AN EXPLORATORY STUDY OF MANUAL PAUSE-RECORD EVENTS IN DIGITAL AUDIO RECORDINGS

by

SHAWN MICHAEL PRUETT

B.A., University of North Carolina –Wilmington, 1991

B.S., Utica College of Syracuse University, 2009

A thesis submitted to the

Faculty of the Graduate School of the

University of Colorado in partial fulfillment

of the requirements for the degree of

Master of Science

Recording Arts Program

2019

This thesis for the Master of Science degree by

Shawn Michael Pruett

has been approved for the

Recording Arts Program

by

Catalin Grigoras, Chair

Jeff M. Smith

Cole Whitecotton

Date: May 18, 2019

Pruett, Shawn Michael (M.S., Recording Arts Program)

An Exploratory Study of Manual Pause-Record Events in Digital Audio Recordings

Thesis directed by Associate Professor Catalin Grigoras

ABSTRACT

The purpose of this thesis is to study manual pause-record events in digital audio recordings in an attempt to prove or disprove the hypothesis that there exist artifacts indicative of a manual pause-record event that can inform and assist an examiner during a forensic task such as authentication of a digital audio recording. This study focused on stereo audio samples in the WAV (PCM) audio file format with 16-bit sample depths recorded at a sampling frequency of 44.1 kHz. The study also utilized six different models of Olympus brand digital audio recorders in an attempt to identify inter-model differences from the same manufacturer. The study found that in many cases artifacts representing a manual pause-record event do exist that can assist an examiner in audio forensic tasks, however, the possibility of identifying global signatures for manual pause record events is very low. The variability observed in this study demonstrates that we have a long way to go in trying to characterize these types of events. The following recorder models were used in this study:

Olympus DM-520	Olympus LS-20M
Olympus DM-550	Olympus WS-700M
Olympus DM-620	Olympus WS-823

The form and content of this abstract are approved. I recommend its publication.

Approved: Catalin Grigoras

This work is dedicated to my wife, Kimberly, and to my sons, Tyler and Eric, for their love and patience through many nights and weekends. It is also for Michael, my grandson, who blessed our family by coming into the world this year.

ACKNOWLEDGEMENTS

I would like to thank professors Catalin Grigoras and Jeff Smith for their invaluable assistance with my education over the years and helping me to see new things and experience new triumphs in the field of media forensics.

I also thank Leah Haloin for putting up with me and Cole Whitecotton for stepping up at the last moment to lend me a hand.

TABLE OF CONTENTS

LIST OF FIGURES

FIGURE

LIST OF ABBREVIATIONS

WAV - Waveform Audio File Format

PCM - Pulse-Code Modulation

FFT - Fast Fourier Transform

CHAPTER I

Introduction

This study was undertaken to determine the feasibility of confirming manual pause-record events in digital audio recordings through time domain and frequency domain analysis techniques. This thesis focuses on the problem as it applies to stereo WAV PCM recordings at 16-bit sample depth. The recordings used as test samples in this study were recorded at a sample rate of 44.1 kHz. The study focused on local analysis techniques and does not take under review any form of structural analysis [1].

The goal of the study is to identify waveform and/or frequency artifacts or signatures that indicate a manual pause-record event has occurred in the hopes that such artifacts or signatures can assist in a forensic authentication task. The tested hypothesis states that there exist pause-record event artifacts in digital audio recordings that are signatures, in general, of a pause-record event. If the first hypothesis is proven false, then an alternate hypothesis to be tested is that there exist such artifacts particular to a specific recording device that can be used for authentication purposes.

The analysis of digital audio recordings in investigatory or judicial settings have become more commonplace today because of the ubiquitous nature of digital devices in today's society. The possible circumstances of a recording vary greatly and include recorded cell phone conversations, interviews recorded with low-to-high quality digital audio recorders or video recorders (with audio), to surreptitious recordings using a hidden microphone and recording system.

A common task assigned to a forensic audio examiner is the authentication of digital audio recordings. Authentication in this regard is the act of proving or disproving that a recording is, in fact, what it claims to be.

The use of handheld digital audio recorders is becoming common place in the field of criminal (and some civil) investigations. Unless the law enforcement agency has a prohibition against it, many investigators choose to record interviews of victims and potential witnesses. Even more so, audio or audio-video recordings of interviews and interrogations of suspects is being offered to the court as evidence in a case.

The authenticity of these recordings may be challenged by the opposing party. In some cases, a person may allege that, in general, the audio evidence is an accurate recording of the event or conversation with the exception that he or she claims that other comments were made during the interview that do not appear on the recording that is being offered as evidence. In such case, one possibility for the discrepancy is that the recorder had been, intentionally or unintentionally, placed on pause during the conversation.

In another hypothetical case, a visual or computational observation of the waveforms or spectra associated with an evidential recording may have identified an inconsistency that has caused one party to claim that the recording has been maliciously altered by the opposing party. It may be of value in this case to be able to show that the inconsistency is a manual pause-record event as opposed to, for example, an intentional forgery.

Of course, there exists the possibility that a pause-record event was executed with malice in an attempt to deceive. At some point it becomes the trier of fact's obligation to make judgment calls based on the evidence at hand. It is the forensic examiner's job to examine and interpret the evidence to the degree that the science allows. In other words, the forensic examiner's burden in this hypothetical is to determine whether or not the noted discontinuity is indicative or potentially indicative of a pause-record event as opposed to some other event.

Another potential application associated with this research is the hypothetical case in which a disclosed manual pause-record event occurred and is stipulated to by all sides. In such case, the analysis of the manual pause-record event may still be useful; if the particular recording device displays during testing a specific signature, it may be useful for authentication of the device itself.

The potential cases or hypothetical situations in which a critical analysis of a manual pause-record event may be called for are many. It is for this reason that studies such as the current thesis are important and may add to the audio forensic examiners' knowledge base and be put to practical application during authentication or other forensic tasks.

Previous Works

While there have been several brief references in the literature concerning the need to identify pause-record events in digital audio, there have been few, if any, research efforts devoted to the topic of manual pause-record events. Historically, when analog magnetic recordings were the primary technology in the field, several well-known practitioners and researches noted the need for identifying such events as start, stop and stop-record pauses.

> "In many cases, an audio forensic expert is called upon to examine taped evidence to provide an opinion on whether or not a tape has been "edited" or "doctored" in any way. Specifically, this translates into an analysis of the temporal sequence of events found on the tape that correspond to record start, pause, and stop operations of one or more tape recording devices. This typically includes the analysis of "record event signatures" corresponding to the interaction of the tape surface with the electrical activation and deactivation of AC-bias record and erase heads, and/or contact with a permanent magnet erase head." [2].

A 1990 paper by Koenig helps to illustrate the differences between an examination of a magnetic-tape analog recording versus the digital variety ubiquitous today; Koenig stated, "As a general rule, record stops produce a cessation of recording followed by a short unrecorded area, equal to the distance between the record and erase heads on the particular unit, and the sound of the erase-head deactivation…" Throughout this paper, Koenig describes physical inspection of the magnetic tape, and in particular marks or artifacts left by the record and erase heads [3]. The difference today being that digital audio recorders are generally solid-state without mechanical moving parts such as record or erase heads, or tape moving on a reel. So, the particulars of the physically related artifacts of the analog days are generally not in play. Several of the other techniques, such as waveform analysis, spectrogram, etc. are generally the same with the exception of the particular artifacts within those domains that are created as a result of the mechanical movements in an analog system.

Koenig and Lacey do an excellent job of describing the new paradigm of dealing with the digital domain in a 2009 work, “Forensic Authentication of Digital Audio Recordings”. Besides their descriptions of a methodology for digital audio authentication, of particular importance to the current study, they state:

> “While not all digital systems produce signatures when they stop and start in the record mode, many do, though the sounds are normally of shorter duration compared to analog events. Test recordings prepared on submitted recorders can be compared to the evidential recording for similarities and differences in timing, shaping, spacing of multiple parts, and rise times for the signatures. Record events produced on consumer-quality recorders can vary considerably among different manufacturers, models, and formats, and sometimes between units with closely spaced serial numbers. Even identical record-mode operations will, at times, result in slightly different waveform shaping on the same recorder” [4].

It is these very concepts that the current study hopes to inform upon, with respect to manual pause-record events.

CHAPTER II

Materials & Methods

This study utilized six digital audio recorders (referred to as recorders A through F) and 11 test recordings. Multiple manual pause-record events were initiated within each test recording. Based on the potentially wide variability expected after reviewing Koenig & Lacey's statements (previously mentioned as [4]), the test recorders were limited to those of the same make; while six different models were tested. The following breaks down the test samples and make & model used for this study:

Test Recording Samples, Recorders & Mode

Test #	Recorder	Make	Model	Recording ID	Mode
1	A	Olympus	DM-520	DM521151	Manual-Pause-Record
2	A	Olympus	DM-520	DM521152	Manual-Pause-Record
3	A	Olympus	DM-520	DM521165	Remote-Pause-Record
4	B	Olympus	DM-550	DM550183	Remote-Pause-Record
5	B	Olympus	DM-550	DM550185	Manual-Pause-Record
6	C	Olympus	DM-620	DM620187	Manual-Pause-Record
7	C	Olympus	DM-620	DM620188	Remote-Pause-Record
8	C	Olympus	DM-620	DM620191	Manual-Pause-Record
9	D	Olympus	LS-20M	LS200033	Manual-Pause-Record
10	E	Olympus	WS-700M	WS700210	Manual-Pause-Record
11	F	Olympus	WS-823	WS8230077	Manual-Pause-Record

This study was undertaken as a survey of the feasibility of using manual pause-record events as utilitarian indicators during digital audio authentication. To this end, the sample recordings used for testing were generated with “real-world” environments in mind (outside of any anechoic chamber or other audio / acoustic boundary laboratory); some of the recordings have a foreground of the voice of the person generating the sample, some have a foreground consisting of an ongoing conversation and some have the generator’s voice with generalized “babble” noise in the background.

All of the test samples were created using an Olympus digital audio recorder model. All of the test events within each sample recording were an activation of the manual pause function of the recorder. With those recorders with the capability, a test recording was also made using a remote control device to initiate the manual pause-record event. In those cases, the remote control device used was an Olympus RS30 remote control. The test recordings range in duration from approximately 30 seconds to just over a minute. Each of the test recordings had a minimum of three pause-record test events. All of the test recordings were created as WAV PCM 16-bit recordings at a 44.1 kHz sampling rate.

Resulting data was reviewed and analyzed using Adobe Audition (version 5.0, build 708) and MatLab R2018b (9.5.0.944444). Excel (version 1902) was used for basic spreadsheet applications.

The methodology applied in this study consisted first of conducting an audio review and critical listening to each of the sample test recordings to identify, if possible, the areas in which the pause-record events occurred. In some cases, this step was assisted by the voice of the person creating the sample whom was identifying the immediate before and after of each manual pause-record event. In other cases, the current author was provided with the times within the sample where the events occurred.

After identifying, where possible, the manual pause-record events in a time-domain presentation using Adobe Audition, the events were segmented into sub-samples for each event, creating a separate audio file for each event (WAV PCM, 16-bit, 44.1kHz). The subsamples were then examined in both the time and frequency domains to identify properties or artifacts that could be attributed to the manual pause-record event.

CHAPTER III

Analysis & Results

The analysis of the test recordings in this study proved challenging. In general, it was found that there was a significant amount of variation between samples of manual pause-record events. In some cases, significant variation was present at the intra-recording level, making any general classification difficult.

A further challenge associated with this study is the fact that the targeted events are transient manifestations of small electrical impulses within low voltage electronic devices. There is no *a priori* knowledge of the characteristics of the event to be evaluated and the amplitude of the impulse or waveform are often non-distinguishable from that of the surrounding noise profile.

Despite these challenges, there are, in some cases, artifacts that may be beneficial to the forensic audio examiner. The remainder of this section exhibits the results of this study, exemplifying both the challenges and potentials associated with manual pause-record events.

Test Recording 1A

Test recording 1A was created on an Olympus model DM-520 digital audio recorder. The recording was created in a "real-world" situation; it was a recording of a small audience to a presentation being given via the internet. The presenter's voice can be heard on the recording, along with at least one member of the small audience. There were three pause-record events initiated within the recording.

Critical listening of the recording presented with very faint clicks at each of the pause-record events. Waveform analysis showed that there were generally more than one impulse-like artifacts at each of the events. This was a case, as denoted above, in which there was much intra-recording variation in the time domain display at the pause-record events. Figure 1 shows the left and right channels of the recording at event 1A_01.

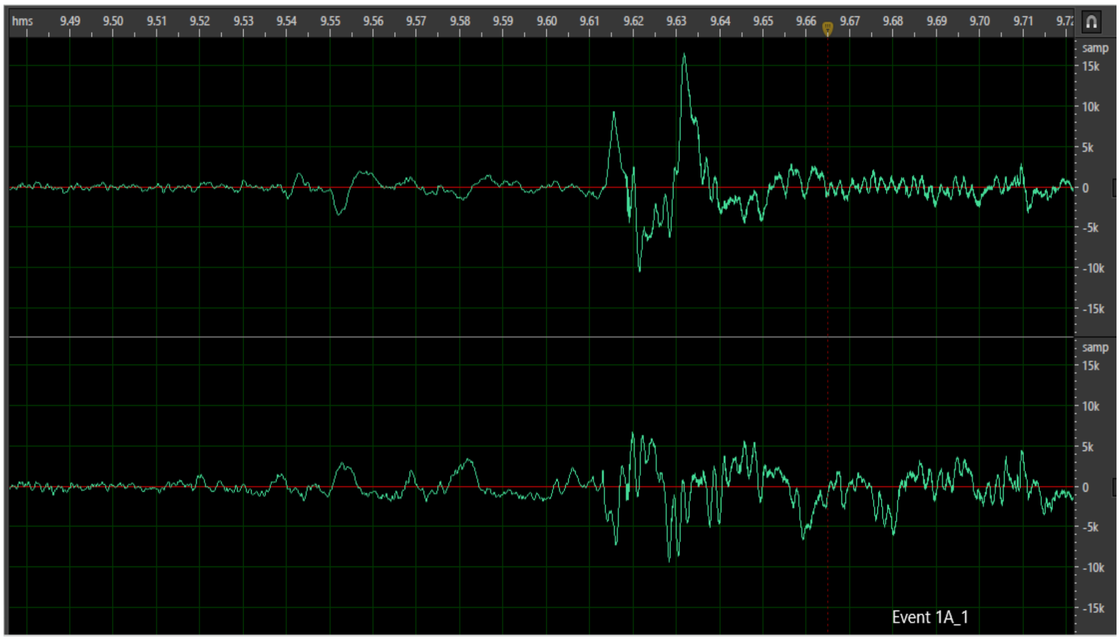

Figure 1: Time domain display of pause-record event 1A_01.

