ANALYSIS OF VOICE ACTIVATED ARTIFACTS

by

KELSEY BLACK

B.S., Marshall University, 2015

B.S., Marshall University, 2015

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

2017

This thesis for the Master of Science degree by

Kelsey Black

has been approved for the

Recording Arts Program

by

Catalin Grigoras, Chair

Jeff M. Smith

Scott Burgess

Date: December 16, 2017

Black, Kelsey (M.S., Recording Arts Program)

Analysis of Voice Activated Artifacts

Thesis directed by Assistant Professor Catalin Grigoras

ABSTRACT

This purpose of this thesis is to analyze voice-activated recording artifacts, using a playback audio created in Adobe Audition. To show how an automated voice recorder with standby mode treats the silence of a recording. This thesis focuses on the WAV PCM format. The WS-550M, WS-560M, and the DM-520 recorders did not have the option to create a WAV PCM file, therefore the WS-550M and the 560M created MP3 files and the DM-520 created a WMA file. Each of the recorders have automated standby mode. The recorders were set to create a WAV PCM that was a 16-bit stereo file at 44kHz. Below is a list of the devices that will be used in this study.

Olympus DM-520
Olympus DM-620
Olympus WS-550M
Olympus WS-560M
Olympus WS-700M
Olympus WS-700M
Olympus WS-750M
Olympus WS-760M
Olympus WS-802
Olympus WS-822
Olympus WS-823
Philips Voice Tracer

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

Approved: Catalin Grigoras

DEDICATION

For my sweet daughter, Jaslynn, without you I wouldn't be where or who I am today. You make me want to become a better person, and strive to be the best that I can be for you. Becoming a parent in graduate school, I gave up more time with you than I would have liked to have given up. Everything I do, I do for you, to ensure that you can have the best of everything you could ever want. I'm extremely proud to be your mommy, I love you baby girl.

I would like to thank my parents and the rest of my family for always being supportive and understanding. Thank you for helping me get through the last seven years of college and graduate school. Thank you for standing by me during those times of extreme stress, swift attitude changes, and everything in between. Most importantly thank you for helping with Jaslynn while I continue my education, I love you.

I would like to thank Wanda Dyke, Brian Morgan, and Josh Brunty for all your help not only throughout my time at Marshall University but for all the help you have given me now. Each of you have had a huge role in helping me get to where I am today, whether it is writing recommendation letters to begin graduate school and my internship, checking up on me, or simply supporting me. The guidance you gave me showed me just who I want to be, and what I am capable of accomplishing. I am truly grateful for each of you, and I honestly can't thank you enough for your support and help.

ACKNOWLEDGEMENTS

I would like to thank my professors Jeff Smith and Catalin Grigoras. The last two years have been challenging, eventful, but most importantly extremely educational. When I first started in the Recording Arts emphasis Media Forensics I was beyond certain that I was way out of my league. That first year you were supportive as I became a parent, you were understanding when I reached out to you. I have learned so much in the last two years, so much of that is already being utilized. I took an incredible opportunity for an honors internship during a very crucial class. During that time, you were supportive, understanding, and helped me to find a way to participate in the class.

I would like to thank Leah and Emma for answering my random questions, helping me get into the classroom, and the helpful reminders. Without the help I received from you I would be lost and behind in the program.

Thank you, Scott Burgess, even though we have not met you agreed to be on my committee. I greatly appreciate you taking the time to help me complete my master’s degree education.

TABLE OF CONTENTS

LIST OF FIGURES

FIGURE

LIST OF ABBREVIATIONS

1. WMA – Windows Media Audio

2. WAV PCM – Waveform Audio File Format, Pulse-Code Modulation

3. MP3 – Motion Picture Experts Group Layer-3

CHAPTER I

INTRODUCTION

This purpose of this thesis is to analyze voice-activated recording artifacts, using a playback audio created in Adobe Audition. To show how an automated voice recorder with standby mode treats the silence of a recording. This thesis focuses on the WAV PCM format. The goal is to show that each recorder with the automatic standby mode records the silence different, whether it be different from recorder to recorder or being different in the length of time being captured from the playback audio. Looking at the different sets of data that was captured from each recorder will show how the WAV PCM format captures the specific playback audio from model to model on the recorders.

As technology is advancing, the need for better understanding on how the automatic standby mode affects a recording is crucial for the Digital Forensics field. Looking at the WAV PCM format is just one area that needs better understanding. This thesis will look at one WMA file, nine WAV PCM files, and two MP3 files, however the focus will be on the WAV PCM files. Right now, what is known is if you have a ten-second generated silence, the automated standby mode of the recorder is entering standby mode as the silence begins. This research will show what happens when the recorders enter standby mode and how it affects the captured playback audio. In the Digital Forensics field recorders are becoming more commonly used to capture audio, so this thesis will help to understand what the recorder does when a silence occurs, and how that affects the outcome of the recording.

Previous Research

The topic of automated standby mode, which is also considered to be voice-activated, is a topic that does not have extensive prior research. There are instances in previous works that a study on it has been suggested. Instances of pause in records were mentioned in an article titled “Tape Analysis and Authentication Using Multi-Track Recorders” (Begault, Brustad, & Stanley, 2005). In their article they said

> “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. “

After reading that, it was evident that a study about the voice-activated artifacts needed to be performed. With the way the technology is changing, and the criminals are evolving with the technology, a study regarding the automated standby mode is becoming increasingly more required. The forensic field needs that understanding of how a recorder handles the automated standby mode. This study goes on to discuss the waveform analysis, which this study shows the waveform of each of the recordings that were taken. However, this study goes on to say that the type of analysis needed for the pause signatures of a recording are not within the scope of that article.

The next article that was reviewed was the “Test Audio Recordings and Their Use in Authenticity Examinations. Database of Properties of Digital Audio Recorders and Recordings.” (Michalek, 2016). This article discusses the digital audio recorders that are becoming available, and how they have so many capabilities among which comes a voice-activated recording. It explains that the evidentiary value of being able to verify the model of a recorder and the parameters associated with that recorder. The author does not go into detail regarding the pause or voice-activated functions, as this article is geared more towards the authenticity of a recording more than it is to provide an understanding of the pause or voice-activated functions. The evidentiary value of knowing how a recorder reacts to an automated standby mode could also be very helpful to the forensics field, especially when it comes to recorded conversations.

Next is an article called “Overview of Audio Forensics” (Maher, 2010), in this article the voice-activated functionality is referred to as a gate. Maher (2010) stated:

> “The noise gate compares the short-time level of its input signal with a pre-determined level threshold. If the signal level is below the threshold, the gate closes and no signal is let through, while if the signal level is above the threshold, the gate opens and allows the signal to pass. “

When thinking about what the voice-activation functionality is doing, it could be considered as a gate. In this instance the “gate” as Maher called it, would be the standby mode once a period of silence has been detected. On a digital recorder like one of the ones used in this thesis study the background noise of the recording area was recognized as silence and the only noise to be recorded was the tones that were supposed to be recorded. So essentially when the recorder recognized the sounds of the air conditioning unit as a silence it had become a gate and was not allowing those sounds to activate the recorder to enter back into recording mode. But once again it does not go into further details about what the voice-activated does, after the gate comparison.

Next is “Audio Forensic Examination” (Maher, 2009), this article is discussing that during an examination the examiner is looking for consistency marks. They are looking for those identifying areas like the record, erase and the pause as well. Mainly the transitions from each of these modes can be seen on the magnetic development of the recording. However, this article does explain that these markers can be helpful during the examination process to identify the recorders. It does not continue or explain more about the functionality of the voice-activated or pause areas to support their evidentiary value. They explain that the examiner is using these markers to determine authenticity which having a better understanding of the voice-activated function could provide an easier identifier for the authenticity of a recording.

Next is the “SWGDE Best Practices for Digital Audio Authentication” (Scientific Working Group on Digital Evidence, 2017), in this article they are laying out the best methods for which an examiner should go about their authentication process. They list questions that each examiner should ask prior to their examination. They state:

> “Additionally, discontinuities and alterations within the questioned recording should be included in the report with an explanation of the cause. Examples would include recording pauses, voice activation discontinuities, etc.”

They are saying that should the examiner find an instance of a pause or other discontinuities they should put it in their report, that they discovered it. Then after they have completed their examination they can say with a reasonable degree of consistency whether the device was paused like the client stated it was or was not. In ‘Appendix A: Sample Case’ (Scientific Working Group on Digital Evidence, 2017) they show a case in which they have two versions of what happened to a recording. One instance it was continuous and the other instance it was paused and restarted, so they use the waveform, and spectrogram analysis to determine if there were any instances of pause/restart in the recording. After they finished testing with the waveform and the spectrogram they used the energy analysis to confirm the results. This article does show that you can determine if there are any instances of pause/restart in each recording. Even though this article does talk about pause/restart further research is needed to gain a better understanding.

Next is the “Forensic Enhancement of Digital Audio Recordings” (Koenig, Lacey, & Killion, 2007). In this article is discussing some of the techniques that can be used to enhance an audio recording. It discusses the process of examination from the equipment and software to the expert testimony. They can discuss how they are able to improve the intelligibility of a voice from a recording. They explain that when they receive an audio file that is not playable they have to include that in their report along with the possible reasons as to why the audio file is not playable. But much like the other articles it does not going into detail about the voice-activated/automated standby. This article is more geared toward enhancing what they are receiving in evidence versus understanding what the voice-activated/automated standby is doing to the recordings.

The last article that was reviewed was “Forensic Authentication of Digital Audio Recordings” (Koenig & Lacey, 2009). This article starts by discussing the materials that are at hand for these types of examinations to take place. They go on to discuss the authenticity examination protocol in which they are determining one of four options for the recording. One of the options is:

> “Has discontinuities in the recording process, including record stops, starts, stop/starts, and amplitude-activated pauses.”

So, for this article the pauses or voice-activated areas are discontinuities. They continue to discuss how they create their test recordings. They go through a case in which an authentication of an audio file was conducted. However, there is a mention of the voice-activated or automated standby but it’s just that a mention. They do not go further into the subject. Which is why the research on this topic should be done, to show what it looks like from a recorder using a specific set of settings.

CHAPTER II

PREPARATIONS

The test that has been designed for this study has a set time limit. In that time limit the noise has its own time frame followed by a specific time frame of generated silence. The playback audio that has been created will be recorded on each of the chosen recorders that have the automated standby mode. The testing will use twelve recorders. Each recorder will record the playback audio that was created for this study. After each recorder has recorded the playback audio recording, the file will then be transferred from the recorder to be analyzed after the testing has completed.

Materials

The software materials that were used in this study were: Microsoft Excel, Mathworks MATLAB, and Adobe Audition. There were two different brands of recorders being used in this study, Olympus and Phillips were the only two types of recorders with automated standby modes being used. There were eleven different Olympus recorders and only one Phillips recorder. Nearly all the recorders are Olympus, this gives the opportunity to see how different models of the same brand react when using the standby mode.

Methods

Using Adobe Audition the playback audio recording was made. The playback audio had 1kHz tones, 2kHz tones, and silence areas. Each area lasted for ten-seconds, starting with the 1kHz tone, then going to a ten-second silence, then going to the 2kHz tone. The playback audio was setup so that it would have two rounds of the 1kHz tones, and the 2kHz tones, and then it would contain three areas of silence. The reason this study used the 1kHz tones and the 2kHz tones instead of a broadband noise goes back to the information that was found while reviewing the previous research. Previous research shows that some recorders will introduce a gap when using the pause-record mode. It was unknown as to whether the recorders being used in this test would introduce a gap, therefore it was needed to use the 1kHz tones and the 2kHz tones to differentiate between them on the spectrogram.

The following figures provides a better understanding of the layout of the playback audio recording that was used. The first figure shows the diagram of how the playback audio should be generated to get the best results. The second figure shows what the playback audio file looks like after being generated.

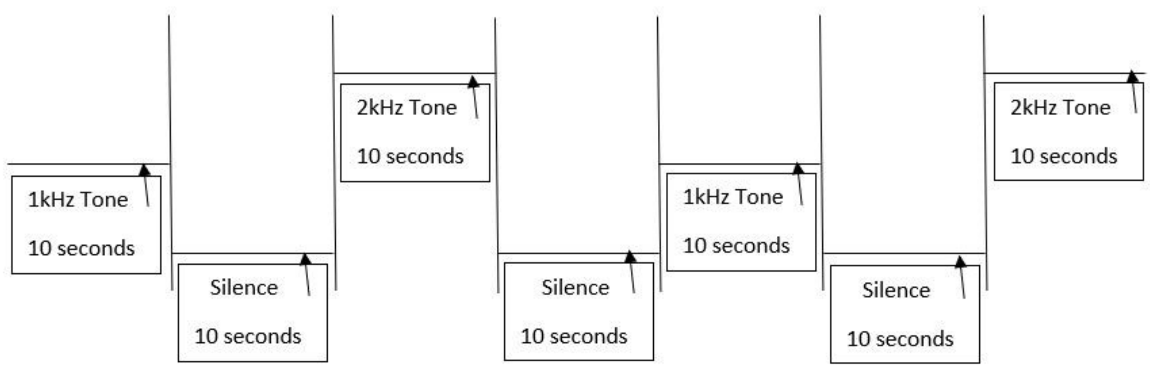


Figure 1.: Diagram showing the layout of the playback audio recording.

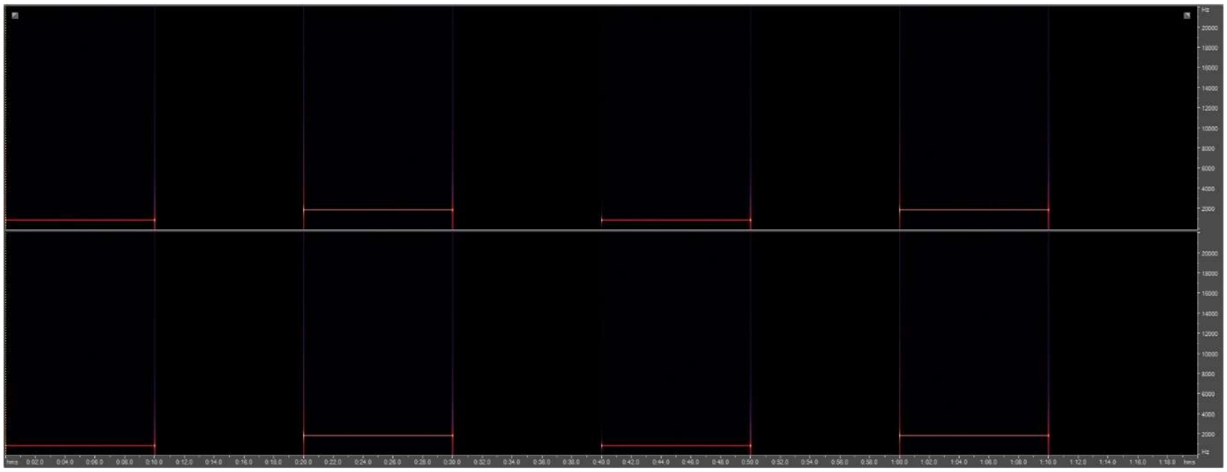


Figure 2.: WAV PCM File generated from the Figure 1. diagram.

This setup for the playback audio recording allows for each recorder to have more than one sample area of silence. It starts with a 1kHz tone lasting for ten-seconds, then it will go to a silence for ten-seconds, then to the 2kHz tone for ten-seconds, then to another silence for ten-seconds, then back to the 1kHz tone for another ten-seconds, then to another silence for ten-seconds, and then it will end with a 2kHz tone for ten-seconds. This test is looking at the areas of silence to see how each recorder captured that ten-seconds of silence.

When generating the 1kHz tone, the base frequency was set to 1000Hz. The modulate and modulation frequency were set to zero. For the frequency components, the first component was set to 100, and components two through five were set to zero. In the phasing area, all settings were set to zero. In the dB Volume area, both the Left and the Right were set to -6. The DC offset was set to zero. The Flavor was set to sine. The duration was set for ten-seconds. Figure 3. shows the settings for the 1kHz tone.

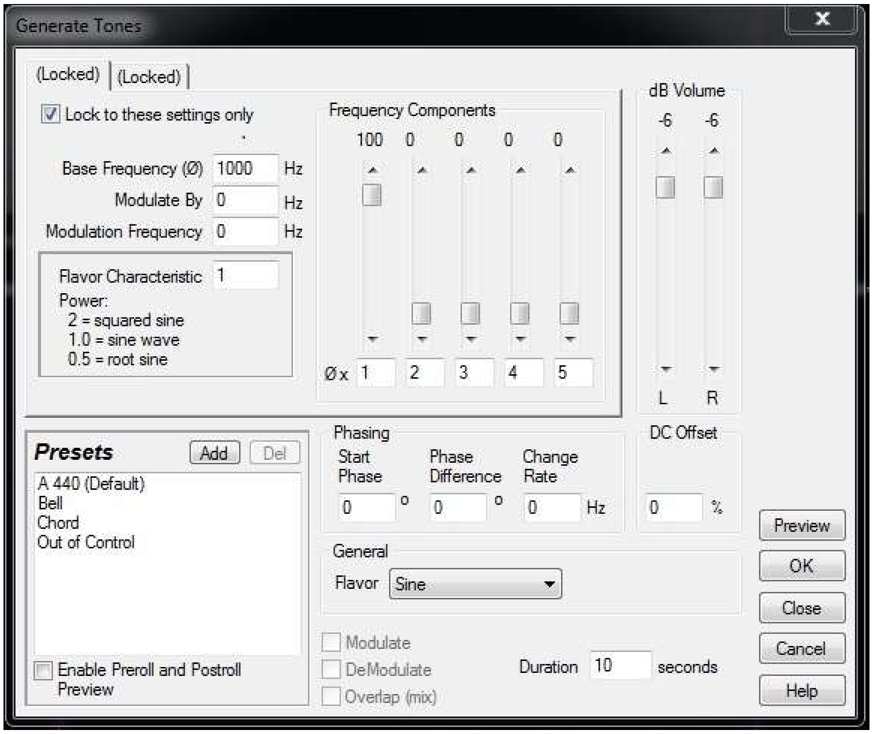


Figure 3.: Adobe Audition 3.0, Generating 1kHz tones.

When generating the 2kHz tone, it needed to have most of the same settings as the 1kHz tone. The base frequency was set to 2000Hz. The flavor characteristic was set to one. The modulate and modulation frequency were set to zero. The frequency components were the same with the first component being set to 100, and components two through five were set to zero. In the phasing area, all settings were set to zero. In the dB Volume area, both the Left and the Right were set to -6. The DC offset was set to zero. The Flavor was set to sine. The duration was set for ten-seconds.

When generating the silence, it was much simpler as the settings had one option that could be changed and that was the duration for which the generated silence was supposed to last. The setting was changed to show ten-seconds. Figure 4. shows the settings for generating silence.

Figure 4.: Adobe Audition 3.0, generating a ten-second silence.

Testing

After the audio file has been created, the testing phase can begin. In the testing phase, the area for testing has background noise to give the test a more realistic setting. The test was setup using two desktop computer speakers. The speakers were placed approximately three inches apart. The recorder was laying down on a desk during the recording time, this allowed for the recorder to be placed approximately one inch centered from the speakers. For the Olympus brand recorders, the microphone is located at the top of the recorders. For the Philips recorder the microphone was in the top of the recorder also. The recorders were placed between the speakers to ensure that both the left and right channel received the tones at the same time at the same volume. To begin the recording process the record button on the recorder was pushed to begin recording, allowing to enter standby mode while pushing the start button to begin playing the recording button. The playback audio file lasts for approximately one minute and twenty seconds. The computer volume is set to 100%. Once the recorder has finished recording the playback audio the record button is pushed once more to complete the recording phase for that device. After the recording has been completed, the recorded file is then transferred to the computer for the analysis phase. Only one recorder is running at a time, this was done to ensure that the recorder could capture the playback audio file as it was being played through both computer speakers, without have the extra sounds of each recorder as they are being started and stopped.

During the testing time, if a noise other than the background noise that the recorder noticed during the beginning of the recording is picked up the recording was started over. The main area of concern were the areas of silence in between the 1kHz and 2kHz tones. The areas of silence before the first 1kHz tone was not a concern as the recorder would have picked up the sound of the recorder being started and then went into standby mode until the playback audio is started. The same goes with the ending of the recording, after the end of the 2kHz tone the recorder would pick up the sound of the recording being stopped. So, to conduct a proper test of the areas of silence, the beginning and end were not taken into consideration for this study.

CHAPTER III

ANALYSIS

The analysis phase was done using Adobe Audition and MATLAB. Using Audition, each recording was loaded into the software to get a better view of what was recorded. Figure 5. will show what the recording looks like after it has been loaded into Adobe Audition.

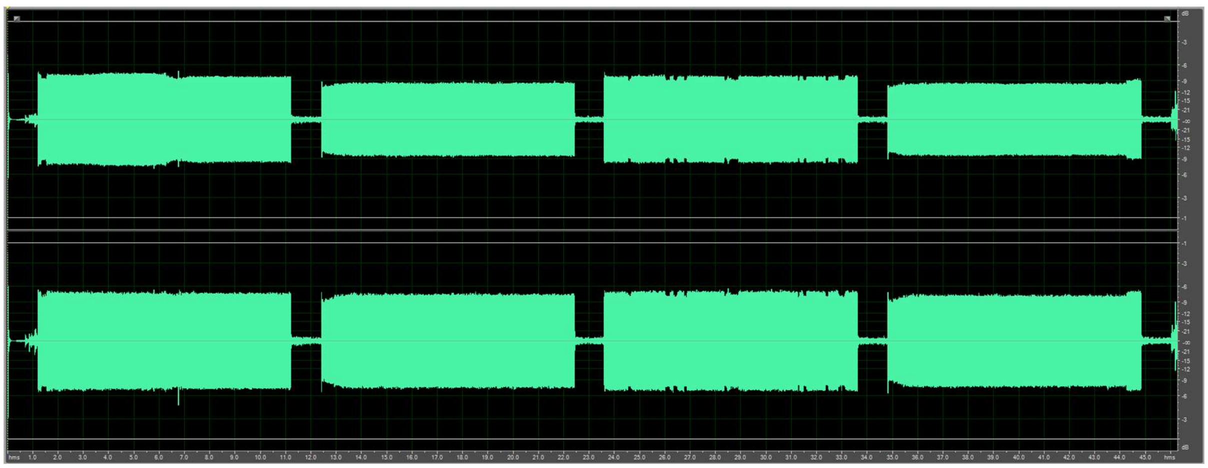


Figure 5.: Olympus DM-520 recording of the playback audio file.

Looking at Figure 5. the information that is being analyzed is the silences, those silences can easily be seen in this recording. Each of those spaces were set for a ten-second time duration which is why the entire playback audio file was one minute and twenty seconds. When looking at the silences we are calculating the number of samples per area of silence, however, the silence at the beginning of the recording will not be calculated and nor will the silence at the end of the recording. This is to ensure that the silence area that is being calculated has not been affect by the sounds of the recorder being started and stopped. When analyzing each of the recordings, the number of samples, the amplitude statistics, and the frequency analysis are taken from each of the middle three silence areas.

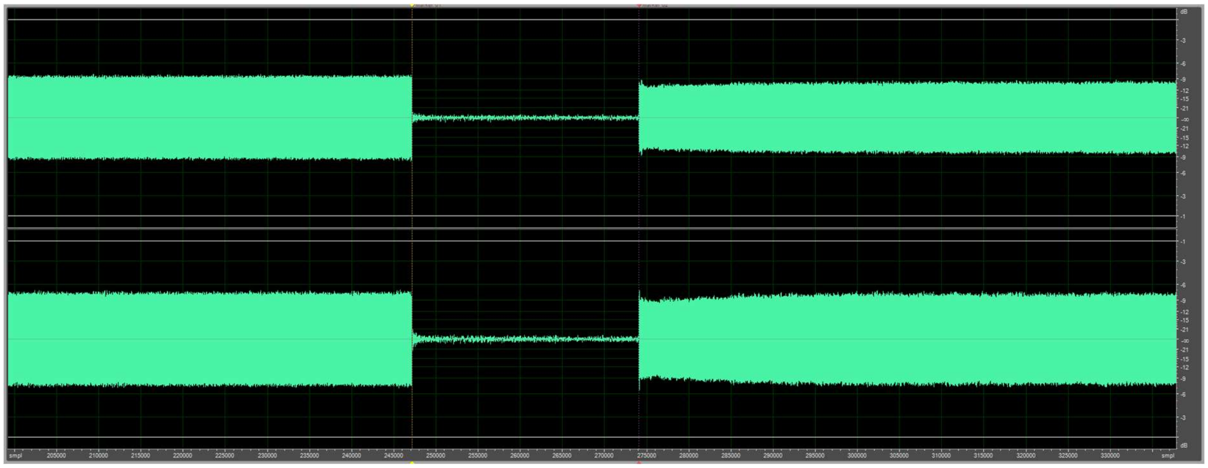


Figure 6.: Olympus DM-520, zoomed in to an area of silence to be analyzed.

Looking at Figure 6. it shows a zoomed in version of the audio recording. It is showing a 1kHz tone followed by a silence and then to the 2kHz tone. That area of silence is what is being analyzed, the region of that silence that will be selected for analysis will be directly following the end of the 1kHz tone and stopping immediately prior to the start of the 2kHz tone.

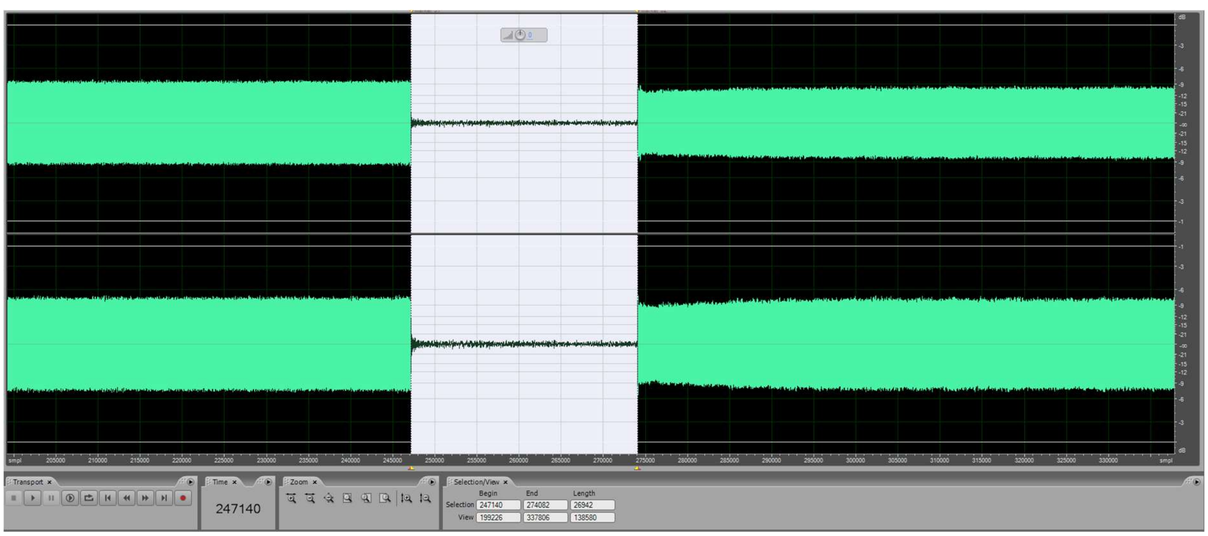


Figure 7.: Olympus DM-520, Number of samples.

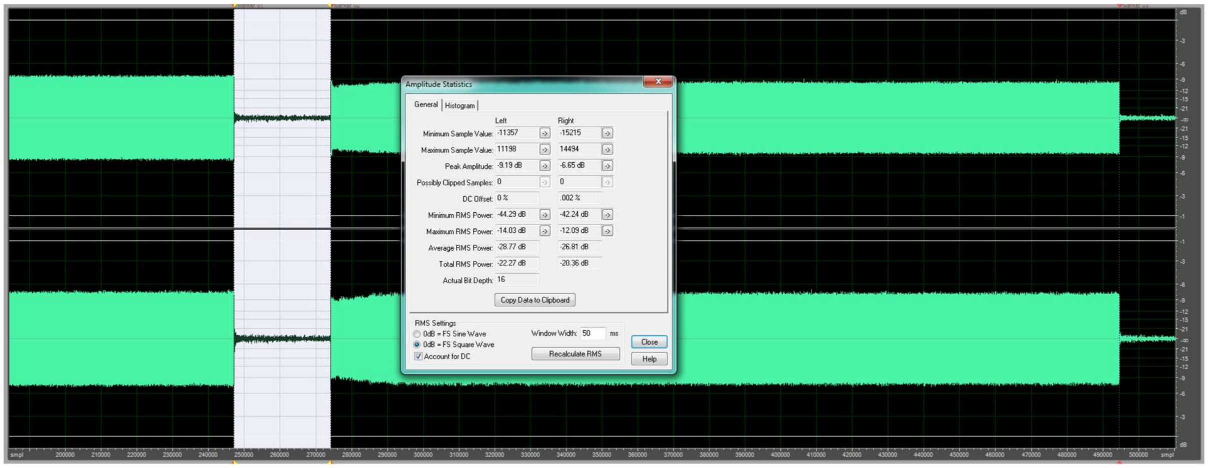


Figure 8.: Olympus DM-520, Amplitude Statistics.

