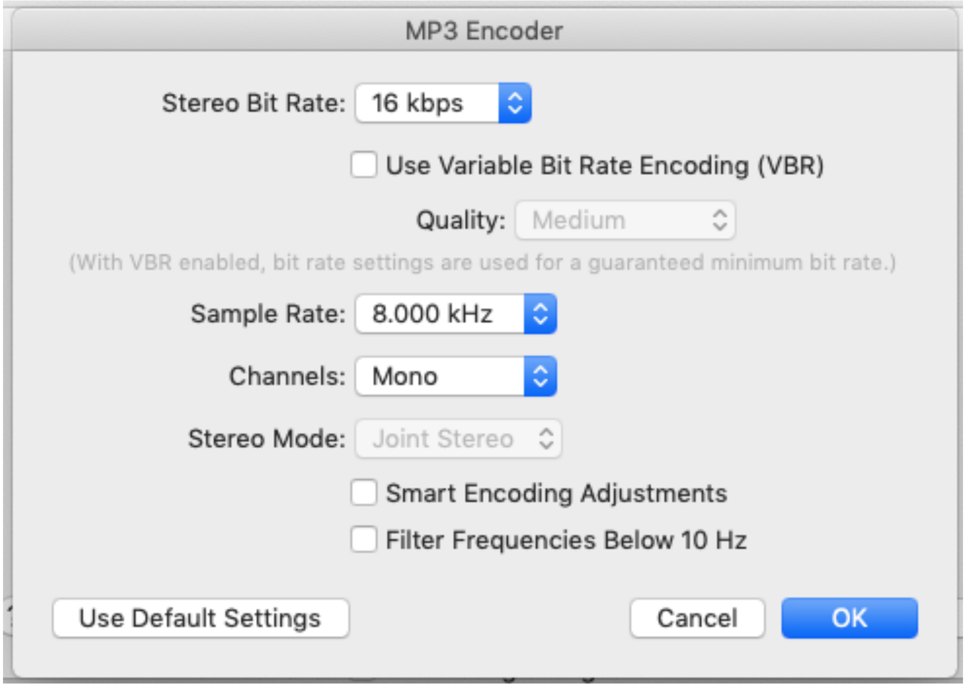

Figure 1.1: iTunes MP3 Encoder

Additionally, the LAME encoder was used with the Audacity interface and was equally easy to use with good control over the variable parameters. Below are two screenshots of the MP3 encoding menus, showing bitrates, stereo/mono, and then sample rate choices.

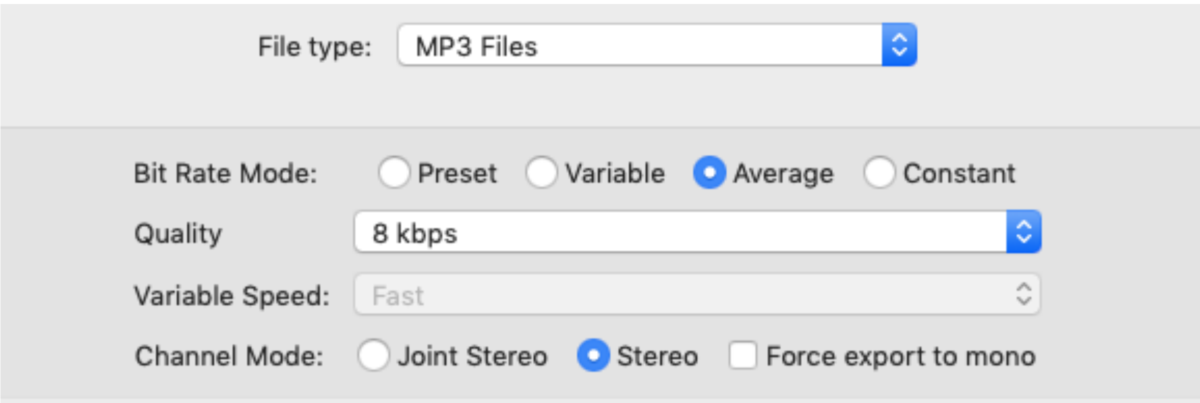

Figure 1.2: LAME Encoder in Audacity 1

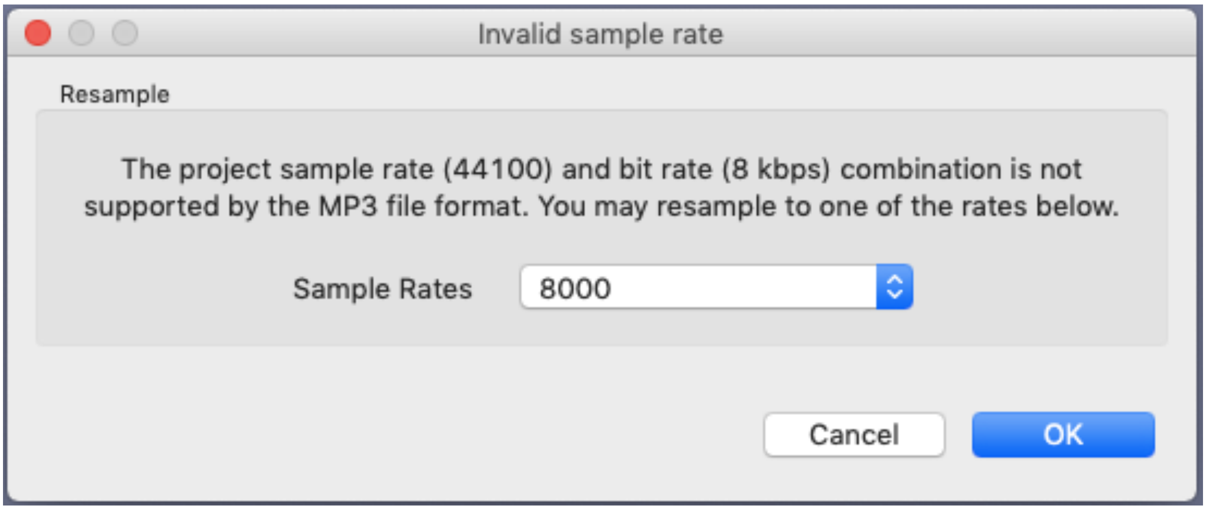

Figure 1.3: LAME Encoder in Audacity 2

This contrasted with other compression codecs, whose parameters were difficult to understand. For example, when trying to export audio to OGG Vorbis or AAC in Audacity, the compression variables and options available were limited to a basic scale of 'quality' ranging between 0 and 10. This lack of information and control meant that it was difficult to understand what was happening in terms of bitrates, sample rates, and other factors in the algorithm. This can be seen in the screenshot below of the OGG Vorbis encoder menu in Audacity.

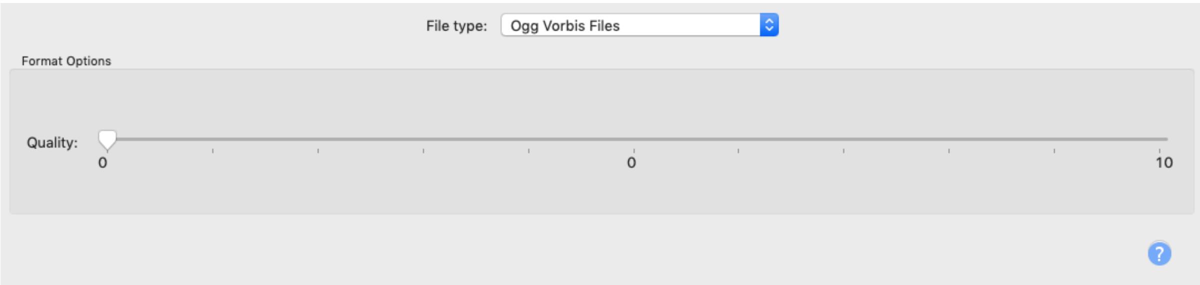

Figure 1.4: OGG Vorbis Encoder in Audacity

Economic Accessibility

Another reason for focusing on the MP3 is its economic accessibility, contributing to its popularity and ubiquity as a format, while also causing it to be simplistically both credited and blamed with radically changing music distribution processes.

The MP3's sonic properties have drawn criticism from audiophiles and sound engineers, a point made clear by the engineering research described in section 3.3.4 and my own discourse analysis of music magazines between 2010-2016 (Reeve-Baker 2016). Criticism of the MP3's aesthetic has also been made from artistic perspectives such as those arguments made by Ryan Maguire, discussed in section 2.5.1, and by points made by practitioners such as Neil Young (Fact 2014).

However, there has also been discourse focusing on industrial, legal, and economic issues, which have attempted to undermine the influence of the MP3.

The MP3, and the Internet file-sharing infrastructure that developed in the late 1990s, can be understood as being 'part of a social movement which has fought the major-label monopoly over the distribution of music' (Sterne 2012, 27-28). A monopoly which used physical and often high-fidelity media for music distribution. While this view can be considered a 'heroic version' of events (Sterne 2012, 27), it does have a degree of validity, made clear by the fact that 'the RIAA saw Napster as a threat and sued to shut it down in April 2000' (Sterne 2012, 207).

Therefore, from the perspective of the consumer, the MP3 presented an inexpensive and accessible means with which to listen to music with a small physical footprint. In contrast, this can result in high-fidelity audio technology, such as vinyl, being considered luxurious and only attainable to those who can afford the format itself, the high-fidelity playback systems, and physical storage. As such, the MP3 became symbolic of aesthetic and economic practices that run counter to the established methods of music distribution.

To consider file-sharing and the MP3 as anticapitalistic and anti-establishment, however, would be overly simplistic. 'It may appear that file-sharing … challenge[s] particular market economies, but that does not necessarily mean that they challenge the broader capitalist condition of music' (Sterne 2012, 216), as even though online piracy circumnavigated the distribution avenues controlled by major music labels, the file sharing of MP3s is still a market activity, which 'generated value for someone' (Sterne 2012 28).

The problem with this, however, is that the MP3 has become a symbol for simplistic arguments that result in it being considered both the sole instrument or scapegoat for complex economic, social, and artistic developments.

1.3 Taxonomy and Methodology

Before the pieces of music submitted in the portfolio could be realised, a methodology for producing material (see section 3.4) and a taxonomy of artefacts (section 3.5) were created, allowing for a greater understanding of the causes and characteristics of compression artefacts.

Aimed at Creative Practitioners

The methodological processes and taxonomy were formalised with the goal of helping creative practitioners recreate compression artefacts and effects. This was done by using a clear method, but also by explaining the artefacts' properties and means of production using technical, qualitative, and figurative descriptions.

This feeds back into the objectives raised earlier of contributing to the developing musical palette of contemporary music, as, if these sounds are to be incorporated into future music, so the method of their production and their specific properties must also be known.

Continued Practice

The development of a taxonomy and methodology builds on a practice of establishing processes for creating artistic materials, akin to examples such as Russolo's noise families (Russolo 2009, 86) and intonarumori (Cascone 2000,14), the aesthetic preferences of

Yasunao Tone (Blake et al. 2009, 235), and the use of plug-ins that recreate media specific noise (see section 2.5.4).

More Effects

The taxonomy included in this project seeks to add more information and depth to existing taxonomies by describing their properties in greater detail and their specific means of production, with visual and sonic examples (see section 3.5 for taxonomy). It also describes artefacts and sub-artefacts which have not been described in the prior research documented in section 3.3.4. These include *amplitude fluctuations* (see section 3.5.6 for more information) within encoded noise and across iterations of cascaded transient signals, as well as *high-flying* and *flightless* birdies (see section 3.5.3 for more information). The taxonomy also acknowledges what it is missing, pointing to areas that need to be investigated further, such as the cause of *delays* in certain encodings (see section 3.5.7 for more information).

Gathering

The taxonomy intends to be a place in which existing research is drawn together from a variety of publications, acting, therefore, as a point of reference or repository with greater breadth. For example, including information from academic papers that focus on possible forms of mitigation of specific artefacts allows precise information regarding the properties and causes of those artefacts to be included. This can then be combined with papers that act as overviews of multiple artefacts, giving more general and accessible information of artefacts and compression.

1.4 Connecting Engineering and Music

As the project seeks to allow other practitioners to use the methodology and taxonomy described here to create artefacts, it hopes to help bridge gaps between different fields of research. Specifically, by connecting musical practices and research into the engineering behind audio compression, hopefully further knowledge can be developed that otherwise might not have been available.

An early example of this regarding noise and music comes from Hermann von Helmholtz's text *Sensations of Tone* (1895). It was in this text that he articulated a shift in ideas concerned with the perception of sound. These new approaches to hearing brought together physical and 'physiological acoustics' with 'musical science and esthetics' (Helmholtz 1895, 1). He did this with the goals of finding common ground in the language, methods, and aims of those areas and broadening the horizons of physics, philosophy, and art which Helmholtz considered to have been 'too widely separated' (ibid). Later, Edgard Varèse hoped for a future of 'composer-scientists to expand the inadequate harmonic vocabulary of the time … and to move music towards ever more distant horizons. The microtonal future' (Rich 2008, 92), and the work of Iannis Xenakis can be seen as clear example of how engineering and music can influence one another.

This project aims to bring the research that has been conducted by those seeking to mitigate compression artefacts, to creating taxonomies of artefacts, and to give general overviews of artefacts, and combine that research with creative practices that use transmission and informational noise as the aesthetic focus of works. This work hopes therefore to act as another stepping stone for future research into noise, music, and the limitations of compression technology.

1.5 Summary: Aims & Contributions

1) To produce and harness compression artefacts, often described as noise, and to use those artefacts as the material for composing with, bringing them into a contemporary musical vocabulary by using specific arrangement techniques and creating pieces of music.
2) To contribute to the exploration of the dynamic relationship between audio signals and media technology, challenging traditional hierarchical relationships between audio and media noise.

3) To create a rigorous and accessible methodology that will allow creative practitioners to produce these artefacts and use them as part of further musical vocabularies.
4) To create a taxonomy that:
    - Describes novel sub-effects and artefacts that have been under represented in other research.
    - Allows practitioners to recognise and recreate compression artefacts.
5) To help connect disparate fields of research, and in turn, lay a foundation upon which new perspectives and conclusions can be arrived at.

1.6 Overview and Structure of Thesis

After this opening introductory chapter, there are three more chapters and a collection of commentaries of the music submitted. Below is a brief overview of the contents and structure of these chapters.

1.6.1 Chapter 2 Artistic Context

The second chapter *Artistic Context* gives examples of several artistic movements, genres, and individuals whose own work is concerned with interruption as a means of exploring similar issues as this project. Three definitions of noise are given: informational, object-oriented, and subject-oriented, followed by a consideration of practitioners who use informational noise as sonic material in expanding musical palettes. Perspectives are drawn from the futurists, glitch, and other musicians who use media, communication technologies, and the MP3 as part of their creative practice.

1.6.2 Chapter 3 Creating Artefacts

Chapter 3 Creating Artefacts is focused on how artefacts are produced, beginning with explanations of some of the processes behind perceptual coding, including psychoacoustic concepts and perceptual coding concepts. After this is a literature review describing various articles that engage with compression artefacts and effects in different ways. This section hopes to make the process of perceptual coding and therefore the production of compression artefacts more easily understood. The rest of this chapter is an in-depth explanation of the methodology used for deliberately producing compression artefacts and the project's own taxonomy.

1.6.3 Chapter 4 Arranging Artefacts

The fourth chapter, *Arranging Artefacts*, is concerned with how artefacts have been arranged and processed to create musical works. It looks at macro, meso, and micro levels of arrangement, followed by a section considering how the arrangement and processing techniques engage with notions of authenticity.

1.6.4 Chapter 5 Commentaries

The fifth chapter of the text consists of commentaries of the pieces of music submitted as part of this thesis. Each of the commentaries follows the same structure, beginning with the title, followed by an overview of the piece, what the piece is trying to investigate, the input material and the encoding parameters used, timings of pieces' sections, the various timbres used in the work, and finally, a step by step analysis of the work.

A commentary for the interludes is also included, giving their input sounds, encoding parameters, time-lengths, purposes (such as giving the listener a respite by contrasting in some way with surrounding works, or to explore certain arrangement techniques), and then a description of the piece.

1.6.5 Chapter 6 Conclusion

The final chapter of the text briefly describes the project's contributions followed by a discussion of the limitations of this research and possible future research, including the possibility of trying to evoke other artefacts, using different input materials and variables, and creating new music using different performance approaches.

1.7 Explanation of Appendix

The appendices are a series of indexes of the tests done as part of the primary research for this project. There are four indexes, which are described below. However, as these indexes describe tests conducted in the process of generating material for analysis and the creation of a taxonomy and compositions, there is more information regarding encoding parameters and input material in methodology chapter section 3.4.

A

Noise Mono Test Index describes tests that used noise colours as the input material (red, pink, white, blue and violet) and were consistently encoded in mono. There are sixty tests in this index, the first thirty were done using the iTunes codec and the other thirty were done using the LAME codec. The parameters are described in the methodology section 3.4.3, but reiterated here are bitrates of 8 kbps and 16 kbps in mono with sample rates of 8 kHz, 16 kHz, and 24 kHz. Each test is described with a spectrogram and an overview of the characteristics of the encoding effects including *bandwidth limitation*, *signal gaps*, and pitched artefacts.

B

Noise Stereo Test Index again used noise colours as the input material but used stereo encoding parameters in the tests, including Normal Stereo and Joint Stereo. There are 120 tests in this index, sixty using the iTunes codec and sixty using the LAME codec. The tests used bitrates of 8/16 kbps and 16/32 kbps in both Joint Stereo and Normal Stereo and sample rates of 8 kHz, 16 kHz, and 24 kHz. Spectrograms and descriptions of encodings were given for each test.

C

Transient Mono Test Index describes tests that used a transient signal as the input material and were then encoded in mono. The transient signal used was a synthesised pluck sound generated by audacity, more information on this can be read in section 3.4.2. There are 12 tests in this index, bitrates again consist of 8 and 16 kbps and sample rates were 8, 16, and 24 kHz, and both the iTunes and LAME codecs were used. Each test is described using a series of waveforms with an overview of the effects of the encodings, including *pre-echo*, *delays*, and *amplitude fluctuations*.

D

Transient Stereo Test Index used the same transient signal as in *Transient Mono Test Index* but encoded it using Normal and Joint Stereo parameters. There are 24 tests in this index that use the same bitrates and sample rates as the other tests, with both the iTunes and LAME codecs. Each test is described using an overview of the kinds of effects generated and includes a series of waveforms. Spectrograms are also included, showing the effect *stereo movement* by removing the mid information, keeping the sides and therefore isolating and summing the stereo differences into a mono audio file. For more information on creating the indexes see section 3.4.5.

1.8 Portfolio

The musical aspect of this thesis lasts an hour in total and consists of six full length compositions and four interludes. The full-length works and the interludes explore the properties of the artefacts and effects in different ways and use a variety of arrangement techniques to highlight properties further drawing on conventions from various styles of music.

The titles of the work and interludes, and the order in which they are arranged in the project, are:

Pluck Red Violet

First interlude: Violet and White

Pink Blue

Second interlude: White and Blue

Blue Red

Red White Blue Violet

Third interlude: White Pink and Violet

White Pink

Fourth interlude: Red and Violet

Red White Blue Pink

Chapter 2 Artistic Context

2.1 Introduction

As this research is concerned with introducing the artefacts of MP3 data compression into a musical vocabulary and having those artefacts act indicatively of their means of production, it has been important to look to other projects that are concerned with using technological interference as a means of exploring new sounds, materiality, and the possibilities of the MP3.

First, this chapter will define interference as a form of informational noise, that being a noise that is part of a communication signal. By explaining the importance of interference to communications technologies, the chapter establishes a conceptual foundation upon which other sections can be better understood. This section of the chapter also gives object-oriented and subject-oriented definitions of noise, as these approaches to noise are also raised.

After this, two important examples are given of artistic movements that seek to expand musical palettes by using interruption and failure. First looking at Luigi Russolo's *The Art of Noises* (2009) and then Kim Cascone's *The Aesthetics of Failure* (2000) it is shown that interruption has been a means of creating new sonic vocabularies since the early 20th century.

The next section considers artistic projects that have used interruption and erosion as a means of investigating the material and processual qualities of various media and formats from which those noises come. Projects include those by Christian Marclay, Maria Chavez, William Basinski, Alvin Lucier, Yasunao Tone, Madonna, Oval, and Alva Noto. This leads to a consideration of how this research uses MP3 artefacts to refer back to the interactive relationship between the sounds being encoded and the encoding algorithm itself. The artefacts, therefore, are concerned with the 'dual concerns of sound itself and sound generation' (Demers 2010, 43), particularly in reference to how the generation of material is reliant upon the relationship between the compressor and the audio.

The final section of this chapter gives an overview of several projects that make use of the MP3 in some way. These include Ryan Maguire's use of audio that is normally removed during the encoding process as the aesthetic focus of his investigation, using it as a means of critiquing a number of aspects to do with the format (2014); Bienoise's use of the MP3 and floppy disk to explore the limits of, and relationship between, those two formats (Force Inc. / Mille Plateaux 2018); Yasunao Tone's use of MP3 errors to trigger other sounds (2009); and finally the development of a plug-in that imitates, aestheticizes, and perhaps undermines the sound of MP3 compression artefacts.

2.2 Defining Interruption/Noise

This sub-chapter gives definitions of three types of noise. The first, *informational noise* is noise that is part of a signal. It is a form of interruption in a channel, rather than a judgement or type of sound and is important for understanding what is meant later in the sub-chapter when technological disruptions are referred to as noise.

After this, two more definitions of noise are given as a reference point for later in the text. The first is *object-oriented noise* which is concerned with the properties of a sound and the second is *subject-oriented noise* which is concerned with the subjective response of a listener (Thompson 2017).

2.2.1 Informational Noise

An important approach to understanding noise in this project is centred on notions of interference or interruptions of a signal. This is noise as understood from an informational perspective, as defined by Marie Thompson using Claude Shannon's general model of communication as the basis, wherein 'noise interferes with the message's exact replication' (Thompson 2017, 55).

Interference and affected signal paths are an inevitable part of communications, as Pierce states in *An Introduction to Information Theory: Symbols, Signals and Noise* ‘communication circuits or channels are imperfect. In telephony and radio, we hear the desired signal against a background of noise, which may be strong or faint and which may vary in quality from the crackling of static to a steady hiss’ (Pierce 1980, 145).

Shannon recognized that noise is ‘*part* of the system’ (Thompson 2017, 49), not external to it as earlier ideas posited, and while Shannon initially intended this theory to be applied to telegraphy and telephony, the implications can be heard throughout communications and media.

As noise is an internally generated part of the signal, it ‘not only disrupts transmission but also is what allows transmission to occur in the first place. In this sense, it is foundational: with no noise, there is no transmitted signal’ (Thompson 2017, 8). The noise is integral to the medium and as such precedes any semantic information. By understanding that noise is intrinsic to technology, so it is possible to recognise media technology as being generators of sonic information, as well as transmitters and archivers of it.

Marie Thompson refers to this as ‘microdisruptions’ that occur ‘at the level of the material medium’ (2017, 42) and the ‘slow decay of the medium’ which introduces these disruptions in the form of ‘additional warbles, pops and crackles … digital materials also face this transformative process of material decay or “bit rot”’ (2017, 64). It is a process whereby sound can be removed resulting in bandwidth limitation or signal gaps, added creating distortion or amplification, and moved in time and space resulting warping and time-smearing.

The presence of the noisy medium is often overshadowed by the ‘symbolic or meaningful content of a message’, but it is, nevertheless, influential as ‘it always leaves a noisy “trace”’ (2017, 61).

2.2.2 Subject and Object-Oriented Definitions of Noise

The other important definitions are object-oriented and subject-oriented noise. Thompson's subject-oriented approach defines noise as 'a value judgement that is made during perception' (2017, 17) - it is noise as a judgement of a sound rather than due to any of its specific properties.

The object-oriented approach recognises 'noise in relation to particular sonic qualities, properties or attributes, rather than in relation to the ear of the beholder' (Thompson 2017, 23). It is a type of noise that is defined by its physical properties, rather than by its relation to its context, taking the form of complex timbres such as white noise.

These definitions are important for understanding Russolo's use of the term noise throughout his manifesto *The Art of Noises* (Russolo 2009).

2.3 Expanding Palettes with Interruptions and Failures

This project is concerned with broadening a musical vocabulary by bringing compression artefacts into musical works. Compression artefacts are, as highlighted by some of the literature described in chapter 3.3.4, noises insofar that they are interferences in a signal, and points of technological failure. This subchapter highlights two movements, futurism and glitch, that use interruptions and failure as their aesthetic focus.

The broadening of musical vocabularies has been a pursuit of composers throughout much of the 20th and 21st centuries. David Keenan states that composers making the 'mistake the central way' to build up a musical 'language' has been something that 'Modernism has always done' (Curran 2016, 43).

Beginning with Russolo's *The Art of Noises* (2009) the idea of including the sounds of the city into the concert hall is introduced, followed by a consideration of glitch music at the turn of the millennium in which the entire practice is oriented around harnessing failure.

While there are other examples of broadened musical palettes, these two have been chosen due to the novelty, and therefore historical importance of the futurists, and the glitch movement's clear articulation of technological malfunction, something that this project is also concerned with.

2.3.1 Futurists

An early example of interruption as noise becoming part of a musical vocabulary comes from Futurist painter Luigi Russolo's manifesto *The Art of Noises* (2009), which describes the modern industrialised cityscape as a possible place from which to harness sounds and 'continually enlarge and enrich the field of sounds' (2009, 86) to make art and music. To Russolo, the sounds of the city can be heard as music, and he describes listening as he moves across a city as 'creating mental orchestrations' (2009, 85).

As Russolo describes these sounds as noises, he is drawing on subject and object-oriented definitions of noise. When describing the *noise-sound* concept, which is a sound made of 'maximum variety' (2009, 75), moving away from 'pure sound' (2009, 86) and towards 'complicated dissonances' (2009, 86) he is alluding to what can be recognised now as object-oriented definition of noise.

Meanwhile throughout the manifesto Russolo returns to subjective responses to sounds and noise, acknowledging them as being both wanted and unwanted. For example, Russolo states 'it's no good objecting that noises are exclusively loud and disagreeable to the ear' (2009, 76) while also explaining the he finds more enjoyment 'in the combination of the noises of trams' and other noises of the cityscape than in listening to the 'eroica' or the 'pastoral' (2009, 76).

To consider these sounds as informational noise, it is worth considering the arguments of R. Murray Shafer. Schafer describes the industrialised soundscape using language consistent with informational definitions of noise. For example, he describes the soundscape of the industrial revolution as 'lo-fi', states that there is 'so much acoustic information that little can emerge with clarity', and uses the phrase 'signal to noise ratio' when describing the 'ultimate lo-fi soundscape' (1994, 71). In contrast, Schafer describes 'hi-fi soundscapes' as being ones in which 'discrete sounds can be heard clearly because of low ambient noise level' (1994, 43).

By using this terminology Schafer renders the sounds of cityscape interruptions within a signal, making them not only noise from object and subject oriented definitions, but also an informational one, and while Schafer may consider these interruptions to be negative, Russolo considered these noises to be musical.

Russolo considered the cityscape to be musical and wanted to bring it into musical works, performances, and concert halls by harnessing and replicating the noises of the cityscape. He stated 'we want to attune and regulate this tremendous variety of noises harmonically and rhythmically' (2009, 85) and to 'enliven the sleepy atmosphere of the concert halls' (2009, 76). Russolo does this by first creating a taxonomy of noises he hears in his cityscape including six categories with various examples in each, described below.

1	2	3	4	5 Noises obtained by percussion on:	6 Voices of animals and men:
Rumbles	Whistles	Whispers	Screeches	Metal	Shouts
Roars	Hisses	Murmurs	Creaks	Wood	Screams
Explosions	Snorts	Mumbles	Rustles	Skin	Groans
Crashes		Grumbles	Buzzes	Stone	Shrieks
Splashes		Gurgles	Crackles	Terracotta	Howls
Booms			Scrapes	Etc.	Laughs
					Wheezes
					Sobs

Table 2.1: Luigi Russolo's Six Noise Families from The Art of Noises (Russolo 2009, 87)

After this, Russolo sought to create these sounds using a set of newly designed instruments called *intonarumori* 'which imitated urban industrial sounds' (Cascone 2000, 14).

It is clear, then, that Russolo hoped for his use of new sounds and noises to be understood as music by categorising and recreating them for compositions and performances. The arrangement of a specific set of noises into forms through regulating and attuning them, combined with performing within performance spaces resulted in the noises becoming understood more clearly as part of a musical palette.

The processes described above are also things that this project does: establishing a set of noises via analysis and a taxonomy is described in Chapter 3, using arrangement techniques described in chapter 4 to create pieces of music, and the performance and presentation of musical works in electroacoustic performances and conferences help to place compression artefacts into a musical palette.

2.3.2 Glitch

The arguments put forward by Russolo involving interruption were taken further later in the 20th century by various artists who harnessed the interruptions of technological malfunction for creating pieces of music. The music being made with these noises has become known as glitch music (Cascone 2000, 12), and its influences, conventions, and conceptual underpinnings are described by Kim Cascone in his paper *The Aesthetics of Failure: "Post-Digital" Tendencies in Contemporary Computer Music* (2000).

Cascone states that it is from 'the "failure" of digital technology' (2000, 13) and 'the exploitation of these anomalous or erroneous noises' (Thompson 2017, 129) that has led to this new style of music. Here, by describing the failure of digital technologies as erroneous noises, the glitch is placed into the definition of informational noise, rendering it not just a failure but an interruption, or as Thompson also describes it, a 'microdisruption' (2017, 42).

Much like Russolo's six noise families or this project's taxonomy, Cascone gives examples of noises that make up the vocabulary of glitch music: 'glitches, bugs, application errors, system crashes, clipping, aliasing, distortion, quantization noise, and even the noise floor of computer sound cards' (2000, 13). The noises listed above by Cascone depict some, if not all, of the possible noises that can be used within the 'new vocabularies in digital media' (Cascone 2000, 16).

Glitch music has also had the opportunity to merge with other existing styles of music and been incorporated into chart music, showing the success of the style in broadening the musical palette of the 'post-digital' early 21st century. This can be heard in Pole's use of a 'broken analog filter' to capture and loop the sounds of its malfunction creating 'minimal click dub' (Krapp 2011, 55), and Madonna's song *Don't Tell Me* (2000) which replicates the sound and effect of digital dropouts by using absolute silence, or 'digital black', with a rhythm that has a 'highly quantised, digitised feel' (Danielsen et al. 2009, 132).

This research uses the informational definition of noise to recognise sonic interruptions and use them as the raw material with which to compose pieces of music. By doing this it contributes towards a tradition in music that recognises specific types of interruptions and incorporates those noises into a musical palette.

2.4 Interruption as a Means of Investigating Materiality and Medium

The noises described above are the raw material for composing, but they also refer back to their means of production and their medium. Just as Russolo sought to highlight the sounds of the industrialised cityscape and glitch artists bring the accident and the failure to the foreground, so this research project also uses compression artefacts as a means of investigating the material and processual aspects of the medium that produced them. By foregrounding media noise in various different ways, so these projects dismantle the ‘hierarchical relationship’ between signal and noise (Thomson 2017, 62), and in turn foreground the medium – material and processes – from which those noises come.

This section of the chapter looks at artists who use ‘the noise of the medium’ as ‘a source of creative potential’ (Thompson 2017, 43), and consider the material as encapsulating ‘the dual concerns of sound itself and sound generation’ (Demers 2010, 43).

When discussing the importance of material and media in experimental music, Marie Thompson posits a series of questions that, she argues, are implicit within an artist’s engagement with technological breakage as a creative material. ‘What can a medium do? … What is its potential? What sounds and effects might it be capable of? What are the ways in which it can function? In what ways can it affect the recorded content?’ (Thompson 2017, 65).

Below are examples of artists who explore the materiality and processes of the medium they work with via the exploration and exploitation of noise generated by that medium.

2.4.1 Vinyl

Christian Marclay

Christian Marclay’s *Record Without a Cover* (1985) was sold without packaging with the intention of damaging the vinyl and creating artefacts, which could be heard in playback foregrounding the noise of the musical medium and ‘emphasizing its material presence (Thompson 2017, 65). His approach is to ‘break or mutilate records by stacking them without sleeves, cracking and then reassembling them with glue, exposing them to dirt and dust, and inviting listeners to walk on them before playing them back’ (Demers 2010, 56). By doing this, the medium is underlined and given a ‘voice’, as, for Marclay, ‘it has an expressive power in itself’ (Marclay 1998). Marclay addresses the materiality and the physicality of the medium through its breakage and re-assemblage. As the record is destroyed, so new physical and sonic material is created.

Maria Chavez

Like Marclay, Maria Chavez uses damaged records with the scratches and noise acting as 'markers of the record's ongoing mutability' (Thompson 2017, 66). Chavez states that the destruction of the medium develops organically, 'naturally ruined on their own. Because I keep them all in backpack without their sleeves, so they're in and out, they move around, they touch each other. So there's always new scratches. Sometimes I'll leave them outside, or leave them in the car, just so they can kind of mold into each other. Some will stay put, some will warp around it' (Rodgers 2010, 98). This creates additional artefacts and also impacts the playback process as the needle skips and breaks, generating new sonic and musical effects with each performance. The sound therefore explores the possibilities of creation through relationships with physical environment, the medium itself, and sonic content.

2.4.2 Tape

William Basinski

William Basinksi's *The Disintegration Loops* (2002) uses decaying and disintegrating tape as the aesthetic, conceptual, and structural focus of the work. The process of creating the work began as an attempt to digitize the audio on the tape. This process brought about the tape's incremental destruction as it was repeatedly played back. Therefore, as the material itself was being destroyed, so new pieces of music were being created.

What is key to these works is repetition and transition. As the material is subjected to many passes through the tape player's mechanism, so the work emerges. For Basinski, and many others, this increasing interruption is symbolic of a transition into a state of mourning, post 9/11 (Demers 2010, 63; Jones 2014).

However, as the work transitions from one sonic state to another, so the relationship between the audio, the tape, and the tape player shifts too.

In the first sonic state, the audio is interrupted by signal gaps created by part of the tape disintegrating through repeated playback. Put another way, the audio signal is affected by the medium (the tape material and the tape player). By the end of the work, however, this relationship is inverted as the sound of the tape and player – the media noise – becomes foregrounded and is then interrupted by the occasional bursts of audio.

The signal gaps in *The Disintegration Loops* have been described as 'silence' (Jiménez-Donaire Martínez 2022, 5; Jones 2014, 9), but this is not true. In these moments of interruption, the media noise is revealed as hum and hiss, and can be heard throughout the work.

This underpins the argument that media noise is foundational and internally generated in transmission, it 'disrupts transmission but also is what allows transmission to occur' (Thompson 2017, 8). The tape material in *The Disintegration Loops*, therefore, is not destroyed, but the opposite, it is revealed through a series of incrementally increasing interruptions to the point that the interrupting noise of the medium transitions and becomes the prominent sound in the work.

Alvin Lucier

In the work *I am Sitting in a Room* (1990) by Alvin Lucier, Lucier records himself speaking onto a tape. This recording is then played back and recorded again, and as that happens, so the acoustic properties of the room in which this process is taking place, act as a filter 'enhancing certain frequencies and dimming others' (Vandsø 2012, 99). Eventually, after many iterations of this process the speech is transformed into an 'abstract, pulsating, broad-spectred sound texture' (ibid).

As with *The Disintegration Loops* repetition is an important part to of this work's construction. Whereas Basinski's work repeatedly plays back a tape loop to create transformation and transition *I am Sitting in a Room* uses the playback *and* recording technologies to move from one sonic state to another.

The processes used by Lucier are therefore akin to cascading, a process whereby a signal is submitted to multiple passes through an encode-decode cycle of a medium. As this is done, the characteristics of the medium become amplified, however, what makes Lucier's approach different is that it is not just the hierarchical relationship between the audio and the medium that is being dismantled, but also that of the physical space in which the process takes place.

The acoustic space therefore becomes another medium in this process of sound transmission, and so while with Basinski's use of tape it is the sonic properties of the tape that is exposed, with Lucier's work it is the sonic properties of the room that are evoked and amplified by the recording and playback technologies.

The room therefore interrupts the audio via cascaded record-playback technologies, allowing the acoustics of the room to be investigated, stripping away the semantic content of the signal.

This work does not explore the materiality of the tape itself, as what it is that is affecting the audio is not the sound of the tape, but the acoustic properties of the room. Instead what is media specific are the recording processes afforded by the tape deck at this point in time. While it is true that 21st century technology allows for easy recording in any context, in 1970 the tape recorder and the possibilities of recording in any context, makes the work media specific.

2.4.3 Compact Discs

Yasunao Tone

In his project *Solo for Wounded CD* (Tone 1997), Yasunao Tone explores the media noise of CDs by undermining technologies that are used in playback for minimising or muting informational noise that is created in the process of decoding information on CDs.

Tone does not create the noise himself but instead exposes media noise by removing the mitigating techniques built into playback technologies. This again exemplifies the informational definition of noise: that interference comes from within the signal, rather than being an external factor. The noise in *Solo for Wounded CD* then becomes indicative of the arguments of information theory, and it is the exposure and exploration of the material that gives Tone new creative vocabularies.

The work explores sounds 'and audio behaviours resulting from new technologies' (Blake et al. 2009, 235). Rather than simply considering the material as an object, which in playback is fixed, Tone uses the material and processes of the CD and CD player as an interactive participant within performances, something that is achieved through his *paramedia* practice, deviating from a technology's original purpose (Blake et al. 2009, 235) and opening up new indeterminate creative spaces (Blank Forms, 2022). These themes are discussed again in section 2.5.3, which is focused on another project of Tone's, *MP3 Deviation* (Tone 2011).

Not all media noise is hidden, however, and as the example below shows, these effects have been used in mainstream popular music too.

Madonna

Danielsen and Maasø's article *Meditating Music: Materiality and Silence in Madonna's 'Don't Tell Me'* (2009) gives various examples in which interference is used as a means of signification of technology and as a musical device. Analysing the song *Don't Tell Me* (2000) by Madonna, the paper shows that the song replicates the sound and effect of digital dropouts by using absolute silence, or 'digital black', with a rhythm that has a 'highly quantised, digitised feel' (Danielsen et al. 2009, 132).

The digital black dropouts are described by Danielsen et al. as moving from being media silences to textual silences, progressing from being mistakes to being intentional and communicative. While the dropout continues to be a sign of digital breakage it also ‘mimics a more or less neutral and almost purely musical pause’ (Danielsen et al. 2009, 131).

While there have been claims of ‘the disappearance of materiality in the age of digital reproduction’ (Danielsen et al. 2009 139), material traces of digital mediation become ‘gradually more opaque as listeners grow accustomed to them’ (Danielsen et al. 2009 140).

Oval

Inspired by a ‘scratched jazz CD from a local library’ creating skips and glitches, the group Oval sampled and sequenced this effect, and then ‘aestheticized the sound, making it listenable’ (Stuart 2003, 50) in the process of making music. Unlike Tone’s exploration of CD errors which embraced the ‘stuttered, skipped and jammed’ sounds of CDs (Stuart 2003, 49), Oval’s use of glitches conforms to ‘basic structures of pop with melodic motifs and repeated phrases formed into a verse-and-chorus type structure (Stuart 2003, 50).

Oval’s approach to interruption and materiality therefore is more focused on harnessing and controlling these sounds, contrasting with other glitch musicians who structure their work with some degree of unpredictability. Scott Hayden Church argues that Oval’s music is an attempt to ‘unfetter the sound of malfunction from its unpleasant connotations and refashion it as more beautiful and listenable’ (Church 2017, 1).

2.4.4 Digital Transmission Technologies

Alva Noto

The examples above explore the noisiness of material created through interactions with their physical environment and by undermining mitigating processes. Either the media specific noise is made by the artist or it is exposed by the artist.

Similarly, Alva Noto uses 'modems, telephones, and fax tones to compose atonal, syncopated soundscapes' (Krapp 2011, 55) in his music, focusing not on the 'information transmitted, but on the enigmatic character of the system of transmission itself' (Collis 2008, 38). Alva Noto's work reflects the relationships between 'the personal author of information and the medium of communication' (Collis 2008, 38) and, in turn, links to a non-anthropocentric perspective towards to the generation of informational noise in those media.

This Research Project

The projects described above use assemblages of types of noise to create and explore new sonic palettes and processes, relationships between decay and creation, movements from media noise to textual noise, and how the medium affects the audio it transmits and archives.

These projects invert traditional hierarchical relationships between audio and technological noise by orienting their work around technological noise and making it their aesthetic focus. The technological noise that these projects described above are concerned with is created irrespective of the audio being archived or transmitted. The sounds of the scratched and warped vinyl records used by Marclay and Chavez, the disintegration of the tape in Basinski's work, and the sounds being created by the CD decoding process used by Tone are not created in response to the audio they carry, but are created regardless of it. Therefore, while these projects challenge traditional hierarchical relationships between audio and media noise, the hierarchy itself remains, only with noise and audio having changed places.

In contrast, this project uses the noise of compression technologies, which is generated in direct response to the audio it is archiving and transmitting. MP3 compression artefacts are used in the project to explore the interactive relationship between the audio recorded on to the MP3 and the encoding algorithm of the MP3. The project does not, therefore, invert the hierarchical relationship between noise and audio, but instead tries to highlight it as being dynamic, with both elements, noise and audio, being necessary for the other's existence, in turn dismantling the hierarchical structure.

This relationship occurs during the process of perceptual coding, described in chapter 3, causing the artefacts and effects to occur. The perceptual coding algorithm analyses audio and makes a series of decisions about what is worth keeping based on a variety of psychoacoustic principles. However, these decisions are triggered by the audio being encoded, changing how the algorithm behaves and therefore creating compression effects, artefacts, and noises. Depending on what is being encoded, such as complex timbres or transient signals, different artefacts will be produced. Equally, if silence were to be encoded, then no compression artefacts would be created at all.

This project hopes that by using the methodology outlined in chapter 3 and the composition and arrangement techniques described in chapter 4, music can be created with artefacts and effects that act as both sounds themselves and refer back to their processes of generation (Demers 2010, 43), allowing the relationships between the compressor and the audio it is encoding to be underlined and heard as having its own 'expressive power'.

2.5 MP3/MP3-like Creative Projects

This section looks at other creative projects that use the MP3 properties and processes as part of their aesthetic focus. First looking at Ryan Maguire's project *The Ghost in the MP3* which used the audio that would normally be removed as its raw material for composing with, the project seeks to critique the MP3's sound quality, the format's means of development, and prevalent usage in a variety of listening contexts. This is then followed by on overview of Bienoise's *Most Beautiful Design* (2018) which acts as a tribute the MP3 and floppy disk, by exploring sonic limitations of both formats through music. Yasunao Tone's *MP3 Deviation* is then considered, which uses the errors caused by MP3 corruption as triggers for other sounds, exploring themes of paramedia and indeterminacy. Finally, the plug-in *Lossy* which imitates the sound of compressed audio is described, and critiqued using arguments put forward by glitch theorist Rosa Menkman.

2.5.1 Ryan Maguire

Researcher and composer Ryan Maguire investigated the sound of MP3s from a critical perspective in his project *The Ghost in the MP3* (Maguire 2014). The investigation focuses on audio that would normally be removed during the MP3 encoding process as its aesthetic focus, using those sounds as the material for creating pieces of music. As Maguire describes it 'focusing on the negative space of MP3 compression, rather than focusing directly on its sonic artifacts' (Maguire 2014, 245).

Maguire's intention is to critique several, interconnected aspects of the MP3: the sound of MP3s themselves, those sounds as indicators of privileged listening preferences, and the ubiquity of those sounds.

The sounds themselves

Maguire states that the project seeks to 'inject' the audio that is removed during the encoding process 'back into contemporary listening spaces' (Maguire 2014, 246). What this shows is that a key concern for the project is the sound of MP3s themselves, an important aspect of which is the removal of sonic information.

This injection of audio removed during the encoding process is achieved by preserving information that is normally erased and erasing information that is normally preserved. Maguire does this using a complex process whereby at first compressed and uncompressed audio files from the same original audio are compared and then the difference between the two files is stored. Maguire then uses two techniques to create the new audio. The first is to 'resynthesize the new matrix' and the second is to 'zero corresponding bins in the original uncompressed file where the difference is null', and, by using these two approaches, greater sonic variety can be produced (2014, 245).

Indicative of privilege

Maguire also considers the sounds of the MP3 to be remnants of a ‘class of privileged sounds’ (Maguire 2014, 246), that act as a residue or indicators of tastes of the engineers who designed the format.

The engineers Maguire refers to are those who conducted listening tests in the developmental processes of the format, and were, primarily ‘white, male, western-european (sic) audio engineers’ (2014, 245). The MP3 codec processes reflects these tastes, and in turn reflects the tastes of the cultures from which those engineers come from, raising problems regarding how styles of music from outside those cultural spheres are represented and affected.

Maguire argues that the format serves the conventions of some styles and the musical tastes of some listeners over others. Hearing the artefacts in this way, as traces of certain cultural values, they become cultural artefacts in their own right. The artefacts therefore exist, Maguire argues, as symbols of privilege rendering the format as a problematic perpetuator of specific types of power structures, favouring those who are already in positions of privilege.

Ubiquity

Maguire states that MP3s are ‘heard everywhere, at home, streaming in stores and public spaces, over high-fidelity car stereo systems’ and not just in suboptimal listening environments (2014, 246). Maguire argues that the MP3 has therefore become a ‘curator’ for these spaces, which excludes ‘a vast territory’ of sonic terrain, and by using the omitted sounds the work hopes to act as a form of ‘resistance, one available mode of cultural critique’ (ibid).

2.5.2 Bienoise

Most Beautiful Design (2018) is a five track 'mini album' (Force Inc. / Mille Plateaux, 2018), by Bienoise, the electronic music project of Alberto Ricca. The five tracks that make up the record are MP3 audio files that have been saved on to a floppy disk, with the work as a whole acting as a tribute to the design of the 3.5" floppy disk and to the functionality of the MP3 format.

The small disk space of the floppy disk necessitated the use of MP3s, as they are 'dextrous' enough to fit onto the floppy disk, albeit with a 'very low bitrate' (Force Inc. / Mille Plateaux, 2018). This low bitrate has resulted in compression artefacts being clearly heard throughout the work, a process bienoise considers to be the revealing 'of new information' with the MP3 acting as an 'instrument' (ibid).

The project is a tribute to both formats, the design of the floppy disk, the dexterity of the MP3, (Force Inc. / Mille Plateaux, 2018) and is concerned with what Ricca has described as 'pushing the limits of instruments, aesthetics, narrative devices' (Ricca 2019).

The project acts similarly to those described in the previous section, insofar that it uses the limits of a format to create a sonic vocabulary, which is indicative of the material and processual aspects of the medium from which it comes.

Unlike those described above, this project explicitly uses two formats to create its aesthetic. The work therefore refers back to a relationship between two formats and their materials and processes. It is by pushing these formats to their limits that the work hopes their definitions can be better understood and their roles in 'the diffusion of music and knowledge' be celebrated (Force Inc. / Mille Plateaux, 2018).

2.5.3 Yasunao Tone

In 2009 Yasunao Tone, in conjunction with the *New Aesthetics in Computer Music* research group, created a project called *MP3 Deviation* (Blake et al. 2009). It was concerned with developing new 'composition and performance software based on the disruption of MP3 data' (Blake et al. 2009, 234). This was a continuation of Tone's earlier approaches and themes that centred on his paramedia practices - those being the deviation from technologies' original purpose to explore new creative areas.

As with *Solo for Wounded CD* (Tone 1997), this project uses the decoding aspect of the format as the means of generating errors. This work, however, is specifically concerned with corrupting MP3 audio files in real-time and using errors and interruptions to control and trigger other audio.

The paper *Yasunao Tone and MP3 Deviation* (Blake et al. 2009) stated that twenty-two different error types were used as triggers, changing parameters of a 'parallel sound processing chain' (Blake et al. 2009, 236), which was separate from the corrupt MP3. By using the errors as triggers for other audio parameters, more importance was put upon the resulting sounds and rather than creating a direct representation of the corrupted MP3.

The research did not seek to 'observe or appreciate' the errors, but instead used them to prompt other sounds that reflected Tone's aesthetic preferences, which include 'short, non-harmonic, often high-pitched sounds with rapid repetitions, wide and narrow-band noise bursts and frequency sweeps' (Blake et al. 2009, 235).

The project is part of a larger thematic drive behind many of Tone's works, that being a realisation of music that is indeterminate, decontrolled, automatist, and concerned with paramedia (Blake et al. 2009, 237).

The artefacts that occurred during the corruption process of the MP3 are not heard directly, perhaps they once were, such as the 'siney' FFT synthesis sounds (Blake et al. 2009, 236), but now are used paramedially. They are used for another purpose and in doing this the format's inner workings are, indirectly, still audible.

2.5.4 Media Artefact Recreation Plug-ins

The audio software company Goodhertz creates plug-ins for DAWs, one of which, *Lossy*, imitates some of the aesthetics of data compressed audio. Their goal, as they state on their website, is to 'degrade digital audio and simulate those quintessential compressed sounds in realtime' (Goodhertz 2022a).

The *Lossy* plug-in does well at creating sounds that are similar to compression artefacts, and aestheticizes them further by adding other functions to the plug-in, such as reverb, dry/wet meter, a filter, and a gate. Additionally, the lossy plug-in can generate this aesthetic in real time, which can lead to greater control over the creative process. The plug-in's real-time nature and extra-functionality help in the creation of an aestheticized version of compression artefacts, rather than an accurate presentation of audio compression.

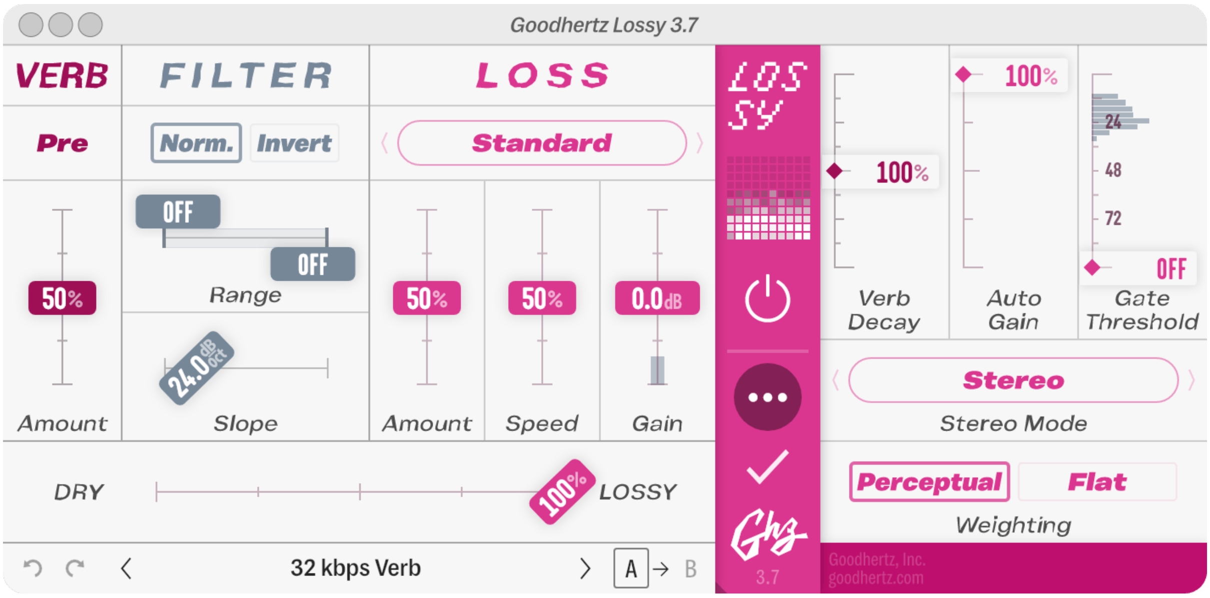

Figure 2.1: Interface of Goodhertz Plug-in Lossy

There are many plug-ins that imitate and replicate the sound of media, the company Goodhertz have several others such as the *Wow Control* which focuses 'on the weird & wild ~modulations~ of analog tape and other less-than-perfect analog playback devices' (Goodhertz 2022b), trying to replicate 'every noise, every wobble' of tape machines (ibid).

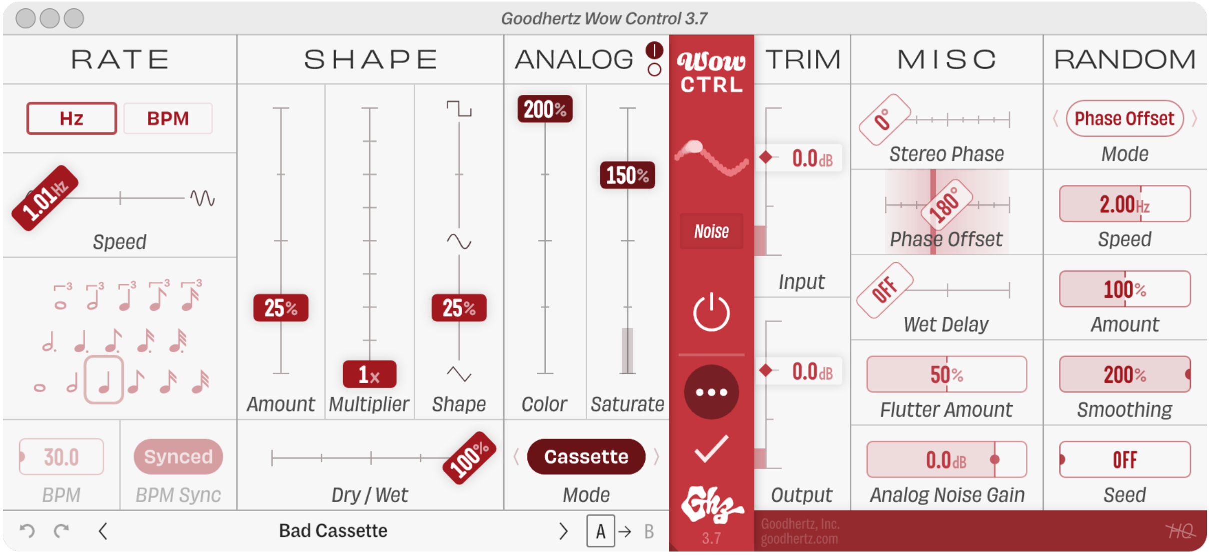

Figure 2.2: Interface of Goodhertz Plug-in Wow Control

The Izotope Vinyl plug-in 'simulates the dust, scratches, warp, and mechanical noise of beloved vinyl records' (Izotope 2022) and Devious Machines *Texture* replicates 'vinyl crackle, tape hiss and digital noise' (Devious Machines 2022).

Figure 2.3: Interface of Izotope Plug-in Vinyl

Figure 2.4: Interface of Devious Machines Plug-in Texture

There are many plug-ins that replicate various types of media artefacts, recreating the sounds of interruption, or Thompson's microdisruptions. The use of plug-ins to re-create the sounds of interruption is what visual glitch theorist Rosa Menkman has described as the 'cultivation of the avant-garde of mishaps and breakages' (2011, 45). To Menkman technological breakages can act radically, the breakage in a flow of information being a reflection on, or metaphor for, other areas of cultural discourse. Software or hardware that simulates failure puts emphasis on design and end products 'rather than on the post-procedural and political breaking of flows' resulting in the moment of technological failure losing its radical status and becoming a commodity (Menkman 2011, 55).

Menkman is highly critical of 'the growing fetishization of nostalgic imperfection' describing it as 'a kind of conceptual virus' (Menkman 2011, 57). She states that the 'standardized, commodified, institutionalizing effects' created by plug-ins that mimic failure allow users to 'handle a broad range of data types and technologies in predetermined, often retro-nostalgic ways, and create what can best be described as an approximation of what originally would have been the materialization of a destabilising break of machine technology' (Menkman 2011, 49).

Menkman's arguments, however, are concerned primarily with plug-ins that recreate glitch effects, and while both are interruptions, glitches and compression artefacts are not the same. The difference between glitches and compression artefacts is that the causes of compression artefacts can be known, as shown throughout chapter 3. The causes of glitches, however, theoretically unknown and unintended (Menkman 2011, 26). Therefore, compression artefacts are already somewhat 'domesticated' (Menkman 2011, 55), as they can be easily re-created using compression codecs or plug-ins.

The plug-in can therefore also be seen as a more accessible means through which to explore compression artefacts, something that this project did in the early stages of researching the sound and musical potential for compression effects.

2.6 Summary

This chapter has illustrated and described an artistic context that closely relates to this project. That context is one that includes creative projects which use technological breakage, interruption, informational noise as the aesthetic focus of their work for the purposes of expanding musical vocabularies, exploring the material and processual properties of the sounds, and looking at how other artists have investigated the MP3.

By considering how Luigi Russolo and Kim Cascone describe their expanding musical palettes so this research contributes towards a modernist tradition but specifically focused on interruption as a means of generating musical material.

Section 2.4 describes artists who use forms of interruption as a means of investigating the materiality of their sounds, a practice this project also contributes towards. This contribution is made clear by the inclusion of technical background information in chapter 3 and the explanation in section 2.4.4 of how MP3 artefacts are media noise indicative of their specific means of production.

Finally, this chapter described other projects that deal directly with MP3s, giving examples from creative projects from Ryan Maguire, Bienoise, Yasunao Tone, and Goodhertz plug-in Lossy.

Chapter 2 has laid out the artistic context for this research, describing the creative practices it belongs to and contributes towards. What will follow in the chapter 3 is an explanation of how the MP3 artefacts have been created, describing perceptual coding and psycho-acoustic concepts and practices, a methodology, and a taxonomy.

Chapter 3 Creating Artefacts

3.1 Introduction

This chapter explains the concepts and processes that lie behind the MP3, those being psychoacoustic principles and their exploitation in perceptual coding. Once important aspects of these processes are explained, a methodology for the intentional production of artefacts is given, and finally a taxonomy of those artefacts.

The chapter begins with a discussion concerning Denis Smalley's concepts of *technological listening* and *source-bonding* wherein the importance of these two practices is described for underpinning arguments made in chapter 2. The next sub-chapter is broken into four sections. The first section looks at psychoacoustic concepts such as critical bands, simultaneous and temporal masking, and perceivable frequency ranges. This is followed by definitions of several key concepts involved in digital audio encoding, such as sample rate, the Nyquist theorem, quantisation, bit depth, bitrate, and frames. Having outlined concepts and given definitions for psychoacoustic and perceptual coding concepts and processes, the third section of this sub-chapter describes a run through of the process of encoding an MP3. The fourth section of this sub-chapter is an overview of prior research that was invaluable in my understanding of psychoacoustics and perceptual coding.

The following sub-chapter deals with the methodology, which was developed during this project for the production of compression artefacts. The sub-chapter explains the importance of various types of input material, such as noise colours and transient signals. This is followed by the controllable variables of the encoders, including bitrates and sample rates. The process of encoding is then described for both the iTunes and LAME codecs, as well as a definition of a key element of the methodology, *cascading*, followed by the importance of compiling encodings for easier analyses. The different kinds of software that were used at different stages of the methodology are given, with explanations as to why some DAWs were better than others, and what was used for analysis. The methodology sub-chapter ends with a consideration about what could be investigated in future tests and experiments using this methodology, including other encoder variables.

Finally, a taxonomy is presented listing seven compression artefacts and effects, with their causes and properties explained and examples given for each one. The artefacts and effects included in this taxonomy are pre-echo, bandwidth limitation, birdies, signal gaps, stereo movement, amplitude fluctuations, and delay.

3.2 Technological Listening and Source-Bonding

It is integral to this project that the effects and artefacts of MP3 compression are created and heard by the listener. While, for this project, the production and perception of technological noise is intended, for Denis Smalley, it is something that should be avoided. Smalley refers to this process as *technological listening* and defines it as being ‘when a listener “perceives” the technology or technique behind the music rather than the music itself, perhaps to such an extent that true musical meaning is blocked’ (1997, 109).

For Smalley, technology should be transparent, stating ‘in spectromorphological thinking we must try to ignore the electroacoustic and computer technology used in the music’s making’ (1997 108) and although this project takes influence from electroacoustic composers and works, the music made as part of this submission requires the technology to be heard.

Another concept developed by Smalley is *source-bonding* and is the ‘tendency to relate sounds to supposed sources and causes’ (Smalley 1997, 110). It describes the process of linking the intrinsic properties of sounds and how they relate to one another within a piece of music with the extrinsic contextual aspects of those sounds, such as their means of production, real or imagined.

Using technological listening, the link between the intrinsic properties of the artefacts as musical material and their extrinsic means of production, results in the music submitted as part of this project acting as a means with which to manifest the arguments made in chapter 2.4.4 – that compression artefacts are produced via a specific relationship between the audio and compression codec. Both the audio being encoded and the encoding technology are necessary for these artefacts to be produced, and, as such, the musical meaning is not blocked by technological listening, in this project, but the opposite, it is revealed.

As such, it is important for the processes of perceptual coding and the properties of the effects and artefacts that come about because of this process to be described.