Figure 2 and Figure 3, when compared to the first event, are indicative of the intra-recording variation. Event 1A_02 displayed a higher quality waveform shape. It was noted that, even with their difference in shape, the maximum peak quantization level values were consistent between events 1A_01 and 1A_02. However, the peak level in event 1A_03 was approximately 33% lower than the first two events.

Figure 2: Time domain display of pause-record event 1A_02.

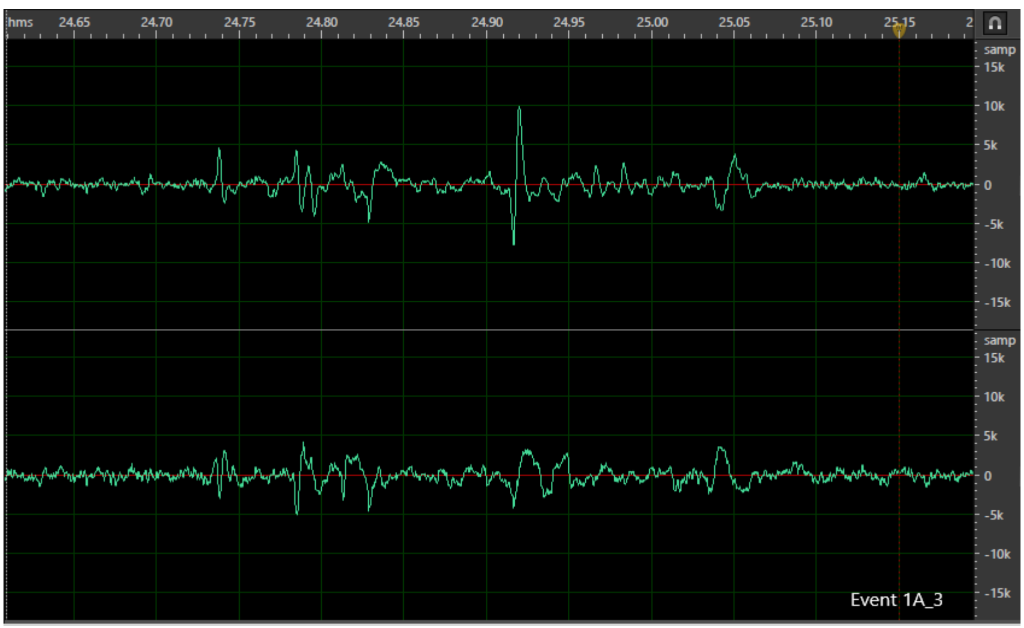

Figure 3: Time domain display of pause-record event 1A_03.

Examination of the spectrogram showed definite spectral activity contemporaneous with the pause-record events. As observed below, there is broad-band spectral activity presenting as a vertical line ranging from faint magnitude near 20 kHz all the way to below 100 Hz, where the magnitude of the frequency content is much greater. The three events are at 9.61 seconds, 18.00 seconds, and 24.91 seconds, respectively. The frequency content is most visible at the 18 second event and shows a significant decrease of the higher frequencies in the 25 second event.

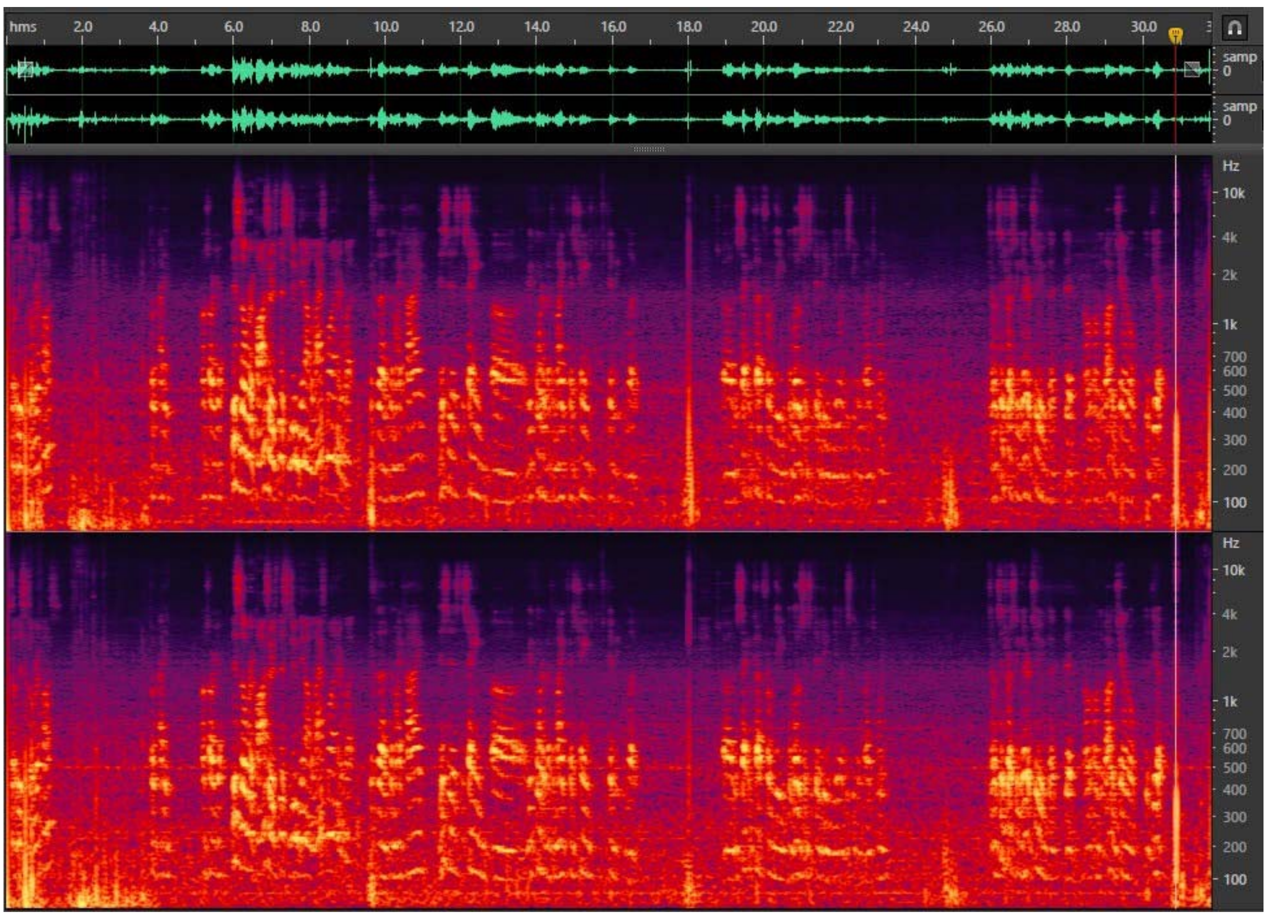

Figure 4: Spectrogram of Test Recording 1A; Resolution 8192 / Blackman-Harris.

This frequency content differentiation between two consecutive sample events can be observed through application of a Fast Fourier Transform function of the event regions. This clearly shows that the low frequency content is relatively consistent between the two samples, while the higher frequencies are much more prominent in Event 1A_02.

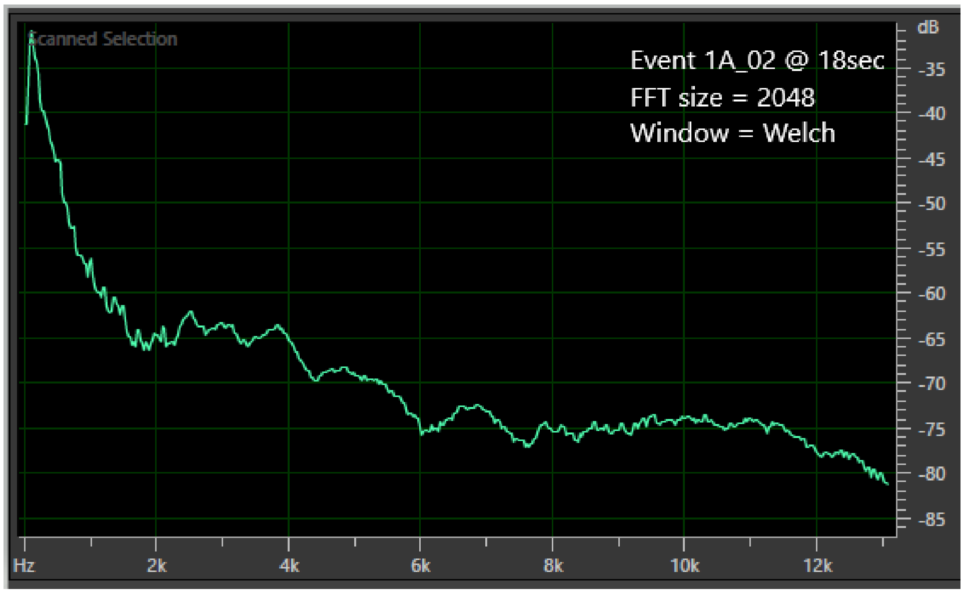

Figure 5: Audition frequency analysis of Event 1A_02.

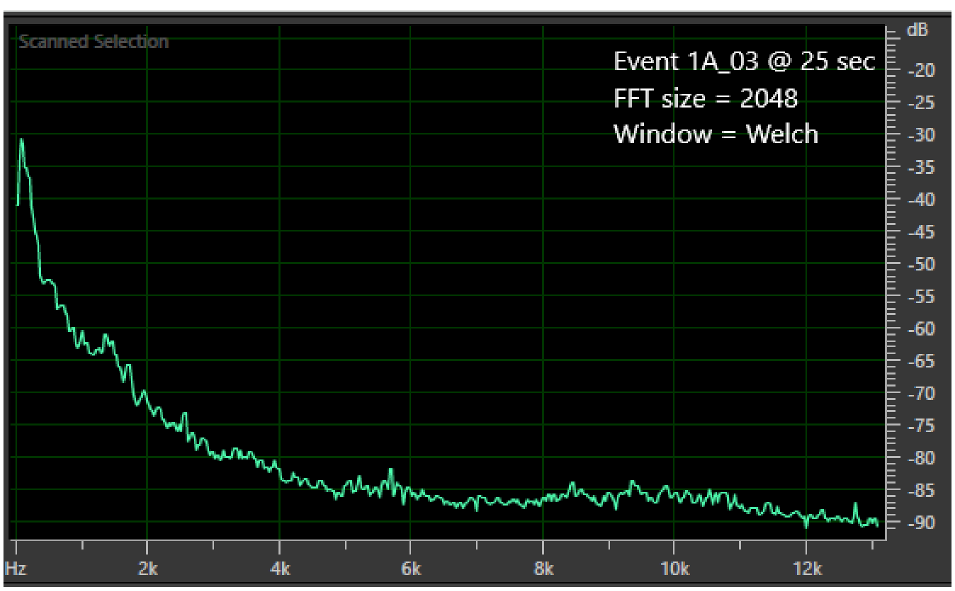

Figure 6: Audition frequency analysis of Event 1A_03.

Test Recording 2A

Test recording 2A was created on the same Olympus model DM-520 digital audio recorder. This recording was made in the same environment as test recording 1A and consecutive to it.

Using the same recording device in the same type of environment, it appeared reasonable to expect that test recording 2A would have similar characteristics as test recording 1A. In fact, the results were similar in that they seem to contain multiple transient components, similarly spaced as those in the 1A test recording. During critical listening, it became obvious that the pause-record events were accompanied by a significant audible click, as opposed to the very faint audibles experienced with test recording 1A. Like that recording, however, more intra-recording variation was added to the mix. Below are the waveform results for the manual pause-record events of test recording 2A.

Figure 7: Time domain display of pause-record event 2A_01.

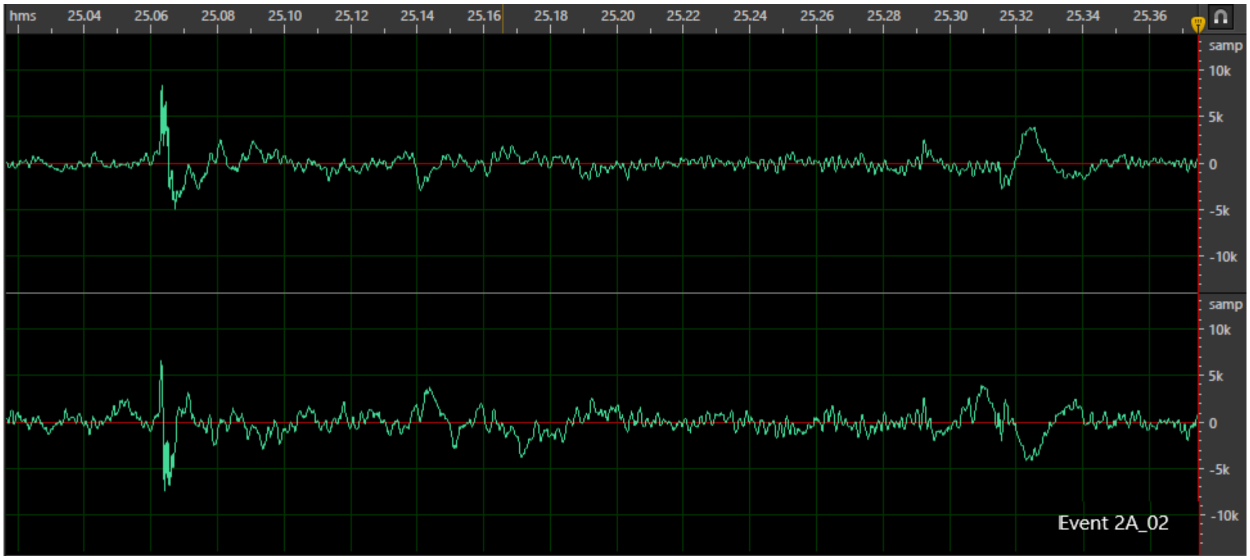

Figure 8: Time domain display of pause-record event 2A_02.

