

Audio Tone Mapping

Or

Bringing Music Out of the Shadows

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The Forensics Software Product, DC Forensics Version 11.08, was used for
all Audio measurements performed and shown within this application note. This
software is available from the Diamond Cut Productions Company.

1.0 Edition
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Introduction

The *Acoustical Era* defines a time when Music was recorded without the use of electrical devices. The phrase *Acoustical* means that the grooves holding the music were created *solely from the energy in the music*. This method of audio recording was the original technique invented by Edison in 1877 and continued to approximately 1925 by the various record companies. During 1925, the Western Electric company introduced a new recording method that both amplified the music and cut the record grooves using the newly developed vacuum tubes and microphones.

This new Electrical Method revolutionized the record industry and provided records that could capture a full range of the music frequencies present in the recording studio.

When the Acoustic Records were produced, some music instruments could not be recorded due to the sound limitations in the mechanical recording technology. Also, the presence of one recording microphone in the shape of a long cone, required a specific placement of musicians in the studio to balance the volume of the recorded sound. The use of the new electric recording freed the musicians to both locate themselves around the microphone in a natural manner and allowed previous instruments that recorded poorly to be used in the song.

For most record companies the fall of 1925 represented a major switch to this new technology; however, the Edison Phonograph Company waited till mid-1927 to fully embrace electric recording.

The period before the use of Electric Recording, the Acoustic Era, contained many new types of music such as Dixieland, Blues, Jazz, Ragtime, and much more. While music continued to be recorded after this major technology change to Electric recording, much of these *new music styles* occurred during the Acoustic recording time.

The goal of this new method of Audio Restoration is to improve the sound of these unique early Acoustic recordings so that they can be heard as close to what was heard while the music was being recorded in the music studio. Musical instruments cannot be added to the recordings, but an improvement can be made

that *counteracts* the changes that were made to the music *by the mechanical recording and playback limitations*.

This note will focus on Acoustic Records manufactured by the Edison Company. The techniques that will be described will be useful for other Phonograph Companies records, i.e. Victor 78 RPM.

Background To This New Method

In the mid 1980's, I had recorded some early Edison Music while visiting my Parents. My father had a number of these old phonographs and records, and I recorded some of his Edison music for my own use on tape cassettes. When my father heard the playback of these tape-recorded songs, he commented that they seem to sound better to him than as heard played on these old phonographs. The tape recorder I used applied ALC (Automatic Level Control) while recording and the result seemed to sound better. Many years later in my retirement, I remembered his comment and began to research how to restore these old songs, which led to writing a book titled *Music Restoration Handbook*. This book uses audio software products from the Diamond Cut Productions company.

The techniques described in this Handbook involved transcribing the music in the record grooves to a digital music file, followed by removal of any distortion from groove deficits and other surface problems. The resulting Acoustic music file represents what was *recorded* at the Edison studio, but not necessarily what was *heard* at the Studio or by a user of an Edison Phonograph.

In general, the restored Acoustic Era Music is enjoyable to hear, but the limitations in the Acoustic Recording process remain and are very prominent in the song. In the past, I tried to improve the sound from these records using a method that created new, low frequencies from the music. This *Acoustical Correction* method (described in my Handbook) did work at times but would often create an Un-Natural sound for Vocals. Other techniques to improve the sound using standard Bass and Treble tone controls; resulted in music that had large amounts of low frequency rumble and surface noise, due to the mechanical recording technology in use at the time.

A better method to improve music from the Acoustical Era was developed when I modified some concepts developed in Photography Image Improvements for use with digital audio files.

New Method

While I was using a Photography software product to modify the shadows and highlights in a picture I had taken, I considered that this type of technology could be applied, with modification, to Acoustic Recording. The original picture image lacked detail in the shadows while still having a good image for the highlights (A common rule in Photography is to expose for the highlights and fix the shadows). The photo software I used (Canon DPP4) provides a tool called *Gamma Adjustment* that allows the brightness of shadow values to be increased via a non-linear mathematical function, while keeping the highlights the same. The pixel amplitude values in the photo corresponding to the shadow areas could be brighten while leaving other area's the same. The human eye responds to light's Amplitude or Luminescence in a logarithmic manner as does the way we hear music. This parallel to *seeing shadows* in a picture and *hearing quiet* passages in a song inspired me to develop a new method.