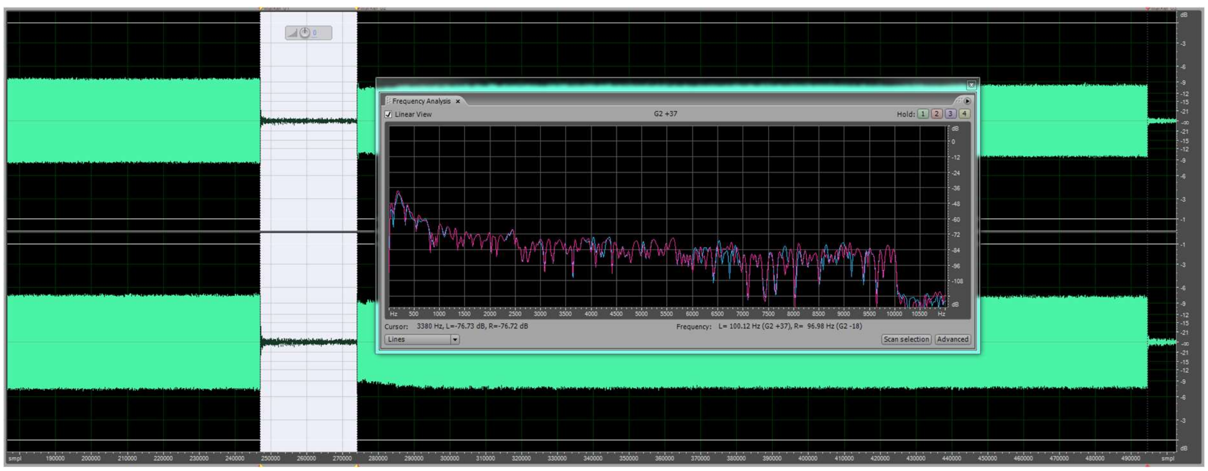


Figure 9.: Olympus DM-520, Frequency Analysis.

Figure 7. shows the number of samples per the selected area of silence. In this case looking at the Olympus DM-520 recorder, the number of samples contained in the first selected silence was 26942. The samples started at 247140 and then ended at 274082. Now that the number of samples for that silence has been determined, it’s time to go on to the amplitude statistics. The amplitude statistics shows the Minimum Sample Value, Maximum Sample Value, Peak Amplitude, Possibly Clipped Samples, DC Offset, Minimum RMS Power, Maximum RMS Power, Average RMS Power, and Total RMS Power, and Actual Bit Depth.

The main information that is being analyzed from this is the Peak Amplitude, the Minimum RMS Power, the Maximum RMS Power, the Average RMS Power, and the Total RMS Power. Figure 8. shows all the information that was obtained looking at the amplitude statistics. Figure 9. shows the frequency of the sampled area, which shows that the area that was sampled does not contain the sound of the tones.

After each of the recordings were completed, they were transferred to the computer one at a time. After transferring, the brand, the model, and the serial number of each recorder was recorded for the results phase. The format for each recording was recorded for the results, to ensure the results of the WAV PCM files were not mistaken with another format. Looking at the number of samples contained within the first silence among all twelve recorders you can see a variation.

Looking at the information in the samples area of Figure 10. the variation can be seen. A similarity can be seen between the model numbers that are close, but that’s just for the first silence in each of these recordings. Using the same recording from the Olympus DM-520, the samples for the second are totaled at 25953, with the beginning starting at 494580 and ending at 520533. Comparing the second silence sampling area to the first sampling area there is less than one thousand samples difference. At this point we can see that this Olympus DM-520 recorder has a similar pattern for their number of samples per the first and second area of silence for this recording.

Now to look at the third silence for this recording. Using the same Olympus DM-520 recording, the third silence number of samples is very close to the number of samples contained in the first silence. The number of samples between the first and the third are only five samples difference. For the third silence the total number of samples was 26947, the number of samples for this area began at 741000 and then ended at 767947. While the beginning and end numbers for the samples are not very close however the total number of samples among all three silences is similar being that are less than one thousand samples in difference.

Looking at the samples for each break, the total number of samples per break was used to calculate the mean and the standard deviation of each recording. The mean and the standard deviation can be seen in the excel spreadsheet shown in Figure 11.

Samples											
Recorder		Format	Break #1			Break #2			Break #3		
Brand	Model	WAV PCM/ MP3/WMA	Begin	End	Length	Begin	End	Length	Begin	End	Length
Olympus	DM-520	WMA	247140	274082	26942	494580	520533	25953	741000	767947	26947
Olympus	DM-620	WAV PCM	460274	495650	35376	936652	974200	37548	1415200	1450579	35379
Olympus	WS-550M	MP3	460000	470000	10000	914080	929416	15336	1373000	1383000	10000
Olympus	WS-560M	MP3	460000	470000	10000	914061	929354	15293	1373000	1383000	10000
Olympus	WS-700M	WAV PCM	442200	493955	51755	935072	987130	52058	1427881	1481726	53845
Olympus	WS-700M	WAV PCM	442579	496432	53853	937467	989361	51894	1430300	1484200	53900
Olympus	WS-750M	WAV PCM	450000	485000	35000	935113	988918	53805	1440000	1475000	35000
Olympus	WS-760M	WAV PCM	450000	485000	35000	934812	988650	53838	1440000	1475000	35000
Olympus	WS-802	WAV PCM	470000	510000	40000	958100	1011825	53725	1460000	1500000	40000
Olympus	WS-822	WAV PCM	470000	515000	45000	961200	1017061	55861	1465000	1505000	40000
Olympus	WS-823	WAV PCM	475000	515000	40000	965000	1020886	55886	1466000	1512000	46000
Philips	Voice Tracer	WAV PCM	465549	597150	131601	1039143	1170716	131573	1612650	1744191	131541

Figure10.: Excel Spreadsheet showing the samples for each break.

Number of Samples per Break							
Format	**Recorder Make/Model**	**Serial Number**	**Break 1**	**Break 2**	**Break 3**	**Mean**	**Standard Deviation**
WAV PCM	Olympus DM-620	100115567	35376	37548	35379	36101	1253.14
	Olympus WS-700M	100124078	51755	52058	53845	52552.67	1129.40
	Olympus WS-700M	100126397	53853	51894	53900	53215.67	1144.84
	Olympus WS-750M	200104369	35000	53805	35000	41268.33	10857.07
	Olympus WS-760M	200110592	35000	53838	35000	41279.33	10876.12
	Olympus WS-802	100137893	40000	53725	40000	44575	7924.13
	Olympus WS-822	100169832	45000	55861	40000	46953.67	8108.97
	Olympus WS-823	100258938	40000	55886	46000	47295.33	8021.82
	Philips Voice Tracer	LFH0882	131601	131573	131541	131571.67	30.02
MP3	Olympus WS-550M	200137081	10000	15336	10000	11778.67	3080.74
	Olympus WS-560M	200126197	10000	15293	10000	11764.33	3055.91
WMA	Olympus DM-520	100104915	26942	25953	26947	26614	572.45

Figure 11:. Excel Spreadsheet showing the mean and standard deviation from total samples of each break.

After noticing the similarities amongst the number of samples just from the Olympus DM-520 a more in depth look at each of the recordings was needed. Not all the recorders had the same closeness in the number of samples for each silence as the Olympus DM-520 does. Looking at the frequency analysis for each of the recordings, it was clear that during the areas of silence there was just the background noise from the room in which the testing was performed. The amplitude statistics of each recording gave us the RMS power information for the left and the right of each recording.

After the information had been put into an excel spreadsheet, MATLAB was then used to run a script to plot the waveform and the energy plots for each of the twelve recordings. Looking at the plots, plot 1 and plot 3 show the same output signal, the amplitude looks alike, however the energy in the right channel looks different.

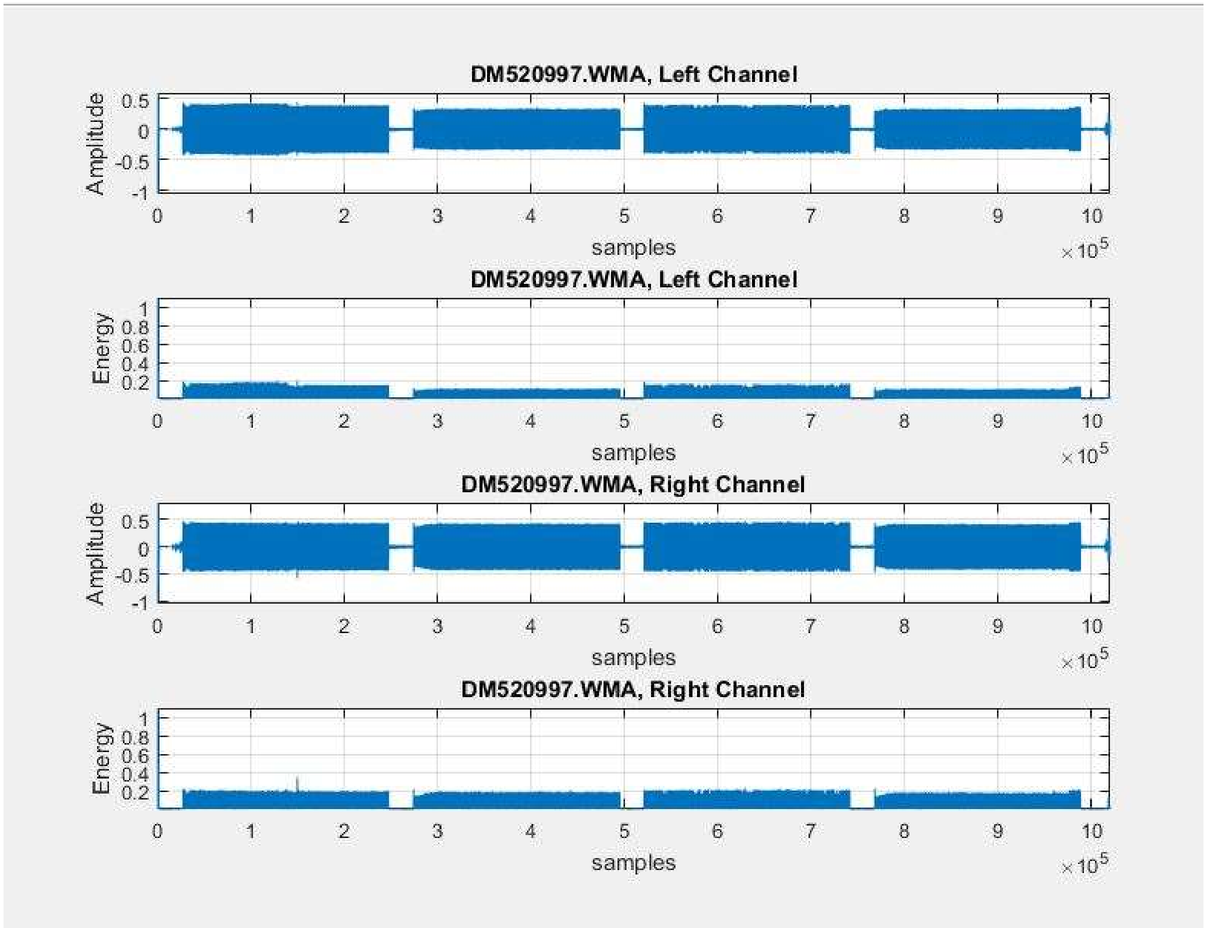


Figure 12.: Olympus DM-520 MATLAB waveform and energy plot for both the left and the right.

During the testing of these recorders, the number of samples per area of silence varied. That is due to a few of the recordings having a zero value at the end of the tones. So, to not have a sample number of zero, the sample size for those files were selected as a smaller area than the rest of the audio files had. This allowed for the number of samples per that area of silence to be something other than zero.

RESULTS

This thesis started with a playback audio file that was generated using Adobe Audition. That audio file was set to have a start of ten-seconds of 1kHz tone, followed by ten-seconds of silence, then ten-seconds of 2kHz tones, then ten-seconds of silence again, then back to ten-seconds of 1kHz tones, then another ten-seconds of silence, and ending with ten-seconds of 2kHz tones. The entire audio file was one minute and twenty seconds long.

Now let's look at the duration of the twelve recorded audio files, the playback audio file was one minute and twenty seconds long. Figure 13. shows the duration of the recorded file from each recorder.

Recorded File Duration			
Brand	Model	Serial Number	Recording Length
Olympus	DM-520	100104915	46 seconds
Olympus	DM-620	100115567	43 seconds
Olympus	WS-550M	200137081	41 seconds
Olympus	WS-560M	200126197	41 seconds
Olympus	WS-700M	100124078	44 seconds
Olympus	WS-700M	100126397	46 seconds
Olympus	WS-750M	200104369	44 seconds
Olympus	WS-760M	200110592	44 seconds
Olympus	WS-802	100137893	45 seconds
Olympus	WS-822	100169832	45 seconds
Olympus	WS-823	100258938	45 seconds
Phillips	Voice Tracer	LFH0882	52 seconds

Figure 13.: Excel Spreadsheet showing the time duration for the recorded file on each recorder.

Just by looking at the duration of each of the recordings you can see that even though the playback audio file had a set time frame of ten-seconds per break of silence, the recorder did not capture that ten-seconds once the recorder entered standby mode.

CHAPTER IV

FUTURE RESEARCH

In this study, the areas of silence to show that the recorder had gone into standby mode showed that the even though the playback audio file had a set ten-seconds of silence the recorder did not record that. The playback audio file was one minute and twenty seconds, after the testing and analysis was completed none of the recorders had a one minute and twenty second recordings. The recordings were less than one minute in duration. Once the recorder has gone into standby mode and essentially paused the recording process the playback audio file was still going which is how the recordings were shorter than the playback audio file. Therefore, the results could show that after the recorder has adapted the background noise of a recording the recorder will remain in standby mode until a different noise level is present before the recording will continue and the recording time itself will remain at the time in which the recorder entered standby mode.

This study was just the beginning of the information that is needed to be explored regarding the voice-activated or automated standby modes. The focus of this study was on the automated standby mode recorders, and WAV PCM files, there was one WMA and two MP3 files that were tested. However, when it comes to the WMA and MP3 files further research is requested, along with the manual standby mode recorders. Testing to determine if there is a possibility that the recorder can show a difference of amplitude among the channels is needed. In this study the 1kHz tones do not have a spike but there is a spike present on the 2kHz tones further research is needed to gain a better understanding of this issue. Testing using broadband noise, real life noises, as well as speech and other noises is requested. There is a need for further research using a different set of computer speakers to determine if the spikes are coming from the speakers or if they are coming from the recorders. This study is just the beginning of the information that is needed to understand the topic of voice-activated artifacts.

BIBLIOGRAPHY

Begault, D. R., Brustad, B. M., & Stanley, A. M. (2005). Tape Analysis and Authentication Using Multi-Track Recorders. 1-7.

Koenig, B. E., & Lacey, D. S. (2009). Forensic Authentication of Digital Audio Recordings. 662-695.

Koenig, B. E., Lacey, D. S., & Killion, S. A. (2007). Forensic Enhancement of Digital Audio Recordings. 352-371.

Maher, R. C. (2009). Audio Forensic Examination. 84-94.

Maher, R. C. (2010). Overview of Audio Forensics. 127-144.

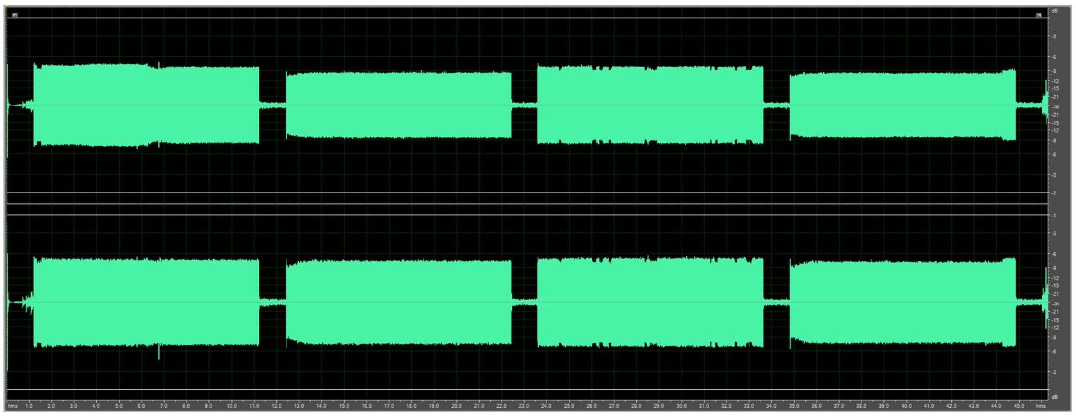
Michalek, M. (2016). Test Audio Recordings and Their Use In Authenticity Examinations. Database of Properties of Digital Audio Recorders and Recordings. *Problems of Forensic Sciences*, 355-369.

Scientific Working Group on Digital Evidence. (2017). SWGDE Best Practices for Digital Audio Authentication. 1-27.

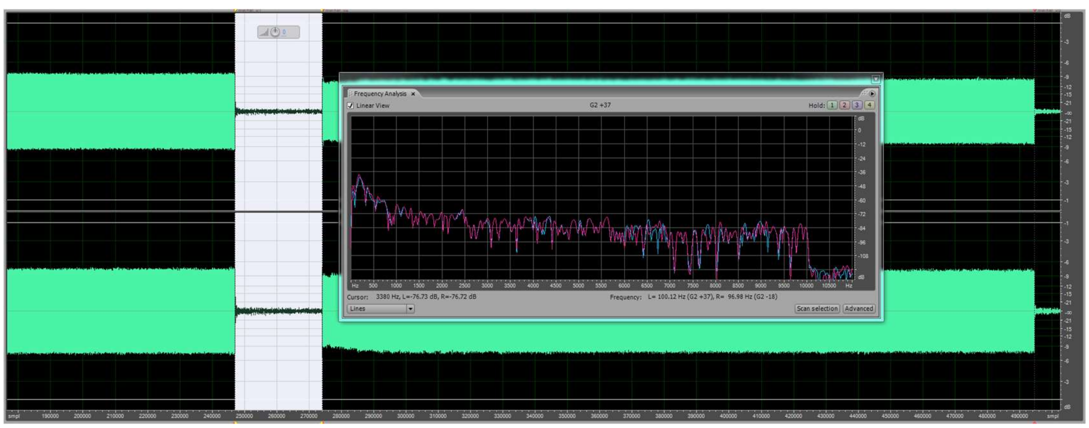
APPENDIX A

OLYMPUS DM-520

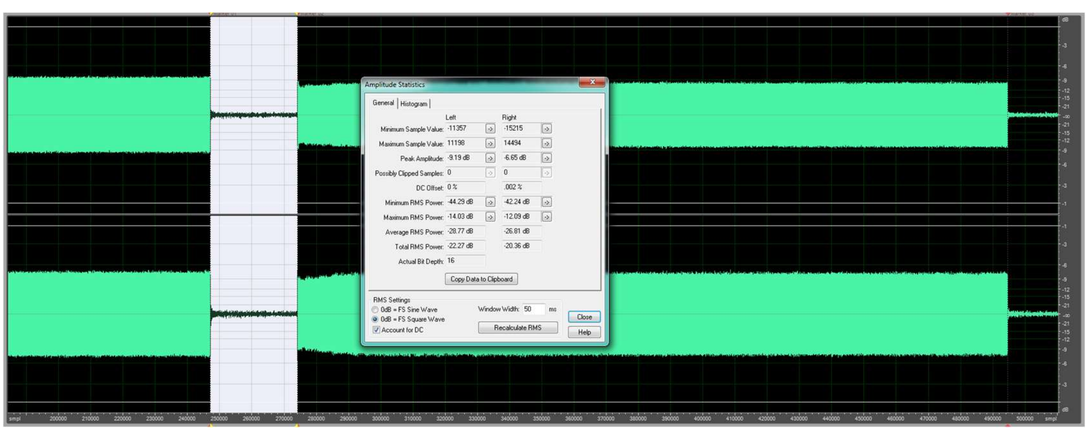
Images of the Olympus DM-520 recording, settings, and MATLAB energy plots.



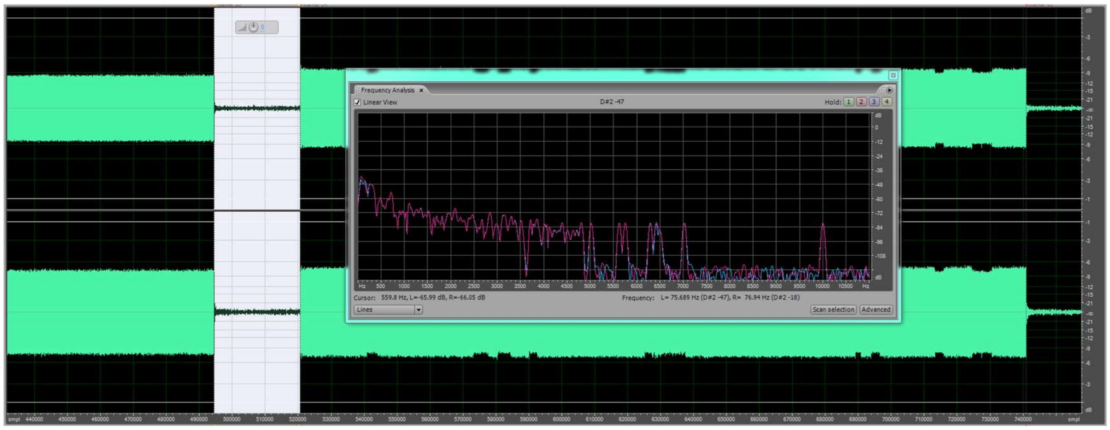
This shows the file that was created when recording the playback audio file.



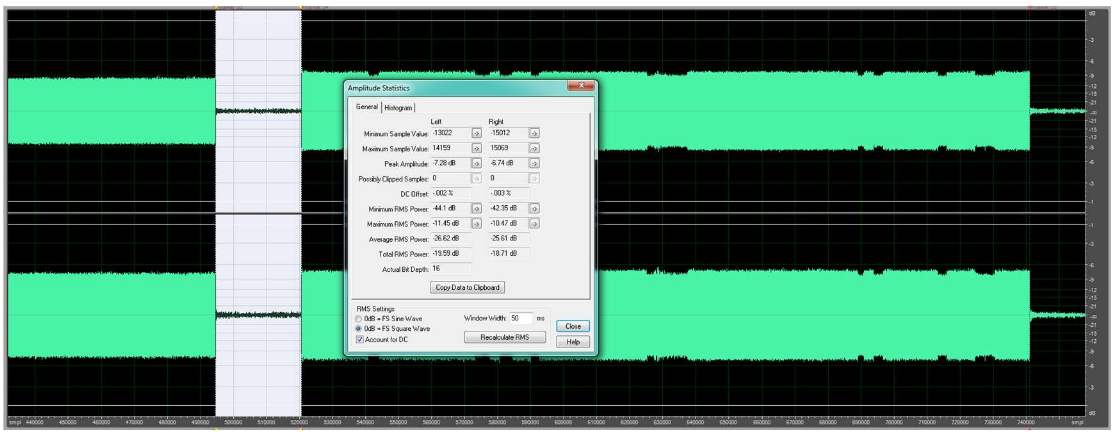
This shows the frequency statistics of the first break.



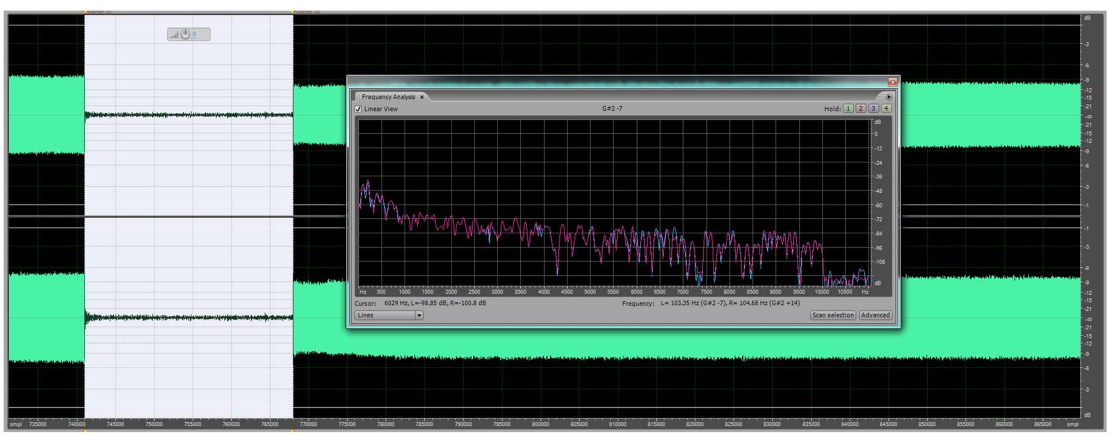
This shows the amplitude statistics of the first break.



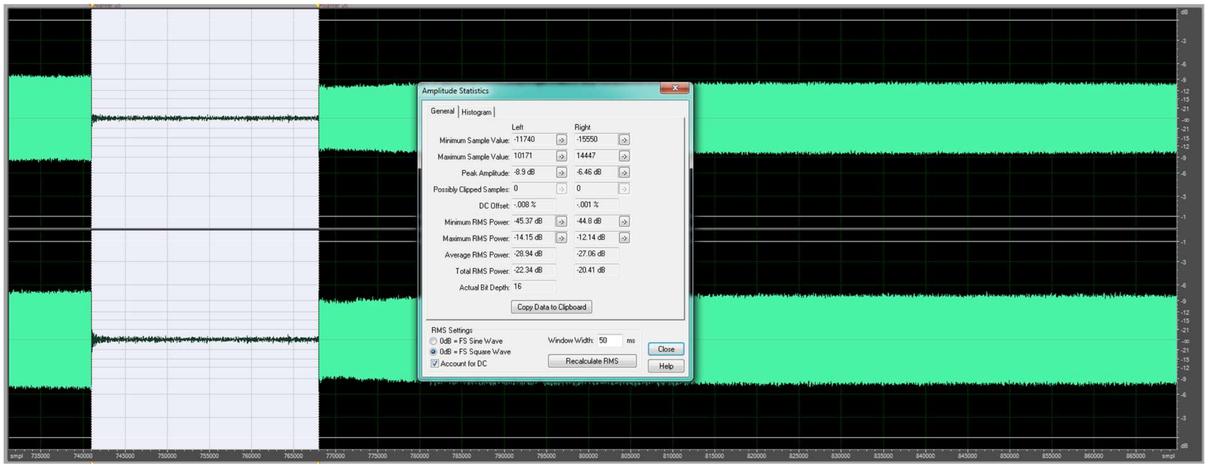
This shows the frequency statistics of the second break.



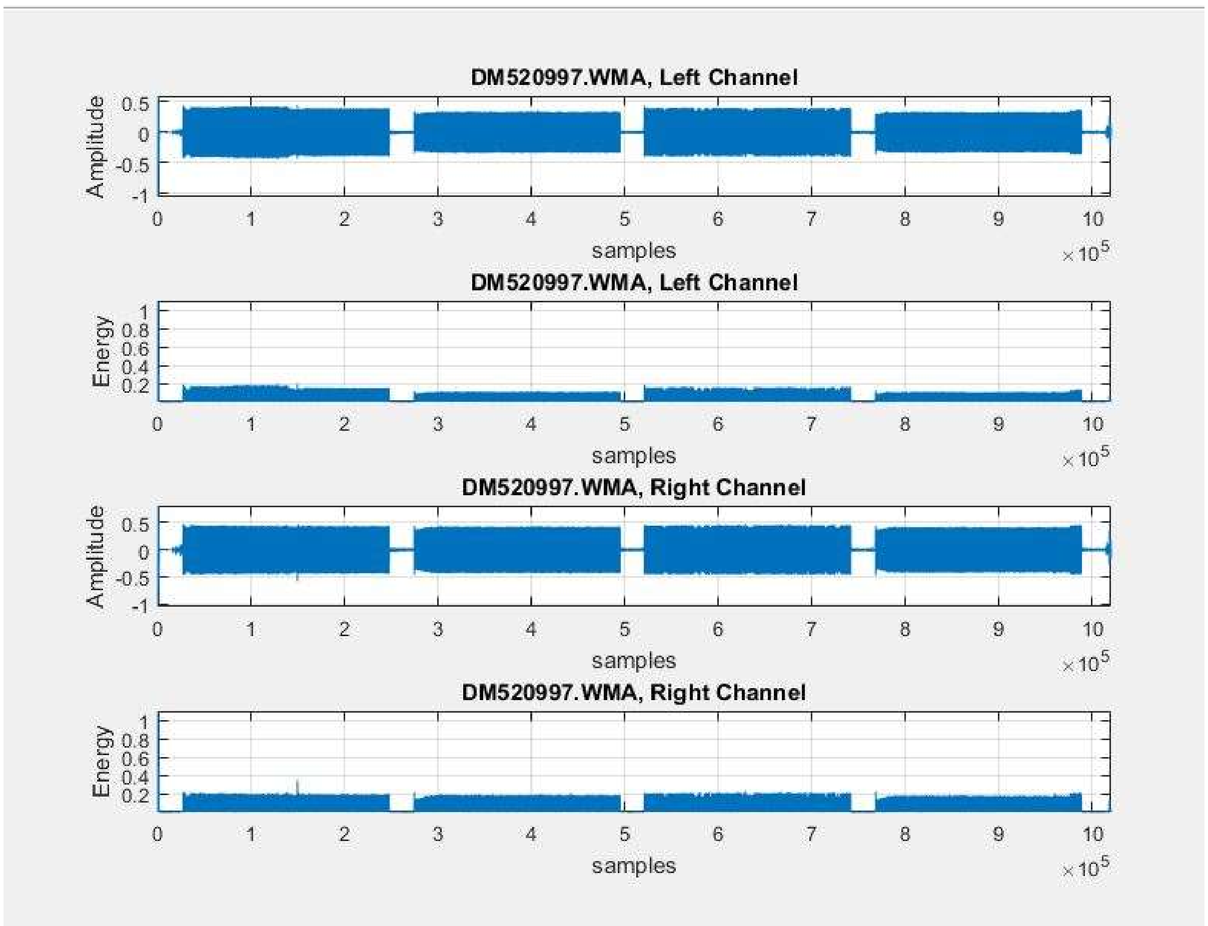
This shows the amplitude statistics of the second break.