3.3 MP3 Encoding Processes

The compression of audio relies on a series of processes which analyse and then either preserve or erase information. This section of the chapter describes the concepts and processes that go on during the encoding process of MP3s, laying a conceptual foundation for a clearer understanding of why artefacts and their properties are created.

The sub-chapter includes a run-through of the encoding process after concepts have been established.

3.3.1 Psychoacoustic Concepts

Psychoacoustics is the area of research that is concerned with understanding how the ear and brain interact as sounds are heard. Researchers involved with this topic have 'proposed a number of analyses as to why the ear works in the way that it does' (Sterne 2006, 834) with a consistent point being that a key relationship between the perception of sound and sound itself is that listeners are unable to 'process all the data available' at a given time (Raissi 2002, 3-4).

This is discussed in greater detail below, but put simply, the psychoacoustic principles in action are that listeners cannot discern between sounds if one is louder than the other and they occupy similar positions in time or if the sounds occur within the same critical band

(Sterne 2012, 21), resulting in an effect called *masking*. Critical bands are explained further below, but briefly, are 24 divisions of frequency that the human auditory system uses to perceive pitch (Raissi 2002, 4; Vaseghi 2007, 464).

Another psychoacoustic phenomenon is that the perceivable frequency range narrows with the age of the listener, commonly shifting from a range of up to 20 kHz to up to 16 kHz by adulthood. In addition to this, other factors can affect perception of sound, including sound pollution and poor listening hardware creating less-than-ideal listening conditions, such as being 'outdoors, in a noisy dorm room, in an office with a loud computer fan, in the background as other activities are taking place and through low-fi or mid-fi computer speakers' (Sterne 2006, 835).

The combination of listeners' inability to hear all available information within sub-optimal listening environments (Maguire 2014, 246), means that it is unnecessary to store and then reproduce all of the original data in an audio file. This is the 'principle upon which the MP3 rests' (Sterne 2006, 834), though this can also be said for all audio data compression.

In the process of deciding which elements should be removed or kept during encoding, psychoacoustic principles are taken advantage of using a combination of techniques referred to as *perceptual coding*. Assumptions are made by the codec about what may or may not be heard due to 'less-than-ideal' listening conditions (Diduck, 2012; Sterne 2006, 835) to determine what data can be removed.

Perceptual coding exploits the masking effects mentioned earlier: the ear's inability to discern a low-amplitude sound that is in close proximity in time or occupy the same critical band as a high-amplitude sound (Vasegh 2007, 465). If the louder sound masks a quieter sound in time, it is referred to as *temporal masking*, whereas if the louder sound masks a quieter sound within the same critical band it is called *simultaneous masking* (Vaseghi 2007, 462).

In order to understand how these processes work, some psychoacoustic principles will be further explained, followed by an explanation of how they are used by the compression codec.

Critical Bands and Simultaneous Masking

The notion of *critical bands* is important in understanding simultaneous masking. The human auditory process splits the perceivable frequency range into 24 critical bands, via segments within the cochlea. These segments act like band-pass filters, with frequency dependent bandwidth (Raissi 2002, 4; Vaseghi 2007, 464; Arteaga 2016, 33). This frequency dependency means that it can be difficult to perceive multiple frequencies that fall into the same band.

If multiple sounds that occupy the same critical band are heard, then the loudest will create a masking threshold, causing quieter sounds in the same critical band to become inaudible (Vaseghi 2007, 466).

Below is the Bark scale, a useful representation of critical bands

Band Number	Central Frequency	Cut-off Frequency (Hz)	Bandwidth (Hz)
1	60	100	80
2	150	200	100
3	250	300	100
4	350	400	100
5	450	510	110
6	570	630	120
7	700	770	140
8	840	920	150
9	1000	1080	160
10	1170	1270	190

11	1370	1480	210
12	1600	1720	240
13	1850	2000	280
14	2150	2320	320
15	2500	2700	380
16	2900	3150	450
17	3400	3700	550
18	4000	4400	700
19	4800	5300	900
20	5800	6400	1100
21	7000	7700	1300
22	8500	9500	1800
23	10500	12000	2500
24	13500	15500	3500

Table 3.1: The Bark Scale (Arteaga 2016, 33)

As shown above, the gaps between each critical band get wider the higher the frequencies.

Temporal Masking

Much like the masking of sounds in the same critical band, quiet sonic events can be masked by loud sonic events that occur within a small interval of time, of less than about 'five milliseconds apart, depending on material' (Sterne 2006, 835).

Temporal masking is a process whereby two sounds occur simultaneously or non-simultaneously, and the louder sound renders the quieter one inaudible due to 'delays in the transmission and cognitive processing of audio signals from the ear to the brain' (Vaseghie 2007, 467; Iwai 1994, 20).

A sound can mask another even if the quieter masked signal occurs before the louder masking signal. This a process known as 'backward masking or pre-masking' (Vaseghi 2007, 468). Additionally, a loud sound can mask another, even if the masked sound occurs after the masking sound has finished a process called ‘forward masking or post-masking’ (ibid).

The backward masking effect lasts about 5 ms and is much shorter than forward making forward masking, which can last up to 300 ms (ibid).

Perceivable Frequency Range

Another psychoacoustic phenomenon in the human auditory process is that human hearing range is substantially less sensitive beyond the thresholds of 20 Hz at the lowest and 20 kHz at the highest frequencies. These minimum audition thresholds become closer with age and exposure to damaging frequencies and volumes and, therefore, by middle age few people can hear above 16 kHz (Corbett 2012; Raissi 2002, 3).

3.3.2 Perceptual Coding Concepts and Processes

The masking effects and the narrowing perceivable frequency range described above are exploited by the compression encoder for the erasing of sonic information. This is referred to as perceptual coding, and consists of various techniques employed by the encoding algorithm in the erasure of information.

In the process of doing this, audio is analysed, sampled, and then described using bits, and for these processes to be understood some encoding concepts will be explained. These include frames, bitrate, sample rate, and the Nyquist Theorem.

The following section explains as simply as possible the concepts and processes involved in analysing, sampling, and describing of audio.

Sample Rate/Sampling Frequency and the Nyquist Theorem

The sample rate is decided upon before encoding occurs and defines how many samples will be taken per second in the process of turning a continuous, analogue signal into a digital one, using discrete values (samples) which represent the fluctuations of sonic information (Vaseghi 2007, 155).

How often, or frequently, these samples are taken is referred to as either the sample rate or sampling frequency, and is measured in Hertz (Hz), or cycles/oscillations per second. When creating a digital description of an audio signal, samples are taken by the codec, documenting the various levels of amplitude and frequency within the signal. The codec must take at least two samples for each oscillation in order to account for the amplitude peak and trough of the wave. This therefore means that the sampling rate must be at least double the frequency rate in order to describe each oscillation's peak and trough accurately, this is what is referred to as the Nyquist Theorem. If the sample rate can account for the most frequent series of oscillations (highest frequency), then the other frequencies, with fewer oscillations, will also be accounted for and also described accurately.

Put another way, the frequency range, or bandwidth, of the signal will be capped at half of the sample rate. For example, if a sample rate of 24 kHz is used, the frequency range will only be described up to 12 kHz, because, to reiterate, there must be at least two samples for the highest frequency (in this case 12 kHz) and there are not enough samples to describe frequencies beyond it. The highest possible frequency that can be described in any given sample rate (half the sample rate) is referred to as the Nyquist frequency.

CD-quality audio consists of 44,100 measurements of a waveform's amplitude per second, it therefore has a sample rate of 44.1 kHz. As seen in the methodology below, sample rates in this project have been between 8, 16, and 24 kHz creating Nyquist Frequencies of 4, 8, and 12 kHz.

Quantisation and bit depth

If sampling, as described above, is the process of creating a discrete unit of time or space, then quantization is the creation of a discrete value within a sample.

Each sample is described as a binary word of 1s and 0s. If more 1s and 0s are used in the formation of a sample, then the measurement is more accurate. This is *bit depth* or *word length*, creating a binary word. As PCM word length can consist of 16 or 24 bits, which could be either a 0 or a 1, “there are no less than 65,536 possible values” (2^{16}) for each measurement (Corbett, 2012).

The creation of the binary word is done via a process called quantisation, and involves some ‘irrevocable errors and possible loss of information’, specifically, called *quantisation noise* (Raissi 2002, 156).

Bitrate

The bitrate is a ‘user option’ (Raissi 2002, 8) of an encoder set prior to the encoding. it dictates the number of bits (binary digits) to be used to represent one second of audio (Corbett 2012, 2). The standard bitrate for MP3 coding is defined in the range of 8 kbps (kilobits per second) to 320 kbps (Vaseghi 2007, 476), a higher bitrate therefore ‘implies that the samples will be measured more precisely giving an improved audio resolution’ (Raissi 2002, 8).

The range in bitrate is due to the necessities of the devices playing back the audio, coupled with the expected listening environment. For example, the lower bitrates would be reserved for streaming on mobile devices, which could have restricted internet speeds, poorer playback hardware, and noisy listening contexts.

If the data sent for encoding still exceeds the bitrate, then the process will be repeated until requirements are met (Corbett, 2012).

Frames

The encoded MP3 signals are divided into smaller fragments called frames. Each frame represents a fraction of a second’s worth of information regarding how sound will be played back. The encoder breaks down each frame into 72 discrete frequency bands and analyses the audio to determine the amplitude to spectra relationship. When parts of the audio with higher amplitude are found, they are kept, and erases areas with low amplitude as the algorithm 'tries to figure out where the most important frequencies are in the sound' (Sterne 2006, 833; Raissi 2002, 8-9).

Windowing

The *Dictionary of Electronics and Electrical Engineering* (Butterfield et al. 2018) defines windowing as being 'the tapering of a sampled signal prior to a transformation being applied in order to reduce the effect of any discontinuities at the edges.' Window length is the portion of time/space that the encoder uses as its basic block for analysis, for example, a coder might use window lengths made of 1024, 512, and 256 samples (Iwai 1994, 21).

3.3.3 Perceptual Coding Process

Now that concepts have been established above, this section will go through the encoding process, highlighting how each step using psychoacoustic and encoding concepts removes audio and creates artefacts, effects, and noise.

The first step is to break the signal into frames, these frames last for a fraction of a second and break down the spectral range to 72 discrete frequency bands. The frame then analyses the 'spectral energy distribution' (Sterne 2006, 833), meaning it is looking for high and low amplitude sounds within the frequency range in the frame, in order to decide which parts of the signal can be kept and which can be removed, based on the *simultaneous masking* process described earlier.

The encoder then decides how much information to retain and remove dependent upon the variables set up before the encoding process began. These variables include bitrate, sample rate, (and bit depth). The encoder then 'calculates a new timbral measurement for each frame based on what it learned about the shape of the incoming signal' (ibid). At this point information is removed using the psychoacoustic principles described above.

The algorithm then negotiates between audio content and bit-rate, depending on the required file size (Corbett, 2012). The lower the bitrate, the fewer bits there will be for the description of audio, causing the encoder to remove a greater amount of relatively low amplitude sonic information (creating amplitude fluctuations, signal gaps, and birdies as complex signal become less complex). Additionally, quantisation noise becomes audible in moments in the form of pre-echo.

There can be an in-built brick wall filter for some encoders, dictated by bitrate, which can reduce the bandwidth/frequency range to 16 kHz or lower, while low sample rates can also create limited bandwidths as the Nyquist frequency also gets lower. Encoders can also add portions of silence to beginnings of encodings creating delays, and stereo movement can occur when the processes described above are applied to both stereo signals independently of one another.

The final step is for the encoder to assemble relevant information and instructions for each frame, which ensure consistent playback on programs and devices (Sterne 2006, 833).

3.3.4 Prior Research on MP3 Artefacts

It has been important to research the reasons why artefacts and effects are created in order to better create and recreate them. Essentially, beginning to understand how and why compression artefacts are made is a key part of the methodology (understanding how to create this material allows further work to be realised effectively), and also a key part of understanding the properties of the artefacts.

In doing this, a variety of papers from different research projects have been collected contributing to an understanding of the processes for creating compression artefacts. Many of these research projects were focused on highly technical processes involved with data compression, discussing the concepts described above, and more, in great detail. While many aspects of these papers were beyond the scope of this research, they were invaluable in their description of psychoacoustics, perceptual coding concepts and practices, and their description of artefacts and their causes.

This sub-chapter is broken into three sections with general themes uniting several of the research projects looked into during the secondary research process of this project. The first looks at papers that were concerned with mitigating and removing artefacts, the second section looks at three papers that act as taxonomies of sonic artefacts lacking an overt agenda beyond describing properties and some references to mitigation techniques, and the third section includes papers and articles that were concerned with acting as reference points explaining properties of artefacts, coding concepts in terms that are accessible and can act as a foundation for future research.

Mitigation of MP3 Artefacts (Birdies, Bandwidth Limitation, and Pre-Echo)

Jonathan Sterne noted in 2006 that 'discussions of the sound of MP3s have been limited largely to audio engineers and audiophiles, who range from dismissals on the basis that MP3s sound 'bad' (eg atkinsons 1999) to analyses of the sonic limitations of MP3s as a 'problem' (eg Eide 2001)' (Sterne 2006, 827). Sterne, here, refers to two articles that were published on websites. The first being from stereophile.com, and the second from mixonline.com, which unfortunately no longer archives the article on there.

This points to a position in popular culture that suggests a negative attitude towards the sound of MP3s. In addition to this, my own MA thesis research from 2016 was a discourse analysis of various articles in popular journals and magazines *Sound on Sound*, *The Wire*, *Fact Mag*, and *Music Tech* which displayed a variety of criticisms towards the sonic properties of MP3s. The research found 147 articles that used the term MP3, ten of which were explicitly critical of the MP3's audio quality, with many more describing the properties of MP3 audio as being problematic and suggesting solutions to these issues (Reeve-Baker 2016).

This project is taking this process of research further by finding and reading academic engineering papers that were concerned, like the articles described above, with tackling the perceived problematic sound of compressed audio.

As the research projects from which these papers come are concerned with creating methods for mitigating compression artefacts they went into much greater depth when describing how and why artefacts are created compared with the articles from my previous research project in 2016.

The paper *Removal of Birdie Artifact…*(Prakash et al. 2004) suggested developing an algorithm that modified bit allocation to preserve critical bands. The paper describes an approach involving a new algorithm 'to overcome the birdie artefact and hence improve the audio quality' (Prakash et al. 2004, 1) (see section 3.5.3 for more information on birdies). The algorithm tries to preserve critical bands from 'vanishing after quantization' due to an increase in quantization noise using low bitrates. (Prakash et al. 2004, 2), as the creation of birdies necessitates complexity and low bitrates. While the paper is concerned with minimising the creation of birdies, it also gives a description of how birdies are created and what their effect is on the audio. This was helpful in my development and understanding of a methodology for their creation as well as contributing to my understanding of processes and concepts such as quantisation, critical bands, signal to noise ratios, mask to noise ratios, and absolute threshold of hearing.

While Prakash et al., proposed a means of modifying the 'internal mechanisms' (Desroches et al. 2015, 1) of the compression process, Desroches et al., proposed a post-processing approach in their paper *Detection and Removal of the Birdies Artifact in Low Bit-Rate Audio* (2015). The paper explains how birdies were detected after encoding and then removed using human and non-human techniques wherein artefacts were identified using a graphical tool. While Desroches differs from Prakash in the design, methodology, and results of their research, their goals are the same and they both give information regarding birdies. The paper acknowledges that birdies are the reduction in complexity of a complex timbre bydescribing their properties as being 'frequency energy variations' (2015, 2) and 'warbling'

(2015, 3), and their cause as being when ‘the encoder leaves spectral holes in the spectrum that, if filled, will remove the artifact’ (2015, 2).

Desroches’ approach claims a more universal application as only the ‘compressed version of the signal’ is needed, rather than embedding the mitigation process into a new encoder. This indicates the desire for engineers to develop a means for altering the sound of compressed audio and to make it available, or ‘universally compatible with any codec’ (2015, 7), for general use even as recently as 2015.

While the previously mentioned studies were concerned with birdies artefacts, Gampp et al. (2017) propose methods for the ‘enhancement’ of low bitrate coding in car audio systems, not only in regards to the suppression of birdies but also the extension of bandwidth (2017, 1).

Gampp et al. describe the properties of bandwidth limitation as having a ‘dull and muffled sound’ (2017, 2), and that it is caused by low bitrates, due to it being ‘a common encoder strategy to limit the audio bandwidth through a lowpass filter to still enable perceptual coding of the remaining low band at decent quality with the available bit budget’ (2017, 2). This enforces what has been observed in this project’s own primary research using codecs and noise, wherein encoders appear to employ brick wall filters, particularly the LAME encoder, at very low bitrates. The birdies effect is described here as being ‘spectral islands’ and ‘reminiscent of a bird’s twitter’ (2, 2017), these descriptions were useful insofar that they acted as a linguistic and conceptual bridge between complex engineering concepts and a layperson’s perception of them.

Pre-echo reduction was a concern for some papers too, including Iwai (1994) and Samaali et al. (2012), and like papers described above, these ones also provided the research with information regarding the causes, characteristics, and effects of the artefacts, as well as other encoding principles.

Iwai’s research is concerned with examining ‘factors which contribute to a pre-echo, and discusses the method of pre-echo detection and reduction’ (Iwai 1994, 2). The paper describes the specific circumstances in which the effect occurs, which are 'situations where silence is broken by a sharp attack' (1991, 8) and states that it is created by the unmasking of quantisation noise 'in the silence preceding the attack' (ibid).

As well as describing how the pre-echo is created, Iwai's paper also gives explanations on encoding concepts such as quantization and windows, and psychoacoustic principles such as temporal masking. While other papers allude briefly to psychoacoustics in a technical way such as 'Perceptual Audio Encoders attempt to model the working of the Ear-Brain combine and the associated perception of sound' (Prakash et al. 2004, 2) Iwai, devotes a paragraph to describing the process of temporal masking, while also including backward masking and forward masking descriptions.

Samaali et al., like Iwai, describes the cause of pre-echo effect as being 'a relatively high quantization noise' in 'the silence before the attack' (Samaali et al. 2012, 431). While the paper's intended readership is one that has a background in engineering - and therefore has limited value to a composer - its use of diagrams and figures to show the waveforms of the artefact made comprehension of their properties easier and more efficient, inspiring the use of images in this project.

Taxonomies

There were a variety of papers whose purpose was not to propose mitigation methods, but rather to act, much like my own taxonomy, as repositories documenting types of digital encoding artefacts, describing their causes and properties. These papers, much like the ones above, gave information regarding perceptual coding concepts, though tended to be more in depth regarding the artefacts' and effects' properties and causes. The mix of expert and non-expert language and use of images also helped to bridge the gap between varying levels of expertise, gave this project a new means of discussing artefacts with more figurative language, and lastly acted as a point of reference for when undertaking primary research and developing this project's own taxonomy.

The paper *Compression Artifacts in Perceptual Audio Coding* by Liu et al. was mostly concerned with bandwidth limitation, birdies, and pre-echo, though it also included various compression effects that have not been covered in other papers, or in this research including 'tone trembling' and 'noise overflow' (Liu et al. 2008, 694). While these artefacts are not researched further in this project, or others that could be found during secondary research, they are certainly areas that could be researched in future projects.

Nonetheless, the paper supplied in-depth technical and figurative descriptions of artefacts, describing birdies as being caused by 'spectral valleys' which are 'mainly due to unsuitable bit-allocation policies or excessive masking energy estimates' (Liu et al. 2008, 681), while also later saying they are 'fishy' (2008, 694). The effect bandwidth limitation was described with the more literal term 'muffled' (2008, 681), and its cause is described clearly in the paper which states 'compression algorithms save bits required for HF and place all available bits to the low-frequency (LF) part, which is more relevant for human hearing' (2008, 682). Finally, the paper uses technical language to describe the cause of the pre-echo effect (2008, 683), though, later also describes it figuratively using the subjective term 'annoying' (2008, 693).

It was this paper's wider range of topics, inclusion of a taxonomy, use of terminology from various levels of expertise, and movement between literal and figurative descriptions of artefacts that made this paper valuable to this project. These qualities made the papers' discussions accessible, while also encouraging a subjective response to the sounds' properties. This, in turn, influenced discussion of compression artefacts in this project, as I tried to make descriptions accessible to intermediate levels of expertise and introduce more figurative descriptions.

Arteaga's *Automatic Detection of Audio Defects* (2016) is a taxonomy that includes an even wider range of audio recording artefacts and effects from analogue and digital sources. While it gives information on a wider variety of media artefacts, this has resulted in relatively less specialist language, making the information more accessible. The MP3 artefacts Arteaga's taxonomy includes, are birdies, pre-echoes, and altered stereo image and includes several mitigation proposal techniques from other papers, some of which have been included above.

General Overviews and Descriptions

Lastly, there were articles that lacked overt criticism, and instead were documents that described perceptual coding techniques and artefacts, acting explicitly as reference points for future research.

Perceptual Audio Coders "What to listen for" (Erne 2001) and *Evaluation of Audio Compression Artifacts* (Martinez 2007), both focus on describing a variety of compression artefacts, providing explanations of their causes, and methods of detecting and analysing artefacts. They both consider the artefacts pre-echo and birdies, though Erne also considers the digital artefact aliasing and loss of stereo image, and Martinez additionally looks into 'an artefact known as reverberation' (2007, 13). They give good amounts of information regarding causes and characteristics of the artefacts, without arguing for mitigation techniques. Instead they act as potential points of reference for future research, with Erne (2001) stating that with its accompanying CD-ROM, its ultimate goal was 'to provide universities, students, researchers, recording engineers, performing artists, musicians, publishers, journalists but also to the interested reader, with a tool, enabling him/her, to enter the real[m] of audio coding' (Erne 2001, 10).

There are three papers, all from 2004 that are concerned with spatial audio coding, and all with the same lead author, Jügen Herre. *From Joint Stereo to Spatial Audio Coding Recent Progress and Standardization* (Herre 2004), *MP3 Surround: Efficient and Compatible Coding of Multi-Channel Audio* (Herre et al. 2004a), and *Spatial Audio Coding: Next-generation efficient and compatible coding of multi-channel audio* (Herre et al. 2004b) all give clear explanations of different types of multi-channel coding. These include parametric coding, binaural cue coding, MP3 surround coding, but most usefully for this project, Normal and Joint Stereo coding, as it is these two types of stereo coding that have been used in the creation of the stereo movement effect.

Finally, from a non-academic publication, Ian Corbett's article *What Data Compression Does To Your music* (2012), published in the magazine *Sound on Sound*, describes a variety of psychoacoustic and coding concepts, with visual and audio examples. This article was a useful guide, using non-specialist language, though still including many key terminologies. While the article includes examples of artefacts, such as loss of bandwidth, pre-echoes, and loss of stereo image, others are mentioned that, unfortunately, were not found in any other publication including 'swirlies' (Corbett 2012, 7).

While some of the perceptual coding processes involved in audio compression have been made clear by the research projects described above, the MP3 codec remains somewhat of a black box system. Therefore, in order to learn more about the compression process, primary research was undertaken wherein the system's inner workings were inferred by analysing and comparing the input and output material of the codec.

3.4 Methodology for Creating Artefacts for Taxonomy and Composition Material

An important means of researching compression artefacts and effects has been to conduct primary research by carrying out experiments and tests wherein colours of noise and transient signals were cascaded through MP3 codecs in the pursuit of intentionally creating compression artefacts.

The methodology used in the creation of artefacts is described in this section of the chapter, first looking at early investigations into creating artefacts using a plug-in and complex timbres. The sub-chapter then considers various input materials and why their properties were valuable for evoking artefacts and describes how their consistencies were important in the investigation of artefacts' properties and causes. The encoding process itself is then described, with a definition of *cascading* - an important element in this methodology used to exaggerate artefacts for easier audition. This is then followed by a description of how encodings were compiled for easier analysis. An overview of the software used is supplied, giving information about which DAWs were best for this method, where material was generated, and how encoders were used. Lastly, some consideration is given to future iterations of this methodology, considering different input materials, whether other encoder variables could be manipulated, and whether other artefacts could be evoked.

3.4.1 Preliminary investigations

Prior to this research project, experiments using wideband timbres from organs and field recordings were filtered using a plug-in that imitates the sound of compressed audio called *Lossy* (discussed further in section 2.5.4). While the Lossy plug-in creates an aestheticized version of compressed audio, these very early investigations led to an interest with using compressors to create genuine artefacts.

As the research project began in early 2019, initial informal enquiries using actual compression encoders began to be used, and indicated that a great deal of sonic variety could be generated if input materials and encoder parameters were manipulated. Therefore, for compression artefacts to be consistently produced and understood, it was necessary that encoding experiments be rigorously controlled, leading to the development of the methodology described below.

3.4.2 Input Materials

Noise Colours

The process for creating artefacts began by encoding white noise using the iTunes MP3 codec. White noise was used because of its complexity, its consistency, and the ease with which it can be generated. Doing this made clear that a wide variety of artefacts could be generated.

Reading on the subject of data compression indicated that there are complex relationships between frequency and amplitude in the encoding process as it takes advantage of psychoacoustic principles. It was therefore clear that for further production of artefacts and understanding of their causes and properties, timbres with consistent complexity, though with different amplitude to frequency relationships should be used as input material, leading to the use of noise colours.

The term noise colour denotes two things: that there is a signal with randomly generated frequencies across the spectral range, and that the energy distribution is, on average, consistent within the signal, though different from one colour to the next.

The noise colours used were violet, blue, white, pink, and red. While white noise has, on average, a flat amplitude across the frequency range, blue noise increases by 3dB for every ascending octave, and violet noise increases by 6dB for every ascending octave. In contrast, pink noise decreases by 3dB, and red noise decreases by 6dB for each ascending octave.

Noise colour	Amplitude Across Spectrum
Violet	+6dB Per Ascending Octave
Blue	+3dB Per Ascending Octave
White	Flat Amplitude across spectrum
Pink	-3dB Per Ascending Octave
Red	-6dB Per Ascending Octave

Table 3.2: Noise Colours and Their Amplitude-Spectral Relationships

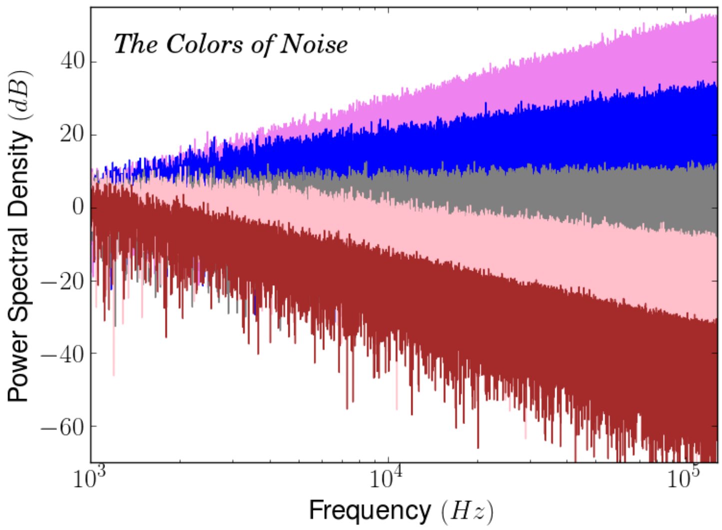

Figure 3.1: Noise Colours (AkanoToE 2022)

White noise was first used as an input material with the iTunes MP3 encoder from April 2019, other noise colours were used from July 2019 onwards. The noise colours highlighted the impact that the encoding process had on timbres with various amplitude to frequency relationships. For example, as compression codecs tend to preserve lower frequency content and high amplitude content, this meant that red noise with higher amplitude in lower frequencies was relatively well preserved, though with limited bandwidth. In contrast, violet noise with low amplitude in its lower frequencies was changed into a series of discrete artefacts, displaying birdies and signal gaps. More on this can be seen in the indexes and is described in the taxonomy.

Audio examples of noise colours can be found in the audio examples folder labelled *Audio Example 3.1 Violet Noise.wav*, *Audio Example 3.2 Blue Noise.wav*, *Audio Example 3.3 White Noise.wav*, *Audio Example 3.4 Pink Noise.wav*, and *Audio Example 3.5 Red Noise.wav*.

Transient Signals

It was made clear from articles by Iwai (1994), Martinez (2007), and Erne (2001), that using a transient signal is a good means with which to generate time-domain, time-smearing artefacts.

The DAW *Audacity* was used to generate and cascade a transient pluck sound as it could be synthesised easily by selecting the ‘Pluck’ option in the ‘Generate’ drop down menu as shown in the screenshot below.

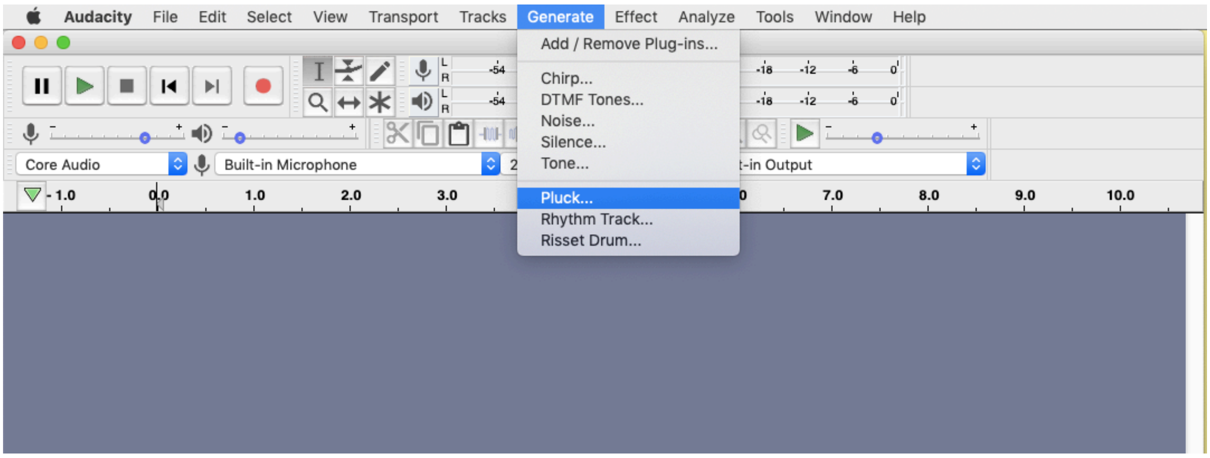

Figure 3.2: Screenshot of Audacity showing menu navigation to generate pluck transient sound

As the papers outlined in section 1.2.4, the most prevalent time-smearing artefact was pre-echo (the increase in amplitude of quantisation noise preceding the attack of a transient signal). Therefore, the pluck sound’s fast attack was the most important aspect of the amplitude envelope. The pluck’s long release allowed for other compression effects to be heard more clearly, such as amplitude fluctuations and was particularly useful when looking at how stereo encoding affects signals.

As with the noise colours, it was the consistency of the pluck sound that meant that it could be seen, to what degree, encoder variables were responsible for producing artefacts. To hear the pluck sound, see *Audio Example 3.6 Pluck.wav*.

In addition to the pluck, more transient signals were generated by repeating an artefact that had been time-compressed using the MIDI function in Ableton Live. This created a series of the same artefact, and was done several times with different originating sounds. Using a series of transient sounds showed how amplitude envelopes and stereo position were impacted when in a series. This investigation was not done extensively, and as the artefacts were being processed and exported from Ableton Live, fidelity could not be guaranteed.

The high amplitude of the attack made clear how over iterations the amplitude can both increase and decrease, and the long release of the pluck made it possible to hear how the signal moved across the stereo field and how amplitude would fluctuate.

Sine Tones and Clusters

Individual sine tones and clusters of sine tones were used, though the only effect that could be heard was in the immediate decoding. When the encoded sine tones and clusters were being played back, a small amount of blurring could be heard when the play back was stopped or restarted. When analysing this audio more closely there were no visible or audible changes indicating that the effects were independent of the audio and, instead, were being created by the playback technology itself. Sine tones were generated, again, using Audacity.

The ratios between frequencies in the clusters consisted of either equal steps between each frequency or a consistent multiplying. A cluster that had equal steps between each frequency included 440 Hz, 880 Hz, 1320 Hz, 1760 Hz, and 2200 Hz – the frequency increasing by 440 Hz each time. A cluster that used frequencies that double with each step included 75 Hz, 150 Hz, 300 Hz, 600 Hz, 1200 Hz, 2400 Hz, and 4800 Hz. Ultimately, it became clear that it was much higher amounts of complexity or changes in amplitude envelope that were needed to create artefacts rather than these relatively simple frequency and tone clusters.

3.4.3 Encoder Variables

As described earlier, bitrates and sample rates are decided upon before encoding, and, as the aim of this project has been to create encoding artefacts, bitrates and sample rates were reduced to the lowest that the encoders would permit. The specific encoding parameters being investigated were bitrates of 8 kbps and 16 kbps in mono, and 8/16 kbps and 16/32 kbps in Joint Stereo and Normal Stereo, while the sample rates used were 8 kHz, 16 kHz, and 24 kHz. Contrasting with recommended MP3 encoding parameters which tend to be bitrates of 128 kbps or 320 kbps and a sample rate of 44.1 kHz.

Though some of the variables of the iTunes and LAME MP3 encoders were different, the bitrates, samples rates, and stereo encoding types were the same and therefore encoding could be done with consistency across both encoders.

Bit depth was not an available variable in the encoding process. However, as lowering it would probably increase quantisation noise, it could be interesting to see how far that process could be pushed in future research.

3.4.4 Encoding and Cascading

The input material was then encoded using the bitrates, sample rates, and mono or stereo settings described above. However, in order to exaggerate artefacts further, audio was subjected to multiple passes through the encode/decode cycle of the compressors, a technique called *cascading*.

Cascading is a technique whereby audio is subjected to multiple passes through a lossy data compression codec, resulting 'in an overall degradation in sound that many listeners find objectionable' (Marston et al. 2005, 3). While cascading is described here as a technique, it is normally considered something to avoid. As a research and development white paper from the BBC states 'broadcasters have experienced significant problems with cascaded audio coding in the broadcast chain following the introduction of digital transmission' (Marston et al. 2005, 5). Similarly, Jonathan Sterne describes this process as 'if you send MP3-coded audio into an MP3 coder, the artifacts of the encoding process are hypertrophied. As a result, the official line is that MPEG audio is an "end-use" format' (Sterne 2012, 235).

Considering the attitudes described above, cascading is thought of as being an unintended and problematic process, creating unwanted effects. This project, however, approaches cascading deliberately and methodically, as a creative technique for producing amplified, or hypertrophied, artefacts.

Signals were encoded and cascaded using the iTunes and the LAME MP3 codecs. The audio was cascaded five times, resulting in six iterations of encoded audio and more pronounced artefacts. The amount of variation between iterations, however, would generally diminish between the 4th and 6th iteration. After making encodings, iterations were compiled into a single audio file, and then, using a spectrogram, analysed both sonically and visually. The software *Sonic Visualiser* was used for creating spectrograms and waveforms, which could then be analysed in detail.

iTunes and Lame Encoding Methods

The iTunes codec allows for adjusting the bitrates and sample rates in the Custom settings of its Preferences. Once set to the necessary bitrates and sample rates, audio was encoded and then cascaded by repeating this action on the most-recently encoded audio output several times. LAME MP3 encoding was done using Audacity as an interface. Parameters of the encoding process were adjusted during the exporting process, exported files were then imported back into Audacity to then be exported again.

By cascading audio through MP3 encoders with low quality settings, it has been possible to exaggerate these effects, and then listen to them using spectrograms, clear headphones, and close to ideal listening environments.

3.4.5 Compiling Encodings and Creating Indexes

The processes described above would be done until there were six iterations of encoded audio, these files were then loaded into a DAW to be compiled and exported as WAVs. They were exported as WAVs after the compiling process so that as much information from the

MP3 cascading process was kept. Having a file of compiled iterations made it easier to analyse and see how the cascading exaggerates the effects and artefacts.

The compiled encodings are presented in the indexes in the appendix. They describe each test individually showing the effects created in each test and how much each signal was affected. These descriptions also make use of spectrograms and waveforms, which typically show the development of the sound as the signal is cascaded.

In order to efficiently analyse and visually depict the stereo movement effect that occurred in the stereo tests which used the transient pluck signal, the mid elements of the audio were removed leaving the side information. This allowed the stereo differences to be isolated, which were then summed into a mono file and presented as spectrograms, as is shown throughout *Transient Stereo Test Index.*

3.4.6 Future Tests

Future research could explore how transient signals with different spectral properties such as sine tone and coloured noise bursts could affect time-smearing artefacts. It would also be interesting to see if bit depth could be adjusted, and if by lowering it quantization noise can be exaggerated, and other artefacts can be generated. Finally, investigating artefacts mentioned in other taxonomies but not in this one could be an interesting area for greater research. This could include, for example swirlies (Corbett 2012), reverberation (Martinez 2007), and blocking artefacts (Malvar 1990; Seelamuntula et al. 2009). More information regarding future developments of this research can be read in chapter 6.1.

3.5 Taxonomy

The taxonomy covers artefacts that have been identified and discussed in previous research such as pre-echo, bandwidth limitation, birdies, and stereo movement, artefacts that have been recognised but have had less research made of them such as signal gaps, delays, and amplitude fluctuations, and sub-artefacts including different types of birdies.

Each section gives descriptions of the causes and properties of the effects and artefacts, with visual examples from spectrograms and waveforms.

3.5.1 Pre-echo

Cause

Iwai (1994) describes the occurrence of pre-echo as being caused by three factors: quantisation noise, window length, and stationarity of the audio signal (1994, 8). Quantisation noise is the noisy side-effect of the quantisation process, wherein 'intervals of data are grouped or binned into a single value' (Ramponi et al. 2016, 506), window length is the portion of time/space that the encoder uses as its basic block for analysis, and stationarity is the level of consistency within the signal. Highly non-stationary is another way of describing a transient signal, or a signal with a high fast attack within a quiet or silent context.

Quantisation noise created in the coding process is normally hidden within a signal below a masking threshold of the louder sound. If, however, the louder sound is preceded by silence, such as a transient signal, then quantisation noise that is hidden in the high-energy attack of the transient signal is spread over the entire length of the window, including the relatively lower energy pre-attack of the signal.

This is because, in this window, the masking threshold for the quantisation noise will have been computed from a portion of the frame after the attack of the transient signal. The quantisation noise is therefore made audible in the low energy portion of the window preceding the attack of the transient creating the pre-echo effect (Vaseghi 2007, 473-4).

Properties

The effect can be a softened or blurred attack, and in most cases a clear hissing, distorted sound immediately before the attack can be heard. It can be seen in the waveform examples below that the attacks of the compressed transient pluck signals are lengthened.

Not only this, but the peak of the signals' attack can be seen to occur later than in the original by roughly 0.05 of a second. Perhaps, therefore, while the pre-echo effect is created by the amplification of quantization noise, our perception of it is emphasised by the attack's peak being delayed.

Example

Below is a series of cascaded pluck transient sounds encoded using the iTunes encoder at 16 kbps and 8 kHz. The pre-echo artefact can be seen here as a slight increase in amplitude before the attack of the signal. The image below shows a waveform of the unencoded pluck at the far left, followed by six iterations of encodings, and can be heard in the *Audio Example 3.7 Pluck 16 8 Comp.wav*.

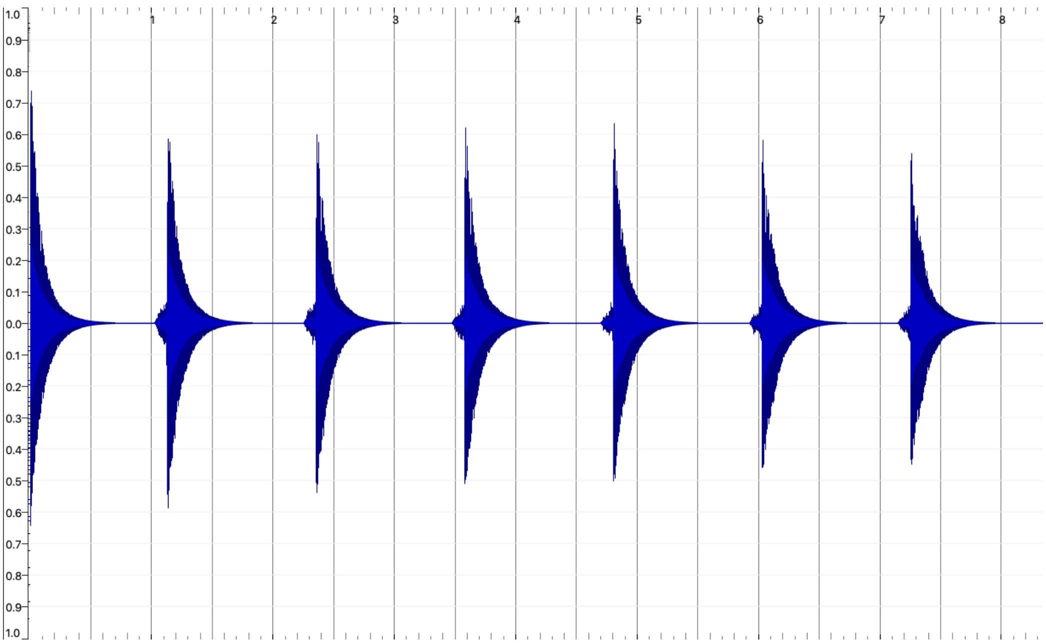

Figure 3.3: Iterations of Cascaded Pluck Using iTunes Encoder Creating Pre-Echo Artefact

Looking more closely at the third encoded transient, the pre-echo can be seen more clearly beginning around 3.48 and ending just before the attack of the transient signal at 3.57.

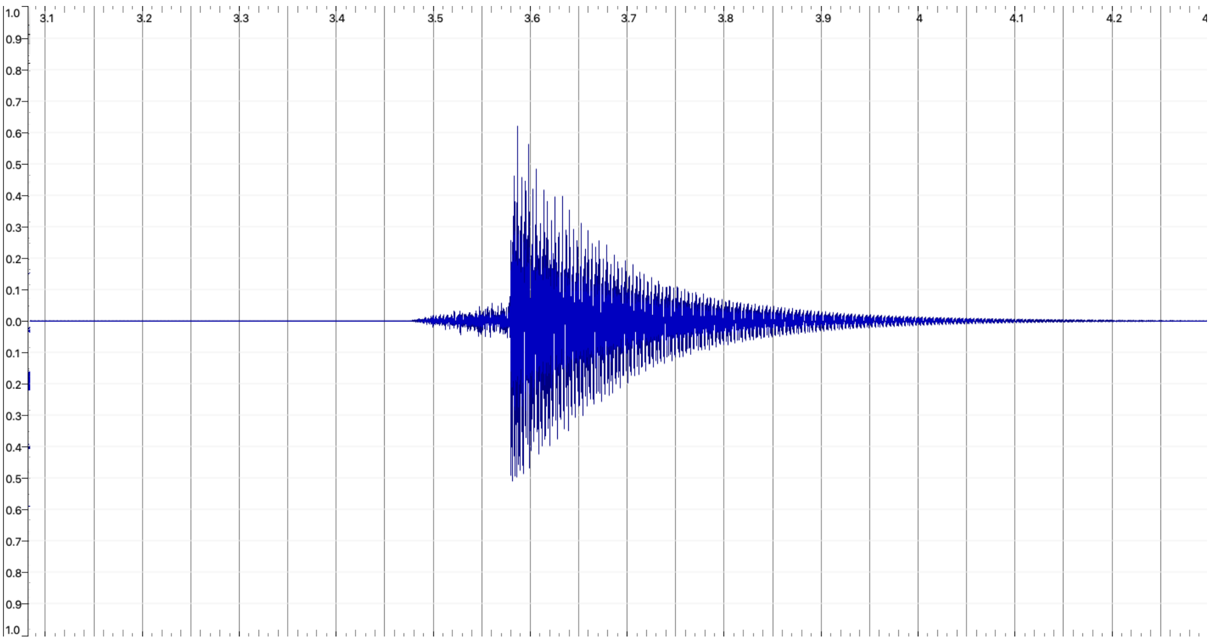

Figure 3.4: Close up of Third Iteration of Cascaded Pluck Using iTunes Encoder Creating Pre-Echo Artefact

3.5.2 Bandwidth limitation

Cause

Most audio compression algorithms will sacrifice high frequency content, preferring to describe lower-frequencies, especially when encoding at low bitrates (Liu et al. 2008, 682). This decision is based on certain psychoacoustic principles that underpin the encoding algorithms. For example, as it is common for adults to lose their ability to hear frequencies above 16 kHz for many listeners frequencies above that point can be erased. Additionally, sub-optimal listening technologies and environments means that higher frequencies could be obscured or not be expressed at all, further justifying their removal. Bandwidth limitation is caused by two processes; low-pass built-in brick-wall filters and the Nyquist rate.

Low Pass Filters

MP3 encoders may use a brick-wall filter (Corbett 2012) to remove audio above 16 kHz. The iTunes MP3 encoder will cut off frequencies at 16 kHz when encoding at 128 kbps, and to retain full bandwidth, MP3s must be encoded above 256 kbps (Corbett 2012, 5). The LAME encoder uses a brick-wall filter more consistently and is triggered by bitrate. It limits bandwidth to 3 kHz when using a bit rate of 8 kbps, and 6 kHz when using a bit rate of 16 kbps.

Nyquist Rate

While the iTunes encoder does use a filter to limit bandwidth, in this set of experiments bandwidth is mostly limited by the Nyquist rate, affecting bandwidth when sample rates are low.

Properties

Bandwidth limitation results in timbres becoming muffled, definition can be lost, and high-frequency rich signals can be significantly degraded (Corbett 2012; Liu et al. 2008).

Examples

The images below show white noise encoded at 16 kbps and 8 kHz using the iTunes encoder. It can be seen that after the initial burst of wide band white noise, the encoded audio's bandwidth becomes limited. It is kept below 4 kHz, the Nyquist frequency of the encoded audio. This example can be heard in *Audio Example 3.8 White Noise 16 8 Comp.wav*.

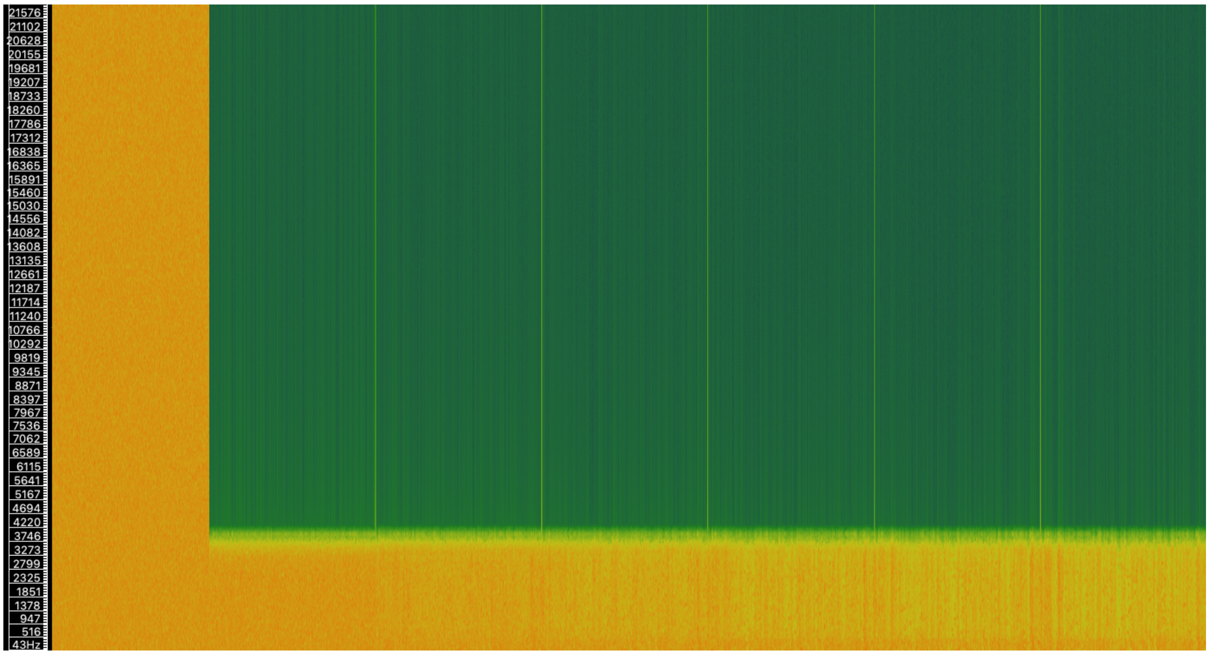

Figure 3.5: Spectrogram of white noise followed by six iterations of encodings using iTunes encoder showing bandwidth limitation

Looking more closely at the encoded audio, again, from white noise encoded at 16kbps and 8 kHz, the cut off at the Nyquist rate can be seen more clearly.

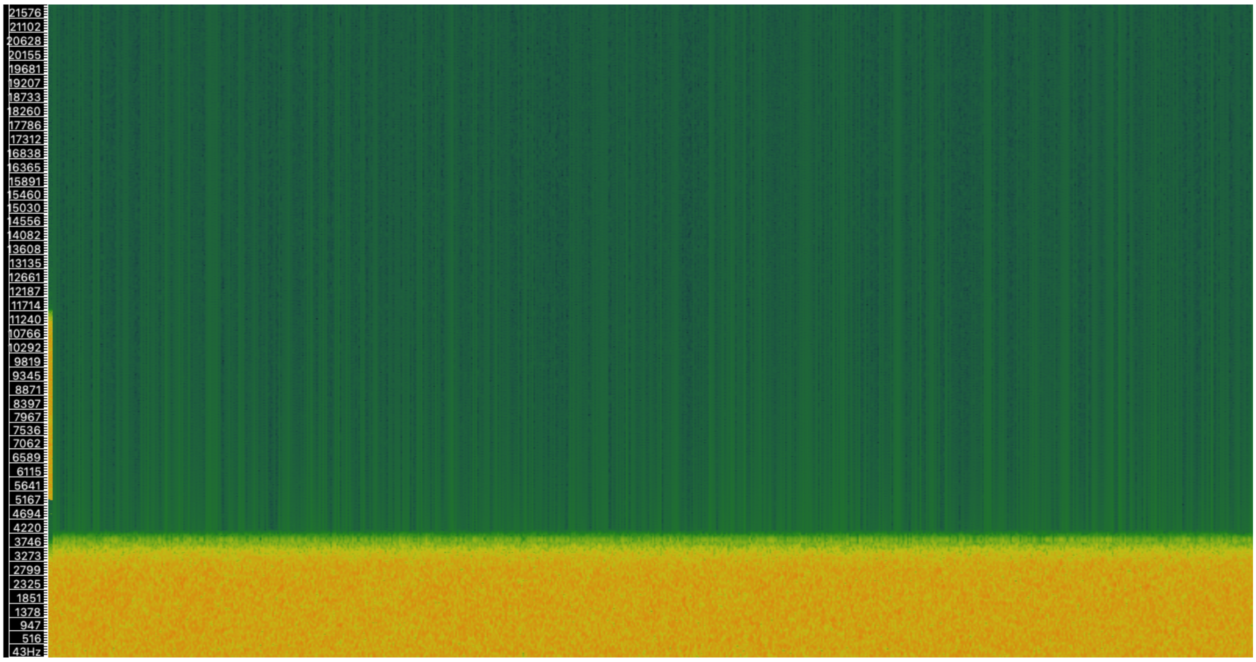

Figure 3.6: Close up of spectrogram of white noise encoded using iTunes encoder showing bandwidth limitation

The images below are of white noise encoded at 8 kbps and 24 kHz using the LAME encoder. Unlike the examples above, the bandwidth has not been limited by the Nyquist rate. Instead, the bandwidth is capped due to a low pass, brick wall filter. The limit of the filter is set by bitrate, not sample rate. It results in a narrower spectral range but a more accurate description of the signal within it. To hear this example, see *Audio Example 3.9 White Noise 8 24 Comp.wav*.

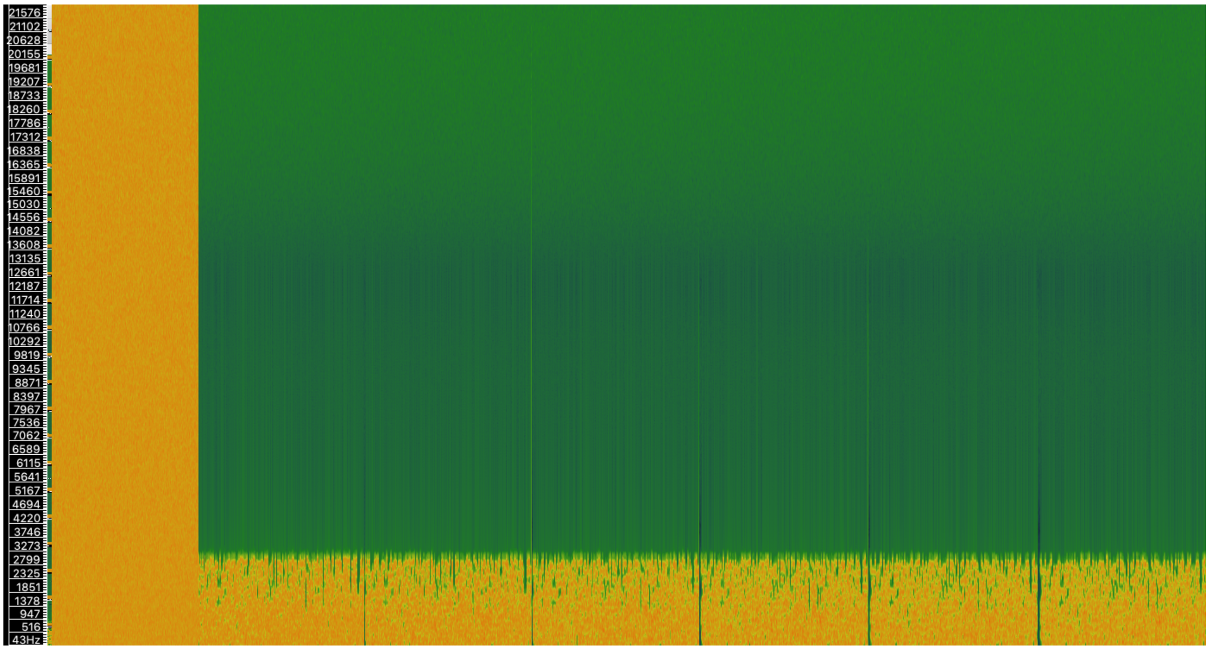

Figure 3.7: Spectrogram of white noise encoded using LAME encoder showing bandwidth limitation

The two images below take a closer look at the spectrogram above. It can be seen even more clearly that the LAME encoder LPF has limited bandwidth to 3 kHz.

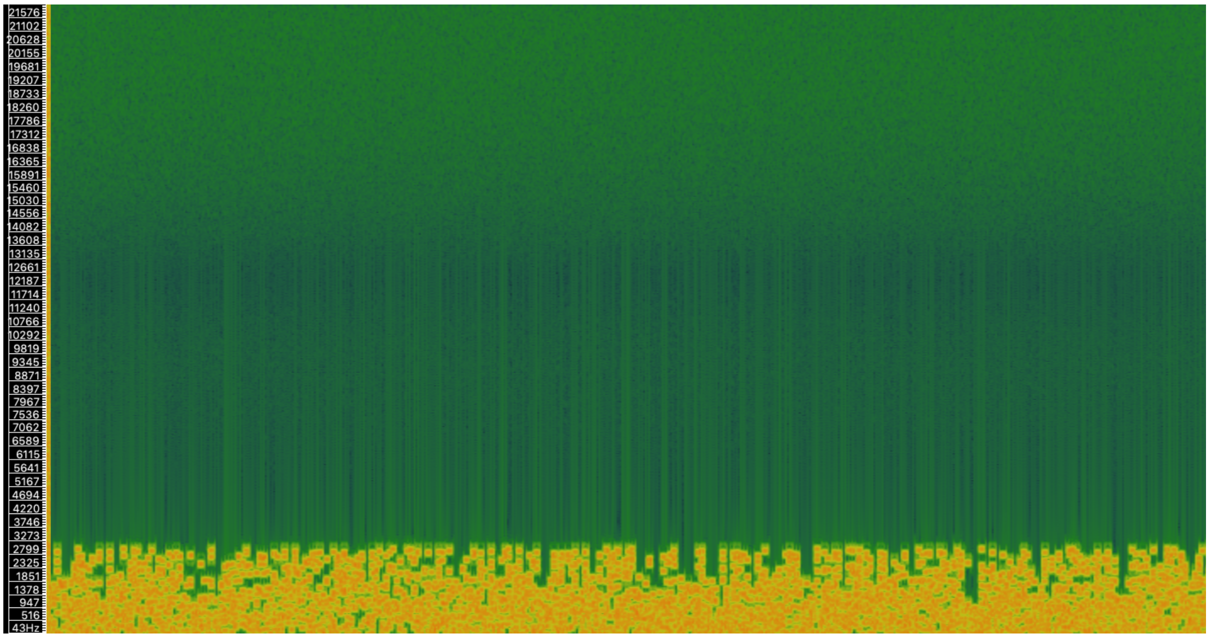

Figure 3.8: Close up of spectrogram of white noise encoded using LAME encoder showing bandwidth limitation

3.5.3 Birdies

High flying birdies & flightless birdies

Cause

The allocation of bits for the description of digital audio can vary widely if bitrate is low and frequency content is complex. In this situation temporal masking will result in a larger proportion of bits being allocated to frequencies that have greater amplitude while signals with lower amplitude will be less accurately described or cut completely. If the complexity of the audio being described is beyond the working capabilities of the bitrate, parts of the signal can be momentarily reduced to zero, resulting in the signal becoming significantly less complex. This reduction in complexity in the signal results in listeners being able to perceive individual pitched fragments of sound from what was originally noise. It is these pitched, fragmented artefacts, reminiscent of a bird's twitter, that are the effect *birdies*.

Though often occurring in the uppermost frequencies, these artefacts can be heard in other areas of the spectrum if there are differences in amplitude within the complex timbre. For example, complex signals that have greater amplitude in higher frequencies, such as violet noise, will preserve those higher frequencies during the encoding, while, the quieter, low frequencies will be poorly described. This creates birdies in those lowermost frequencies which are described here as *flightless birdies.*

If a complex signal with greater amplitude in the lower frequencies is encoded, such as red noise, then higher, quieter frequencies will be poorly described resulting in pitched artefacts in those higher frequencies described here as *high-flying birdies*.

Properties

The momentary disappearance and reappearance of frequencies within a complex timbre results in perceivable fragments of rapidly changing pitches that are reminiscent of a bird's twitter. As described above, birdies can appear in difference areas of the spectrum due to different input material and bitrates.

Examples

High-flying Birdies

The spectrograms below are of pink noise encoded using LAME at a bitrate of 8kbps and a sample rate of 24 kHz. The birdies can be seen here as the discrete artefacts in the higher frequency bands of the signal, roughly between 2 kHz and 4 kHz. To hear, see *Audio Example 3.10 Pink Noise LAME 8 24 Comp.wav*.

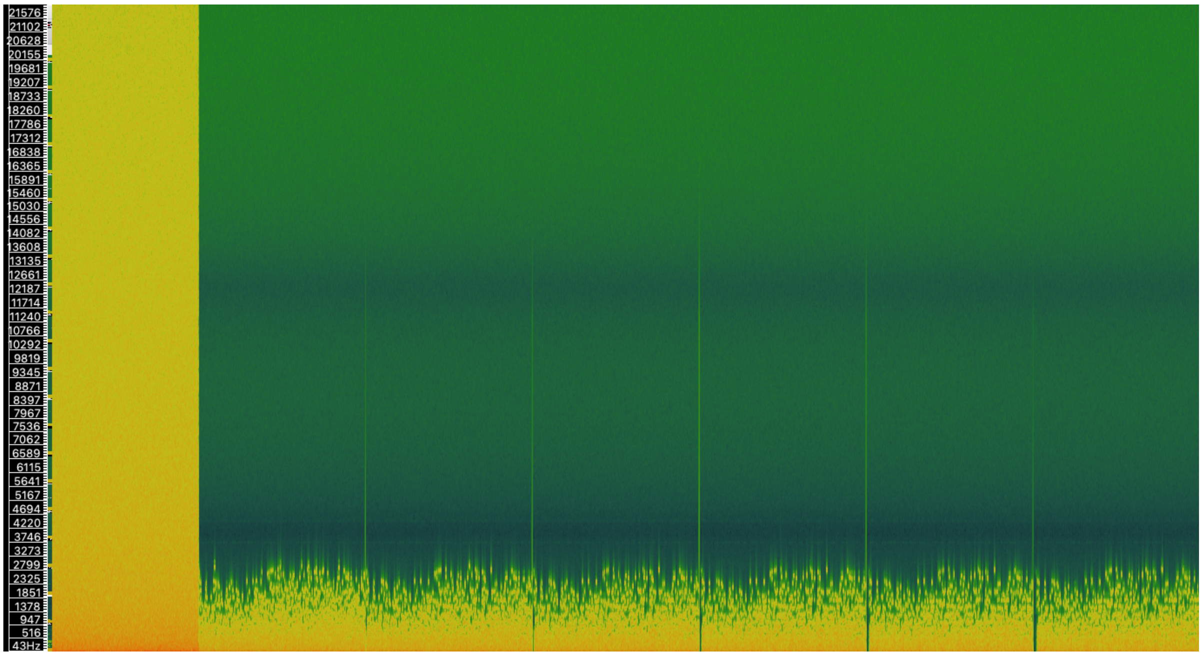

Figure 3.9: Spectrogram showing high-flying birdies

Looking more closely at the same encoded audio, the birdies artefacts can be seen more clearly. While there is still continuous noise up to roughly 500 Hz, beyond this point, up to roughly 3 kHz, the birdies artefacts can be seen, as discrete sounds with space around them.