After working on several photos to bring up the shadow details, I thought that the same idea might be useful in Acoustic Music, as the music had many tones that were recorded at a low level or *in the shadows*. A typical Photography Image Adjustment (From Canon DPP4 Software) is shown in Figure 1.

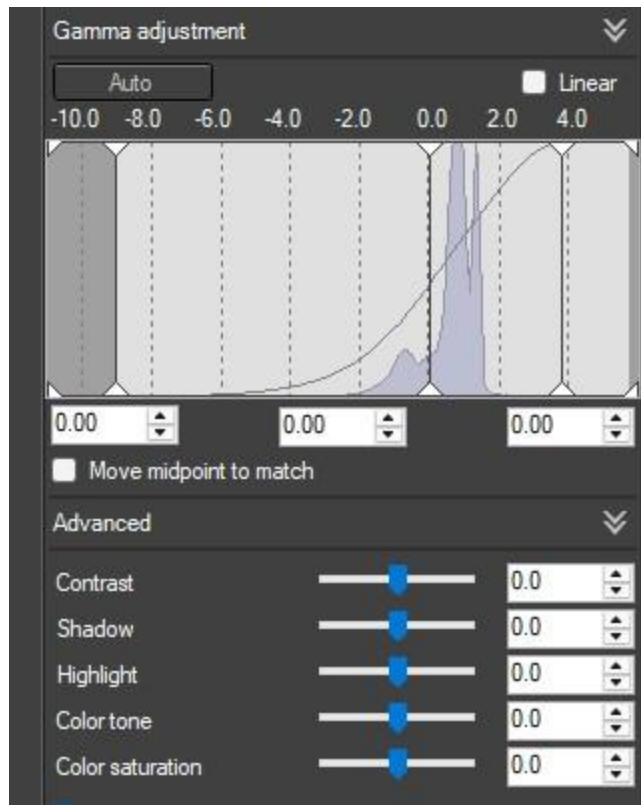


Figure 1 Photography Software for Tone Adjustments

This idea of using a non-linear function to improve Acoustic Recordings led to two experiments regarding Acoustic music. One was to investigate how the Playback of a song, using an original Edison Phonograph, differs from a restored transcription using the methods in my Handbook. The second experiment was to take the transcribed music and pass it through a non-linear function that would amplify the low values while leaving the higher values as recorded. The gain in amplitude would start high and then gradually be reduced. This type of curve shape can be called a *Sigmoid Function*.

The observation made many years ago by my father regarding sound improvement via ALC for these recordings' fits, in general, into this method.

Comparison Between Transcribed Music & Edison Phonograph Music

In these experiments, an Acoustic recorded Edison Record “Mary Lou,” by Duke Yellman and His Orchestra was used to compare the mechanical playback of the record verses using the result from a modern electrical turntable and cartridge. This record was recorded in 1926 but still used the Edison Acoustic recording process. The mechanical playback of the record used an Edison Sheriden S-9 Diamond Disc Phonograph made in the same period (1920’s) as the record. A microphone was placed about two feet in front of the horn opening to record the music. The resulting digital music file was 16 bits deep and used 44.1 thousand samples per second.

This same record was also played back on a turntable using a magnetic cartridge to transcribe the music. After a transfer to a digital file, the surface noise and groove distortions from wear were removed which then produced a cleaned-up file 16 bits deep and samples 44.1 thousand per second. No frequency modifications were made to the Transferred Digital Music File. The only changes were removal of noise.

Note: The specific methods used to produce the Clean Transferred file can be found in my Book “Music Restoration Handbook”.

These two versions, record played back on period phonograph and transcribed using magnetic cartridge, were compared and when heard sounded significantly different. A picture of the Edison Diamond Disc Record is in Figure 2; the period Edison Phonograph is in Figure 3 and the turntable used to transcribe the song is in Figure 4.