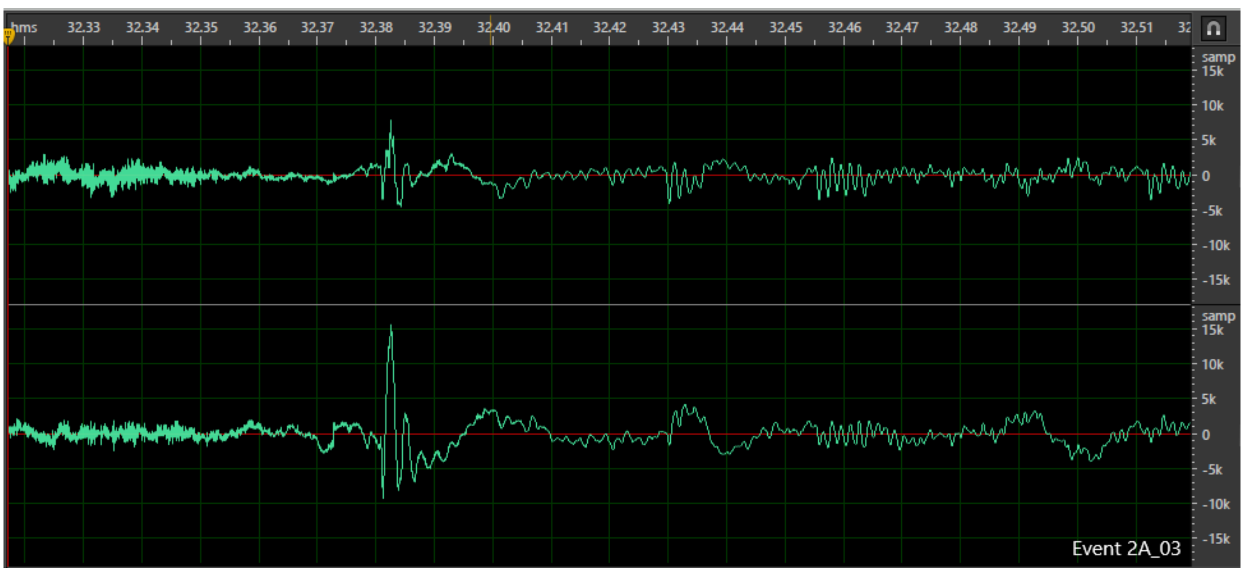

Figure 9: Time domain display of pause-record event 2A_03.

Frequency domain analysis of test recording 2A identified similar broadband artifacts as those that appeared in test recording 1A; the bulk of the frequency components showing up below 10 kHz. The spectrogram below shows the three pause-record events (identified by vertical white dashed line added to assist the reader).

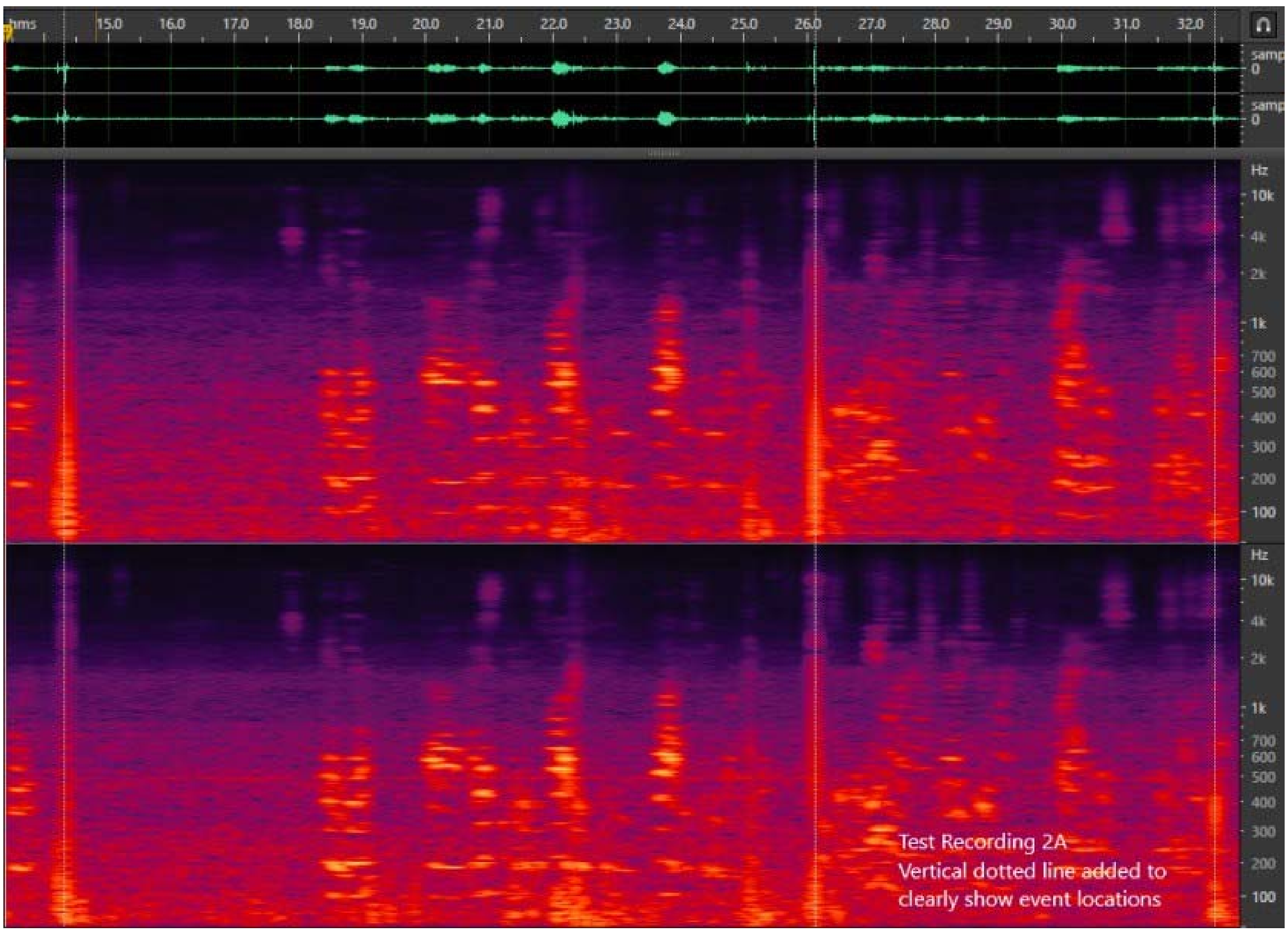

Figure 10: Spectrogram of Test Recording 2A frequency components below 10 kHz; Resolution 8192 / Blackman-Harris.

As expected, the frequency analysis of an event in test recording 2A has a similar slope appearance to the 1A samples; however, the 2A events display lower magnitudes of the various frequencies than the 1A examples, especially in the range of 2 kHz to 6 kHz. The Audition generated spectrum corresponding to event 2A_02 is provided here as example.

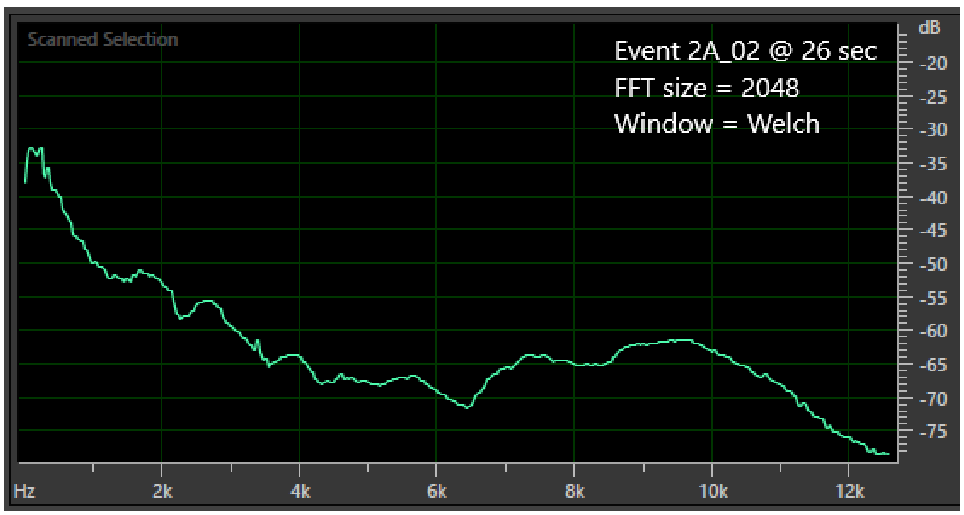

Figure 11: Audition frequency analysis of Event 2A_02.

From the perspective of an attempt to generally categorize the character of these transient events, the multiple variations, especially those displayed in the waveforms, were challenging. Therefore, potential *external* causes for the variations were contemplated with the idea being that there may be reasons for some variation that lie outside of the electrical impulses within the device. In particular, it seemed plausible that the mechanical influence exerted on the digital recorder when a button is pushed by a finger and the resulting vibrations may be picked up by the microphone. This, of course, would be highly randomized in its response and would potentially limit the ability of a forensic examiner to confidently draw conclusions about manual pause-record events in some cases. In an attempt to address this issue, it was decided to evaluate manual pause-record events that are initiated via a remote control. Not all of our test recorders had this capability but, three of them did. The Olympus models DM-520, DM-550 and DM-620 (test recorders A, B and C, respectively) had this capability. Therefore, three of the test recordings in this study were conducted by initiating the manual pause-record events with a remote control device. The remote control device used was an Olympus RS30 remote control.

Test Recording 3A

Test recording 3A was again created on the same Olympus model DM-520 digital audio recorder. This recording was made in a quieter environment with only the voice of the sample creator in the foreground and light noise in the background. Again, an Olympus RS30 remote control was used to initiate the targeted events.

Differences between this test recording and the previous two were immediately obvious upon examination. At the critical listening stage, the pause-record events of this sample were inaudible to this examiner. Waveform analysis proved challenging in that the transients were now singular and at very low amplitude. In fact, the pause-record artifacts in this recording appear to be very similar to what an examiner would expect to see in a butt-splice manipulation [5]. This examiner was unable to even identify the event in the case of the third event

(3A_03), therefore, the three examples presented here are the first two and then the fourth events of the recording. Remembering that this is the same recording device used in the first two test recordings, a quick review of the time domain plots here indicate that there does appear to be a substantial component of the variations that may be caused by the vibrations associated with physical contact when a button on the device is pushed.

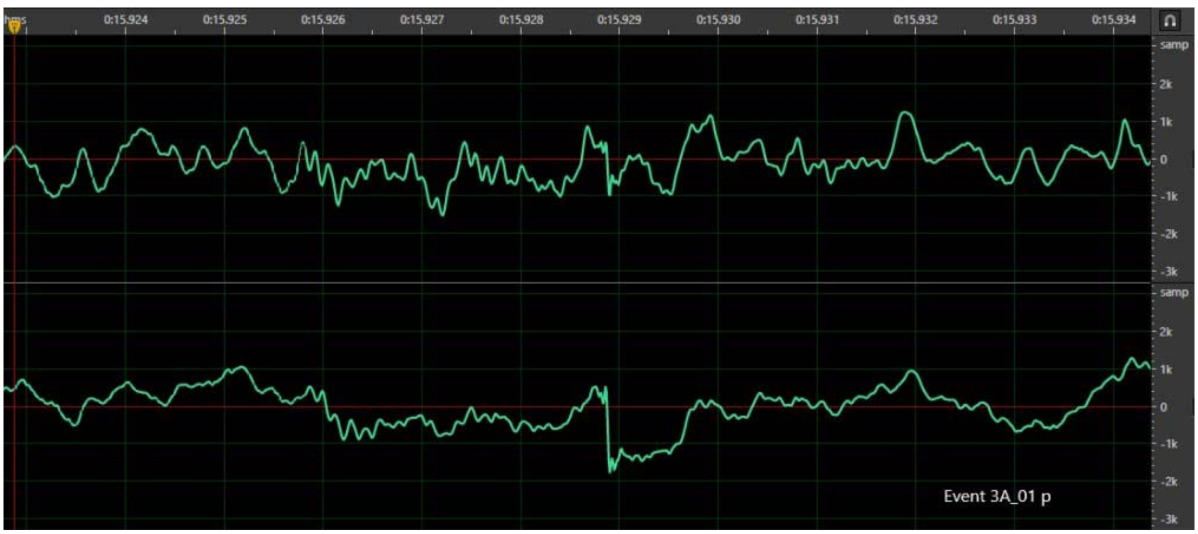

Figure 12: Time domain display of pause-record event 3A_01.

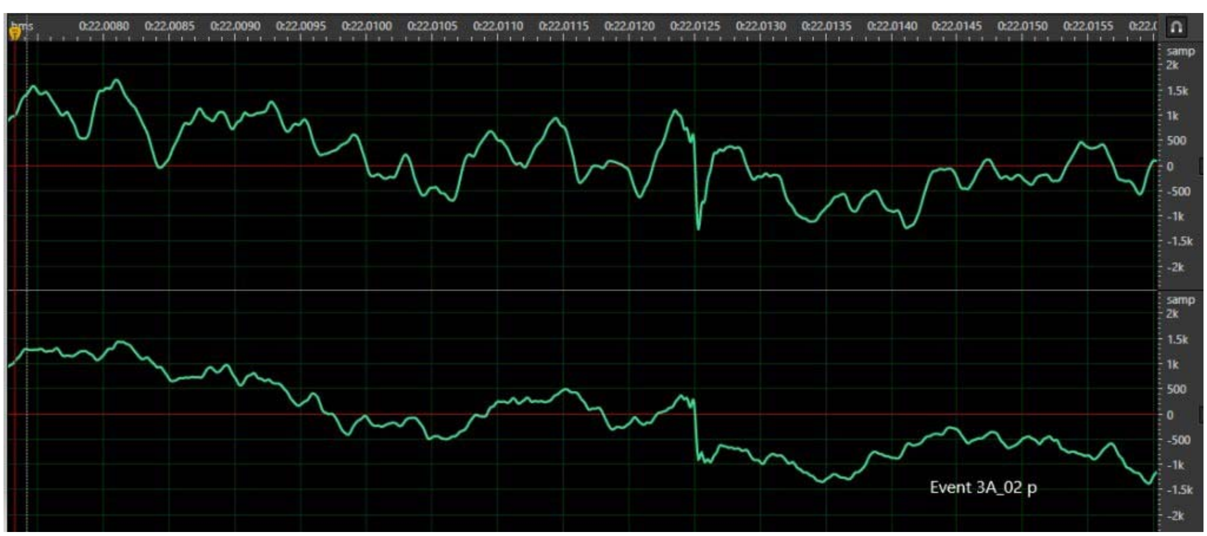

Figure 13: Time domain display of pause-record event 3A_02.