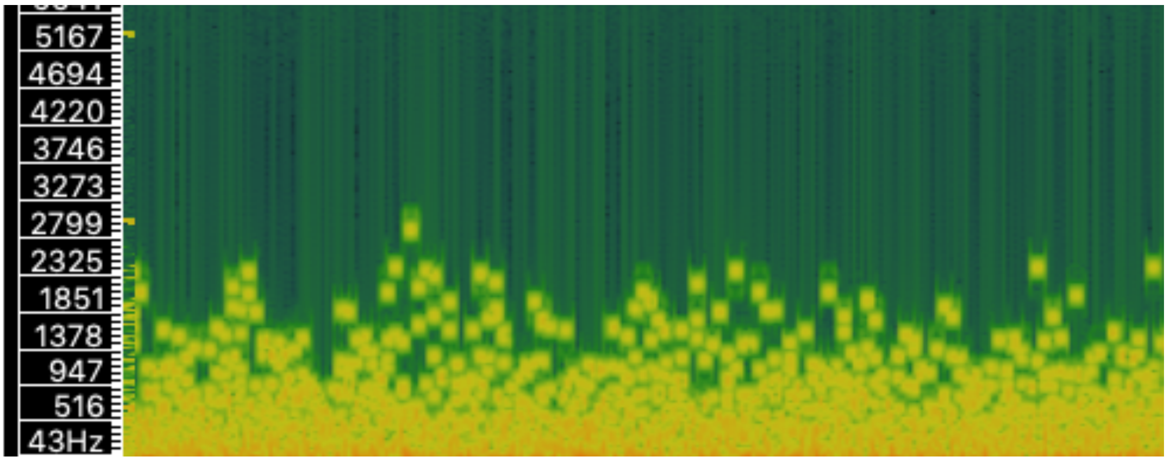

Figure 3.10: Close up of spectrogram showing high-flying birdies

Flightless Birdies

The examples below are of violet noise encoded using the iTunes encoder set to 8 kbps and 16 kHz. Lower frequencies in violet noise have low amplitude, therefore they are cut due to perceptual coding favouring higher amplitude content. This has created discrete artefacts in the lower regions of the encoded audio, creating birdies in those lower frequencies. To hear example, see *Audio Example 3.11 Violet Noise iTunes 8 16 Comp.wav*.

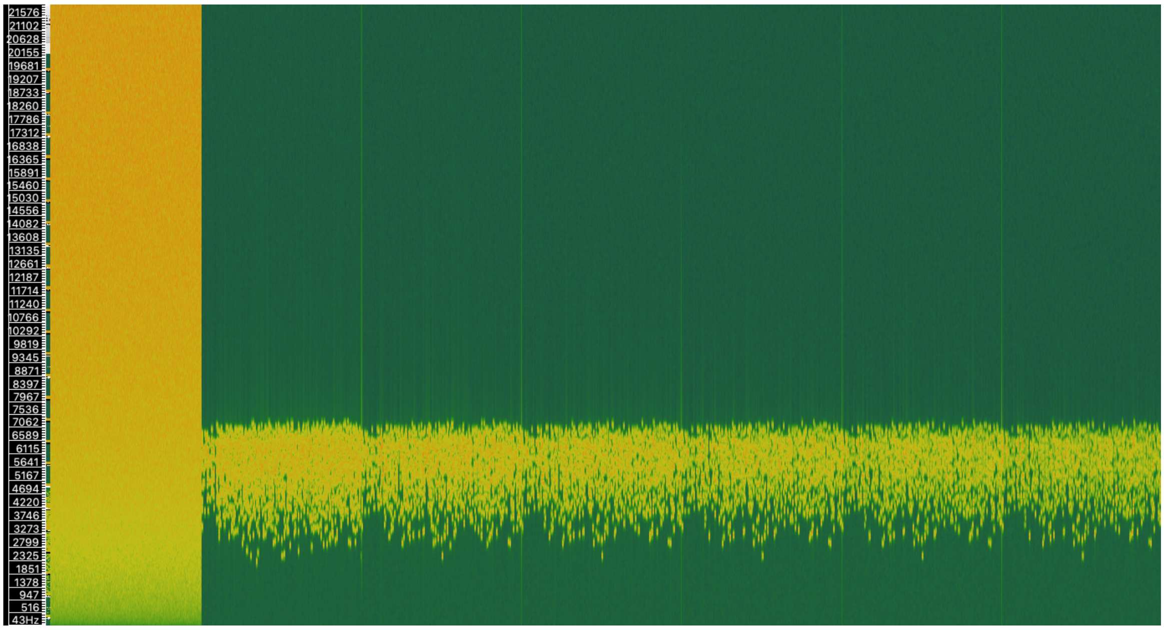

Figure 3.11: Spectrogram showing flightless birdies

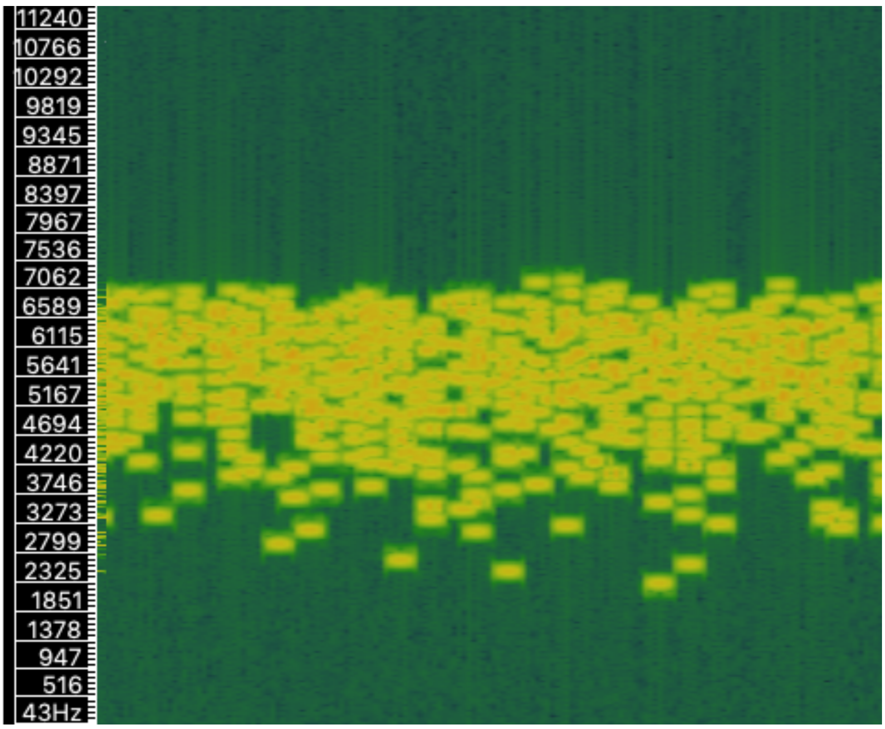

Figure 3.12: Close up of spectrogram showing flightless birdies

3.5.4 Signal Gaps

Cause

When there are insufficient bits to describe a complex timbre, the effects of temporal masking, which favours moments of high amplitude over moments of low amplitude, will become exacerbated. This can result in moments of low amplitude being reduced to zero, creating gaps in the signal.

Properties

The process described above results in gaps of silence within a signal, the effect can be jarring, creating abrupt movements and gestures, suddenly shifting between noisy artefacts, pitched artefacts, and then silence. *Signal gaps* occur abruptly and, while are technically an absence of sound, their placement within a signal results in them being a form of sonic variation.

Signal gaps could be heard as a more extreme version of *amplitude fluctuations* (discussed below), however, the reason I have categorised them separately is because while *amplitude fluctuations* are shifts in a continuous signal, *signal gaps* are abrupt changes and discontinuous.

Example

The images below are of violet noise encoded using the iTunes encoder at a bitrate of 8kbps and a sample rate of 24 kHz. Using these parameters results in fewer bits over a relatively wide bandwidth of 12 kHz causing the bits to be stretched over a wider bandwidth, and signal gaps to occur. Signal gaps can be seen here as the wave form is reduced to a straight line. To hear example, see *Audio Example 3.12 Violet Noise iTunes 8 24 Comp.wav*.

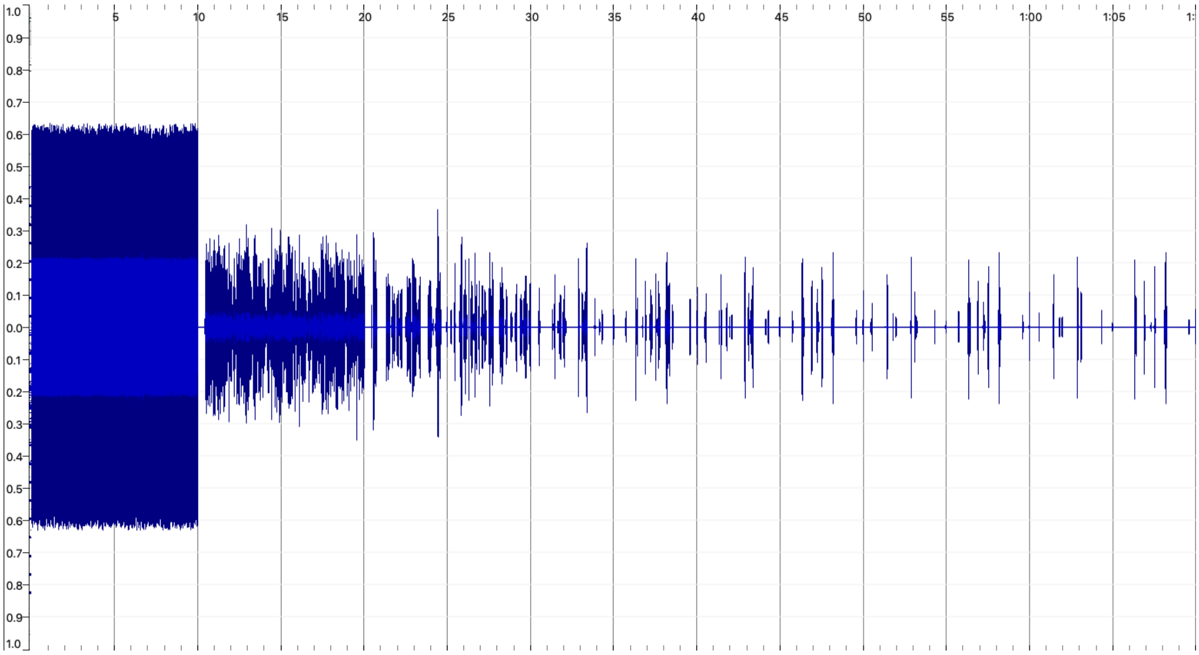

Figure 3.13: Waveform showing signal gaps

Below is a closer look at the same signal, gaps can be seen even more clearly.

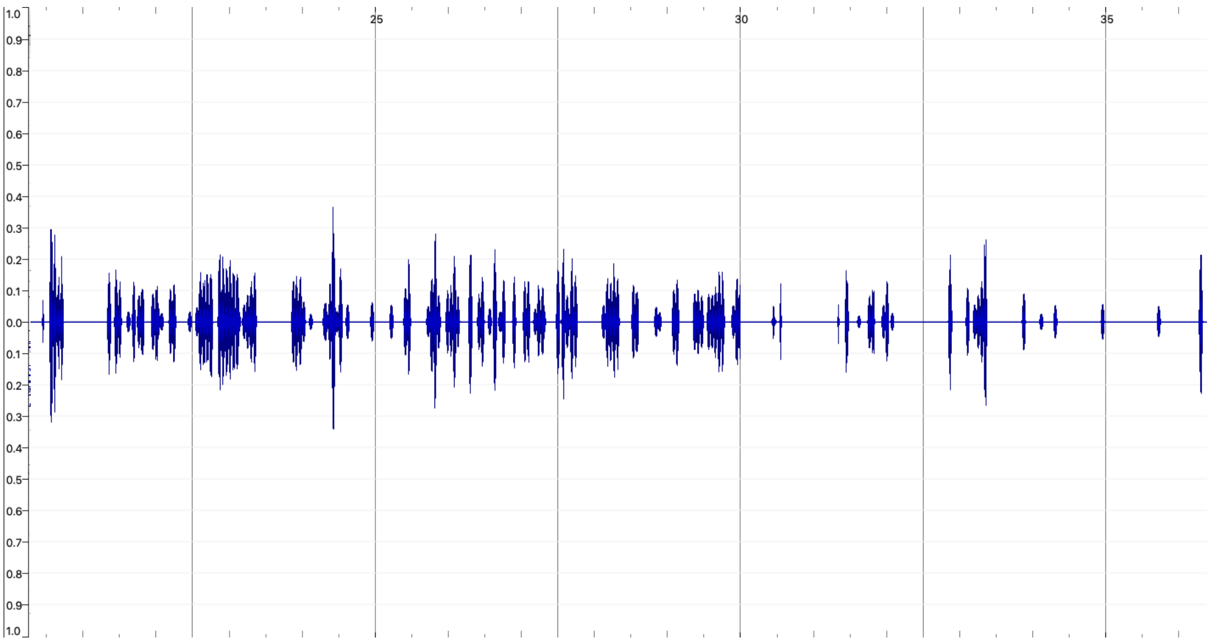

Figure 3.14: Close up of signal gaps

3.5.5 Stereo Movement

Causes

When encoding audio using various stereo encoding options, signals can become inconsistent and slightly move across the stereo field. To create stereo movement, two stereo encoding techniques were used: Normal Stereo, which is also known as Independent Stereo Coding, and Joint Stereo.

Normal/Independent Coding

Normal/Independent stereo coding processes the stereo channels independently rather than summing similarities. Therefore, if bitrate is low it can result in inaccurate descriptions on one or both stereo channels creating differences between the two channels. This results in the impression of stereo movement across the stereo field if the input originally had the same information in each of the stereo channels (Corbett 2012).

Joint Coding – Mid/Side and Intensity Stereo

Joint Stereo coding uses two audio coding techniques that code multiple audio channels 'in order to achieve a higher coding efficiency than would be possible by separate coding of the channels' (Herre et al. 2004b, 2) exploiting the redundancies and irrelevancies between the two channels. The techniques used in Joint Stereo are *Mid/Side Stereo Coding* and *Intensity Stereo Coding*, and may be combined by selectively applying them to different frequency regions (Herre et al. 2004a).

M/S coding uses two channels to code audio, however unlike normal stereo coding which uses the left and right stereo channels discretely, in M/S one channel sums and stores information that is identical on the left and right channels (the Mid), while the other channel stores the differences between the two channels (the Sides). As the Sides contain a much smaller amount of information compared with a typical left or right stereo channel, the file size is reduced. (Corbett 2012). According to Herre M/S Coding 'basically preserves the full spatial information, it may be applied to the full audio spectral range without the danger of introducing severe artifacts' (Herre 2004, 158).

The Intensity Stereo technique sums the channels together but at higher frequencies and is used at low bit rates where file size is critical (Corbett 2012). It uses this process because of 'the fact that the perception of high frequency sound components mainly relies on the analysis of their [amplitude envelopes]' (Herre 2004, 158), rather than their position in the stereo field. The potential loss of spatial information is 'considered to be less annoying than other coding artifacts' (ibid). As such, higher frequencies are described best by this method. However, 'extending intensity stereo processing towards low frequencies can cause severe artefacts' (ibid), particularly when encoding signals with decorrelated stereo components.

Conclusion

The iTunes encoder resulted in similar artefacts for both Joint and Normal stereo encoding, indicating that intensity coding might have been used more in Joint Stereo, while Normal encoding, predictably, created stereo movement. However, the LAME encoder created significantly fewer artefacts using Joint stereo coding than with Normal stereo. Additionally, the LAME Normal coding created substantial stereo movement compared with all other stereo encodings using either the iTunes or LAME codecs.

Properties

The characteristics of these artefacts is, as already described, motion and movement, where the was none before. This can create a sense of unsteadiness, and if layered, spinning and dizzying effects can be created.

Example

Below is a visual representation of the stereo movement effect. The pluck transient was encoded using the LAME encoder at a bitrate of 16 kbps and a sample rate of 16 kHz using the Normal Stereo option. After encoding and cascading, the mid channel audio was removed and the side audio was kept, allowing the stereo differences and movement to be isolated. These differences were then summed and made into a mono track allowing for easier depiction using a spectrogram. What can be seen in the spectrogram below is that the differences between the two stereo channels increases with each iteration, becoming louder as well as longer.

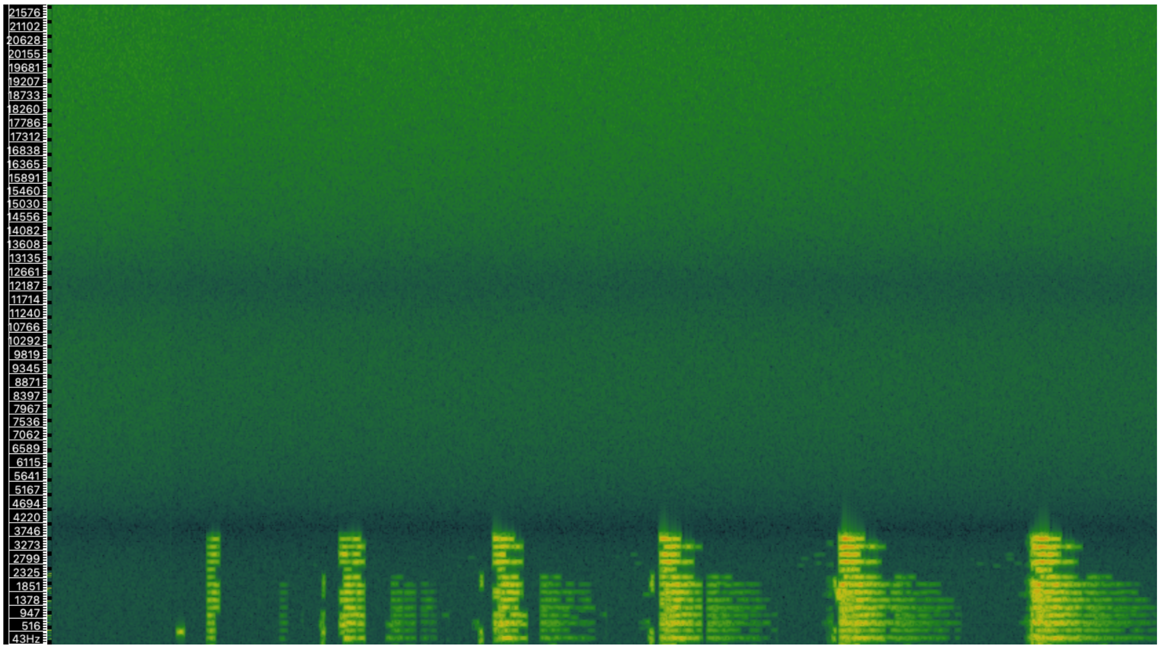

Figure 3.15: Spectrogram showing stereo movement encoded pluck.

To hear the examples above see *Audio Example 3.13 Pluck Normal Stereo LAME 16 16 Comp.wav* and *Audio Example 3.14 Pluck Normal Stereo LAME 16 16 Comp Removed Mid Summed Sides.wav*.

3.5.6 Amplitude fluctuations

Cause

Much like with Birdies and Signal Gaps, Amplitude fluctuations are created when the temporal masking technique favours high amplitude over low amplitude signals to such an extent that moments of low amplitude decrease in amplitude across the entire frequency spectrum. Unlike Signal Gaps, however, these moments are not reduced to zero, therefore creating continuous fluctuations, rather than a discontinuous series of silences and artefacts.

When cascading transient signals, it can be seen and heard that the peaks of the attacks change in amplitude across iterations. This is caused by the cascaded signals being subjected to the same compression algorithms each time, and by slightly shifting in amplitude, creating different results.

Properties

The effect of this in complex signals is shifting textures, at times creating a whooshing sound, the changing amplitude of transients' attacks creates variation over several iterations of cascaded signals, and the fluctuations in amplitude in reverb tails and envelope releases create rough and unstable qualities, creating a disintegrating effect.

Examples

The examples below show, firstly a series of encoded transient artefacts and secondly a series of iterations of encoded white noise. The transient artefacts have been encoded at 8 kbps and 16 kHz and the white noise has been encoded at 16 kbps and 16 kHz. Both sets of encoding have been done using the iTunes encoder.

It can be seen in the series of encoded transients that the point of highest amplitude varies from iteration to iteration. Moving from left to right, the first signal is unencoded and has an amplitude peak during its attack of slightly more than -1.33dB, the encoded iterations' amplitudes are -2.11dB, -0.49dB, 0dB, -7.64dB, -8.28dB, -9.05dB. This can be heard in the *Audio Example 3.15 Pluck iTunes 8 16 Comp.wav*.

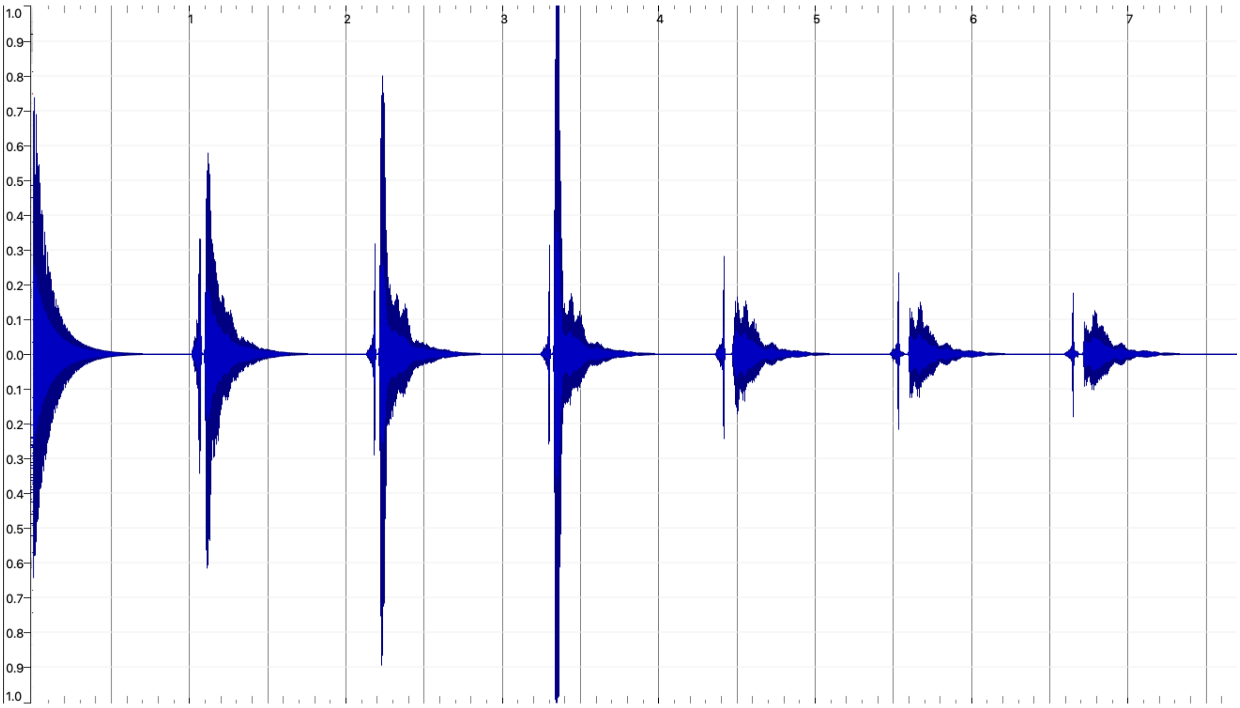

Figure 3.16: Iterations of encoded pluck sound showing amplitude fluctuations

The example below is of white noise encoded at 16 kbps and 16 kHz. Whereas the example using transient signals shows how amplitude of an attack can change over encoding iterations, the example below, using noise, shows clearly how amplitude can vary within a single iteration.

Shifts in amplitude can be seen in later encoding iterations as the changing columns of yellow and orange within the signal. To hear this example, see *Audio Example 3.16 White Noise iTunes 16 16 Comp.wav*.

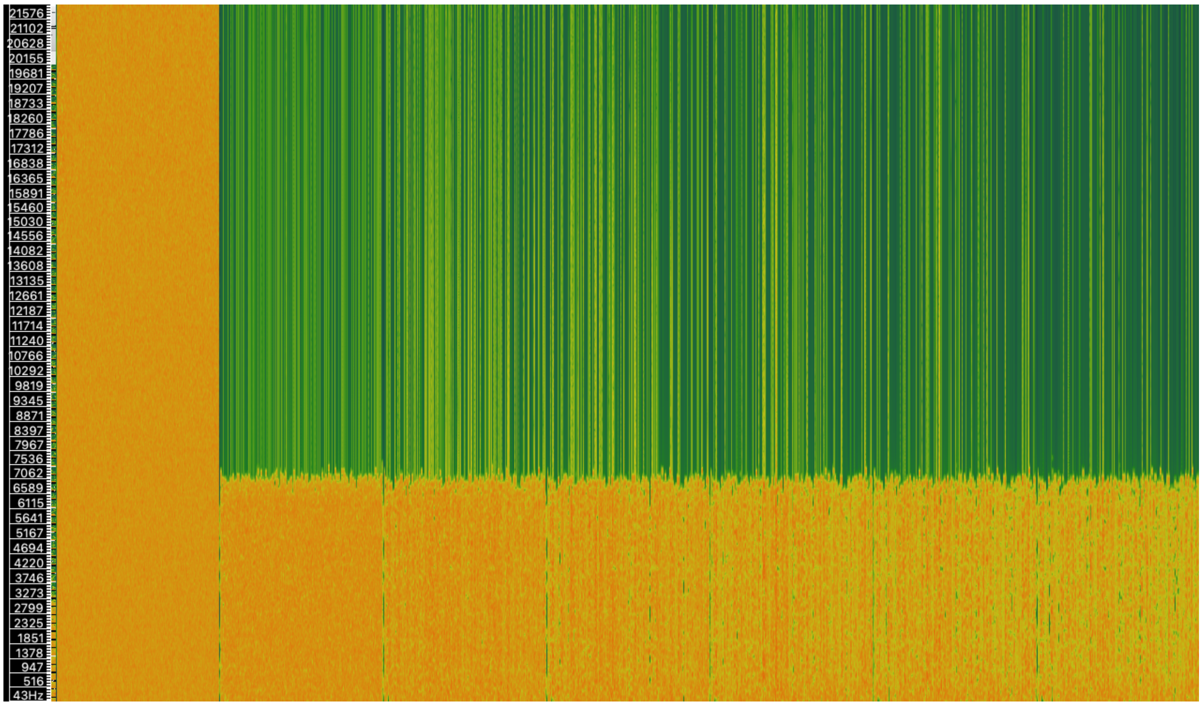

Figure 3.17: Spectrogram showing amplitude fluctuations in encoded white noise

The image below is a closer view of later iterations of the same encoded white noise in the image above. It can be even more clearly seen that there are variations in the amplitude spanning the frequency range of the audio, without the signal being reduced to zero and creating gaps.

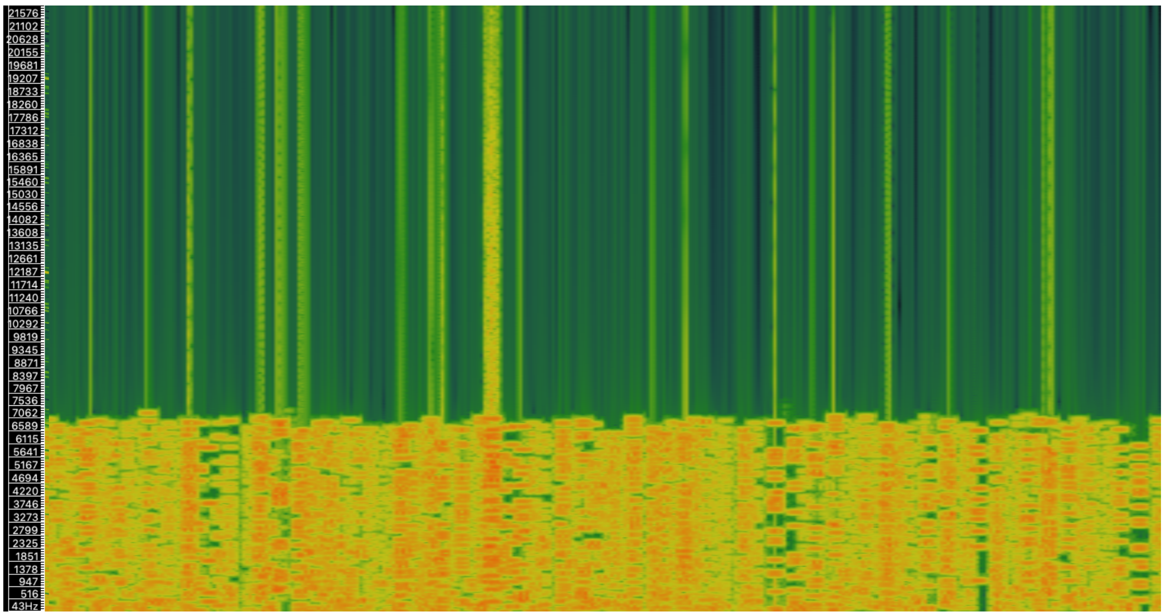

Figure 3.18: Close up of spectrogram showing amplitude fluctuations in encoded white noise

3.5.7 Delay

Causes

Silence is added to the beginning of a signal when audio is encoded as an MP3. If bitrate is low enough, and if audio is cascaded, this can cause a perceptible delay at the start of the audio. If the signal is cascaded, more silence is added and the delay will increase, creating cumulative delays.

The closest explanation found is from the website lame.sourceforge.io frequently asked questions page, which states:

> All *decoders* I have tested introduce a delay of 528 samples. That is, after decoding an mp3 file, the output will have 528 samples of 0's appended to the front. This is because the standard MDCT/filterbank routines used by the ISO have a 528 sample delay … ISO based encoders (BladeEnc, 8hz-mp3, etc) use a MDCT/filterbank routine similar to the one used in decoding, and thus also introduce their own 528 sample delay. A .wav file encoded & decoded will have a 1056 sample delay (1056 samples will be appended to the beginning) (Taylor 2000).

It can be seen, therefore, that delays are caused by filters, a point that is expanded upon by Curtis Roads who states that filters work by delaying a copy of either the input or output signals slightly (by one or several sample periods) and then combining it with the remaining output or input signal, respectively (Roads 1995, 185). Delay is therefore a result of a filtering process that is integral to creating an MP3.

Properties

Silence is added to the beginning of an iteration of cascaded audio, creating an increasing delay with each iteration. This seems similar to a signal gap, though there is an important distinction between the two: a signal gap occurs in the middle of a signal and the silence is not added but rather a chunk of the signal is zeroed. A delay is the addition of silence to the beginning of an encoding, nothing has been removed from the signal for this to occur.

Example

The example below shows white noise encoded busing the LAME encoder at a bitrate of 16 kbps and a sample rate of 8 kHz. The delay effect can be seen at the beginning of each iteration, and the delay is added to each cascaded iteration so it accumulates and increases with each encoding. To hear example, see *Audio Example 3.17 White Noise 16 8 Comp.wav*.

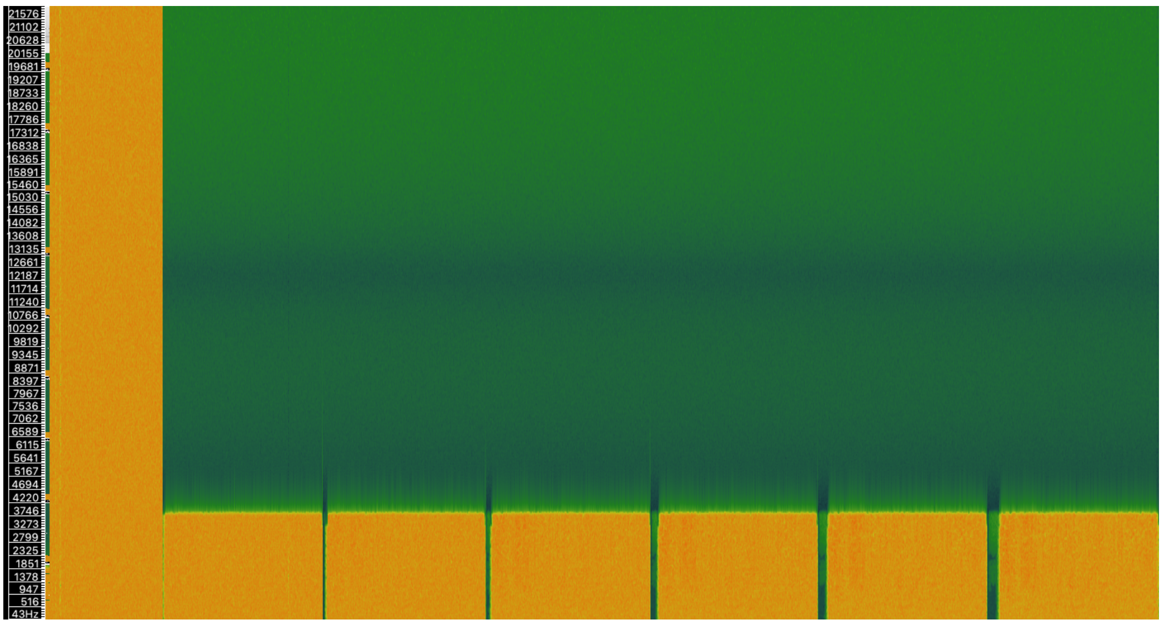

Figure 3.19: Spectrogram showing cumulative delays in encoded white noise

3.6 Chapter Summary

Chapter 3 gave a description of the perceptual coding practices that take advantage of psychoacoustic principles in order to compress audio and, in turn, create compression artefacts and effects.

Chapter section 3.3 described key concepts and practices involved in perceptual coding that are relevant for understanding why and how compression artefacts are generated. By understanding psychoacoustic principles such as masking and the narrowing of the perceivable range of frequencies, it can be more clearly understood why compression algorithms are able to affect audio to the extent that they do. Additionally, by understanding perceptual coding practices, the methodology can be more easily explained and, hopefully, understood.

The list of articles and papers included in section 3.3.4 displayed the range of texts looked into, what the purposes of those texts were, and where they came from. They have been important in laying a foundation, upon which some of the primary research of this project could be developed and understood. Ultimately, section 3.3 is intended to act as a point of reference for understanding terminology, concepts, and practices that are mentioned later in this text.

Section 3.4 describes the methodology of how artefacts explored in this research were created. Building on the concepts and secondary research from section 3.3, this section lays out how the primary research was undertaken in order to create material for composing with and a taxonomy. For further information on the tests done using the methodology described above see the appendixes which describe the results of each test individually in the form of indexes.

The taxonomy lists seven artefacts and effects that have been used in this project, it gives overviews of each effect, describing causes, properties, with examples and images. The list of artefacts in the taxonomy is not exhaustive, but consists of those that have been researched the most, such as in papers in 3.3.4 or are most easily heard during analysis.

Chapter 4 Arranging Artefacts

4.1 Introduction

The chapter is split into four sections, the first three illustrate the techniques used for processing and organizing artefacts into works of sound-based electroacoustic music, taking influence from electroacoustic, microsound, glitch, and mid-century composers for macro, meso, and micro-temporal and spectral arrangement. The structure of this part of the chapter follows three time-scales beginning with macro, then meso, and then finally micro, and are described by Curtis Roads as:

- *Macro* The time scale of overall musical architecture or form, measured in minutes or hours, or in extreme cases, days.
- *Meso* Divisions of form. Groupings of sound objects into hierarchies of phrase structures of various sizes, measured in minutes or seconds.
- *Micro* Sound particles on a time scale that extends down to the threshold of auditory perception (measured in thousandths of a second or milliseconds).

(Roads 2001, 3-4).

The fourth section considers issues surrounding the authenticity of the artefacts, relating to the perceived loss or strengthening of authenticity.

The first section looks into how macroscale formal decisions are made, considering bottom up, top down, multi scale, and intuitive approaches to arrangement, and how these various approaches have been used in the project.

The second section is concerned with how sounds have been arranged on a meso level. Structures at the meso length time scale consist of various densities and masses of sounds, how space has been used, and what kinds of rhythm are made use of in the works. Approaches from Xenakis, Roads, Smalley, Ligeti, Ryoji Ikeda, and others have influenced the project.

The third section considers the micro level, considering various approaches to timbre and material. Issues considered in this section are concerned with microtonality of the artefacts, using the artefacts' properties as triggers for other sonic events, re-compressing artefacts, tone and noise continuums, and amplification and pitch-shifting.

The final section of this chapter considers theories posited by Moore (2002) and Taylor (1997) concerned with authenticity in music, and how they relate to this project in respect to processing and arrangement techniques resulting in compromised or strengthened authenticities.

4.2 Macro Structures

This section considers approaches to structuring form on the macro level. These approaches include top down, bottom up, multiscale, and intuitive approaches.

Roy Bennet's *Music Dictionary* defines the term *form* as something that is used 'to describe the basic plan or structure of a composition' and to create a complete and satisfactory whole (Bennet 2002, 113). The use of the term 'plan' can imply a predetermination towards the composition process, and can be referred to as top down. In the top down approach, the macroform is designed first, substructures are then developed, and lastly sound material is generated or produced to fill in higher level structures (Roads 2015, 291).

In contrast, form can also come from the sound material itself. This is described as a bottom-up approach; which Roads defines as being a result of lower level processes, such as the generation of sound material from which substructures emerge and macroform develops (2015, 291).

Multiscale planning is one in which micro, meso, and macro levels influence one another in the process of creating the work, with sounds being freely organised at all temporal levels (Roads 2015, 19).

Composer's intuition is an approach which lays greater responsibility upon the composer for constructing the work on a moment-by-moment basis and requires greater reflection. It is a process that draws on the composer's cultural background and creative practices to creative compositional rules.

This project has at times used a combination of all of the above approaches, with some having greater weight over others. Outlines of how these approaches were used are given below, beginning with the top down approach, followed by bottom up, multiscale, and intuitive approaches for arrangement.

4.2.1 Top-Down

Traditional pre-conceived forms rely on harmony to create and develop themes, however, the material used in this project does not rely on the 12-tone scale, and at times lacks pitched properties altogether. It is therefore impractical to consider those as useful structures, and instead sensible to consider the macro and meso forms that have developed throughout the 20th and 21st centuries by electroacoustic and art-music composers and theorists whose methods for structure reflect the nature of the material being used.

The top-down approach to macroform 'considers macrostructure as a preconceived global plan' (Roads 2001, 12). This plan is then filled in later with material and corresponds to a 'traditional notion of form in classical music' (Roads 2001, 12). In Europe, the top down approach to form is normally associated with pre-modernist composers who used forms including fugue, rondo, and sonata (Bennet 2002, 113).

While the works in this project do not subscribe to the conventions of traditional forms from the classical era of western art music, some pre-conceived structural notions were used before pieces were begun in earnest. A common structure throughout this project has been a tripartite system whereby different types of material are introduced in the first and second sections, and then combined in the third section, balancing consistency and variation in the work's structure. Though structural plans were set out, they were not strictly followed and other elements were usually added to give greater variety, tension, or resolution.

For example, the first section of the piece *Blue Red* uses groups of time-stretched rasping artefacts, edited transient artefacts, artefacts that have been time-stretched and pitch-shifted up, and sound object length artefacts (see time 0' – 2'21). The second section drops those musical parts but introduces layers of slowly repeating parallel phrases made from time-stretched discrete artefacts (2'21 – 6'40), and the third section combines these elements to increase complexity and density (6'40 – 11'32).

However, there are elements that are used in all three sections, such as re-encoded transient artefacts, and artefacts that have been time-stretched and pitch shifted down to create pedal notes. Additionally, there are musical parts in the third section that are not used in the previous two, including encoded noise with cumulative delays and layers of quickly repeated parallel phrases of artefacts.

The macro approach here is, as stated above, loosely followed, and a combination of approaches have been used. The prescribed plan acts more as a guide, than as a fixed structure.

4.2.2 Bottom-Up, Form from Material

A bottom-up approach 'conceives of form as the result of a process of internal development provoked by interactions on lower levels of musical structure' (Roads 2001, 13). This approach uses the generation of material and the construction of substructures to create macro form.

Regarding this process, Sefchovich states that it is from the construction and exploration of sound materials that musical structure can emerge (Sefchovich 2003, 19), or put another way 'when creating musical material the composer may not have a definitive idea of the piece, nor of how this material could be incorporated into the discourse' (Sefchovich 2003, 82). Therefore, it is important not only to create musical material, but also to create a consistent, unified vocabulary, from which syntax can emerge.

An example of this can be heard in Varèse's work *Ameriques* (Varèse 1996) in which 'the unifying materials is rhythmic rather than melodic' (Rich 2008, 89) and as such there is 'no evidence of melodic shapes as traditionally perceived, nor of the consequential progression from one perceptible idea to the next' (ibid). The work moves away from top down structural approaches, and traditional thematic development, centred around harmonic and melodic motivic progression, and instead through exploration of the rhythmic properties of the material creates arrangements of sounds that 'vibrate and collide within a vast musical continuum' (ibid).

The unifying and consistent vocabulary of this project is, clearly, that of compression artefacts. However, as this is an electronic work it is important to consider how processing that has been applied to the artefacts can impact the palette of material.

A unified collection of sonic material is important, but so too is its exploration. Church argues that in glitch music, conventional form is tyrannical, and that structure emerges through repetition and timbral experimentation, using editing and layering (Church 2017, 10).

Julio Cesar d'Escriván Rincón states that with the processing potential available to composers now, the 'control of amplitude, pitch and timbre modulation, panning and low frequency oscillation, as well as … control of various digital signal processing parameters' results in a 'very strong position to take *sound design as composition* seriously' (1991, 19).

For example, time-stretching has allowed the spectromorphological properties of the artefacts generated in this research to act as sub-structural elements as they develop at the mesostructural level of the work. Additionally, the process gives the artefacts' properties more time to be heard. This effect can be heard throughout the project, in various pieces and in various ways, as they have been arranged and organized differently.

An example of how time-stretching has been used to create meso-level structures includes *clustering*. Clustering is an arrangement technique whereby blocks of sustained frequencies unfold ‘as individual lines are added to or removed’ (Roads 2001, 15). This technique can be best heard in the first section of *Pink Blue* (0’ – 2’18), in which clusters are made of meso-length artefacts created with time-stretched pink noise artefacts. These artefacts lend themselves to the clustering technique due to their spectromorphologies, specifically, their discrete amplitude envelopes and their developing microtonalities. The clustering allows for a balance between consistency and development in the work, creating tension and resolution as the macro-structure unfolds. The clustering technique results in sonic microstructures rising to ‘the temporal level of a harmonic progression’ (Roads 2001, 13) and is discussed in greater detail later in this chapter (see 4.3.1).

Another example of time-stretched artefacts is that of encoded noise with continuous properties, lending itself to a *streaming* meso-structural arrangement: ‘a combination of moving layers’, continuous and sustained (Smalley 1997, 117).

This can be heard in the opening moments of *Red White Blue Pink* (see section 5.6 Red White Blue Pink for more information), wherein three sounds can be heard: sound object length artefacts, a low-pitched drone, and a higher drone. The two drones are made from time-stretched encoded noise that has created a continuous series of artefacts, and are layered to create the streaming effect. The sound object length artefacts move too fleetingly to have any impact on the macro structure on their own, however, it is the spectromorphologies of the time-stretched artefacts that allow the formation of substructures and, in turn, macroform to develop. Again, more can be read on streaming below in section 4.3.1.

The approach to processing described above uses the properties of the material to create meso-level arrangements, which in turn produces structure at the macro level. However, digital processing allows practitioners to edit and arrange sounds at macro, meso, and micro time-scales, and as such an approach to macro form that reflects this diversity can also be considered.

4.2.3 Multiscale

Roads suggests that a multiscale approach encourages the organisation of sounds freely at all steps in the compositional process (Roads 2015, 19) and includes elements from both bottom-up and top-down methods, or as Sefchovich states 'transformations and combining sound materials are by no means independent stages in composition' (Sefchovich 2003, 20).

An integral part of working with multi-scale approaches is being able to access multiple temporal layers of the work, including the micro-timescale. Accessing microtime, however, has only been available since the development of digital synthesis, giving composers the ability to access the internal structure of sound (Vaggione 1996, 34). The multiscale approach is therefore apt when composing digital music, and is one employed in microsound works by composers such as Horacio Vaggione.

In the paper *Mutation and processuality in the musical thought of Horacio Vaggione* (2005), Pascale Criton states:

> Vaggione incorporates the paradigm of complexity through the options of a corpuscular, multi-scale approach. He integrates the workings of interactive relationships with actions ranging from local to global. In doing so, he adopts what could be called a theoretical and technical approach to energetic-dynamic morphologies (Criton 2005, 372).

Criton goes on to say that 'the morpho-dynamic interactivity of Vaggione's music raises simultaneity to the rank of an aesthetic.' (Criton 2005, 380). Vaggione's multi-scale approach, which uses the local and global creates dynamic morphologies that can be heard simultaneously, or as Criton also describes it 'a single perspective, in which all is "held"' (2005, 380).

Criton states that the Vaggione works that best display this simultaneous, multi-scale approach are *Schall*, *Rechant*, and *Nodal* (ibid). In this project, a multi-scale approach is used in several works including the third section of *Blue Red* (6’40 – 11’32) in which ten musical elements can be heard. These consist of clusters of meso level time-stretched artefacts, layers of rhythmically displaced phrases at their natural micro time-scale, encoded blue and red noise creating various textures, time-stretched and pitch-shifted artefacts creating pedal notes lasting for minutes at a time, and various others that sit at local and global levels being heard simultaneously.

Another example is *First Interlude Violet* in which artefacts’ amplitude envelopes have been edited, making them shorter, and using them to create cloud structures, while simultaneously having time-stretched streaming artefacts, their morphologies developing alongside the shifting densities of the microsonic artefacts.

The multiscale approach allows top-down and bottom-up organisational approaches to feedback into one another. However, it is ultimately the composer who chooses how to approach the compositional process. As Sefchovich states ‘decisions are constantly being taken, and at the same time an awareness of musical language and structure grows, and constant improvement of the material's suitability for particular musical purposes opens new possibilities of discourse’ (Sefchovich 2003, 20).

4.2.4 Intuition

D'Escriván Rincón posits in his dissertation *Creative Intuition as a Compositional Strategy in Electroacoustic Music* (1991) that intuition as a means of structural arrangement relies on improvisation, as musical ideas must be created and reacted to instantly, and it cannot be the product of ‘speculative thought … the music must flow coherently unhindered by rationalization’ (1991, 26). As this project is not performance oriented, and the works are fixed, this might seem irrelevant, however, d'Escriván Rincón goes on to state that there are still rules that ‘regulate the musical act’ (1991, 27). These rules are ‘the result of cultural background’ and ‘performance practice’ (ibid), which could be considered akin to compositional practice. D'Escriván Rincón goes on to argue that the process of performing-composing is a ‘moment to moment process’ (ibid).

Xenakis criticises this way of approaching intuition, however, stating that it is romantic and that it believes in immediacy, and that music ‘imperiously demands reflection’ unless it is to risk ‘falling into trivial improvisation, impression, and irresponsibility’ (Xenakis 1992, 181).

He goes on to state that ‘when scientific and mathematical thought serve music, or any human creative activity, it should amalgamate dialectically with intuition’ (1992, 181). The sonic result thus obtained is not guaranteed a priori by calculation. Intuition and experience must always play their part in guiding, deciding, and testing (Xenakis 1992, 81).

While this definition of intuitive composition oriented around fleeting moments is true, so intuitive processes can also take place on slower time-scales of composition. Xenakis’ musique concrete work *Concret PH* (Xenakis 2017), for example, was constructed by ‘piecing together innumerable scraps of tape’ on which were the sounds of ‘hot coal and burning material’ (Di Scipio 1998, 204). Unlike some other of Xenakis’ works, the arrangement was ‘not the result of mathematical operations but was approached by the composer intuitively, in the manner of sound sculpture’ (Roads 2001, 64-65).

Intuitive decision-making is referred to by Vaggione as ‘craftsmanship’, and much like Xenakis states above considers a balance between the formalist and the intuitive as important.

Drawing on personal experience as a means of guiding compositional practices is necessary to create a coherent piece of music. To rely on formalisation, or prescribed macro and meso structures, whether those be classical forms, generative processes, or the idiosyncratic syntax of an established composer must be negotiated in the decision-making process with the craftsmanship and intuition of the composer, whether that be on a moment-by-moment scale or a reflective one.

This can be heard on micro, meso, and macro levels in this project, as granule size artefacts are arranged directly and intuitively by hand in *First Interlude Violet* to change in density and create structure for the interlude. This can also be heard in *Pink Blue* concerning how clusters build and decay over several minutes. These decisions are informed by the material, as described in section 4.2.2, but also by my own intuitive approach to the structuring of artefacts in space and in time to create moments of tension and resolution as densities build and decay.

4.3 Meso Structure

This section considers the arrangement of artefacts on the meso time-scale looking at masses, space, and rhythm.

The first section, masses, considers various arrangements that involve varying densities of sound objects, including clusters, clouds, streams, weaves, and flocks. This section also introduces a neologism for the description of a specific type of sound which has a complex timbre but is also arranged in a flocking structure. The second section considers how sounds are structured in and across space.

The final section looks into how rhythm has been used to create musical sub-structures. These include how repetition is used to create displacement and sparse periodic articulations. Rhythm is also considered in how it can be used to evoke failure, and finally, how complex noise bursts are used in a structural capacity.

4.3.1 Masses

Xenakis 'denounced' polyphony in 1954 and demonstrated the contradictions of serial music, 'in its place I proposed a world of sound-masses, vast groups of sound-events, clouds, and galaxies governed by new characteristics such as density, degree of order, and rate of change, which required definitions and realizations using probability theory' (Xenakis 1992, 182). While the music in this project does not use probability to discern structures of groups of sounds, the types of groupings, such as masses, have their conceptual and aesthetic origins (if not their specific method of construction) in compositions such as those by Xenakis.

It is at the meso level that sound interactions such as sound masses, textures, and clouds and other formations of artefacts occur. Masses of sounds have been used in the project as a means of exploring micro-harmonic relationships and spectromorphological properties of the compression artefacts. They can also act as a means of establishing structure, as masses build and diminish in density, timbre, volume, and position in space so development can occur, creating tension and release.

Michel Chion refers to these kinds of groupings as 'accumulations', defining them as 'discontinuous', 'prolonged', and 'characterised by the disordered piling up of microsounds which are fused together by their similarity' and he gives examples being twittering birds and clouds in works by Xenakis (Chion 2009, 152).

Clusters

A key type of sound mass used in this project is a *cluster* defined by Curtis Roads as being sustained frequencies that 'fuse into a solid block … musical development unfolds as individual lines are added to or removed from this cluster' (Roads 2001, 15).

Note/tone-clusters are defined by Roy Bennet as being when 'several adjacent notes [are played] simultaneously' (Bennet 2002, 207), and Cowell in *New Musical Resources* describes them as chords 'built from major and minor seconds' (Cowell 1996, 118). The effect is particularly effective using keyboard instruments (Bennet 2002, 207) due to their polyphonic qualities, making it easier for seconds to be played.

These tone-clusters relate to the western 12-tone scale and have been used by a variety of works by 20th and 21st century composers, including in the opening of Ligeti's *Volumina* in which the performer is instructed 'beide hände auf dem-selben manual' (Ligeti 1967, 4) meaning – both hands on the same manual (organ keyboard played with the hands not the feet).

While using 12-tone clusters can create tension and resolution, using microtonal clusters whose spectral properties morph over time allows for a wider range of possibilities. More recently, clusters have been used by electronic composers to explore microtonality, including Hubert Howe's work *19-Tone Clusters* (2010). This piece uses 19-tone equal temperament, which divides the octave into 19 equal steps allowing for a microtonal approach to harmony.

As the name *19-Tone Clusters* suggests, the piece arranges the microtonal sine tones into cluster forms. The clusters are '5-note chords duplicated through three to four octaves above the note' (Howe 2020, 98). The piece moves from one cluster to the next, shifting in density and micro-harmonies to create variety as the work develops.

In this project, the cluster technique has also been an effective means of exploring and using the inherent microtonal spectral properties of artefacts to create sonic development.

The artefacts that are ideal to be arranged in clusters are those that are discrete due to signal gaps occurring before and after them, combined with amplitude envelopes that have slow attacks and slow releases relative to their size. These time-stretched clusters become meso-level arrangements, which build and decay in density, and in turn, create a sense of structural development.

The reduced spectral complexity of the artefacts also causes them to have pitched properties, and when time-stretched their spectromorphologies can be heard more clearly. The layering and clustering techniques therefore allow their microtonal properties to be explored, and to create variation and tension in the work.

Clusters were used in the piece *Pink Blue*, between 0' and 2'20. Each cluster has an envelope, which increases and then decreases as layers are added and then removed. There are three main cluster peaks, with movement between these peaks as artefacts enter and leave, and a fourth cluster towards the end that was not arranged but came about as a result of the characteristics of the time-stretched artefact itself. This section is explained in greater detail in the work's commentary in section 5.3.

Streams and Weaves

Ligeti creates densely woven musical structures in several of his works, including *Atmosphères* (Ligeti 2002), using a technique he refers to as *micropolyphony*. He describes the process as 'the polyphonic structure does not actually come through, you cannot hear it; it remains hidden in a microscopic, underwater world, to us inaudible' (Várnai et al. 1983, 14-15).

Eric Drott goes into more detail describing the causes and effects of the technique saying it is 'the circulation of independent voices within a narrow ambitus [which] produces a masking effect, the overlapping of parts interfering with their segregation into distinct streams. Individual threads become difficult to discern and, as a result, merge into a fused fabric' (Drott 2011, 7).

This effect is similar to a structuring technique called *streaming*, described by Smalley and Roads as 'a combination of moving layers', continuous and sustained (Smalley 1997, 117-118) using narrow bandwidths and high densities to generate streams (Roads 2001, 106).

Many of the works in this project's portfolio use the structuring processes described above: multiple layers of musical parts, merging into sound masses with their spectral range restricted within a narrow bandwidth creating dense fusions of sound. The continuous nature of audio encoded using low sample rates makes it ideal for these techniques, as when bandwidth is narrower so bits are not stretched, which would result in signal gaps. Additionally, time-stretching encoded noise allowed for the properties of encodings to be heard at a slower, manageable rate. As their properties were mostly pitched, these structuring techniques provided the opportunity for works to explore microtonal relationships and shifting timbres, in a continuously evolving series of gestures that gave the works an unbroken sense of development.

The piece *Red White Blue Violet* (see section 5.5 for information on the work) uses the streaming effect in the first section of the work. At 0'30 two time-stretched clips of encoded red noise are introduced and fade out at 2’00. These clips of time-stretched encoded red noise are reintroduced in the third section of the piece at 3’09 and stop being audible at 7’05. The encoded red noise has similar timbral qualities, and as they are panned left and right, the streaming effect has more impact as their morphologies interact with one another across the stereo field. In addition to these two clips of time stretched encoded red noise, there are also individual blue noise and white noise artefacts that have been time stretched which add to the streaming effect by sitting in different spectral positions.

Clouds

Cloud formations are constructed from sound-points, granular sounds, ‘a large number of short elementary sonic particles’ (Fischman 2003, 49). They are masses made from microsounds, and are ‘a particular case of sounds of continuous variation’ (Xenakis 1992, 13). Sonic development and variation in these structures can be created by changing amplitudes, internal tempi, density, harmonicity, and spectrum (Roads 2001, 15).

There are two occurrences of intentionally structured cloud arrangements in this project, the first is in *First Interlude Violet* and the second is in *Second Interlude White and Blue* (see section 5.9 for more information on both interludes). A consistent description of the particles, grains, or points, that make up a cloud is that they are short, lasting ‘a few hundredths of a second’ (Fischman 2003, 49) ‘sometimes even a few thousandths of a second’ (Di Scipio 1998, 204). In order to replicate this, in both interludes pitched artefacts from violet noise and blue noise were edited so that only the attack of the original artefacts can be heard, creating microsonic transient artefacts. While the artefacts generated in this project are micro-sonic, editing them to make them even shorter made them more effective for arranging into clouds, as they are easier to discern within a mass, and in turn, so too the shifting densities.

An early example of a work made using cloud arrangements is *Concret PH* (Xenakis 2017) by Xenakis, in which fragments of sound were arranged, creating a ‘new and larger texture’ (Rossetti et al. 2019, 207). Xenakis considered *Concret PH* to be ‘a cloud formed by sound dust, like sonic gas. It is a cloud of sound dust within which there are constellations of grains that constitute the sonic form' (Rossetti et al. 2019, 211). The 'constellations of grains constitute the sonic form' does not only relate to the meso structure, but also the macro. As *Concret PH* (Xenakis 2017) is only 2'44 in length, and there are few musical components in the work, the focus is the cloud itself whose development, although nuanced and slight, occurs on the level of 'intensity, density and brightness' (Rossetti et al. 2019, 210).

Similarly, in this project, the cloud arrangements in the interludes impact both the meso and macro levels, as there is little time to introduce other timbres and sounds or develop substantially within the confines of the interlude. What development does occur, is in amplitude and density, with a straightforward developmental arc of increasing and decreasing in density and amplitude.

Flocking

Another effect that has been used within this project is *flocking*, described by Denis Smalley as short discontinuous sounds that are flux. Smalley goes further, saying: it is the 'loose but collective motion of micro- or small object elements whose activity changes in density need to be considered as a whole' (Smalley 1997, 117). The flock texture differs from clouds insofar that, while both are composite textures, clouds are masses of microsounds or points, whereas flocks consist of small sound object elements that are active, gestural, and have greater internal energy and variety. The flocks that appear in this project can be described using Smalley's term 'turbulence' which is characterised by irregularity and involving 'confused spectromorphological entwining, but nevertheless tend[ing] to concur in their chaos' (Smalley 1997, 117).

What makes this organisation of sounds important in this project is that it can occur organically when complex timbres are encoded.

While some techniques and signal processes are used to arrange artefacts by hand, emphasising or drawing attention to the properties of audio compression, the flocking texture can be created organically as a result of the encoding process. While this raises the question of whether it could be considered an encoding effect or artefact itself, I posit that it is not, because the output is too similar to its input. Though perceptibly less complex compared with its input material, the timbre is still complex enough to be considered object-oriented noise, and therefore it is too similar to its input material to be a compression effect or artefact.

Additionally, lifting the *term* flocking from its earlier as a usage of a means of describing sonic textures and movement in electroacoustic music, and placing it into the vocabulary of compression artefacts and effects unnecessarily widens and complicates the meaning of the word. These sounds are similar to birdies in their flock-like arrangement, however, they lack the pitched properties of the birdies effect. Therefore, to consider it a sub-artefact of birdies is also incorrect.

Instead, a different term could be used, one which describes the occurrence of flocking sounds in compression, which are akin to the artefact birdies, but with some of the complexity of the noise colour input material.

This term could be *noids*. The word is a reference to several other, similar terms: *noise* and *boids*, and also by extension *birds* and the suffix *-oid*. Boids is a compound of bird-oid, which are objects that exhibit a class of '*polarized*, *noncolliding*, *aggregate motion*' (Reynolds 1987, 25). It is a term used by Craig Reynolds to describe the movement of objects within a model that simulates collective behaviours, specifically, 'flocks' (1987). As the suffix *-oid* denotes form or resemblance, therefore describing the objects as bird-oids reflects their flocking behaviour. In creating the compound *boid* so it is slightly more efficient means of communicating the object and its behaviour.

If this project were to co-opt the term *boids*, however, there would be some mistranslation. Reynolds states that boids 'interact strongly in order to flock correctly' (1987, 26). This differs from flocking compression artefacts as they do not interact with one another, but instead, their properties are reflections of the complexity of noise that was encoded.

It is therefore necessary to reflect this in the terminology, resulting in the addition of the word *noise* to this compound, creating the term *noids*. The definition of *noids*, therefore, is:

the slight reduction in complexity of an object-oriented noise so that individual artefacts become perceivable without the overall effect falling below the threshold of what is described as a complex timbre. Using the term *noids* does not infringe or confuse the already existing terminologies flocking, birdies, or boids.