Both music files were Normalized to a standard Amplitude value (0 dB) when played back.



Figure 2 Edison Diamond Disc Record



Figure 3. Edison Diamond Disc Phonograph Model S-9



Figure 4 Reloop Turntable & Magnetic Cartridge

The Edison Phonograph produced a nice loud sound with details in the music. The transcribed song had a nice clean sound but seemed somewhat lacking in volume and instrument detail. A significant difference was not expected, but clearly the music from the Edison Phonograph provided a better sound. The question was *why did the record sound better using the original Phonograph?*

Frequency Spectrums

The DC Forensics Software was used to produce these Frequency Spectrums of the two music sources and revealed a difference between the two different playback methods. They are shown in Figure 5.

The White Trace is the Edison Phonograph Music as heard by the microphone. The Yellow Trace is the result from the Electrical Transcription. Both Amplitudes of the digital files were Normalized to a standard amount (0 dB).

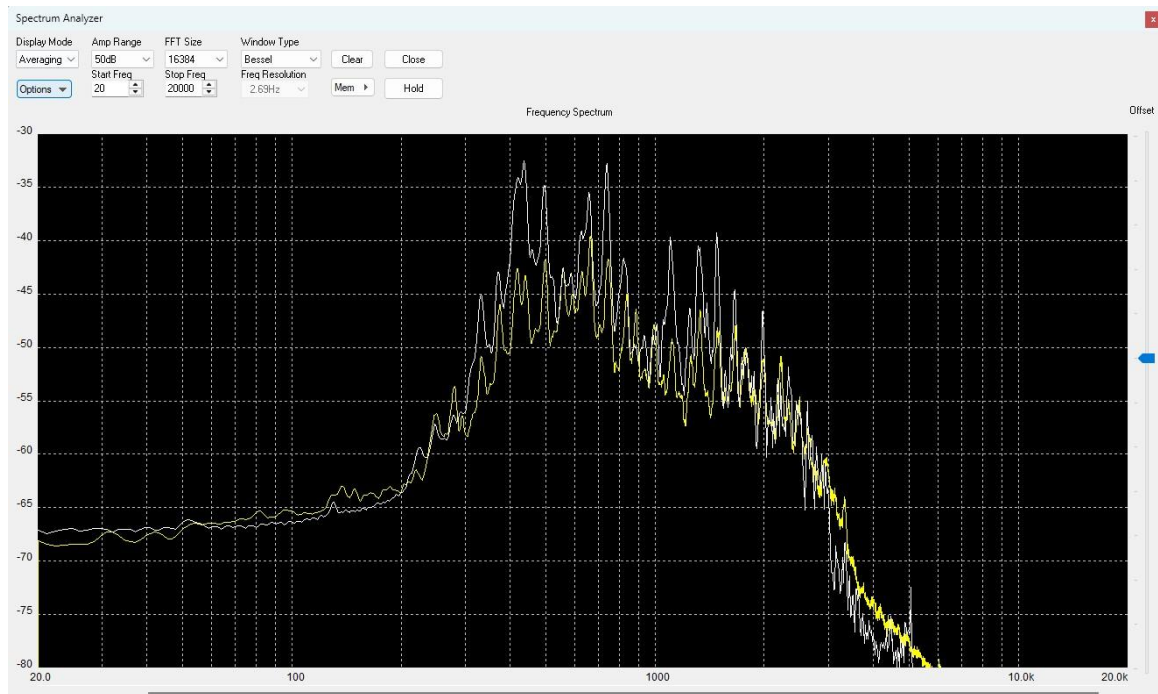


Figure 5. Frequency Spectrums between Mechanical (White) and Electrical Playback (Yellow)

Both curves show a limited audio frequency range, but the White trace shows extra amplitude (peaking) for some frequencies while the yellow trace is significantly lower over the range of the music.