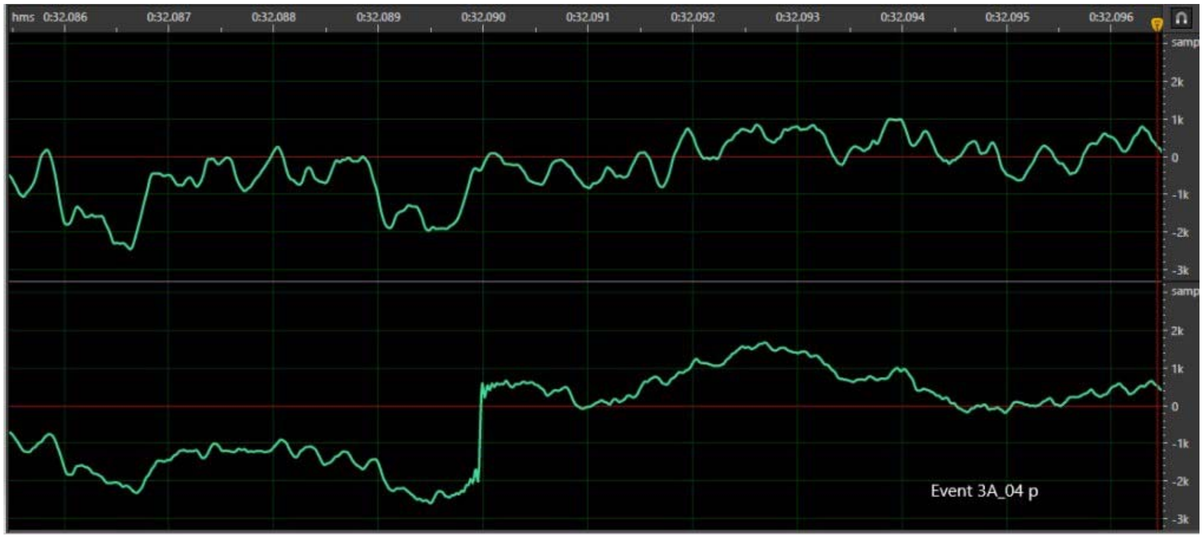

Figure 14: Time domain display of pause-record event 3A_04.

While test recording 3A was difficult in the waveform analysis, the frequency analysis at the pause-record events compared to other periods in the recording was very interesting. Below you see that there is a lot of activity at the very low frequency range:

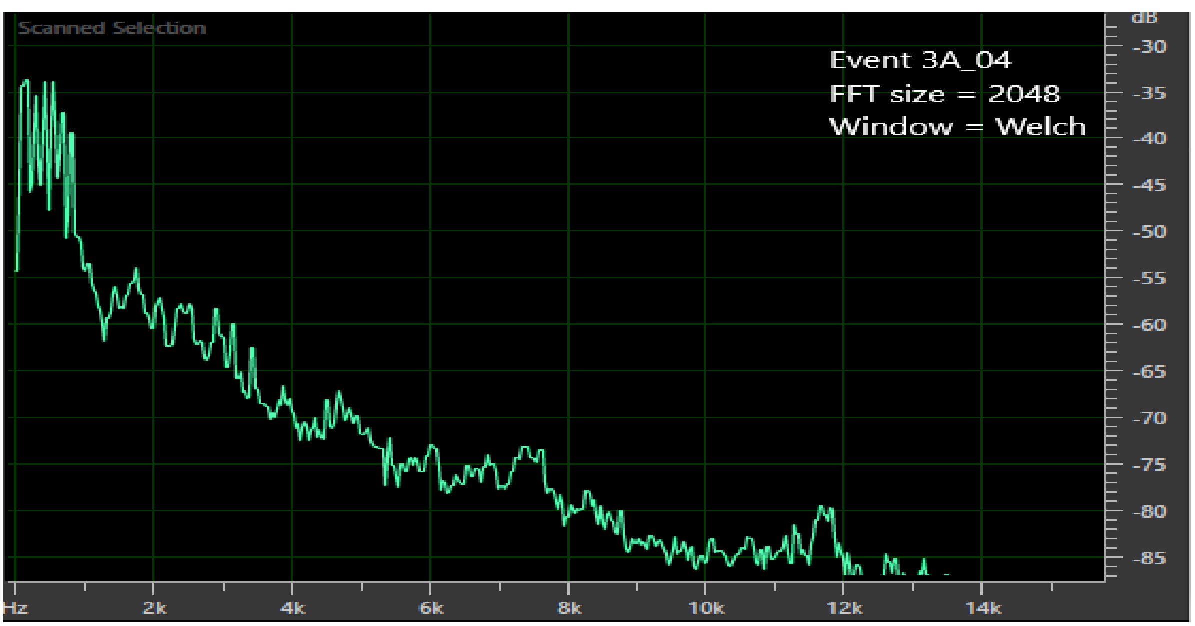

Figure 15: Audition frequency analysis of pause-record event 3A_04.

The FFT frequency analysis results were confirmed with the spectrogram. If looking at the spectrogram at the very low frequency areas, vertical bars are present from 20 Hz to the bottom, generally at the location of the pause-record events.

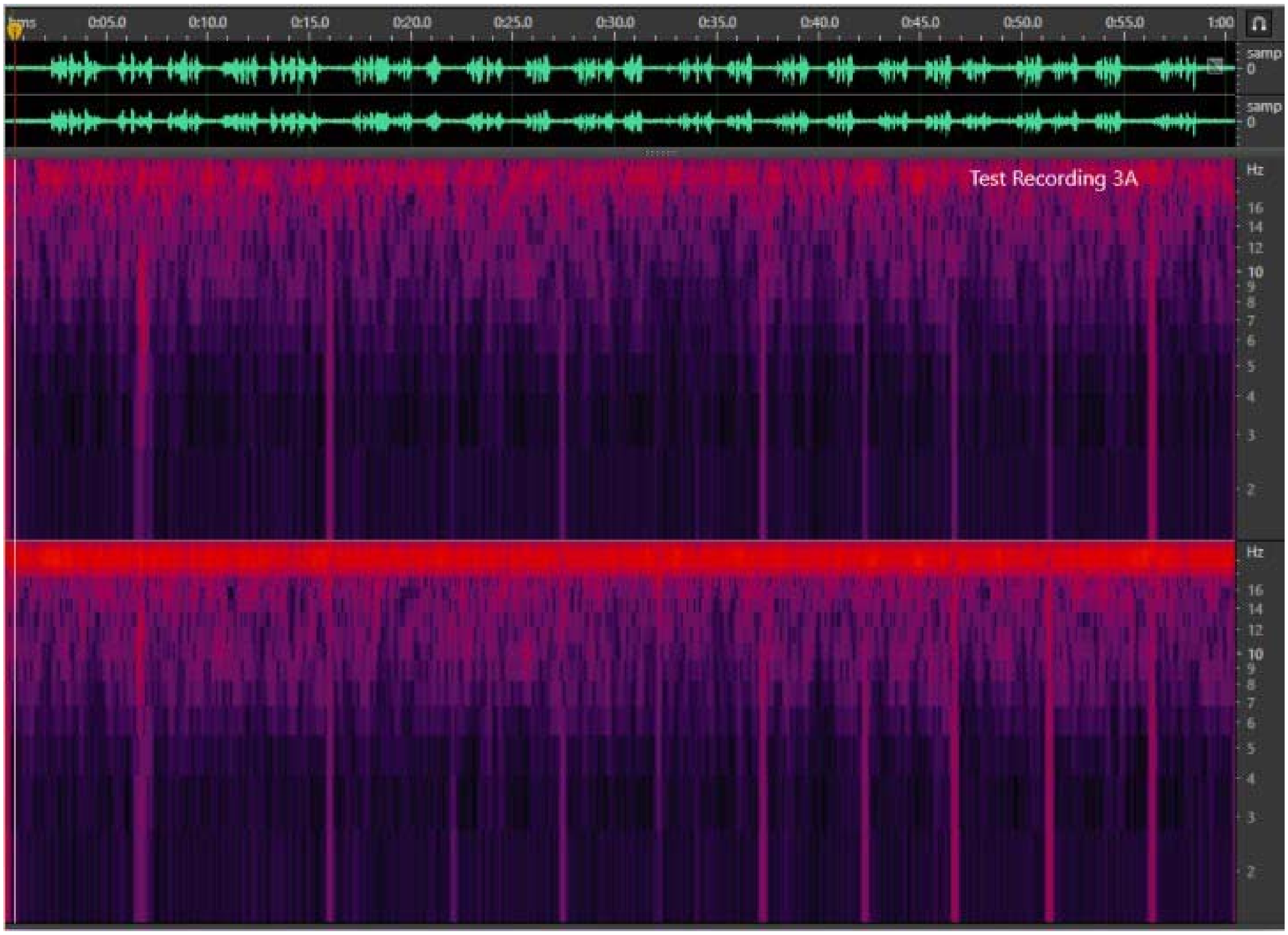

Figure 16: Spectrogram for Test Recording 3A; Resolution 8192 / Blackman-Harris.

Test Recording 4B

Test Recording 4B was created on an Olympus DM-550 digital audio recorder. The manual pause-record events in this recording were initiated with the remote control device. The time domain analysis on this recording was particularly difficult as the pause-record events present as very low energy events, often mimicking butt-splice type artifacts. The author was not able to locate all of the events in the waveform, even with an outstanding indicator in the spectrogram. The waveform events that I identified with confidence were all found through the discontinuities at approximate 3.1 kHz in the spectrogram:

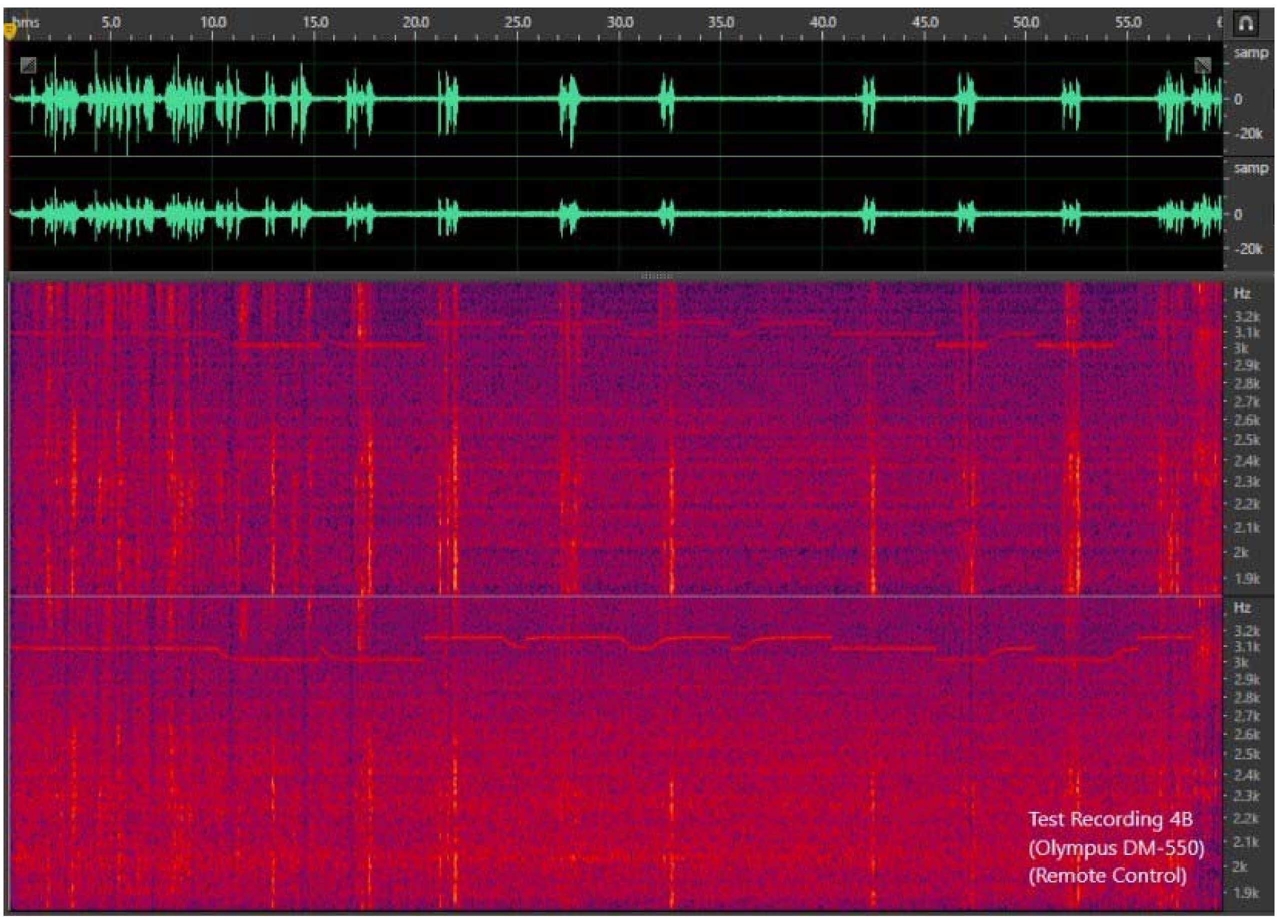

Figure 17: Spectrogram for Test Recording 4B; Resolution 4096 / Blackman-Harris.

Examples of the waveform artifacts are below:

Figure 18: Time domain display of pause-record event 4B_01.

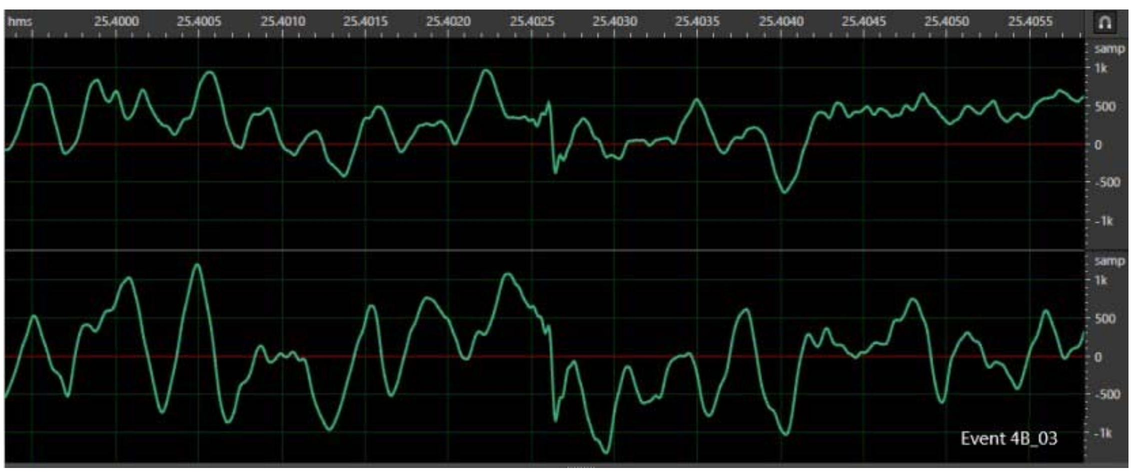

Figure 19: Time domain display of pause-record event 4B_03.