Naturally occurring noisy flocking textures, or noids, can be heard throughout most the second section in *Pluck Red Violet* (from 3’38 – 5’06), briefly in *Pink Blue* from 6’00 – 6’20, and in *Red White Blue Pink* for most of the second section from 3’42 – 6’28. The term is used in the pieces’ respective commentaries: 5.2 Pluck Red Violet, 5.3 Pink Blue, and 5.7 Red White Blue Pink.

4.3.2 Space

The works explore space in a variety of ways, and can be better understood using Denis Smalley’s concepts involving space and spatiomorphology. Space is used in the project, firstly, to separate timbres, resulting in better articulation and reception of spectromorphological developments and textures, and secondly, to create moments of variation in a work not only stereophonically, but also in terms of depth, and to display the artefact stereo movement.

Space in fusion and fission

Space is used in this project to separate sounds that might otherwise fuse together. The streaming arrangement, as discussed earlier, can create sonic fusions and fissures, if the streams are made of sounds that sit in separated points within spectral space, which is defined as being the impression of space within ‘the range of audible frequencies’ (Smalley 2007, 56). Sounds can be kept separate, therefore, by occupying different spectral positions within spectral space. However, sonic elements can also be separated in stereo space too. Through growth processes and motion, sounds that are similar in spectral space but distinct in physical space, can interplay as they fuse and fissure.

This can be heard in *Blue Red* (see section 5.4 for more information) during the second section in which multiple tracks of similar sounding, repeated time stretched blue noise artefacts are rhythmically displaced and panned (from 2'21 – 6'40) (see section 4.3.3 for further explanation on displacement). As the displaced artefacts' relative temporal positions shift, the spatial positions also appear to move. When artefacts are played simultaneously they create a new fused sound, when artefacts are positioned discretely their distinct spectromorphologies can be heard, or when they are positioned close to one another the impression of compound sounds breaking up can be created.

This can be heard again in *Red White Blue Violet* (section 5.5) wherein two clips of encoded red noise are played simultaneously, beginning at 0'30 and lasting until 1'45 in the first section, then reappearing in the third section at 3'23 until 6'40. However, because each is positioned in either the left or right ear, their undulating spectromorphologies which are similar in terms of spectral space, though different in terms of specific spectromorphologies, create moments of fission and fusion. The moments of difference highlight the physical space of the work, the moments of similarity fuse together creating a sound across the stereo field and a narrower sense of space. For more information on this piece see section 5.5 Red White Blue Violet.

The piece *White Pink* (section 5.6) uses continuous periodic tones and discontinuous periodic rhythms throughout its duration (see section 4.4.1 Rhythm to Tone for more information on continuous tones and section 4.3.3 for information on discontinuous rhythms). The tones and rhythms are doubled, panned, and syncopated resulting in the exploration of the work's space as artefacts move rapidly across the stereo field. These timbres sit on the threshold of dis/continuity and, in turn, the threshold of fission and fusion.

This technique was influenced by Ryoji Ikeda's use of panned and rapidly repeating microsounds which verge on becoming continuous tones and can be heard throughout his work *+/-* (1996), particularly the opening three tracks *Headphonics 0/0*, *Headphonics 0/1*, and *Headphonics 1/0-*.

Variation in Position

The encoded red noise used in *Red White Blue Violet* (section 5.5) discussed above (occurring between 0'30 – 1'45 and 3'23 – 6'40) highlights another use of space: distance, or, foreground and background. The encoded red noise sits firmly at the back of the work, with other sonic figures including the fast-paced rhythmic gestures in the first and third sections in the foreground. The spatial and positional differences between these musical parts are created through amplitude, spectral positions, and amplitude envelopes.

In *White Pink* (5.6), white and pink noise bursts generally move slowly in certain spatial directions. However, they also occasionally jump suddenly from one spatial position to another. These spatial jumps create variation in the piece as their jumps are wide and unexpected, and they do not subscribe to the slower movement that the noise bursts had been following before. Use of noise bursts is discussed further towards the end of section 4.3.3.

Stereo Movement Effect

When encoding using stereo settings, stereo movement can occur (for more information on stereo movement see section 3.5.5). This effect causes sudden movement for sounds where there was none before, creating a sense of unsteadiness and instability.

This can be heard in two works *Pluck Red Violet* (section 5.2) and *Blue Red* (section 5.4). In *Pluck Red Violet* movement subtly occurs in encoded transient pluck sounds throughout the piece, but most clearly in the first section 0'00 – 3'07. Time-stretching was used to give more time for the effect to be perceived, and layering time-stretched stereo movement artefacts creating an exaggerated and slightly disorienting effect.

In *Blue Red* (section 5.4) a series of identical artefacts were re-encoded creating a number of additional effects, one of which was stereo movement. These fade in at 1'32 and continue until 6'40. A series of re-encoded artefacts are then reintroduced at 8'00 until the end of the work. The stereo positions shift from one artefact to the next, which, when combined with the amplitude fluctuations and changing envelopes creates a greater sense of gesture, and, as the variation does not develop predictably, a sense of instability and tension.

4.3.3 Rhythm

As is stated in sections 2.3.2, 2.4.4 and 2.5.4, glitch music and glitch theory have been important when researching compression artefacts as interruptions and, in turn, how interruptions could be used musically. Therefore, when considering rhythmic arrangement techniques, glitch musicians and composers who were occupied with notions of failure were considered.

The influence of glitch artists Ryoji Ikeda and Alva Noto in this project's works can be heard most clearly during moments of repeated rhythmic phrases and noise bursts. These can be heard in *Blue Red* and *White Pink* (see sections 5.4 and 5.6, respectively, for more information on these works).

Repetition

Glitch music uses repetitions of a glitch so that the attention of the audience is moved from the foreground to the background (Church 2017, 8; Cascone 2000, 13). Put another way by repeating a glitch, so it becomes more apparent and can become a musical feature. This allows the failure to be the aesthetic focus of the work, and is a technique that has been used in this project in two ways. The first is a process called *rhythmic displacement* and the second is *discontinuous periodic rhythms*.

Repetition - Rhythmic Displacement

Rhythmic displacement is defined by Pieter C. van den Toorn as 'shifts in metrical alignment of repeated motives, themes, and chords' (Toorn 2004, 468). It was a technique used by Stravinsky, as Toorn states evidence of Stravinsky's use of repetition and displaced rhythms 'can be found on virtually any page of Stravinsky's music' (Toorn 2004, 473), but goes on to give the example of ‘the A–D–C–D fragment in the horns in the “Ritual of the Rival Tribes” and “Procession of the Sage”’ (ibid) in *The Rite of Spring* (Stravinsky 2017).

When different audio clips, which are different lengths, are repeated, layered, and played simultaneously, shifting alignments occur creating variation on a sub-structural level due to their displaced rhythmic characteristics. Motives are not developed but, instead, variation is created as the different characteristics of series of artefacts interact in new ways with each repetition, while the continuation of the overall aesthetic draws the audience’s attention to the properties of the artefacts.

This technique can be heard in the third section of *Blue Red* (section 5.4) using layers of repeated clips of blue noise artefacts (from 7’28 – 9’56). The clips are at their original time-scale, creating a rapidly shifting example of the effect. This technique was also used with single time-stretched artefacts, which had been organised into a series and slowly repeated over a longer period of time. This can be heard in the second section of the piece *Blue Red* (2’21 – 6’40), in which five layers of slowly repeating different time-stretched discrete blue noise artefacts are played simultaneously. As well as each series being made of a different artefact, they also have different lengths of time between each repetition, creating the rhythmic displacement, and as the artefacts phase in and out of time with one another, so new alignments occur.

Repetition - Discontinuous Periodic Rhythms

As discussed earlier in the *clouds* subsection in 4.3.1, some artefacts were edited so that only the attack of the sound could be heard, creating a transient, percussive, and microsound timbre. These transient artefacts were then repeated at tempos between 0.5 Hz and 8 Hz to create periodic rhythms.

Discontinuous periodic rhythms have been constructed in this project using edited artefacts and placed periodically. For example, in *White Pink* edited artefacts are placed at equal periods of 8 Hz, or 480 beats per minute, and can be heard from 2’22 – 5’50. The piece *Red White Blue Pink* also uses discontinuous periodic rhythms, at tempos of 0.5 Hz (in section one: 0’00 – 3’42 and section three: 7’43 – 8’59) and 1 Hz (in most of section three 7’43 – 8’10).

As stated above, repetition can draw attention to the artefact being repeated, but it can also have the effect of creating moments of relief and tension. For example, the work *Red White Blue Pink* (5.7) uses this technique to create contrast with the other musical elements in the work that are irregular and non-metric, the variety giving some relief to the work. However, it is also the consistency of the repetition and the lack of development that can create a sense of tension as resolution and development are withheld, an effect that is pronounced most clearly at the end of the work.

Evoking Failure

While repetition can be used as a means of drawing attention to failure, it can also be used as a means of alluding to it.

Ligeti has stated ‘I have always been fascinated by machines that do not work properly’ (Várnai et al. 1983, 16) and uses the term *meccanico* to describe moments and movements in his compositions that reflect this interest. Ligeti uses the term meccanico in ‘a general way, referring to portions of any of his compositions that remind him of machinery gone awry, rather than to those using any specific compositional techniques’ (Clendinning, 1993, 192). However, there are some compositional techniques Ligeti uses that evoke this interest in a direct form.

Ligeti states ‘transposed into music, the ticking of malfunctioning machinery occurs in many of my works’ (Várnai et al. 1983, 16). This can be heard in the third movement of his second-string quartet (2005) wherein pizzicato rhythms that build and decay in tempo and rhythmic complexity allude to ‘recalcitrant machinery, unmaneagable automata’ (Várnai et al. 1983, 17) through their transient timbral properties and repetitive nature.

This is similar to glitch composers who either use or evoke technological failure within their music through the use of transient, pizzicato-like timbres such as the track *Module 6* from the album *Transform* (Alva Noto 2001) by Alva Noto, or *Tanzen* from Pole's *1* (Pole 1998) which includes sparse pops and cracks of varying dynamics and dense rhythms.

While the use of repeated transient sounds in this project was influenced by glitch composers described above, Ligeti's use of repeated transients shows how similar forms emerge when articulating technological failure in music, even when from seemingly disparate stylistic spheres.

As technological failure is expressed and explored by glitch artists and Ligeti in similar ways, by using brief note lengths, sounds, or noises in repetitive rhythms that build and decay, it could be seen that this means of expressing technological failure is an example of form coming from a material whose timbral qualities are borne out of technological failure. Illustrating the important link between failure, material properties, and sub-structural arrangements.

This can be heard in the transient artefacts throughout the project, particularly in the repetitive elements described in the previous two subsections. A clear example of this can be heard in the work *Blue Red*. From 1'08 there is the introduction of a metronomic series of transient artefacts, which have pizzicato-like qualities, reminiscent of Ligeti's approach.

This idea, however, is extended as this series of transient artefacts are then re-encoded, creating more artefacts and increasing the amount of literal malfunctioning. The idea is extended because the meccanico technique is designed to figuratively refer to mechanical failure rather than digital. Therefore, it was considered necessary for the use of this technique in this project to go further, and use this technique to draw out digital failures too.

Inclusion of Noise as Complex Timbre (Object-Oriented Noise)

Bursts of complex, object-oriented noise are used by glitch composers Ikeda and Alva Noto as structural markers at points in works where development occurs. For example the track *+..* by Ikeda from the album *+/-* (1996) begins with a series of four clicks followed by a burst of noise with a pitched artefact, after which another series of eight clicks and then a much faster series of clicks occur. The burst of noise is a moment of interference, but acts as a marker of change.

This project uses this technique in several pieces as both repeated noise bursts and in longer forms that crescendo and diminuendo. The piece *White Pink* (5.6) uses bursts of noise in its second section from 3’45 – 5’50, the noise bursts acting as forms of interference which underpin structural shifts. For example, at 4’34, a noise burst is used to mark the abrupt change between the end of a time-stretched artefact and a series of white noise artefacts.

Clearly, unencoded noise is not a compression artefact, however its inclusion in the project has been to act as a form of interference referring figuratively back to the artefacts’ nature as interferences within signals; to give relief to some of the pieces through timbral variation; and finally, to give pieces and artefacts a form of sonic context. Context in the sense that including the input material gives the listener the opportunity to hear what has been affected, and therefore to appreciate further the changes that have occurred, and in turn, the properties of the artefacts and effects of the compression process.

4.4 Micro

This section of the chapter is concerned with approaches towards the micro properties of the artefacts, those being on the levels of micro-time, microtone, and micro amplification.

These approaches include the use of artefacts’ properties to create new sonic material using repetition, triggering, and recompression. This sub-chapter also considers techniques such as amplification and pitch-shifting that make inaudible properties audible. The final section looks at the importance of processes used in the methodology for creating specific properties.

4.4.1 New Material

Techniques were explored that use the properties of the artefacts as a means with which to create new sonic material. For example, by repeating an edited transient artefact at a high enough frequency, a tone can be created, which exhibits the spectral property of the repeated artefact as one of its key characteristics. Another technique consists of using transient artefacts within a clip of encoded noise as a means of establishing new rhythmic structures via triggering. Lastly, this sub section looks at how, by recompressing edited artefacts, more artefacts and effects can be created.

Rhythm to Tone/Timbre – The Rhythmic Continuum – Continuous Periodic Tones

The technique of creating discontinuous periodic rhythms with edited transient artefacts as described in section 4.3.3, was taken further by increasing the amount of repetitions of the artefact to the point that individual artefacts fuse into a continuous tone or timbre. Rossetti et al. posit that pitches and rhythms could be two ends of the same scale wherein and that 'according to [Stockhausen]' the point at which our perception of a series of periodic sounds shifts from rhythm to tone is '1/16 of a second' (Rossetti et al. 2020, 158), and is referred to in this text as *continuous periodic tones*.

The spectral characteristics of the tone were caused by the artefacts' inherent spectral qualities. The technique contrasts with drones made using time-stretched artefacts, as it has a consistent pitch within the works, acting as a counterpoint to the shifting spectromorphologies of the time-stretched encoded audio and artefacts. This technique was used in several pieces, for example it can be heard in the work *Red White Blue Violet* from 0'20.

The rhythmic continuum was described by Henry Cowell in *New Musical Resources*, stating 'a parallel can be drawn between the ratio of rhythmical beats and the ratio of musical tones' giving the example of how, by doubling the frequency of sonic events so the tone will be one octave higher than before (Cowell 1996, 50). While the frequency of the artefact's repetitions is not high enough to create additional tones, the timbre still sits on the rhythm to noise continuum, as it is a continuous sound that is born out of an extremely fast rhythm.

The process was demonstrated musically by Karlheinz Stockhausen in *Kontakte* (Stockhausen 2014), wherein a continuous tone moves down in pitch, and as it gets lower, so the continuous tone changes into a ‘discontinuous sound figure with a periodical rhythm’ (Rossetti et al. 2020, 158).

Repetition, as Church stated, can be used to move the point of listening from the foreground to the background (Church 2017, 8), and this technique can be heard to take that argument further by using repetition to go so far as to create a new timbre, while also foregrounding the artefact.

By repeating an artefact that has been edited to the micro-timescale to the point that artefacts fuse to become a continuous tone, the rhythm to tone continuum can be explored, a new timbre can be created, and the spectral properties of the artefact being repeated can be heard in a new way.

Triggers

An important technique used in this project was to use the properties of a series of artefacts to trigger other sonic events.

Using the transient properties of a series of artefacts as triggers for other compression artefacts allowed the rhythmic structures inherent in the encoded audio to be the prominent sonic characteristic in a new musical element. By using this technique, compression artefacts and effects are not only new sonic material themselves, but also a means of creating new structures and new musical parts.

The effect was achieved by converting an audio clip of a series of artefacts to a MIDI clip using the ‘convert drums to new midi track’ function in Ableton Live. This function used the transient properties in the audio clip as markers for reconstructing the rhythm in MIDI. This was then used as the rhythm structure for a limited number of samples, creating a defined palette and meaning that the idiosyncrasies of the artefacts’ spectromorphologies did not draw attention away from the rhythmic properties of the artefact series.

In addition to their rhythmic placement, artefacts were edited, making them more transient and percussive as a means of increasing the rhythmic qualities of the series of artefacts. This technique was used in the piece *Red White Blue Violet*, and uses series of artefacts from white, violet, and blue encoded noise, creating rhythms and timbres with different properties.

4.4.2 Inaudible to Audible

The second section of the sub-chapter is concerned with using amplification and pitch shifting to allow properties that are normally below or above the threshold of perception to be heard.

Amplification and pitch shifting clarity

By changing the volume of tracks in Ableton Live, either by fixing the position of faders or by using automation, the works could be mixed better creating a more coherent piece of music, while also giving certain characteristics of the artefact's greater clarity and definition. For example, in *Pluck Red Violet* volume automation was used to make the stereo movement effect that was a feature throughout the work, louder, while also reducing the volume of the clip as the pre-echo artefacts ended.

Pitch-shifting is also used to draw out characteristics of the artefacts that would otherwise be inaudible. Properties that are subsonic can be brought into the area of perception using the pitch-shifting function in Ableton Live or to make sounds more palatable. This process can be heard at the start of *Blue Red*, in which a pitch-shifted artefact results in a high-pitched ringing.

The processes described above have been used by 'many composers of musique concrete' (Roads 2015, 86) who amplify and pitch-shift to create 'dramatic gestures' such as Maggi Payne's *FIZZ* (Payne 2010) in which water fizzing is amplified into a 'massive crescendo'

(Roads 2015 86), and in the program notes to *Concret PH*, Xenakis stated that he explored the ‘realm of extremely faint sounds highly amplified’ (Roads 2001, 65).

Time-stretching

Time-stretching is a technique that has been discussed throughout this chapter, and therefore will not be discussed too much further. However, to give a brief overview, time-stretching is a technique that has allowed the artefacts that sit at the micro-temporal level to become mesostructures. By doing this their properties can be perceived more easily, and the artefacts themselves can become musical features within works.

4.4.3 Importance of Method

The final section of the sub-chapter is concerned with processes used in the creation of artefacts that are integral to certain properties. These include the importance of process to the microtonal qualities of the artefacts, the use of complex noise to create various timbres, and cascading to exaggerate artefacts and effects further.

Microtonality and Codec/Noise

As the pitched qualities of compression artefacts can sit anywhere in the spectrum/bandwidth, their pitches lack any relation to western twelve-tone scale. Instead, the positions they occupy in the spectrum sit at the microtonal level. When time-stretched artefacts’ spectral properties can be heard to slowly shift from one microtone to another and, when these time-stretched pitched artefacts are layered and clustered, so this spectral morphing becomes more pronounced, creating complex microtonal movements.

The processing and sub structural arrangement of pitched artefacts was guided by the microtonal properties of the material. However, it should be recognised that the material for this project, and therefore its tonal and microtonal properties, is owed to its process of production.

This project uses methods and technologies that allow for the production of pitched audio that can plausibly consist of any frequencies within the bandwidth (up to the Nyquist threshold), and as such it is the codec/noise as instrument that creates the opportunity for exploration of those microtones.

Pitch-noise Continuum

Curtis Roads considers pitch and wideband complex noise to be at opposite ends of a 'continuum of sonic effects' (Roads 2015, 209) and that through transformation sound can move through 'all intermediary states' (Roads 2015, 208). This transformation is achieved by using various techniques and approaches, including filtering.

The process of filtering wideband noise was used by composers including Stockhausen and Gottfried Michael Koenig in works such as *Gesang der Jungling* (Stockhausen 2014) and *Essay* (Koenig 2002), *Terminus I* (ibid), *Terminus II* (ibid), respectively (Roads 2015, 100).

The method for producing artefacts in this project has taken a similar approach. Using wideband noise as a primary material, and then filtering it using a compression codec to create artefacts and effects, has created a set of sounds that sit at various points on the pitch-noise continuum.

An early source of inspiration for filtering wideband signals was through experimenting with recordings of tone clusters played on an organ and processing it using the MP3 imitation plug-in *Lossy*. As these investigations predate this programme of research, they are an example of how filtering complex timbres has been an important practice from the earliest stages of this project.

Cascading

The process of cascading, which can be read about in further detail in the methodology subsection in chapter 3.4, exaggerated and amplified the characteristics of the encoding process, by submitting a signal to multiple passes through the encode/decode cycle. The reason for this was to create better defined articulations of the compression effects, this allowed for the artefacts and effects to be analysed more easily and to become sound objects with which to compose music. This process can, therefore, be heard throughout the project, but arguably most clearly with the effect cumulative delays, which are delays that occur at the beginning of chunks of encoded audio getting longer with each encode/decode cycle.

4.5 Compromised Authenticity and Hyperreality

Now that the previous sections of this chapter have looked at how the artefacts have been arranged temporally and spectrally, this section will consider whether the arrangement of these artefacts affects their properties to a degree that the sounds are perceived as being less authentic as compression artefacts or if the arrangement of these artefacts underpins the properties of the artefacts, creating a hyperreal expression of them.

The first section of this sub-chapter will consider theories of authenticity described by Moore and Taylor and apply them to this project, while the second section considers perspectives by Creshevsky in order to understand processing and arrangement as a means of highlighting the properties of the artefacts, creating hyperreal versions of them.

4.5.1 Compromised Authenticity

First Person Authenticity and Technological Mediation

Allan Moore's *Authenticity as Authentication* (2002), describes a typology for understanding authenticity in popular music with the concept that most strongly relates to this section of the project as being 'first person authenticity' (Moore 2002). Moore defines first-person authenticity as being when a composer or performer 'succeeds in conveying the impression that his/her utterance is one of integrity, that it represents an attempt to communicate in an unmediated form with an audience' (Moore 2002, 214).

Therefore, authenticity is concerned with immediacy (Moore 2002, 211), being unmediated, and allowing the music to be traced back to 'an initiatory instance' or origin, resulting in the distance between its origin and its manifestation to be 'wilfully compressed to nil' (Moore 2002, 213). This form of authenticity can be affected, therefore, by various mediating factors, including commercialism and social class. However, it can also be mediated, and therefore undermined, by technology.

Moore states that 'technological mediation (whether a reliance on signal modifiers, ever more powerful means of amplification, and even technical mastery in many spheres) is equated with artifice' (Moore 2002, 213), and gives the example of a folk club that objected to performers playing 'traditional' music using electronic instruments (Moore 2002, 212).

In this project, however, the originator of the artefacts is not a performer or composer but is the process of perceptual coding, and the act of technological mediation can be seen as in the amplification, processing, and arrangement of artefacts using DAWs and plug-ins. By arranging and processing the artefacts in the creation of musical works, it could be considered to increase the distance between the origin of the artefacts and their manifestation in the pieces of music, affecting how the authenticity of the artefacts are perceived and resulting in a breakdown of referentiality to their origin. For example, by time-stretching artefacts their original timescale is disrupted, by pitch-shifting artefacts their original spectral properties change, and the amplification of artefacts moves them away from being subtle or understated to being artificially apparent.

It has been a key concern throughout the project that the process of perceptual coding can still, plausibly, be recognised. If the arrangement and processing techniques affects artefacts' properties to a point whereby they are no longer recognisable as artefacts, they in turn no longer act referentially to their process of production, perceptual coding.

There is, however, a counter argument positing that by arranging the artefacts in the ways described in this chapter their sense of authenticity is not undermined or even just preserved, but is highlighted, exaggerated, and made *hyperreal*.

4.5.2 Processing as Hyperreality

Hyperrealism, in music, is a term used by Noah Creshevsky to describe an aesthetic or musical language that is 'constructed from sounds that are found in our shared environment ("realism"), handled in ways that are somehow exaggerated or excessive ("hyper")' (Windleburn 2021, 403). Creshevsky achieves this effect by sampling moments from pre-existing musical works to comment on cultural issues concerned with 'contemporary consumer-oriented, mass-mediated and information-rich society' (ibid).

In addition to Creshevsky, Curtis Roads has also used the term *hyperrealism* to mean the act of amplifying and exaggerating the properties of sounds using processing. Hyperreal amplification, for example, is the 'exaggeration of feeble sounds for expressive effect' (Roads 2015, 86) and can take many forms, including any dynamically compressed audio or massively amplified performance nuance and turning almost subsonic sounds into 'massive sonic events' (ibid).

In Creshevsky's approach, the sounds with which he composes belong to a 'shared environment ("realism")' (Windleburn 2021, 403) and his sampling of those sounds and exaggerated use of them in musical arrangements with them creates a sense of hyperreality and hyper connection between their origins and their new manifestations.

The artefacts used in this project can be heard as belonging to the shared environment of compressed digital audio, and, using the processing techniques described in this chapter, their properties have been exaggerated. For example, by time-stretching artefacts, their real-time nature is lost but the listener has a better opportunity to perceive those characteristics; using pitch-shifting the original spectral properties change but also the properties that would have sub or super-sonic are more clearly heard; and amplification can make a sound that might have been masked by other events foregrounded and heard.

As Moore argued, authenticity is something we 'ascribe to' (Moore 2002, 220) a musical work, therefore the perception of artefacts' properties are important, and the processing and arrangement techniques used here help to create an exaggerated, hyperreal version of them, reinforcing their characteristics and strengthening the link between the sounds, their origins, and in turn their impression of authenticity.

The exaggeration of these properties also exaggerates the referentiality between the artefacts and perceptual coding. The arrangement, processing, cascading and ultimately the music itself underpin authenticity, rather than compromising it.

4.6 Summary

Chapter 4 gave an overview of how artefacts and effects were arranged and processed to create pieces of music, with an awareness of how the properties of the artefacts themselves lead to or favoured certain arrangements and processing techniques.

The chapter began by discussing various methods for macro structural organisation, and considered top down, bottom up, multiscale, and intuitive approaches. This was followed by descriptions of meso level arrangements of artefacts including clusters, streams, clouds, flocks, and weaves with the addition of the term *noids*. Spatial effects were described including fusion and fission and stereo movement, and finally, rhythmic devices and how they could be used to create variation and evoke failure, were described. The micro level aspects of artefacts were then discussed, including micro-time, microtone, and micro amplification. Using properties of sounds to trigger other sounds was a fruitful technique and amplification, pitch-shifting, and time-stretching were described as being processes that allowed properties of artefacts that would normally be inaudible to be heard. Finally a section concerned with authenticity and compositional arrangement and processing was discussed.

Chapter 5 Commentaries

5.1 Introduction

The commentaries laid out in this chapter describe each piece of music individually, and then summarise the interludes afterwards. The order of works discussed in this chapter differs from their order in the portfolio insofar that the portfolio has been arranged so that the works and interludes between them introduce new musical elements to the project gradually. Here, however, works are discussed first, followed by interludes.

Each commentary includes screenshots of the arrange windows from their respective Ableton Live projects. The audio clips have been assigned certain colours and those colours are referred to in parentheses when the musical element associated with that colour is being discussed.

Works

Beginning with *Pluck Red Violet* and *Pink Blue*, works that use time-stretched artefacts and encoded noise in streams, weaves, and clusters as key arrangement techniques; moving on to *Blue Red* and *Red White Blue Violet*, which explore rhythmic structures including sparse metronomic rhythms and rhythms triggered by the transients of another series of artefacts. *Red White Blue Violet* also explores the rhythm to tone continuum creating new timbres, and is used to greater extent in *White Pink*. Finally, *Red White Blue Pink* combines many of the techniques from the previous pieces.

Interludes

The interludes act as palette cleansers, contrasting with the works around them and giving the listener a respite from the arrangement techniques used in the longer works, while also introducing musical elements into the project.

The first interlude contrasts with the droning timbres of *Pluck Red Violet* and *Pink Blue* by using cloud arrangements of edited artefacts, and introduces arrangements that explore the rhythm to tone continuum. The second interlude continues with these techniques, while the third interlude uses time-stretched drones to contrast with the more rhythmic works around it, *Red White Blue Violet* and *White Pink*. Lastly, the fourth interlude uses unencoded noise with artefacts layered beneath to create contrast with *White Pink* and the final work *Red White Blue Pink* which use sparse rhythms and drones.

5.2 Pluck Red Violet

Title of Work

Pluck Red Violet

Brief Background and Overview

The piece was written between March and April 2021 and is comprised of two sections. The first section uses stereo movement and pre-echo effects to create and explore nuanced and subtle sonic variation. Arrangement techniques are kept to time-stretching and layering in order to exhibit the properties of the stereo movement effect clearly. The second section uses encoded noise and the cumulative delays effect with panning to create timbral contrast and movement, with streaming time-stretched encoded audio.

Investigations

An important artefact used in this work is pre-echo. As the input material used to create the pre-echo was a synthesised pluck sound, there was also a pitched aspect to the timbre, meaning that there were both complex and pitched elements in the pre-echo artefact. Therefore, the pre-echo causes a change in timbre in regards to both its amplitude envelope and its spectral properties, while also retaining some harmonic aspects, giving the work a wider sonic palette to explore.

The piece also uses the stereo movement effect. Though the movement is subtle, the moments in which it occurs have been time-stretched, which gives more time for the movement to be perceived, and then layered to increase impact. The layered stereo movements effect creates a sense of motion that at times results in a spinning, disorienting sensation.

In the second section of the piece, there are series of red and violet noise encoded using the LAME codec, which adds delay to the audio it encodes, and when cascaded the delay will increase with each iteration. The encoded noise is repeated, layered, and staggered, and panning is used to separate the different clips of encoded noise, highlighting the changing lengths of the delays over the course of the section. The delay is an absence of audio, however, when considering informational definition of noise, it is its relationship with the signal that it is disrupting that results in its definition. The delay, therefore, is a change of sound, rather than an absence of it.

Inputs and Encoding Variables

Pluck Transient:
8 kbps 16 kHz NS
8 kbps 8 kHz NS
16 kbps 16 kHz NS
16 kbps 24 kHz NS
8/16 kbps 24 kHz JS
16/32 kbps 8 kHz JS

Red Noise
8 kbps 24 kHz

Violet Noise
8 kbps 24 kHz

Structure and Musical Elements

Section 1 – 0’00 – 3’07

Section 2 – 3’07 – 5’52

Below is a screenshot of the Ableton Live project’s arrange window of the whole work with the sections delineated using orange lines.

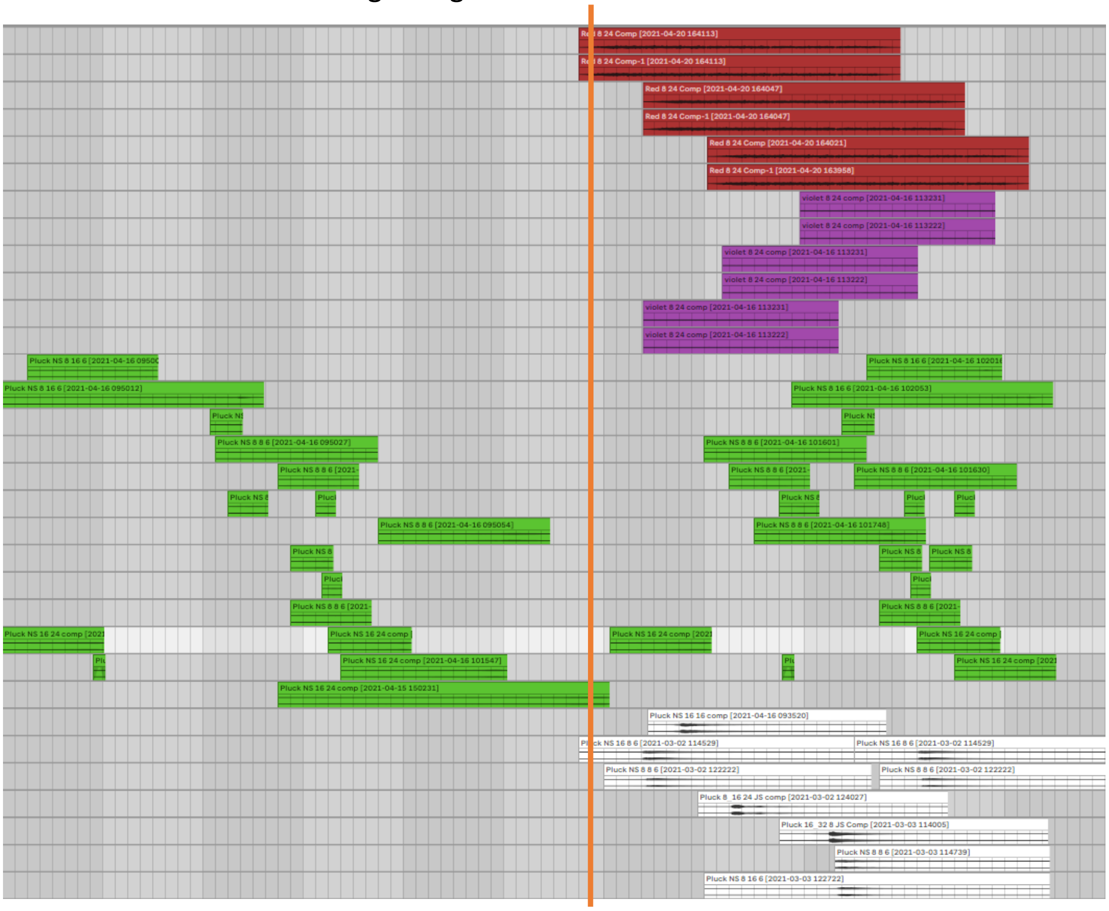

Figure 5.1: Screenshot of Ableton Live project showing overview of piece Pluck Red Violet

1) Green: Edited and time-stretched pre-echoes from an encoded synthesised pluck
2) White: Unedited time-stretched encoded synthesised plucks showing stereo movement
3) Red and Purple: Cumulative delays in encoded red and violet noise

Analysis

Section 1

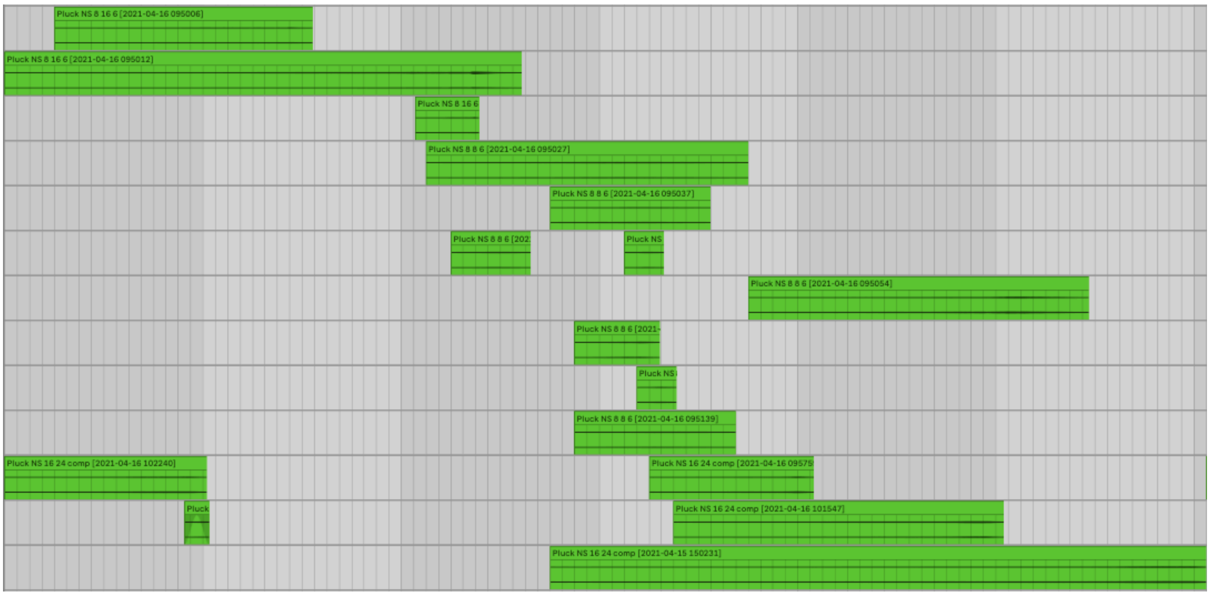

Figure 5.2: Screenshot of Ableton Live project showing first section of piece Pluck Red Violet

Above is a screenshot of the Ableton Live project's arrange window showing the first section of this piece.

The first section lasts until 3'07 and consists entirely of time-stretched pre-echoes from an encoded synthesised pluck (green). They have been edited so that the only the attack of the signal is used, as this part of the sound is where the pre-echo effect and stereo movement effects can be heard.

The plucks have been cascaded at the bitrates, sample rates, and stereo encoding settings described above to create both the pre-echo and stereo movement effects. The encoded plucks are time-stretched to varying lengths and then layered for two reasons: to give the listener greater ability to hear the stereo movement effect and to create a streaming effect of moving layers, allowing the densities and spectra to morph and develop. Additionally, artefacts and effects are amplified making their properties more easily heard, particularly in regards to the stereo movement that normally occurs in the quieter, later stages of the amplitude envelope.

Panning is not used at all in this section, allowing the stereo movement effect to be clearly heard and give this section its spatial, gestural quality.

Pitched properties from the pluck sound can be heard in the pre-echo, creating moments of microtonality. These pitched properties were likely created when parts of the complex timbre of the pre-echo became reduced to pitched artefacts as the sounds were re-encoded in the cascading process. This microtonality therefore is a direct result of the compression process, showing the importance of the method upon creating these sounds, and in turn allowing the artefacts and effects to refer back to the processual elements of the medium that created them.

This can be heard at the very beginning of the work at 0’05, when a frequency of 1.2 kHz is followed by a lower frequency of 775 Hz at 0’09. This is then proceeded by a sequence of frequencies between 0’14 and 0’28 ranging between 258 Hz and 3.6 kHz. There are other pitched moments that occur in this section, such as a small cluster at 0’31 and a very clear bell-like timbre at 0’43. These effects can be heard throughout the piece.

From 1’15 to 1’24, and then again from 1’38 to 1’50, duplicated pre-echoes, which have been time-stretched to varying lengths, are layered resulting in their spatial-temporal properties creating a spinning vertigo-like effect, giving the impression that the listener is surrounded or engulfed by the artefacts.

The artefacts are layered, resulting in sounds fusing into one another. The artefacts are spectrally similar throughout the section creating a continuous streaming sound, and while at times the stereo movement can help to separate the perception of individual artefacts, when they move back into the same stereo space, fusion can recur.

The section concludes at 3’07 as the time-stretched pre-echoes fade out and the encoded red and violet noise fade in.

Section 2

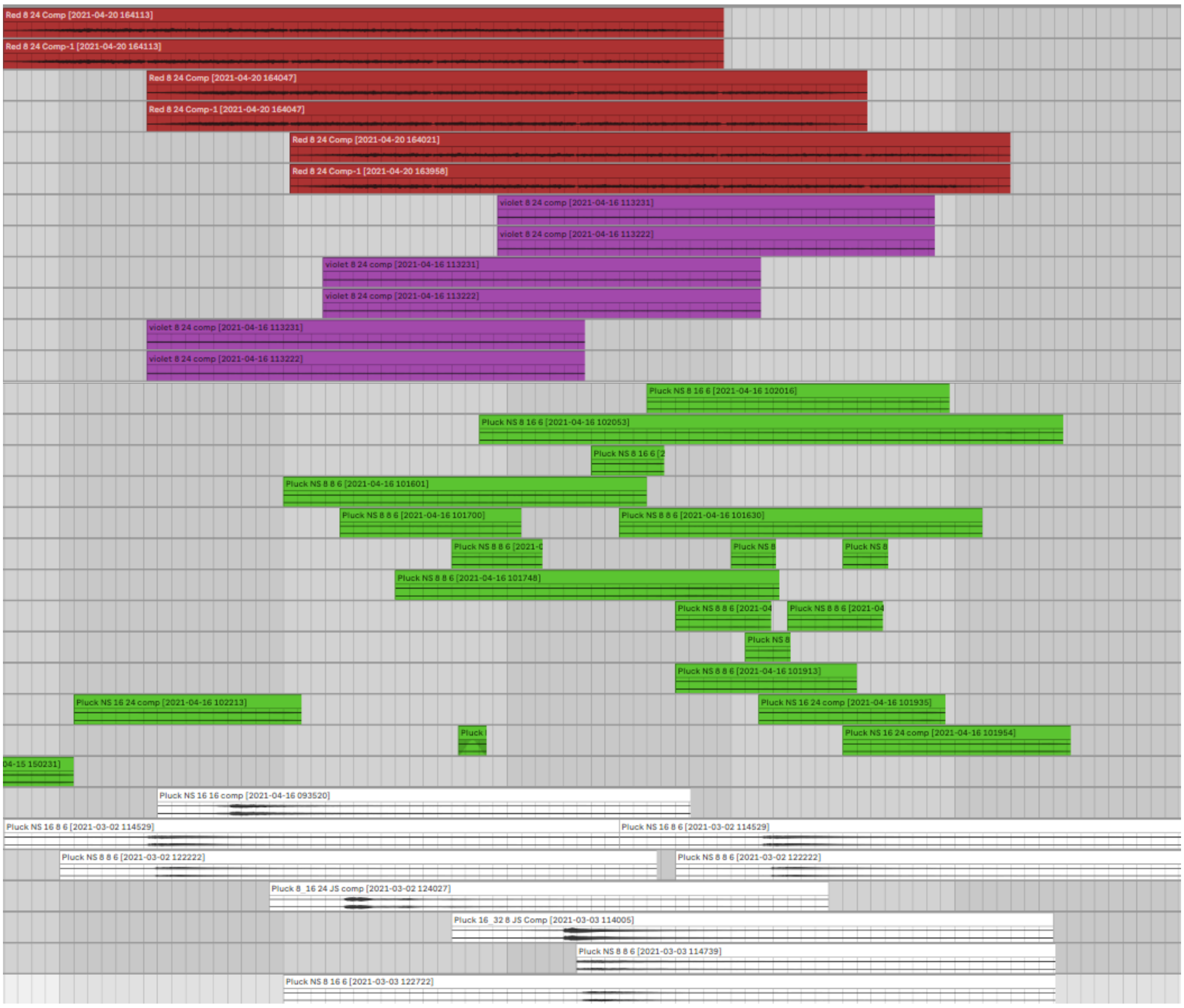

Figure 5.3: Screenshot of Ableton Live project showing overview of second section of piece Pluck Red Violet

Above is a screenshot of the Ableton Live project's arrange window showing the second section of the piece. The encoded red noise (red) and the encoded violet noise (purple) include cumulative delays, which are discussed later in this commentary. The edited and time-stretched pre-echoes are reintroduced (green), and time-stretched encoded synthesised plucks with stereo movement are introduced (white).

The second section begins at 3'08 as encoded red noise fades in with encoded violet noise also being audible from 3'38. These create flocking effects, which last for most of the second section until they fade out at 5'10. The flocking violet noise lacks pitched properties but is still less complex than the unencoded noise and therefore can be considered an example of *noids* as defined in chapter 4.3.1.

The encoded noises have been paired and staggered, as can be seen in the Ableton Live screenshot above, highlighted in red and purple. As red and violet noises sit in different areas of spectral space, they do not clash with one another and have different timbral properties. The red noise, which sits lower in the spectrum, has a warbling quality while the violet noise, which is higher, has a hissing characteristic.

The encoded red and violet noises were compressed using the LAME encoder, which adds a portion of silence to the start of an encoding, creating the cumulative delays effect when encodings are cascaded. Therefore, the cascading process in this example acts not only as a means of exaggerating the effect, but also as a means of establishing structure. As the delays increase with each iteration of encoding, so there is a degree of predictability and slight variation.

The delays in the red noise can be heard at 3’24, 3’44, 4’05, 4’26, 4’46, and 5’07, and are highlighted in the screenshot below using arrows that point to the approximate point in time that the delays are occurring.

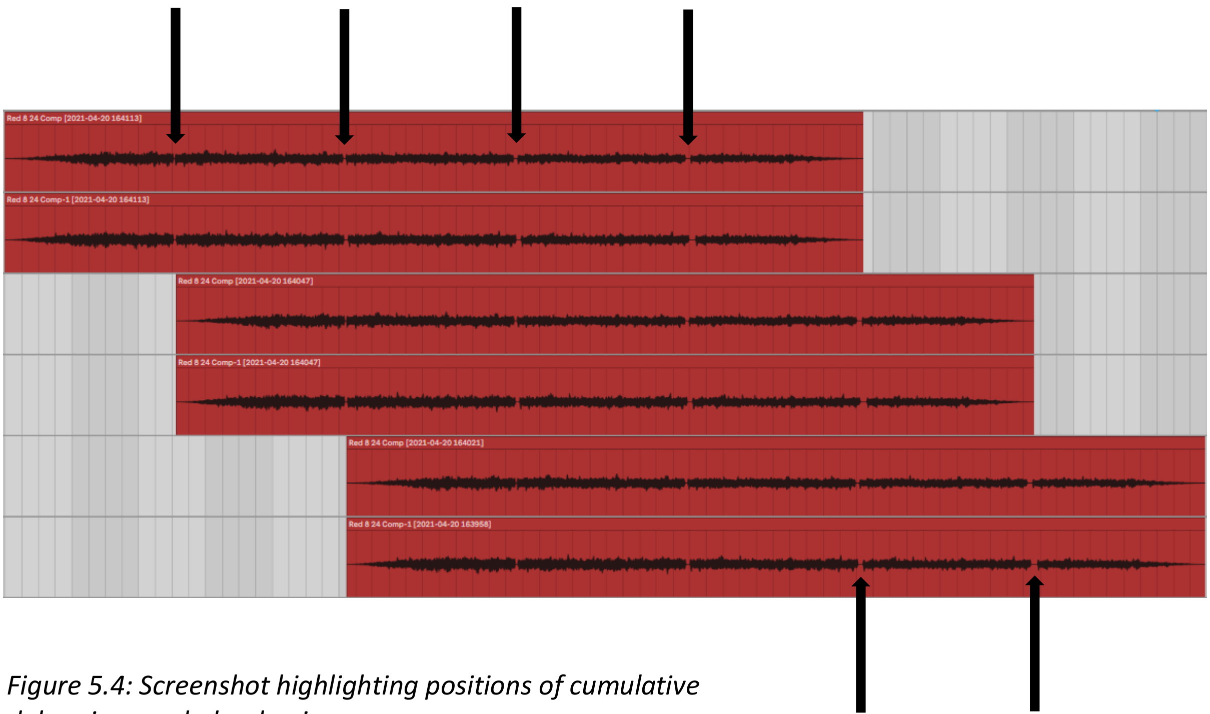

Figure 5.4: Screenshot highlighting positions of cumulative delays in encoded red noise

Delays in the violet noise can be heard at 3’37, 3’49, 4’02, 4’14, 4’27, 4’40, 4’52, and 5’05, and are highlighted in the screenshot below using arrows that point to the approximate point in time that the delays are occurring.

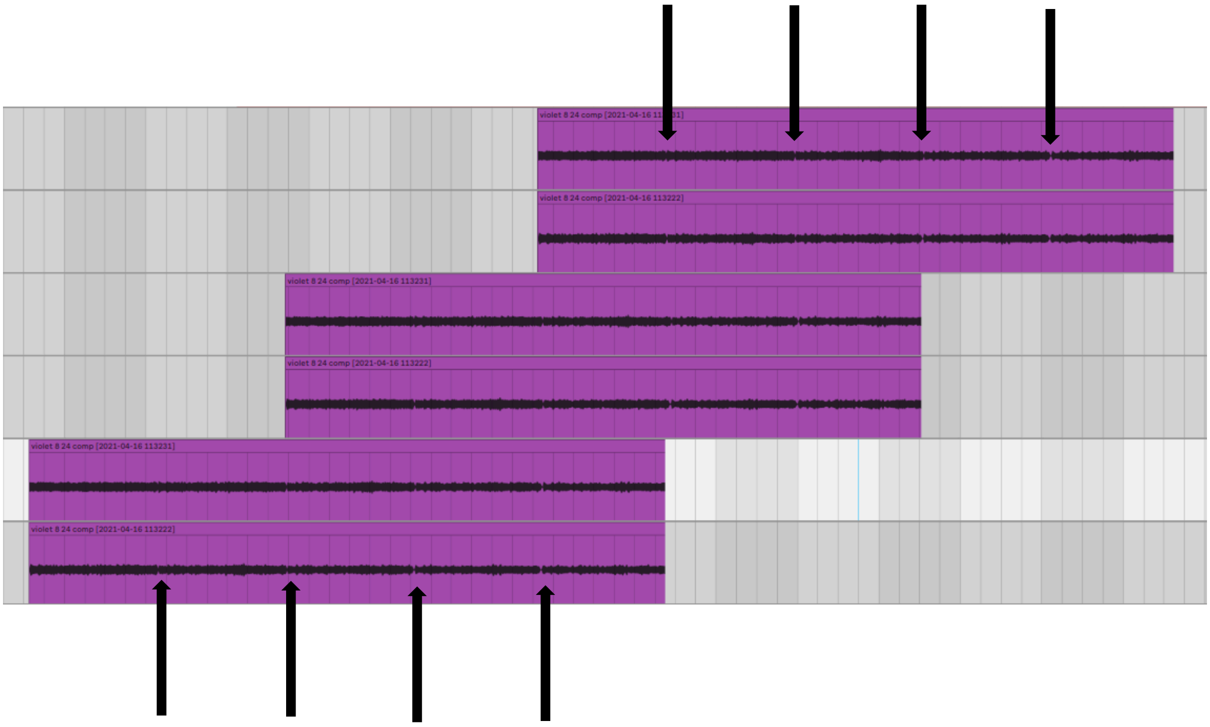

Figure 5.5: Screenshot highlighting positions of cumulative delays in encoded violet noise

The cumulative nature of the delays means that over time they get longer. As the clips are staggered this increase in time can become noticeable as delays from different tracks of encoded noise do not synchronise. Therefore, the times for the delays listed above are approximates for multiple delays.

The unsynchronised nature of the delays becomes even more noticeable due to the panning and can result in multiple delays occurring at slightly different moments in time and at different points in space. When the delays do synchronise, however, the sudden loss of timbral complexity can create a moment of uncertainty before being reintroduced moments later.

The time-stretched pre-echo (green) used at the very start of the work is reintroduced at 3’14 and additional time-stretched pre-echo effects are introduced at 3’50. While they are the same audio clips from the first section, their arrangement is different, creating variation with the work's defined material. This gives the piece a greater sense of structure as the work develops.

Contrasting with the other encoded plucks, the last set of musical elements is introduced at 3'26 and is made from unedited time-stretched encoded plucks (white). As they are unedited, they include the pre-echo effect in the attack portion of the sound and also more stereo movement in the envelope's release. They are arranged in clusters of either two or three encoded pluck sounds in order to exaggerate the properties of the artefacts. The encoded noise fades out by 5'08 leaving the time-stretched encoded pluck fading out as the piece ends.

5.3 Pink Blue

Title of Work

Pink Blue

Brief Background and Overview

The work was written in January and February 2021 and takes influence from Ligeti and investigates inherent microtonal relationships using time-stretched pitched artefacts from pink and blue noise in cluster and streaming arrangements. The work makes use of pink noise artefacts which sit as high as 4 kHz, while blue noise artefacts can be heard as high as 10 kHz. Later in the work, flocking arrangements of artefacts can be heard, as well as unencoded noise.

The overall structure is split into three sections. The first two sections use clustering techniques of meso length artefacts created from pink noise in the first section and blue noise in the second section to exhibit the spectral properties of artefacts. The third section combines streaming meso length pink noise artefacts, with micro and sound-object length blue noise artefacts of various lengths to exhibit a variety of timbres, textures, and arrangement techniques. Bursts of raw blue noise appear throughout the third section, eventually acting as the final texture into which the other artefacts disappear.

Investigations

The piece takes influence from Ligeti's *Atmosphères* (Ligeti 2002) and *Volumina* (Ligeti 2006) as it explores the microtonal qualities of pitched artefacts and their idiosyncratic spectromorphologies using cluster, weave, stream, and micropolyphonic approaches to arrangement. Using time-stretching and these arrangement techniques the evolving microtonal properties of the artefacts create shifting densities, microharmonic variation, and moments of tension and resolution.

The time-stretched artefacts in this work are within the timescale of the sound object and at the meso level of time division. This, combined with their discrete properties makes them more easily structured into cluster formations that build and decompose over several seconds.

The time-stretching and clustering of artefacts means that as their spectra and timbres morph, creating complex shifting microtonal relationships and allowing the work to explore the artefacts' properties within structured development. This creates a balance between the shifting properties of the artefacts and the consistent clusters they are organised within giving the work moments of tension and resolution as the first two sections develop.

Microtonal relationships also result in the phenomenon known as *beats*, which occurs when two 'nearly equal simple tones' (Helmholtz 160, 1895) are heard simultaneously. The effect is that 'the intensity of the tone will be alternately greater and less in regular succession' (Helmholtz 146, 1895). The number of beats in an arbitrary length of time is equal to the difference in frequencies of two tones within the same length of time. For example, if a frequency of 100 Hz and another frequency of 102 Hz are heard simultaneously, they will produce 2 beats per second. In this work, however, the developing spectral properties of the artefacts mean that the beats phenomenon appears, develops, and disappears as artefacts' spectromorphologies evolve.

In the third section, artefacts and encoded noise are layered, exaggerating their inherent streaming and weaving qualities and allowing artefacts' spectromorphologies to develop in a continuous and sustained form. The streaming mesostructure's spectromoprholgy is unpredictable and constantly changing creating tension, over which other sounds can be used to create new structures and moments of resolution.

The work uses the various spectral positions of the pitched artefacts to create harmonically distinct musical elements. Pitched artefacts from pink noise sit in a low register, while blue noise pitched artefacts are much higher, therefore using pink noise artefacts in the first section followed by blue noise artefacts is an effective way to create variation and structure in the piece.

In addition to the clusters and streams of artefacts, there is also a twenty second period in which an arrangement of artefacts described as flocks or clouds can be heard. The flock is discontinuous and in flux and made of micro time-scale artefacts. What differs from the stream and cluster arrangements, however, is that while the former two were layered by hand and time-stretched, the flocking arrangement occurs organically via encoding. The flocking grouping of sounds is one of a variety of natural organisations of encoded complex timbres in which a level of complexity can still be heard while still sitting below the threshold of noise, a phenomenon referred to in Chapter 4.3.1 as *noids*.

Inputs and Encoding Variables

Pink Noise
8 kbps 24 kHz

Blue Noise
16 kbps 24 kHz
8 kbps 24 kHz

Structure and Musical Elements

Section 1 – 0’00 – 2’18

Section 2 – 2’18 – 4’40

Section 3 – 4’40 – 9’30

Below is a screenshot of the Ableton Live project’s arrange window of the whole work with the sections delineated using orange lines.

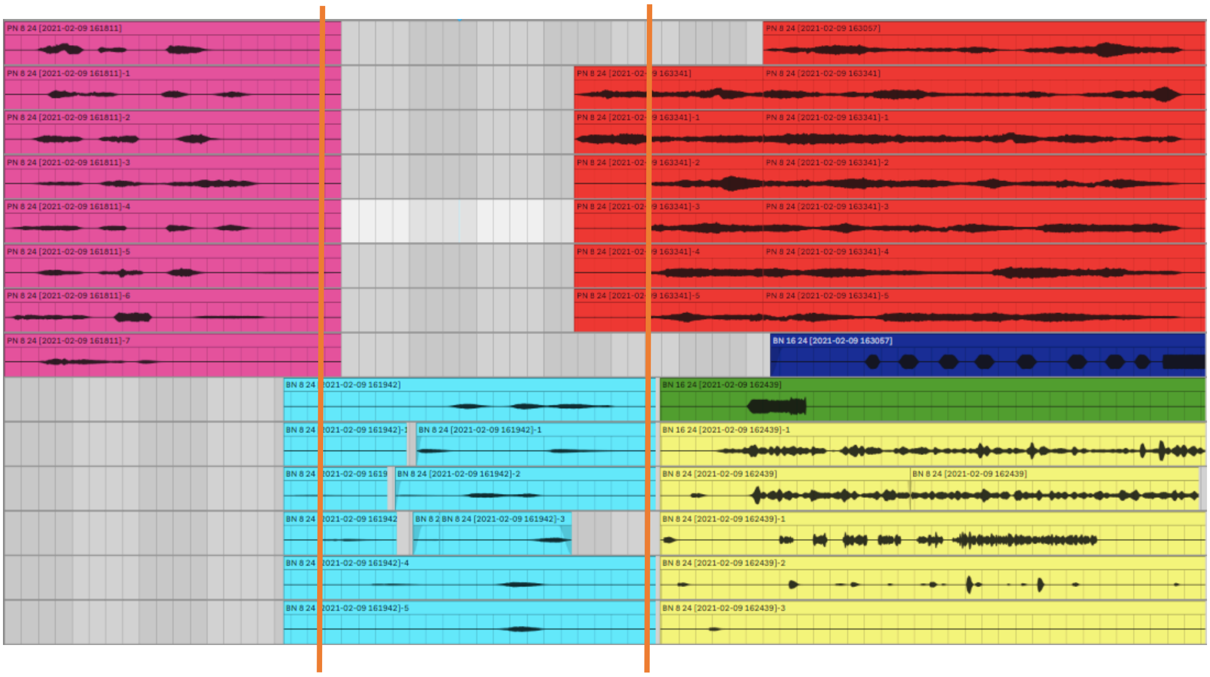

Figure 5.6: Screenshot of Ableton Live project showing overview of piece Pink Blue

The work’s various musical elements can be seen in the screenshot of the Ableton Live project and spectrogram above, and are described below with reference to the colours of audio clips.

1) Pink: Clusters of pink noise artefacts.
2) Light Blue: Clusters of blue noise artefacts.
3) Red: Continuous, streaming lines of time-stretched pink noise artefacts.

4) Dark Blue: Unencoded blue noise.
5) Green: Crescendo of blue noise followed by flocking artefacts.
6) Yellow: Time-stretched sound-object length blue noise artefacts.

Analysis

Section 1

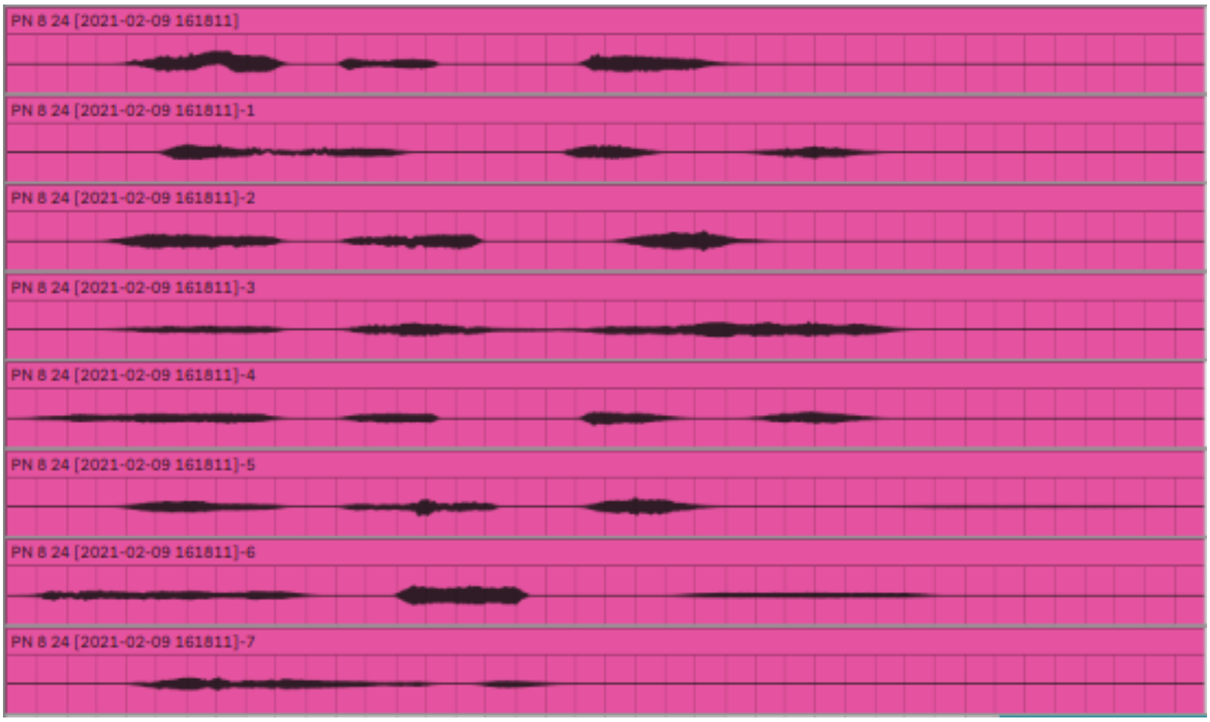

Figure 5.7: Screenshot of Ableton Live project showing overview of first section of piece Pink Blue

Above is a screenshot of the Ableton Project's arrange window showing the first section of the work, which consists entirely of time-stretched pink noise artefacts that have been arranged in clusters (pink).

As pink noise has a higher amplitude in its lower frequencies when it is encoded those louder lower frequencies are preserved while quieter higher frequencies are erased. This results in pink noise artefacts, such as these, being below 3.5 kHz. The spectral space, that is the 'distance between the lowest and highest audible sounds' (Smalley 1997, 121) is therefore narrow, though there is enough spectral space for densities and spectromorphologies of multiple artefacts to develop.