This shows the frequency statistics of the third break.



This shows the amplitude statistics of the third break.

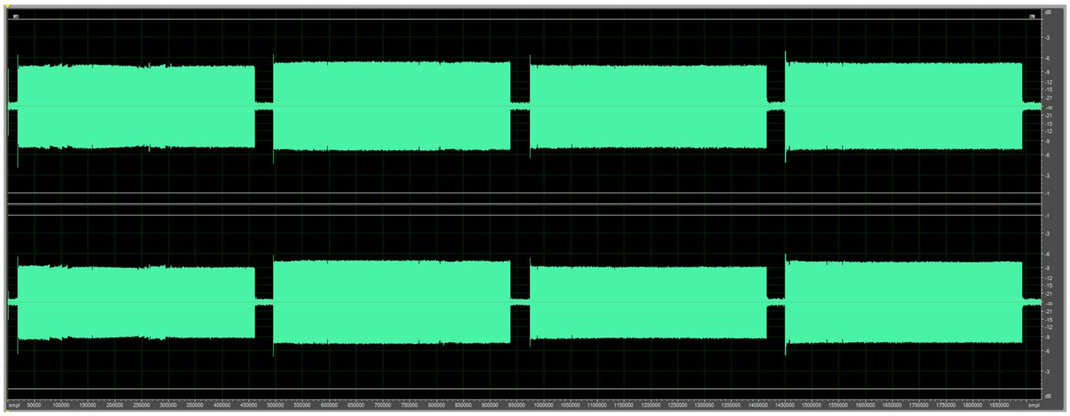


This shows the MATLAB Amplitude and Energy plots.

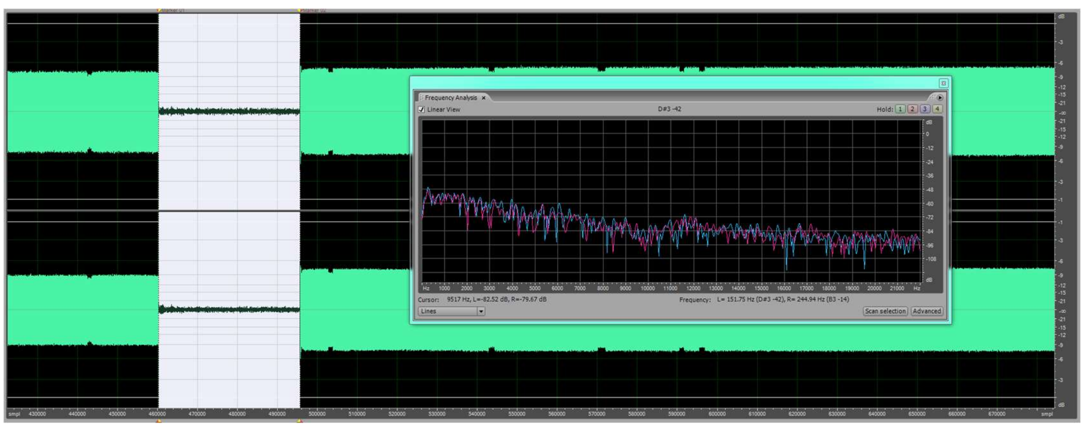
APPENDIX B

OLYMPUS DM-620

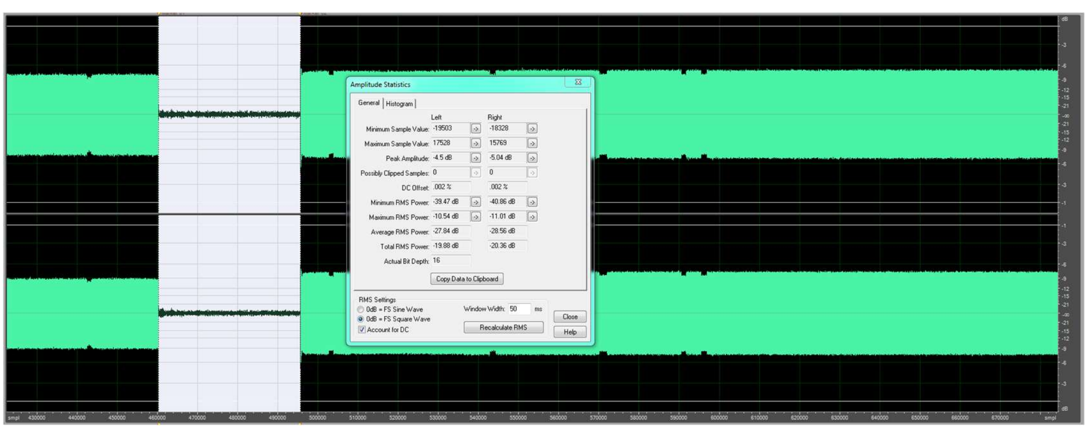
Images of the Olympus DM-620 recording, settings, and MATLAB energy plots.



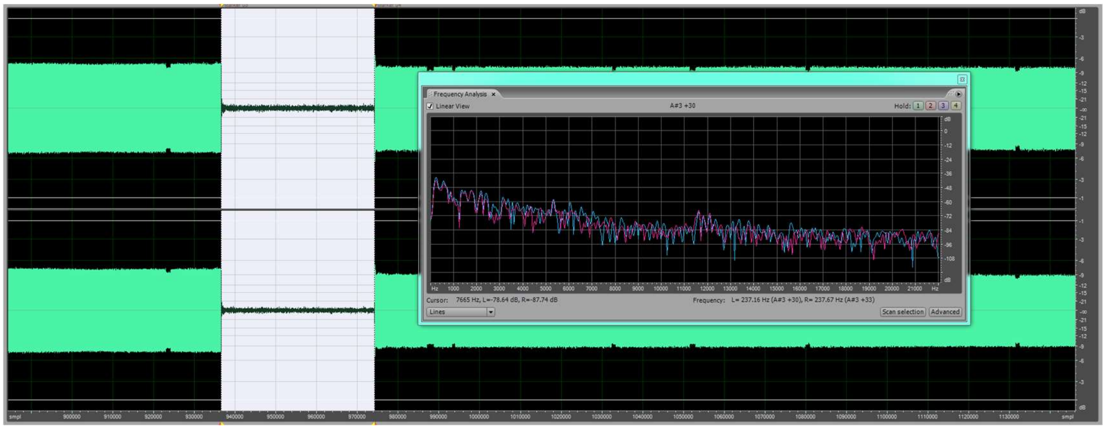
This shows the file that was created when recording the playback audio file.



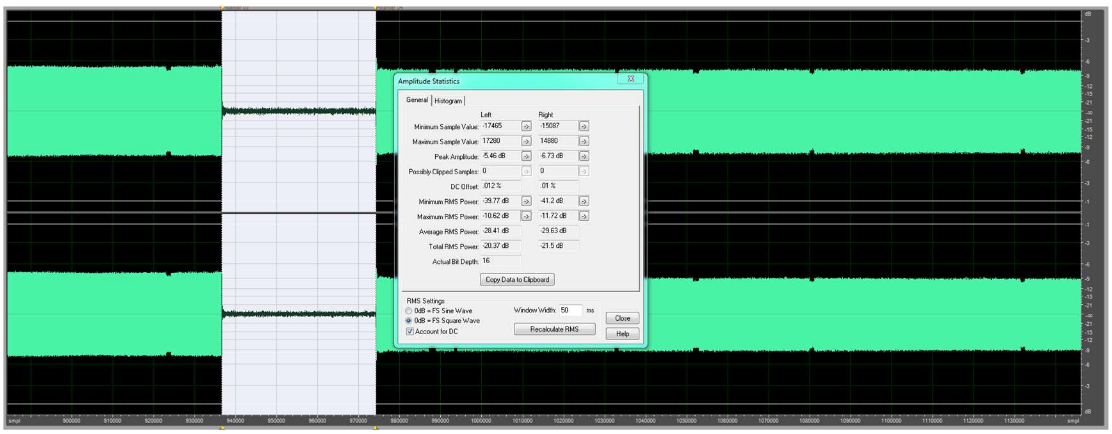
This shows the frequency statistics of the first break.



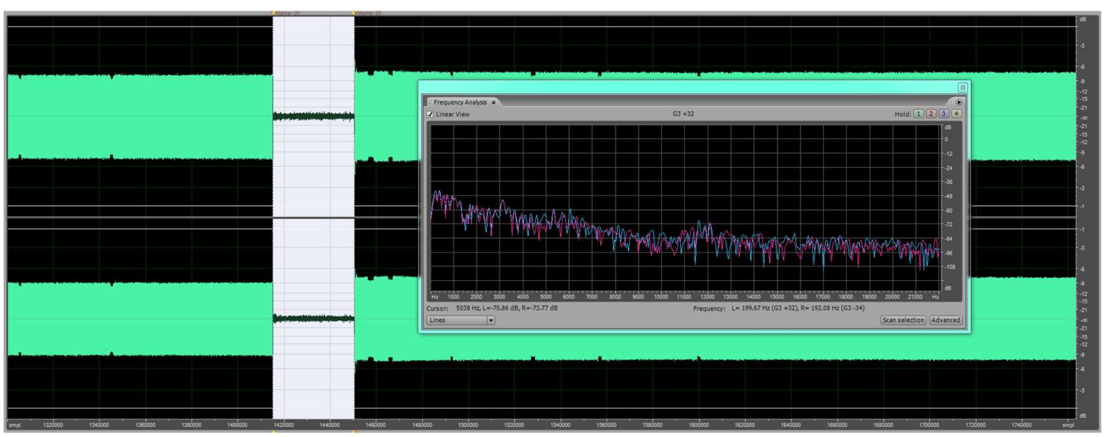
This shows the amplitude statistics of the first break.



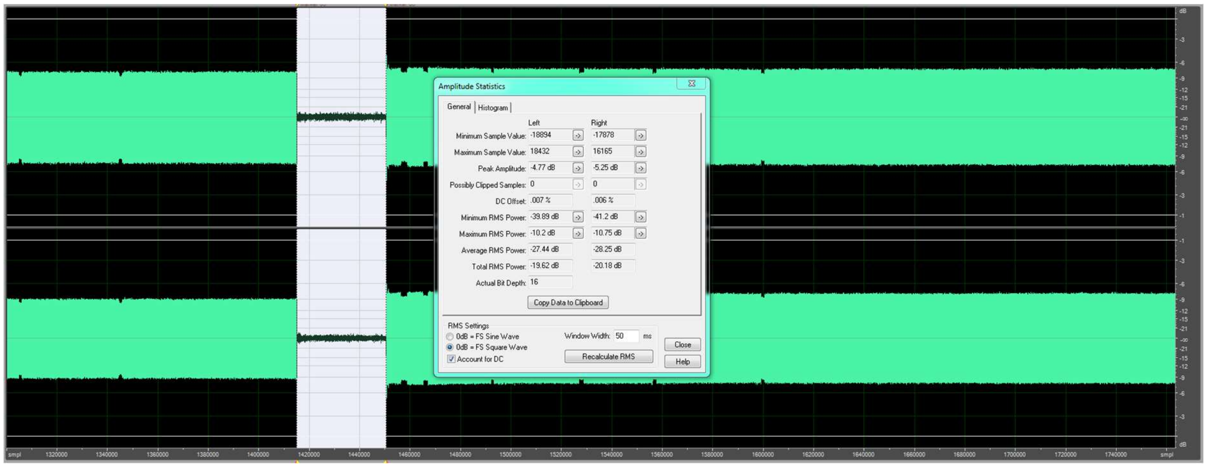
This shows the frequency statistics of the second break.



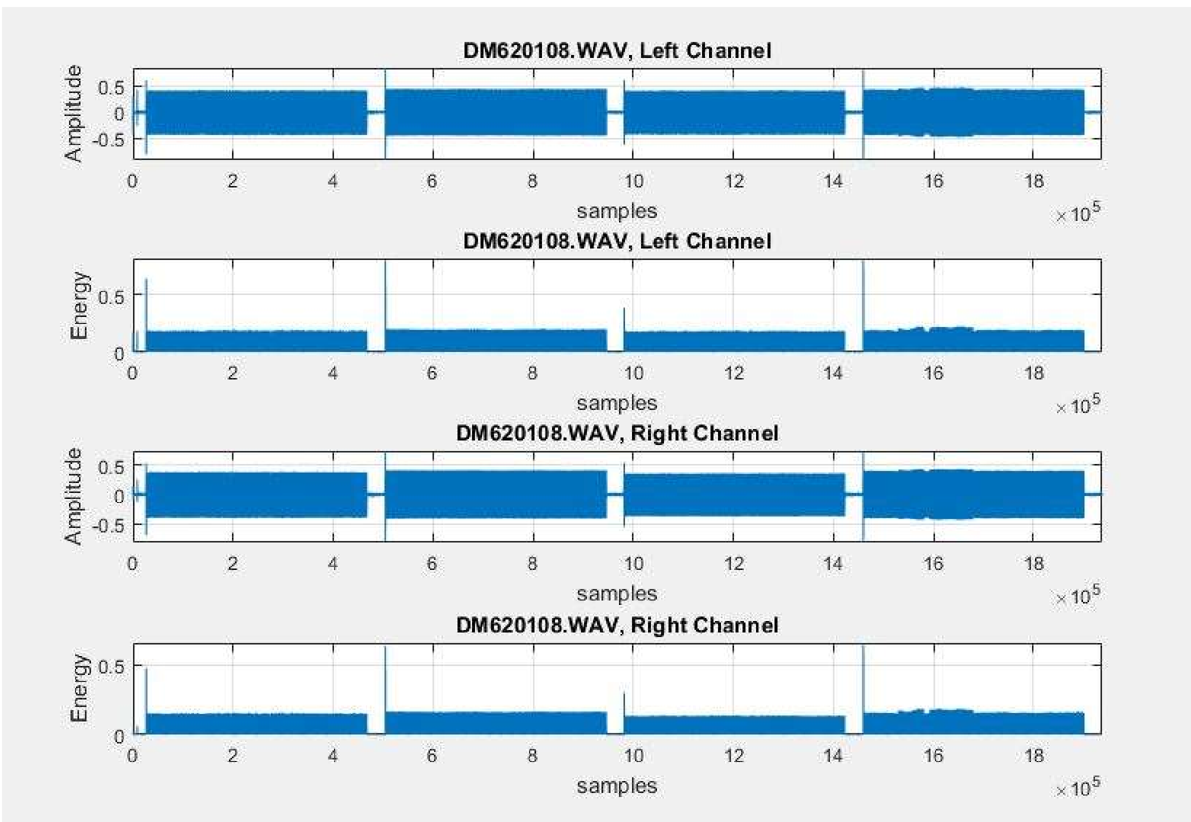
This shows the amplitude statistics of the second break.



This shows the frequency statistics of the third break.



This shows the amplitude statistics of the third break.

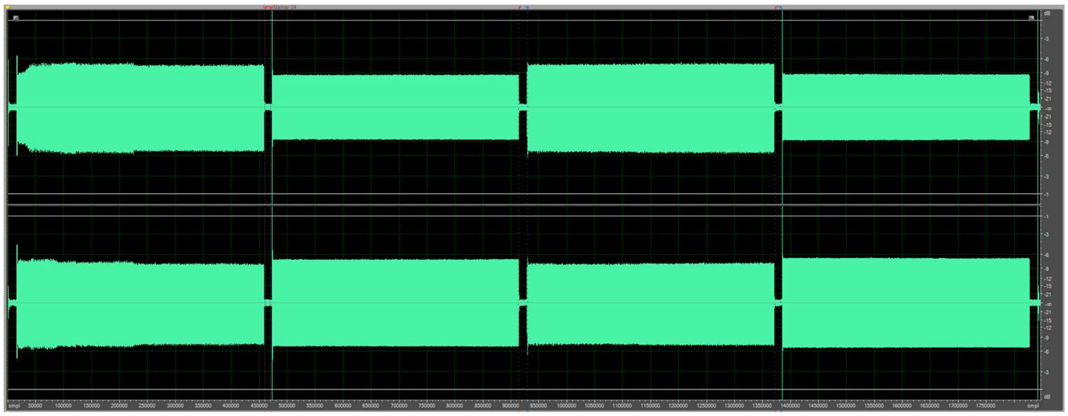


This shows the MATLAB Amplitude and Energy plots.

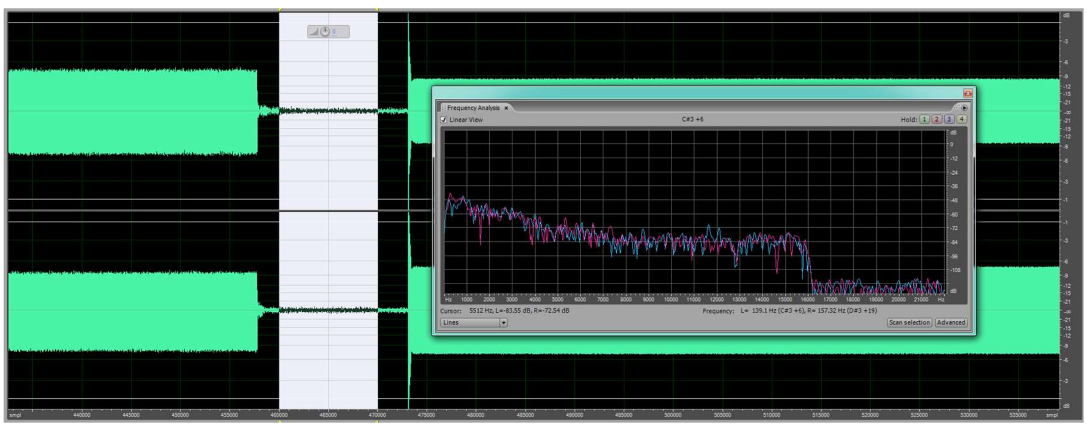
APPENDIX C

OLYMPUS WS-550M

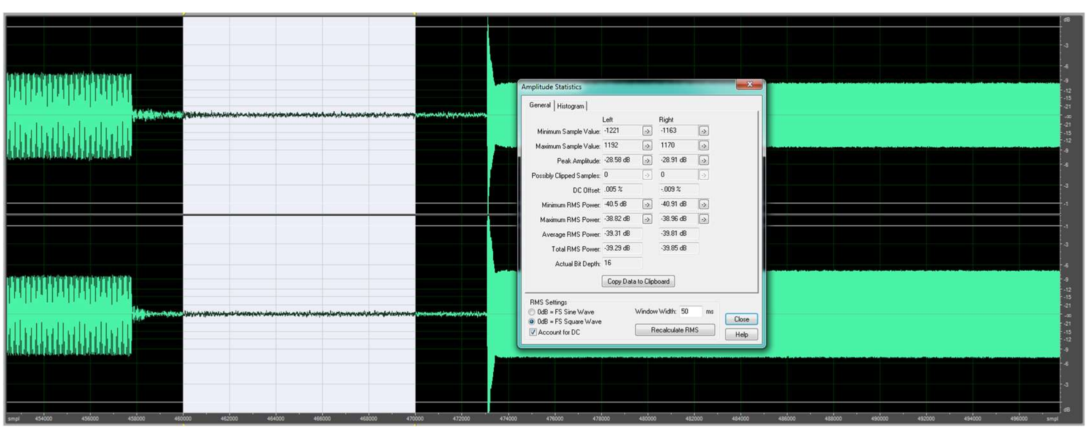
Images of the Olympus WS-550M recording, settings, and MATLAB energy plots.



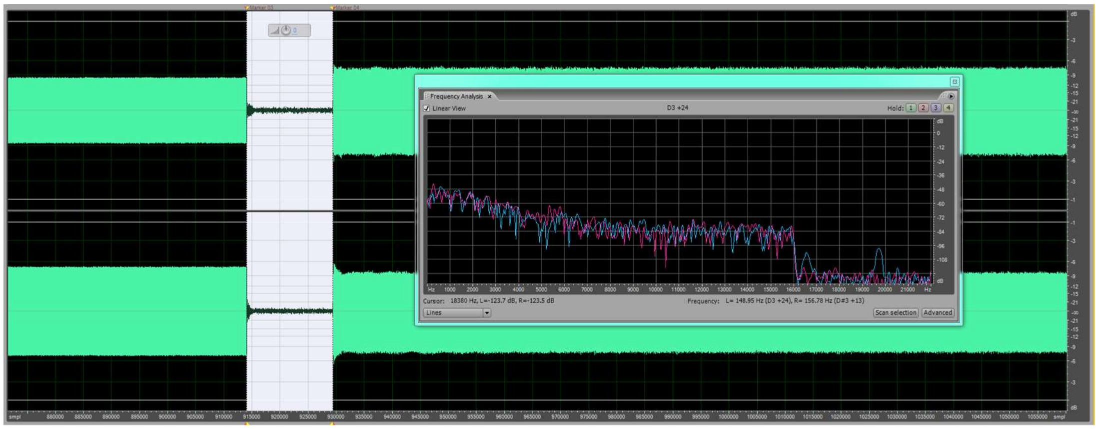
This shows the file that was created when recording the playback audio file.



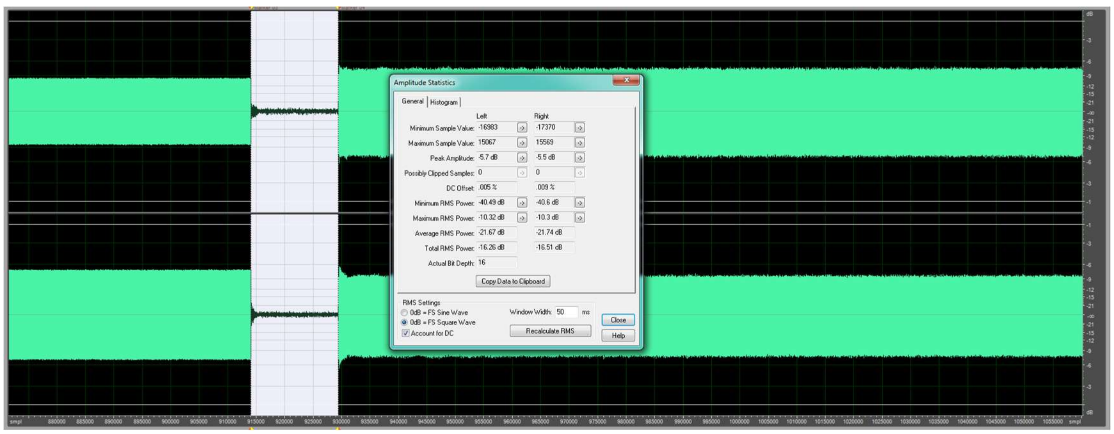
This shows the frequency statistics of the first break.



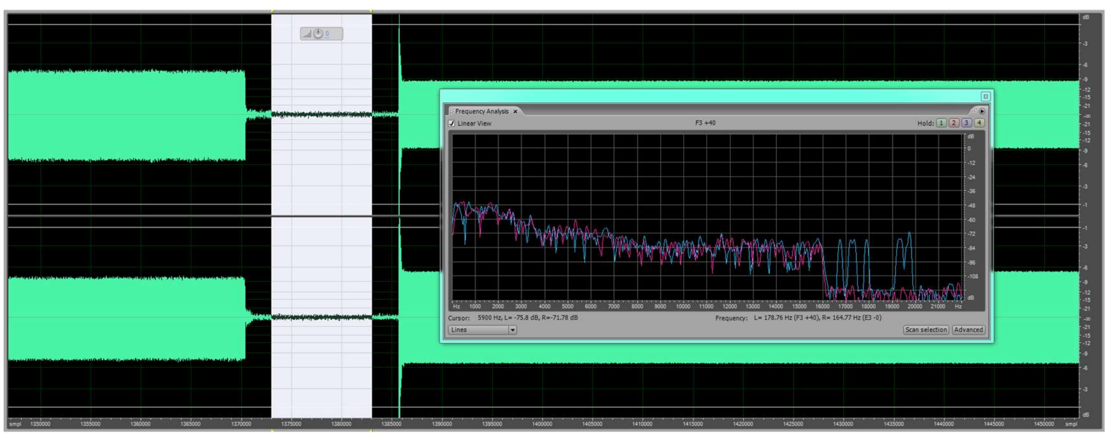
This shows the amplitude statistics of the first break.



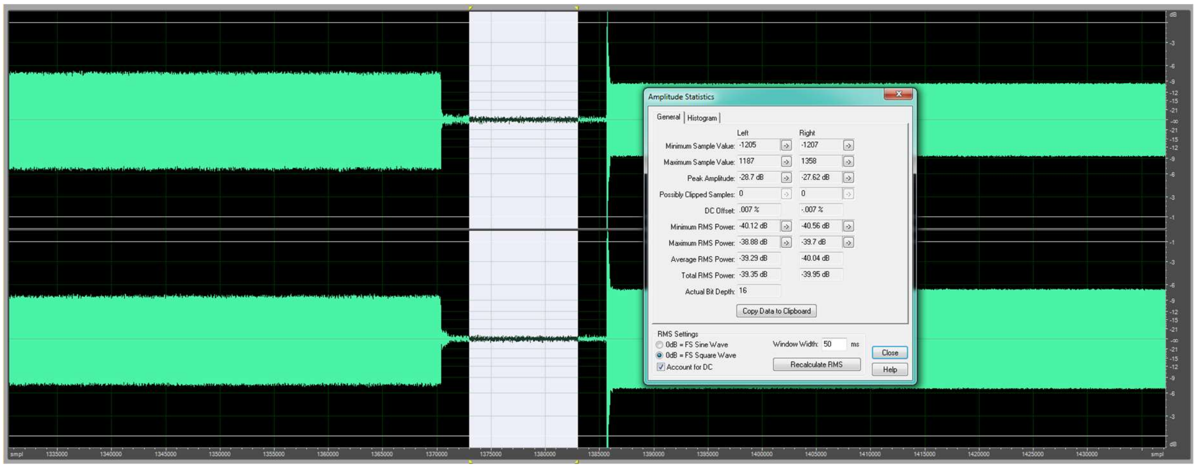
This shows the frequency statistics of the second break.