Figure 20: Time domain display of pause-record event 4B_05.

Test Recording 5B

Test Recording 5B was created on the same Olympus DM-550 recorder as Test Recording 4B. The targeted test events in this recording, however, were initiated manually. This recording was created in a public space with a broad range of background noise and "babble". The 31 kHz line that was present in the previous recording was not present here.

The results of the waveform analysis showed greater variability and higher energy artifacts than in 4B. Again, this makes sense if we consider that manual initiation adds vibration that is incorporated into the recording. There was no apparent value in the frequency analysis. The waveforms of the pause-record events are below.

Figure 21: Time domain display of pause-record event 5B_01.

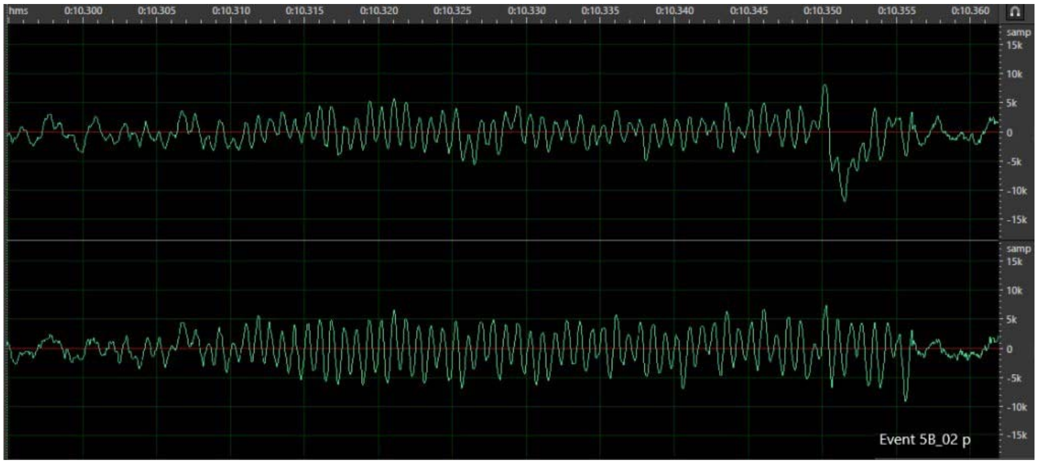

Figure 22: Time domain display of pause-record event 5B_02.

Figure 23: Time domain display of pause-record event 5B_03.

Figure 24: Time domain display of zoom of event 5B_03.

Test Recording 6C

Test Recording 6C was created on an Olympus DM-620 digital audio recorder. The pause-record events in this recording were initiated manually. Waveform analysis showed that these were low amplitude events. There is also much variability between the first sample event and the following two.

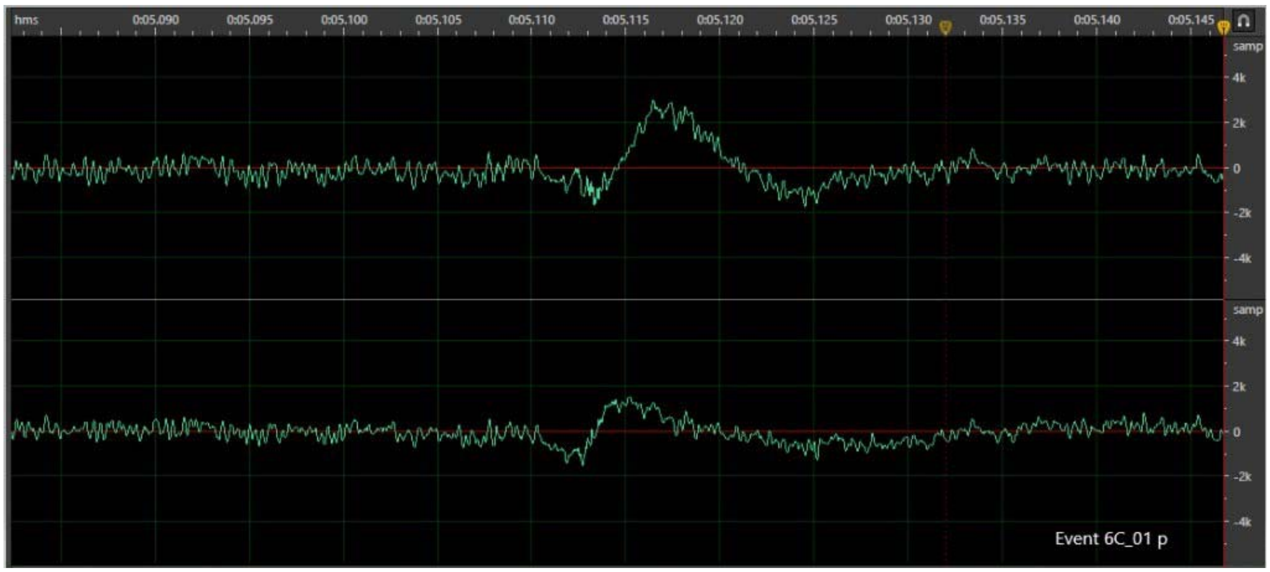

Figure 25: Time domain display of pause-record event 6C_01.

Figure 26: Time domain display of pause-record event 6C_02.

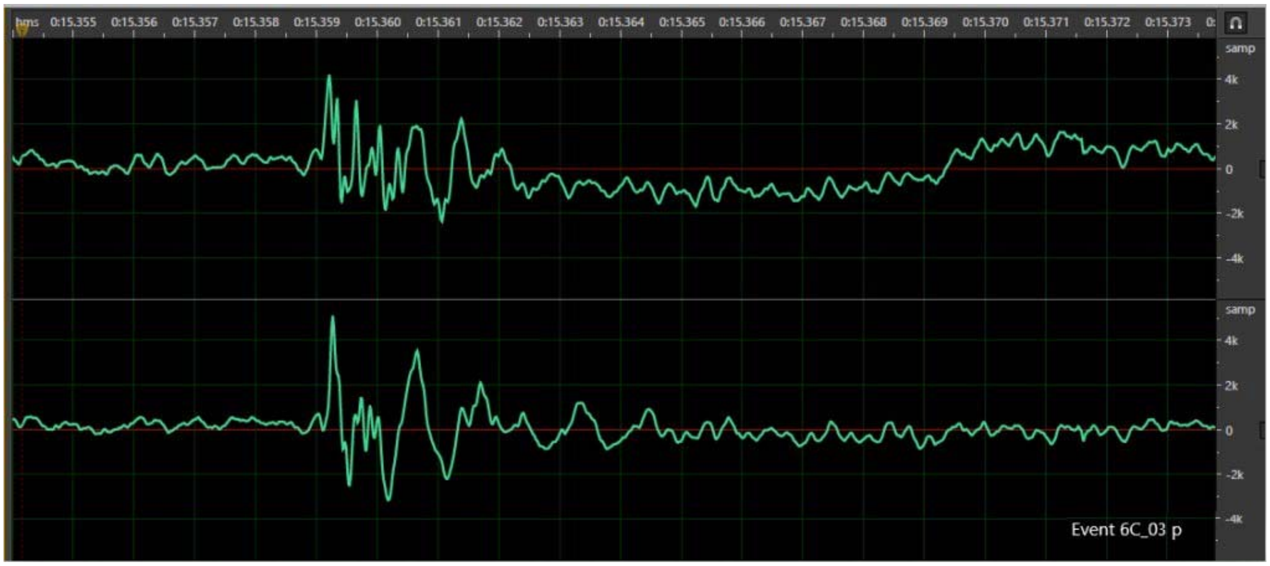

Figure 27: Time domain display of pause-record event 6C_03.

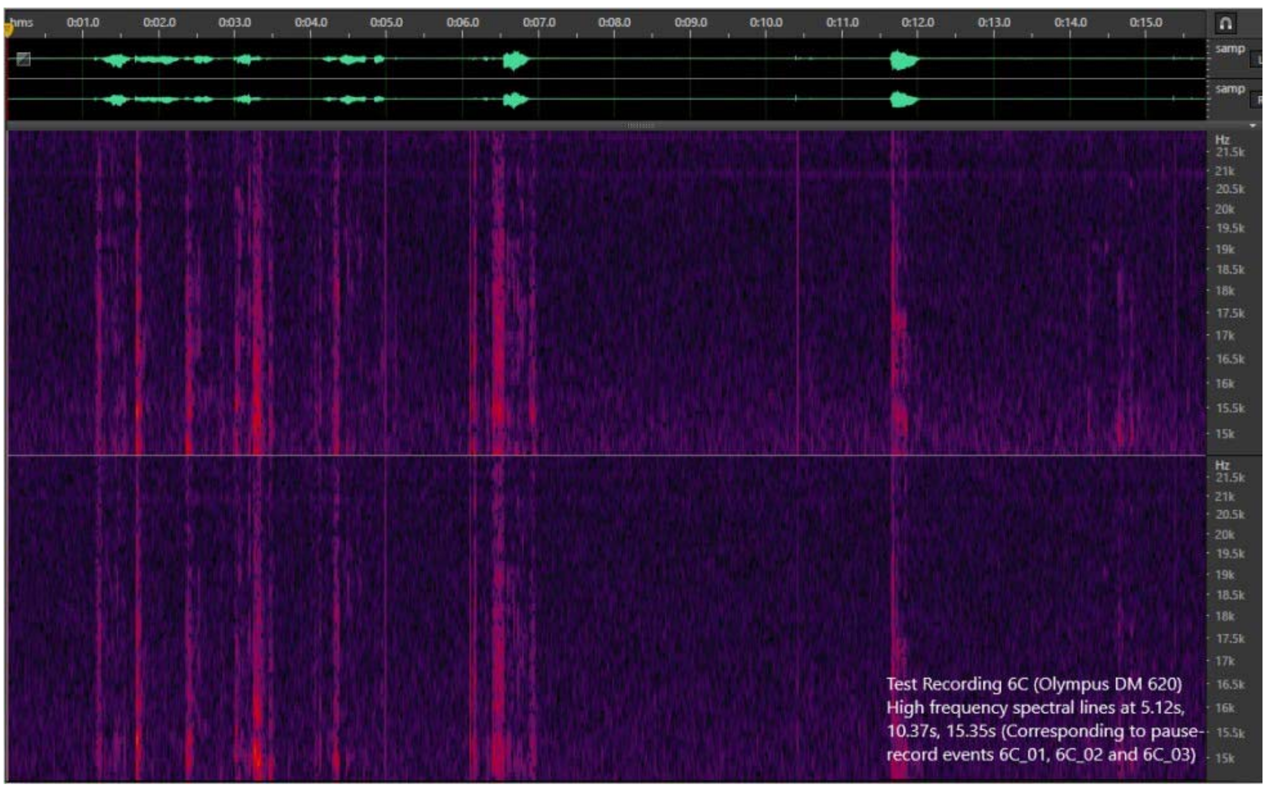

Figure 28: Spectrogram for Test Recording 6C; Resolution 4096 / Blackman-Harris.

Test Recording 7C

Test Recording 7C was created on the same Olympus DM-620 digital audio recording as 6C, with event initiation conducted by remote control. The waveforms of these sample events are more consistent in their general shapes and are still very low amplitude events. This is another case where spectrogram artifacts were instrumental in locating the low-energy waveforms; specifically, horizontal line breaks at 3.1 kHz.

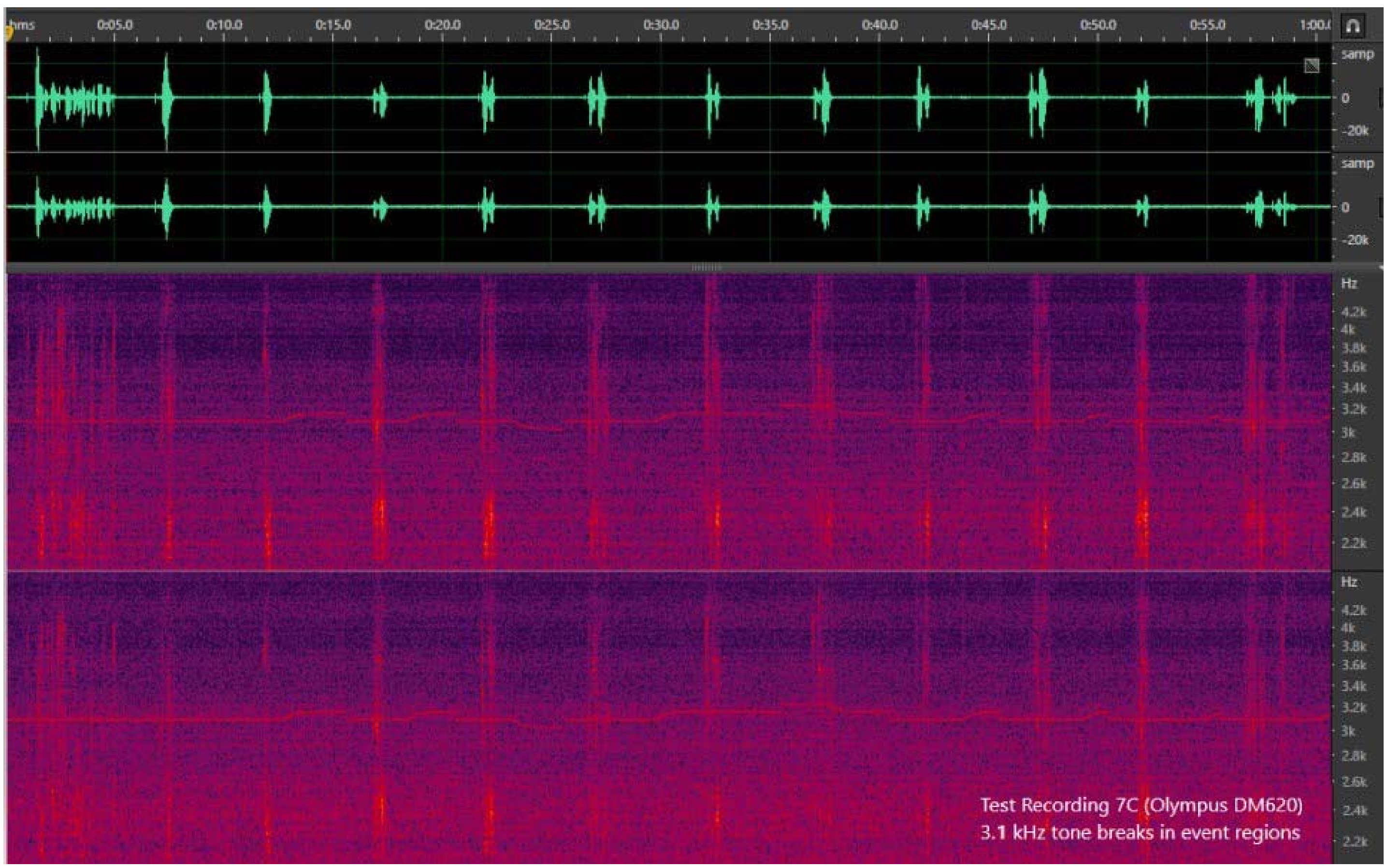

Figure 29: Spectrogram for Test Recording 7C; Resolution 4096 / Blackman-Harris.