The artefacts have been time-stretched, making them sound-object length and placing them into the meso level of time division and allowing them to be structured more easily, particularly as clusters. The microtonal and discrete properties of these artefacts make them ideal for the clustering technique, as it highlights the properties of the artefacts and creates variation as their microtonalities and specific amplitude envelopes interact.

There are eight tracks in total in this section, with various stereo positions, adding a sense of movement as the lines fade in and out. While the audio sits within the same spectral space the, the stereo position of the artefacts allows for moments of fusion and fission occur as spectromorphologies go through moments of similarity and difference. In turn, the shifting densities of the artefacts in stereo space creates moments of instability and tension.

There are several clusters that occur in this section, with spectral movement between them as they rise and fall in density, amplitude, and spectral colour. The clusters in this section create complex shifting microtonal relationships within an evolving structure.

Section 2

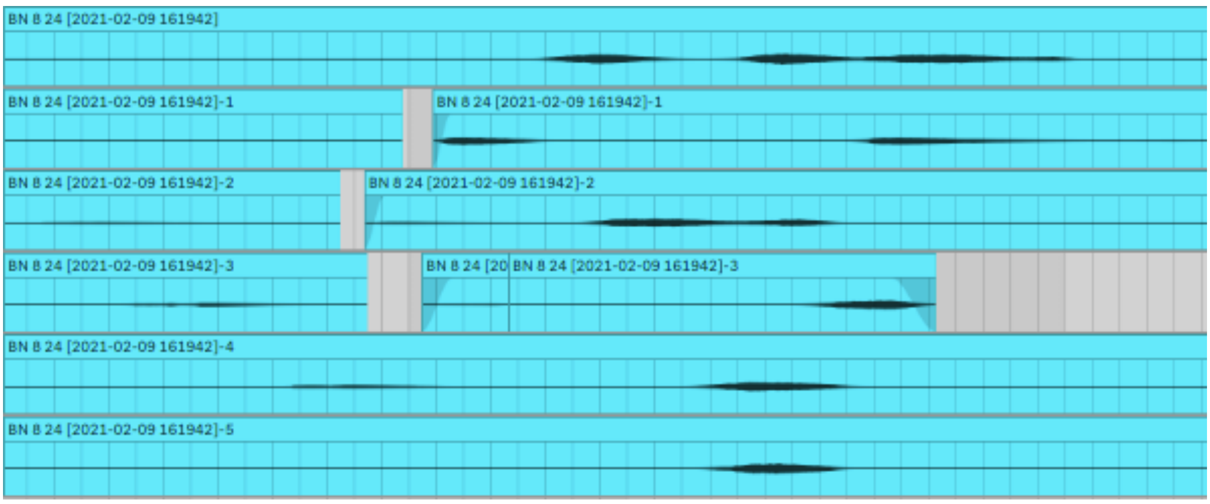

Figure 5.8: Screenshot of Ableton Live project showing overview of second section of piece Pink Blue

Above is a screenshot of the Ableton Live arrange window showing the second section of the piece, which consists entirely of time-stretched blue noise artefacts that have been arranged sparsely at first, and then in clusters later. Blue noise has greater amplitude in higher frequencies and, using the encoding variables outlined above, has created artefacts that sit in a frequency range from 5 kHz to 11 kHz.

Four of the six tracks are panned to the centre with one being panned 28L and the last 27R, which decreases the sense of space and movement.

The artefacts in section 2 are made of high frequencies and low amplitudes, at times making them almost inaudible, creating contrast with the first section. The number of artefacts used increases as the section develops, from one at a time to two, three and four-artefact clusters.

The first four artefacts are on their own, and begin at 2’18, the second artefact begins halfway through the first, and has a rasping quality, developing into a consistent tone. The third artefact in this section begins at 2’55 and lasts until 3’10 and consists of a fairly constant tone. The fourth artefact begins with complexity, but also a strong frequency running throughout.

The rest of section 2 consists of four clusters, the first is made of two artefacts. The next cluster also consists of two artefacts, at similar frequencies to the first. It begins as the previous cluster fades out, at 3’32 and lasts until 3’59. The third and fourth clusters fuse into one another. The third cluster begins at 3’59 and ends at 4’26, while the fourth cluster begins at 4’18 until the section ends at around 4’40.

This section displays more subtle characteristics of compression artefacts, and shows that artefacts can move between different types of timbral quality. While the section includes mostly quiet, high-pitched spectral properties, there are also complex timbres that occur, giving the section textural variation, while also contrasting with section one which was spectrally dense with a range of dynamics.

Section 3

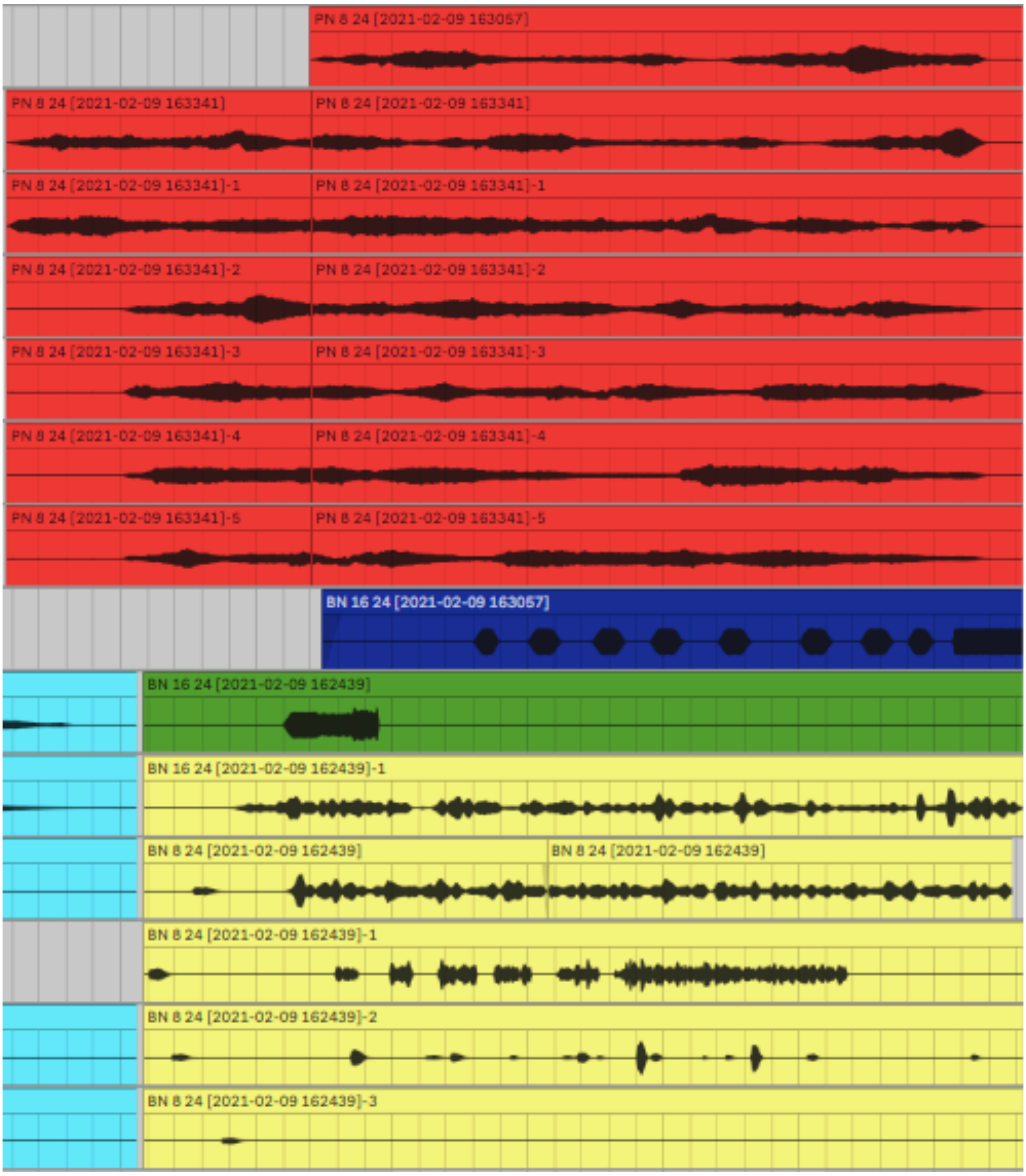

Figure 5.9: Screenshot of Ableton Live project showing overview of third section of piece Pink Blue

The above screenshot shows the third section of the piece in the project's Ableton Live arrange window. Encoded pink noise that has been time-stretched and layered (red), with time-stretched sound-object length blue noise artefacts (yellow). There are also waves of unencoded blue noise (dark blue) and a crescendo of blue noise followed by flocking artefacts (green).

This section begins at 4'40 with the reintroduction of time-stretched pink noise artefacts, though here they are structured using a streaming technique (red). These time-stretched pink noise artefacts are layered and each track has a fixed stereo position. As with moments in section one, here there are also examples of musical elements that occupy similar spectral positions fusing and fissuring over time, as the sounds morph in different stereo positions.

Blue noise artefacts are also reintroduced at various time lengths with some being as brief as several seconds and others merging into continuous morphologies. For example, at 5'12 discrete sound object length blue noise artefacts are introduced and at 5'36 two lines of continuous blue noise artefacts are introduced continuing for most of this section. As the pink and blue artefacts sit in different areas of the spectrum, they both contribute to the streaming effect.

At 5'52 the first in a series of unencoded blue noise fades in, which enters and leaves ten times. This first wave of blue noise, however, is succeeded by micro timescale blue noise artefacts at 6'00 (green). Using the artefacts at their natural timescale has resulted in a flocking effect naturally occurring within the encoded audio, showing that the encoding process can also create meso-structural elements, the sounds themselves can also be considered an example of *noids* as discussed in chapter 4.3.1.

Additionally, the beats phenomenon can be heard at different times in this section, for example from 7'18 to 7'22, they can be heard to slow down and the speed up again. This phenomenon occurs when nearly equal simple tones are heard simultaneously, the microtonal nature of pitched artefacts therefore increases the likelihood of beats occurring. As the microtonal pitched artefacts move closer to and further from one another in pitch, so the beats increase and decrease in speed, creating subtle rhythms within the shifting layers of artefacts.

As this section progresses with these elements, the spectromorphologies of the artefacts give a constant sense of change, with the waves of unencoded blue noise adding structure and tension to the section and acting as the final texture of the work into which the other timbres disappear as they fade out.

5.4 Blue Red

Title of Work

Blue Red

Brief Background and Overview of Structure

Early drafts of the work were written in September 2021 and were then developed in January and February 2022. One of the goals was to create timbral variation by re-encoding series of artefacts, affecting their stereo positions and amplitude envelopes. The work also seeks to explore how rhythmically displaced phrases of different lengths interact with one another over time to create variation with the material.

The piece's length is 11'32, it is made predominantly from blue noise artefacts with some encoded red noise, and it consists of three sections. The first and second sections introduce various musical elements, while the third sections combines them and adds further elements.

Investigations

One of the key techniques explored in this work is the re-encoding of a series of identical artefacts, resulting in further changes to the properties of individual artefacts within the series. The changes that occurred were to the stereo positions, amplitudes, and envelopes of artefacts, creating the time-smearing effect pre-echo, amplitude fluctuations, and shortened envelopes. The artefacts were affected individually, resulting in variation across the series.

The stereo position shifts from one artefact to the next, caused when encoding at low bitrates using stereo encoding processes, more of which can be read about in the taxonomy section of the text. The stereo movement combined with the amplitude fluctuations and changing envelopes creates a greater sense of gesture, and, as the variation does not develop predictably, a sense of instability and tension.

Pitch-shifting was used to make artefacts' properties that would not be heard at their normal pitch audible, while also making use of spectral areas that might not be explored due to bandwidth limitation. This does not counter the effect of bandwidth limitation, but instead allows the pitch-shifted artefacts to stand out as they are used sparingly.

Another structural technique this work explored was how rhythmically displaced phrases made from artefact series of different lengths interacted with one another over time. The result was the creation of variation as artefacts phased in and out of time with one another, creating new rhythms, harmonies, and timbral relationships.

Authenticity was an important aspect of this work. In an earlier draft of the work, stereo movement and envelope changes were evoked using an auto panning processor, rather than created with a compressor. The auto-pan plug-in changed the stereo position and envelopes, but, re-encoding the series of artefacts resulted in authentic stereo movement, signal drop out, amplitude fluctuations, and artefact envelope changes. It was important to do this as there was a clear difference in timbre between the two processes. The sounds made with the plug-in were louder and more gestural, but the artefacts made using the compressor had the added effect of pre-echo and amplitude fluctuations.

Also, perhaps most importantly, as this project is concerned with the properties of data compressed audio, it is important to present those artefacts directly. This project seeks to exhibit as many properties of these artefacts as possible, and the most efficient means of doing that is to use a real compressor.

The last section of the work uses cumulative delays, which are additional lengths of silence at the start of a clip of encoded audio, therefore becoming longer with each cascade. The cumulative delays help to create structural development as the delays increase over the course of the section.

In addition to the structural effects, the suddenness of the delays creates moments of suspense, which are resolved with the reintroduction of the encoded noise. As the work reaches its conclusion, all elements, except for this one, fade out. When the now unaccompanied encoded noise drops out as the final abrupt gesture of the piece, the expectation that it will be resolved is unfulfilled creating a suspenseful ending to the work.

Inputs and Encoding Variables

Blue Noise
8 kbps 8 kHz (Lame)
8 kbps 16 kHz
8 kbps 24 kHz

Red Noise
8 kbps 8 kHz (Lame)

Structure and Musical Elements

Section 1 – 0’00 – 2’21
Section 2 – 2’21 – 6’40
Section 3 – 6’40 – 11’32

Below is a screenshot of the Ableton Live project’s arrange window of the whole work with the sections delineated using orange lines.

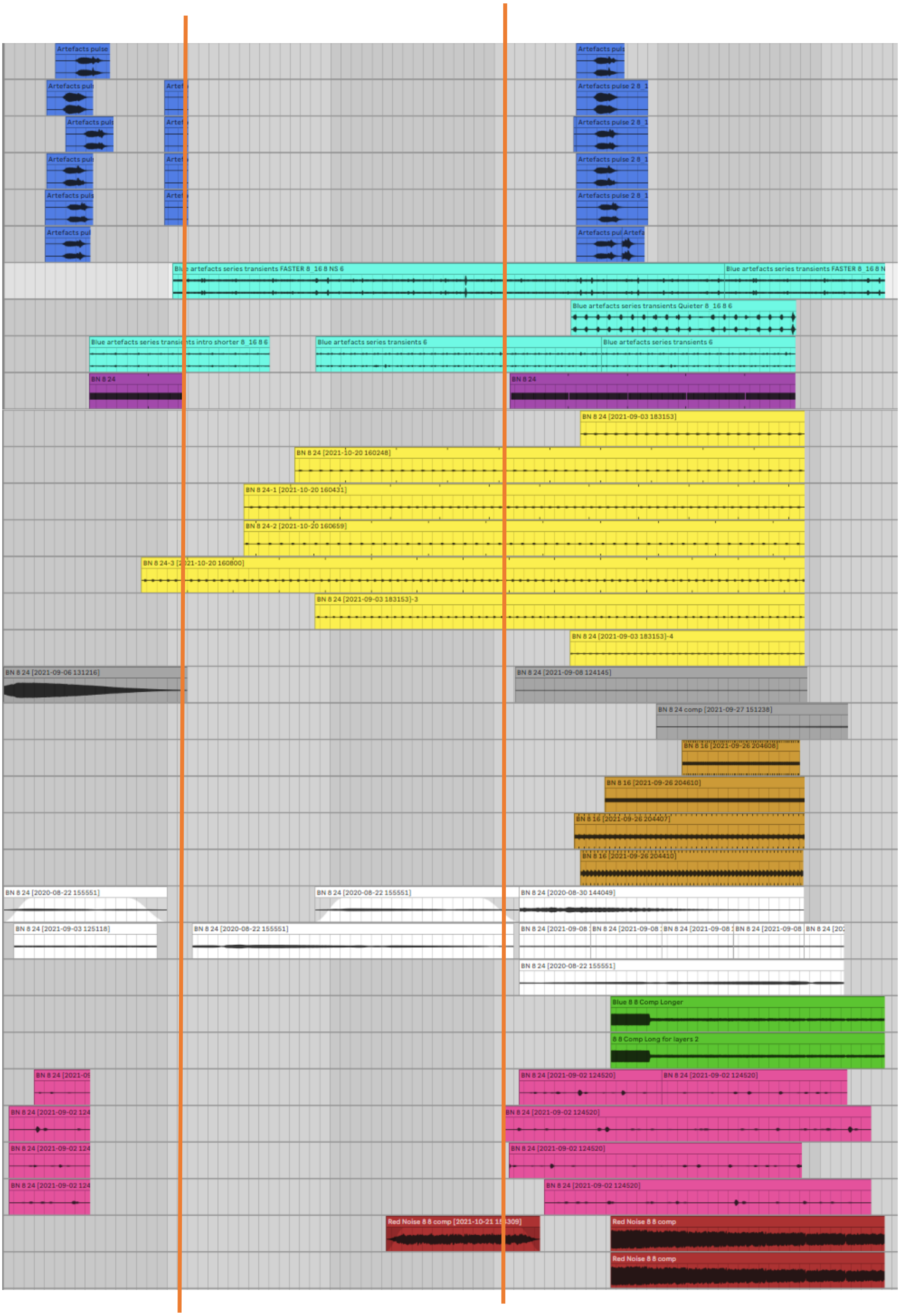

Figure 5.10: Screenshot of Ableton Live project showing overview of piece Blue Red

The work’s musical elements can be seen in the screenshot of the Ableton Live project and spectrogram above, and are described below with reference to the colours of audio clips.

1) Dark Blue: Clusters of time-stretched artefacts that have created a distorted, rasping quality.
2) Light Blue: Re-encoded series of blue noise transient artefacts.
3) Purple: Discontinuous periodic rhythms made using edited blue noise transient artefacts.
4) Yellow: Layers of rhythmically displaced phrases made from time-stretched discrete blue noise artefacts.
5) Grey: Time-stretched artefacts which have been pitch-shifted up.
6) Brown: Layers of rhythmically displaced phrases made from clips of blue noise artefacts.
7) White: Time-stretched artefacts that have been pitch-shifted down creating a pedal note.
8) Green: Encoded blue noise with cumulative delays.
9) Pink: Sound object length blue noise artefacts.
10) Red: Encoded red noise with cumulative delays.

Analysis

Section 1

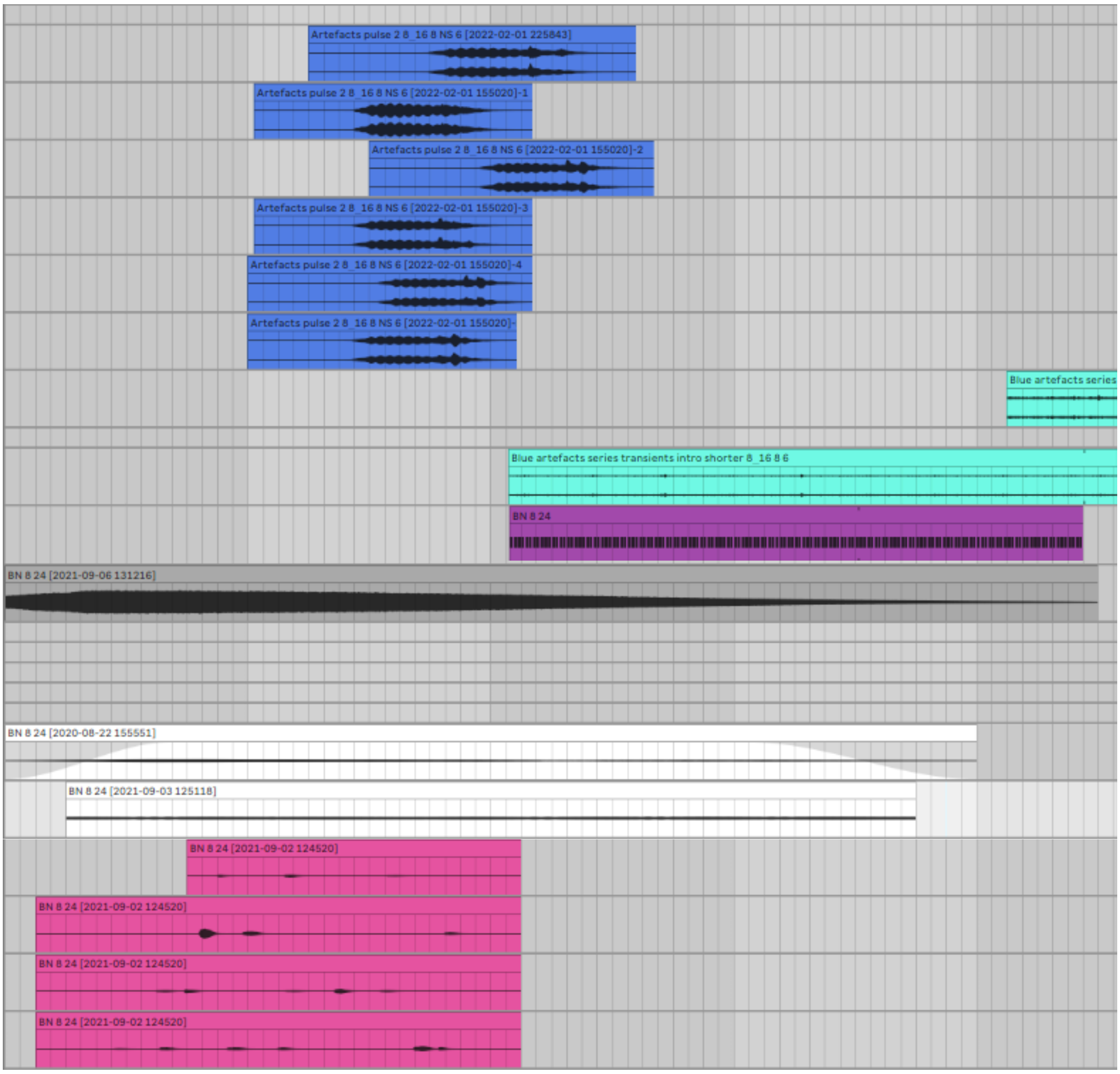

Figure 5.11: Screenshot of Ableton Live project showing overview of first section of piece Blue Red

Section one has six musical elements that include a time-stretched and pitch-shifted artefact which has created a high-pitched ringing (grey), sound object length blue noise artefacts (pink), two time-stretched and pitch-shifted artefacts creating a bass pedal note (white), clustered time stretched artefacts that have created a distorted, rasping effect (dark blue), a discontinuous periodic rhythm of blue noise artefacts (purple), and that same series of blue noise artefacts re-encoded (light blue).

The first section begins with the time-stretched and pitch-shifted ringing artefact at a very high pitch (grey). The artefact lasts until 2’05, fading out as the section concludes. It has been pitch-shifted up to draw out new timbral characteristics of the artefacts that would not normally be heard and to create variety in pitch in the work. The artefact is time-stretched, quiet, and high-pitched creating a subtle and consistent beginning to the piece.

At 0’21 the pedal note is introduced (white), which is made from two time-stretched and pitch-shifted down blue noise artefacts, and acts as a bass drone throughout the section, with some spectromorphological changes as the section develops.

Four tracks of time-stretched and pitch-shifted down sound object length artefacts are introduced at 0’14 continuing until 1’00 (pink), each of which sits in a different stereo position. The different stereo positions of these artefacts contrast with the drones, and introduce a theme of stereo, spatial movement that is explored later in the work.

A cluster of rasping sounds occurs between 0’57 and 1’09, made by re-encoding time-stretched blue noise artefacts using a normal stereo setting (dark blue). These artefacts have been created through re-encoding artefacts using stereo settings, creating new textures and subtle stereo movement. A sense of distance is created due to the artefacts’ spectral properties, and disintegrating texture as decreases in amplitude.

The droning, pitch-shifted down, and rasping artefacts of the opening moments of the piece combine to create a brooding and ominous atmosphere. This atmosphere, however, is altered when a discontinuous periodic rhythm of edited transient artefacts every 2 Hz/0.5 seconds (purple) is introduced at 1’08.

This series of transients was then re-encoded to make the final musical element of the section, which is introduced at 1’32 (light blue) and displays stereo movement, amplitude variation, and changing amplitude envelopes introducing variation into the piece at a higher tempo.

This type of rhythm is similar to the meccanico approach used by Ligeti, wherein pizzicato rhythms evoke notions of mechanical failure. In this example, however, the re-encoding of the series of transient sounds goes further than evoking the idea of failure as the sounds are heavily affected by the encoding processes and therefore are literal failures.

This final element was encoded using a normal stereo setting, creating stereo movement and time smearing artefacts, and by using a series of transients, it is possible to hear how the encoder has caused the amplitude envelope and stereo placement to change from one transient to the next.

The section ends at 2’21 when all of the elements used in the first section have faded out.

Section 2

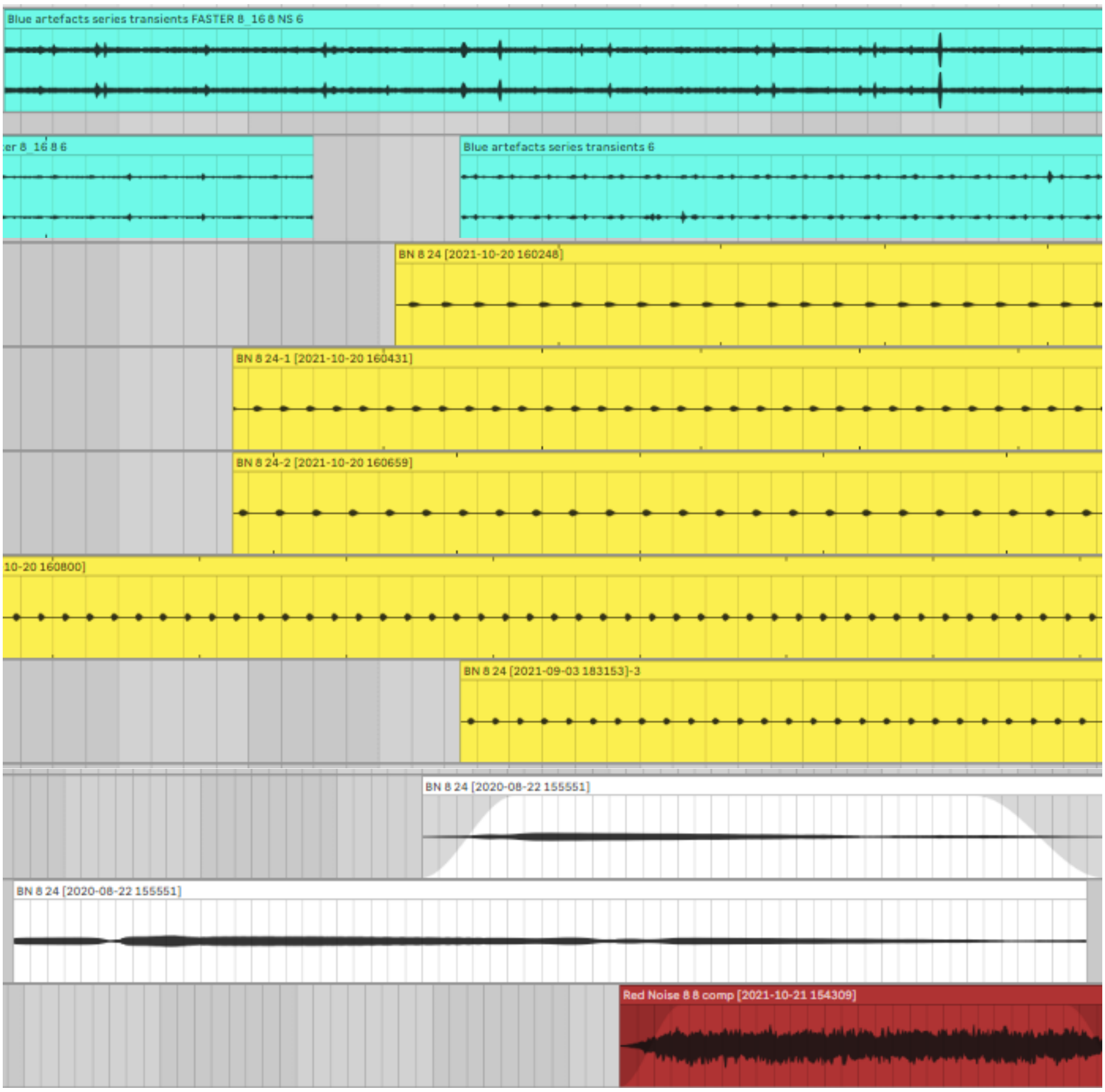

Figure 5.12: Screenshot of Ableton Live project showing overview of second section of piece Blue Red

Section 2 begins at 2’21 and lasts until 6’40. There are five musical elements in section 2, including two series of re-encoded transients (light blue), rhythmically displaced phrases of time-stretched blue noise artefacts made using five tracks that drift in and out of time with one another (yellow), another pedal note made from two tracks (white), and encoded continuous red noise (red).

A re-encoded series of transient artefacts fades in as the second section begins, with the artefacts appearing every quarter of a second, or 4 Hz, and increasing in volume gradually throughout the section.

Five tracks of rhythmically displaced phrases of time-stretched blue artefacts are slowly introduced, the first fading in before the first section has finished, at roughly 1’50. The different tracks sit at different spatial positions and have different lengths of time between each artefact creating a slowly evolving effect as artefacts phase in and out of time with one another. These last for the majority of the section and explore moments of fusion and fission as the similar sounding artefacts interact with one another in time and space (for more information see section 4.3.2).

The series of re-encoded artefacts used in section 1 is introduced at 4’04, but can be difficult to hear until 4’50. These re-encoded artefacts again depict shifting stereo positions, changing amplitude envelopes, pre-echo, and amplitude fluctuations showing how the compression process can affect transient signals differently in a series. They also create variation at a faster tempo compared with the slower moving and rhythmically displaced artefacts (in yellow).

Two time-stretched and pitch-shifted down artefacts act as pedal notes throughout this section. Using an auto pan plug-in on one of the tracks, a slow pulsing effect is created giving variation in volume and stereo position.

As a whole the section is sparse, and gives the listener time to hear the details of the various shifts in timbre in the re-encoded series of transient artefacts, while variation occurs at a slower time-scale with the rhythmically displaced artefacts.

The section comes to an end as a clip of encoded red noise fades in at 5’10 with all of the artefacts fading out at 6’40.

Section 3

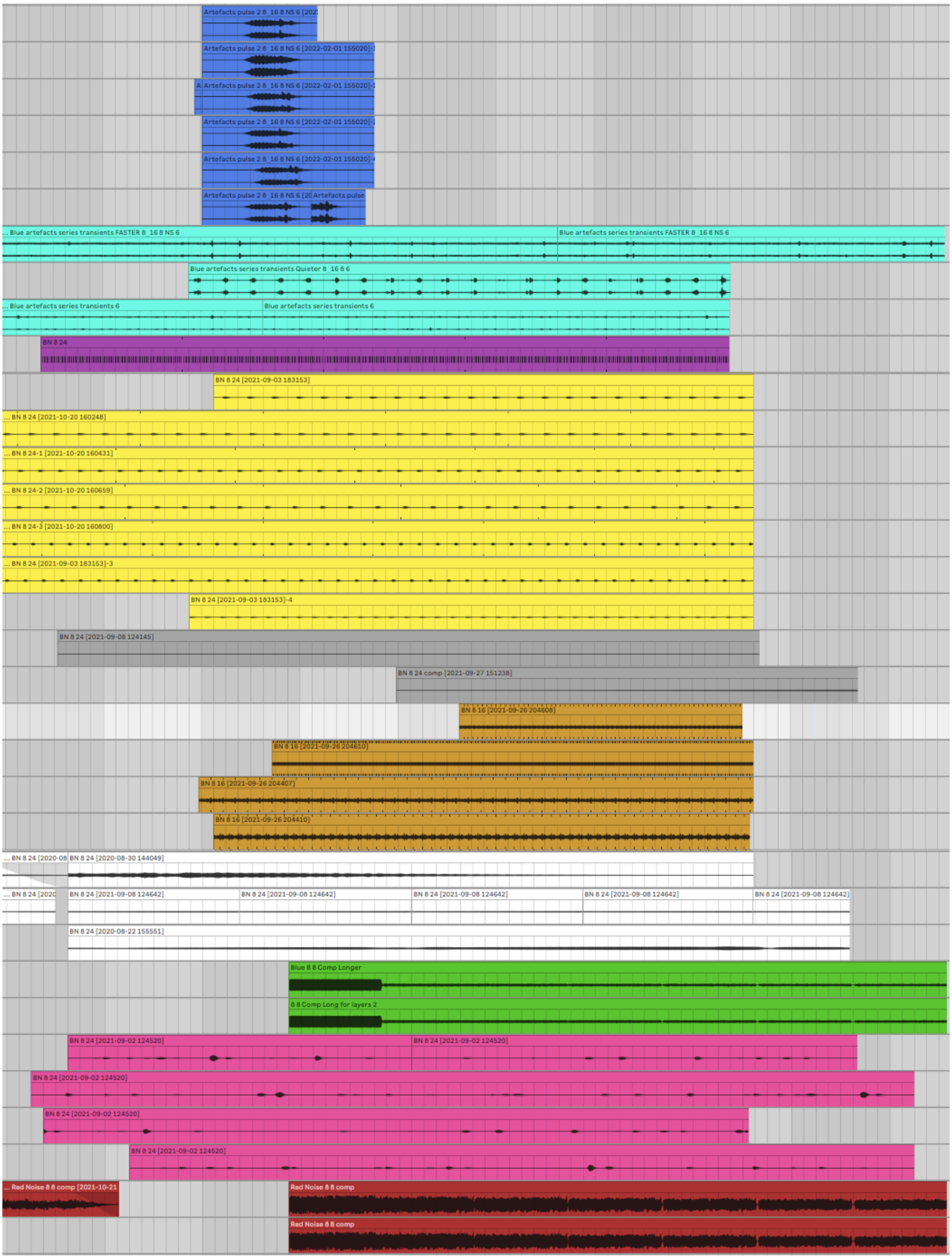

Figure 5.13: Screenshot of Ableton Live project showing overview of third section of piece Blue Red

Section 3 begins at 6’40 and consists of 10 musical elements, 7 of which occurred in sections 1, 2, or both. The three new elements are encoded red noise with cumulative delays (red), encoded blue noise with cumulative delays (green), and rhythmically displaced clips of encoded blue noise artefact series (brown) which can be heard from 7’28 and continue for most of the section.

The section begins with time-stretched and pitch-shifted blue noise artefacts (white) with one at a frequency of roughly 1 kHz, while the other two acts as a pedal bass note, and use the auto pan plug-in again, creating a regular pulse.

The time-stretched and pitch-shifted high-pitched ringing drone from the opening of the piece (grey) fades in again from 7’00.

Sound object length blue noise artefacts can be heard fading from the start of the section (pink) and from 7’20 the discontinuous periodic rhythm made using edited blue noise artefacts can also be heard (purple).

The section makes use of higher tempo rhythms, such as the re-encoded transient artefacts that have also been heard throughout the work (light blue), and the rhythmically displaced blue noise artefacts, introduced at 7’28, which have been kept at their original timescales (brown). The rhythmically displaced blue noise artefacts are layered and in their natural timescale resulting in rapid, almost textural, repetitions that overlap with one another creating intersecting rhythms and gestures.

The clusters of rasping artefacts from the first section can be heard again from 7’45 (dark blue) and at 7’56 unencoded red (red) and blue (green) noise fades in. This noise is followed by its encoded iterations which are continuous and have increasingly long delays at the beginning of each iteration, creating cumulative delays. The consistency of cumulative delays gives this section of the work a sense of structure, showing the importance of the methodology, particularly cascading, in creating not only sonic material for the work but also effects that create formal and structural properties.

Two tracks of re-encoded transient series of artefacts fade in at around 8’15, most clearly heard after the unencoded red noise crescendo finished at around 8’30.

The rhythmically displaced time-stretched artefacts are reintroduced at 8’34. As the section develops all but the encoded red and blue noise fade out. The iterations continue with the delays increasing until the final iteration stops and is not replaced, which in turn results in a moment that is conclusive in its abrupt silence, while also suggesting tension as it subverts expectations by not being reintroduced.

5.5 Red White Blue Violet

Title of Work

Red White Blue Violet

Brief Background and Overview

The piece was written between June and August 2021, and makes use of a technique wherein artefact’s rhythmic properties are used to trigger other artefacts. The work also explores the rhythm to tone continuum by repeating artefacts to the point that a continuous tone is created. Additionally, time-stretched streaming artefacts are also used, and a technique in which series of artefacts is duplicated and played simultaneously, with one quantized. These techniques allow for the exhibition of intrinsic rhythmic characteristics and spectral properties of the artefacts, and to refer to the temporal shifts that occur during the encoding process. The work is in three sections, with the first and third using all of the musical elements, and the second mostly comprising of a duplicated series of artefacts.

Investigations

The first musical element in this work uses a technique whereby the transient properties of a series of artefacts act as triggers for other compression artefacts, allowing the rhythmic structures inherent within the encoded audio to be the prominent sonic characteristic. The artefacts and effects therefore are not only new sonic material but also a means of creating new structures. The encoding process has allowed for effects and artefacts to be created; as well as long form structural processes via iterations of cascading. However, using a series of artefacts in this way also opens up the opportunity to explore sub-structures and rhythms using the properties of the artefacts.

The work also uses edited artefacts to create continuous periodic tones allowing some of the spectral characteristics of the artefacts to be heard consistently over an extended period of time and to also act as pedal notes and drones. This contrasts with the time-stretched artefacts, whose shifting spectromorphologies are at meso-length timescale allowing their properties to be perceived, to explore microtonal harmonic relationships, while contributing to the work's sonic and musical development over the course of the piece.

The second section is brief and uses an audio clip of a series of artefacts, which was duplicated and panned. One of these duplicated clips was quantized while the other was left in its original rhythm. This creates the effect of shifting rhythms between the ears, while also evoking certain techniques used by compression algorithms in which sounds are binned into neighbouring frames and windows changing their position in time. The artefacts in this section are at sound object length, meaning they, and their rhythmic structures, can be heard easily.

The artefacts described above are, for a short time, the only sounds in the second section. A key characteristic of the this section is the effect *signal gaps*, which depict silence as a form of interference, creating moments of tension as sonic gestures are broken and interrupted.

Inputs and Encoding Variables

Red Noise
8 kbps 8 kHz

Blue Noise

8 kbps 24 kHz

White noise

8 kbps 16 kHz

8 kbps 24 kHz

Violet Noise

8 kbps 24 kHz

Structure and Musical Elements

Section 1 – 0’00 – 2’04

Section 2 – 2’04 – 3’09

Section 3 – 3’09 – 7’54

Below is a screenshot of the Ableton Live project’s arrange window of the whole work with the sections delineated using orange lines.

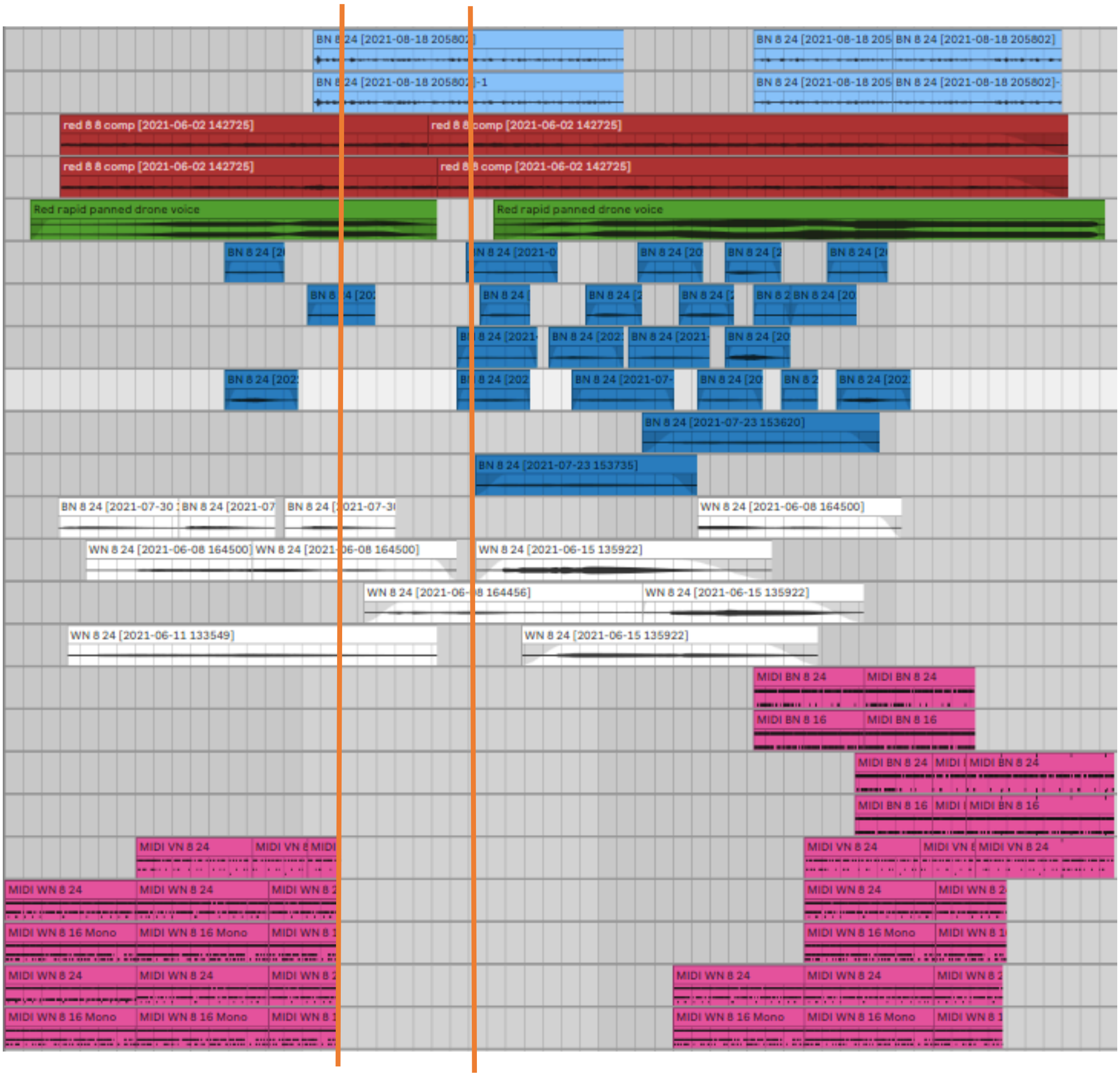

Figure 5.14: Screenshot of Ableton Live project showing overview of piece Red White Blue Violet

The work's musical elements can be seen in the screenshot of the Ableton Live project and spectrogram above, and are described below with reference to the colours of audio clips.

1) Pink: Edited artefacts from white, violet, and blue noise arranged using another series of artefacts as triggers in MIDI
2) Red: Time-stretched clips of encoded red noise which have been panned
3) Green: Continuous periodic tone made using edited artefacts
4) White and Blue: Time-stretched discrete white and blue artefacts

5) Light Blue: Sound object length blue noise artefacts, panned and with one quantised

Analysis

Section 1

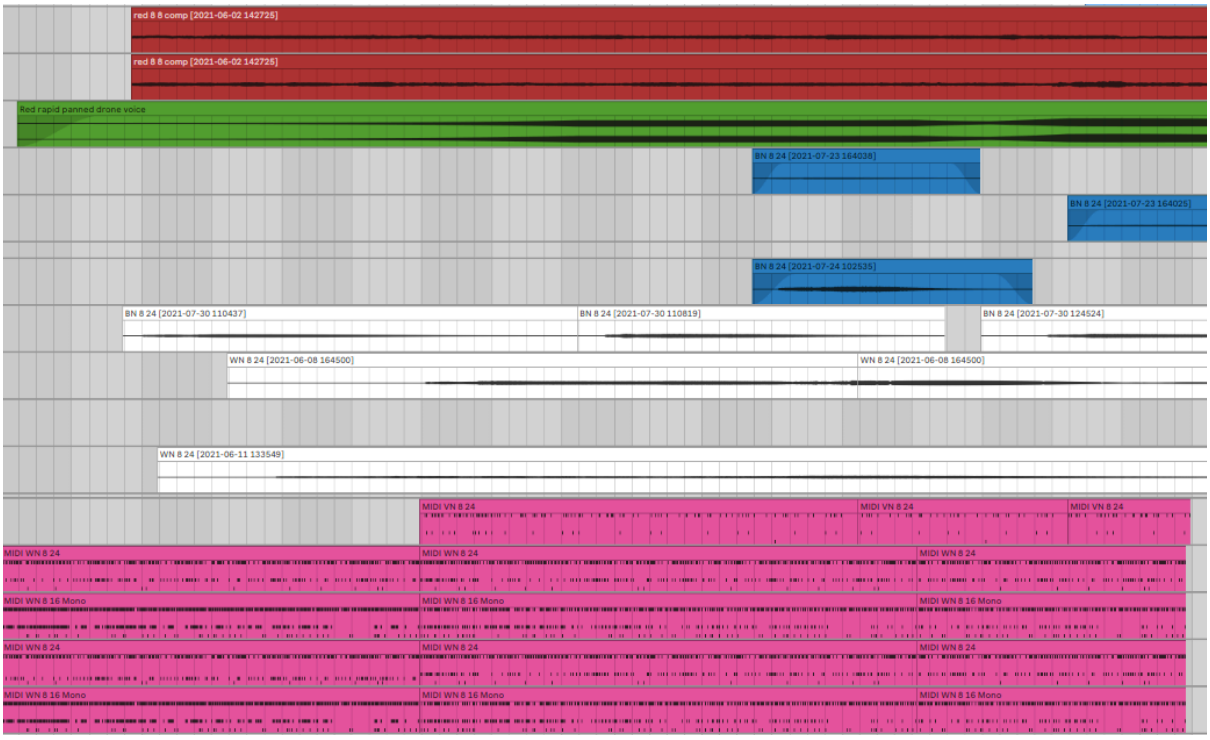

Figure 5.15: Screenshot of Ableton Live project showing overview of first section of piece Red White Blue Violet

The first section lasts until 2’04 and uses a variety of musical elements. The first comes from a technique wherein the transient properties of a series of artefacts are used as triggers for other compression artefacts, allowing the rhythmic structures inherent within the encoded audio to be the prominent sonic characteristic (pink).

This was done by converting a clip of artefacts from audio to MIDI using the ‘convert drums to new midi track’ function in Ableton Live. This used the transients of the artefacts in the audio clip as markers for reconstructing the rhythm in the MIDI clip. The rhythm was then reconstructed using a limited number of samples, creating a defined palette and meaning that idiosyncrasies of the artefacts' spectromorphologies did not draw attention away from the rhythmic properties of the artefact series.

Another means of highlighting the rhythms of the artefact series was to edit the MIDI notes so that just the attack of the artefacts could be heard, making them more percussive, and placing them onto a micro timescale.

The piece begins with four tracks using the techniques described above wherein white noise is used as both the clip from which the transients act as triggers and the artefacts which are being triggered. Two of these tracks are panned left, one is panned right, and the last in centred. At 0'56 a fifth track enters, made using the same process as the others, though with artefacts made using violet noise.

Below is a screenshot taken from the arrange window of the work's Ableton Live project showing how the different elements that make up the section have been arranged. The track at the top is the rhythm made of edited violet noise artefacts, while the four below it, are made from white noise artefacts.

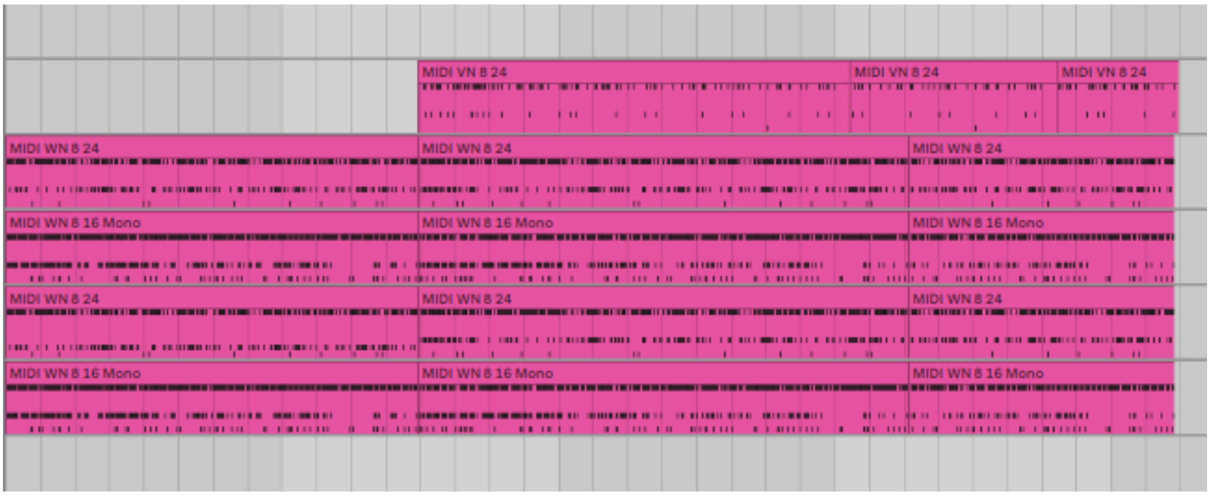

Figure 5.16: Screenshot of Ableton Live project showing the musical element made from triggered artefacts in section one

A red noise artefact that has been to create a continuous periodic tone, and enters at 0'20 (green).

Two clips of time-stretched encoded red noise enter at 0’30, with the two tracks panned left and right respectively (red). They are layered and their spectromorphologies result in a streaming effect. Additionally, their undulating spectromorphologies which are similar in terms of spectral space, though different in terms of specifics, create moments of fission and fusion. The moments of difference highlight the physical space of the work, the moments of similarity fuse together creating a sound across the stereo field narrower sense of space.

The encoded red noise is positioned at the back of the work, with other sonic figures including the fast-paced rhythmic gesture in the foreground. The difference between these elements, and the positions they occupy in distance, is created through amplitude, spectral positions, and amplitude envelopes.

There are also individual blue noise artefacts that have been time-stretched. As they sit higher in the frequency range, so they contribute to the streaming effect but are also spectrally distinct. Much like the time-stretched blue noise artefacts, there are also some time-stretched white noise artefacts which also fade in and out due to their automated volumes, again, contributing to the streaming effect. The drone and time-stretched artefacts exist at the level of meso timescale, seconds and minutes in length, and are structured in streams.

At 0’47 the envelopes of the MIDI arranged artefacts (pink) are edited further, making them even shorter, more transient and percussive.

The MIDI arranged edited artefacts (pink), time-stretched drones (red), continuous periodic tones (green), and time-stretched white and blue artefacts (white and blue) continue in this section until they fade out or stop. All of the MIDI arranged white noise artefacts stop at 1’52, and the violet noise artefacts fade out, stopping completely by 2’04.

The drones and other artefacts overlap with the second section, fading out completely by 2’56.

Section 2

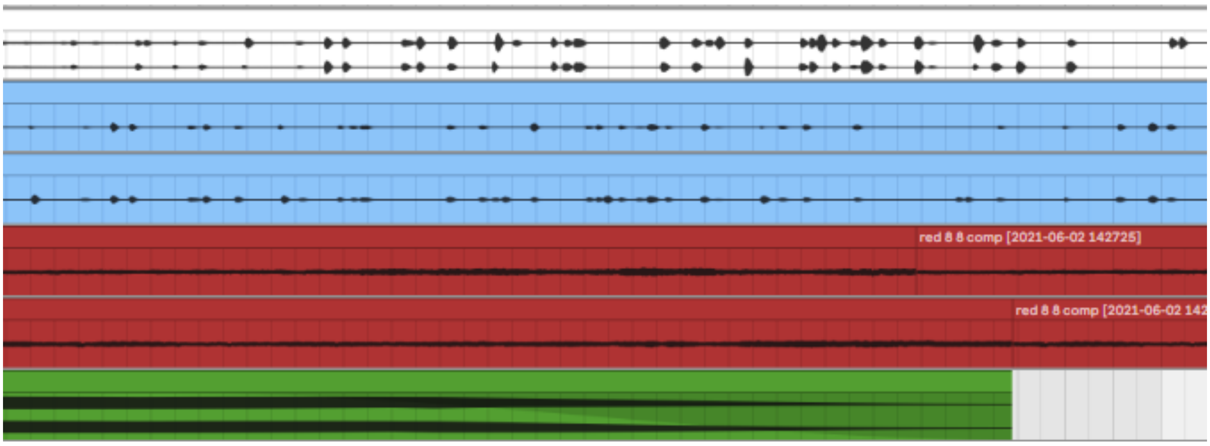

Figure 5.17: Screenshot of Ableton Live project showing overview of second section of piece Red White Blue Violet

The second section begins at 2’04 with time-stretched discrete artefacts at sound object length becoming the most prevalent element in the section, between 2’40 and 3’09 (light blue).

The artefacts which have been doubled, set across two tracks and panned. one of the clips has been quantized using the ‘warp’ function in Ableton Live creating variation between the quantized and unquantized clips.

This creates the effect of shifting rhythms between the ears, while also evoking certain techniques used by compression algorithms in which sounds are binned into neighbouring frames and windows changing their position in time and affecting their amplitude envelopes. The section lasts from 2’04 to 3’09 when parts from the first section are reintroduced and the piece transitions into the third section.

Section 3

Figure 5.18: Screenshot of Ableton Live project showing overview of third section of piece Red White Blue Violet

Above is a screenshot of part of the Ableton Live arrange window showing the third section of the piece.

The third section begins at 3’09 as the musical elements from the first section continuous periodic tones (green), the time-stretched panned continuous encoded red noise, the sound object length blue and white noise artefacts, and the triggered artefacts (pink) are reintroduced.

The continuous periodic tone re-enters the piece at 3’09 (green) and fades out at 7’40, while the time-stretched encoded red noise (red) re-enters at the same point and stops being audible at 7’05.

Additionally, from 5’36 the quantized and unquantized blue noise sound object artefacts (light blue) from section 2 are reintroduced and fade out at 7’09.

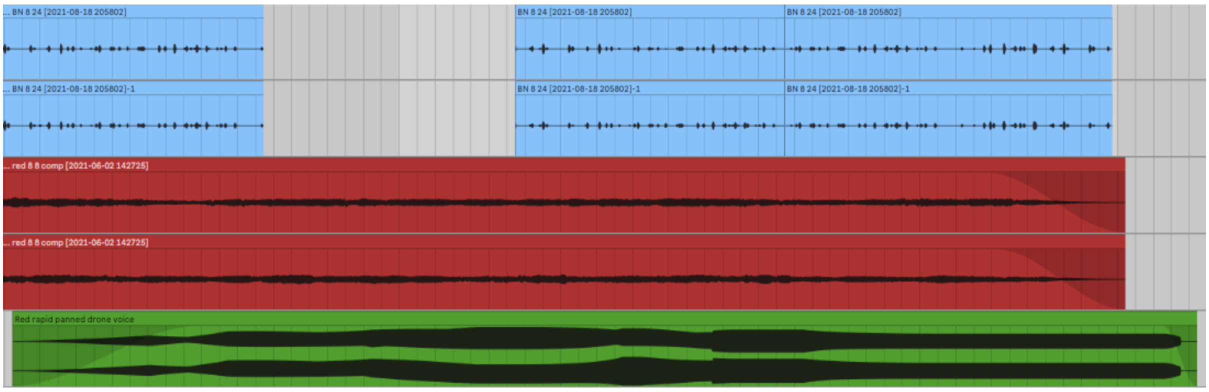

Figure 5.19: Screenshot of Ableton Live project showing three musical elements from section two

The amount of time-stretched blue noise and white noise artefacts increase and are layered creating a streaming effect. These artefacts fade out between 6’05 and 6’10 though can be difficult to hear due to the sonic complexity of the section. The arrangement of these artefacts in the third section is shown in the image below.

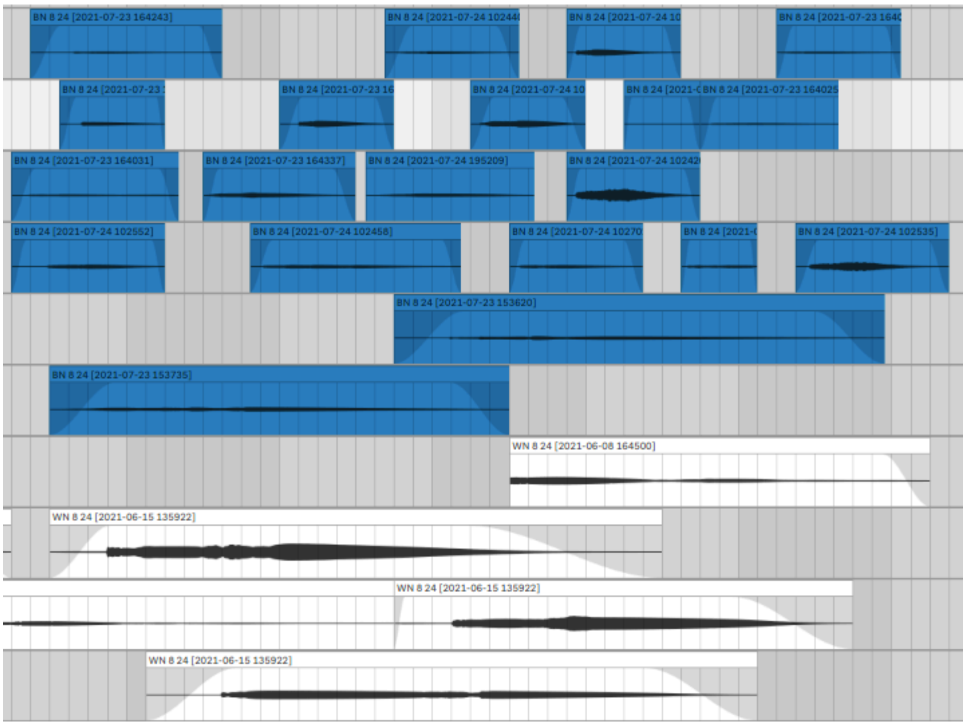

Figure 5.20: Screenshot of Ableton Live project showing time-stretched blue and white noise artefacts

At 4’51 the artefacts triggered by other transient signals are reintroduced (pink). The original five tracks from the first section continue as they were at the end of section 1 and another four tracks are made with blue noise artefacts are added, two of which are panned left and the other two are panned right. The layers begin and end at different points and can be seen below.

Figure 5.21: Screenshot of Ableton Live project showing the musical element made from triggered artefacts in section three

The piece ends gradually, with all of the musical elements fading away except for the rhythmic MIDI blue noise, which finishes abruptly as the piece concludes.

5.6 White Pink

Title of Work

White Pink

Brief Background and Overview

The piece was written between August and September 2021 and explores the rhythm to tone continuum using continuous periodic tones made with edited artefacts, and noise bursts influenced by the work of Alva Noto and Ryoji Ikeda, to explore how interference can underpin a sense of structure. Time-stretched artefacts are used to create crescendos and tension, while bursts of unprocessed artefacts break tension by contrasting with the other material in the work. The work is split into two sections: the first section introduces most of the musical elements and the second section explores their structural effects over three subsections.

Investigations

Two similar elements in this work are the continuous tones made from periodically arranged artefacts at frequencies of 16 Hz and 32 Hz and the time-stretched artefacts, both of which act as drones, lasting for sustained periods of the work and explore different properties of artefacts.

The continuous periodic tones exhibit some of the inherent pitched characteristics of the artefact over a sustained period of time, creating an effect that was influenced by the work of glitch composer Ryoji Ikeda. The time-stretched artefacts, however, use the intrinsic spectromorphologies of the artefacts to create sonic development over time and, subsequently helping in reinforcing the work's structure. Although some of the time-stretched artefacts are not layered, their spectromorphologies have multiple layers of sonic development, allowing for the streaming effect to occur as an essential property of the time-stretched artefact.

The composition sought to investigate forms of interference as a structural tool. However, the structural interferences in this work are contrived insofar that they have been arranged and edited to create sudden shifts and development in the work. The interferences in the composition therefore refer figuratively back to the artefacts' nature as interferences within signals, via interferences within the composition. Additionally, this also places the work into a glitch music tradition of using noise is part of its fundamental material.

Inputs and Encoding Variables

White Noise
8 kbps 16 kHz
8 kbps 24 kHz

Pink Noise
Unencoded

Structure and Musical Elements

Section 1 – 0'00 – 2'16
Section 2 – 2'16 – 5'50

Below is a screenshot of the Ableton Live project's arrange window with an orange line showing the work's sections.