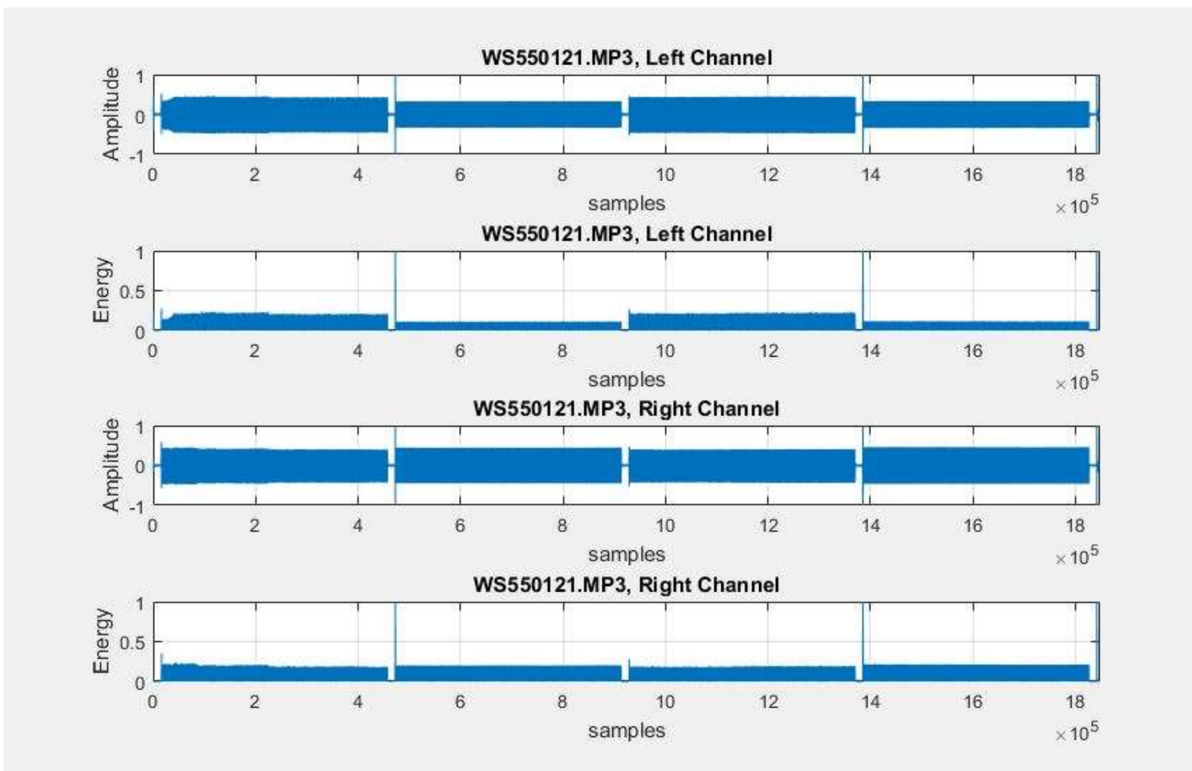
This shows the amplitude statistics of the second break.



This shows the frequency statistics of the third break.



This shows the amplitude statistics of the third break.

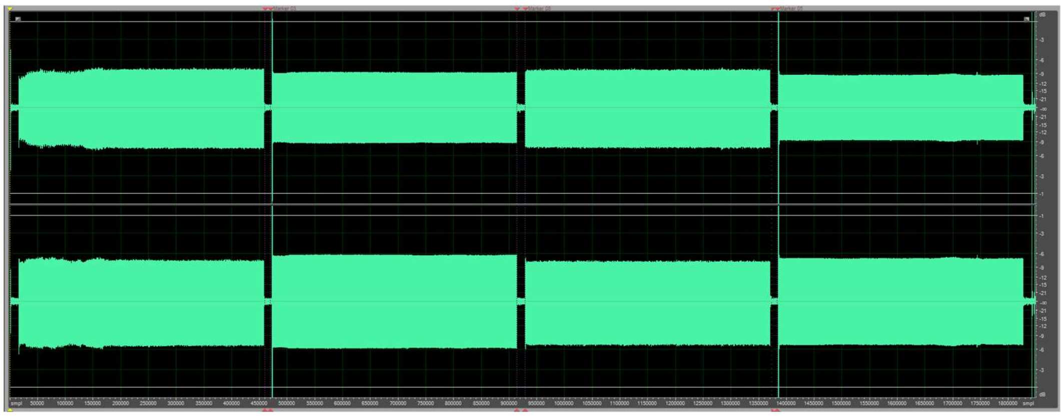


This shows the MATLAB Amplitude and Energy plots.

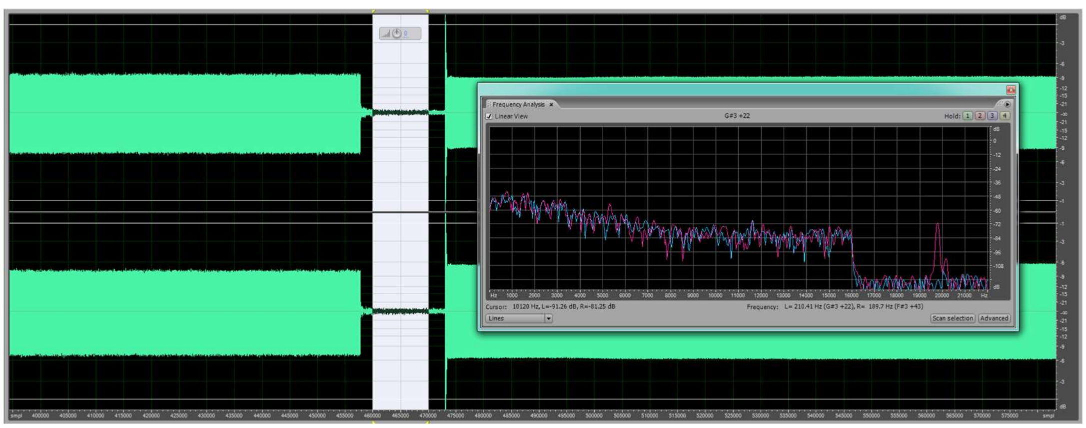
APPENDIX D

OLYMPUS WS-560M

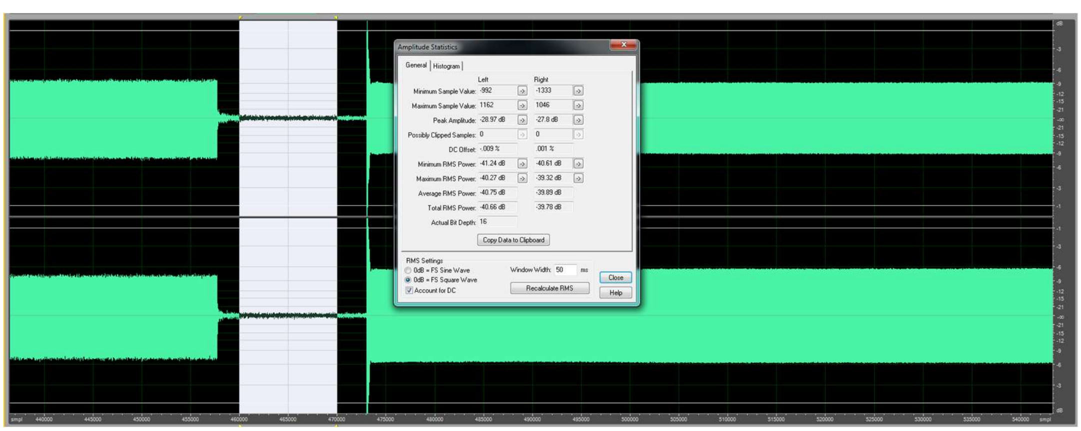
Images of the Olympus WS-560M recording, settings, and MATLAB energy plots.



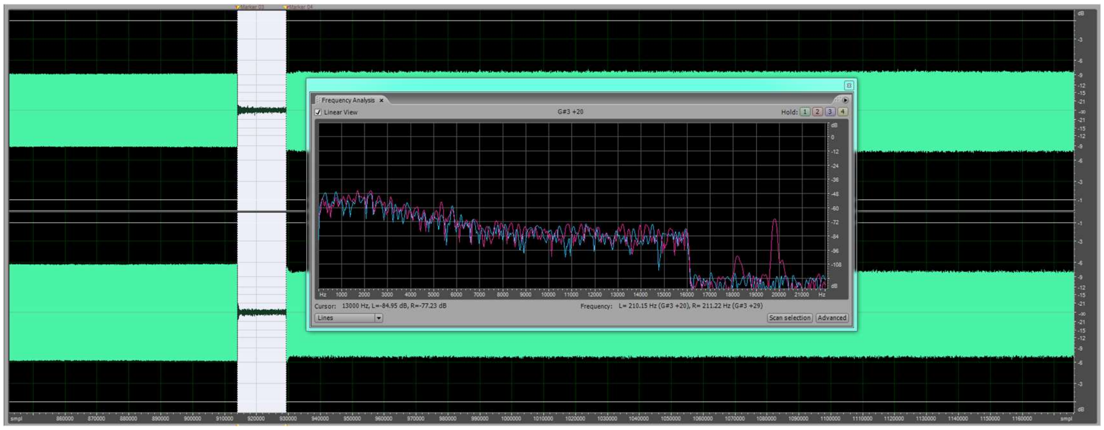
This shows the file that was created when recording the playback audio file.



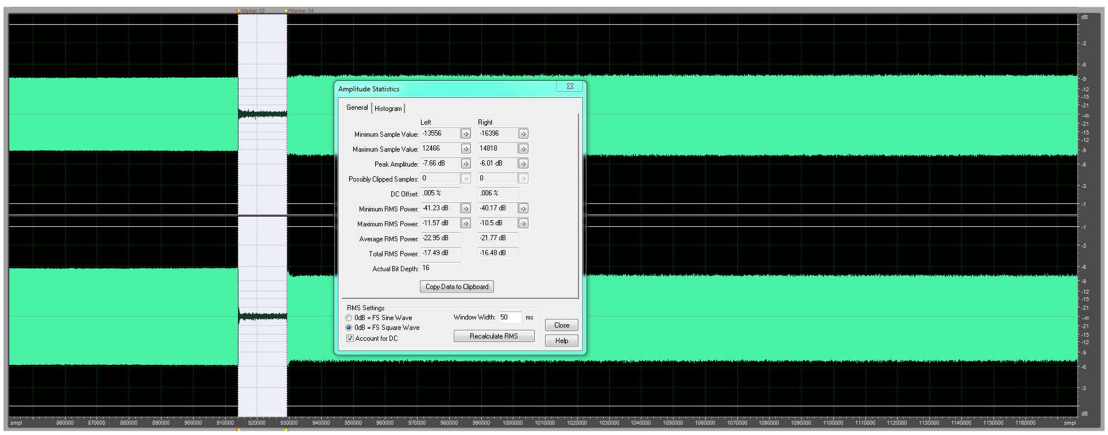
This shows the frequency statistics of the first break.



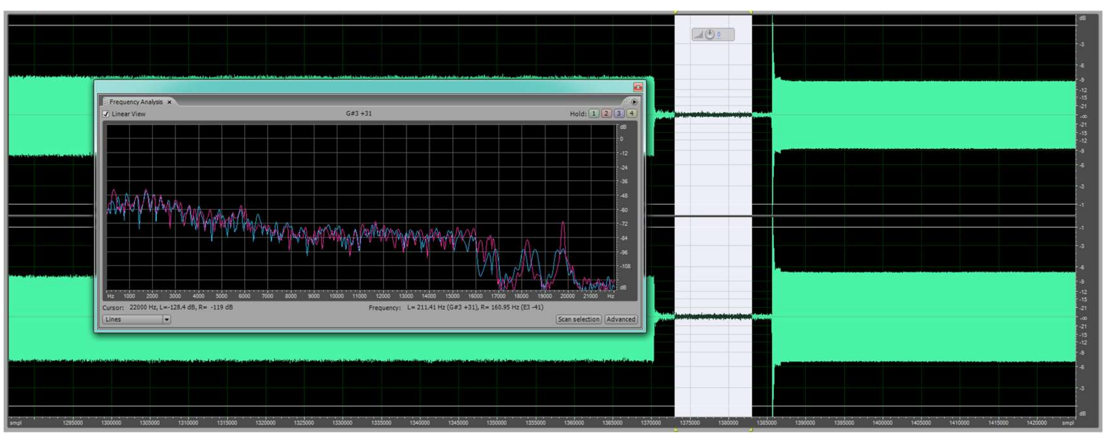
This shows the amplitude statistics of the first break.



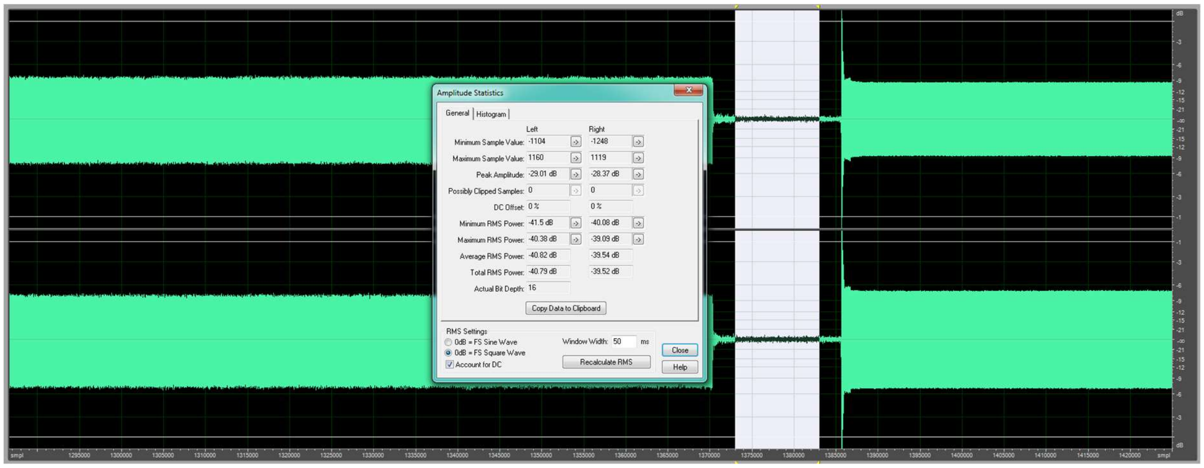
This shows the frequency statistics of the second break.



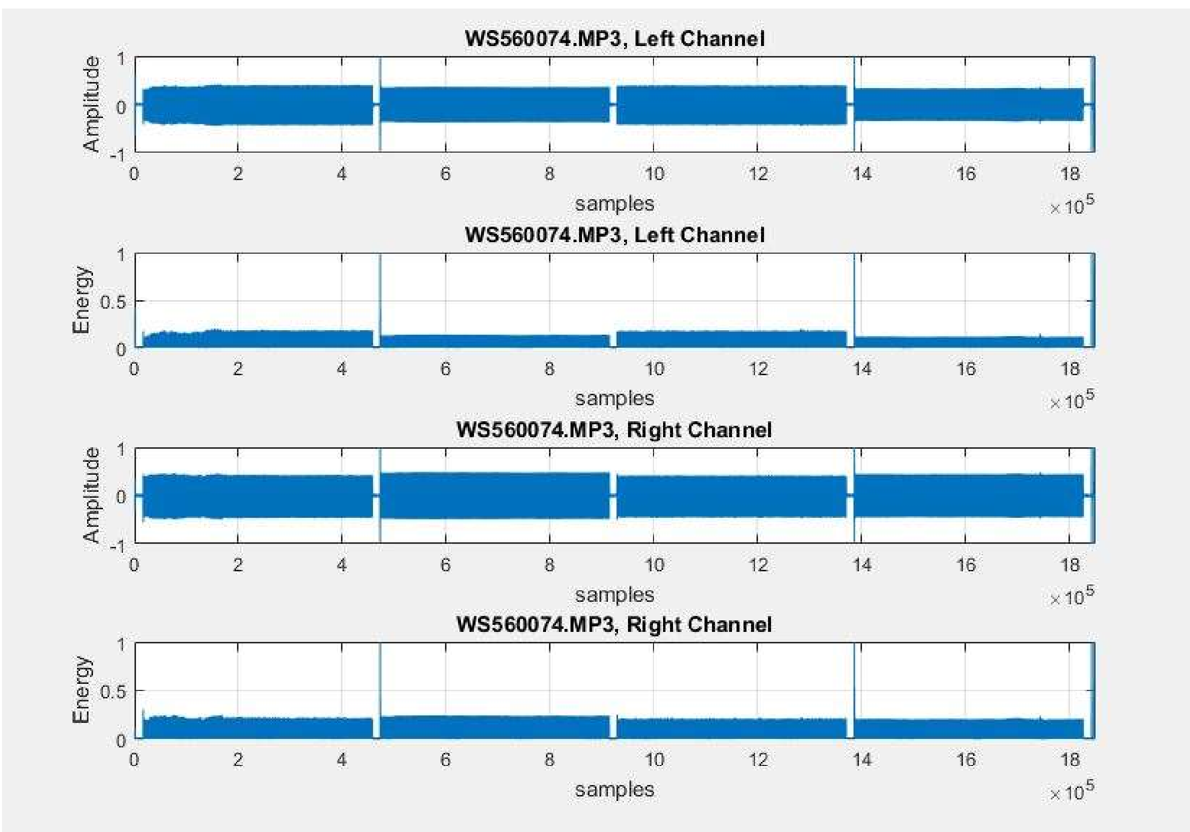
This shows the amplitude statistics of the second break.



This shows the frequency statistics of the third break.



This shows the amplitude statistics of the third break.

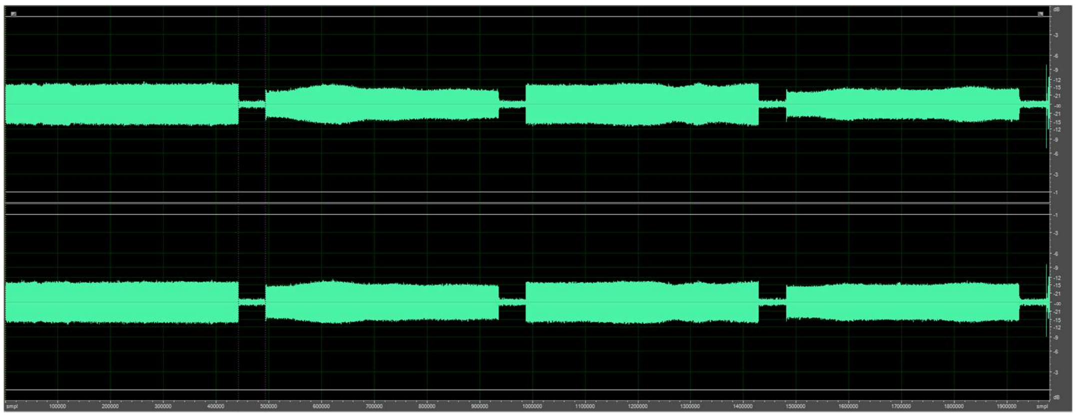


This shows the MATLAB Amplitude and Energy plots.

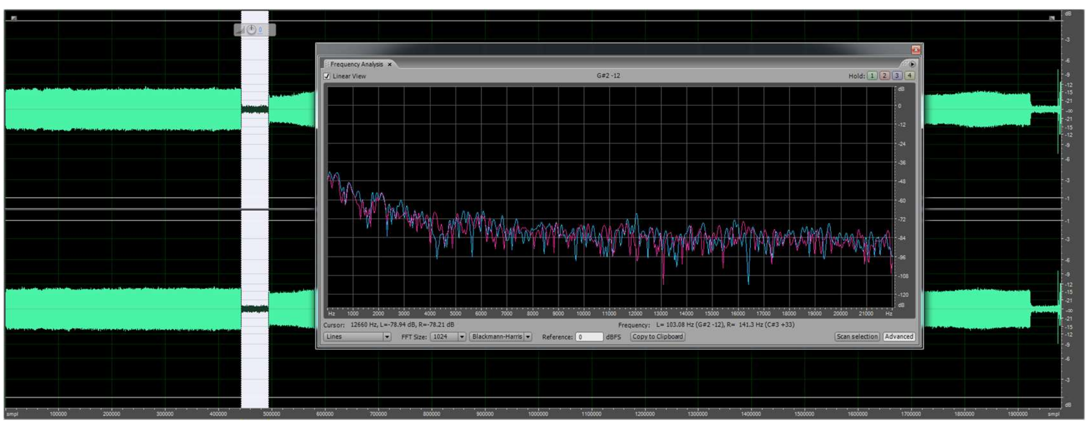
APPENDIX E

OLYMPUS WS-700M

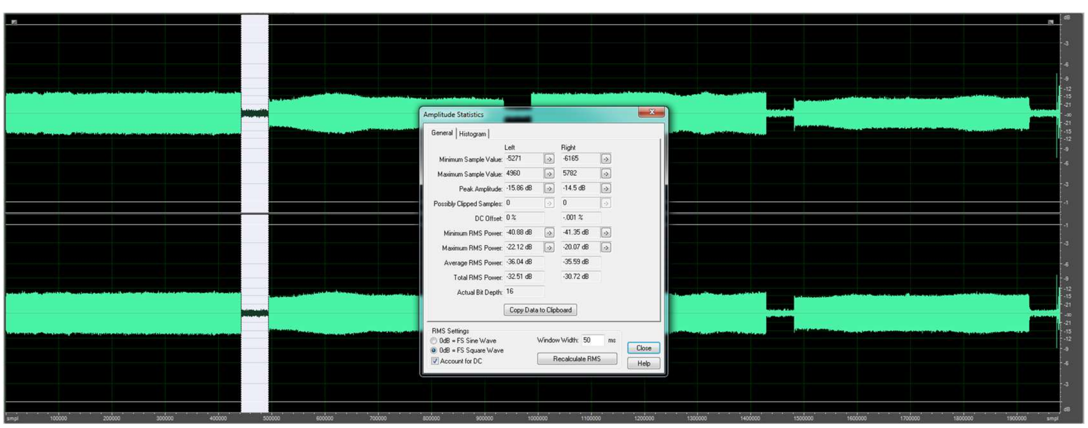
Images of the Olympus WS-700M recording, settings, and MATLAB energy plots.



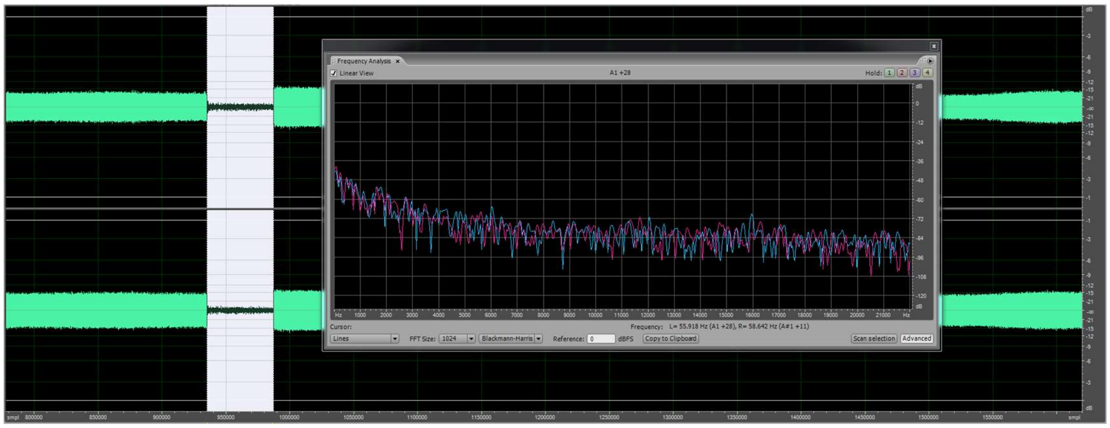
This shows the file that was created when recording the playback audio file.



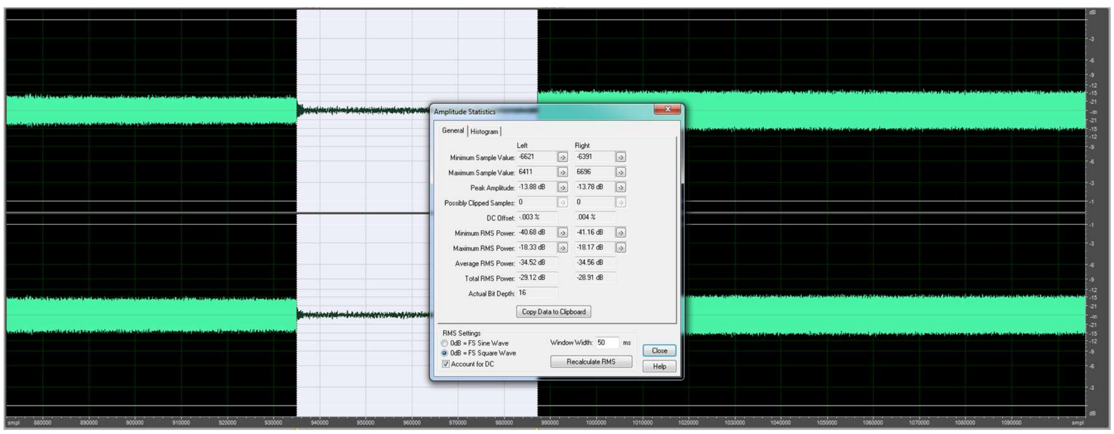
This shows the frequency statistics of the first break.



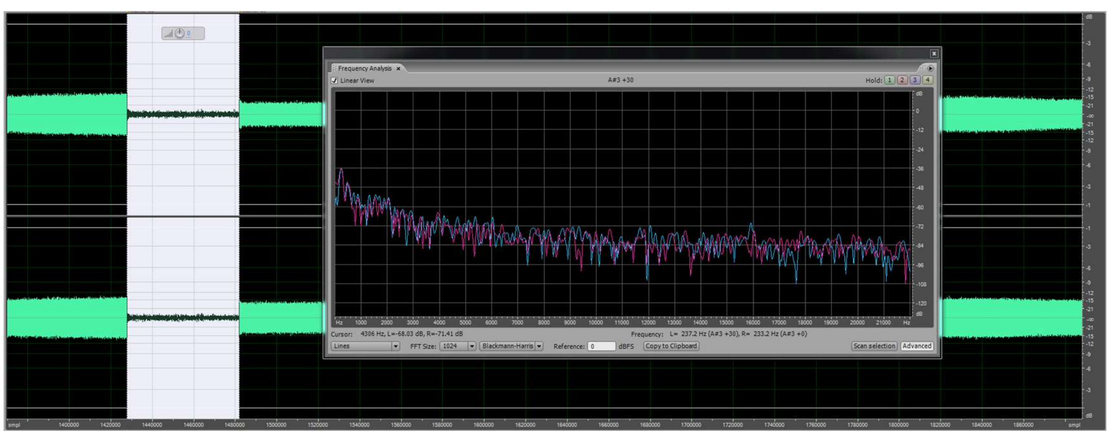
This shows the amplitude statistics of the first break.



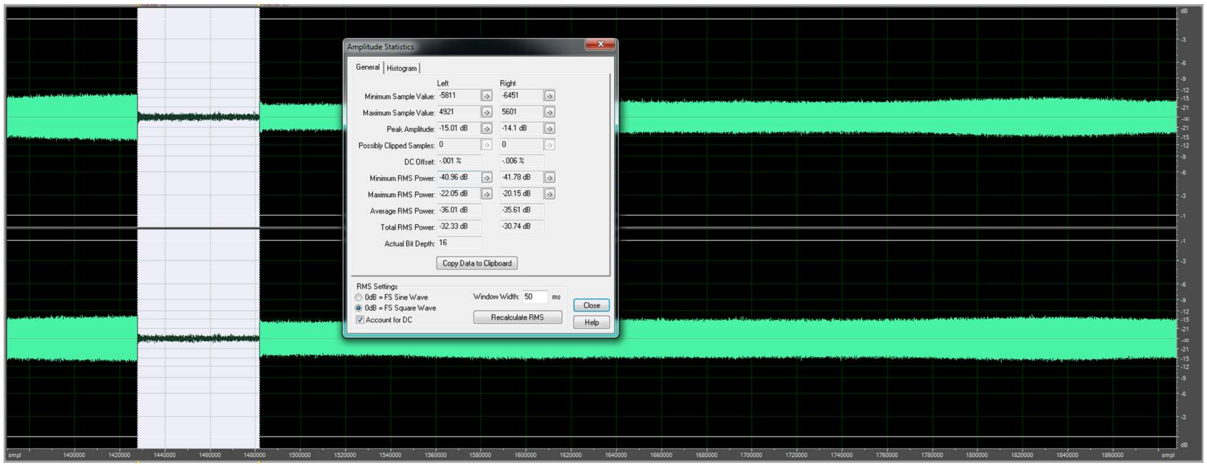
This shows the frequency statistics of the second break.