Figure 30: Time domain display of pause-record event 7C_01.

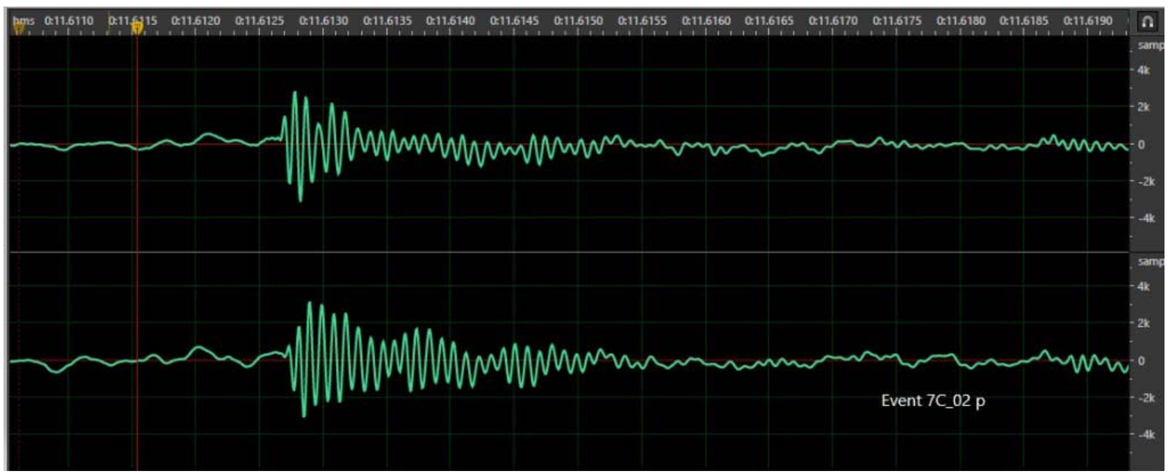

Figure 31: Time domain display of pause-record event 7C_02.

Figure 32: Time domain display of pause-record event 7C_03.

Test Recording 8C

Test Recording 8C was created on the same Olympus DM-620 digital as 6C and 7C. The manual pause-record events in this sample were initiated manually. The waveforms here were of slightly higher amplitudes then the other DM-620 samples. The left channel of the first event is similar to what we see with butt-splice manipulations. The right channel of the same is generally undefined.

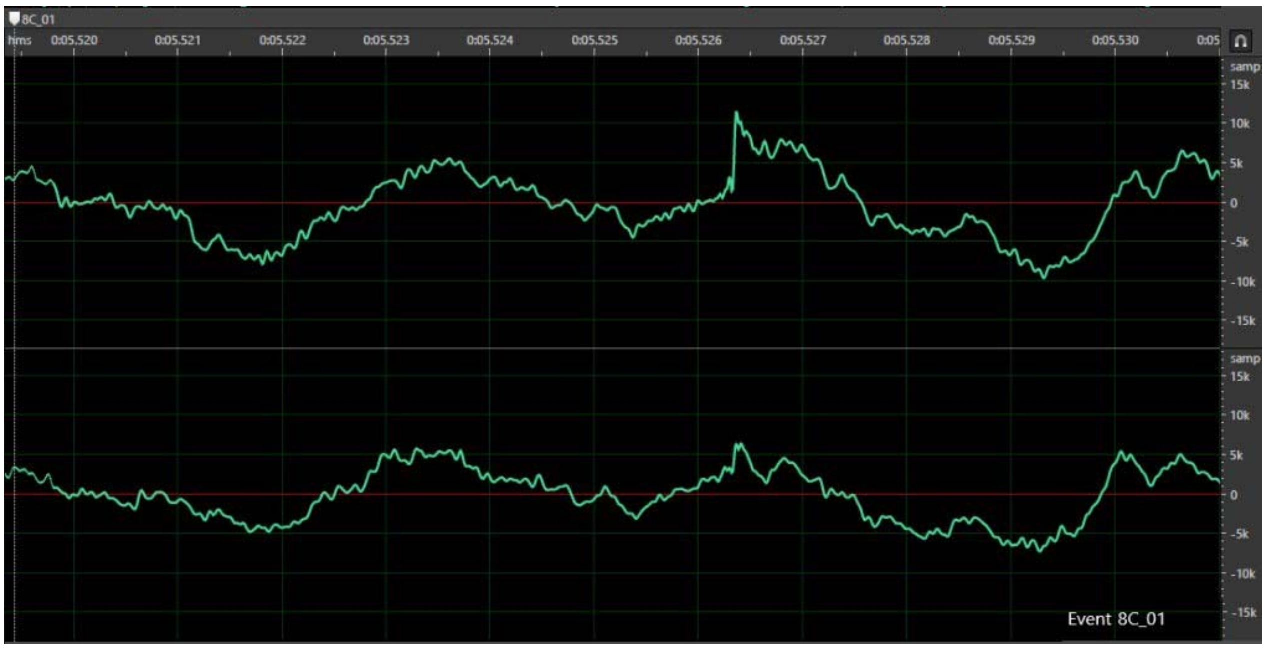

Figure 33: Time domain display of pause-record event 8C_01.

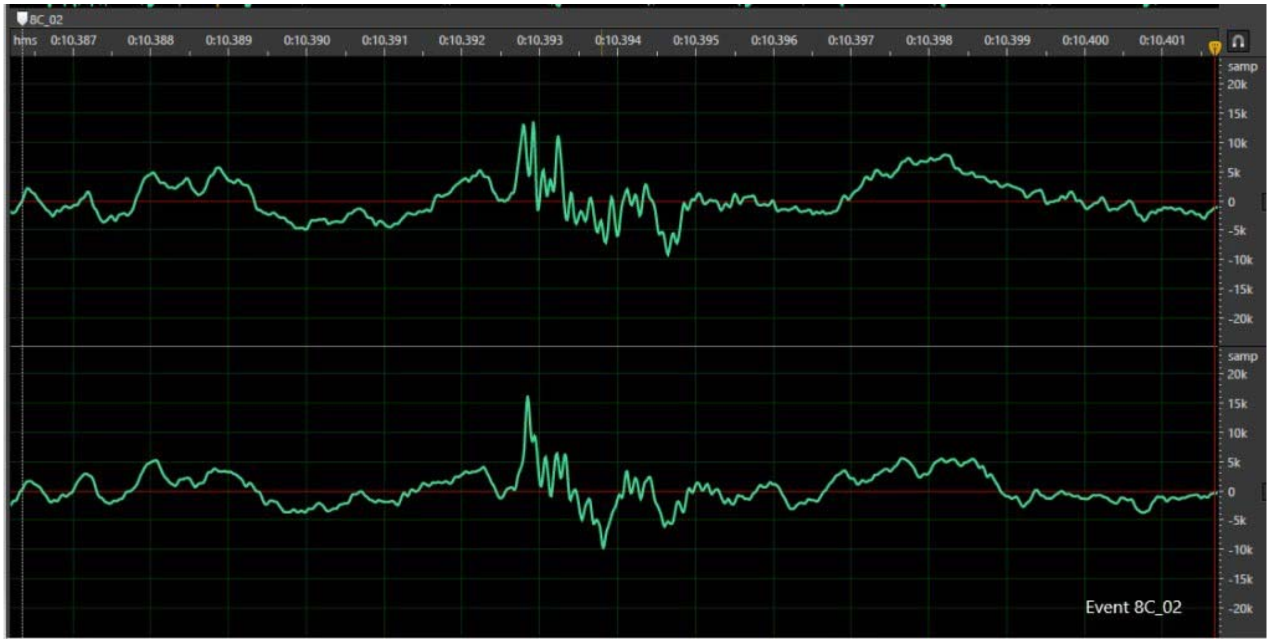

Figure 34: Time domain display of pause-record event 8C_02.

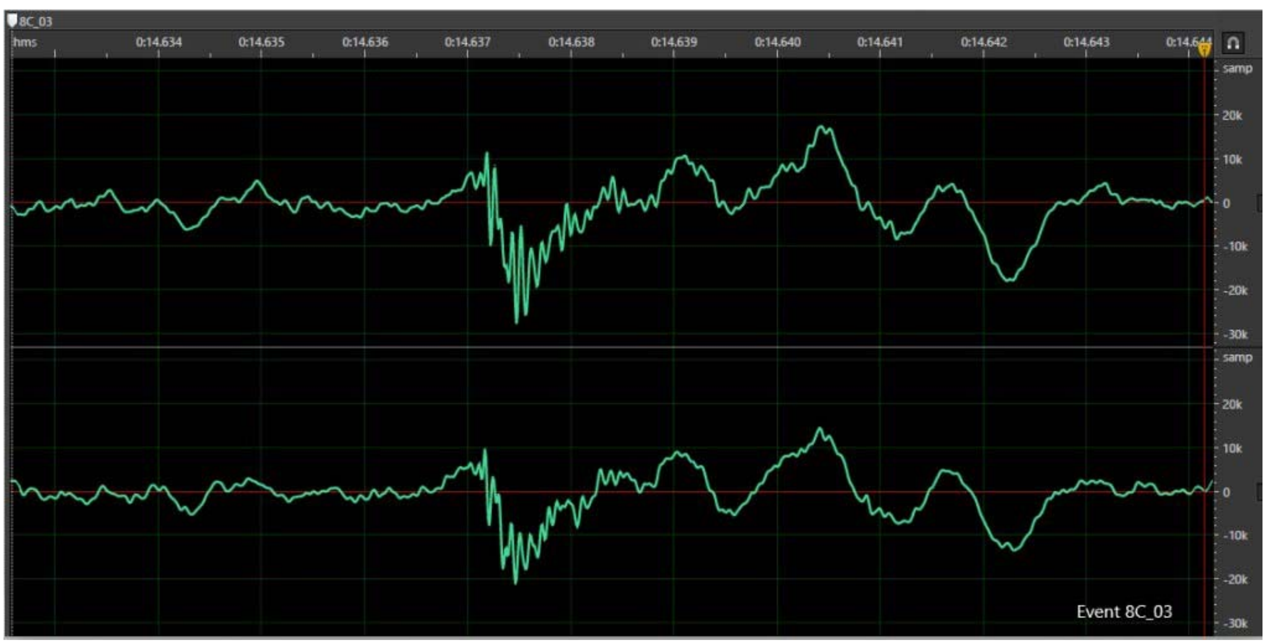

Figure 35: Time domain display of pause-record event 8C_03.

The spectrogram of test recording 8C displayed a thin vertical line from 20kHz and below at the pause-record events. Below shows the thin broadband lines at 5.52 sec (Event 8C_01) and 10.40 sec (Event 8C_02). There is a slight audible click associated with some of these events, however, the recording was produced in a public space with background “babble”.

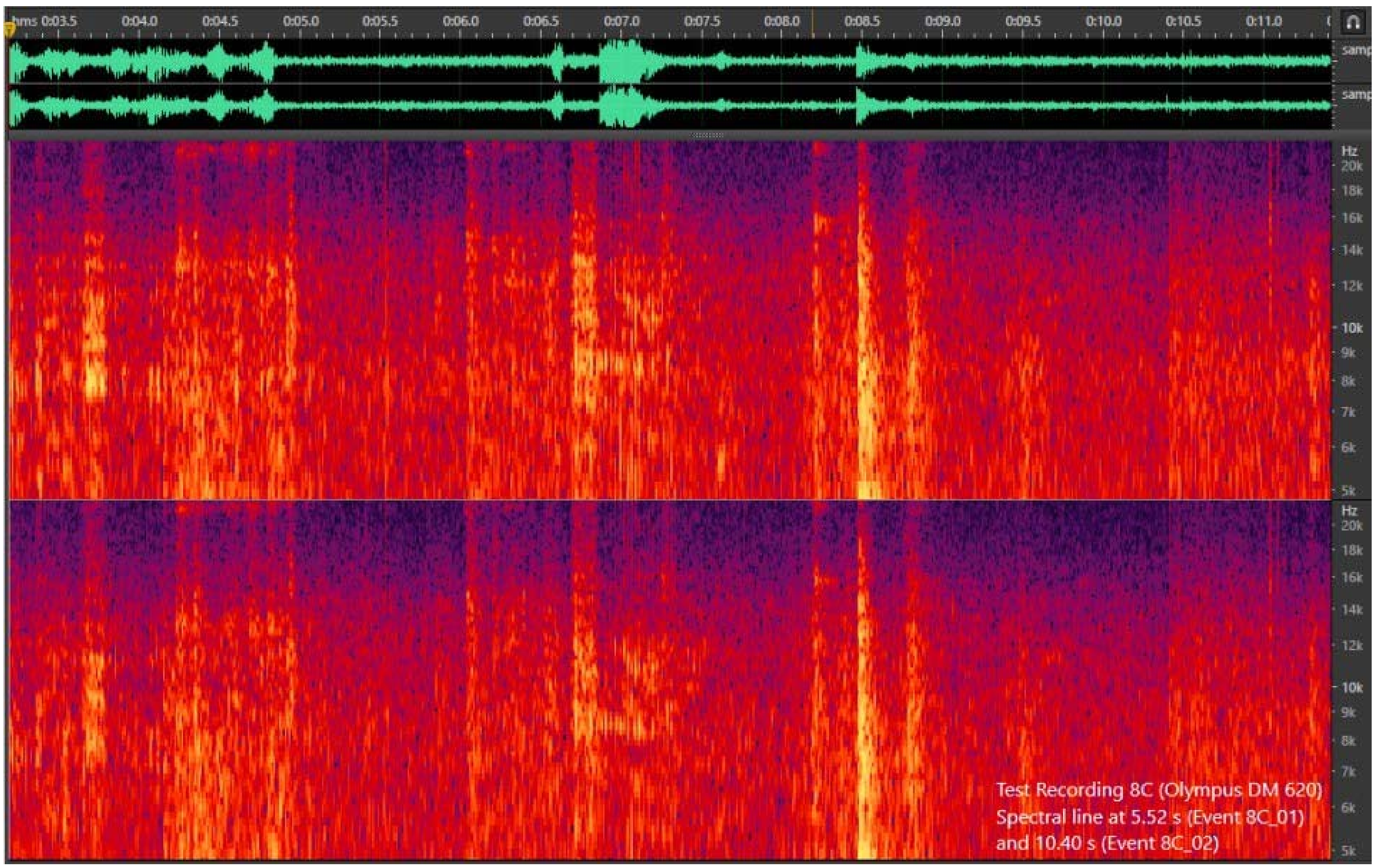

Figure 36: Spectrogram for Test Recording 8C; Resolution 2048 / Blackman-Harris

Test Recording 9D

Test recording 9D was created with an Olympus LS-20 digital audio recorder. This is the only test recording we have for this particular device. The targeted events were initiated manually. The events were very low energy in nature but relatively consistent in time domain analysis. Breaks of a slightly descending horizontal tone were evident at around 3.1 kHz and greatly assisted in locating the event waveforms.