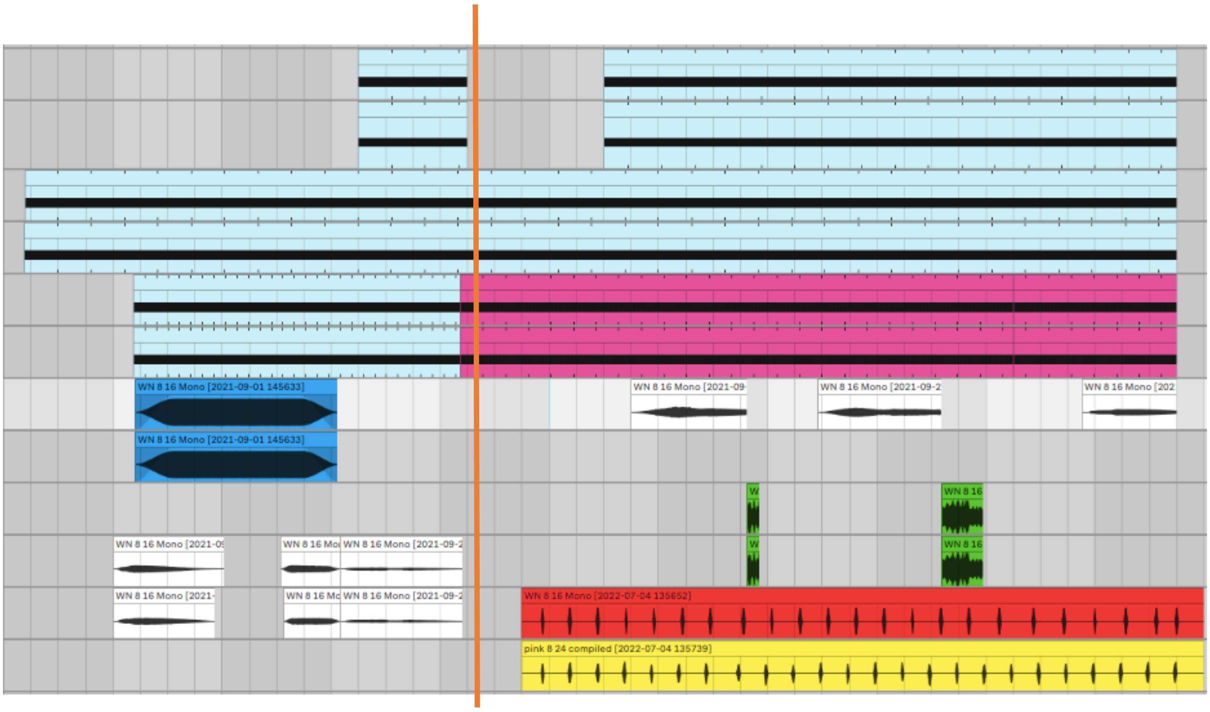

Figure 5.22: Screenshot of Ableton Live project showing overview of piece White Pink

The work's musical elements can be seen in the screenshot of the Ableton Live project and spectrogram above, and are described below with reference to the colours of audio clips in the Ableton Live project and numbered boxes in the spectrogram.

1) Light Blue: Various continuous periodic tones made using edited artefacts
2) Pink: Discontinuous Periodic rhythm made using edited artefacts at 8 Hz
3) Dark Blue: Unencoded white noise
4) White: Time-stretched artefacts
5) Red and Yellow – Bursts of unencoded noise (white noise in Red and pink noise in Yellow)
6) Green: white noise artefacts

Analysis

Section 1

Figure 5.23: Screenshot of Ableton Live project showing overview of first section of piece White Pink

Section one begins with a fade in of two of the continuous periodic tones. They are drones created by a series of white noise artefacts at frequencies of 32 Hz desynchronised by one 64th of a second and then panned left and right (light blue).

The image below shows the two desynchronised duplicate MIDI clips with the edited artefact represented as the thin black line.

Figure 5.24: Two panned audio clips of continuous periodic tones

Two more similar drones enter at 0’58, with frequencies of 16 Hz and again, desynchronised and panned. The desynchronization is eccentric, creating what is essentially shuffle rhythm at high tempo. Another continuous tone enters at 1’45 lasting until 2’10 at a frequency of 32 Hz.

This technique is used five times throughout the first section and can be seen represented by the green columns in the zoomed in spectrogram below.

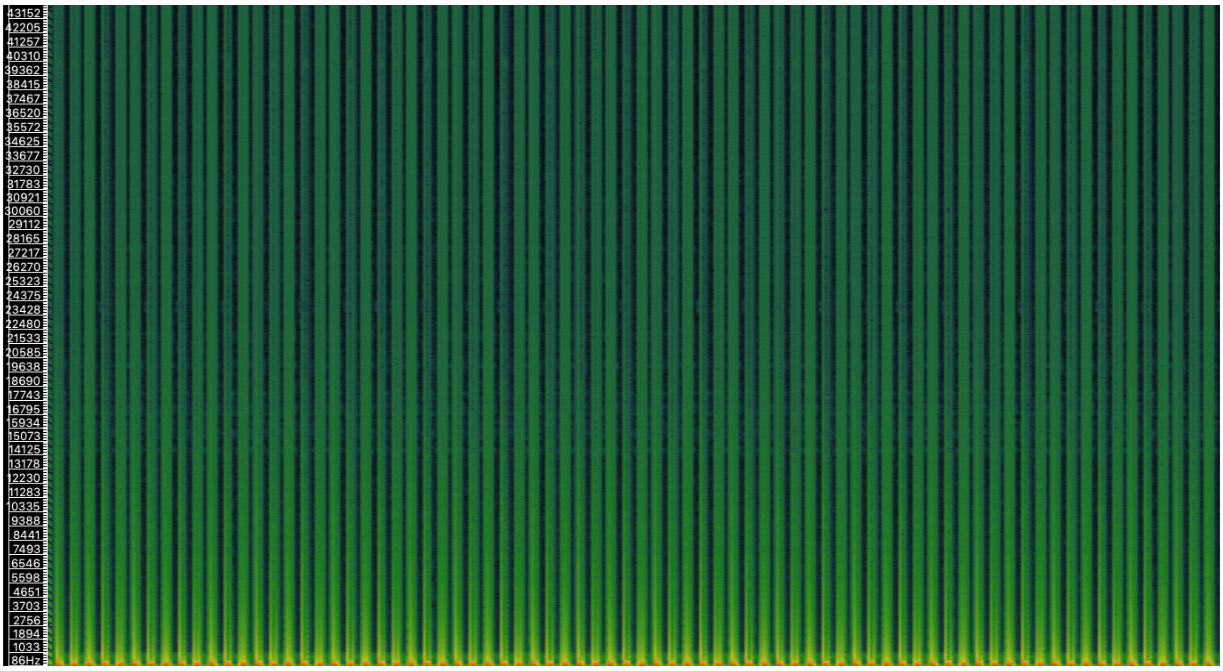

Figure 5.25: Close up of a spectrogram showing continuous periodic tones

This technique uses the compression artefacts to create a new timbre , and while the spectromorphologies of the artefacts are not exhibited, the spectral characteristics of the new timbre is caused by the artefacts' inherent tonal properties.

As the timbre has a consistent pitched character, it contrasts and counterpoints with the time-stretched white noise artefacts, which appear throughout the work (white). In the first section the time-stretched artefacts add a contrasting texture to the continuous periodic tones by having a shifting spectromorphology. The first time-stretched white noise artefacts to occur in this piece is at 0'36, establishing the musical element before its more structural use in the second section.

A twenty-second clip of white noise fades in at 0'39 and fades out at 1'35 (dark blue). It is made of two different clips of white noise that are then panned so that they both move from being either left or right into the centre and back out again. The timbre of the noise is complex, therefore when the two different tracks are both in the centre of the stereo field it sounds like one audio clip. The specific differences between the clips of noise happen at such a fast rate that they are beyond perception. As the two tracks' stereo positions move outwards, however, the differences between the two clips of noise become perceptible, resulting in them becoming distinct. In turn, this allows for the widening of the stereo field mirroring the widened stereo field caused by the desynchronised and panned continuous artefact tones.

The first section ends as the continuous tones and the time-stretched artefacts fade out at 2'16.

Section 2

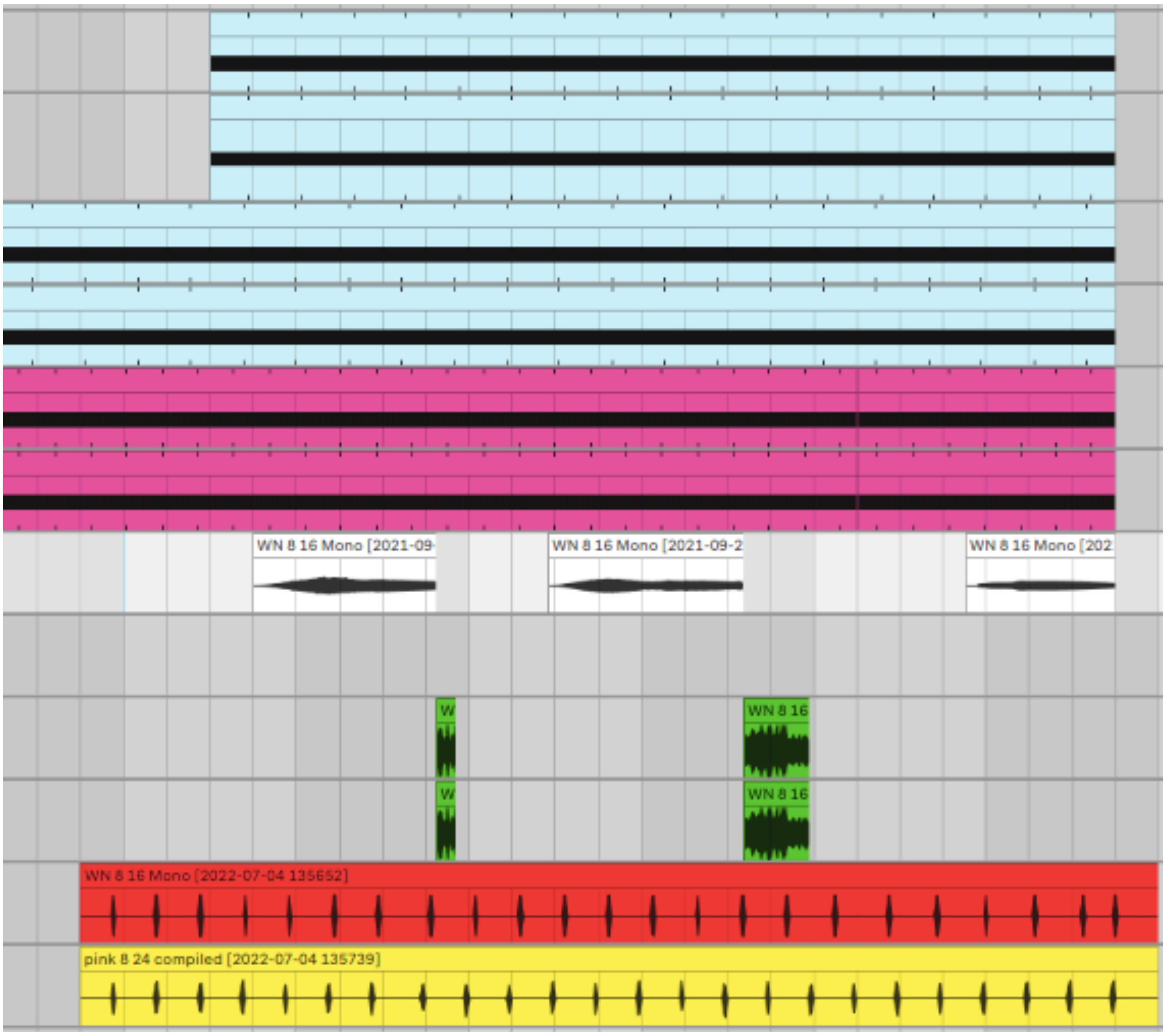

Figure 5.26: Screenshot of Ableton Live project showing overview of second section of piece White Pink

The second section is structured in three parts:

i 2’16 – 3’41

ii 3’41 – 4’47

iii 4’47 – 5’50

Section 2 begins at 2’16, at which point the two desynchronised panned clips of continuous periodic tones at frequencies of 32 Hz can be heard. These continuous periodic tones fade out at 2’46 and re-enters at 2’55. It drops out again, abruptly, at 3’38 before fading back in at 4’30 (light blue).

At 2’22 a new musical element is introduced which consists of two desynchronised (pink), panned clips of discontinuous periodic rhythms made of artefacts at frequencies of 8 Hz. This element marks a timbral and structural shift in the work. While the first half of the piece consists of continuous drones with various timbral characteristics, the second section is rigorously structured and the rhythmic quality of the periodic artefacts anticipates this development.

At 3’47 another continuous periodic tone is introduced, and fades out at 4’35 before being fading in again at 4’50 (light blue).

A series of white noise bursts begins at 2’38, placed to the right in the stereo field. The bursts of white noise are spaced out equally and placed right at first, then left from 3’46 and finally centred from 4’52 until the piece ends. Bursts of pink noise are also introduced at 3’43 placed in the right ear, and then gradually move from right to left, back to right and then centred until the end of the piece. The change in stereo position of these noise bursts occurs as the section’s structure develops (white noise bursts are red, pink noise bursts are yellow).

Bursts of unencoded noise can be heard throughout the second section and are used as a means of reinforcing structure as they mark timbral shifts and the introductions of other musical elements. For example, at 4’34 a burst of white noise marks a shift between the end of a time-stretched artefact (green).

Each sub-section in section two culminates with a crescendo of a time-stretched white noise artefact (white). These crescendos create tension, and the first two crescendos are followed by clips of white noise artefacts at their original timescale (green). The white noise artefacts are gestural and with a variety of pitched and noisy qualities, contrasting with the continuous tones and time-stretched artefacts which drone and develop slowly. The gestural white noise artefacts act as moment of relief, breaking the tension from the crescendo drones. It also gives the listener the opportunity to hear the artefacts in their unprocessed form, while their short burst-length and contrasting context keeps their appearance unpredictable and compelling.

The work ends at the peak of the third crescendo, with the final sounds being a burst of pink noise followed by a lone burst of white noise, which gives the work a sense of closure.

5.7 Red White Blue Pink

Title of Work

Red White Blue Pink

Brief Background and Overview

This piece was originally two separate works that, when played together, fit well in terms of structure, timbre, and spectral positioning. The two original works were White and Pink, written in March 2021, and Red White Blue written in August 2021. The two pieces were restructured and merged in August 2021. This created a work that had a fuller sound while also avoiding the problem of having two similar pieces in the portfolio. The overall structure of the piece consists of three sections, with streaming time-stretched white noise artefacts being used throughout and combined with other elements, such as sound object length artefacts and discontinuous periodic rhythms made using transient artefacts to establish variation and contrast.

Investigations

Layered, streaming continuous encoded audio and discrete artefacts are used throughout the work to explore microtonal relationships and changing sprectromorphologies, creating variation and contrast with other sounds. These contrasting sounds include discrete artefacts that are at different lengths, giving the listener the opportunity to hear the properties of the artefacts at different speeds, creating gestural moments at micro, sound object, and meso levels of time-division.

Many of the artefacts are kept in their unedited series, meaning signal gaps occur between the discrete artefacts. As signal gaps are interruptions within the signal path, so they are defined by that signal, meaning that they are not so much an absence of sound but instead, a variation of it. This variation is used here to create uncertainty as gestures are interrupted, and tension when signal gaps are long. The work also features a phenomenon described in chapter 4.3.1 as *noids*.

The discontinuous periodic rhythms give the listener repeated opportunities to hear some of the properties of an artefact. However, it is the consistent arrangement that results in contrast in the work. The artefacts are microsonic and have been arranged discontinuously and periodically. These techniques are influenced by glitch artists, such as Ryoji Ikeda and Alva Noto who use regular, periodic rhythms in their work with microsound timbres. The pulse contrasts with the morphologies of other elements, which are irregular and non-metric. This contrast gives some relief to the work, and the project more widely, but its consistency and lack of development also creates a sense of tension as resolution or change is withheld.

Inputs and Encoding Variables

White Noise
8 kbps 24 kHz

Red Noise
8 kbps 8 kHz
16 kbps 24 kHz Joint Stereo

Blue Noise
8 kbps 24 kHz

Pink Noise
16 kbps 16 kHz
16 kbps 24 kHz

8/16 kbps 8 kHz Joint Stereo

8/16 kbps 8 kHz Normal Stereo

Structure and Musical Elements

Section 1 – 0’00 – 3’42

Section 2 – 3’42 – 7’34

Section 3 – 7’43 – 8’59

Below is a screenshot of the Ableton Live project’s arrange window of the whole work with the sections delineated using orange lines.

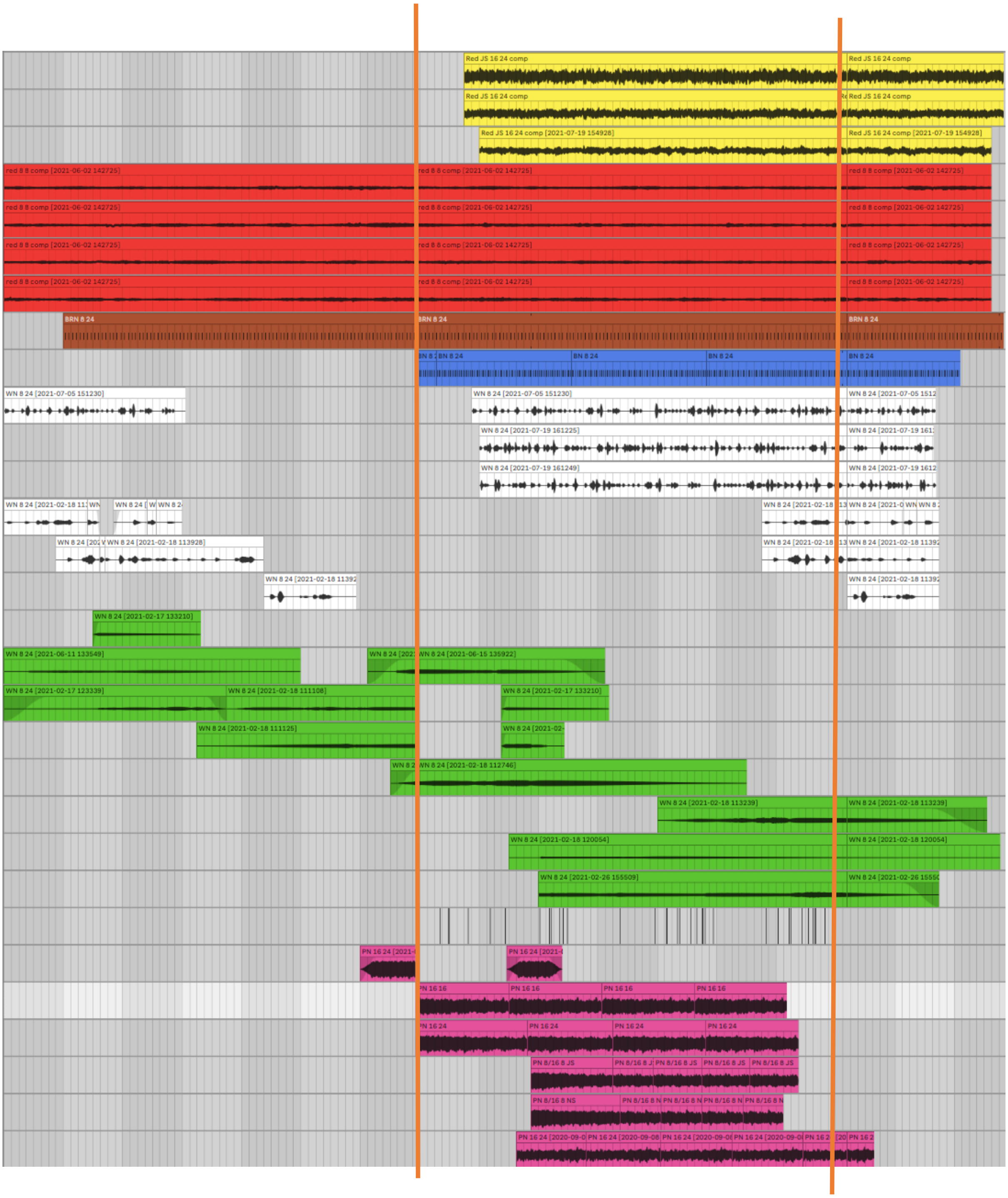

Figure 5.27: Screenshot of Ableton Live project showing overview of piece Red White Blue Pink

The work's musical elements can be seen in the screenshot of the Ableton Live project and spectrogram above, and are described below with reference to the colours of audio clips.

1) White: Short sound object length white noise artefacts

2) Green: Long sound object length white noise streaming artefacts
3) Red: Slow moving time-stretched continuous encoded red noise
4) Brown: Discontinuous periodic rhythm made using edited red noise artefacts at a frequency of 0.5 Hz
5) Pink: Unencoded and encoded pink noise
6) Black: Microsound length white noise artefacts
7) Yellow: Faster moving time-stretched continuous encoded red noise
8) Blue: Discontinuous periodic rhythm made using edited blue noise artefacts at a frequency of 1 Hz

Analysis

Section 1

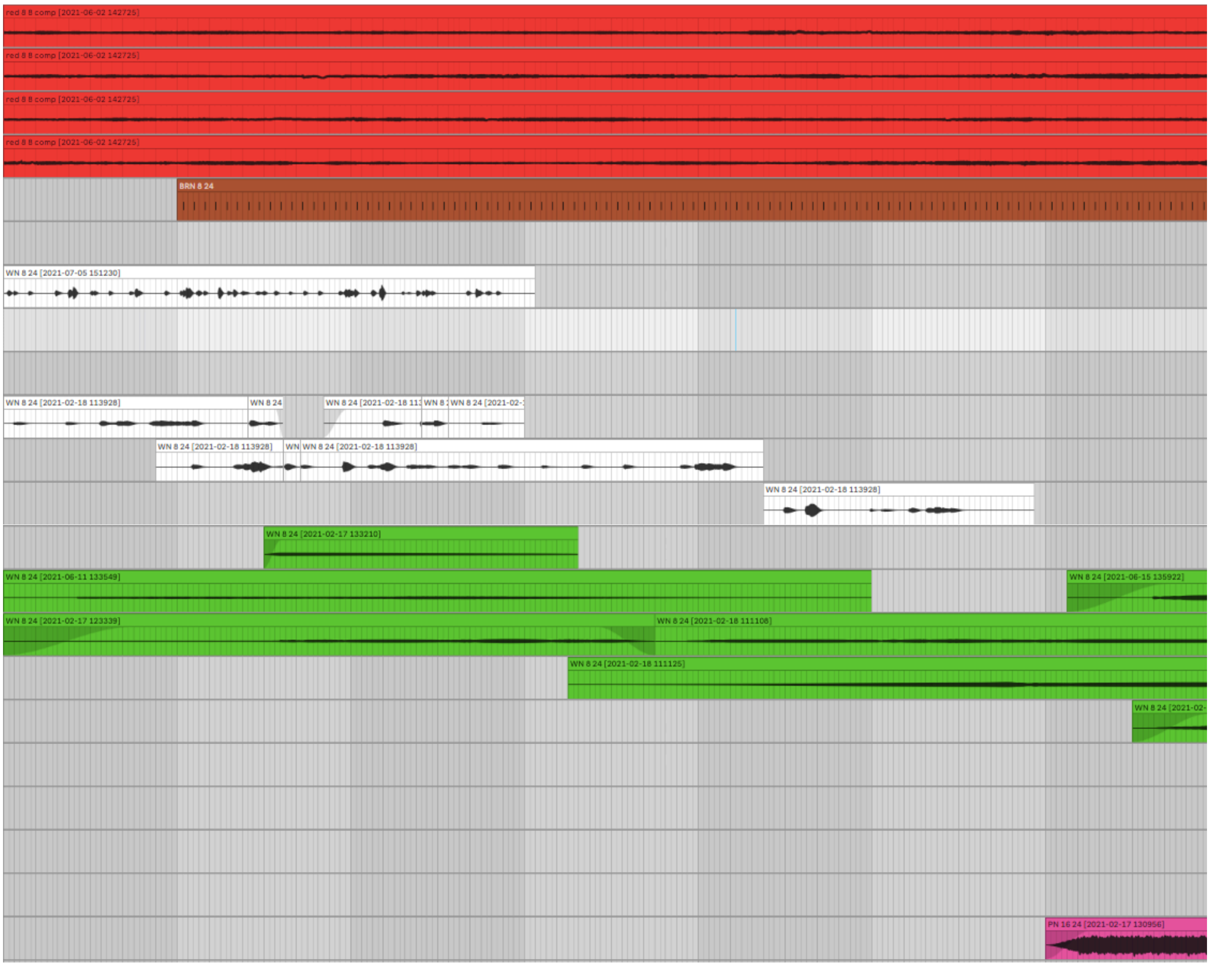

Figure 5.28: Screenshot of Ableton Live project showing overview of first section of piece Red White Blue Pink

Above is a screenshot of section one in the Ableton Live project arrange window showing the four elements used in this section.

The first section lasts until 3’41 and consists of four musical elements: discrete, short sound object length artefacts, which are transient but not on the micro timescale (white) and massively time-stretched artefacts which stream and drone (green), both of which are made using encoded white noise. The time-stretched white noise artefacts last throughout the entire piece, while the sound object length artefacts drop out at 3’00, and are reintroduced later in the work.

The other two elements are a massively time-stretched encoded red noise and a discontinuous periodic rhythm made using edited red noise artefacts. The time-stretched encoded red noise can be heard from 1’45 (red) while the discontinuous periodic red noise artefacts can be heard from 1’17 (brown), and both of these continue until the end of this section.

The time-stretched encoded white noise (green) consists of five separate audio clips in the first section, with only a maximum of three being played at once. The layers of the encoded white noise creates a streaming effect, as their spectral characteristics morph over time combined with the shift in their spatial movement due to the use of automated panning.

The discrete sound object length white noise artefacts (white) range in length between fractions of seconds and several seconds, and while some of the tracks have a fixed spatial position that is off-centre or have some stereo automation, they do not move too close to the extremities of the stereo field.

The time-stretched clips of encoded red noise (red) are layered across four tracks. One is panned right and another is left, another is panned 25L and the last is panned 25R. The time-stretched encoded red noise contributes to the streaming effect already being created by the time-stretched white noise artefacts, and as they sit in different areas of the spectral range and have different stereo positions, so they can be heard more easily as ‘a combination of moving layers’ which are continuous and sustained (Smalley 1997, 117).

The spectral difference can be seen below in the zoomed in spectrogram of the first section. The time-stretched white noise artefacts are highlighted in the rectangle labelled 1 and the time-stretched red noise artefacts are highlighted in the rectangle labelled 2. Additionally, while it might seem as though these two sets of artefacts are close to one another, the spectral range is over 40 kHz, giving the false impression of greater proximity due to the larger frame of reference.

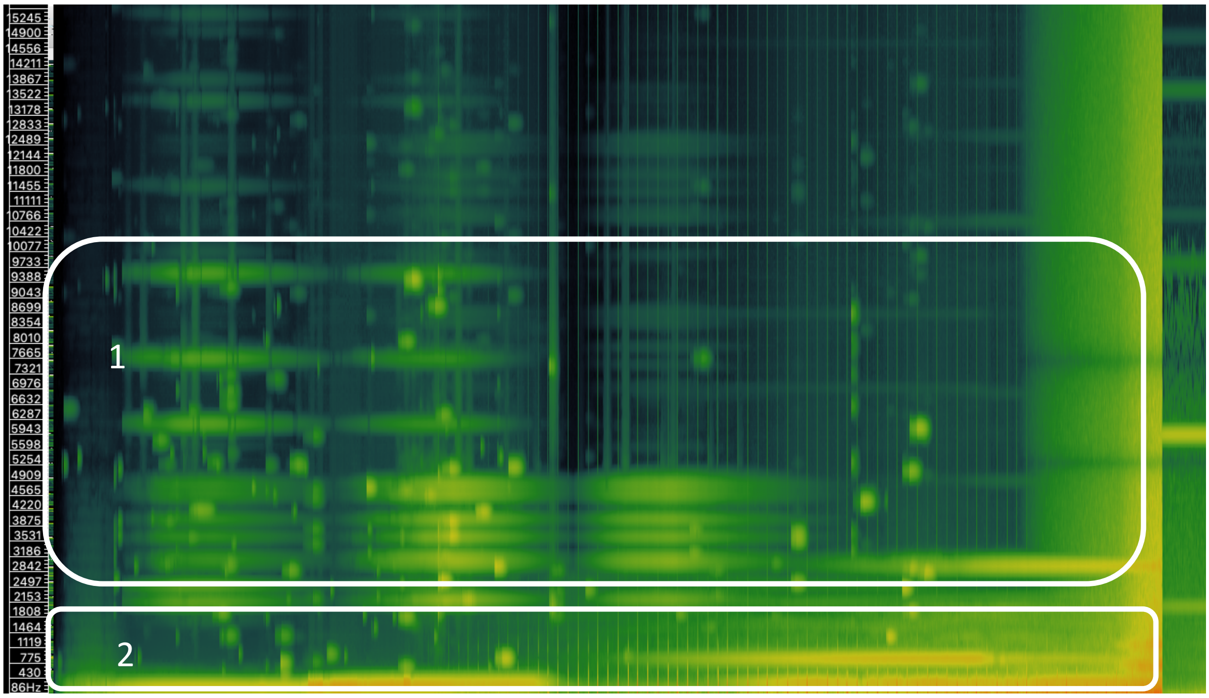

Figure 5.29: Spectrogram showing spectral positions of time-stretched white noise and time stretched red noise artefacts

The fourth musical element of the section is a discontinuous periodic rhythm made using red noise artefacts (brown). The artefacts are microsonic and have been arranged periodically, at a frequency of 0.5 Hz (brown). This techniques is influenced by glitch artists, such as Ryoji Ikeda and Alva Noto who use regular, periodic rhythms in their work with microsound timbres. The pulse contrasts with the encoded noise and time stretched artefacts, which have irregular and non-metric morphologies. This contrast gives some relief to the work, and the project more widely, but its consistency and lack of development also creates a sense of tension as resolution or change is withheld.

The effects created by the discontinuous periodic rhythm and the streaming artefacts of this first section are brought to an abrupt end when unencoded pink noise is introduced and crescendos over a thirty second period before most of the musical parts in the first section dropout, including the noise crescendo.

Section 2

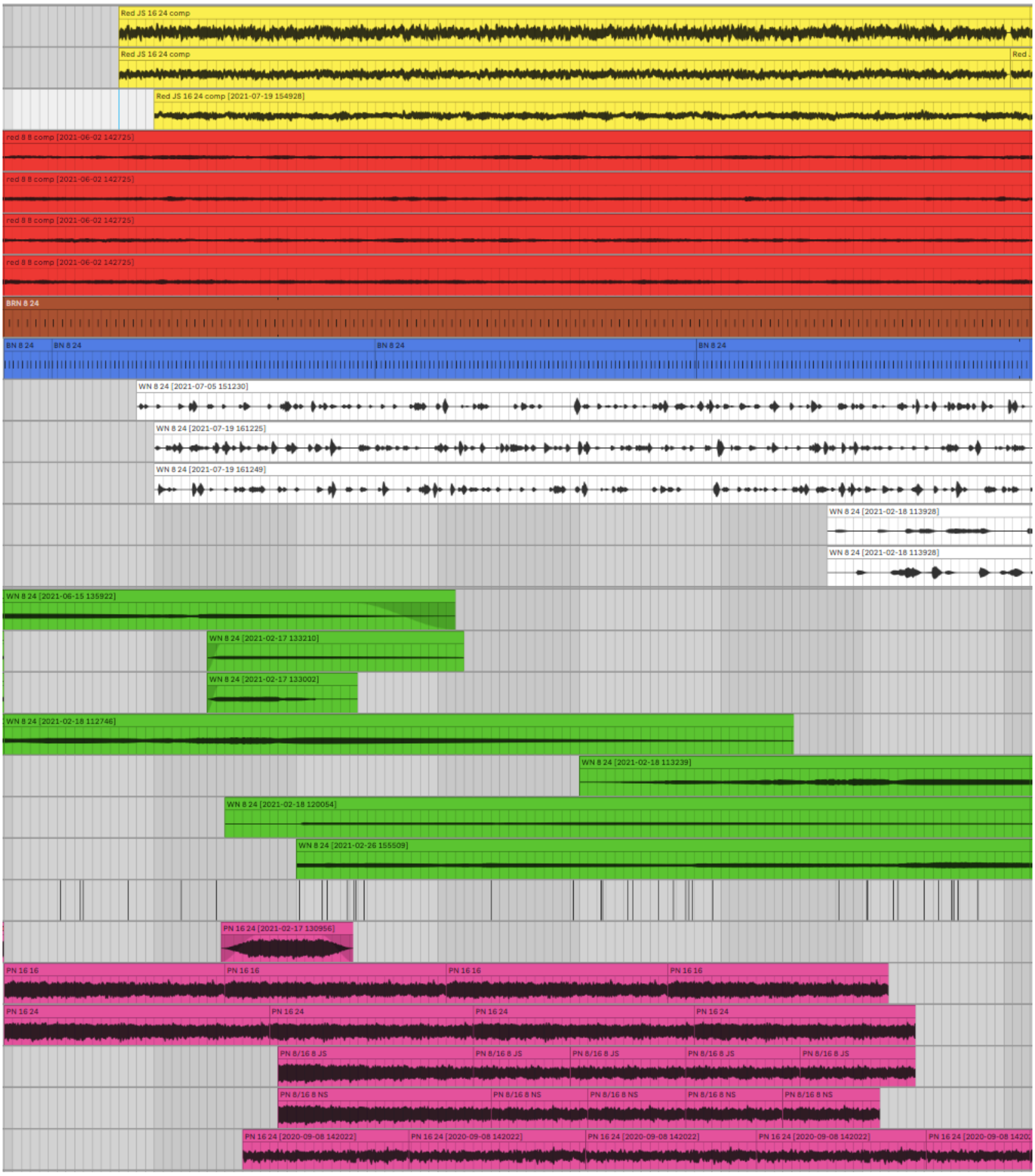

Figure 5.30: Screenshot of Ableton Live project showing overview of second section of piece Red White Blue Pink

Section 2 begins at 3’41 with a sudden shift in timbre as the crescendo of unencoded pink noise ends. Two of the time-stretched encoded red noise drones continue quietly (red) and another time-stretched white noise artefact with higher spectral properties can be heard from the start of this section (green).

In addition to these continuing drones and time-stretched artefacts, new ones are added, including two tracks of encoded pink noise which are panned left and right (pink). The pink noise is at its normal time scale, which creates a flocking effect, described by Denis Smalley as discontinuous, in flux, and the ‘loose but collective motion of micro- or small object elements whose activity changes in density need to be considered as a whole’ (Smalley 1997, 117).

At 4’30 another clip of unencoded pink noise is introduced lasting for 23 seconds before changing at 4’54 when more encoded pink noise is introduced, resulting in five tracks. The new tracks also have a flocking effect, as they are in their natural microsound timescale. Two of these tracks are also panned left and right, while the fifth in centred.

The arrangement of the encoded pink noise in section two can be seen in the screenshot below of the Ableton Live project.

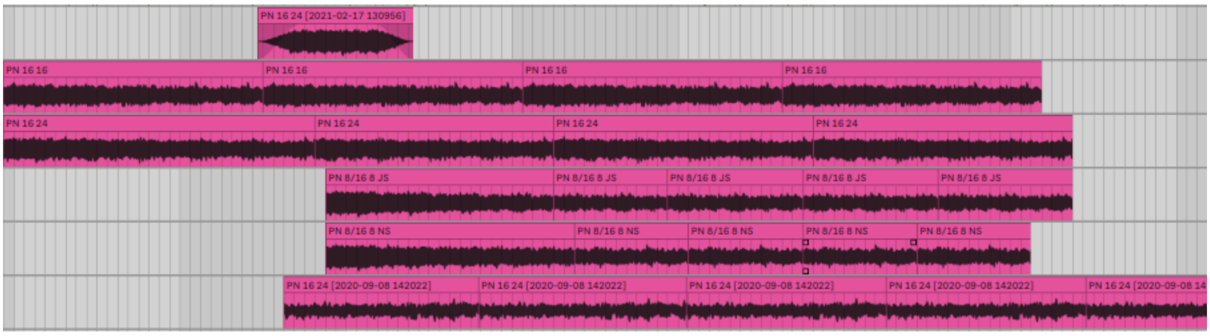

Figure 5.31: Arrangement of encoded pink noise in Ableton Live project

Adding to this flocking effect are three tracks of encoded red noise that are slightly time-stretched, creating gestures at a slower pace to the encoded pink noise, but still in flux and with a collective motion at a sound object time scale (yellow).

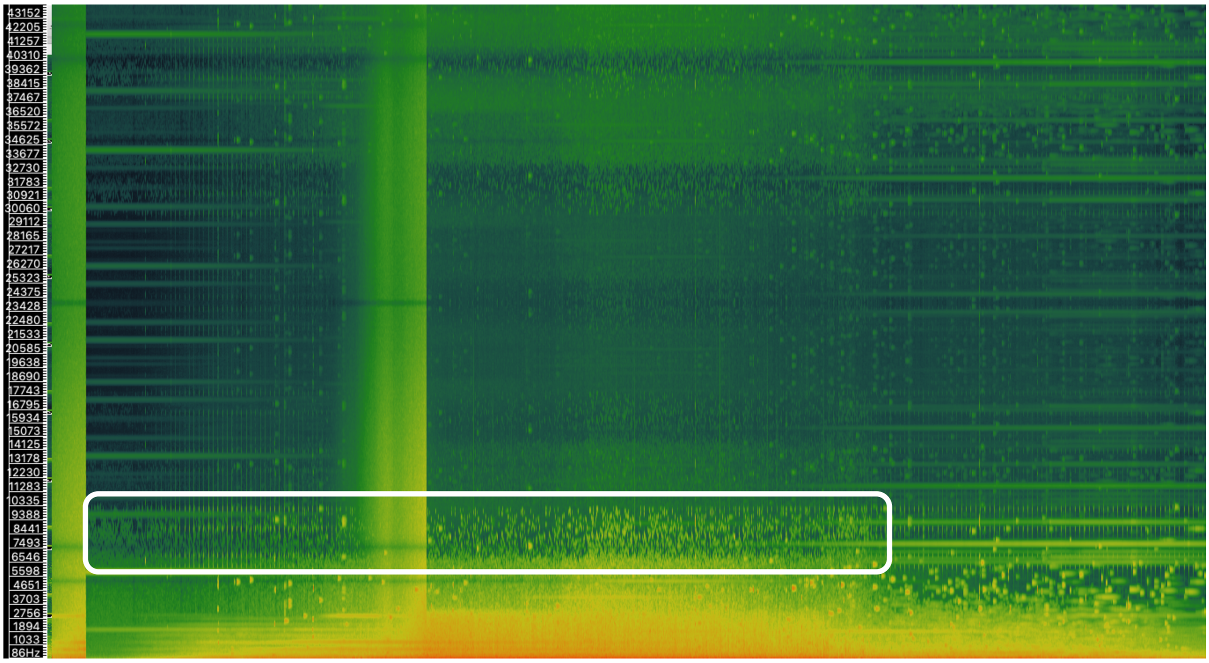

Figure 5.32: Flocking effect of pink noise highlighted with white rectangle

Another discontinuous periodic rhythm made of a blue noise artefact at a frequency of 1Hz (blue) fades in at 3’50 and lasts throughout the section.

At 3’50 the encoded red noise from the first section fades back in along with the discontinuous periodic rhythm using a red noise artefact (brown), sound object length white noise artefacts and more time-stretched white noise artefacts.

At 3’54 discrete micro time scale white noise artefacts (black) begin to sporadically appear until 7’22. These are shown below in the screenshot of the Ableton Live workstation highlighted using a white rectangle.

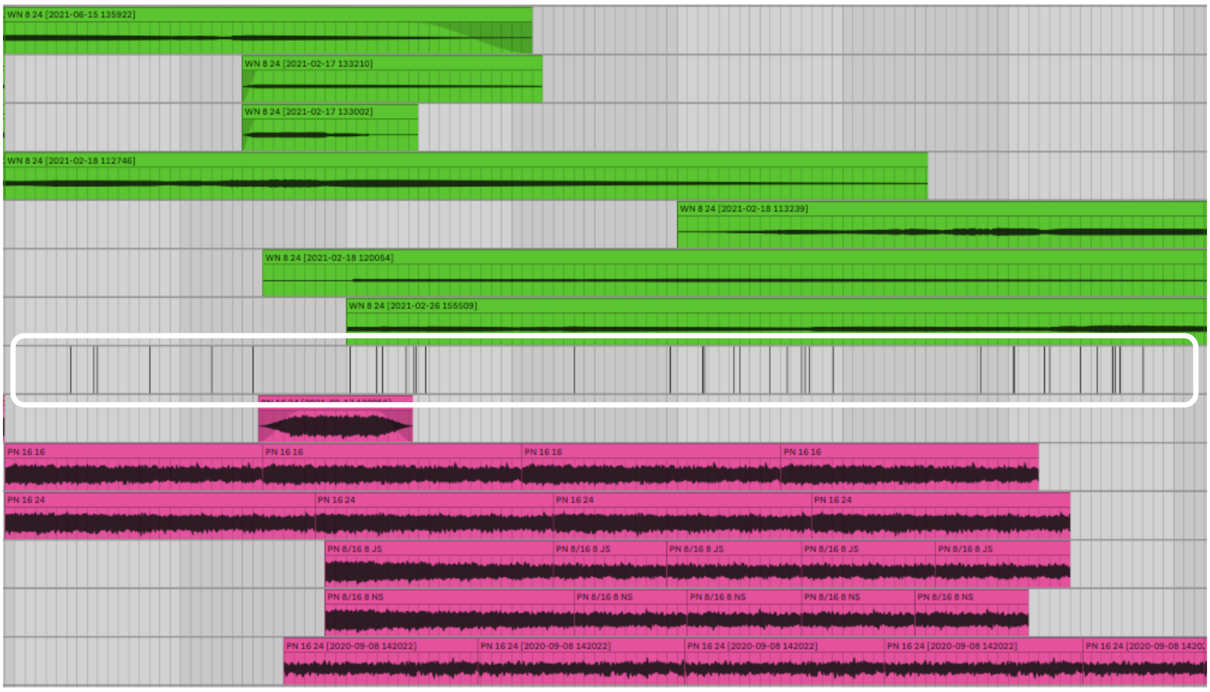

Figure 5.33: Arrangement of discrete micro timescale white noise artefacts highlighted with white rectangle

The streaming layers and flocking artefact textures increase in intensity throughout the section, particularly after 4’54, after the second pink noise crescendo and when all of the musical material has been introduced.

As the section comes to an end at 7’34, the flocking, encoded pink noise and two of the three tracks of flocking red noise fade out, leading to the beginning of section 3.

Section 3

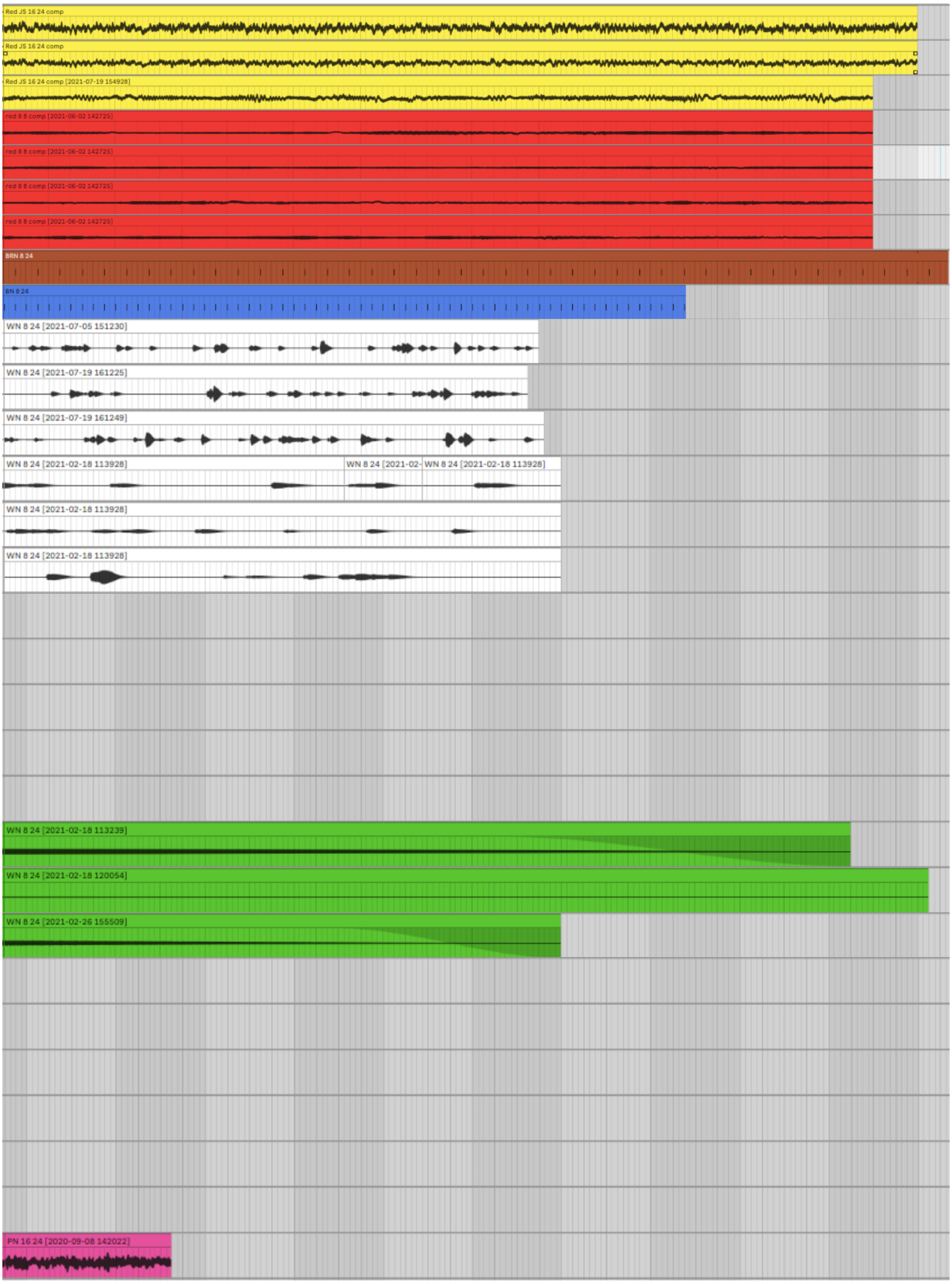

Figure 5.34: Screenshot of Ableton Live project showing overview of third section of piece Red White Blue Pink

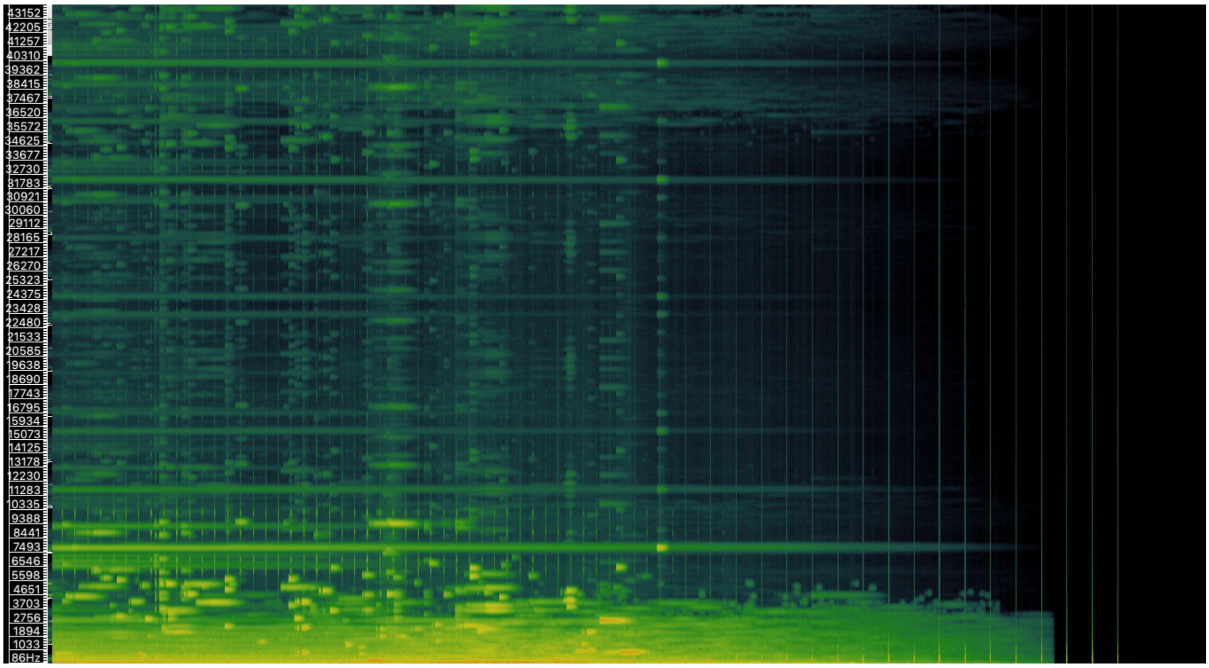

Figure 5.35: Spectrogram of third section of piece Red White Blue Pink

Section 3 begins at 7'34 and consists of the sound object length artefacts made from white noise (white), a time-stretched white noise artefact (green), with time-stretched encoded red noise (red and yellow). The two discontinuous and periodically arranged rhythms of artefacts also continue (blue and brown), with the blue noise artefact fading out whereas the red noise artefact continues until the very end of the piece, all of which can be seen in the spectrogram above.

5.8 Interludes

The interludes in this project act as a break from the works in terms of length and musical elements. The interludes are shorter than the works, ranging between 1'54 and 2'38, contrasting with the works which are 5'50 at shortest and 11'32 at longest. Additionally, the musical elements used in the interludes contrast with those used in the surrounding works, creating a greater sense of respite. They consist of only one movement each, normally structured with the building and then decaying of a sound mass, while also adding to the progression of musical material in the overall project, as they introduce musical elements which are used in later interludes and works.

First Interlude Violet and White

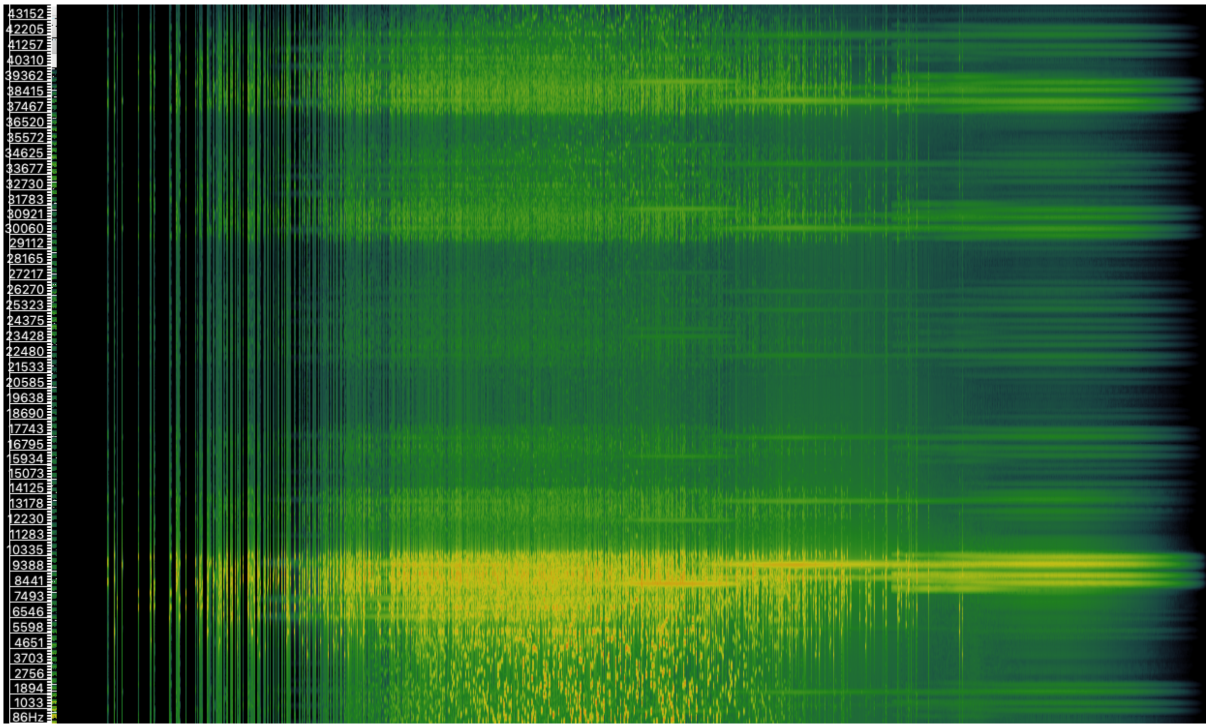

Figure 5.36: Spectrogram of First Interlude Violet and White

White Noise 8 24

Violet noise 8 24

Length 2’04

Purpose: The first interlude seeks to contrast with neighbouring works *Pluck Red Violet* and *Pink Blue* which use time-stretched artefacts to create clusters and streams. The interlude uses edited artefacts to create cloud arrangements that shift in density, and repetitions to create drones. The use of these techniques at this stage has two effects: to act as a momentary respite from the long form works that use time-stretched artefacts, and to introduce these two new elements that will be used again later in the project.

The work uses cloud arrangement, syncopated panned continuous periodic tones, unprocessed artefacts, and time-stretched artefacts. The cloud arrangements increase in density, but remain fragmented, similar to a *stratus* cloud (Roads 2001, 16).

The interlude begins with a cloud arrangement consisting of edited artefacts that have been made by encoding violet noise at 8 kbps and 24 kHz. These parameters resulted in significant signal gaps and therefore discrete artefacts.

As the cloud increases in density, a syncopated panned continuous periodic tone made with violet noise artefacts is introduced, with the density of the cloud and amplitude of the drone increasing until 0’40.

At 0’32 unencoded white noise artefacts are introduced, encoded at 8 kbps and 24 kHz, again creating signal gaps, discrete gestural artefacts.

Time-stretched violet noise artefacts are introduced, contrasting with the continuous periodic tone in that their timbre is less textured, and has a shifting spectromorphology. The timbres of the continuous tone and the time-stretched drones, however, fuse at points in the interlude.

From 0’40 the density of the cloud does not increase and the other elements do not get louder. Development occurs as spectromorphologies develop, new periodic continuous tones are introduced, the cloud shifts on a micro-temporal level, and unprocessed artefacts continue to occur.

The unprocessed artefacts begin to fade out at 1’10, with the cloud also becoming less dense. The two continuous tones continue to develop, beginning to fade out at 1’57 and fading out completely at 2’03.

Second Interlude White and Blue

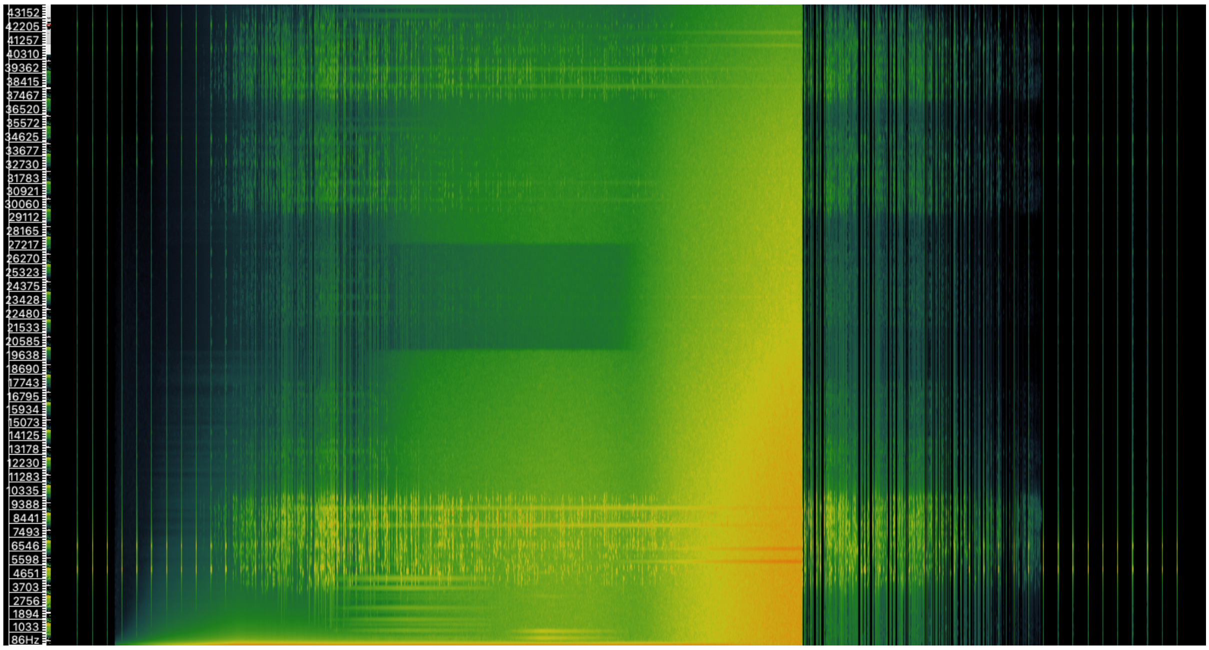

Figure 5.37: Spectrogram of Second Interlude White and Blue

Blue noise 8 24

Unencoded white noise

White noise 8 24

Length 2’38

Purpose: the interlude reintroduces the oscillating artefact technique, though at a lower register made from white noise artefacts, and the cloud technique using blue noise artefacts. It also introduces the use of a sparse rhythm made from one repeated blue noise artefact. There are also time-stretched white noise artefacts and unencoded white noise. As before, neighbouring works use time-stretched artefacts throughout, therefore by using continuous periodic tones contrast is created, the change creating a relief between the longer works.

The interlude begins with a sparse rhythmic blue noise artefact pulse, followed by a continuous periodic tone made using a white noise artefact. Cloud-like formations of blue noise artefacts begin to appear at 0’22 and increase in amplitude, though with shifting density throughout. At 0’38 time-stretched white noise artefacts are introduced.

Unencoded white noise is introduced at 0’45, with a time-stretched blue noise artefact that has a consistent pitched spectromorphology. These two timbres crescendo until 1’43, at which point they, and several other elements stop abruptly leaving only the cloud-like formations of artefacts and the sparse rhythmic artefact continuing.

The cloud-like formations of artefacts fade out, becoming completely silent by 2’15, with the blue noise periodic rhythm continuing until 2’34.

Third Interlude White Pink and Violet

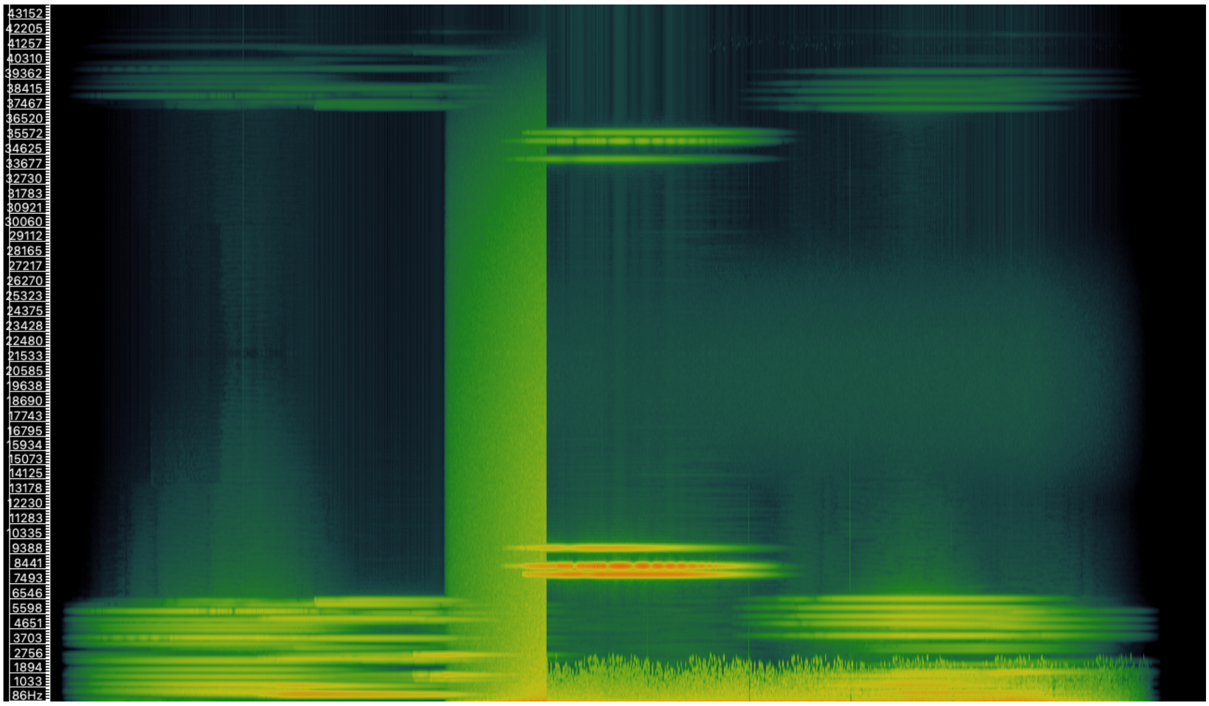

Figure 5.38: Spectrogram of Third Interlude Pink and Violet

White noise 8 16

Violet noise 8 24

Unencoded pink noise

Pink noise 8 24

Length 1’54

Purposes: This interlude uses time-stretched artefacts for two reasons: to contrast with neighbouring works *Red White Blue Violet* and *White Pink*, which make greater use of rhythm and noise bursts, and to restate a key technique used in earlier works. The use of unencoded noise gives some sonic context, and the artefacts that follow the noise exhibit the effects of compression in a direct and unprocessed approach.