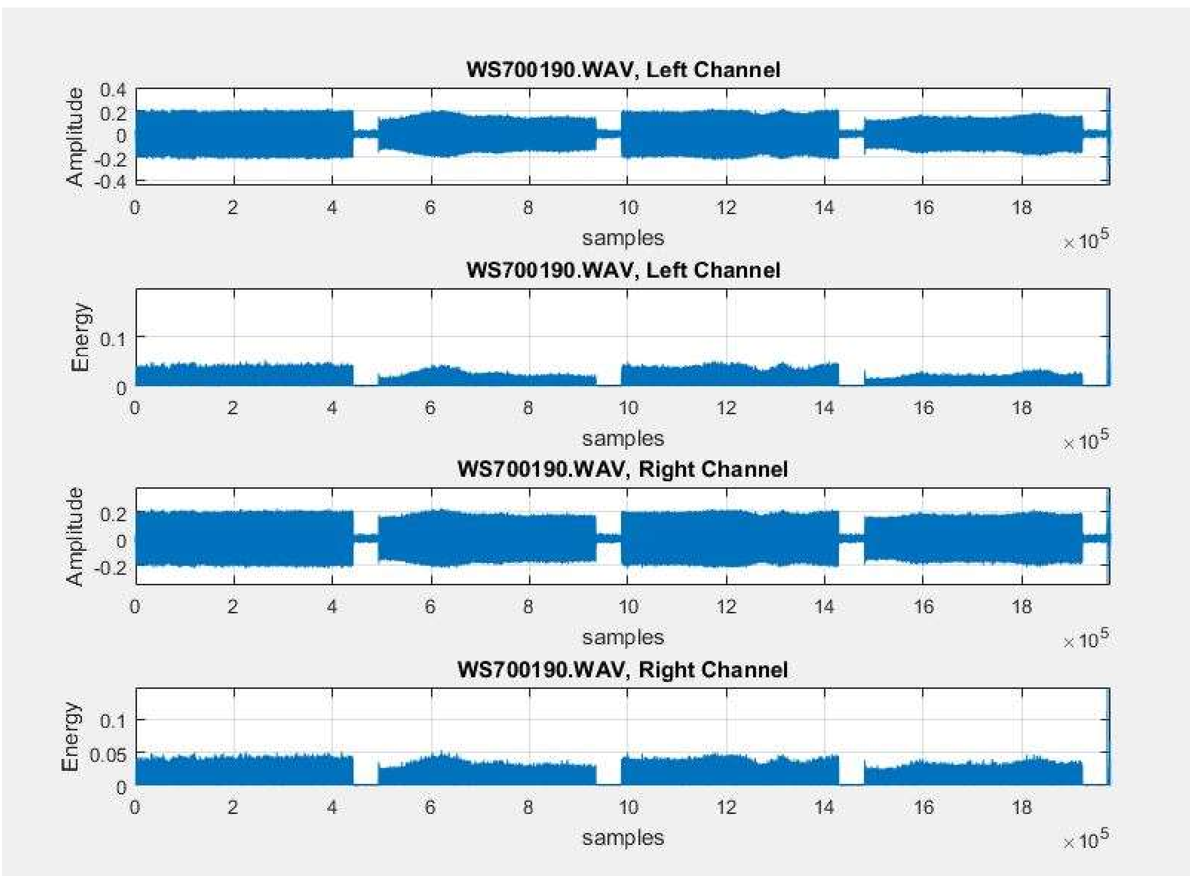
This shows the amplitude statistics of the second break.



This shows the frequency statistics of the third break.



This shows the amplitude statistics of the third break.

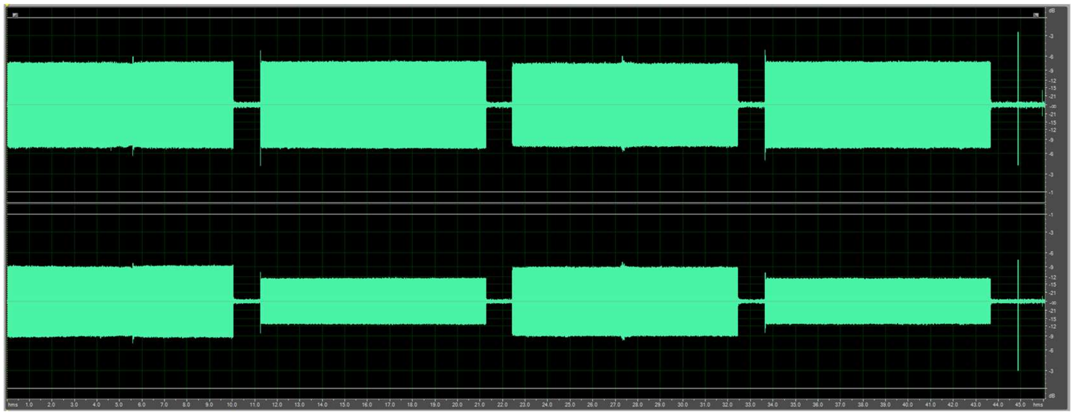


This shows the MATLAB Amplitude and Energy plots.

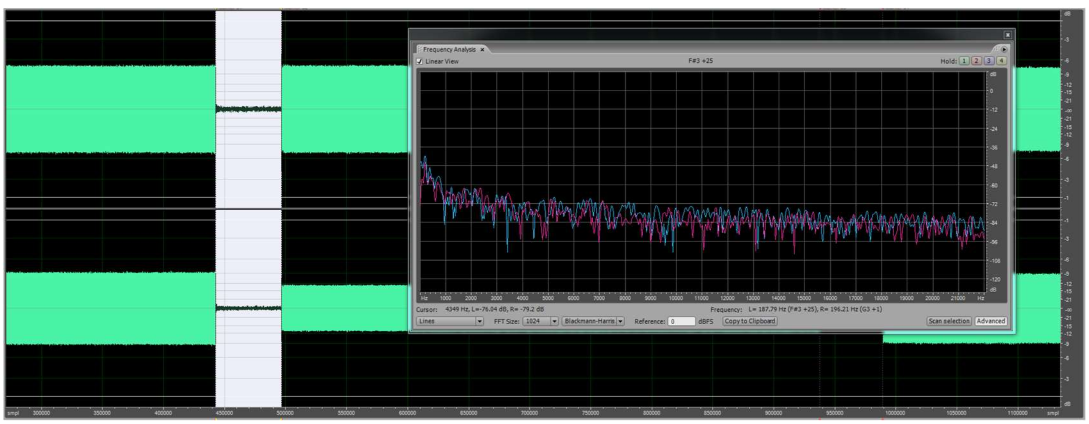
APPENDIX F

OLYMPUS WS-700M

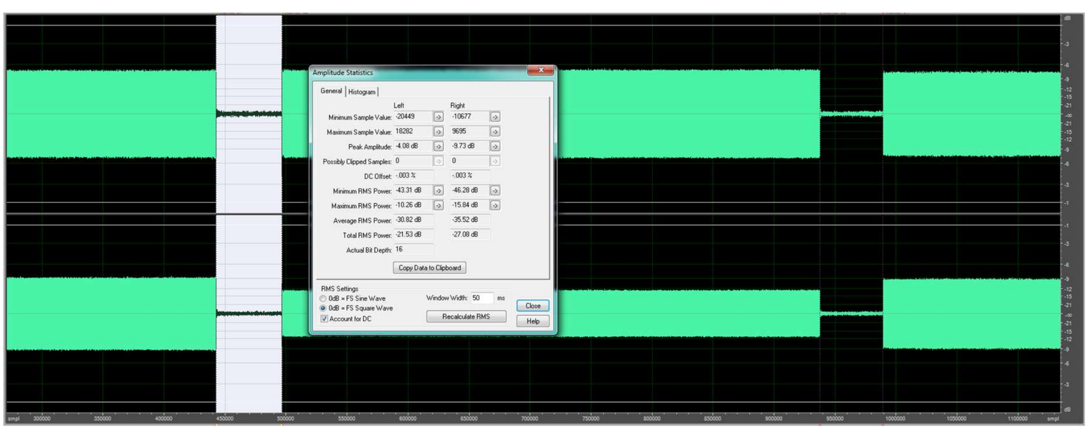
Images of the second Olympus WS-700M recording, settings, and MATLAB energy plots.



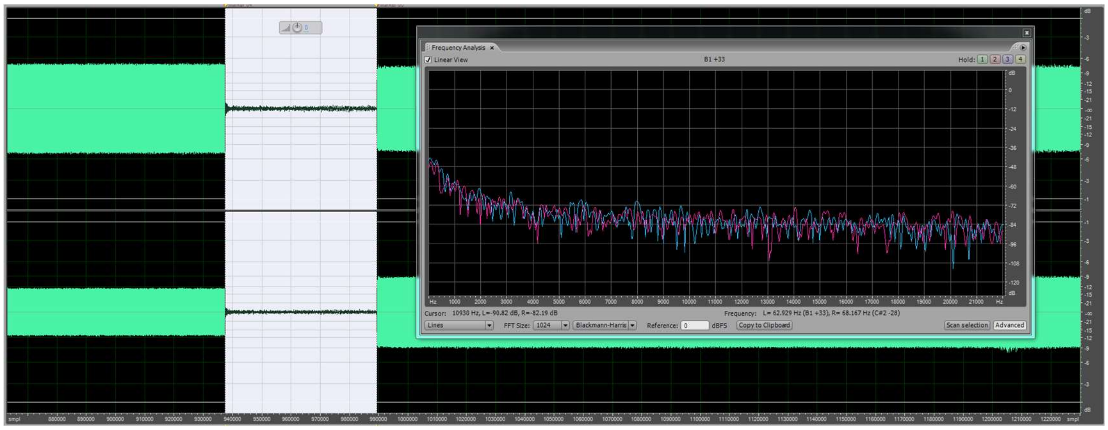
This shows the file that was created when recording the playback audio file.



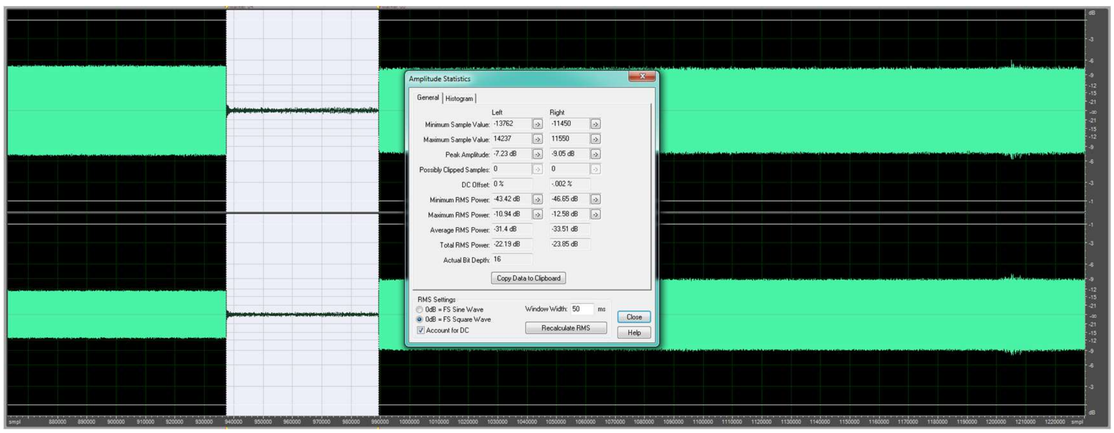
This shows the frequency statistics of the first break.



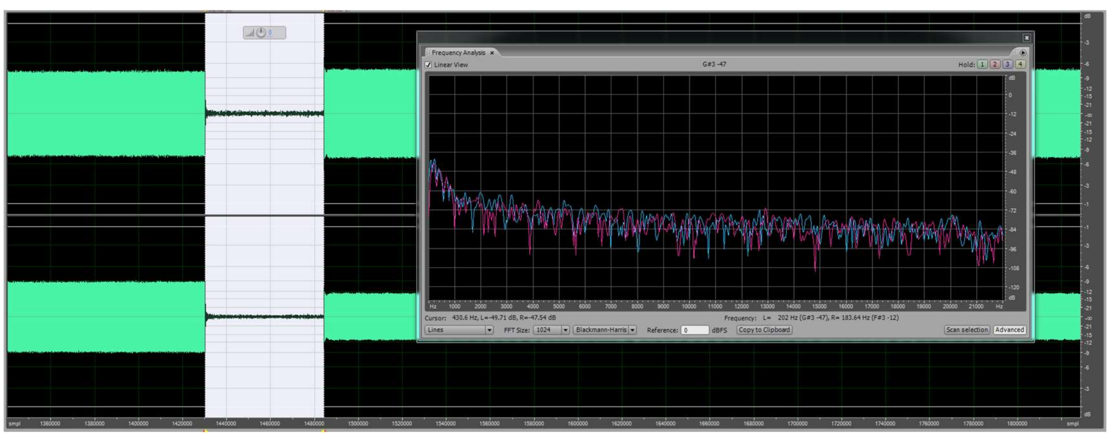
This shows the amplitude statistics of the first break.



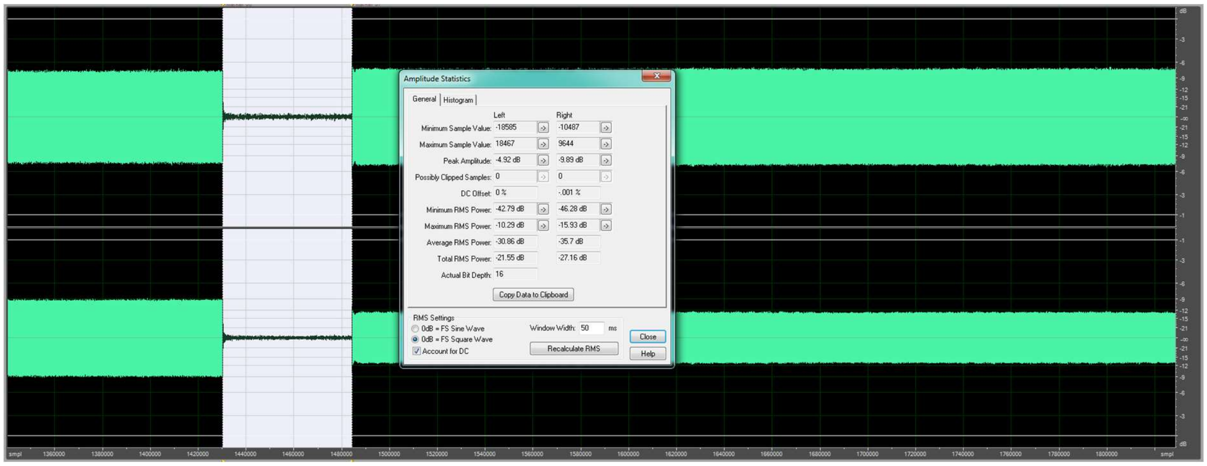
This shows the frequency statistics of the second break.



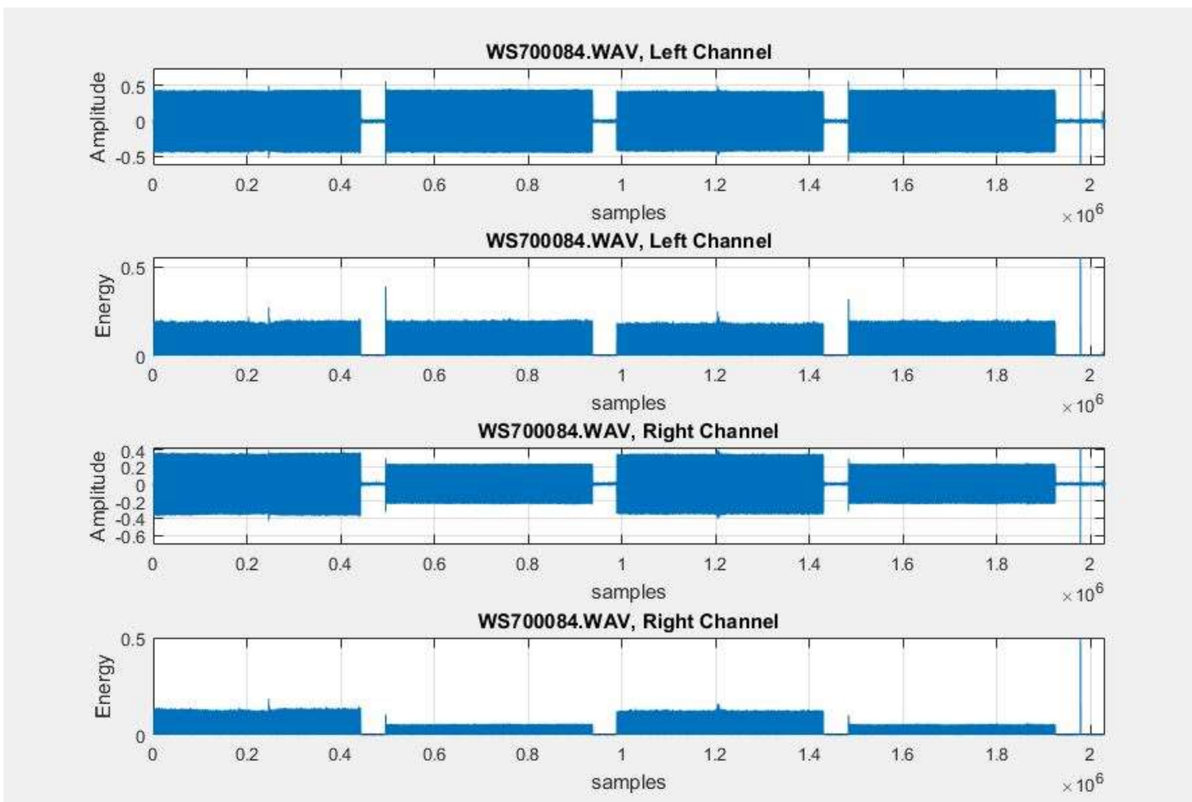
This shows the amplitude statistics of the second break.



This shows the frequency statistics of the third break.



This shows the amplitude statistics of the third break.

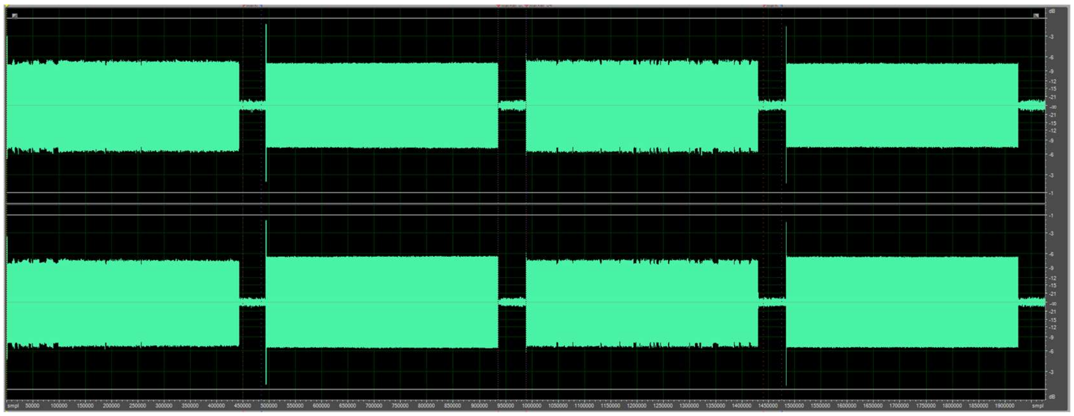


This shows the MATLAB Amplitude and Energy plots.

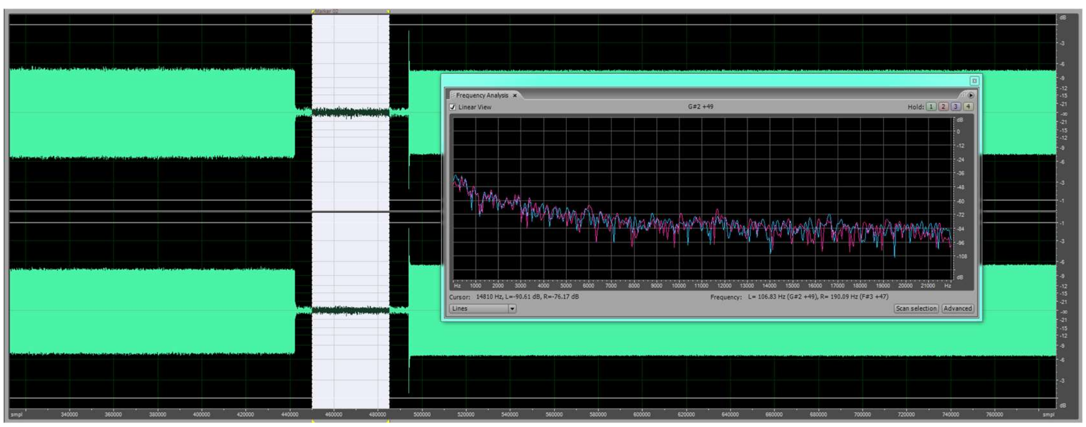
APPENDIX G

OLYMPUS WS-750M

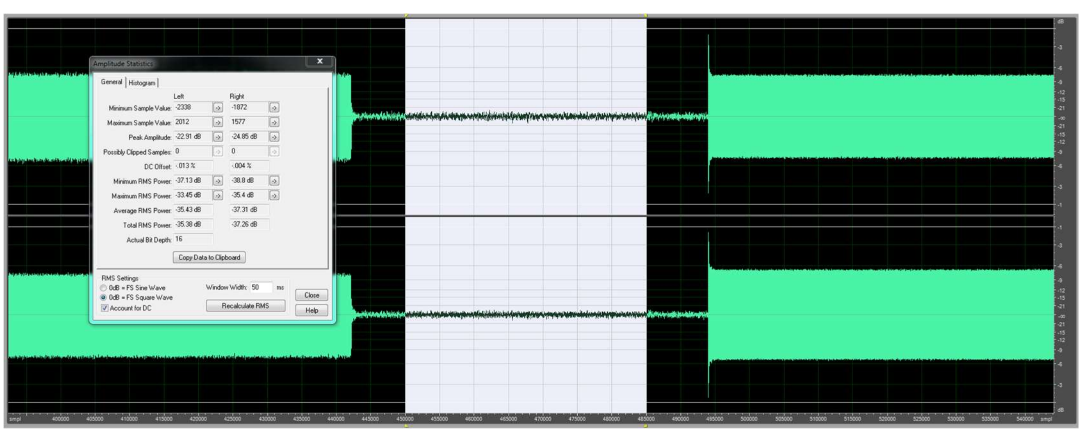
Images of the Olympus WS-750M recording, settings, and MATLAB energy plots.



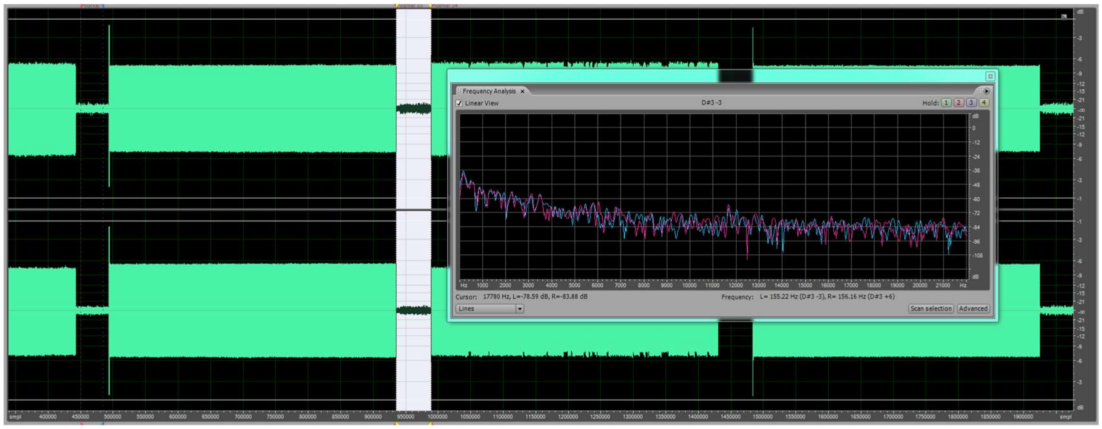
This shows the file that was created when recording the playback audio file.



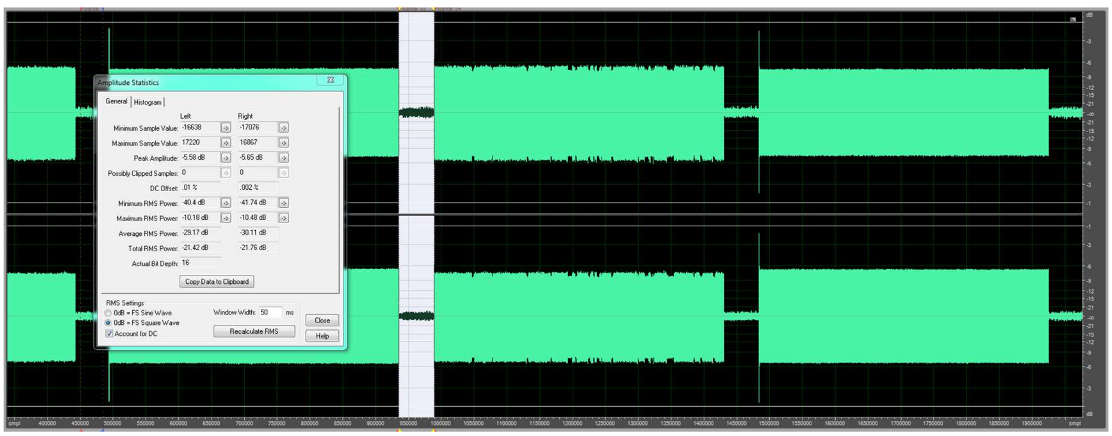
This shows the frequency statistics of the first break.



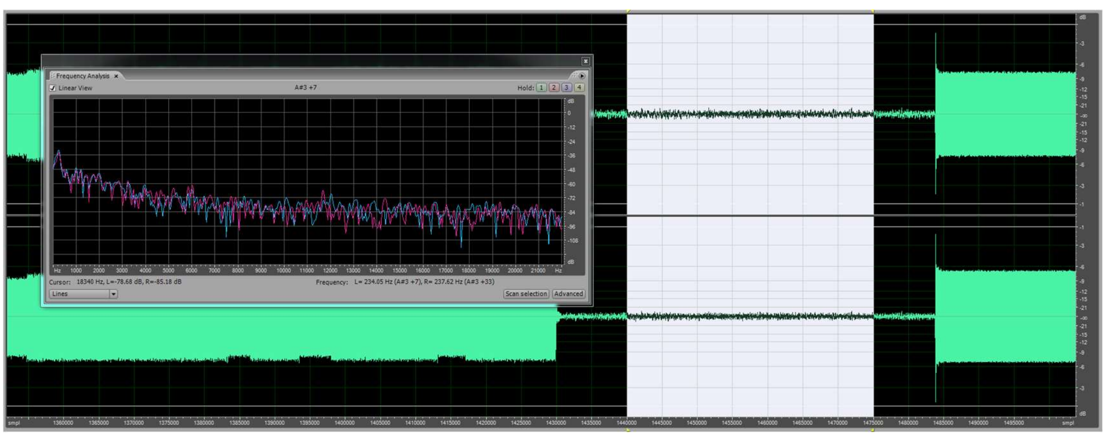
This shows the amplitude statistics of the first break.



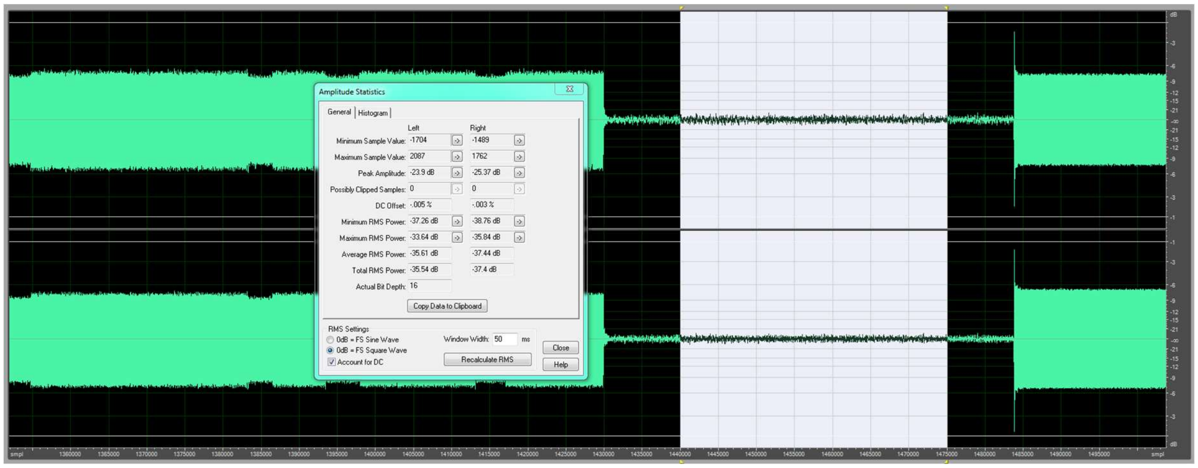
This shows the frequency statistics of the second break.