These curves demonstrate that the Edison Phonograph's mechanical playback components were designed to amplify certain recorded frequencies over

the range of the music. While the Edison audio engineers (Early 20th Century) lacked high-tech audio equipment, they did find mechanical methods to extract as much sound as possible from the record grooves. There is a noticeable boosting in music tones by using the mechanical playback components from what was placed into the music record grooves.

The question remains if the design of the mechanical playback system compensated for the recording technology or the playback technology (or both)?

Statistics

In addition to a comparison of the frequency spectrums between the mechanical and electrical playback, another method used for analysis was to measure the *statistics* of the digital files. The DC Forensics Software provides this ability.

The digital data for the music files consists of individual digital words of 16 bits with unique values spaced apart every 23 microseconds (44.1 thousand times a second). Due to the plus and minus nature of the signal, the range of the amplitude values is positive 32K to minus 32K.

The entire song's digital values were processed to measure the RMS (Root Mean Sum) and the Crest Factor (Peak Amplitude divided by the RMS value). The Crest Factor is a useful indication of the dynamic range of the song, as it indicates the highest level of music compared to the overall *intensity* of the song (RMS).

Many audio measurements are possible, some using frequency filters and complex algorithms; however, these statistical measurements were used with very good results. The software used to create the file statistics includes other useful measurements and the results are shown in Figures 6 and 7.

Start Time = 00:00.0000
 Stop Time = 03:55.3084
 Selected Region = 03:55.3084sec
 Selected Samples (Mono) = 10377104
 Sample rate = 44100Hz
 Bit Depth = 16 Bits
 RMS = 5.6k samples
 Rectified Avg = 2.1k samples
 Max Pos Peak = 32k samples
 Max Neg Peak = 32k samples
 Crest Factor = 5.84

Figure 6 Edison File Statistics

Start Time = 00:00.0000
 Stop Time = 03:53.1171
 Selected Region = 03:53.1171sec
 Selected Samples (Mono) = 10280468
 Sample rate = 44100Hz
 Bit Depth = 16 Bits
 RMS = 3.2k samples
 Rectified Avg = 1.1k samples
 Max Pos Peak = 24k samples
 Max Neg Peak = 32k samples
 Crest Factor = 10.22

Figure 7 Clean Transcribed Statistics

Compare the Crest Factor between the two versions of the same song. The Edison Phonograph's music has a significantly *lower* value (5.84) versus the Level Two Transcribed song (10.22). When the Crest Factor is converted to dB value, the Phonograph's Factor is 15.33 dB, while the transcribed music is 20.19 dB or almost 5 dB different.

These statistics demonstrate that the Edison Phonograph yields a song with less deviation from a music power value than that transcribed using a magnetic cartridge. The Transcribed Music *Shadows or Weak levels* are much lower than the highest amplitude while the Phonograph's differences are less. This results in hearing a distinct difference between the playbacks.

The use of the frequency spectrums and the music statistics can provide a way to measure how changes to the music digital values impact the overall sound of the music.

Next, a new method was developed to integrate Photography Tone Mapping into audio music.

Audio Tone Mapping Method

A non-linear math function was selected with a S shape, like the Photography technique, to modify the signal levels in the song. The input to the function would be the transcribed and noise free music. The result from using this function will be called an Enhanced Music File.

This function is available using the DC Forensics 11.08 software and is a fifth order polynomial with the form of:

$$Y = A0 + A1X^1 + A2X^2 + A3X^3 + A4X^4 + A5X^5 \quad EQ(1)$$

Where Y is the Output values and X are the input values for each digital word. This Equation (1) has a general form and after various values for the A variables were tried, a specific function was created to amplify the weak values in the music while maintaining the higher values. This function was graphed for an input from -1.0 to +1.0 using the A coefficient values:

$$A0 = 0.0 \quad A1 = 1.750 \quad A2 = 0.060 \quad A3 = -1.270 \quad A4 = -0.060 \quad A5 = 0.520$$

The resulting graph for this function (using Excel) is in Figure 8. Notice that low X values Map to slightly larger Y values and that as the X values become larger, the Y values are close to the same as the input X values. This equation is designed to simulate Photo Tone Mapping and will increase the volume for the quiet music passages.