The interlude begins with two time-stretched white noise artefacts which continue, with the spectromorphologies developing. At 0’38 unencoded pink noise is introduced and crescendos until 00.48 at which point a series of encoding iterations. Six iterations of pink noise encoded at 8 24, creating a flocking effect, and as the LAME encoder was used, so cumulative delays can be heard at the beginning of each iteration. At this point three time-stretched violet noise artefacts fade in, replacing the time-stretched white noise artefacts that had faded out. At 1’10 and 1’20 two more time-stretched white noise artefacts are introduced, which fade out with the unprocessed pink noise artefacts at 1’48.

Fourth Interlude Red and Violet

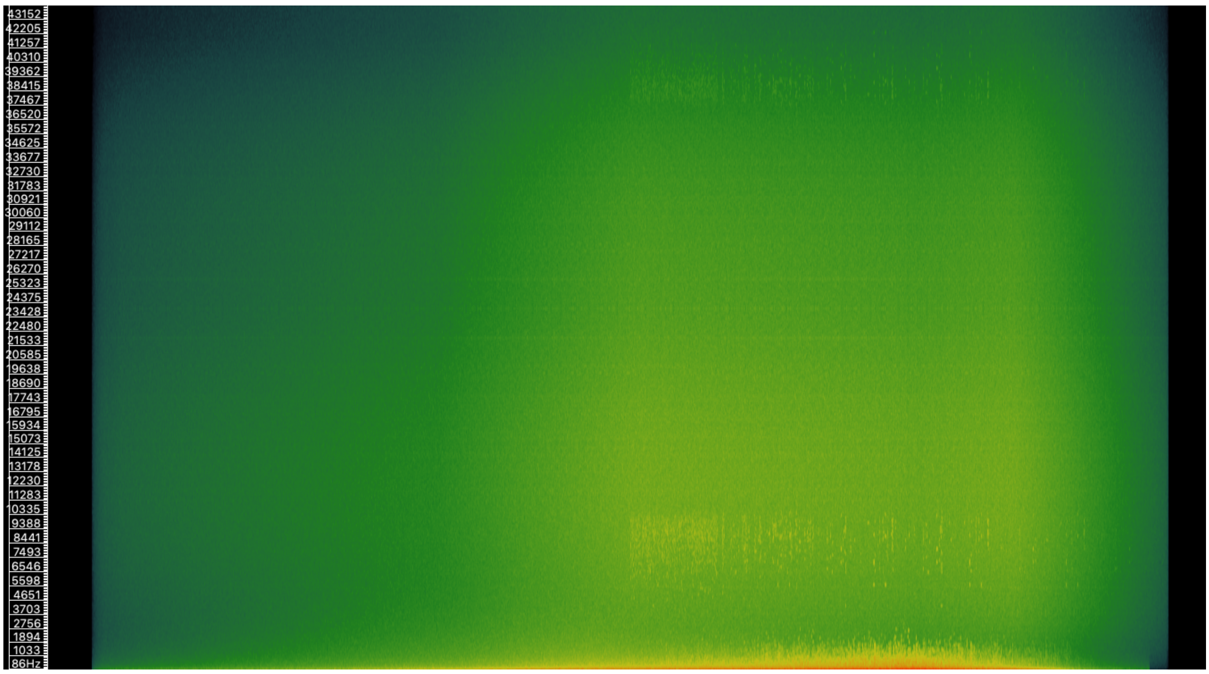

Figure 5.39: Spectrogram of Fourth Interlude Red and Violet

Unencoded red noise

Unencoded violet noise

Red noise 8 24

Red noise 8 16

Violet noise 8 24

Length 2’00

Purpose: The fourth interlude sought to contrast with neighbouring works by using unfiltered noise with artefacts layered beneath, as opposed to the *White Pink* and *Red White Blue Pink* which made use of bursts of noise, sparse minimal rhythms, and pitched drones from repeated artefacts and time-stretched artefacts.

Work layered two clips of violet noise with two clips of red noise. Each clip is different and panned, to give width to the complexity of the texture. Violet and red noise have different frequency to amplitude relationships, with red noise decreasing by six dB for each ascending octave, and violet noise increasing by six dB for each ascending octave. This results in an complex timbre, made up of two discernible textures.

More red noise is added, followed by a series of encoding iterations. Six iterations of red noise encoded at 8 kbps and 24 kHz, which are panned right, while six iterations of red noise encoded at 8 kbps and 16 kHz are panned left. As these two encodings use different sample rates, there is variety in their bandwidth, though similarity in the more general properties of the encoded noise. These two clips are panned allowing the differences and similarities to create fissures and fusions in their timbres.

The final musical element consists of a series of artefacts from encoded violet noise. The interlude fades out at 1’34.

Chapter 6 Conclusion

This composition portfolio and thesis has demonstrated a novel approach to the use of MP3 compression artefacts as sound material in composition. The technological noise and artefacts used by artists described in chapter 2.4 are created irrespective of the audio, and therefore while those works invert the traditional hierarchical relationships between media noise and audio, the hierarchical structure remains. In contrast, compression artefacts are specifically created through a process and relationship between the audio being encoded and the perceptual coding process itself. The artefacts studied in this research project therefore dismantle the traditional hierarchical relationships between audio and the medium insofar that they demonstrate the absolute dependency each has for the other to exist.

By using compression artefacts as the sonic material in the project's compositions, the portfolio expands the sound palette of 21st century post-digital composition while also combining approaches to macro, meso, and micro structure from glitch, electroacoustic, and the works of mid-20th century composers, resulting in a collection of compositions that have a novel approach to material and form. By combining the aesthetics of failure with formal approaches from the styles of music described above, the project also seeks to challenge the convention in electroacoustic music of using sound material that is from high-fidelity source recordings while also seeking to expand structural approaches in glitch music.

6.1 Limitations and Future Developments

The limitations of the project point towards future developments and areas of possible research, and include a range of possible ideas, such as producing other compression artefacts, experimenting using other input materials and coding variables, and new musical possibilities to explore real-time and spatialised performances.

6.1.1 Input Materials and Encoding Parameters

The project uses noise colours and signals with fast attacks and slow releases to evoke and investigate different effects. However, future research into the generation of compression artefacts could also benefit from using more types of input material. For example, it could be interesting to see how time-smearing artefacts are affected or created by using transient signals with different spectral properties, such as sine tone bursts, cluster bursts, and noise colour bursts.

Using different input materials such as pitched inputs would allow other effects such as 'blocking artefacts' (Malvar 1990 & Seelamuntula et al. 2009) and 'reverberation' (Malvar 1990 & Martinez 2007) to be evoked, discussed further in the next section.

In addition to other input materials, the encoding variables explored could also be widened to include bit depth and types of bitrate. Experimenting with bit depth and cascading could result in quantization noise becoming audible, and in turn other artefacts being generated, and it could be interesting to see if there are major differences between variable and constant bitrates on the creation of artefacts.

6.1.2 Other Artefacts

The previous research into compression artefacts suggested that there are a number of other sonic side-effects that have not been explored in this project. These include 'swirlies' (Corbett 2012), 'blocking artefacts' (Malvar 1990 & Seelamuntula et al. 2009) 'reverberation' (Malvar 1990 & Martinez 2007), and a variety of other artefacts such as 'tone trembling' 'tone shift' 'noise overflow' and 'tonal spike' which are briefly described in the paper by Liu et al. (2008, 693).

These artefacts were not explored or investigated in this project due to several reasons: it was not possible to observe some artefacts due to a limited set of input materials; a lack of information regarding their causes and properties meant that it was not possible to create or recognise certain artefacts; a lack of understanding on the part of the part of the author regarding certain aspects of the compression process meaning artefacts could not be recreated; and the limited amount of research made from more than one or two researchers made it difficult to establish a consensus.

Swirlies

Corbett's article in sound on sound was one of the earliest articles I read that described compression artefacts. It is not academic, but supplies a substantial amount of information regarding various artefacts. After reading other papers concerned with compression artefacts, it became clear that all but one of the effects and artefacts Corbett describes could be found in other research, the one missing, however, is called 'swirlies'.

Corbett describes 'swirlies' as being 'the rapid coming and going of lower-level frequency content' (Corbett 2012). He also states that they are a 'common artefact', though no other mention of them has so far been found in other research and the little amount of information in the article made it difficult to investigate further, though it could be that they have been misidentified as another artefact elsewhere.

It could be interesting to find out more about these artefacts as from Corbett's description of them as being 'grainy' and 'raspy' they could add an interesting timbre to the palette of compressed sounds (ibid).

Blocking

Blocking artefacts are the focus of papers by Malvar (1990) and Seelamuntula et al. (2009) and are described as being produced by 'abrupt transitions occur[ing] at the frame boundaries' (2009, 523), or, as described by Malvar 'blocking artifacts arise because the concatenation of the reconstructed blocks generates signal discontinuities across block boundaries' (Malvar 1990, 1043). Their properties are described as being 'clicking sounds' (2009, 523).

The papers are focused on mitigating these artefacts, and therefore describe the causes and properties of these artefacts briefly, understandably moving on to their mitigation processes. In addition to the brevity with which these articles describe these artefacts my own understanding of the processes described was limited. As described above, having a better understanding of compression techniques might have allowed this project to include blocking artefacts into the range of sounds investigated.

These artefacts could be interesting to recreate and explore, giving future musical projects that are focused on compression artefacts a range of sounds to use that also include 'clicking' transient signals.

Ringing Artefacts and Reverberation

Papers by Martinez and Malvar both refer to an effect called 'reverberation' though Malvar claims that reverberation is an effect caused by 'ringing artefacts' (1990, 1048). It could be therefore that the appearance of reverberation is a property of ringing artefacts.

Malvar states that the ringing artefacts are caused because 'the quantization errors on the transform coefficients generate signal reconstruction errors that last for the entire block duration' (1990, 1043). As with artefacts above, these two papers use language, graphics, and formulas that are beyond the author's expertise. Though, future research into these processes to create ringing artefacts and reverberation could be done using pitched input materials, which are then cascaded and would add an interesting set of sounds to future creative projects.

Liu's Taxonomy

The paper by Liu et al. *Compression Artifacts in Perceptual Audio Coding* (2008) provides a taxonomy of seventeen compression artefacts, including 'tone trembling' 'tone shift' 'noise overflow' and 'tonal spike' with information regarding how these artefacts are generated, their properties, and what sort of input material causes them and what methods can be used to mitigate them (2008, 693).

The list of artefacts is broad and the paper describes their causes and characteristics well, but again, many of these artefacts were not included into this research project because they were not discussed in any other research that could be found.

Additionally, some artefacts appear to have different names in this paper compared with others, such as 'Tone-Leakage' (2008, 683) which looks to be very closely related to *Stereo-Movement* described in various other papers. Some artefacts also appear to be very closely related to one another such as *Noise Amplification Around Attack* and *Pre-Echo* (2008, 683). Further investigation of the artefacts described in this paper would be very fruitful, not only in giving creative practitioners more sounds to use in the creation of new music, but also in understanding more about compression processes and the relationships between compression effects.

6.1.3 New Music

Acoustic Performances of Future Compositions

The music submitted here comprises of fixed media electronic works. They therefore lack any overt performative aspects, other than real-time repositioning of stereo channels on multiple speakers in a performance space. Limiting the creative practice to fixed media electronic works has allowed the music to explore the properties of the artefacts involved in this project in great depth.

While it was beyond the scope of this project, it is a goal of future research and creative practice to use compression processes as a means by which to determine musical properties that can be replicated on acoustic instruments and performed in real-time.

Using noise as an input and with certain encoding parameters, pitched artefacts can be created and act as the guide for microtonal works. These microtonal acoustic pieces would likely use similar sonic arrangements as in this project including streams, weaves, and clusters, though the affordances and limitations of the instruments would also be interesting to explore.

These affordances and limitations could include using extended techniques to reproduce non-tonal properties of artefacts. Though untuned percussion would also be practical solution for achieving these sounds combined with strings due to the ease with which microtonality can be explored using them.

Some composition studies have already been made combining fixed media artefacts with acoustic twelve-tone instrumentation, in which the 12-tone instrument plays the closest note to the frequency of an artefact. The relationships between the equal tempered 12-tone tuning of the instruments and their relatively stable timbres combined with the microtonal and unstable spectromorphologies of the artefacts creates interesting moments of tension and resolution as their spectral properties get closer to or further from one another.

Greater Exploration of Space

The use of stereo output for the works was due to the technical constraints of working on the compositions at home during lockdown. There were also early notions that the pieces would suit being heard on the kinds of playback technology that MP3s and compression technologies are designed for: ‘headphones’ and ‘low-fi or mid-fi computer speakers’ (Sterne 2006, 833). The preferred listening contexts are through high fidelity stereo equipment, whether that be using headphones or speakers, it is important for the details of the artefacts to be heard clearly.

While the works submitted as part of this research project explore space in terms of stereo field, distance, and spectral space, these characteristics could be investigated further using multi-channel or diffused playback systems future compositions. For example, the different spectral positions of encoded red noise and encoded violet noise could be exaggerated by playing them back at different physical positions within a multichannel system, and the effect *stereo movement* could also be further highlighted by having the effect played across multiple speakers.

6.1.4 Further Research: Engineering and Musical Influences

Further researcher could benefit from including engineering perspectives, allowing for a deeper understanding of the principles behind perceptual coding, and, in turn, an even more critical and controlled approach to the topic. Additionally, further creative research could take influence from a wider range of music, incorporating the stylistic conventions and artistic concepts allowing the future investigations to explore the musical, artistic, and conceptual potential of these sounds with greater depth.

6.2 Personal Reflections

The continued use and development of compression technologies in music and communications, encourages the continued investigation of their functions and artefacts. Through creative research, further investigation into the limitations, problems, and affordances of these technologies can emerge, and in turn challenge signal-noise hierarchies, consider the symbolic representations of compression artefacts, or widen even further the sonic palette available for music-making.

This research project has demonstrated the effectiveness of using a range of catalogued MP3 artefacts, intentionally produced using a rigorous methodology of cascading compression processes, to compose some austere but engaging sound-based electroacoustic music. The music draws on the arrangement and processing techniques of mid-20th century electronic and experimental composers, contemporary glitch and electroacoustic music, and theorists and practitioners from the sonic and visual arts. It has provided opportunities to learn in detail about the causes and properties of compression artefacts and their place within noise music traditions and theories, particularly concerning the role of noise as an expression of dynamic and active relationships between audio and media. Conducting this research has been a privilege and a pleasure, giving me the opportunity to advance my own knowledge and creative practice while also acting as a strong foundation upon which future creative practice can take place.

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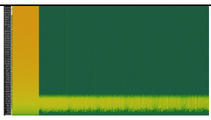
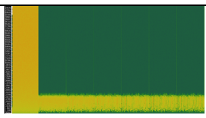
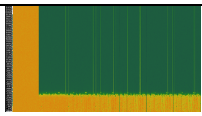
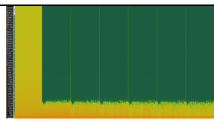
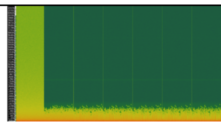
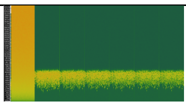
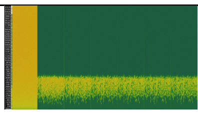
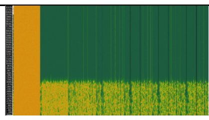
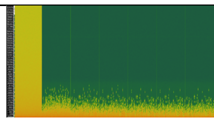
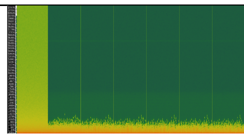
Appendix A

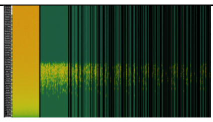
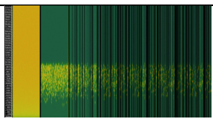
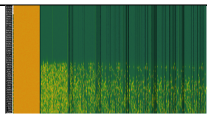
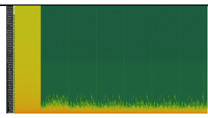
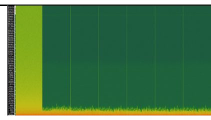
A.1 Noise Mono Test Index

	Violet	Blue	White	Pink	Red
iTunes 8 kbps 8 kHz	 Bandwidth Limit: 500 Hz – 4 kHz. Capped due to Nyquist. Lowest frequency is 500 Hz due to amplitude of frequencies below that being too quiet and therefore cut/not described.	 Bandwidth Limit: 500 Hz – 4 kHz. Capped due to Nyquist. Lowest frequency is 500 Hz due to amplitude of frequencies below that being too quiet and therefore cut/not described.	 Bandwidth Limit: 0 – 4 kHz. Capped due to Nyquist. Amplitude of White noise means that all frequencies below Nyquist are described to some degree. Description is ok but there are discernible pitched	 Bandwidth Limit: 0 – 4 kHz Capped due to Nyquist. Amplitude of Pink noise favours lower frequencies and therefore means that all frequencies below Nyquist are described to some degree.	 Bandwidth Limit: 0 – 4 kHz Capped due to Nyquist. Amplitude of Red noise favours lower frequencies and therefore means that all frequencies below Nyquist are described to some degree. Description is poor but there are some

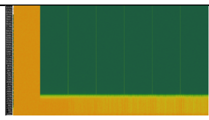
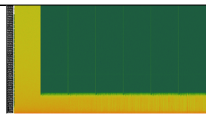
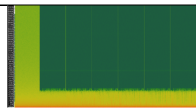
	Discernible artefacts, though still mostly complex. Some pitched artefacts in lower frequencies, which are poorly described but not enough to call Birdies. Amplitude fluctuations throughout but continuous signal. No signal Gaps Reflections above Nyquist Increasingly degrades with each iteration	Discernible artefacts, though still mostly complex. Some pitched artefacts in lower frequencies (0.5-1k.), which are poorly described but not enough to call Birdies. Amplitude fluctuations throughout with some signal gaps occurring in later iterations. Reflections above Nyquist Increasingly degrades with each iteration	artefacts. These pitched artefacts are embedded within better descriptions of the noise. Amplitude fluctuations throughout with some signal gaps occurring in later iterations. Delay at the start of later iterations Reflections above Nyquist Increasingly degrades with each iteration	Description is ok but there are some discernible pitched artefacts. These pitched artefacts are from the higher frequencies which are poorly described due to their lower amplitude. These pitched artefacts become more pronounced in later iterations, and are embedded within better descriptions of noise. There is a noticeable difference between the two timbres.	discernible pitched artefacts. These pitched artefacts are from the higher frequencies which are poorly described due to their lower amplitude. Lower frequencies are discernible as a continuous sound. No signal Gaps

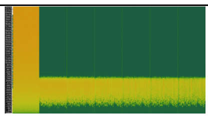
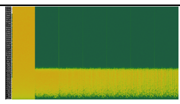
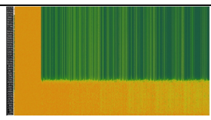
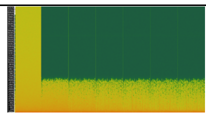
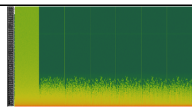
				Amplitude fluctuations throughout but continuous signal. No signal Gaps	
iTunes 8 16	 Bandwidth Limit: 2kHz – 7.3kHz. Highest frequency is just below Nyquist. Lowest frequency is 2kHz due to lower amplitude in lower frequencies causing them to not be described. Higher sample rate stretches bitrate causing	 Bandwidth Limit: 1kHz – 8kHz. Highest frequency is just below Nyquist. Lowest frequency is 1kHz due to lower amplitude in lower frequencies causing them to not be described. Higher sample rate stretches bitrate causing	 Bandwidth Limit: 0 – 7kHz Capped due to Nyquist. Amplitude of White noise means that all frequencies below Nyquist are described to some degree. Description is poor. Higher sample rate stretches bitrate causing greater fragmentation	 Bandwidth Limit: 0 – 8kHz Capped due to Nyquist. Amplitude of Pink noise favours lower frequencies and therefore means that all frequencies below Nyquist are described to some degree. Description is poor from the outset.	 Bandwidth Limit: 0 – 4kHz Capped due to Low Pass Filter built into encoder, triggered by amplitude and bitrate. Amplitude of Red noise favours lower frequencies and therefore means that all lower frequencies are described to some degree

	greater fragmentation. Greater spectral gaps and degradation in lower frequencies 2-4k. Higher sample rate creates finer/shorter artefacts. Increased likelihood of discrete and discernible artefacts. Discernible artefacts, mostly pitched. Lower amplitude areas are described poorly, resulting in Birdies in the lower	greater fragmentation throughout description. Higher sample rate also creates finer/shorter artefacts. This results in discernible artefacts throughout signal creating birdies. Most prominent are Flightless Birdies between 1.2 and 2.8kHz.	throughout description. Higher sample rate also creates finer/shorter artefacts. This results in discernible artefacts throughout signal creating birdies. Delay at the start of each iteration. Increasingly degrades.	Higher sample rate stretches bitrate and creates finer/shorter artefacts. This creates discernible, pitched artefacts throughout description. These pitched artefacts are from the higher frequencies which are poorly described due to their lower amplitude. Sound is fairly continuous, no signal gaps.	Description is poor from the outset. Though bitrate is not stretched, higher sample rate creates still finer/shorter artefacts. Which can be seen/heard in higher frequencies, and are discrete and pitched. These pitched artefacts are from the higher frequencies which are poorly described due to their lower amplitude.

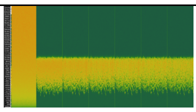
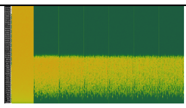
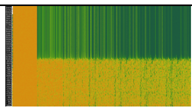
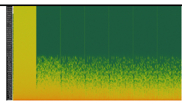
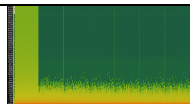
	frequencies. (Flightless Birdies)				
iTunes 8 24	 Bandwidth Limit: 4kHz-11kHz High is just below Nyquist. While the lower limit caused by low amplitude frequencies being cut Noise is described poorly from the outset due to the higher sample rate stretching the low bitrate and creating finer artefacts. Discernible pitched artefacts can be	 Bandwidth Limit: 2kHz – 11kHz. High is just below Nyquist. While the lower limit caused by low amplitude frequencies being cut Noise is described poorly from the outset due to the higher sample rate stretching the low bitrate and creating finer artefacts. Discernible pitched artefacts can be	 Bandwidth Limit: 0 – 12kHz Capped due to Nyquist. Amplitude of White noise means that all frequencies below Nyquist are described to some degree. Noise is described poorly from the outset due to the higher sample rate stretching the low bitrate and creating finer artefacts.	 Bandwidth Limit: 0 – 4kHz. Capped due to Low Pass Filter built into encoder, triggered by amplitude and bitrate. Amplitude of Pink noise favours lower frequencies and therefore means that all frequencies below Nyquist are described to some degree. Noise is described poorly from the	 Bandwidth Limit: 0 – 2kHz Capped due to Low Pass Filter built into encoder, triggered by amplitude and bitrate. Amplitude of Red noise favours lower frequencies and therefore means that all frequencies below Nyquist are described to some degree. Description is poor from the outset.

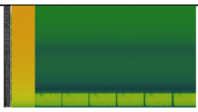
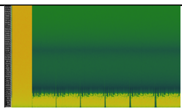
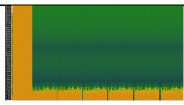
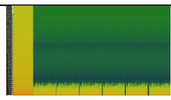
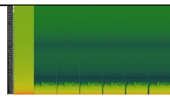
	heard clearly. There are some complex artefacts, but not many at all. This results in Birdies across the frequency range. The poor description results in Signal Gaps throughout the iterations, and iterations degrade to such an extent that by the third iteration, there are longer periods of signal gaps than of artefacts.	heard clearly. There are some complex artefacts, but not many at all. This results in Birdies across the frequency range. The poor description results in Signal Gaps throughout the iterations, and iterations degrade.	Texture is very sparse. Discernible pitched artefacts can be heard clearly. There are some complex artefacts, but not many at all. This results in Birdies across the frequency range. The poor description results in Signal Gaps throughout the iterations, and iterations degrade.	outset due to the higher sample rate stretching the low bitrate and creating finer artefacts. This creates discernible pitched artefacts throughout, particularly in the higher frequencies, which are described poorly due to lower amplitude. Lower frequencies are also less complex and so have discernible pitches. Sound is fairly	Though bitrate is not stretched, there are still artefacts in higher frequencies, which are discrete and pitched. These pitched artefacts are from the higher frequencies which are poorly described due to their lower amplitude. Lower frequencies are also less complex and so have discernible pitches, though is not discrete artefacts, more continuous. Sound is fairly continuous, no signal gaps.

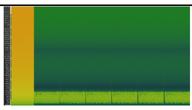
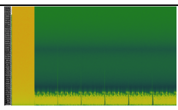
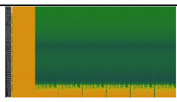
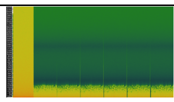
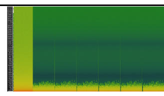
				continuous, no signal gaps.	
iTunes 16 8	 Bandwidth Limit: 0 – 4kHz High capped by Nyquist higher bitrate is capable of describing practically all frequencies below. Good description of Noise with no discernible artefacts. Amplitude fluctuates in later iterations. Iterations degrade over time, with very patchy	 Bandwidth Limit: 0 – 4kHz. High capped by Nyquist higher bitrate is capable of describing practically all frequencies below. Good description of Noise with no discernible artefacts. Amplitude fluctuates in later iterations. Iterations degrade over time, with very patchy	 Bandwidth Limit 0 – 4kHz Capped due to Nyquist. Amplitude of White noise means that all frequencies below Nyquist are described to some degree. Higher bitrate is capable of describing practically all frequencies below. Good description of Noise with few discernible artefacts. Some	 Bandwidth Limit: 0 – 4kHz Capped due to Nyquist. Amplitude of Pink noise favours lower frequencies and therefore means that all frequencies below Nyquist are described to some degree. Description of noise is ok with no discernible artefacts. Amplitude fluctuates from second iteration.	 Bandwidth Limit: 0 – 4kHz Capped due to Nyquist. Amplitude of Red noise favours lower frequencies and therefore means that all frequencies below Nyquist are described to some degree. Description of noise is ok with no discernible artefacts. Amplitude fluctuates from second iteration. Reflections about Nyquist

	amplitude in last three iterations. No pitched artefacts, but changing amplitude with complex timbre creates a 'whooshing' effect. reflections above Nyquist	amplitude in last three iterations. Some pitched moments, but overall still complex timbre changing amplitude with complex timbre creates a 'whooshing' effect. reflections above Nyquist	pitched artefacts can be heard embedded within the noise being described. Amplitude fluctuates in later iterations.	Reflections about Nyquist	
iTunes 16 16	 Bandwidth Limit: 1 – 8kHz. Highest frequency is due to Nyquist, lower limit caused by low amplitude in lower frequencies causing them	 Bandwidth Limit: 500Hz – 8kHz Highest frequency is due to Nyquist, lower limit caused by low amplitude in lower frequencies	 Bandwidth Limit: 0 – 8kHz Capped due to Nyquist. Amplitude of White noise means that all frequencies below Nyquist are described	 Bandwidth Limit: 0 – 8kHz Capped due to Nyquist. Amplitude of Pink noise favours lower frequencies and therefore means that all frequencies	 Bandwidth Limit: 0 – 7kHz Capped due to Nyquist. Amplitude of Red noise favours lower frequencies and therefore means that all frequencies below Nyquist are

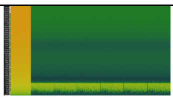
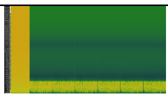
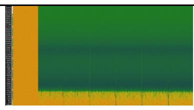
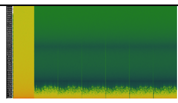
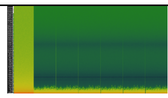
	not to be described. Higher bitrate describes noise fairly well. Lower frequencies are sacrificed due to lower amplitude resulting in pitched artefacts Flightless Birdies (1-2k). These Birdies from lower frequencies give pitched character over the dense complex timbre of higher frequencies. Amplitude fluctuations moving in columns.	causing them not to be described. Higher bitrate describes noise fairly well. Lower frequencies are sacrificed due to lower amplitude resulting in pitched artefacts Flightless Birdies (500 - 1kHz). These Birdies from lower frequencies give pitched character over the dense complex timbre of higher frequencies. Amplitude fluctuations	to some degree. Higher sample rate means that bits are stretched and creates finer artefacts. Some pitched artefacts can be heard embedded within the noise being described. Amplitude fluctuations moving in columns. Degrading with each iteration. Rapid/dynamic movement	below Nyquist are described to some degree. Higher bitrate describes noise fairly well. Noise is best described between 0-4k. above 4k, though, there are discernible artefacts. Between 0-4k there are amplitude fluctuations. Above 4k artefacts are mostly still mostly complex. Degrades with each iteration.	described to some degree. Description is poor. Higher sample rate stretches bits and creates finer artefacts. Pitched artefacts can be heard embedded within the noise being described. Between 5-6k birdies can be heard. Lower frequencies densities are also patchy resulting in a rumbling Amplitude fluctuations moving in columns.

	Degrading with each iteration.	moving in columns. Degrading with each iteration.			Degrading with each iteration.
iTunes 16 24	 Bandwidth Limit: 2 – 12kHz. Higher limit caused by Nyquist. Lower frequencies are cut due to low amplitude. Flightless Birdies again between 2.5 and 4.5 kHz No gaps, continuous overlapping. Degrades over time.	 Bandwidth Limit: 500Hz – 11kHz Higher limit caused by Nyquist. Lower frequencies are cut due to low amplitude High sample rate straining bitrate causing lots of pitched artefacts. Poor description of noise. Clearest are Flightless Birdies 1 - 2.5kHz	 Bandwidth Limit: 0 – 10kHz Capped due to Nyquist. Amplitude of White noise means that all frequencies below Nyquist are described to some degree. High sample rate straining bitrate causing lots of pitched artefacts. Poor description of noise. Higher sample rate means that	 Bandwidth Limit: 0 – 10kHz Capped close to Nyquist. Amplitude of Pink noise favours lower frequencies and therefore means that all frequencies below Nyquist are described to some degree. High sample rate straining bitrate causing lots of pitched artefacts. Poor description of noise.	 Bandwidth Limit: 0 – 8kHz Capped due to Low Pass Filter built into encoder, triggered by amplitude and bitrate. Amplitude of Red noise favours lower frequencies and therefore means that all frequencies below Nyquist are described to some degree. High sample rate straining bitrate causing lots of

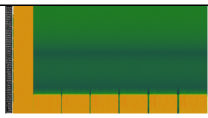
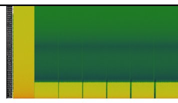
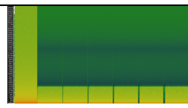
		Degrades over time.	bits are stretched but also giving a wider range of pitches. Continuous, dynamic and rapid texture. Degrades over time	Pitched artefacts Birdies throughout. Bits are stretched but also giving a wider range of pitches.	pitched artefacts. Poor description of noise. Pitched artefacts Birdies throughout. Bits are stretched but also giving a wider range of pitches.
	Violet	Blue	White	Pink	Red
Lame 8 8	 Bandwidth Limit: 250Hz – 3kHz Capped probably due to Nyquist, but could be in-built LPF. Lowest frequency is 250Hz due to amplitude of frequencies	 Bandwidth Limit: 0Hz – 3kHz Capped probably due to Nyquist, but could be in-built LPF. Noise is fairly well described. There are some discernible artefacts	 Bandwidth Limit: 0Hz-3kHz Capped probably due to Nyquist, but could be in-built LPF. Amplitude of White noise means that all frequencies below Nyquist are described	 Bandwidth Limit: 0 – 3kHz Capped probably due to Nyquist, but could be in-built LPF. Amplitude of White noise means that all frequencies below Nyquist are described	 Bandwidth Limit: Bandwidth Limit: 0 – 3kHz Capped probably due to Nyquist, but could be in-built LPF. Amplitude of Red noise favours lower frequencies and therefore means that all frequencies

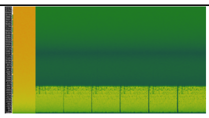
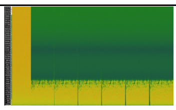
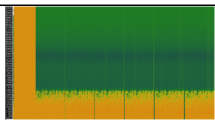
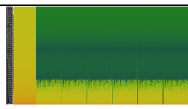
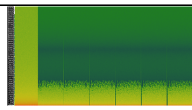
	below that being too quiet and therefore cut/not described. Description fairly good. Still complex signal. No discernible artefacts. Some amplitude fluctuations but not many. Signal Gaps: Delay at the start of each iteration, which increases with each iteration.	between 2.5-3kHz, though they are still relatively noisy. Some amplitude fluctuations but not many. Signal Gaps: Delay at the start of each iteration, which increases with each iteration.	to some degree. Fairly good description. Discernible artefacts that are almost pitched, but overall still complex. Amplitude does not diminish overall. Delay at beginning, which increases with each iteration. Iterations do not degrade.	to some degree. Description is ok. There are discernible pitched artefacts in the upper frequencies, but lower frequencies are well described. Amplitude does not diminish overall. Delay at beginning, which increases with each iteration.	below Nyquist are described to some degree. Description is ok. There are pitched artefacts in the higher frequencies. Lower frequencies are better described, more consistent noise. Amplitude is consistent, iterations don't diminish in quality. Delay at beginning, which increases with each iteration.
Lame 8 16	 Bandwidth Limit: 500Hz - 3kHz.	 Bandwidth Limit: 150Hz-3kHz	 Bandwidth Limit: 0-3kHz	 Bandwidth Limit: 0 – 3kHz	 Bandwidth Limit: 0 – 2.8kHz

	Capped due to in-built LPF, considering the sample rate is 16kHz and the Nyquist would be 8kHz. Lowest frequency is 500Hz due to amplitude of frequencies below that being too quiet and therefore cut/not described. Description is OK. Higher sample rate creates finer/shorter artefacts, discernible artefacts, though not discrete. Still complex signal	Capped due to in-built LPF, considering the sample rate is 16kHz and the Nyquist would be 8kHz. Lowest frequency is 150Hz due to amplitude of frequencies below that being too quiet and therefore cut/not described. Description is OK. Higher sample rate creates finer/shorter artefacts, discernible artefacts which are pitched in the upper frequencies.	Capped due to in-built LPF, considering the sample rate is 16kHz and the Nyquist would be 8kHz. Amplitude of White noise means that all frequencies below Nyquist are described to some degree. Fairly poor description. Discernible artefacts, some pitched in higher frequencies, but mostly still complex signal. Amplitude fluctuations to the point of	Capped due to in-built LPF, considering the sample rate is 16kHz and the Nyquist would be 8kHz. Amplitude of Pink noise means that all frequencies below Nyquist are described to some degree. Description is fairly poor. There are discernible pitched artefacts in the upper frequencies, but lower frequencies are described ok. Amplitude does not diminish	Capped due to in-built LPF, considering the sample rate is 16kHz and the Nyquist would be 8kHz. Amplitude of Red noise favours lower frequencies and therefore means that all frequencies below Nyquist are described to some degree. Description is ok. There are pitched artefacts in the higher frequencies. Lower frequencies are better described, more consistent noise. This is due to the amplitude

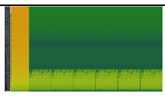
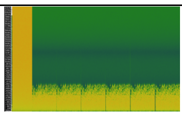
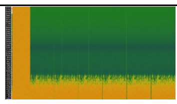
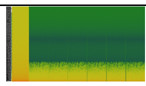
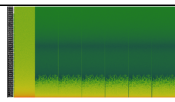
	Iterations are very similar throughout. Though there is an increasing Delay at the beginning of each iteration.	Iterations are very similar throughout. Though there is an increasing Delay at the beginning of each iteration.	almost creating signal gaps. Iterations are very similar throughout. Though there is an increasing Delay at the beginning of each iteration.	overall and iterations a similar throughout Delay at beginning, which increases with each iteration.	characteristics of red noise. Lower frequencies are louder and therefore preserved better. Amplitude is consistent, iterations don't diminish in quality. Delay at beginning, which increases with each iteration though shorter than with lower sample rate.
Lame 8 24	 Bandwidth Limit: 600Hz – 3kHz Capped due to in-built LPF, considering the sample rate is 24kHz and the	 Bandwidth Limit: 0-3kHz Capped due to in-built LPF, considering the sample rate is 24kHz and the	 Bandwidth Limit: 0-3kHz Capped due to in-built LPF, considering the sample rate is 24kHz and the	 Bandwidth Limit: 0-3kHz Capped due to in-built LPF, considering the sample rate is 24kHz and the	 Bandwidth Limit: 0 – 2kHz Capped due to in-built LPF, considering the sample rate is 24kHz and the

	Nyquist would be 12kHz. Lowest frequency is 600Hz due to amplitude of frequencies below that being too quiet and therefore cut/not described. Description is fairly poor. Higher sample rate creates finer/shorter artefacts. Lower frequencies have discernible pitched artefacts. Flightless Birdies. Overall fairly continuous	Nyquist would be 12kHz Lower frequencies are most poorly described due to lower amplitude in the original signal. However, there are still some artefacts that reach to very low frequencies. Description is fairly poor. Higher sample rate creates finer/shorter artefacts. There are clear distinct artefacts throughout bandwidth.	Nyquist would be 12kHz Amplitude of White noise means that all frequencies below Nyquist are described to some degree. Fairly poor description. Discernible artefacts, lots are pitched, particularly in higher frequencies. Overall signal is patchier, due to higher sample rate creating finer artefacts. Birdies. Overall fairly continuous except for	Nyquist would be 12kHz Amplitude of Pink noise means that all frequencies below Nyquist are described to some degree. Poor description. Lots of pitched artefacts (birdies). Higher frequencies are very patchy. Lower frequencies are fairly continuous. Delays at the start of each iteration. Delays are shorter than in	Nyquist would be 12kHz Amplitude of Red noise favours lower frequencies and therefore means that all frequencies below Nyquist are described to some degree. Description is poor. There are pitched artefacts in the higher frequencies. Lower frequencies are better described, more consistent noise. But bandwidth is limited to such an extent that preserved frequencies are still pitched and drone-like, rumble. Not

	except for delays at the start of each iteration. Delays are shorter than in encodings with lower sample rate.	Pitched artefacts are embedded within complex signal. Delays are shorter than in encodings with lower sample rate.	delays at the start of each iteration. Delays are shorter than in encodings with lower sample rate.	encodings with lower sample rate.	complex, not noisy. Overall fairly continuous except for delays at the start of each iteration. Delays are shorter than in encodings with lower sample rate.
Lame 16 8	 Bandwidth Limit: 200Hz-4kHz Capped probably due to Nyquist, but could be in-built LPF. Lowest frequency is 200Hz due to amplitude of frequencies	 Bandwidth Limit: 0 – 4kHz Capped probably due to Nyquist, but could be in-built LPF. Very good description except for bandwidth limitation.	 Bandwidth Limit: 0 – 4kHz Capped probably due to Nyquist, but could be in-built LPF. Amplitude of White noise means that all frequencies below Nyquist are described	 Bandwidth Limit: 0 – 4kHz Capped probably due to Nyquist, but could be in-built LPF. Amplitude of Pink noise means that all frequencies below Nyquist	 Bandwidth Limit: 0 – 4kHz Capped probably due to Nyquist, but could be in-built LPF. Amplitude of Red noise favours lower frequencies and therefore means that all frequencies below Nyquist are

	below that being too quiet and therefore cut/not described. Description very good except for bandwidth limitation. Still complex signal. No discernible artefacts. No amplitude fluctuations Only Signal Gaps at the beginning of each iteration. Delay increases with each iteration	Slight degradation between iterations. Fluctuating amplitudes, but still complex signal. No pitched Delay, increasing at beginning of each iteration.	to some degree. Very good description except for bandwidth limitation. No discernible artefacts. Small amount of amplitude fluctuation. Delay, increasing at beginning of each iteration.	are described to some degree. Very good description, except for bandwidth limitation. No artefacts. Lower amplitude overall. Delay, increasing at beginning of each iteration.	described to some degree. Very good description except for bandwidth limitation. No artefacts. Lower amplitude overall. Delay, increasing at beginning of each iteration.
Lame 16 16	 Bandwidth Limit: 150Hz-5.5Khz	 Bandwidth Limit: 0 – 6kHz	 Bandwidth Limit: 0-5.5kHz	 Bandwidth Limit: 0 – 5.5kHz	 Bandwidth Limit: 0 – 5.5kHz

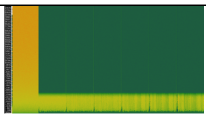
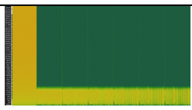
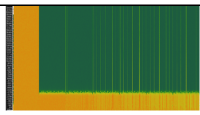
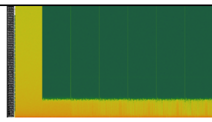
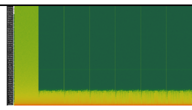
	Capped due to in-built LPF, considering the sample rate is 16kHz and the Nyquist would be 8kHz. Lowest frequency is 150Hz due to amplitude of frequencies below that being too quiet and therefore cut/not described. Description is OK. Discernible artefacts, though not discrete. Still complex signal. Iterations are very similar throughout. Though there is	Capped due to in-built LPF, though increased bitrate has heightened bandwidth limit. Good description of noise. Distinct artefacts, but mostly complex. Few are pitched. Whooshing effect. Iterations are very similar throughout. The Delay at the beginning of each iteration is shorter than	Capped due to in-built LPF, though increased bitrate has heightened bandwidth limit. Amplitude of White noise means that all frequencies below Nyquist are described to some degree. Ok description. Distinct artefacts, but mostly complex. Few are pitched. Iterations are very similar throughout. The Delay at the beginning of each	Capped due to in-built LPF, though increased bitrate has heightened bandwidth limit. Amplitude of Pink noise means that all frequencies below Nyquist are described to some degree. Ok description. Distinct artefacts in higher frequencies, but mostly complex in middle and lower frequencies. Few are pitched.	Capped due to in-built LPF, though increased bitrate has heightened bandwidth limit. Amplitude of Red noise favours lower frequencies and therefore means that all frequencies below Nyquist are described to some degree. Ok description except for bandwidth limitation. Distinct artefacts in higher frequencies, but mostly complex in middle and lower frequencies. Few are pitched. Iterations are very similar throughout. The

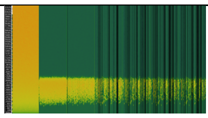
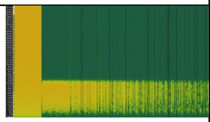
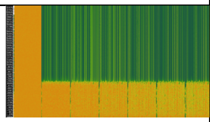
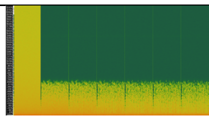
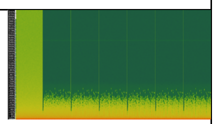
	an increasing Delay at the beginning of each iteration. Encoder’s frequency bands can be clearly seen. Artefact density can be seen to markedly change at clear points in spectrum.	with lower sample rates. Encoder’s frequency bands can be clearly seen. Artefact density can be seen to markedly change at clear points in spectrum.	iteration is shorter than with lower sample rates. Encoder’s frequency bands can be clearly seen. Artefact density can be seen to markedly change at clear points in spectrum.	Iterations are very similar throughout. The Delay at the beginning of each iteration is shorter than with lower sample rates.	Delay at the beginning of each iteration is shorter than with lower sample rates.
Lame 16 24	 Bandwidth Limit: 150Hz-5.5Khz Capped due to in-built LPF, considering the sample rate is 24kHz and the Nyquist would be 12kHz.	 Bandwidth Limit: 0 – 6kHz Capped due to in-built LPF. Description is OK. Higher sample rate creates finer/shorter,	 Bandwidth Limit: 0 – 6kHz Capped due to in-built LPF. Description is OK. Higher sample rate creates finer/shorter,	 Bandwidth Limit: 0 – 6kHz Capped due to in-built LPF. Description is fairly good. Higher sample rate creates finer/shorter, discernible	 Bandwidth Limit: 0 – 5.5kHz Description is ok. Higher sample rate creates finer/shorter, discernible artefacts, discrete and pitched. Though still mostly complex.

	Lowest frequency is 150Hz due to amplitude of frequencies below that being too quiet and therefore cut/not described. Description is poorer. Higher sample rate creates finer/shorter, discernible artefacts, discrete and pitched. Though still mostly complex. Pitched artefacts are in the higher frequencies of the signal.	discernible artefacts, discrete and pitched. Though still mostly complex. Pitched artefacts are in the higher frequencies of the signal (4-6kHz). Iterations are very similar throughout. Though there is an increasing Delay at the beginning of each iteration. Encoder's frequency bands can be clearly seen. Artefact density can be seen to markedly	discernible artefacts, discrete and pitched. Though still mostly complex. Pitched artefacts are in the higher frequencies of the signal (4-6kHz). Iterations are very similar throughout. There is an increasing Delay at the beginning of each iteration, though it is shorter overall compared with lower sample rates.	artefacts, discrete and pitched. Though still mostly complex. Pitched artefacts are in the higher frequencies of the signal (4-6kHz). Iterations are very similar throughout. There is an increasing Delay at the beginning of each iteration, though it is shorter overall compared with lower sample rates.	Amplitude of Red noise favours lower frequencies. Higher frequencies are described poorly, resulting in pitched artefacts around 4-6kHz. Iterations are very similar throughout. There is an increasing Delay at the beginning of each iteration, though it is shorter overall compared with lower sample rates.

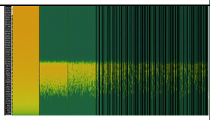
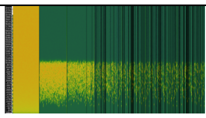
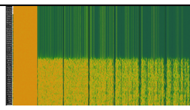
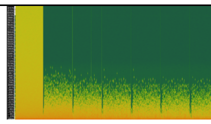
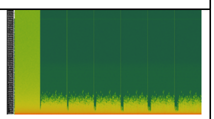
	Iterations are very similar throughout. Though there is an increasing Delay at the beginning of each iteration. Encoder's frequency bands can be clearly seen. Artefact density can be seen to markedly change at clear points in spectrum.	change at clear points in spectrum.			

A.2 Noise Stereo Test Index

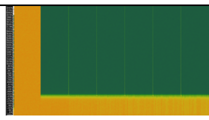
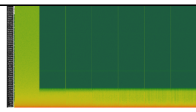
	Violet	Blue	White	Pink	Red
iTunes 8/16 8 JS	 Bandwidth Limit: 500Hz – 4kHz Capped due to Nyquist. Lowest frequency is 500Hz due to amplitude of frequencies below that being too quiet and therefore cut/not described. Discernible artefacts, though still mostly complex. Some pitched artefacts in	 Bandwidth Limit: 4kHz Capped due to Nyquist. Almost all frequencies described below cap. Some very low frequencies poorly described but not perceivable. Reflections above Nyquist Good description of noise. No discernible artefacts.	 Bandwidth Limit: 0 – 4kHz Capped at Nyquist with all frequencies described below cap. Reflections above Nyquist. Description of noise is consistently complex. One or two pitched artefacts. Good description at first followed	 Bandwidth Limit: 0 – 4kHz Capped at Nyquist with all frequencies described below cap. Description is fairly good at start. Consistently complex and noisy, but with some pitched moments. Amplitude fluctuations from third iteration onwards.	 Bandwidth Limit: 0 – 3.4kHz Capped below Nyquist with all frequencies described below cap. Description is good. Consistently complex, no pitched artefacts. Amplitude fluctuates a bit.

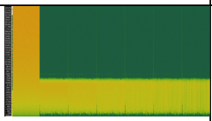
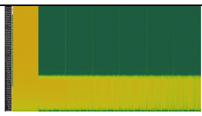
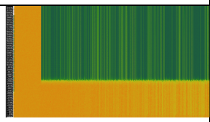
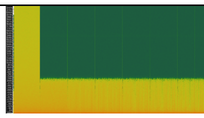
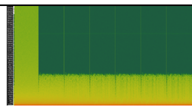
	lower frequencies, which are poorly described but not enough to call Birdies. Amplitude fluctuations. Whooshing effect Signal Gaps: Slight delay at the start of each iteration, perhaps more like a drop in amplitude, but increases with each iteration to the point that it is a signal gap.	Amplitude fluctuations throughout, though very clear from third iteration onwards.	by substantial amplitude fluctuations.		
iTunes 8 16 16 JS					

	Bandwidth Limit: 1.4 – 7.6 kHz Capped below Nyquist. Lowest frequency is 1.4kHz due to amplitude of frequencies below that being too quiet and therefore cut/not described. Description is poor. Bitrate is clearly struggling creating discrete artefacts after the second iteration, creating the	Bandwidth Limit: 300Hz – 7.5kHz Capped below Nyquist. Lowest frequency is 300Hz due to amplitude of frequencies below that being too quiet and therefore cut/not described. Description is poor. Bitrate is clearly struggling creating discrete artefacts after the second iteration. The artefacts are both complex	Bandwidth Limit: 0 – 7.2kHz Capped below Nyquist. Bitrate is struggling. Description is fairly poor. Discernible pitched artefacts throughout. Though still complex signal. Signal gaps occurring at the beginning of each iteration.	Bandwidth Limit: 0 – 7kHz Capped below Nyquist. Frequencies described below cap to some degree. Bitrate is struggling. Description is fairly poor. Discernible pitched artefacts throughout. Mostly complex, birdies in higher frequencies, low pitches rumbling. Signal gaps occurring at the beginning	Bandwidth Limit: 0 – 6.2 Capped below Nyquist. Frequencies described below cap to some degree. Description is fairly poor. Discernible pitched artefacts throughout. birdies, low pitches rumbling. Signal gaps occurring at the beginning of each iteration

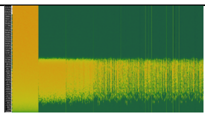
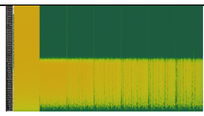
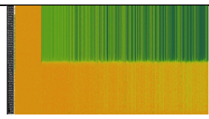
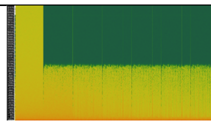
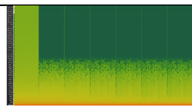
	artefacts Birdies. Signal gaps from second iteration onwards Columns of black are artefacts of the DAW used to compile iterations (logic).	and simple creating noisy bursts and also Birdies. Low birdies are clear from the outset, though as iterations progress, higher ones become increasingly pronounced. Lots of signal gaps.		of each iteration.	
iTunes 8/16 24 JS	 Bandwidth Limit: 3 – 11kHz Capped below Nyquist. Lowest frequency is 3kHz due to amplitude of frequencies	 Bandwidth Limit: 1.4kHz – 11kHz Capped below Nyquist. Lowest frequency is 1.4kHz due to amplitude of frequencies	 Bandwidth Limit: 0 – 10kHz Capped below Nyquist. Description is poor.	 Bandwidth Limit: 0 – 10kHz Capped below Nyquist. Frequencies described below cap to some degree.	 Bandwidth Limit: 0 – 5kHz Capped by LPF Frequencies described below cap to some degree.

	below that being too quiet and therefore cut/not described. Description is very poor. Bitrate is clearly struggling creating discrete artefacts after the second iteration, creating the artefacts Birdies. Signal gaps from second iteration onwards Columns of black are artefacts of the DAW used	below that being too quiet and therefore cut/not described. Description is poor. Bitrate is clearly struggling creating discrete artefacts after the second iteration, creating Birdies. Signal gaps from second iteration onwards Columns of black are artefacts of the DAW used to compile	Bitrate is clearly struggling creating pitched artefacts (Birdies) from first iteration. Amplitude decreases overall with each iteration. Signal gaps from second iteration onwards	Description is very poor. Bitrate is clearly struggling creating pitched artefacts (Birdies) from first iteration. Amplitude decreases overall with each iteration. Delay at beginning of each iteration, increases with each iteration.	Description is fairly poor. Discernible pitched artefacts throughout. birdies, low pitches rumbling. Delay occurring at the beginning of each iteration and increasing.

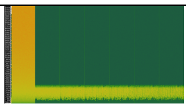
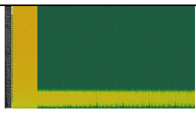
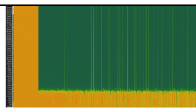
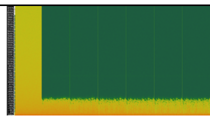
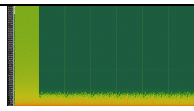
	to compile iterations (logic). Towards the end, there is more silence than noise.	iterations (logic).			
iTune s 16/3 2 8 JS	 Bandwidth Limit: 0 – 4kHz High capped by Nyquist higher bitrate is capable of describing practically all frequencies below. reflections above Nyquist Good description of Noise with no	 Bandwidth Limit: 0 - 4kHz High capped by Nyquist higher bitrate is capable of describing practically all frequencies below. reflections above Nyquist Good description of	 Bandwidth Limit: 0 – 4kHz Capped due to Nyquist. Reflections above Nyquist. Good description of Noise with very few discernible artefacts.	 Bandwidth Limit: 0 – 4kHz Capped due to Nyquist. Frequencies described below cap to some degree. Good description of Noise with very few discernible artefacts.	 Bandwidth Limit: 0 – 4kHz Capped due to Nyquist. Frequencies described below cap to some degree. Good description of Noise with very few discernible artefacts.

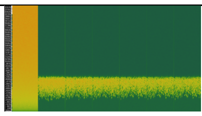
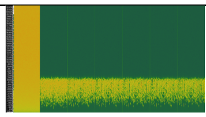
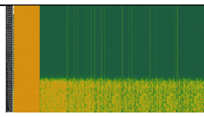
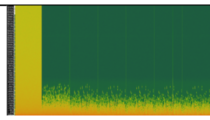
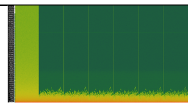
	discernible artefacts. There is a fairly consistent band of noise 2.5-3.5kHz Amplitude fluctuates in later iterations. Iterations slightly degrade over time, with very patchy amplitude in last three iterations.	Noise with no discernible artefacts. Amplitude fluctuates in later iterations. Iterations slightly degrade over time, patchy amplitude in last three iterations.	Amplitude fluctuates in later iterations. Iterations slightly degrade over time, patchy amplitude in last three iterations.	Amplitude fluctuates in later iterations. Iterations slightly degrade over time, patchy amplitude in last three iterations.	Slight click/noise burst at start of each iteration. Some patchy amplitude in later iterations.
iTunes 16/32 16 JS	 Bandwidth Limit: 200Hz – 7.8kHz	 Bandwidth Limit: 150Hz – 7.7kHz	 Bandwidth Limit: 0 – 7.5kHz	 Bandwidth Limit: 0 – 7.3kHz	 Bandwidth Limit: 0 – 7.2kHz

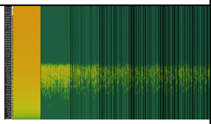
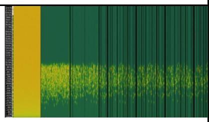
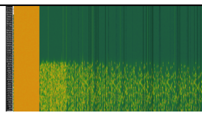
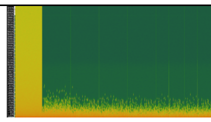
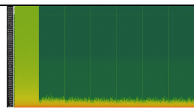
	Capped below Nyquist. Lowest frequency is 200Hz due to amplitude of frequencies below that being too quiet and therefore cut/not described. However, higher bitrate means better description overall. Some reflections above Nyquist. Fairly good description. Some discernible artefacts but still mostly complex.	Capped below Nyquist. Lowest frequency is 150Hz due to amplitude of frequencies below that being too quiet and therefore cut/not described. However, higher bitrate means better description overall. Some reflections above Nyquist. Fairly good description. Some discernible artefacts but still mostly complex.	Capped below Nyquist. Fairly good description. Some discernible artefacts but still complex. Amplitude Fluctuations in later iterations.	Capped below Nyquist. Frequencies described below cap to some degree. Description is OK at start. Still complex, though some pitched artefacts at the start of each iteration. Amplitude fluctuations.	Capped below Nyquist. Frequencies described below cap to some degree. Description is good at start but degrades after second. Still complex, not pitched artefacts. Amplitude fluctuates.

	Amplitude Fluctuations in later iterations, overall amplitude decreases.	Amplitude Fluctuations in later iterations, overall amplitude decreases.			
iTunes 16/32 24 JS	 Bandwidth Limit: 1.5-11.3kHz Capped below Nyquist. Lowest frequency is 150Hz due to amplitude of frequencies below that being too quiet and therefore cut/not described.	 Bandwidth Limit: 300 – 11kHz Capped below Nyquist. Lowest frequency is 150Hz due to amplitude of frequencies below that being too quiet and therefore cut/not described.	 Bandwidth Limit: 0 – 10kHz Capped below Nyquist. Description is ok. Discernible artefacts. But still mostly complex. Amplitude fluctuations.	 Bandwidth Limit: 0 – 10kHz Capped below Nyquist. Frequencies described below cap to some degree. Description begins OK but is fairly poor toward end.	 Bandwidth Limit: 0 – 10kHz Capped below Nyquist. Frequencies described below cap to some degree. Description begins OK but is fairly poor toward end.

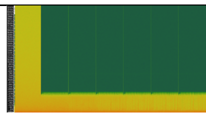
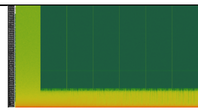
	Description is poor. Bitrate is clearly struggling creating discrete artefacts after the second iteration, creating the artefacts Birdies. Mostly pitched artefacts, though still some bursts of noise in later iterations. Signal gaps from third iteration onwards	Description is Ok at first, but becomes poor. Bitrate is struggling, creating discrete artefacts after third iteration. Both pitched and noisy artefacts Amplitude fluctuations, particularly at the start of iterations. Signal gaps towards end.		Bitrate becomes stretched, creating pitched artefacts. Amplitude fluctuations	Bitrate becomes stretched, creating pitched artefacts, though still lots of complexity in description. Amplitude fluctuations

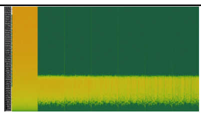
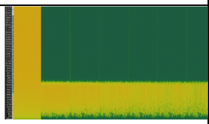
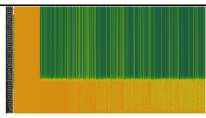
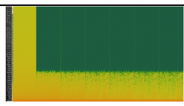
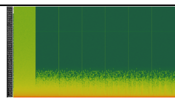
iTune s 8/16 8 NS	 Bandwidth Limit: 700Hz – 4kHz Capped at Nyquist. Lowest frequency is 700Hz due to amplitude of frequencies below that being too quiet and therefore cut/not described. Reflections above Nyquist. Description is OK. Some pitched artefacts in	 Bandwidth Limit: 170Hz – 4kHz Capped at Nyquist. Lowest frequency is 170Hz due to amplitude of frequencies below that being too quiet and therefore cut/not described. Reflections above Nyquist. Description is OK. Some pitched artefacts in	 Bandwidth Limit: 0 – 4kHz Capped due to Nyquist. Frequencies described below cap to some degree. Description of noise is consistently complex. One or two pitched artefacts. Good description at first followed by substantial amplitude fluctuations.	 Bandwidth Limit: 0 – 3.4kHz Capped below Nyquist. Frequencies described below cap to some degree. Description of noise is fairly good. Mostly complex, though there are pitched artefacts in higher frequencies. Amplitude fluctuations in later iterations.	 Bandwidth Limit: 0 – 3.1kHz Capped below Nyquist. Frequencies described below cap to some degree. Description is fairly poor. Discernible pitched artefacts in higher frequencies. Amplitude fluctuates. Not much degradation after first iteration.