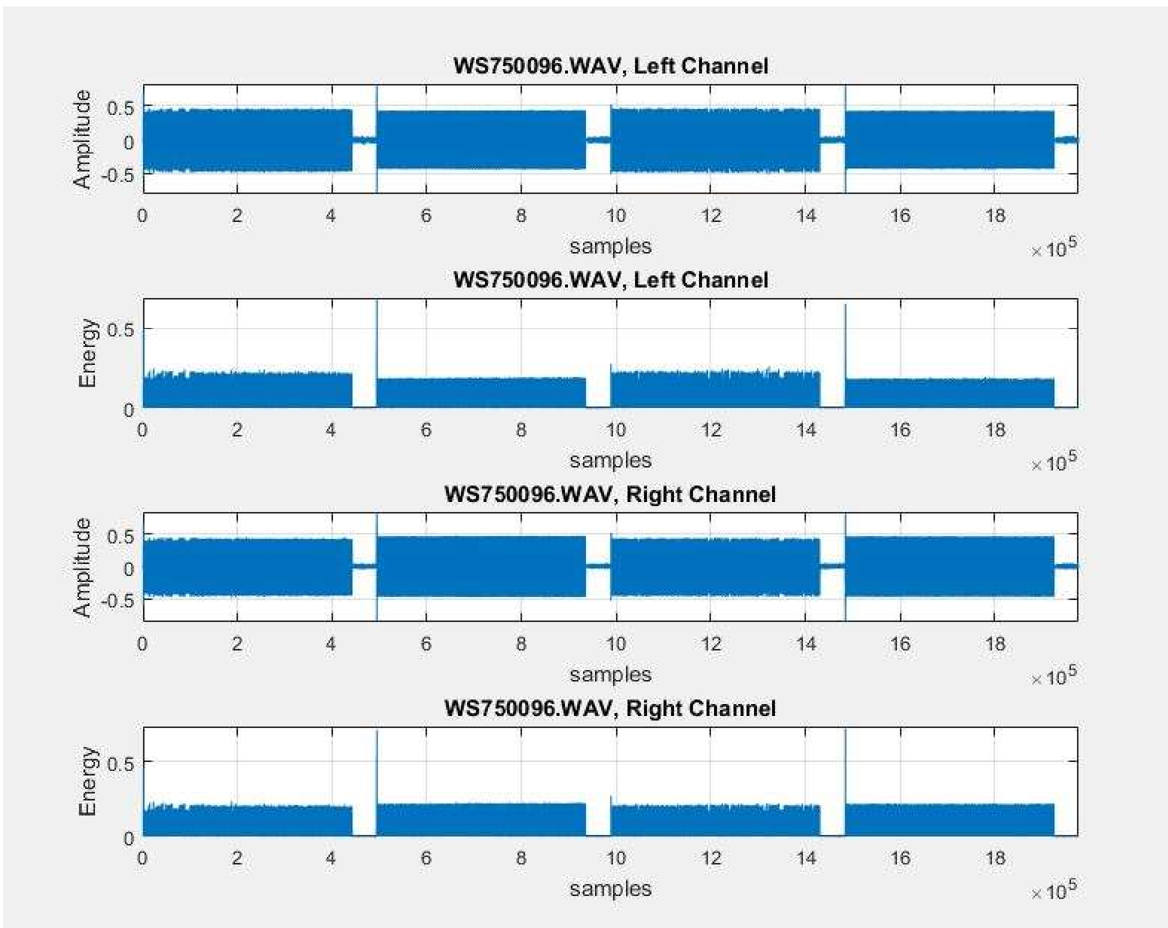
This shows the amplitude statistics of the second break.



This shows the frequency statistics of the third break.



This shows the amplitude statistics of the third break.

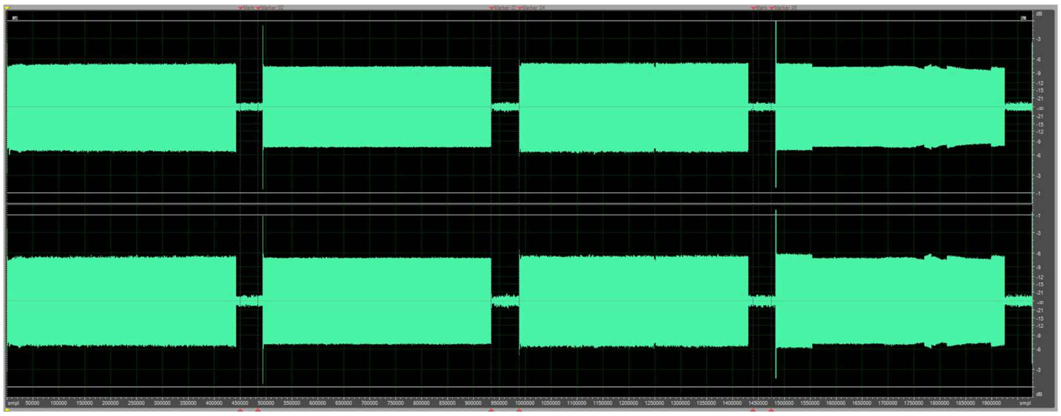


This shows the MATLAB Amplitude and Energy plots.

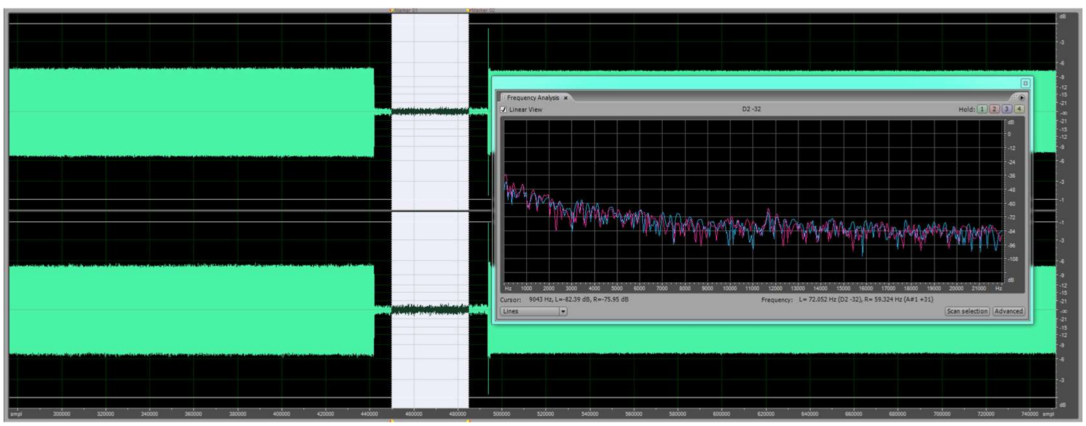
APPENDIX H

OLYMPUS WS-760M

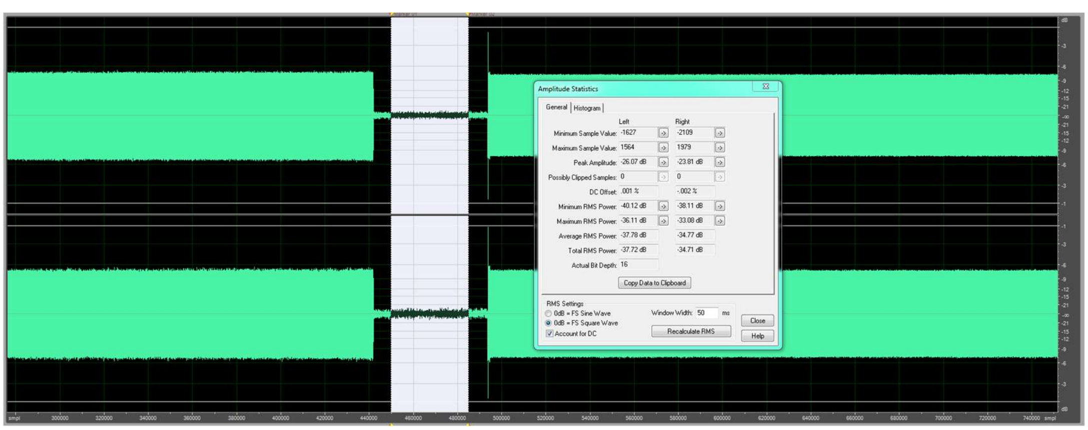
Images of the Olympus WS-760M recording, settings, and MATLAB energy plots.



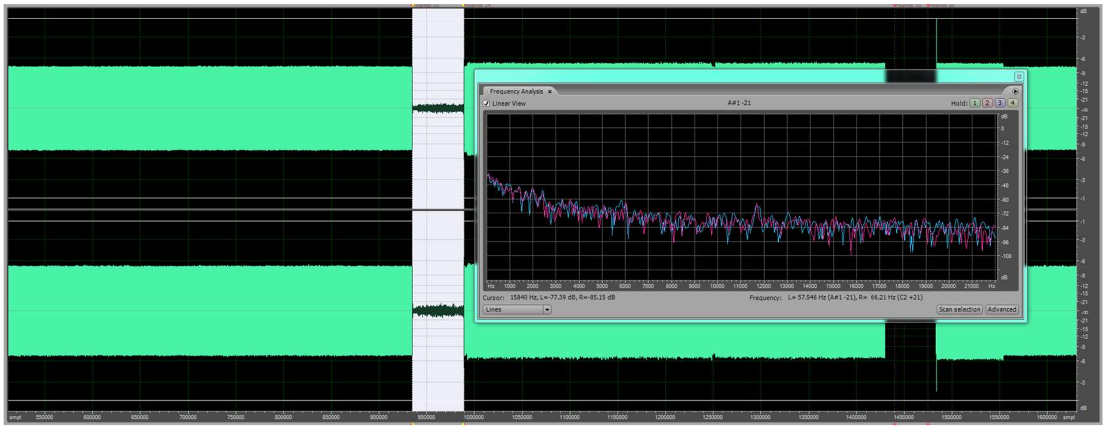
This shows the file that was created when recording the playback audio file.



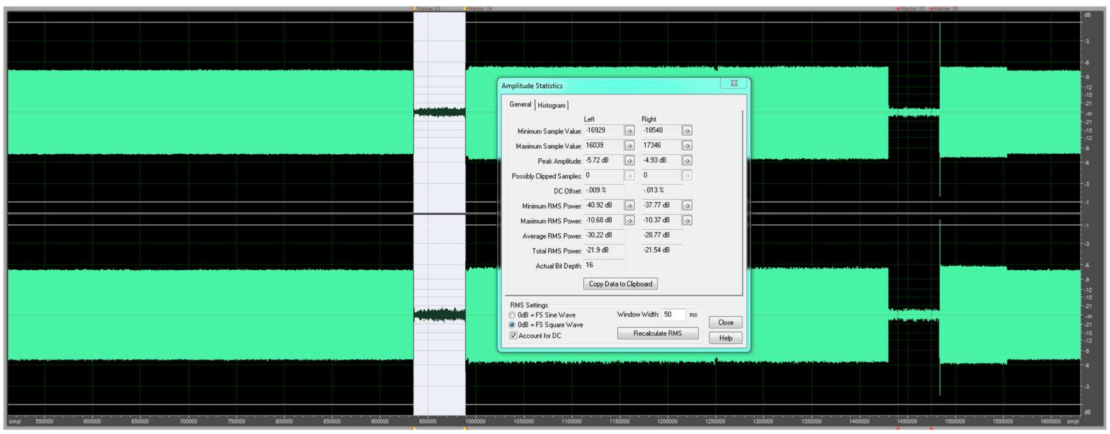
This shows the frequency statistics of the first break.



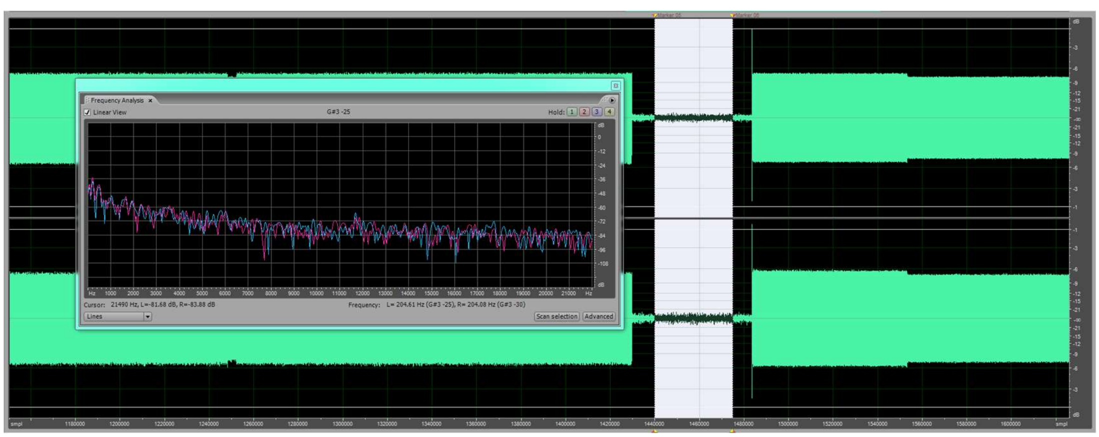
This shows the amplitude statistics of the first break.



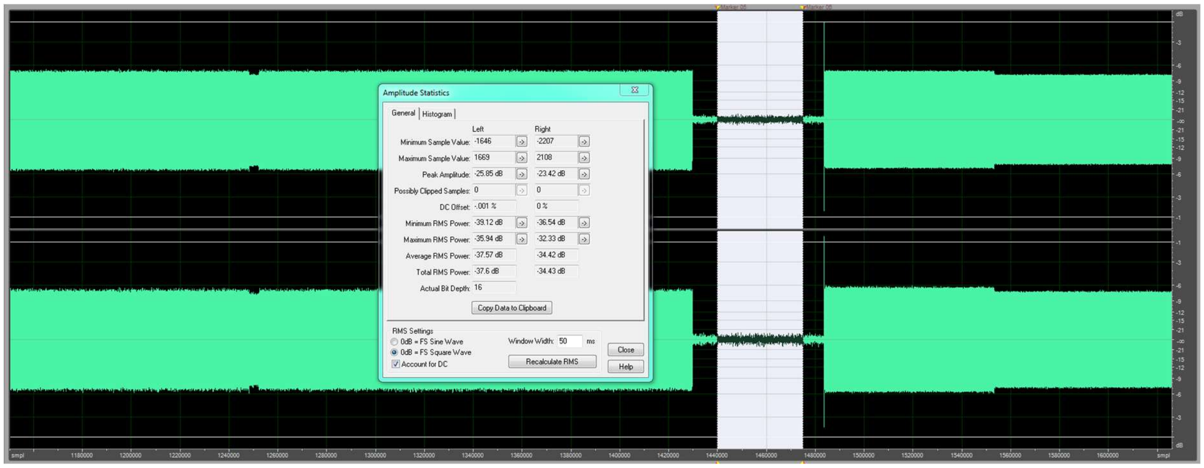
This shows the frequency statistics of the second break.



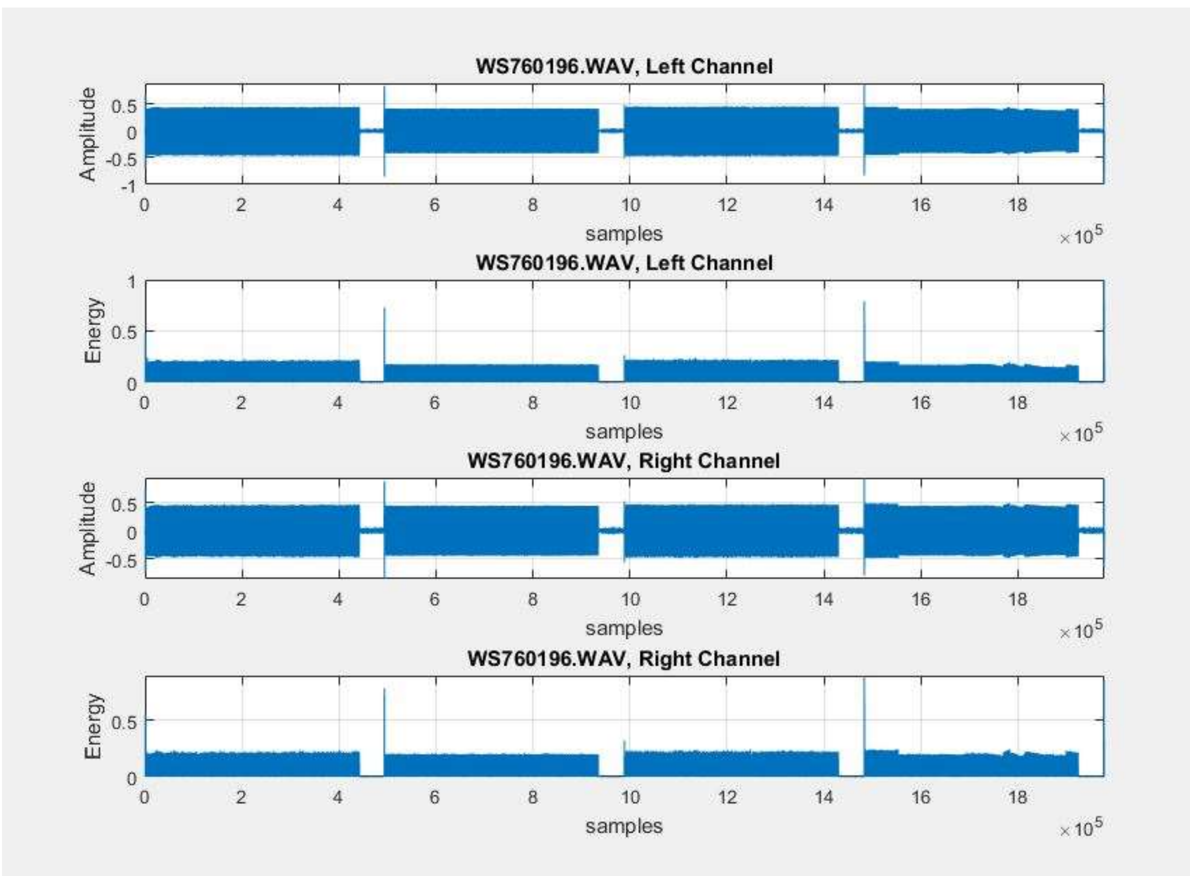
This shows the amplitude statistics of the second break.



This shows the frequency statistics of the third break.



This shows the amplitude statistics of the third break.

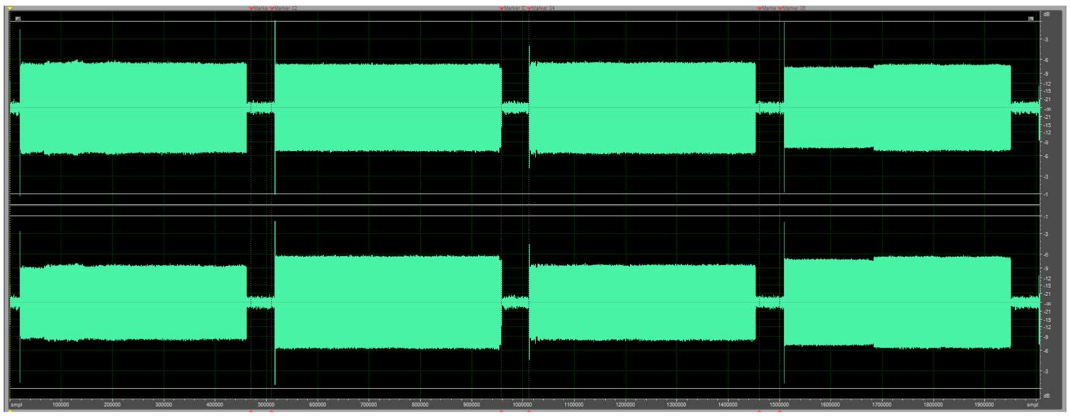


This shows the MATLAB Amplitude and Energy plots.

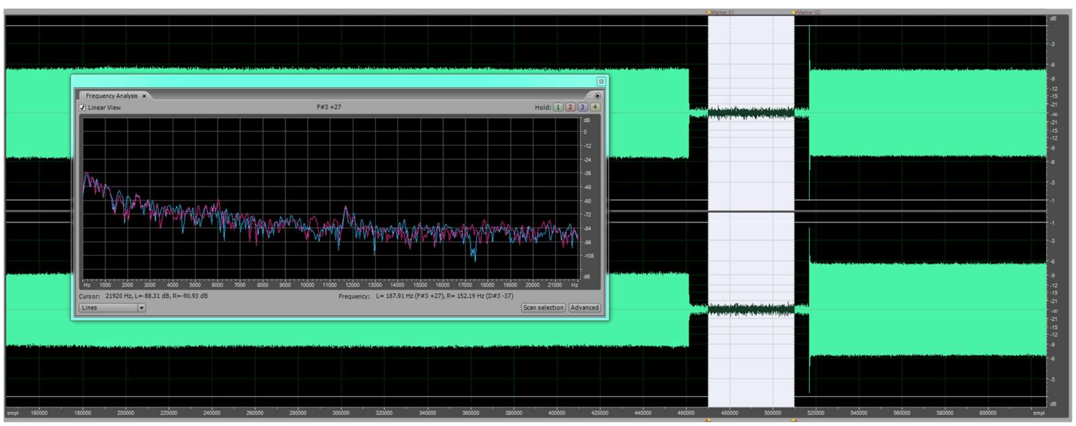
APPENDIX I

OLYMPUS WS-802

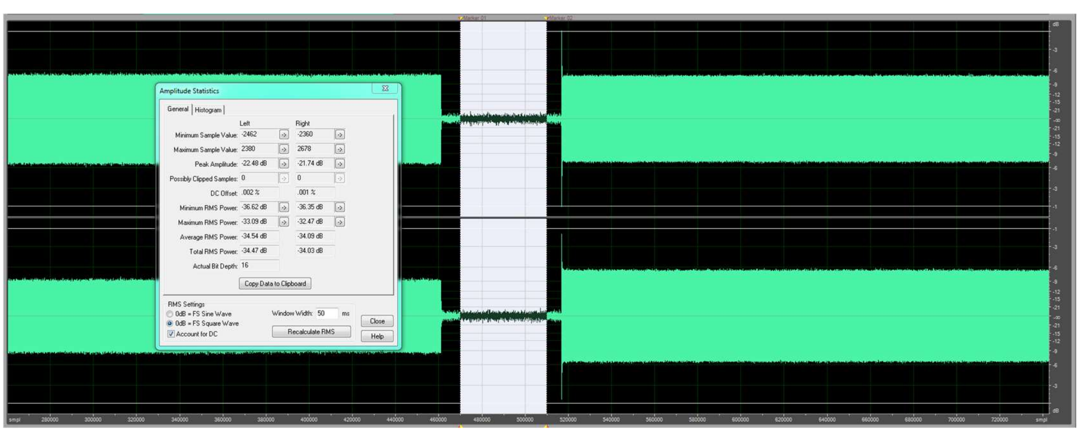
Images of the Olympus WS-802 recording, settings, and MATLAB energy plots.



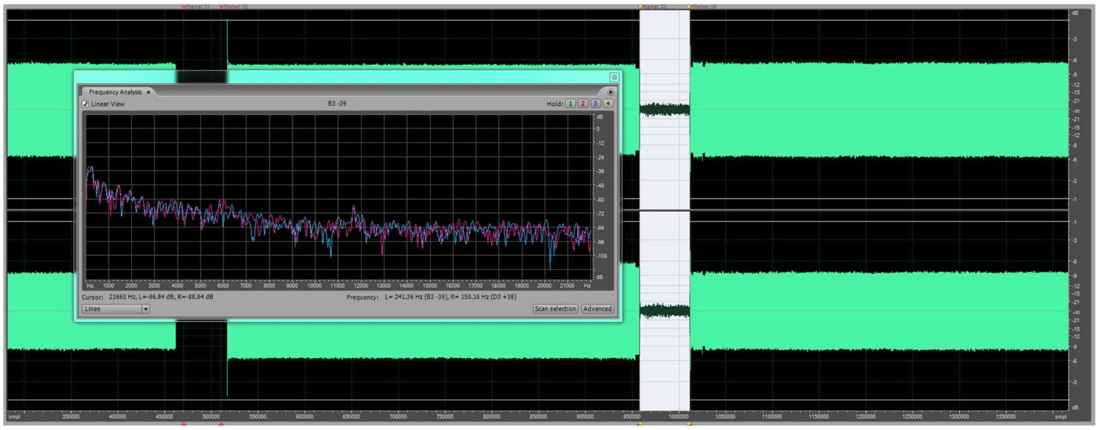
This shows the file that was created when recording the playback audio file.



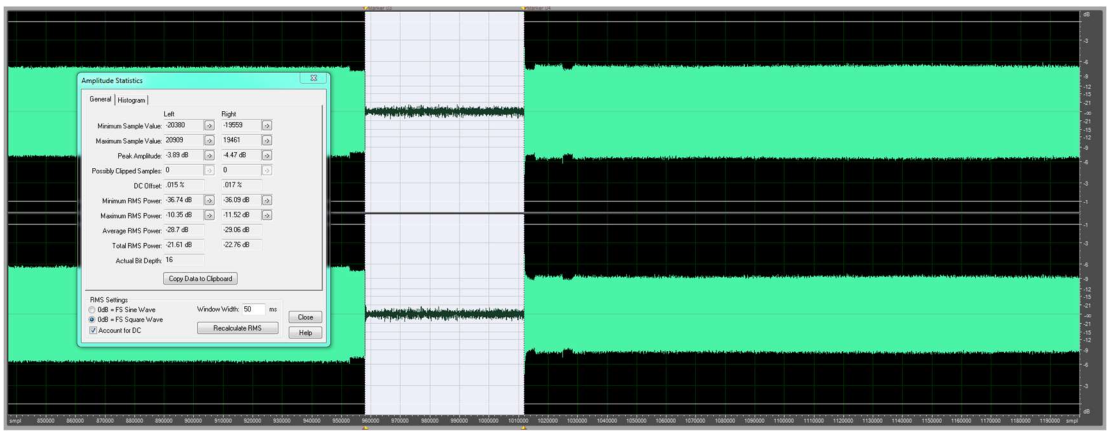
This shows the frequency statistics of the first break.



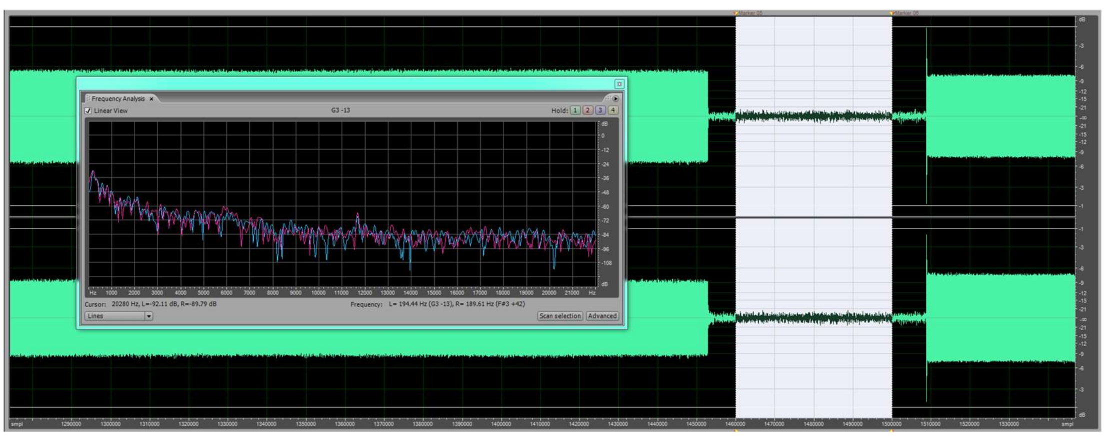
This shows the amplitude statistics of the first break.



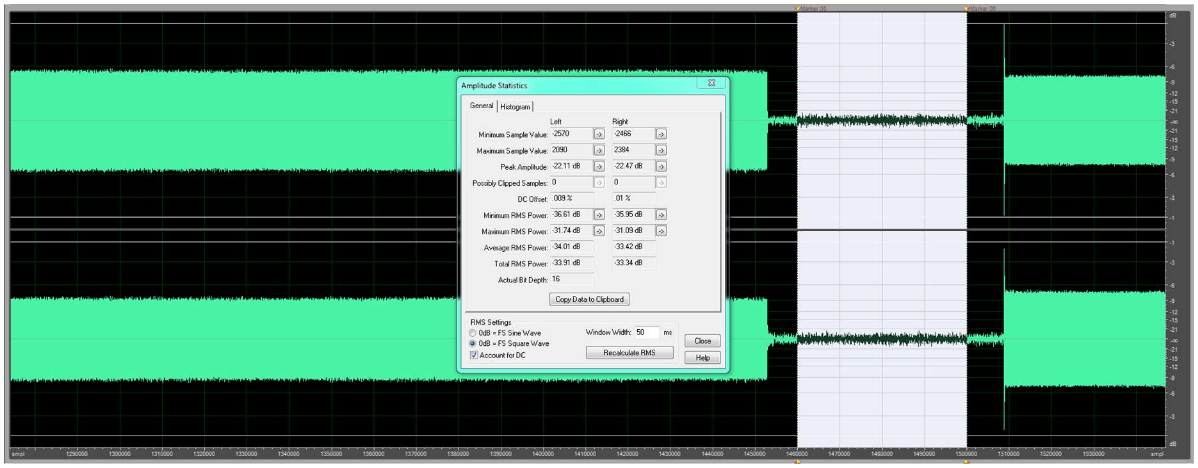
This shows the frequency statistics of the second break.