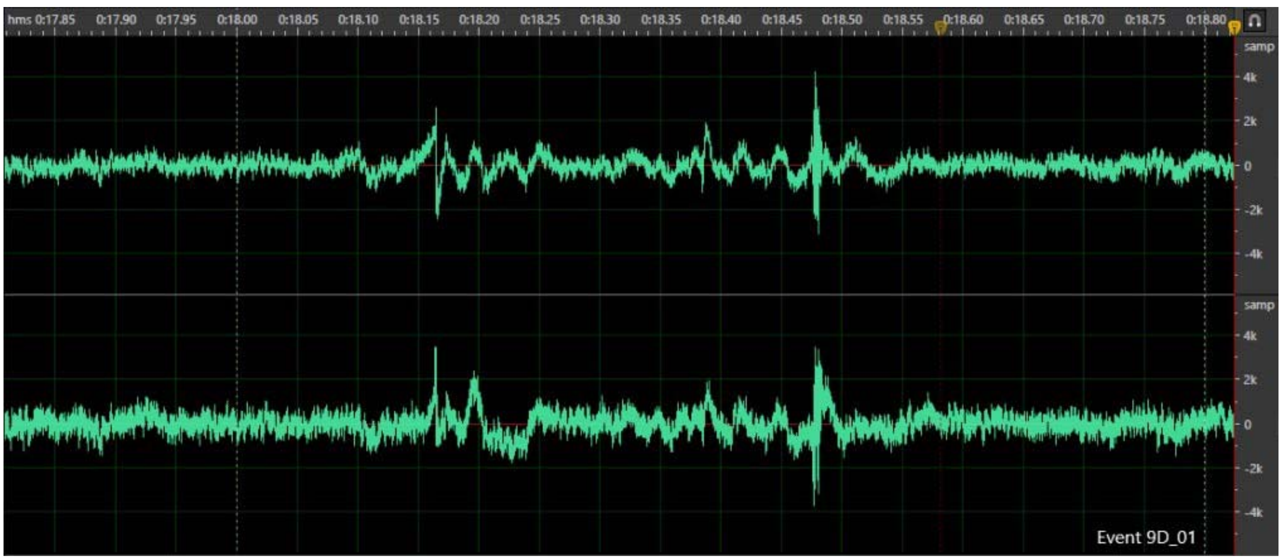

Figure 37: Time domain display of pause-record event 9D_01.

Figure 38: Time domain display of pause-record event 9D_02.

Figure 39: Time domain display of pause-record event 9D_03.

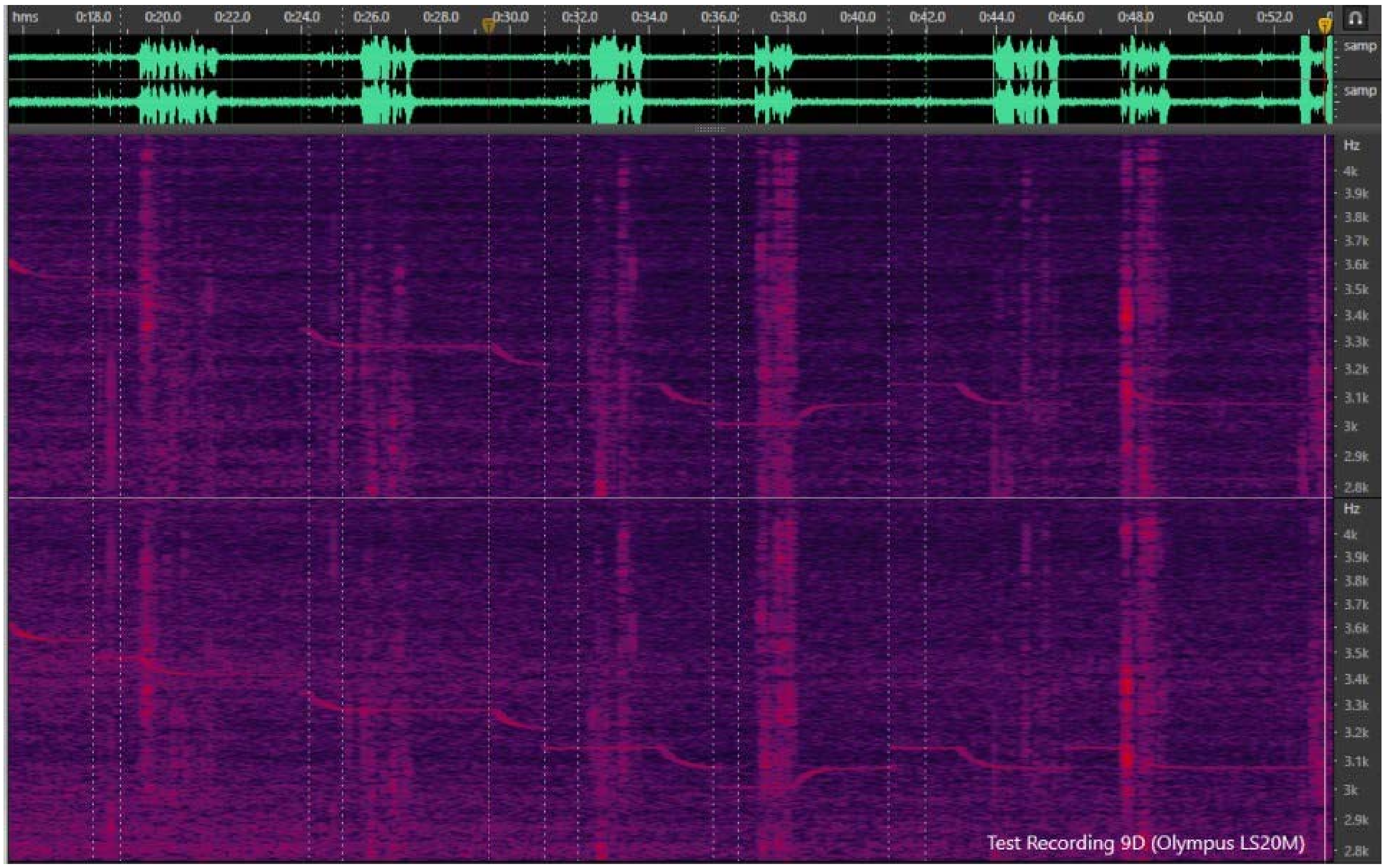

Figure 40: Spectrogram for Test Recording 9D; Resolution 2048 / Blackman-Harris.

Test Recording 10E

Test recording 10E was created with an Olympus WS-700M digital audio recorder. This is the only test recording we have for this recorder. There is substantial "babble" in the background of the audio. There was a slight click and drop-off at each of the pause-record events in this sample. The events were low amplitude, butt-splice-like, and difficult to locate. Locating them within the waveform was assisted by spectrogram vertical indicators at each pause-record event descending from 40 Hz. The waveforms and spectrogram follow.

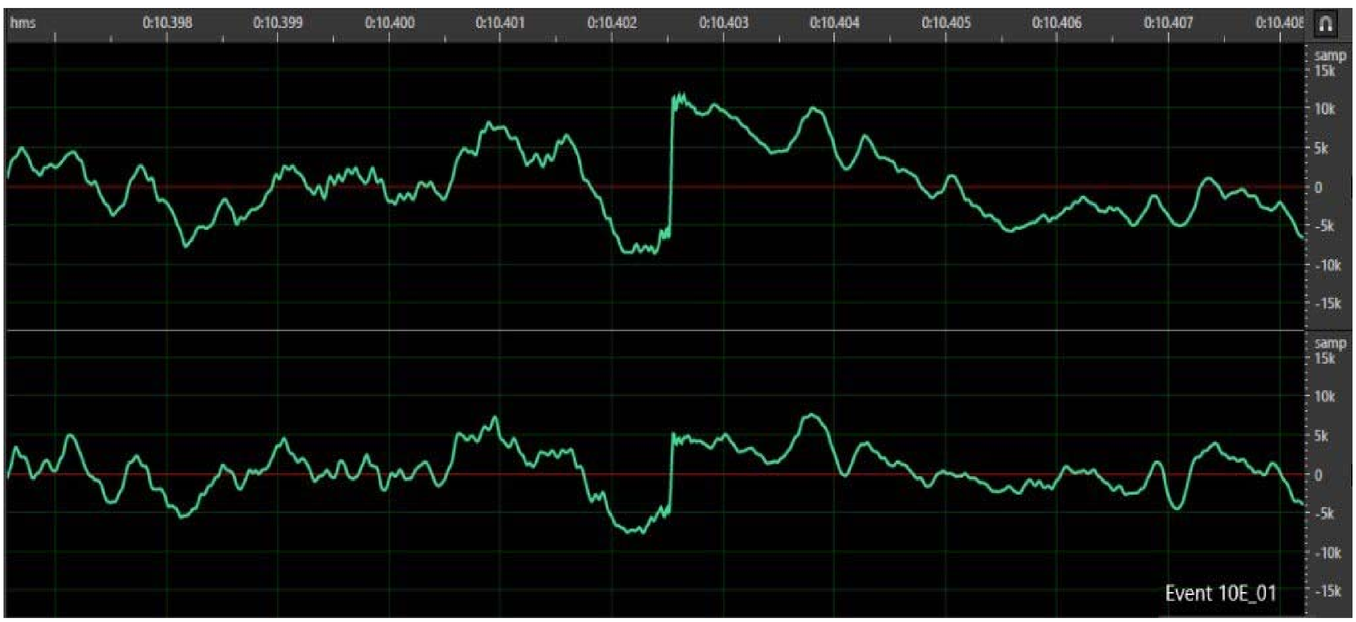

Figure 41: Time domain display of pause-record event 10E_01.

Figure 42: Time domain display of pause-record event 10E_02.

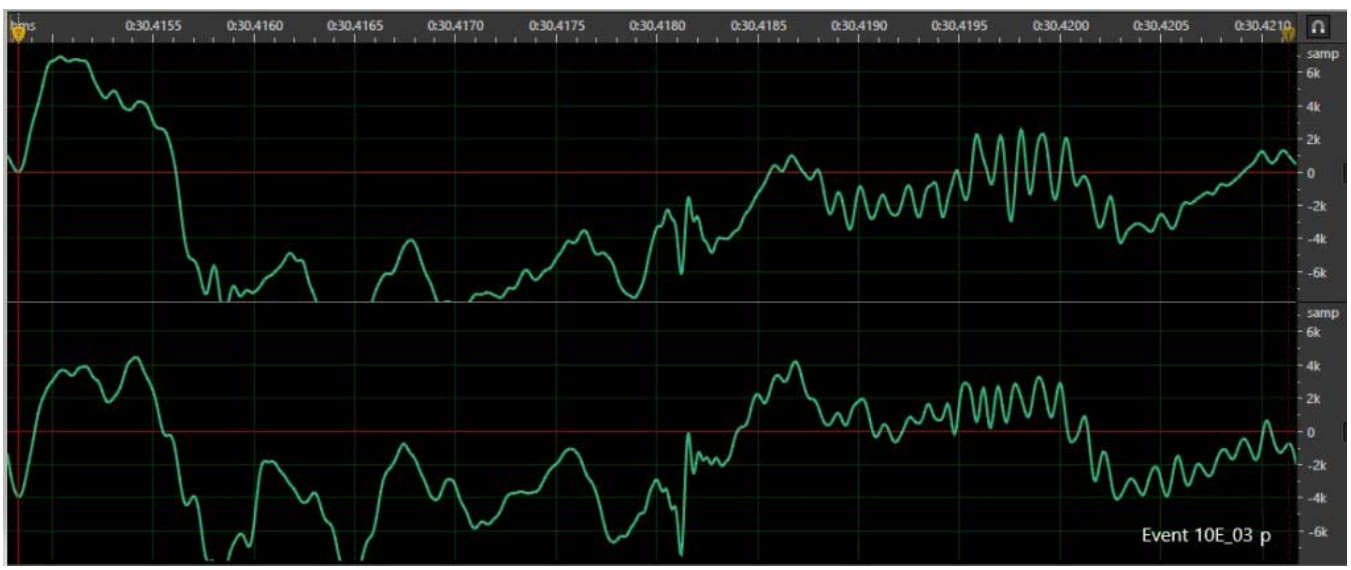

Figure 43: Time domain display of pause-record event 10E_03.