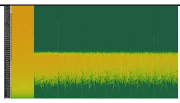
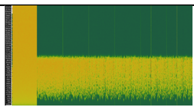
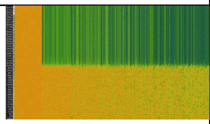
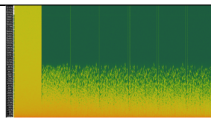
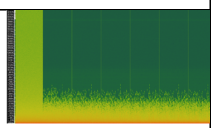
	lower frequencies, which are poorly described but not enough to call Birdies. Still mostly complex overall. Amplitude fluctuations.	lower frequencies but not enough to call Birdies. Still mostly complex overall. Amplitude fluctuations. Signal gaps at beginning of iterations.	Signal gaps from third iteration onwards. Lots of clipping.		
iTunes 8/16 16 NS	 Bandwidth Limit: 2.2 – 7.3kHz Capped below Nyquist. Lowest frequency is 2.2kHz due to lower amplitudes below this threshold.	 Bandwidth Limit: 1kHz – 7.4kHz Capped at Nyquist. Lowest frequency is 170Hz due to amplitude of frequencies below that being too	 Bandwidth Limit: 0 – 7kHz Capped below Nyquist. Frequencies described below cap to some degree.	 Bandwidth Limit: 0 – 6.2 Capped below Nyquist. Frequencies described below cap to some degree. Description is poor. Lots of	 Bandwidth Limit: 0 – 3.4 Capped due to LPF Frequencies described below cap to some degree. Description is fairly poor. Pitched

	These lower frequencies are sacrificed for better descriptions elsewhere. Bitrate is stretched due to larger sample rate. Poor description of noise. Lots of pitched artefacts – Birdies.	quiet and therefore cut/not described. Bitrate is stretched due to larger sample rate. Description is poor creating lots of pitched artefacts - Birdies. No complexity.	Bitrate is stretched due to larger sample rate. Description is poor creating lots of pitched artefacts - Birdies. No complexity. Signal gaps in later iterations.	pitched artefacts. Lots of birdies. In second from last iteration, there is a noise burst.	artefacts throughout. Birdies. Little degradation after first iteration. Noise bursts at start of each iteration.
iTune s 8/16 24 NS	 Bandwidth Limit: 2.5 – 10kHz Capped due to built-in LPF. Lowest frequency is 2.5kHz due to	 Bandwidth Limit: 1.8kHz – 10kHz Capped due to built-in LPF. Lowest frequency is	 Bandwidth Limit: 0 – 10kHz Capped below Nyquist. Frequencies described	 Bandwidth Limit: 0 – 6.2kHz Capped due to LPF Frequencies described	 Bandwidth Limit: 0 – 2.9kHz Capped due to LPF Frequencies described

	lower amplitudes below this threshold. These lower frequencies are sacrificed for better descriptions elsewhere. While the lowest frequency described is 2.5kHz, it is much lower than the second lowest, which is around 4kHz. Description is very poor. Bitrate is stretched due to larger sample rate, creating	1.8kHz due to lower amplitudes below this threshold. These lower frequencies are sacrificed for better descriptions elsewhere. Description is very poor. Bitrate is clearly struggling to describe noise, creating birdies and signal gaps. Black columns are an artefacts of the DAW (Logic) used to compile iterations.	below cap to some degree. Description is very poor. Bitrate is clearly struggling to describe noise, creating discernible pitched artefacts throughout (Birdies) and signal gaps. Black columns are an artefacts of the DAW (Logic) used to compile iterations.	below cap to some degree. Description is poor. Bitrate is clearly struggling to describe noise, creating discernible pitched artefacts throughout (Birdies)	below cap to some degree. Description is fairly poor. Discernible pitched artefacts throughout (Birdies). Lower frequencies rumbling.

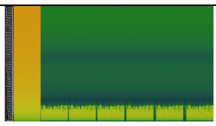
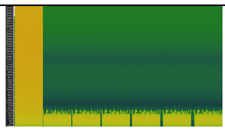
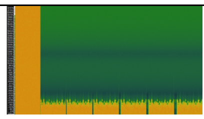
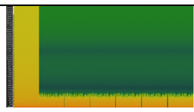
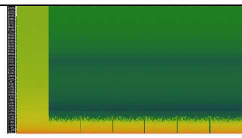
	Birdies and signal gaps. Black columns are an artefacts of the DAW (Logic) used to compile iterations.				
iTunes 16/328 NS	 Bandwidth Limit: 0 – 4kHz Capped at Nyquist. Higher bitrate can describe almost all frequencies below. Reflections above. Very good description. No discernible artefacts.	 Bandwidth Limit: 0 – 4kHz Capped at Nyquist. Higher bitrate can describe almost all frequencies below. Reflections above. Very good description. No discernible artefacts.	 Bandwidth Limit: 0 – 4kHz Capped due to Nyquist. Frequencies described below cap to some degree. Very good description. No discernible artefacts.	 Bandwidth Limit: 0 – 4kHz Capped due to Nyquist. Frequencies described below cap to some degree. Very good description. No discernible artefacts. Amplitude fluctuations	 Bandwidth Limit: 0 – 4kHz Capped due to Nyquist. Frequencies described below cap to some degree. Reflections above nyquist Good description.

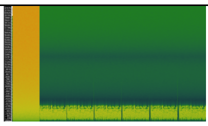
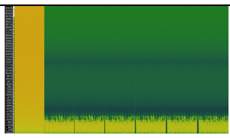
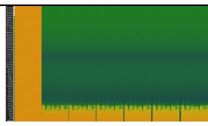
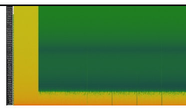
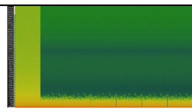
	Amplitude fluctuations from third iteration. Iterations slightly degrade over time, with very patchy amplitude in last three iterations.	Amplitude fluctuations from third iteration. Iterations slightly degrade over time, with very patchy amplitude in last three iterations.	Amplitude fluctuations from third iteration. Iterations slightly degrade over time, with very patchy amplitude in last three iterations.	from third iteration. Iterations slightly degrade over time, with very patchy amplitude in last three iterations.	No discernible artefacts. Amplitude fluctuations from second iteration. Iterations slightly degrade over time, with patchy amplitude in last three iterations.
iTunes 16/32 16 NS	 Bandwidth Limit: 860 – 7.8 kHz Capped at Nyquist Lowest frequency is 860Hz due to lower amplitudes below this	 Bandwidth Limit: 250Hz – 7.5kHz Capped at Nyquist Lowest frequency is 860Hz due to lower amplitudes below this	 Bandwidth Limit: 0 – 7.4kHz Capped below Nyquist. Frequencies described below cap to some degree.	 Bandwidth Limit: 0 – 7kHz Capped below Nyquist. Frequencies described below cap to some degree.	 Bandwidth Limit: 0 – 7kHz Capped below Nyquist. Frequencies described below cap to some degree.

	threshold. These lower frequencies are sacrificed for better descriptions elsewhere. Description is ok. There are discernible pitched artefacts in lower frequencies but still mostly complex. Amplitude fluctuations throughout. Deteriorates over time.	threshold. These lower frequencies are sacrificed for better descriptions elsewhere. Description is ok. There are discernible pitched artefacts in lower frequencies and some in uppermost too, but still mostly complex. Amplitude fluctuations throughout. Deteriorates over time	Description is OK. Consistent description of noise. Discernible artefacts are still complex. Substantial amplitude fluctuations. Deteriorates over time	Description is ok at start but struggles after first iteration. Mostly complex, but some pitched artefacts.	Description is fairly poor. Starts ok, with some complexity, but also lots of pitched artefacts. Lower frequencies well described, rumbling. Amplitude fluctuates toward end.
iTunes 16/3					

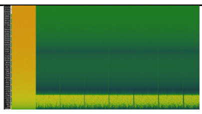
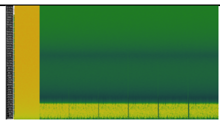
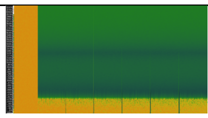
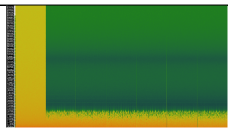
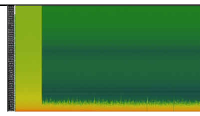
2 24 NS	Bandwidth Limit: 2.4 – 11kHz Capped by Nyquist. Lowest frequency is 2.4kHz due to lower amplitudes below this threshold. These lower frequencies are sacrificed for better descriptions elsewhere. Reflections above Nyquist. Description is quite poor. Lots of discernible, pitched artefacts. Rapid Birdies.	Bandwidth Limit: 900Hz – 11kHz Capped by Nyquist. Lowest frequency is 900Hz due to lower amplitudes below this threshold. These lower frequencies are sacrificed for better descriptions elsewhere. Description is poor. Pitched artefacts throughout. Birdies. Some signal gaps in later iterations.	Bandwidth Limit: 0 – 10.9kHz Capped below Nyquist. Frequencies described below cap to some degree. Bitrate is struggling. Description is poor. Discernible pitched artefacts throughout. Birdies. Overall amplitude decreases over time.	Bandwidth Limit: 0 – 10.6kHz Capped below Nyquist. Frequencies described below cap to some degree. Description is poor. Discernible pitched artefacts throughout. Birdies. Some noise bursts.	Bandwidth Limit: 0 – 7.5kHz Capped due to LPF. Frequencies described below cap to some degree. Description is fairly poor. Has complexity, but there are discernible pitched artefacts in the higher frequencies.

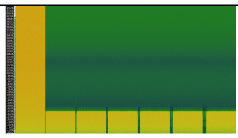
	Amplitude reduces over time.	Amplitude reduces over time.			

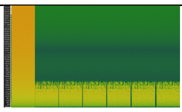
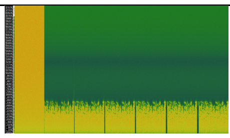
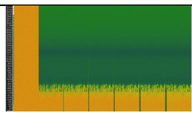
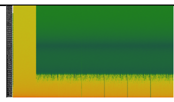
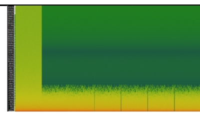
	Violet	Blue	White	Pink	Red
LAME 8 8 JS	 Bandwidth Limit: 200 – 3.1kHz Capped below Nyquist. Lowest frequency is 200Hz due to amplitude of frequencies below that being too quiet and therefore cut/not described.	 Bandwidth Limit: 0 – 3kHz Capped below Nyquist. Frequencies described below cap to some degree. Description is ok. Discernible pitched artefacts in higher frequencies but mostly complex.	 Bandwidth Limit: 0 – 3kHz Capped below Nyquist. Frequencies described below cap to some degree. Description is ok. Pithed artefacts in higher frequencies, but	 Bandwidth Limit: 0 – 3kHz Capped below Nyquist. Frequencies described below cap to some degree. Description is fairly poor. Pitched artefacts in higher frequencies and some complexity in lower ones.	 Bandwidth Limit: 0 – 2.9kHz Capped below Nyquist. Frequencies described below cap to some degree. Description is ok. Pitched artefacts in higher frequencies and some complexity in lower ones.

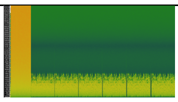
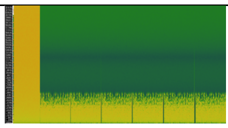
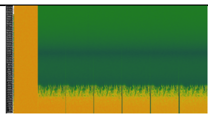
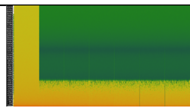
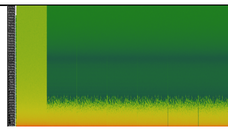
	Description is ok. Discernible artefacts, though still mostly complex. Some pitched artefacts in higher frequencies. Signal Gaps: delay at the start of each iteration, increases with each iteration.	Artefacts are larger due to lower sample rate. Signal Gaps: delay at the start of each iteration, increases with each iteration.	others are complex. Artefacts are larger due to lower sample rate. Signal Gaps: large delay at the start of each iteration, increases with each iteration.	Artefacts are larger due to lower sample rate. Delays at the start of each iterations, increasing with each iteration, creating signal gaps. Does not significantly degrade after second iteration.	Artefacts are larger due to lower sample rate. Delays at the start of each iterations, increasing with each iteration, creating signal gaps. Does not significantly degrade after second iteration.
LAME 8 16 JS	 Bandwidth Limit: 200 – 3kHz Capped due to LPF	 Bandwidth Limit: 0 – 3kHz Capped due to LPF Frequencies described below	 Bandwidth Limit: 0 – 3kHz Capped due to LPF	 Bandwidth Limit: 0 – 3kHz Capped due to LPF	 Bandwidth Limit: 0 – 3.1kHz Capped due to LPF

	Description is poor. Discernible pitched artefacts throughout. Some complexity but mostly pitched. Delays at the start of each iterations, increasing with each iteration, creating signal gaps. Does not significantly degrade after second iteration.	cap to some degree. Description is fairly poor. Lots of pitched artefacts in higher frequencies. lower frequencies are still fairly complex. Delays at the start of each iterations, increasing with each iteration, creating signal gaps. Does not significantly degrade after second iteration. Texture is finer due to higher sample rate.	Frequencies described below cap to some degree. Description is ok. Pitched artefacts in higher frequencies, others are still fairly complex. Delays at the start of each iterations, increasing with each iteration, creating signal gaps. Does not significantly degrade after second iteration. Texture is finer due to higher sample rate.	Frequencies described below cap to some degree. Description is fairly poor. Pitched artefacts throughout some complexity in lower frequencies. Artefacts are smaller due to higher sample rate. Delays at the start of each iterations, increasing with each iteration, creating signal gaps. Higher sample rate creates shorter delays. Does not significantly	Frequencies described below cap to some degree. Description is fairly poor. Pitched artefacts throughout some complexity in lower frequencies. Artefacts are smaller due to higher sample rate. Delays at the start of each iterations, increasing with each iteration, creating signal gaps. Higher sample rate creates shorter delays. Does not significantly

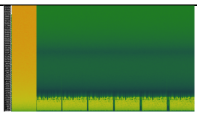
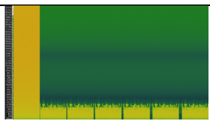
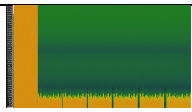
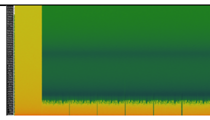
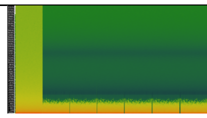
				degrade after second iteration.	degrade after second iteration.
LAME 8 24 JS	 Bandwidth Limit: 300 – 3kHz Capped due to LPF Description is fairly poor. Some complexity in higher frequencies, but discernible pitched artefacts in lower frequencies. Flightless Birdies. Delay at start of each iteration, delay increases with each iteration, but	 Bandwidth Limit: 200 – 3kHz Capped due to LPF Description is fairly poor. Discernible pitched artefacts throughout signal. Delay at start of each iteration, delay increases with each iteration, but not as much as lower sample rates. Does not significantly degrade after second iteration Finer texture again due to higher sample rate.	 Bandwidth Limit: 0 – 3kHz Capped due to LPF Frequencies described below cap to some degree. Description is poor. Discernible pitched artefacts throughout signal. Short delay at start of each iteration, delay increases with each iteration, but not as much	 Bandwidth Limit: 0 – 2.9kHz Capped due to LPF Frequencies described below cap to some degree. Description is fairly poor. Pitched artefacts throughout some complexity in lower frequencies. Artefacts are smaller due to higher sample rate. Short delay at start of each	 Bandwidth Limit: 0 – 2.9kHz Capped due to LPF Frequencies described below cap to some degree. Description is poor. Pitched artefacts throughout. Lower frequencies are pitched, but continuous, not artefacts. Artefacts are smaller due to higher sample rate.

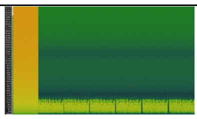
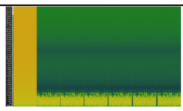
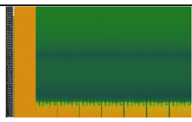
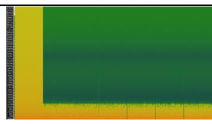
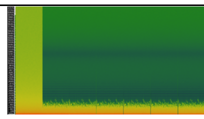
	not as much as lower sample rates. Does not significantly degrade after second iteration		as lower sample rates. Does not significantly degrade after second iteration Finer texture again due to higher sample rate.	iteration, delay increases with each iteration, but not as much as lower sample rates. Does not significantly degrade after second iteration.	Short delay at start of each iteration, delay increases with each iteration, but not as much as lower sample rates. Does not significantly degrade after second iteration.
LAME 16 8 JS	 Bandwidth Limit: 0 – 4kHz Capped at Nyquist Frequencies described below cap to some degree. Very good description of noise.	 Bandwidth Limit: 0 – 4kHz Capped at Nyquist Frequencies described below cap to some degree. Very good description of noise.	 Bandwidth Limit: 0 – 4kHz Capped at Nyquist Frequencies described below cap to some degree. Very good description of noise.	 Bandwidth Limit: 0 – 3.8kHz Capped at Nyquist Frequencies described below cap to some degree. Very good description of noise.	 Bandwidth Limit: 0 – 3.8kHz Capped at Nyquist Frequencies described below cap to some degree. Very good description of noise.

	No artefacts. Delays at the start of each iterations, increasing with each iteration, creating signal gaps. Does not degrade after second iteration.	No artefacts. Delays at the start of each iterations, increasing with each iteration, creating signal gaps. Does not degrade after second iteration.	No artefacts. Delays at the start of each iterations, increasing with each iteration, creating signal gaps. Does not degrade after second iteration.	No artefacts. Delays at the start of each iterations, increasing with each iteration, creating signal gaps. Does not degrade after second iteration.	No artefacts. Delays at the start of each iterations, increasing with each iteration, creating signal gaps. Does not degrade after second iteration.
LAME 16 16 JS	 Bandwidth Limit: 100 – 5.5kHz Capped due to LPF Description is OK. Complexity in lower frequencies, but higher frequencies	 Bandwidth Limit: 0 – 5.5kHz Capped due to LPF Frequencies described below cap to some degree. Description is ok. There are some pitched artefacts,	 Bandwidth Limit: 0 – 5.6kHz Capped due to LPF Frequencies described below cap to some degree.	 Bandwidth Limit: 0 – 5.5kHz Capped due to LPF Frequencies described below cap to some degree. Description is ok. There are some	 Bandwidth Limit: 0 – 5.5kHz Capped due to LPF Frequencies described below cap to some degree. Description is ok. Pitched artefacts

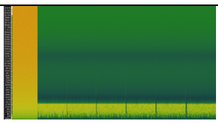
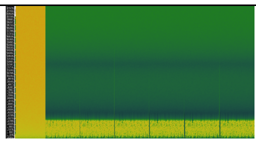
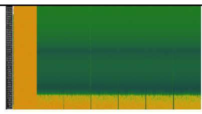
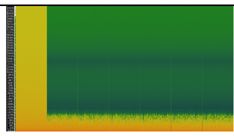
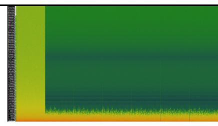
	have discernible artefacts which are both pitched and complex. Delays at the start of each iterations, increasing with each iteration, creating signal gaps. Does not degrade after second iteration. Iterations are very similar throughout.	though almost completely complex still. Delays at the start of each iterations, increasing with each iteration, creating signal gaps. Does not degrade after second iteration. Iterations are very similar throughout.	Description is ok. There are some pitched artefacts, though almost completely complex still. Delays at the start of each iterations, increasing with each iteration, creating signal gaps. Texture is finer due to higher sample rate. Does not degrade after second iteration. Iterations are very similar throughout.	pitched artefacts, though almost completely complex still. Delays at the start of each iterations, increasing with each iteration, creating signal gaps. Texture is finer due to higher sample rate. Does not degrade after second iteration. Iterations are very similar throughout.	in higher frequencies. Complexity in lower ones. Delays at the start of each iterations, increasing with each iteration, creating signal gaps. Texture is finer due to higher sample rate. Does not degrade after second iteration. Iterations are very similar throughout.
LAME 16 24 JS					

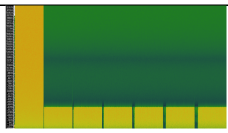
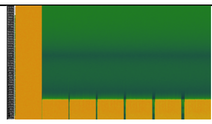
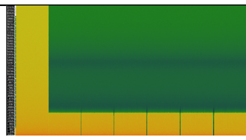
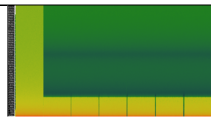
	Bandwidth Limit: 200 – 5.6 kHz Capped due to LPF Description is fairly poor. There is still complexity in the signal, mostly lower frequencies. Higher frequencies have discernible pitched artefacts. Birdies. Delays at the start of each iterations, increasing with each iteration, creating signal gaps. Does not degrade after	Bandwidth Limit: 0 – 5.7kHz Capped due to LPF Frequencies described below cap to some degree. Description is ok. There is still complexity in the signal, mostly lower frequencies. Higher frequencies have discernible pitched artefacts. Delays at the start of each iterations, increasing with each iteration, creating signal gaps. Does not degrade after second iteration. Iterations are very similar throughout.	Bandwidth Limit: 0 – 5.7 Capped due to LPF Frequencies described below cap to some degree. Description is fairly ok. Some discernible pitched artefacts in higher frequencies. Though still mostly complex signal. Short delays at the start of each iterations, increasing with each iteration, creating signal gaps.	Bandwidth Limit: 0 – 5.7kHz Capped due to LPF Frequencies described below cap to some degree. Description is fairly ok. Pitched artefacts in higher frequencies, complex signal in lower frequencies. Shorter delays at the start of each iterations, increasing with each iteration, creating signal gaps. Does not degrade after second iteration. Iterations are very	Bandwidth Limit: 0 – 5.5kHz Capped due to LPF Frequencies described below cap to some degree. Description is ok. Pitched artefacts in higher frequencies. Complexity in lower ones. Delays at the start of each iterations, increasing with each iteration, creating signal gaps. Texture is finer due to higher sample rate. More and smaller artefacts.

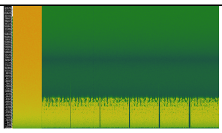
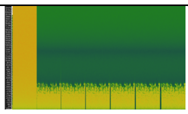
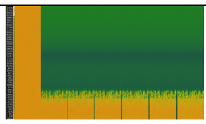
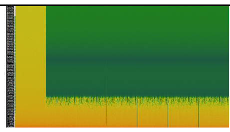
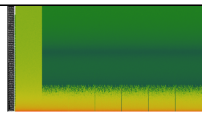
	second iteration. Iterations are very similar throughout.	Finer texture again due to higher sample rate.	Does not degrade after second iteration. Iterations are very similar throughout. Finer texture again due to higher sample rate.	similar throughout. Finer texture again due to higher sample rate.	Does not degrade after second iteration. Iterations are very similar throughout.
LAME 8 8 NS	 Bandwidth Limit: 200 – 3kHz Capped below Nyquist Description is ok. Signal is mostly complex with few discernible pitched artefacts in upper frequencies.	 Bandwidth Limit: 0 – 3kHz Capped below Nyquist Frequencies described below cap to some degree. Description is quite good. Very few artefacts, signal is still mostly complex.	 Bandwidth Limit: 0 – 3.1kHz Capped below Nyquist Frequencies described below cap to some degree. Description is fairly good. Some pitched artefacts in higher	 Bandwidth Limit: 0 – 3kHz Capped below Nyquist Frequencies described below cap to some degree. Description is fairly good. Some pitched artefacts in higher frequencies,	 Bandwidth Limit: 0 – 3kHz Capped below Nyquist Frequencies described below cap to some degree. Description is fairly good. Some pitched artefacts in higher frequencies.

	Low sample rate creates larger artefacts, less smooth texture. Delays at the start of each iterations, increasing with each iteration, creating signal gaps. Does not degrade after second iteration. Iterations are very similar throughout.	Pitched artefacts in higher frequencies and fairly large due to low sample rate. Delays at the start of each iterations, increasing with each iteration, creating signal gaps. Does not degrade after second iteration. Iterations are very similar throughout.	frequencies, though still complex overall. Artefacts are larger due to lower sample rate. Longer delays at the start of each iterations, increasing with each iteration, creating signal gaps. Does not degrade after second iteration. Iterations are very similar throughout.	though still complex overall. Artefacts are larger due to lower sample rate. Longer delays at the start of each iterations, increasing with each iteration, creating signal gaps. Does not degrade after second iteration. Iterations are very similar throughout.	Artefacts are larger due to lower sample rate. Artefacts are larger due to lower sample rate. Longer delays at the start of each iterations, increasing with each iteration, creating signal gaps. Does not degrade after second iteration. Iterations are very similar throughout.
LAME 8 16 NS	 Bandwidth Limit: 300 – 3kHz	 Bandwidth Limit: 0 – 3.1kHz	 Bandwidth Limit: 0 – 3.1kHz	 Bandwidth Limit: 0 – 3kHz	 Bandwidth Limit: 0 – 3kHz

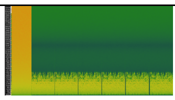
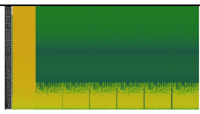
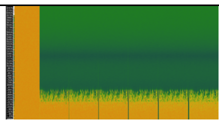
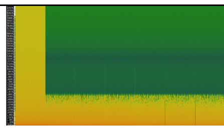
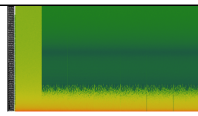
	Capped due to LPF Description is fairly poor. There are discernible pitched artefacts in higher frequencies. There are artefacts throughout signal, but still complex. Increased sample rate creates finer artefacts. Delays at the start of each iterations, increasing with each iteration, creating signal gaps.	Capped due to LPF Frequencies described below cap to some degree. Description is fairly poor. There are discernible pitched artefacts in higher frequencies. There are artefacts throughout signal, but still complex. Increased sample rate creates finer artefacts. Delays at the start of each iterations, increasing with each iteration, creating signal gaps. Does not degrade after second iteration. Iterations are very	Capped due to LPF Frequencies described below cap to some degree. Description is ok. Discernible pitched artefacts in higher frequencies, and some in lower ones. Overall fairly complex still. Increased sample rate creates finer artefacts. Delays at the start of each iterations, increasing with each iteration,	Capped due to LPF Frequencies described below cap to some degree. Description is ok. Some pitched artefacts in higher frequencies, though still complex overall. Artefacts are smaller and more of them due to lower sample rate. Shorter delays at the start of each iterations, increasing with each iteration, creating signal gaps. Does not degrade after second	Capped due to LPF Frequencies described below cap to some degree. Description is fairly poor. Pitched artefacts in higher frequencies. Lower frequencies are pitched, and artefacts can be discerned. Artefacts are smaller and more of them due to lower sample rate. Shorter delays at the start of each iterations, increasing with each iteration,

	Does not degrade after second iteration. Iterations are very similar throughout.	similar throughout.	creating signal gaps. Does not degrade after second iteration. Iterations are very similar throughout.	iteration. Iterations are very similar throughout	creating signal gaps. Does not degrade after second iteration. Iterations are very similar throughout
LAME 8 24 NS	 Bandwidth Limit: 400 – 3kHz Capped due to LPF Description is quite poor. Discernible artefacts throughout, fairly complex, but with pitched artefacts in lower frequencies.	 Bandwidth Limit: 0 – 3kHz Capped due to LPF Frequencies described below cap to some degree. Description is fairly poor. Discernible artefacts throughout, fairly complex, but with pitched artefacts in lower frequencies.	 Bandwidth Limit: 0 – 3kHz Capped due to LPF Frequencies described below cap to some degree. Description is fairly poor. Pitched artefacts throughout signal, mostly in higher	 Bandwidth Limit: 0 – 2.9kHz Capped due to LPF Frequencies described below cap to some degree. Description is fairly poor. Pitched artefacts throughout signal, mostly in higher frequencies.	 Bandwidth Limit: 0 – 2.8kHz Capped due to LPF Frequencies described below cap to some degree. Description is poor. Pitched artefacts in higher frequencies. Lower

	Increased sample rate creates finer artefacts. Delays at the start of each iterations, increasing with each iteration, creating signal gaps. Does not degrade after first iteration. Iterations are very similar throughout.	Increased sample rate creates finer artefacts. Delays at the start of each iterations, increasing slightly with each iteration, creating signal gaps. Does not degrade after first iteration. Iterations are very similar throughout.	frequencies. lower frequencies are still slightly complex. Increased sample rate creates finer artefacts. Short delays at the start of each iterations, increasing slightly with each iteration, creating signal gaps. Does not degrade after first iteration. Iterations are very similar throughout.	Increased sample rate creates more and finer artefacts. Short delays at the start of each iterations, increasing slightly with each iteration, creating signal gaps. Does not degrade after first iteration. Iterations are very similar throughout.	frequencies are pitched, and artefacts can be discerned. Rumbling. Artefacts are smaller and more of them due to lower sample rate. Shorter delays at the start of each iterations, increasing with each iteration, creating signal gaps. Does not degrade after second iteration. Iterations are very similar throughout
LAME 16 8 NS		 Bandwidth Limit: 0 – 4kHz		 Bandwidth Limit: 0 – 3.9kHz	 Bandwidth Limit: 0 – 3.9kHz

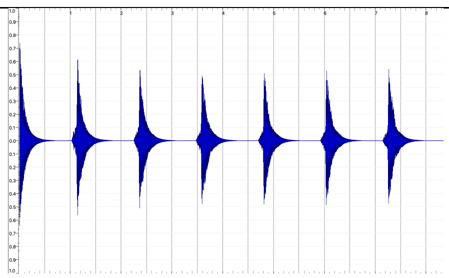
	Bandwidth Limit: 300 – 3.8 kHz Capped at Nyquist Description is good. No artefacts. No fluctuations. Delay at start of each iteration. No degradation after first iteration.	Capped at Nyquist Frequencies described below cap to some degree. Description is good. No artefacts. No fluctuations. Delay at start of each iteration. No degradation after first iteration.	Bandwidth Limit: 0 – 3.9kHz Capped at Nyquist Frequencies described below cap to some degree. Description is very good. No artefacts. No fluctuations. Delay at start of each iteration. No degradation after first iteration.	Capped at Nyquist Frequencies described below cap to some degree. Description is very good. No artefacts. No fluctuations. Delay at start of each iteration. No degradation after first iteration.	Capped at Nyquist Frequencies described below cap to some degree. Description is very good. No artefacts. No fluctuations. Delay at start of each iteration. No degradation after first iteration.
LAME 16 16 NS	 Bandwidth Limit: 100 – 5.5kHz	 Bandwidth Limit: 0 – 5.5kHz Capped due to LPF	 Bandwidth Limit: 0 – 5.5kHz	 Bandwidth Limit: 0 – 5.5kHz Capped due to LPF	 Bandwidth Limit: 0 – 5.5kHz Capped due to LPF

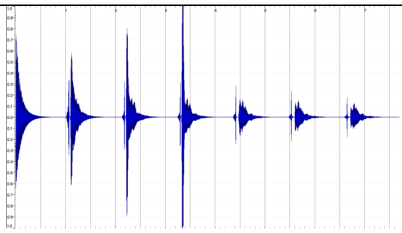
	Capped due to LPF Description is ok. Fairly complex, though with discernible pitched artefacts in higher frequencies. Delays at the start of each iterations, increasing with each iteration, creating signal gaps. Iterations are very similar throughout	Frequencies described below cap to some degree. Description is ok. Discernible artefacts in higher frequencies. lower frequencies still complex. Delays at the start of each iterations, increasing with each iteration, creating signal gaps. Iterations are very similar throughout Finer artefacts with higher sample rate.	Capped due to LPF Frequencies described below cap to some degree. Description is ok. Discernible artefacts in higher frequencies. lower frequencies still complex. Delays at the start of each iterations, increasing with each iteration, creating signal gaps. Iterations are very similar throughout	Frequencies described below cap to some degree. Description is ok. Discernible pitched artefacts in higher frequencies. Finer and more frequent artefacts with higher sample rate. Lower frequencies still complex. Delays at the start of each iterations, increasing with each iteration, creating signal gaps. Iterations are very similar throughout	Frequencies described below cap to some degree. Description is ok. Discernible artefacts in higher frequencies. Artefacts are finer and more of them due to higher sample rate. Lower frequencies are still fairly complex. Delays at the start of each iterations, increasing with each iteration, creating signal gaps.

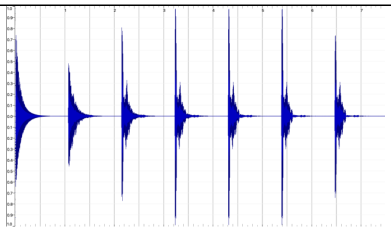
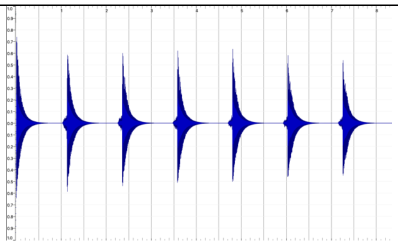
			Finer artefacts with higher sample rate.		Iterations are very similar throughout
LAME 16 24 NS	 Bandwidth Limit: 100 – 5.7kHz Capped due to LPF Description is ok. Still fairly complex, though pitched artefacts can be heard in higher frequencies. Delays at the start of each iterations, increasing with each iteration, creating signal gaps.	 Bandwidth Limit: 0 – 5.7kHz Capped due to LPF Frequencies described below cap to some degree. Description is ok. Discernible artefacts in higher frequencies - other frequencies still complex. Delays at the start of each iterations, increasing with each iteration, creating signal gaps. Iterations are very similar throughout	 Bandwidth Limit: 0 – 5.7kHz Capped due to LPF Frequencies described below cap to some degree. Description is fairly poor. Discernible artefacts in higher frequencies - other frequencies still fairly complex. Higher sample rate creates more artefacts.	 Bandwidth Limit: 0 – 5.7kHz Capped due to LPF Frequencies described below cap to some degree. Description is fairly poor. Discernible artefacts in higher frequencies - other frequencies still fairly complex. Higher sample rate creates more and finer artefacts.	 Bandwidth Limit: 0 – 5.4kHz Capped due to LPF Frequencies described below cap to some degree. Description is fairly poor. Discernible artefacts in higher frequencies. Artefacts are very short and more of them due to higher sample rate. Lower frequencies are

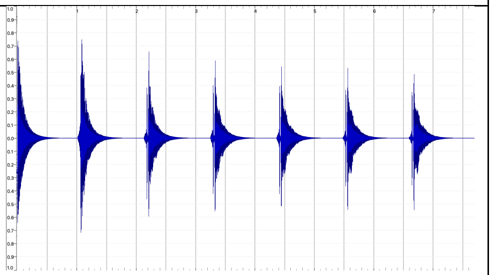
	Iterations are very similar throughout	Finer artefacts with higher sample rate.	Delays at the start of each iterations, increasing with each iteration, creating signal gaps. Iterations are very similar throughout	Short delays at the start of each iterations, increasing with each iteration, creating signal gaps. Iterations are very similar throughout	still fairly complex. Short delays at the start of each iterations, increasing with each iteration, creating signal gaps. Iterations are very similar throughout

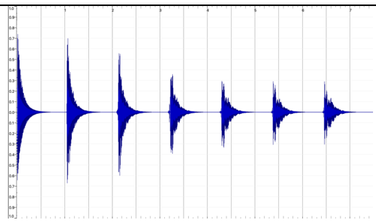
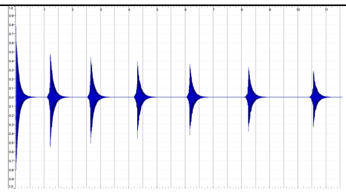
A.3 Transient Mono Text Index

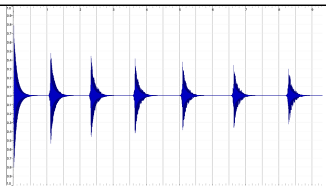
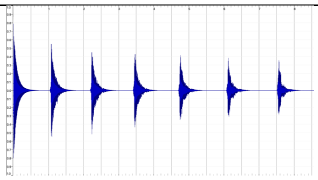
	Pluck
iTunes 8 8	 Pre-Echo softens attack throughout.

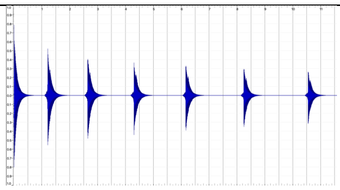
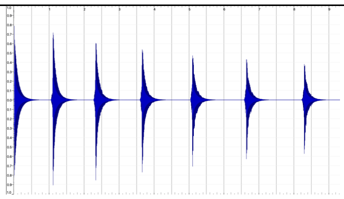
	Delay increases with each iteration. Amplitude. Unencoded pluck is loudest, followed by an increase in amplitude of attacks until the fourth, after which the fifth and sixth iterations' attacks decrease in amplitude. Does lower sample rate result in change in texture?
iTunes 8 16	 Pre-Echo: the pre-echo is separated from the attack, and the delay between the pre-echo and attack increase with each iteration. There is an additional, quieter pre-echo between the initial one and the attack. Delay does not seem to increase for each pluck with each iteration. (though, as stated above, the delay between the pre-echo and attack does)

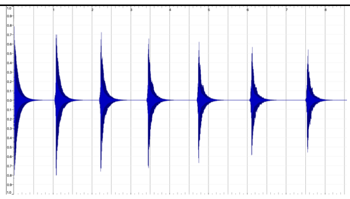
	Amplitude: Amplitude increases for first, second, and third iterations followed by a substantial drop in amplitude for the fourth, fifth, and sixth plucks.
iTunes 8 24	 Pre-echo is much shorter and not complex. It is clearly pitched. Delay increases with each iteration by one tenth of a second. Amplitude Envelope attack increases and decreases, like before, with third, fourth, and fifth iterations being the loudest. As the sound decays, a second peak can be seen, and other smaller amplitude variations occur.
iTunes 16 8	 Description is ok.

	Pre-Echo is clear and complex. Softens attack in each iteration but doesn't change much after first iteration. Delay: after first iteration, time between iterations is similar. Amplitude is very similar throughout.
iTunes 16 16	 Pre-Echo is clear, though as with 8 16, it separates from the attack of the signal, after the first iteration. Still a complex noise. Delay between pre echo and attack does not increase. Delay increases by 1.5 tenths of a second. Amplitude Envelope: Attack decreases with each iterations.

iTunes 16 24	 Pre-echo throughout. Slightly increases with each iterations. Becomes slightly separated after second iteration. Delay of roughly a tenth of a second for each iteration. Amplitude Envelope: Attack decreases with each iterations. As the sound decays, a other peak can be seen, and other smaller amplitude variations occur.
LAME 8 8	 Pre-echo throughout, and is consistent throughout. Delay increases with each iteration. Amplitude Envelope: Attack decreases with each iteration.

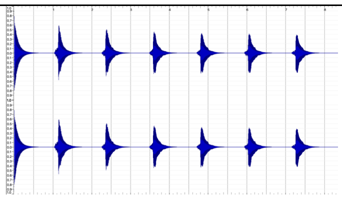
LAME 8 16	 Pre-echo throughout, and is consistent throughout. Delay increases with each iteration. Amplitude Envelope: Attack decreases with each iteration. Amplitude of Decay is less consistent.
LAME 8 24	 Pre-echo throughout, and is consistent throughout. Delay increases with each iteration. Amplitude Envelope: Attack decreases with each iteration. Amplitude of Decay is less consistent.

LAME 16 8	 Pre-echo throughout, and is consistent throughout. Delay increases with each iteration. Amplitude Envelope: Attack decreases with each iteration. Amplitude of Decay is less consistent – an additional peak can be seen in the decay.
LAME 16 16	 Pre-echo throughout, and is consistent throughout. Delay increases with each iteration. Amplitude Envelope: Attack decreases with each iteration.

LAME 16 24	 Pre-echo throughout, though less pronounced. Delay increases with each iteration. Amplitude Envelope: Attack increases for first and second iterations but then decreases for the third, fourth, fifth, and sixth iterations.

A.4 Transient Stereo Test Index

<table>
<tr><td></td><td>Pluck</td></tr>
<tr><td>iTunes

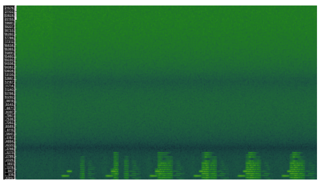
8/16 8 JS</td><td>

Description is ok.

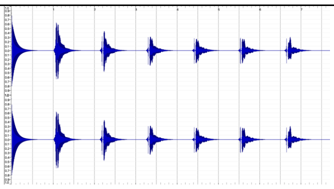
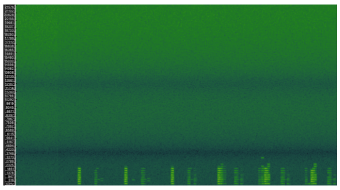
Pre-Echo is clear and complex. Softens attack in each iteration but doesn’t change much after first iteration.

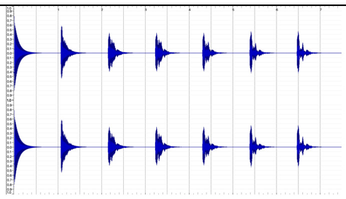
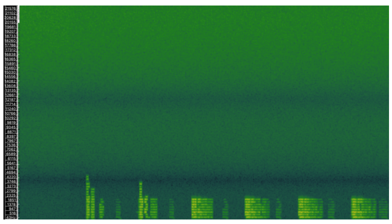
Delay: after first iteration, time between iterations is similar.

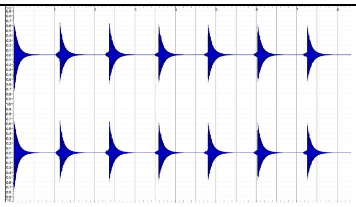
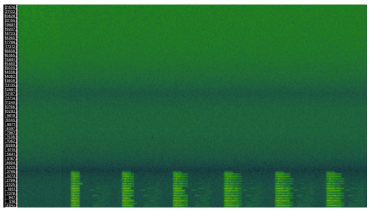
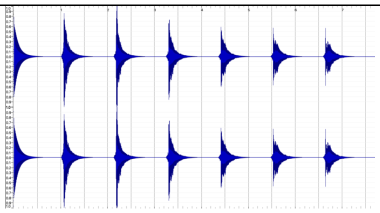
Amplitude is very similar throughout.

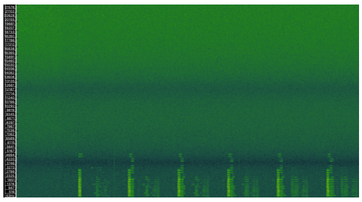
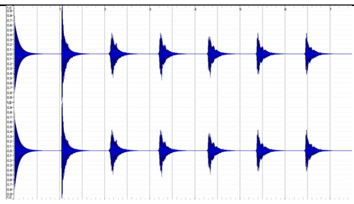


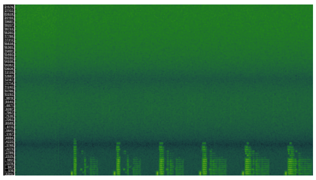
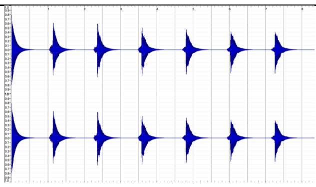
Stereo movement: removed mid and summed sides depicts stereo differences as being quiet but increasing with each</td></tr>
</table>

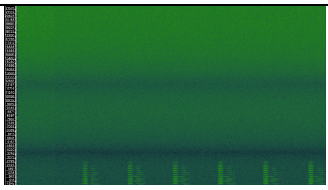
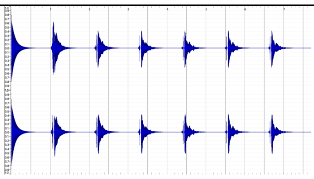
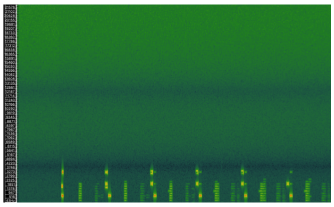
	iteration. Showing a discrepancy between the stereo channels.
iTunes 8/16 16 JS	 Pre-echo the pre-echo is separated from the attack Delay does not to increase for each iteration. Attack decreases with each iteration. Amplitude of Decay is less consistent.  Stereo movement: removed mid and summed sides depicts stereo differences as being quiet but increasing with each iteration. Showing a discrepancy between the stereo channels.

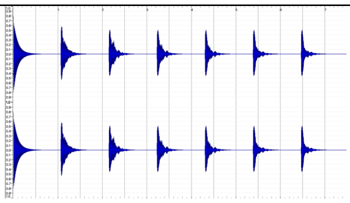
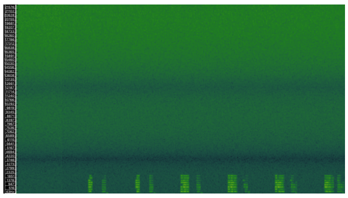
iTunes 8/16 24 JS	 Very little pre-echo. If any it is pitched not complex. Delay does not to increase for each iteration. Attack decreases after first iteration but is consistent after that. Amplitude of Decay degrades, less consistent with each iteration.  Stereo movement: removed mid and summed sides depicts stereo differences as being quiet but increasing with each iteration. Showing a discrepancy between the stereo channels.

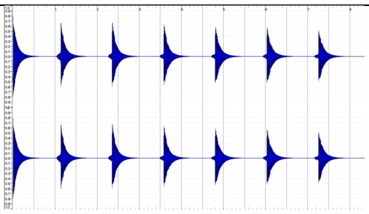
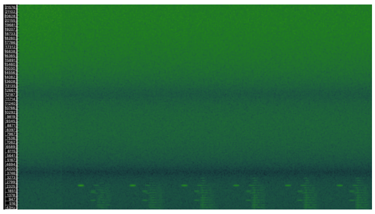
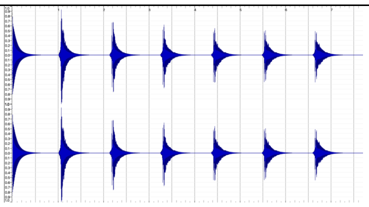
iTunes 16/32 8 JS	 Pre-Echo is clear and complex. Softens attack in each iteration but doesn't change much after first iteration. Delay: after first iteration, time between iterations is similar. Amplitude is very similar throughout.  Stereo movement: removed mid and summed sides depicts stereo differences as being quiet but increasing with each iteration. Showing a discrepancy between the stereo channels.
iTunes 16/32 16 JS	

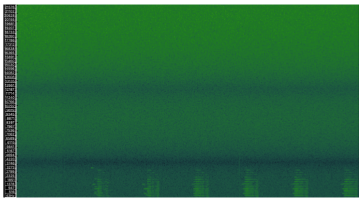
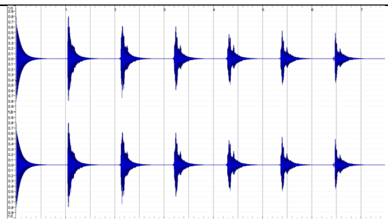
	Very little pre-echo. If any it is pitched not complex. Delay does not to increase for each iteration. Amplitude of attack increases until second iteration, and then decreases after that. Though not. Great deal of difference.  Stereo movement: removed mid and summed sides depicts stereo differences as being quiet but increasing with each iteration. Showing a discrepancy between the stereo channels.
iTunes 16/32 24 JS	 Small amount of pre-echo. Time between events is consistent – no noticeable delay.

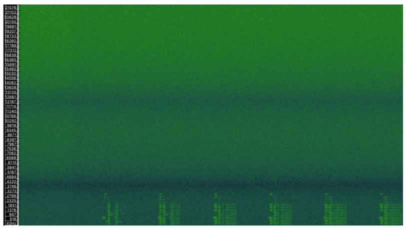
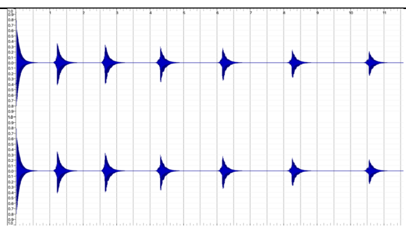
	Amplitude increases for first transient, then decreases and remains consistent for remaining transients.  Stereo movement: removed mid and summed sides depicts stereo differences as being quiet but increasing with each iteration. Showing a discrepancy between the stereo channels.
iTunes 8/16 8 NS	 Pre-Echo is clear and complex. Softens attack in each iteration but doesn't change much after first iteration. Delay: after first iteration, time between iterations is similar. Amplitude is similar throughout, though slightly decreases.

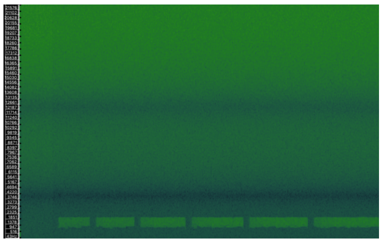
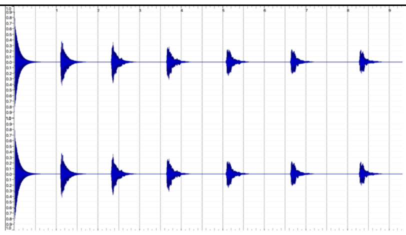
	 Stereo movement: removed mid and summed sides depicts stereo differences as being quiet but increasing with each iteration. Showing a discrepancy between the stereo channels.
iTunes 8/16 16 NS	 pre-echo is separated from the attack Delay does not to increase for each iteration. Attack decreases with each iteration. Amplitude of Decay is less consistent.  Stereo movement: removed mid and summed sides depicts stereo differences as being quiet

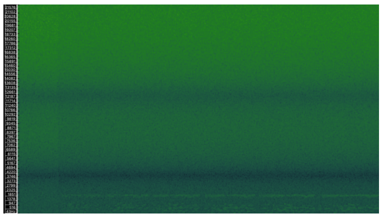
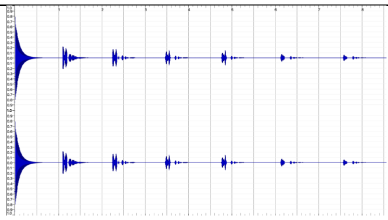
	but increasing with each iteration. Showing a discrepancy between the stereo channels.
iTunes 8/16 24 NS	 Very little pre-echo. If any it is pitched not complex. Delay does not to increase for each iteration. Attack decreases after first iteration but is consistent after that. Amplitude of Decay degrades, less consistent with each iteration.  Stereo movement removed mid and summed sides depicts stereo differences as being quiet but increasing with each

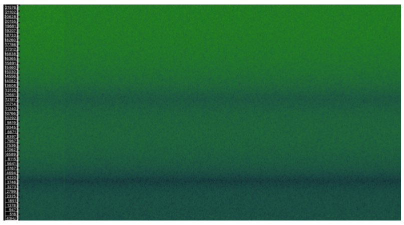
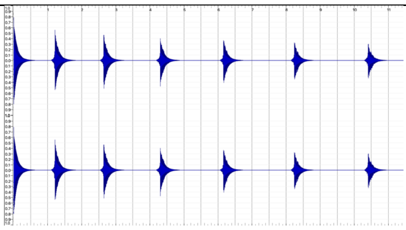
	iteration. Showing a discrepancy between the stereo channels.
iTunes 16/32 8 NS	 Pre-Echo is clear and complex. Softens attack in each iteration but doesn't change much after first iteration. Delay: after first iteration, time between iterations is similar. Amplitude is very similar throughout.  Stereo movement: removed mid and summed sides depicts stereo differences depicting a barely perceptible artefact.
iTunes 16/32 16 NS	

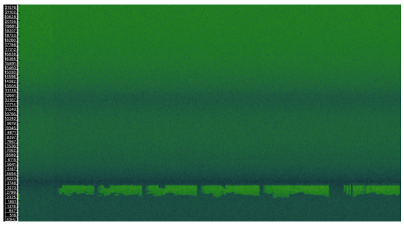
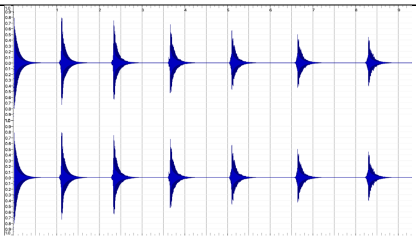
	Small amount of pre-echo though still complex. Pre-echo is separate from attack, creating two attacks with an imperceptible gap between. Delay does not to increase for each iteration. Amplitude of attack decreases after first iteration.  Stereo movement: removed mid and summed sides depicts a small discrepancy between the stereo channels, the result is in an imperceptible artefact.
iTunes 16/32 24 NS	 Small amounts of pre-echo, if any. though sixth iteration has a separated pre-echo.

	Delay does not to increase for each iteration. Attack decreases after first iteration but is consistent after that. Amplitude of Decay degrades, less consistent with each iteration.  Stereo movement: removed mid and summed sides depicts a small discrepancy between the stereo channels, the result is in an imperceptible artefact.
LAME 8 8 JS	 Pre-echo throughout softens attack.

	Delay increases with each iteration. Attack decreases after unencoded pluck. Attacks decrease slightly as iterations progress, but not by much. Decay is consistent.  Stereo movement: removed mid and summed sides depicts a small discrepancy between the stereo channels, the result is in an imperceptible artefact.
LAME 8 16 JS	 Less pre-echo Delay increases with each iteration.

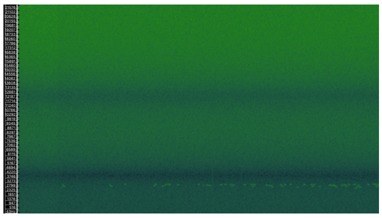
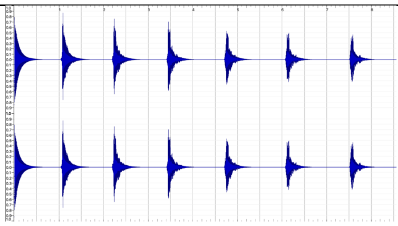
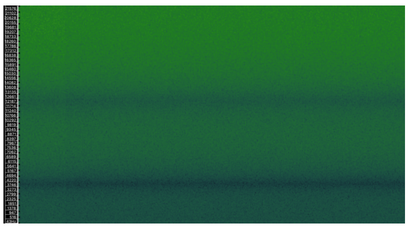
	Attack decreases after unencoded pluck. Attacks lower decreases lightly as iterations progress, but not by much. Decay degrades and is less consistent with each iteration.  Stereo movement: removed mid and summed sides depicts a small discrepancy between the stereo channels, the result is in an imperceptible artefact.
LAME 8 24 JS	 Signal amplitude is inconsistent to the point that it is difficult to know whether pre-echo is in effect. There does not seem to be much of a delay between iterations.

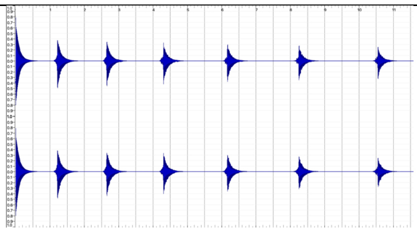
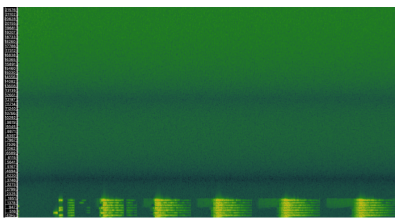
	AS stated above, amplitude is degrading considerably and creating very inconsistent envelopes. Getting significantly quieter as iterations progress.  Stereo movement: removed mid and summed sides depicts no discrepancy between the stereo channels.
LAME 16 8 JS	 Pre-echo throughout softens attack. Delay increases with each iteration. Attack decreases after unencoded pluck. Attacks decrease slightly as iterations progress, but not by much.

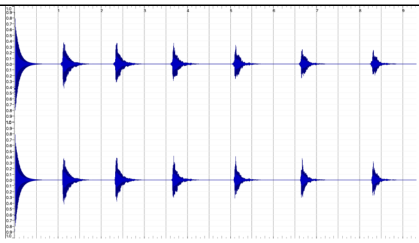
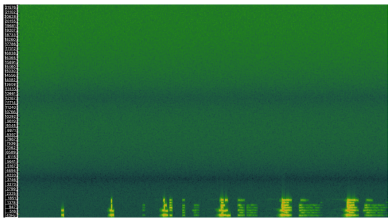
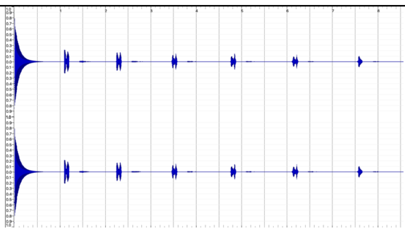
<table>
<tr><td></td><td>Decay is consistent.

Stereo movement: removed mid and summed sides depicts a discrepancy between the stereo channels resulting in a barely perceptible artefact.</td></tr>
<tr><td>LAME 16
16 JS</td><td>
Less pre-echo

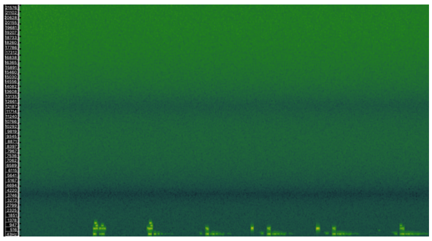
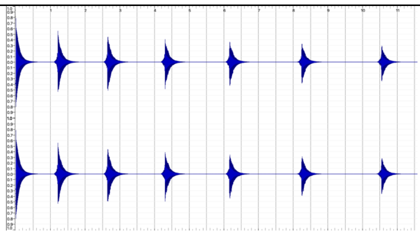
Delay increases with each iteration.

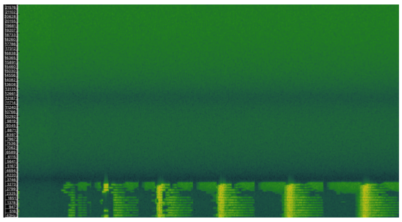
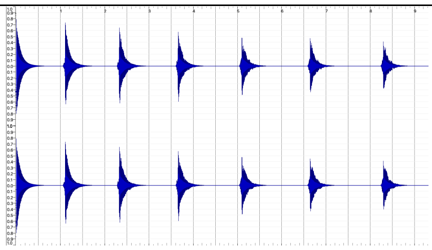
Attack decreases after unencoded pluck. Attacks lower decreases lightly as iterations progress, but not by much.</td></tr>
</table>

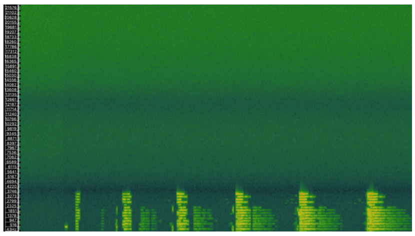
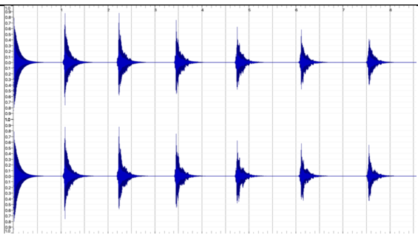
	Decay degrades and is less consistent with each iteration.  Stereo movement: removed mid and summed sides depicts a very small discrepancy between the stereo channels, resulting in an imperceptible artefact.
LAME 16 24 JS	 Short pre-echo. Still complex. Delay increases, but not as much as lower sample rates. Attack decreases from start, and decay becomes less consistent.  Stereo movement: removed mid and summed sides depicts no

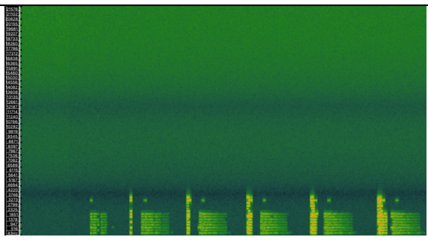
	discrepancy between the stereo channels.
LAME 8 8 NS	 Short pre-echo. Increasing delay with each iteration. Attack decreases after unencoded pluck. Attacks decrease slightly as iterations progress, but not by much. Decay is consistent.  Stereo movement removed mid and summed sides depicts clear discrepancies between the stereo channels. Resulting in clearly audible artefacts.

LAME 8 16 NS	 Very short pre-echo. Delay increases with each iteration. Attacks decrease slightly as iterations progress, but not by much. Decay degrades and becomes less consistent.  Stereo movement: removed mid and summed sides shows clear discrepancies between the stereo channels. Resulting in clearly audible artefacts.
LAME 8 24 NS	

	Signal amplitude is inconsistent to the point that it is difficult to know whether pre-echo is in effect. Delay slightly increases between iterations As stated above, amplitude is degrading considerably and creating very inconsistent envelopes. Getting significantly quieter as iterations progress.  Stereo movement: removed mid and summed sides shows clear discrepancies between the stereo channels. Resulting in audible artefacts.
LAME 16 8 NS	

	Pre-echo throughout softens attack. Delay increases with each iteration. Attack decreases after unencoded pluck. Attacks decrease slightly as iterations progress, but not by much. Decay is consistent.  Stereo movement removed mid and summed sides of the stereo channels shows clear discrepancies between the stereo channels. Resulting in clearly audible artefacts.
LAME 16 16 NS	 Less pre-echo

	Delay increases between iterations Attack decreases in amplitude with each iteration. Decay is slightly inconsistent  Stereo movement removed mid and summed sides of the stereo channels shows clear discrepancies between the stereo channels. Resulting in clearly audible artefacts.
LAME 16 24 NS	 Slight pre-echo Delay between iterations. Attack decreases in amplitude with each iteration. Decay degrades as iterations progress. Inconsistent

	 Stereo movement: removed mid and summed sides of the stereo channels shows clear discrepancies between the stereo channels. Resulting in clearly audible artefacts.