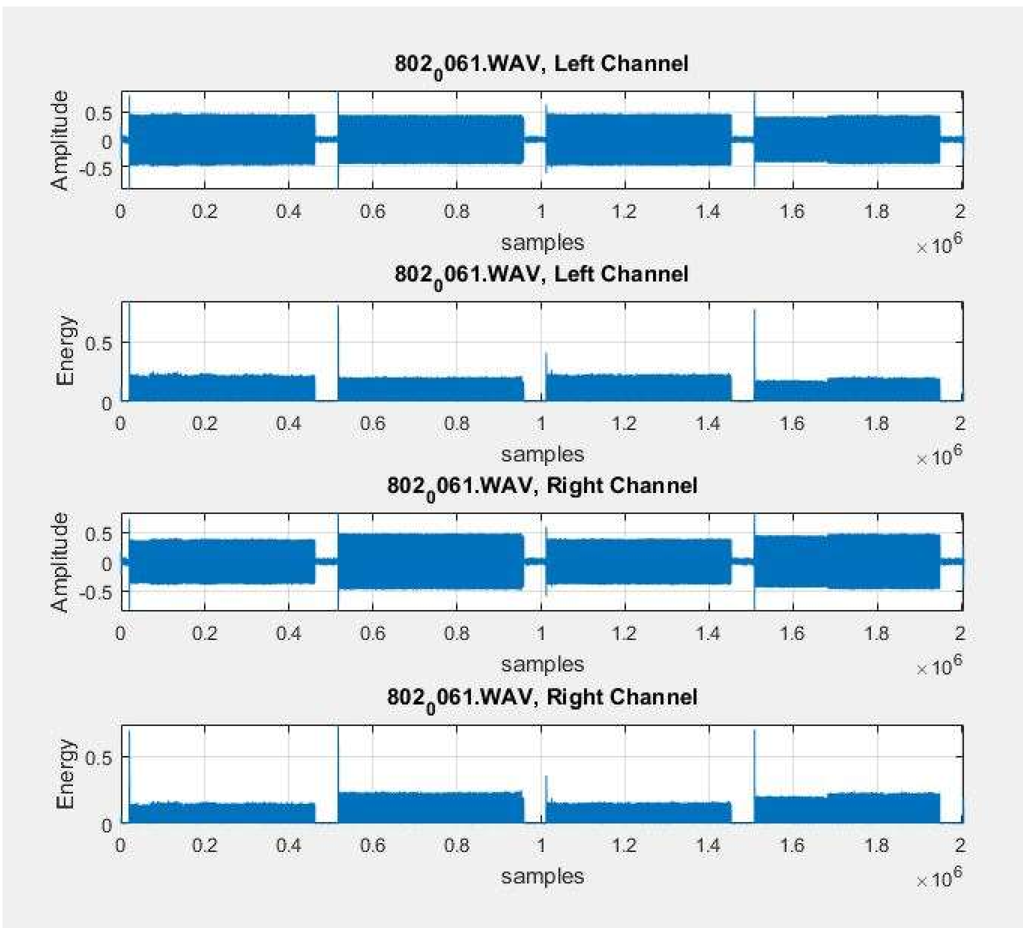
This shows the amplitude statistics of the second break.



This shows the frequency statistics of the third break.



This shows the amplitude statistics of the third break.

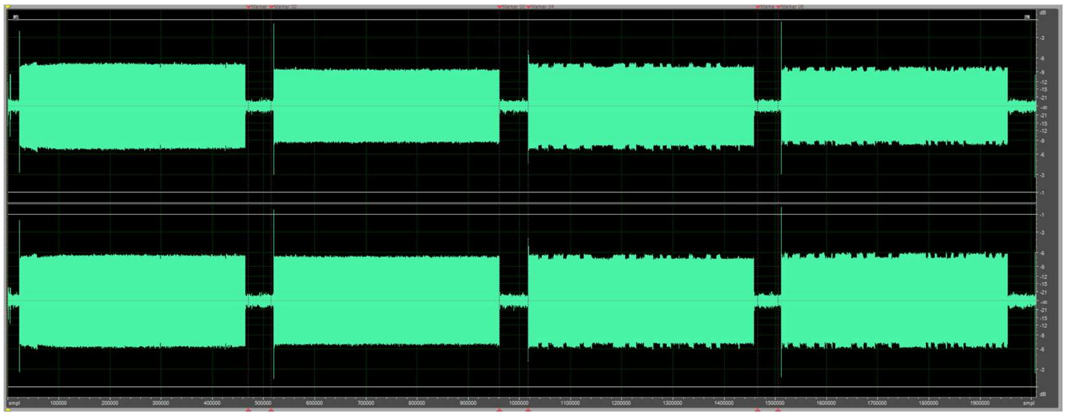


This shows the MATLAB Amplitude and Energy plots.

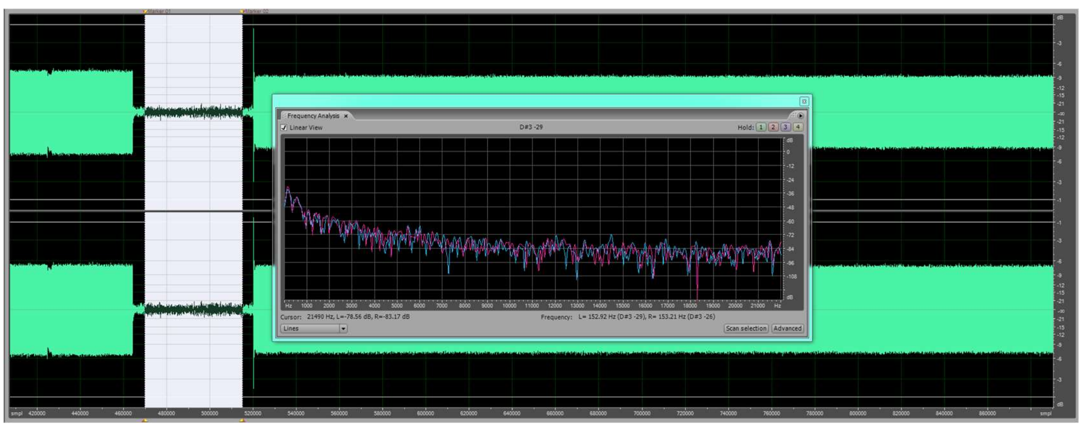
APPENDIX J

OLYMPUS WS-822

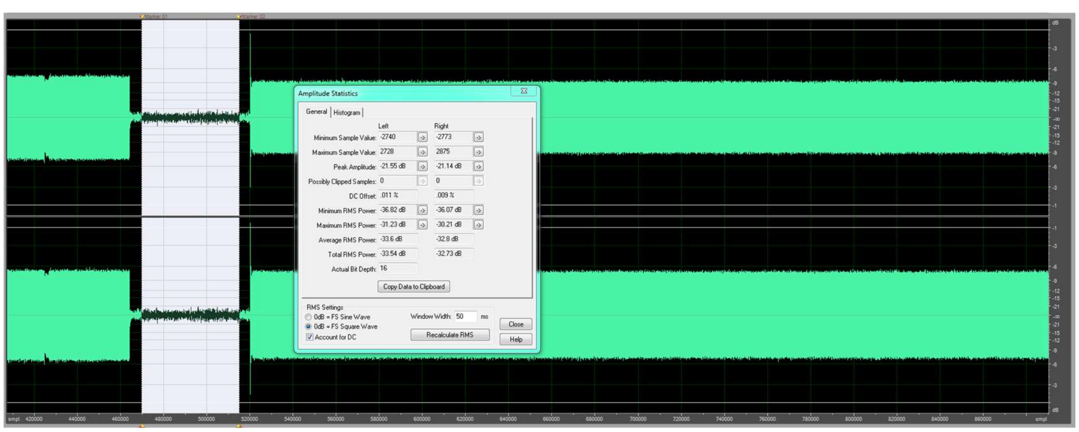
Images of the Olympus WS-822 recording, settings, and MATLAB energy plots.



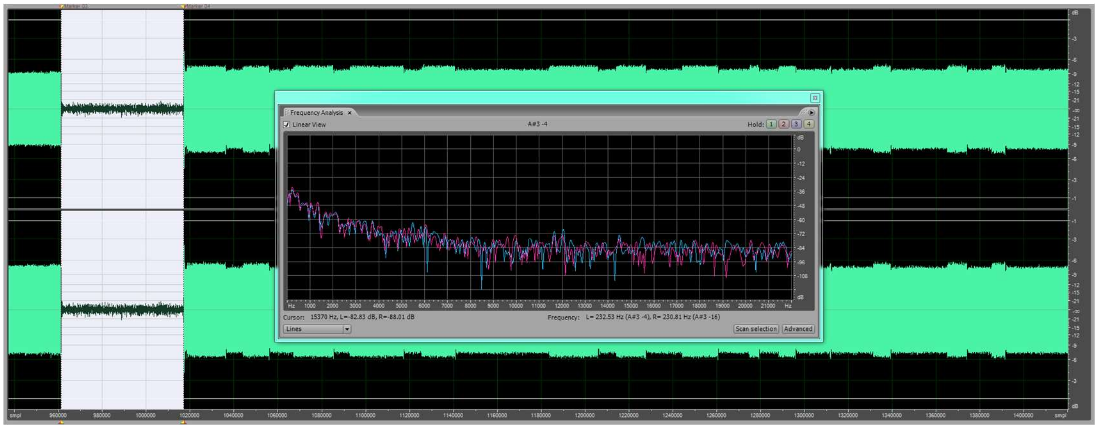
This shows the file that was created when recording the playback audio file.



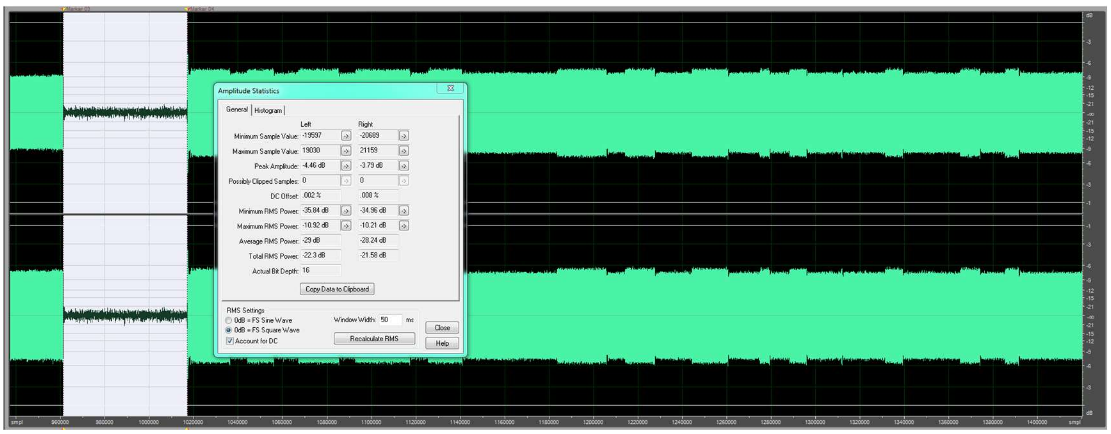
This shows the frequency statistics of the first break.



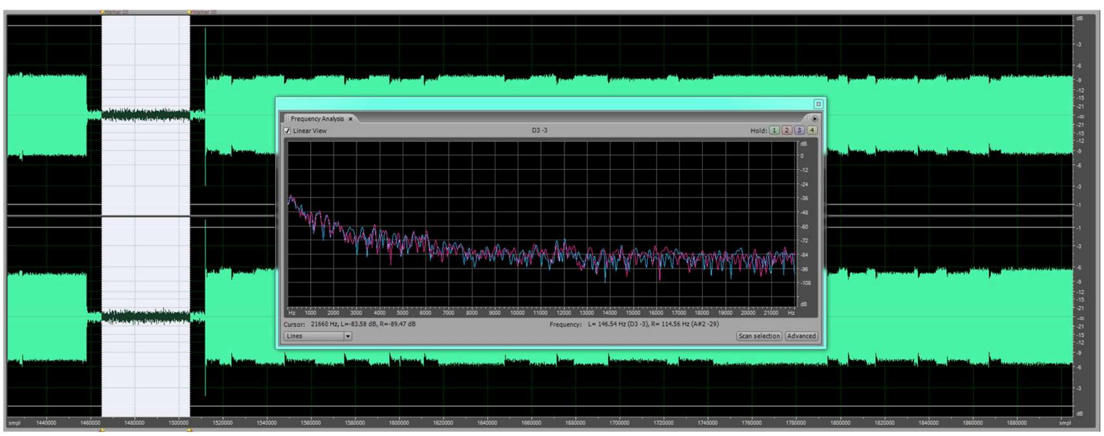
This shows the amplitude statistics of the first break.



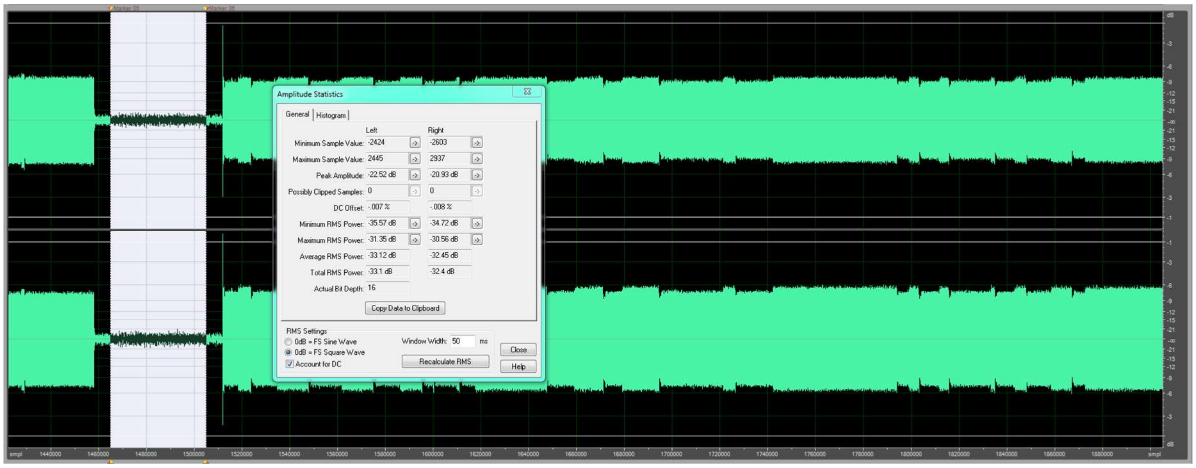
This shows the frequency statistics of the second break.



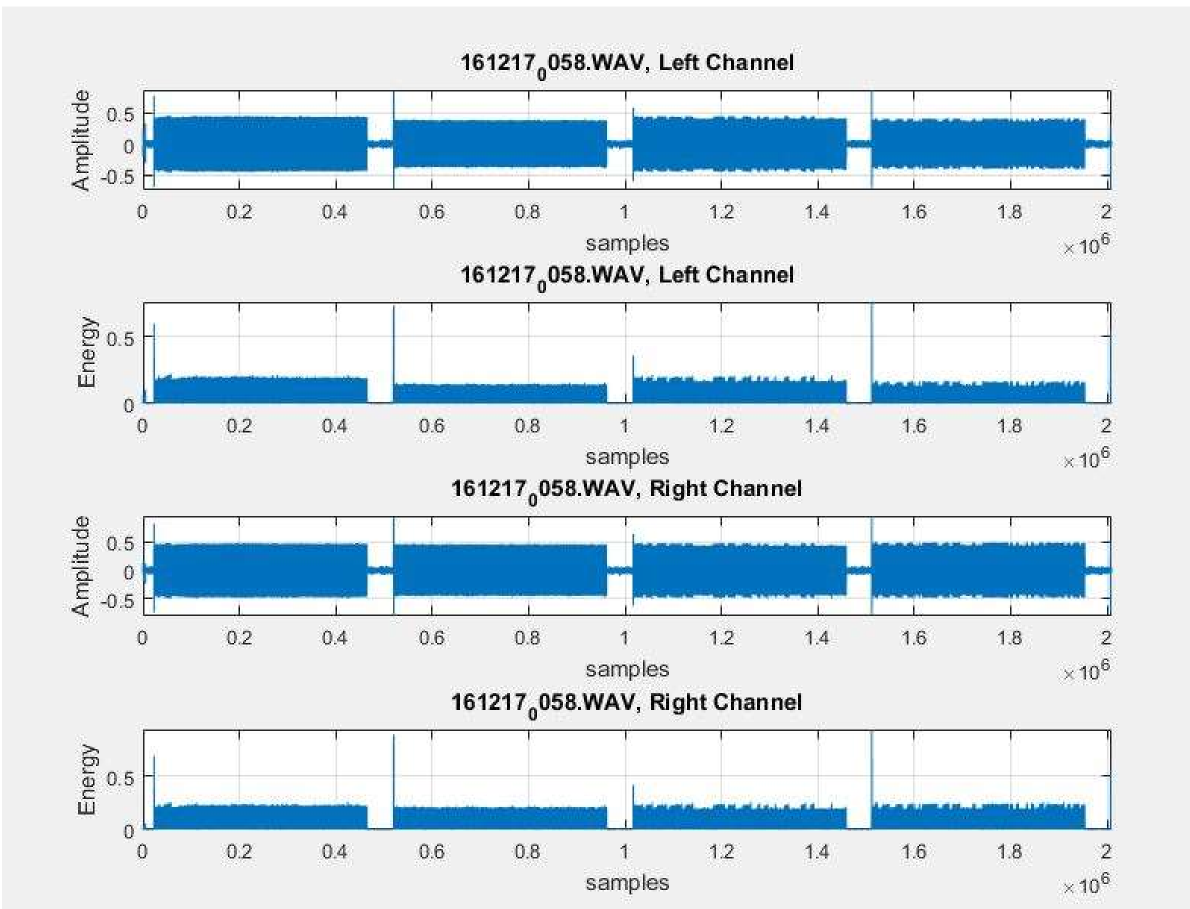
This shows the amplitude statistics of the second break.



This shows the frequency statistics of the third break.



This shows the amplitude statistics of the third break.

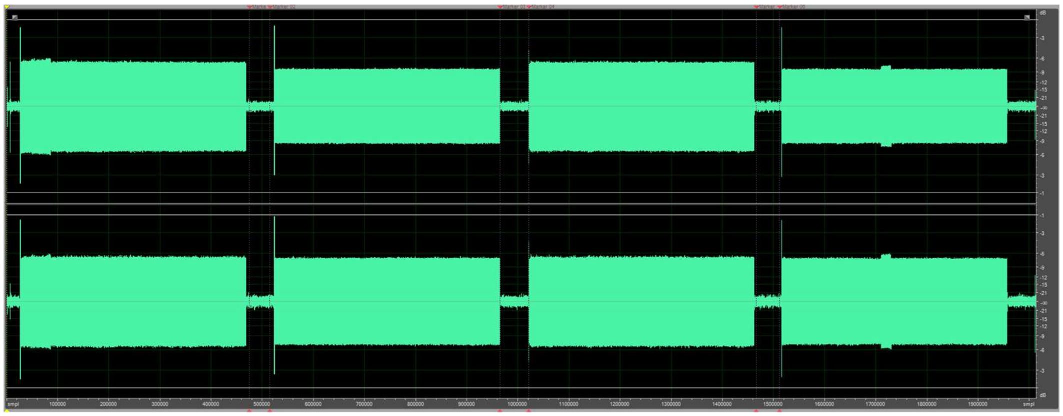


This shows the MATLAB Amplitude and Energy plots.

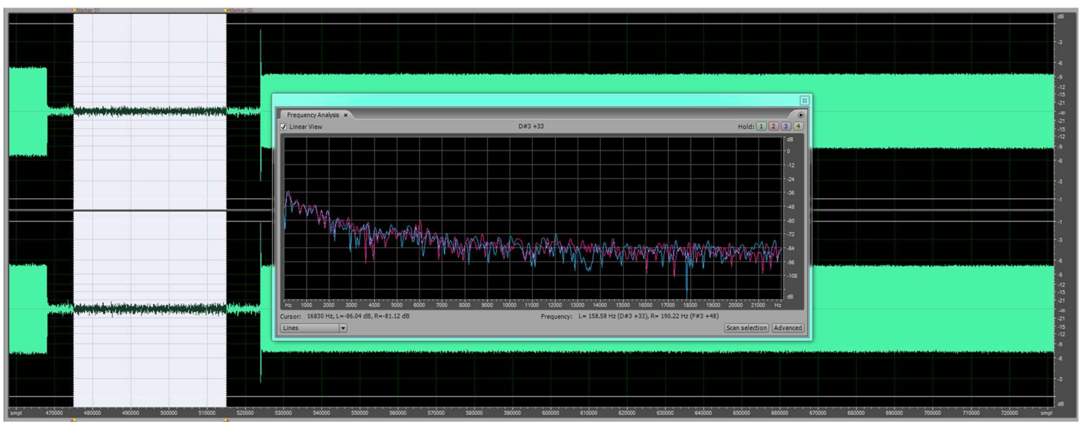
APPENDIX K

OLYMPUS WS-823

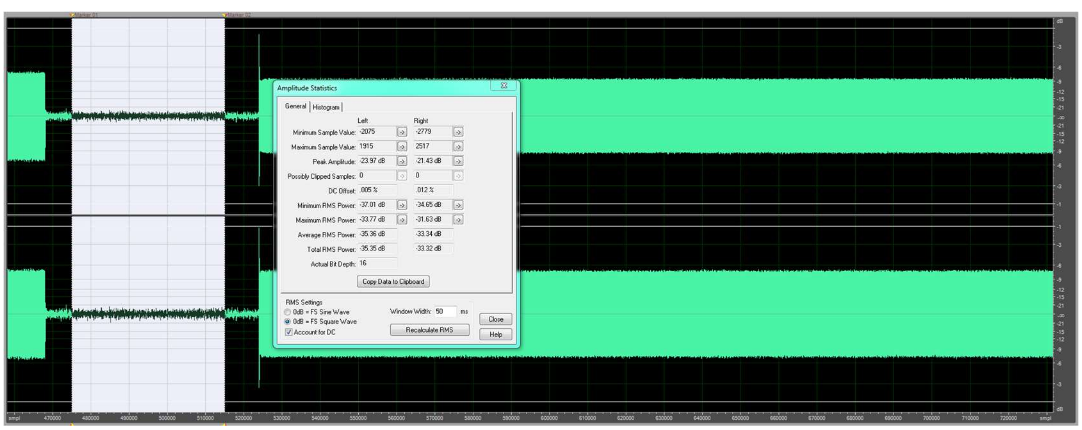
Images of the Olympus WS-823 recording, settings, and MATLAB energy plots.



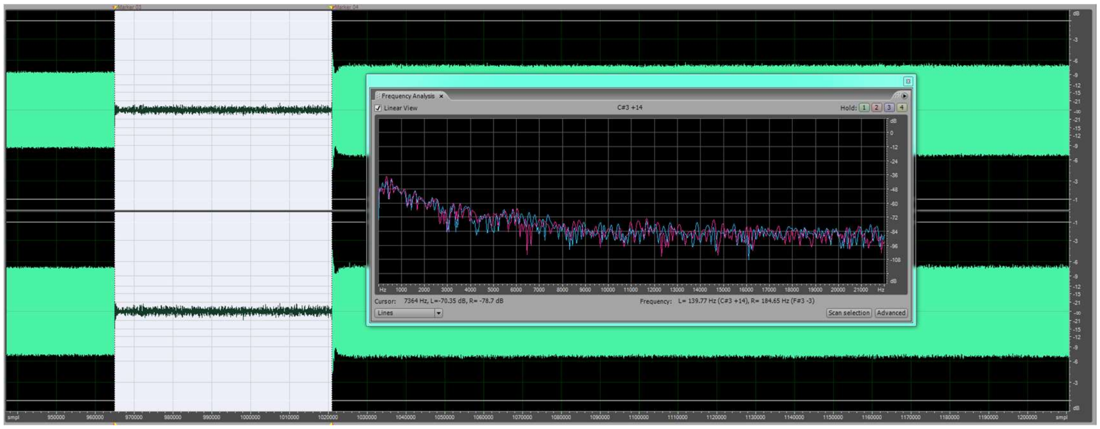
This shows the file that was created when recording the playback audio file.



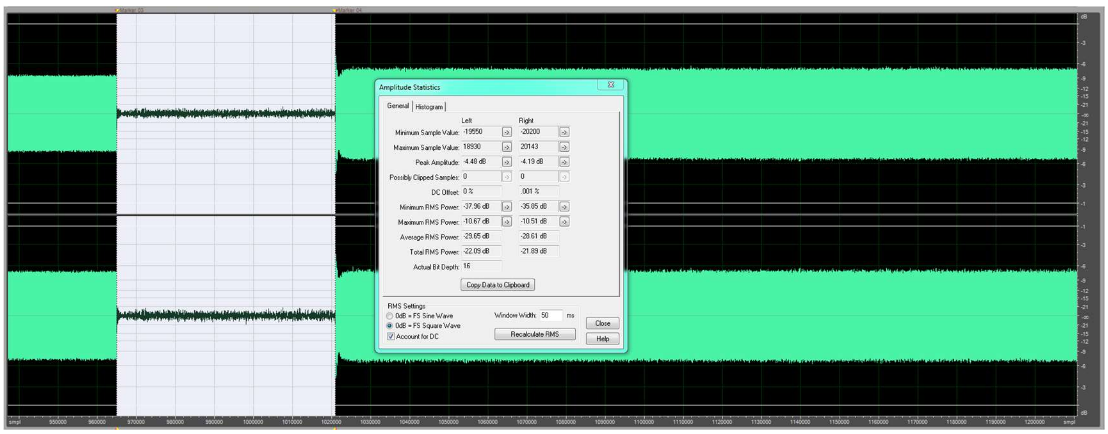
This shows the frequency statistics of the first break.



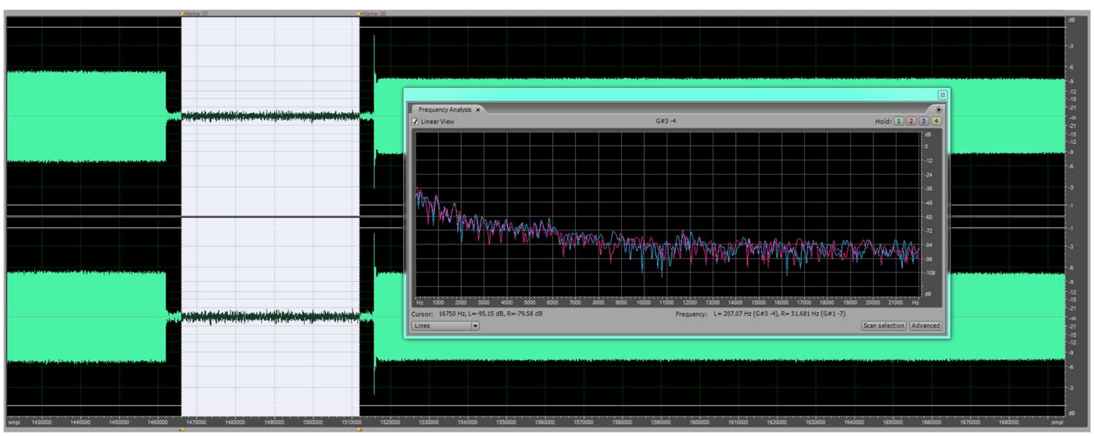
This shows the amplitude statistics of the first break.



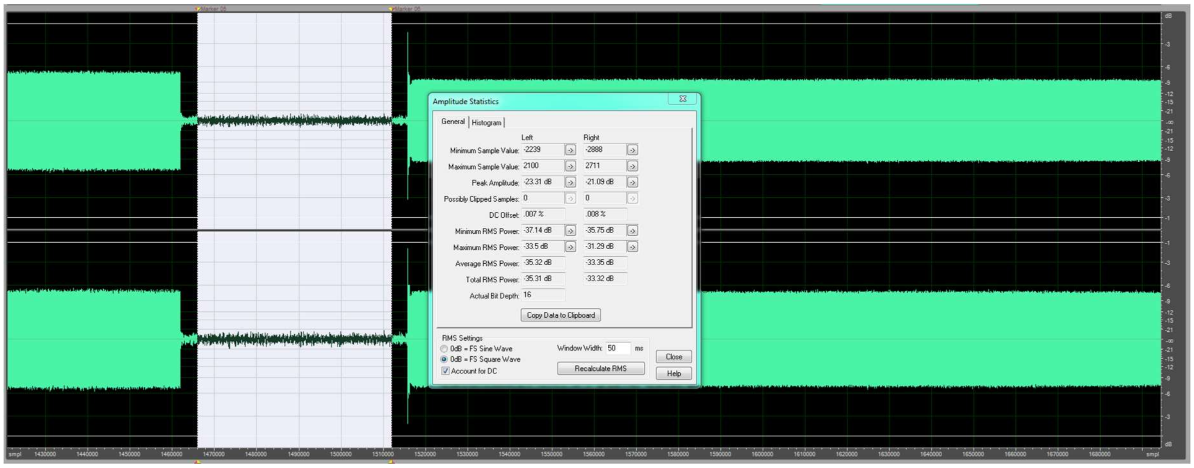
This shows the frequency statistics of the second break.