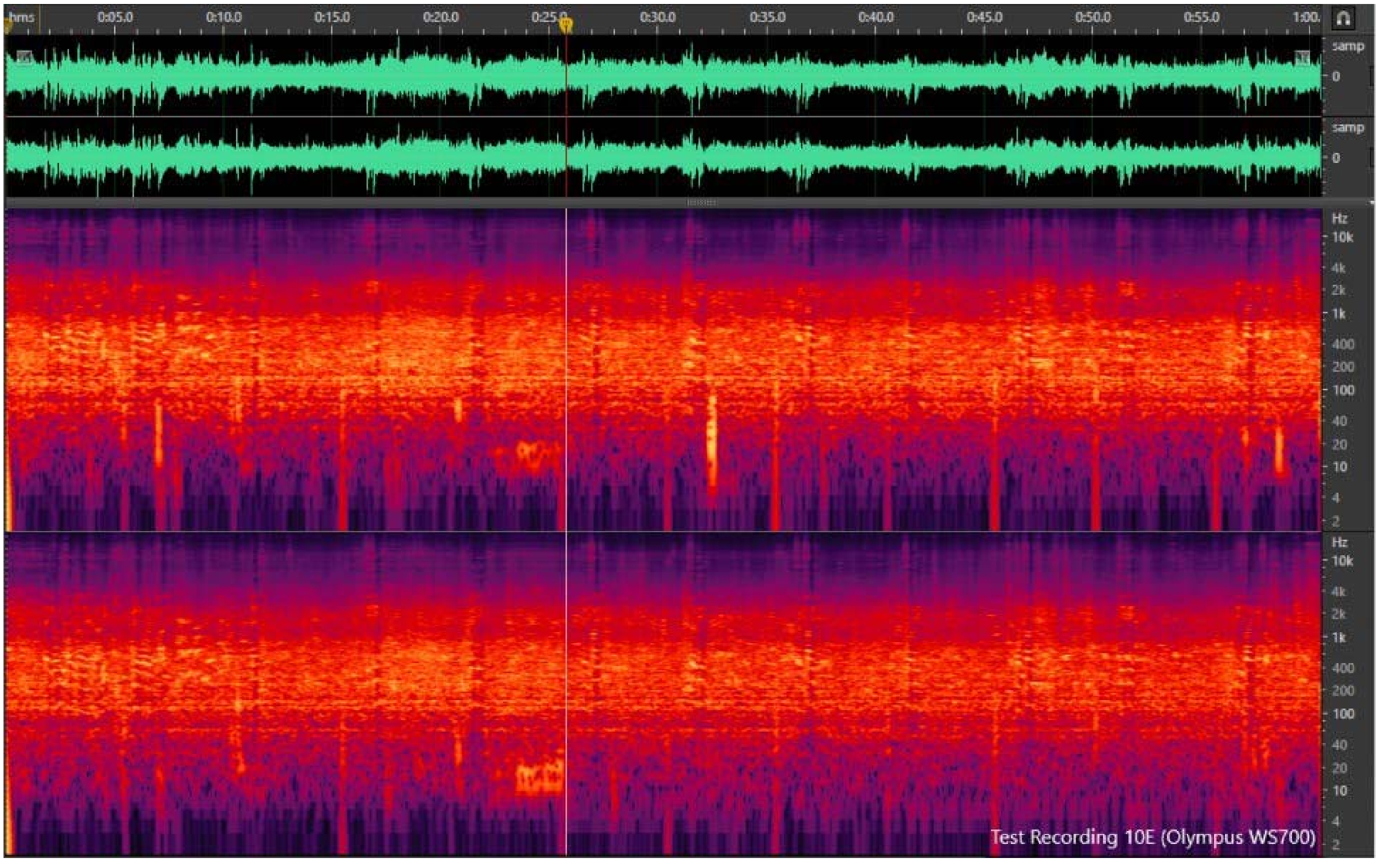

Figure 44: Spectrogram for Test Recording 10E; Resolution 2048 / Blackman-Harris.

Test Recording 11F

Test recording 11F was created with an Olympus WS-823 digital audio recorder. This is the only test recording we have for this recorder. The results from this recorder are interesting. The manual pause-record events consist of multiple components in the waveform. Where they are relatively well defined (Events 11F_01 and 11F_02), there are two groupings that have start points 0.23 seconds apart.

Critical listening of this recording indicated that there were two clicks heard for each pause-record event. Combined with visual real-time waveform analysis, it became apparent that the clicks were associated with the first grouping of components. Furthermore, a review of the associated spectrogram showed that there were distinct side-by-side vertical bands for the click pairs. The first band descended to the floor from approximately 10kHz and the second band descended from approximately 700 Hz. The waveforms and spectrogram are presented below.

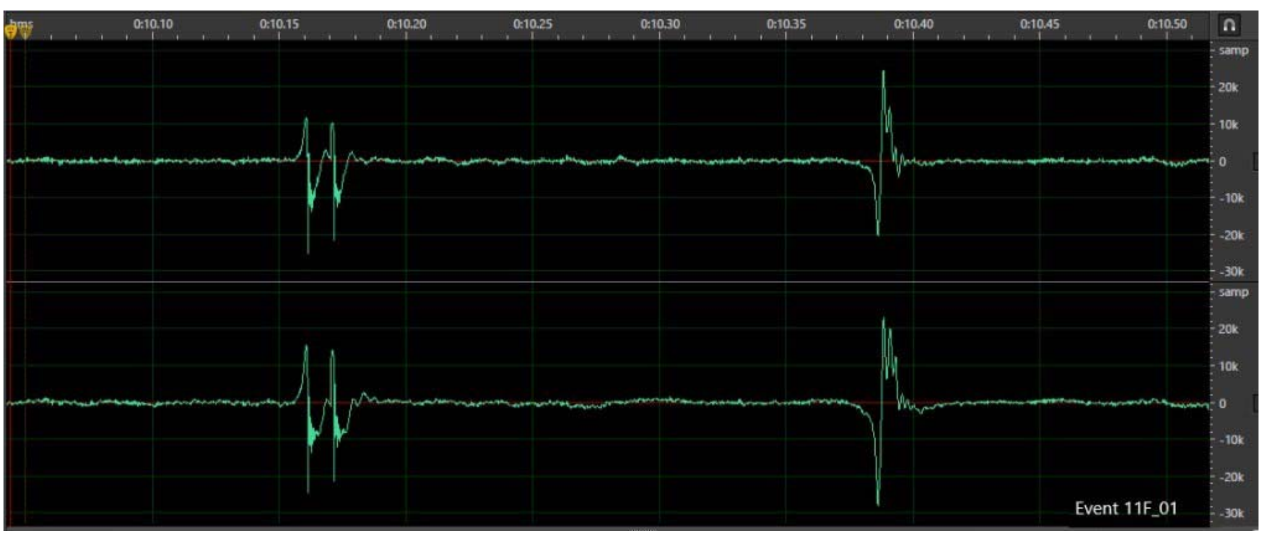

Figure 45: Time domain display of pause-record event 11F_01.

Figure 46: Time domain display of pause-record event 11F_02.

Figure 47: Time domain display of pause-record event 11F_03.

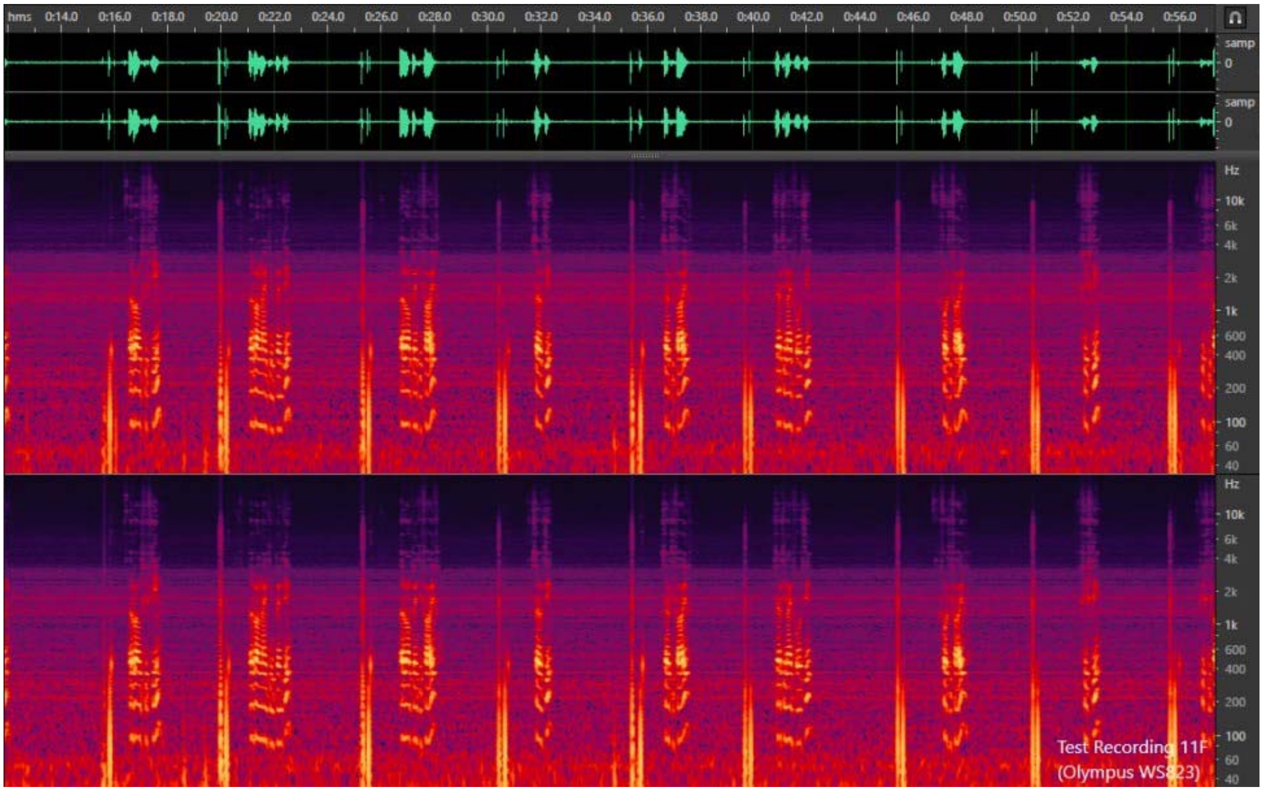

Figure 48: Spectrogram for Test Recording 11F; Resolution 4096 / Blackman-Harris.

CHAPTER IV

Conclusions & Future Research

This study was conceived with two hypotheses in mind. The first hypothesis was that there existed certain artifacts that could be differentiated as global signatures of a manual pause-record event in digital audio recordings and that these artifacts can be measured to add value to a forensic digital audio authentication exam.

A second hypothesis was proposed in the case that the first hypothesis was shown to be false. The second hypothesis is that a specific digital audio recorder will display consistent characteristics at manual pause-record events, such that a signature for such events could be identified for that specific recorder and exploited by a forensic examiner during authentication examinations.

This study has shown the first hypothesis to be false. The variability observed with manual pause-record events is great enough that it is reasonable to expect that no such artifacts or signatures can be said to be a *global* indication of pause-record events across the majority of recorders.

The validity of the second hypothesis is still an open question. The intra-recording variability observed in this study indicates that in most circumstances there probably will not be a standard signature or artifact that can be said to be consistently present and indicative of a specific recording device. To make such a claim, we would need to see some consistency between different recordings from the same device. Not only did we not see this but, we observed significant variability within the same recording.

This study has also shown that at least some of the intra-recording variability may stem from the vibrations caused by the mechanical act of pushing a button on the recorder. Further research needs to look at this possibility and determine if some standard artifact(s) may be hidden under the variable responses caused by the mechanical act.

This study did focus on a single manufacturer of digital audio recorders. Further research needs to be conducted to determine if the level of variability observed in this study holds true for other name brands as well.

None of these results, however, suggest that a qualified examiner cannot formulate an opinion on whether particular artifacts do or do not indicate a manual pause-record event in a specific situation. The totality of the circumstances, combined with the experience of the examiner and an opportunity to examine and interrogate the original recording device certainly could lead to conclusions of high confidence.

This study itself showed that certain characteristics or artifacts, especially in the frequency domain, have the ability to indicate that a pause-record or similar event has occurred. An example is the case where tonal bands are shown to be discontinuous at the point of the pause-record event. This is a strong indicator; however, we cannot label such a case as a common signature that we should always expect to be there. That would require that a tonal band is always in the recordings of a particular device. Such a circumstance can be labeled as a contingency-type signature that takes the form, "if a tonal band is present, then sudden breaks in the band may be indicative of a pause-record event". It is not, however, a signature that an examiner should come to expect to be there.

Further research also needs to be conducted in differentiating between butt-splice manipulations and certain pause-record events. This study showed that pause-record events, especially in the time domain, can take on characteristics that mimic butt-splice manipulations.

This study has shown that one can expect significant variability when dealing with manual pause-record events. Waveforms can range from butt-splice-like manifestations to impulse response-type waveforms to quick sinusoidal type forms. What they generally all have in common is that they are transient and usually of low energy. Any examiner wishing to draw conclusions about a possible pause-record event situation should follow protocol best practices and conduct test examinations upon the alleged recording device, if at all possible. Even with the displayed diversity, a practitioner who is armed with knowledge of the characteristics of the device in question may be successful in coming to a high-confidence decision concerning manual pause-record events.

Works Cited

[1] D. L. Rappaport, "Establishing a standard for digital audio authenticity: A critical analysis of tools, methodologies, and challenges," National Center for Media Forensics, Denver, 2012.

[2] D. R. Begault, B. M. Brustad and A. M. Stanley, "Tape analysis and authentication using multi-track recorders," in *Audio Engineering Society; 26th International Conference*, Denver, 2005.

[3] B. Koenig, "Forensic authentication of digital audio recordings," *Journal of the Audio Engineering Society,* vol. 38, no. 1/2, pp. 3-33, 1990.

[4] B. E. Koenig and D. S. Lacey, "Forensic authentication of digital audio recordings," *Journal of the Audio Engineering Society,* vol. 57, no. 9, pp. 662-695, 2009.

[5] C. Grigoras and JM Smith, “Audio enhancement and authentication”, in *Digital and Document Examination ,* 2018, pg 47 – 59.

APPENDIX

Test Recording Sample Data and Settings

SAMP	Recorder	Make	Model	SAMPLE ID	Mode	Conditions
1	A	Olvmous	DM-520	DM521151	Manuai-Pause-Rec	Mic Sense: Middle
2	A	Olympus	DM-520	DM521152	Manuai-Pause-Rec	Mic Sense: Middle
3	A	Olvmous	DM-520	DM521165	Remote-Pause--Rec	Mic Sense: Middle
4	B	Olvmous	DM-550	DM550183	Remote-Pause-Rec	Mic Sense: Low·LCF:off·
S	B	Olvmous	DM-550	DM550185	Manuai-Pause-Rec	Mic Sense: Low·LCF:off· Babble noise
6	C	Olvmous	DM-620	DM620187	Manuai-Pause-Rec	Mic Sense: Mid·Rec Lev:Man·LCF: off
7	C	Olympus	DM-620	DM620188	Remote-Pause--Rec	Mic Sense: Mid;Rec Lev:Man 5; LCF:off
8	C	Olvmous	DM-620	DM62091	Manuai-Pause-Rec	Mic Sense: Mid;Rec Lev:Man 5; LCF:off· Babble noise.
9	D	Olvmous	LS-20M	LS200033	Manuai-Pause-Rec	Mic Sense: Middle
10	E	Olympus	WS-700M	WS700210	Manuai-Pause-Rec	Mic sense: Mid;Manual 5;LCF:off
11	F	Olvmous	WS-823	190318-0077	Manuai-Pause-Rec	Mic sense: Mid· Manual S·LCF:off