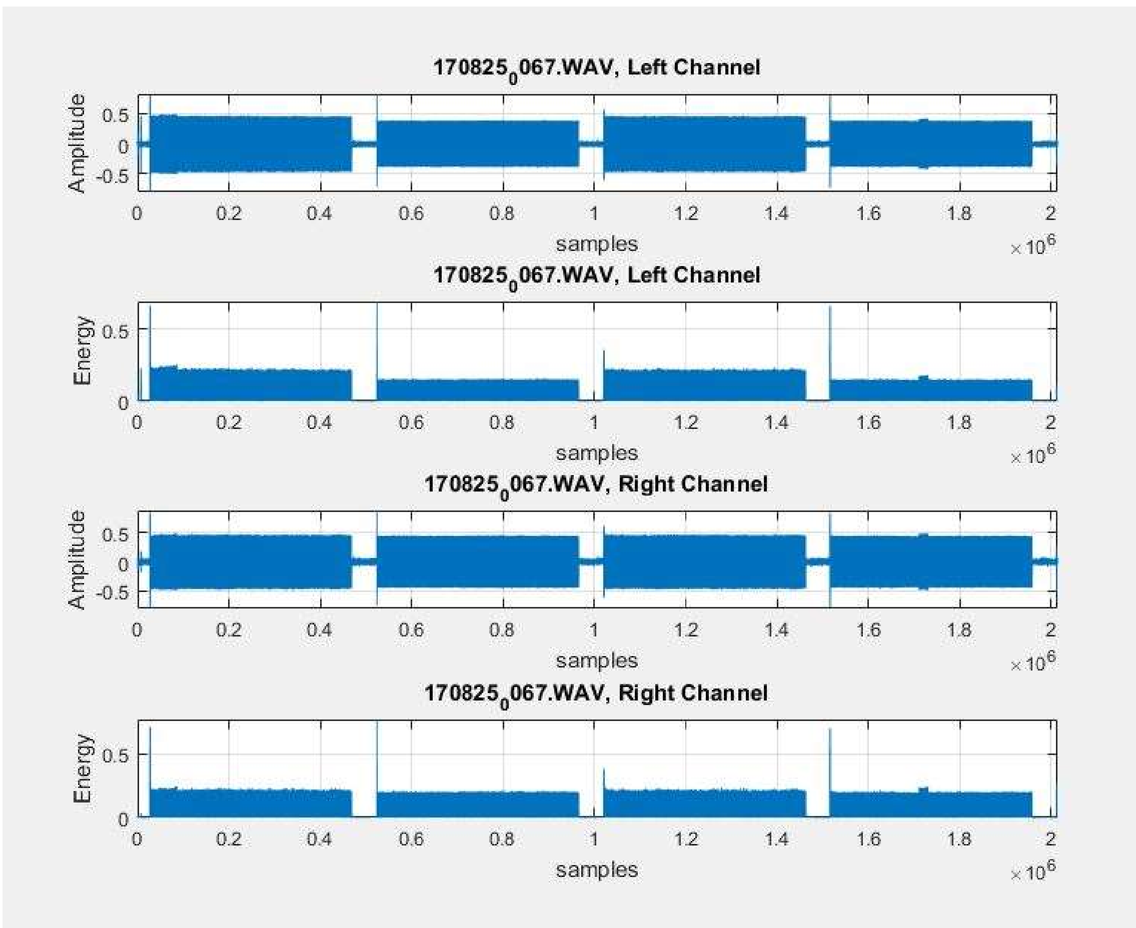
This shows the amplitude statistics of the second break.



This shows the frequency statistics of the third break.



This shows the amplitude statistics of the third break.

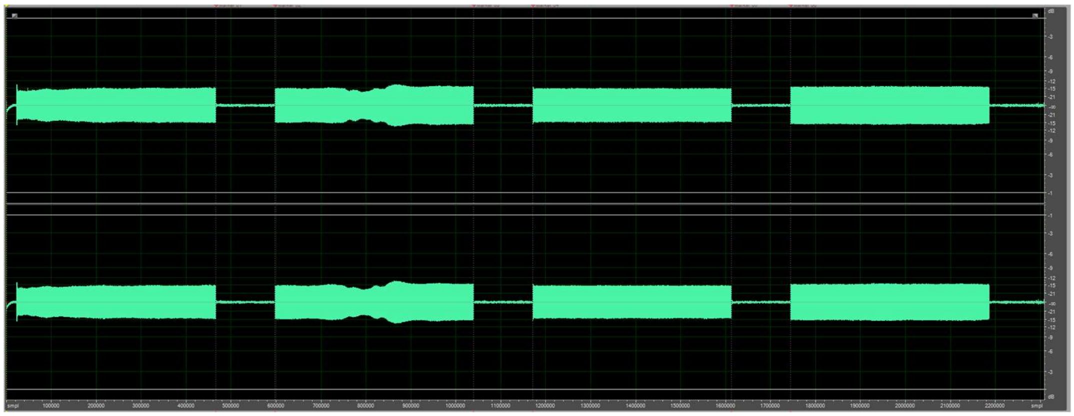


This shows the MATLAB Amplitude and Energy plots.

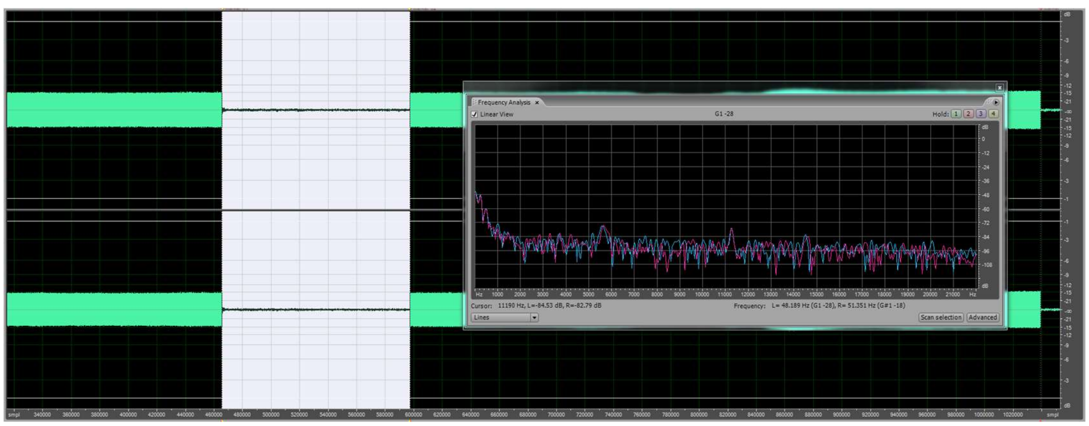
APPENDIX L

PHILIPS VOICE TRACER

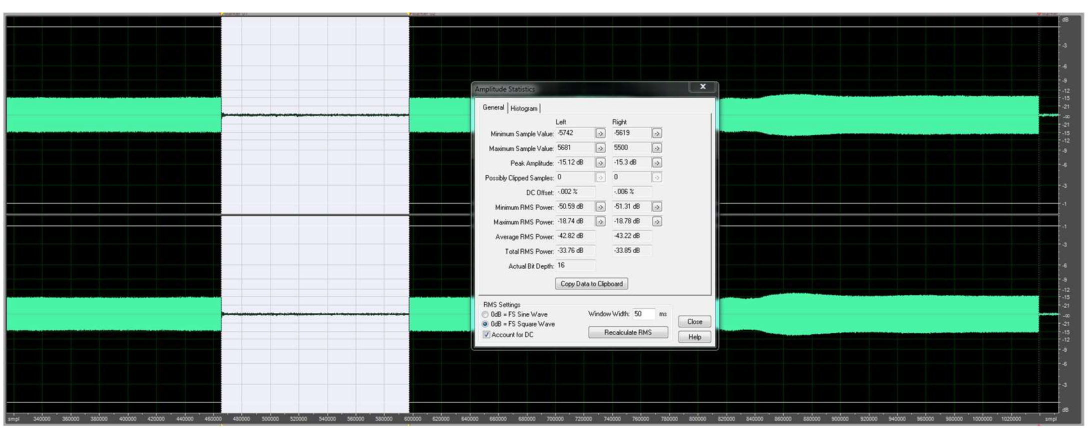
Images of the Philips Voice Tracer recording, settings, and MATLAB energy plots.



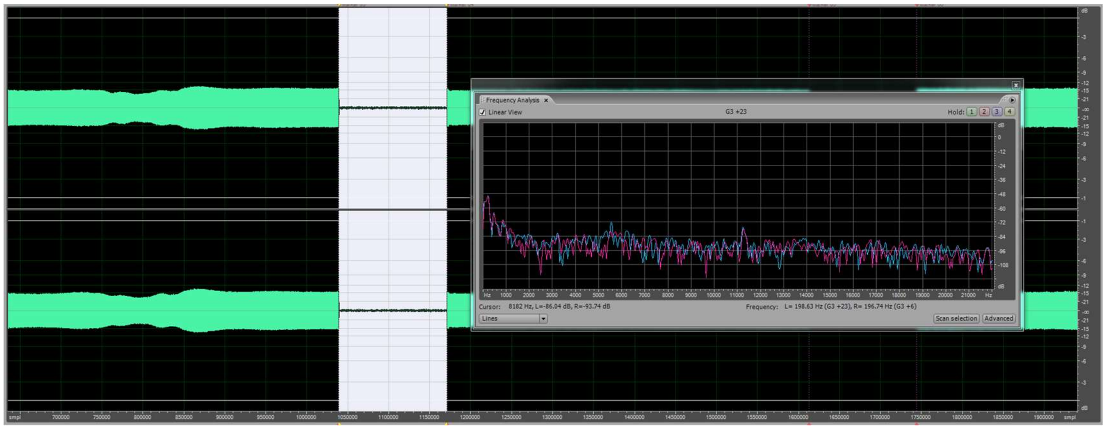
This shows the file that was created when recording the playback audio file.



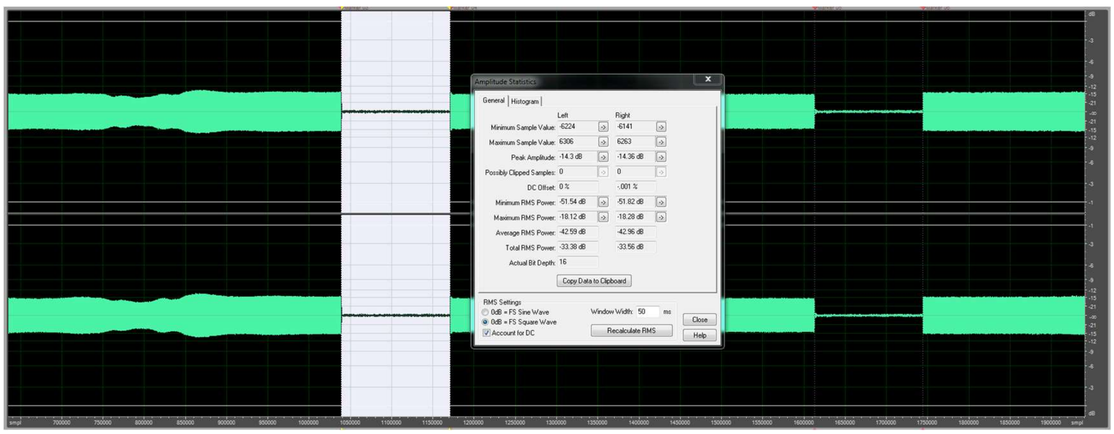
This shows the frequency statistics of the first break.



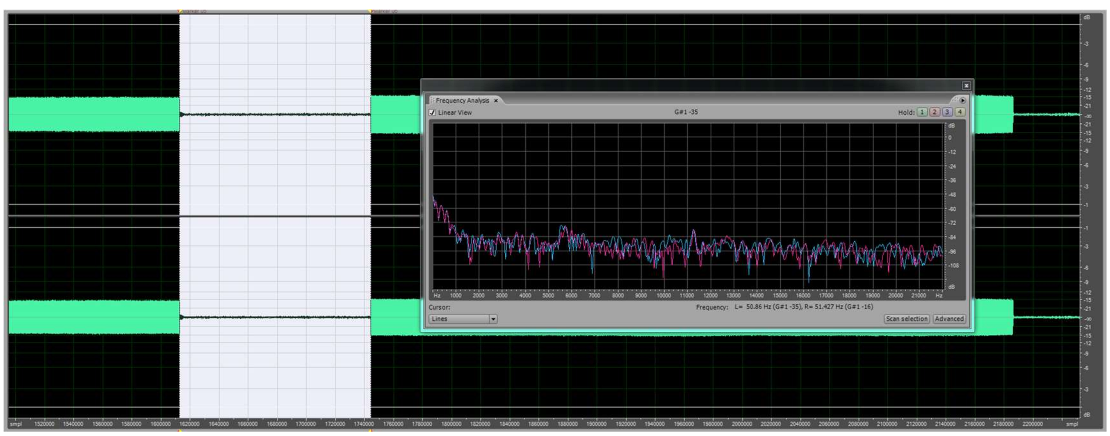
This shows the amplitude statistics of the first break.



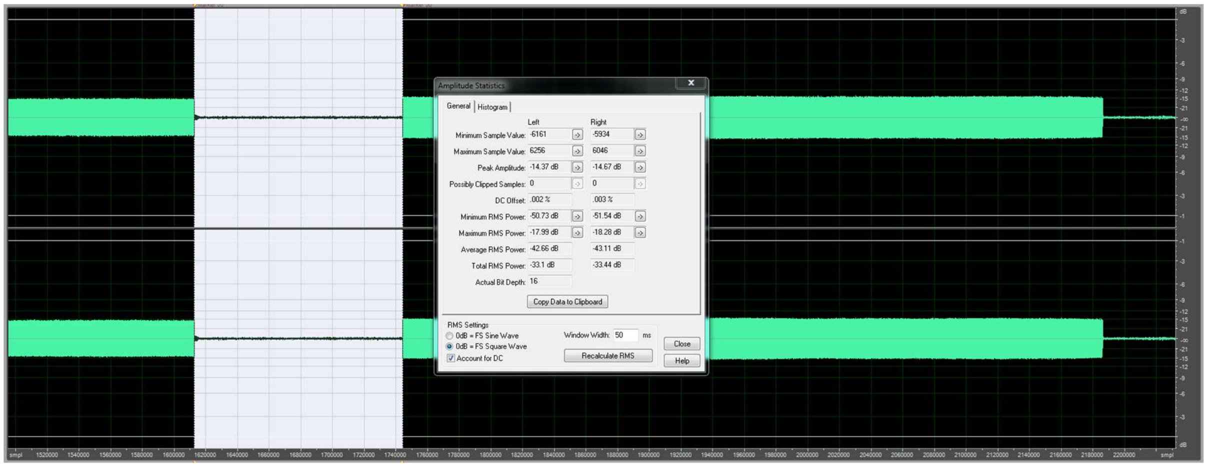
This shows the frequency statistics of the second break.



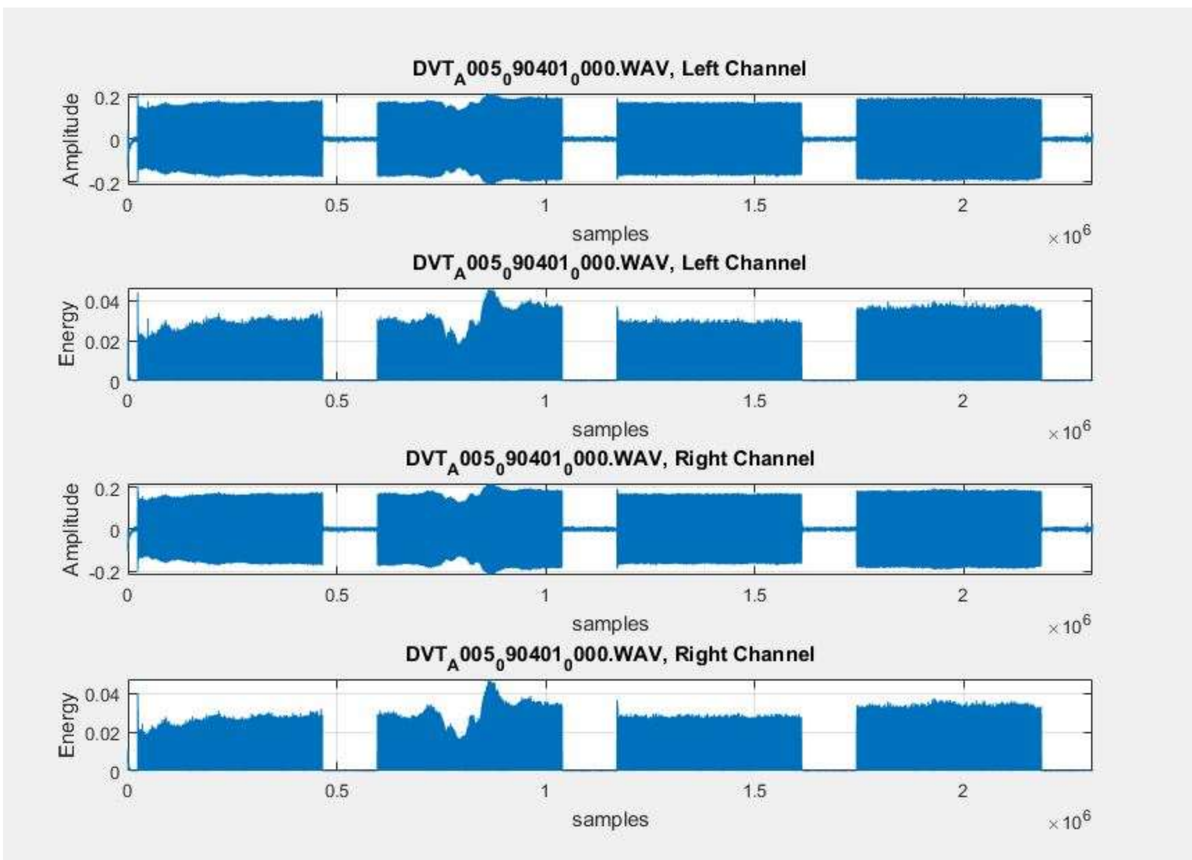
This shows the amplitude statistics of the second break.



This shows the frequency statistics of the third break.



This shows the amplitude statistics of the third break.



This shows the MATLAB Amplitude and Energy plots.

APPENDIX M

EXCEL SPREADSHEETS

BREAK #1

Images of the Excel spreadsheets that contain all the information that was analyzed from the recordings.

Break #1																
Recorder		Format	Samples			Peak Amplitude (dB)		Minimum RMS Power (dB)		Maximum RMS Power (dB)		Average RMS Power (dB)		Total RMS Power (dB)	
Brand	Model	WAV PCM/ MP3/WMA	Begin	End	Length	Left	Right	Left	Right	Left	Right	Left	Right	Left	Right
Olympus	DM-520	WMA	247140	274082	26942	-9.19	-6.65	-44.29	-42.24	-14.03	-12.09	-28.77	-26.81	-22.27	-20.36
Olympus	DM-620	WAV PCM	460274	495650	35376	-4.5	-5.04	-39.47	-40.86	-10.54	-11.01	-27.84	-28.56	-19.88	-20.36
Olympus	WS-550M	MP3	460000	470000	10000	-28.58	-28.91	-40.5	-40.91	-38.82	-38.96	-39.31	-39.81	-39.29	-39.85
Olympus	WS-560M	MP3	460000	470000	10000	-28.97	-27.8	-41.24	-40.61	-40.27	-39.32	-40.75	-39.89	-40.66	-39.78
Olympus	WS-700M	WAV PCM	442200	493955	51755	-15.86	-14.5	-40.88	-41.35	-22.12	-20.07	-36.04	-35.59	-32.51	-30.72
Olympus	WS-700M	WAV PCM	442579	496432	53853	-4.08	-9.73	-43.31	-46.28	-10.26	-15.84	-30.82	-35.52	-21.53	-27.08
Olympus	WS-750M	WAV PCM	450000	485000	35000	-22.91	-24.85	-37.13	-38.8	-33.45	-35.4	-35.43	-37.31	-35.38	-37.26
Olympus	WS-760M	WAV PCM	450000	485000	35000	-26.07	-23.81	-40.12	-38.11	-36.11	-33.08	-37.78	-34.77	-37.72	-34.71
Olympus	WS-802	WAV PCM	470000	510000	40000	-22.48	-21.74	-36.62	-36.35	-33.09	-32.47	-34.54	-34.09	-34.47	-34.03
Olympus	WS-822	WAV PCM	470000	515000	45000	-21.55	-21.14	-36.82	-36.07	-31.23	-30.21	-33.6	-32.8	-33.54	-32.73
Olympus	WS-823	WAV PCM	475000	515000	40000	-23.97	-21.43	-37.01	-34.65	-33.77	-31.63	-35.36	-33.34	-35.35	-33.32
Philips	Voice Tracer	WAV PCM	465549	597150	131601	-15.12	-15.3	-50.59	-51.31	-18.74	-18.78	-42.82	-43.22	-33.76	-33.85

BREAK #2

Break #2

Recorder		Format	Samples			Peak Amplitude (dB)		Minimum RMS Power (dB)		Maximum RMS Power (dB)		Average RMS Power (dB)		Total RMS Power (dB)	
Brand	Model	WAV PCM/ MP3/WMA	Begin	End	Length	Left	Right	Left	Right	Left	Right	Left	Right	Left	Right
Olympus	DM-520	WMA	494580	520533	25953	-7.28	-6.74	-44.1	-42.35	-11.45	-10.47	-26.62	-25.61	-19.59	-18.71
Olympus	DM-620	WAV PCM	936652	974200	37548	-5.46	-6.73	-39.77	-41.2	-10.62	-11.72	-28.41	-29.63	-20.37	-21.5
Olympus	WS-550M	MP3	914080	929416	15336	-5.7	-5.5	-40.49	-40.6	-10.32	-10.3	-21.67	-21.74	-16.26	-16.51
Olympus	WS-560M	MP3	914061	929354	15293	-7.66	-6.01	-41.23	-40.17	-11.57	-10.5	-22.95	-21.77	-17.49	-16.48
Olympus	WS-700M	WAV PCM	935072	987130	52058	-13.88	-13.78	-40.68	-41.16	-18.33	-18.17	-34.52	-34.56	-29.12	-28.91
Olympus	WS-700M	WAV PCM	937467	989361	51894	-7.23	-9.05	-43.42	-46.65	-10.94	-12.58	-31.4	-33.51	-22.19	-23.85
Olympus	WS-750M	WAV PCM	935113	988918	53805	-5.58	-5.65	-40.4	-41.74	-10.18	-10.48	-29.17	-30.11	-21.42	-21.76
Olympus	WS-760M	WAV PCM	934812	988650	53838	-5.72	-4.93	-40.92	-37.77	-10.68	-10.37	-30.22	-28.77	-21.9	-21.54
Olympus	WS-802	WAV PCM	958100	1011825	53725	-3.89	-4.47	-36.74	-36.09	-10.35	-11.52	-28.7	-29.06	-21.61	-22.76
Olympus	WS-822	WAV PCM	961200	1017061	55861	-4.46	-3.79	-35.84	-34.96	-10.92	-10.21	-29	-28.24	-22.3	-21.58
Olympus	WS-823	WAV PCM	965000	1020886	55886	-4.48	-4.19	-37.96	-35.85	-10.67	-10.51	-29.65	-28.61	-22.09	-21.89
Philips	Voice Tracer	WAV PCM	1039143	1170716	131573	-14.3	-14.36	-51.54	-51.82	-18.12	-18.28	-42.59	-42.96	-33.38	-33.56

BREAK #3

Break #3																
Recorder		Format	Samples			Peak Amplitude (dB)		Minimum RMS Power (dB)		Maximum RMS Power (dB)		Average RMS Power (dB)		Total RMS Power (dB)	
Brand	Model	WAV PCM /MP3/WMA	Begin	End	Length	Left	Right	Left	Right	Left	Right	Left	Right	Left	Right
Olympus	DM-520	WMA	741000	767947	26947	-8.9	-6.46	-45.37	-44.8	-14.15	-12.14	-28.94	-27.06	-22.34	-20.41
Olympus	DM-620	WAV PCM	1415200	1450579	35379	-4.77	-5.25	-39.89	-41.2	-10.2	-10.75	-27.44	-28.25	-19.62	-20.18
Olympus	WS-550M	MP3	1373000	1383000	10000	-28.7	-27.62	-40.12	-40.56	-38.88	-39.7	-39.29	-40.04	-39.35	-39.95
Olympus	WS-560M	MP3	1373000	1383000	10000	-29.01	-28.37	-41.5	-40.08	-40.38	-39.09	-40.82	-39.54	-40.79	-39.52
Olympus	WS-700M	WAV PCM	1427881	1481726	53845	-15.01	-14.1	-40.96	-41.78	-22.05	-20.15	-36.01	-35.61	-32.33	-30.74
Olympus	WS-700M	WAV PCM	1430300	1484200	53900	-4.92	-9.89	-42.79	-46.28	-10.29	-15.93	-30.86	-35.7	-21.55	-27.16
Olympus	WS-750M	WAV PCM	1440000	1475000	35000	-23.9	-25.37	-37.26	-38.76	-33.64	-35.84	-35.61	-37.44	-35.54	-37.4
Olympus	WS-760M	WAV PCM	1440000	1475000	35000	-25.85	-23.42	-39.12	-36.54	-35.94	-32.33	-37.57	-34.42	-37.6	-34.43
Olympus	WS-802	WAV PCM	1460000	1500000	40000	-22.11	-22.47	-36.61	-35.95	-31.74	-31.09	-34.01	-33.42	-33.91	-33.34
Olympus	WS-822	WAV PCM	1465000	1505000	40000	-22.52	-20.93	-35.57	-34.72	-31.35	-30.56	-33.12	-32.45	-33.1	-32.4
Olympus	WS-823	WAV PCM	1466000	1512000	46000	-23.31	-21.09	-37.14	-35.75	-33.5	-31.29	-35.32	-33.35	-35.31	-33.32
Philips	Voice Tracer	WAV PCM	1612650	1744191	131541	-14.37	-14.67	-50.73	-51.54	-17.99	-18.28	-42.66	-43.11	-33.1	-33.44

NUMBER OF SAMPLES PER BREAK

Number of Samples per Break							
Format	**Recorder Make/Model**	**Serial Number**	**Break 1**	**Break 2**	**Break 3**	**Mean**	**Standard Deviation**
WAV PCM	Olympus DM-620	100115567	35376	37548	35379	36101	1253.14
	Olympus WS-700M	100124078	51755	52058	53845	52552.67	1129.40
	Olympus WS-700M	100126397	53853	51894	53900	53215.67	1144.84
	Olympus WS-750M	200104369	35000	53805	35000	41268.33	10857.07
	Olympus WS-760M	200110592	35000	53838	35000	41279.33	10876.12
	Olympus WS-802	100137893	40000	53725	40000	44575	7924.13
	Olympus WS-822	100169832	45000	55861	40000	46953.67	8108.97
	Olympus WS-823	100258938	40000	55886	46000	47295.33	8021.82
	Philips Voice Tracer	LFH0882	131601	131573	131541	131571.67	30.02
MP3	Olympus WS-550M	200137081	10000	15336	10000	11778.67	3080.74
	Olympus WS-560M	200126197	10000	15293	10000	11764.33	3055.91
WMA	Olympus DM-520	100104915	26942	25953	26947	26614	572.45

LEFT POWER PER BREAK

Left Power per Break						
Format	Recorder Make/Model	Break 1	Break 2	Break 3	Mean	Standard Deviation
WAV PCM	Olympus DM-620	-19.88	-20.37	-19.62	-19.96	0.38
	Olympus WS-700M	-32.51	-29.12	-32.33	-31.32	1.91
	Olympus WS-700M	-21.53	-22.19	-21.55	-21.76	0.38
	Olympus WS-750M	-35.38	-21.42	-35.54	-30.78	8.11
	Olympus WS-760M	-37.72	-21.9	-37.6	-32.41	9.10
	Olympus WS-802	-34.47	-21.61	-33.91	-30.00	7.27
	Olympus WS-822	-33.54	-22.3	-33.1	-29.65	6.37
	Olympus WS-823	-35.35	-22.09	-35.31	-30.92	7.64
	Philips Voice Tracer	-33.76	-33.38	-33.1	-33.41	0.33
MP3	Olympus WS-550M	-39.29	-16.26	-39.35	-31.63	13.31
	Olympus WS-560M	-40.66	-17.49	-40.79	-32.98	13.41
WMA	Olympus DM-520	-22.27	-19.59	-22.34	-21.4	1.57

RIGHT POWER PER BREAK

Right Power per Break						
Format	Recorder Make/Model	Break 1	Break 2	Break 3	Mean	Standard Deviation
WAV PCM	Olympus DM-620	-20.36	-21.5	-20.18	-20.68	0.72
	Olympus WS-700M	-30.72	-28.91	-30.74	-30.12	1.05
	Olympus WS-700M	-27.08	-23.85	-27.16	-26.03	1.89
	Olympus WS-750M	-37.26	-21.76	-37.4	-32.14	8.99
	Olympus WS-760M	-34.71	-21.54	-34.43	-30.23	7.52
	Olympus WS-802	-34.03	-22.76	-33.34	-30.04	6.32
	Olympus WS-822	-32.73	-21.58	-32.4	-28.90	6.34
	Olympus WS-823	-33.32	-21.89	-33.32	-29.51	6.60
	Philips Voice Tracer	-33.85	-33.56	-33.44	-33.62	0.21
MP3	Olympus WS-550M	-39.85	-16.51	-39.95	-32.10	13.50
	Olympus WS-560M	-39.78	-16.48	-39.52	-31.93	13.38
WMA	Olympus DM-520	-20.36	-18.71	-20.41	-19.83	0.97