The symmetry for this function is important (Odd), as you want the positive and negative values to undergo the same relative change in values. Also a negative value stays as a negative value, and a positive value stays as a positive value.

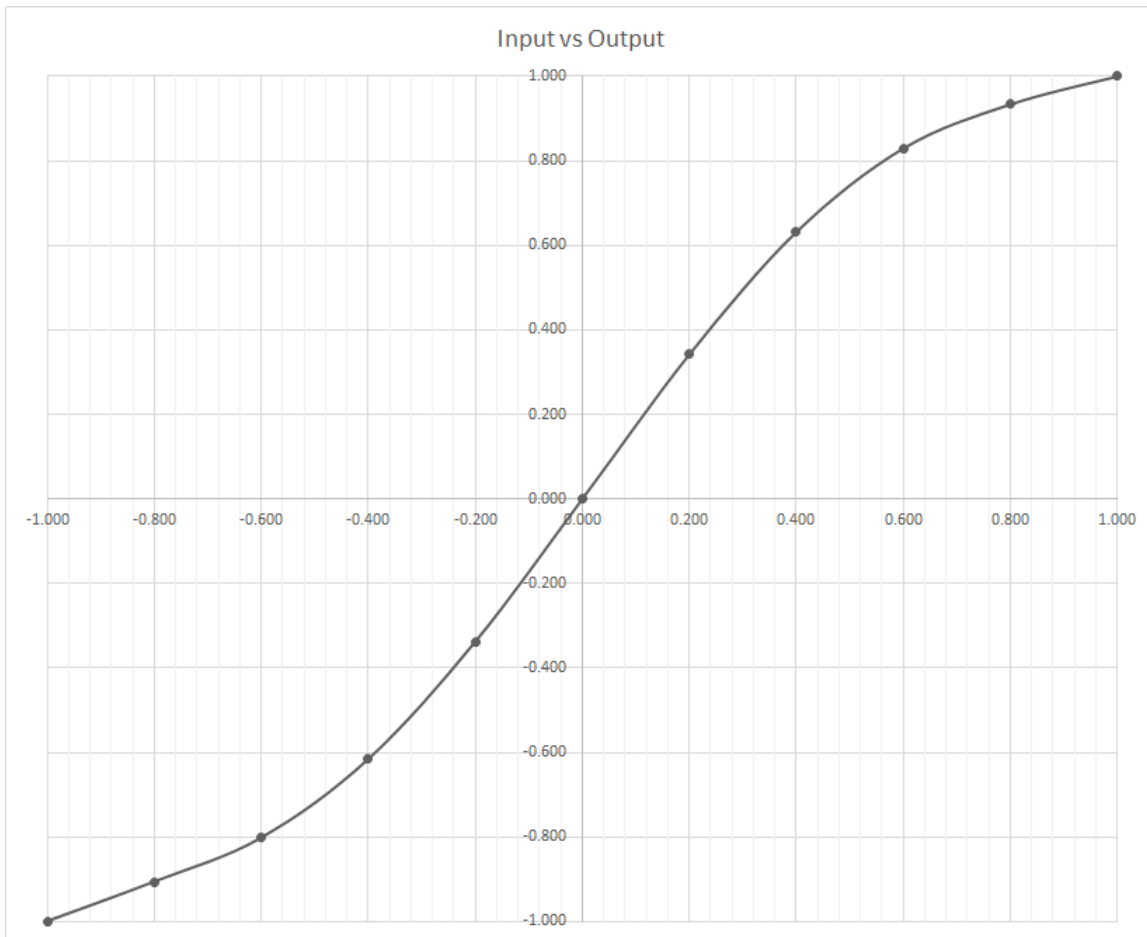


Figure 8 Input vs Output for Equation 1

This math function was applied to the Clean Transcribed Music file. The result of this data change will be called an Enhanced Music file.

The Frequency Spectrum of this new file is in figure 9. The White graph is the previous Clean Transcribed File, and the Yellow is the new Enhanced Music file. As was done before, an Amplitude Normalization to the data was performed after the equation was used.

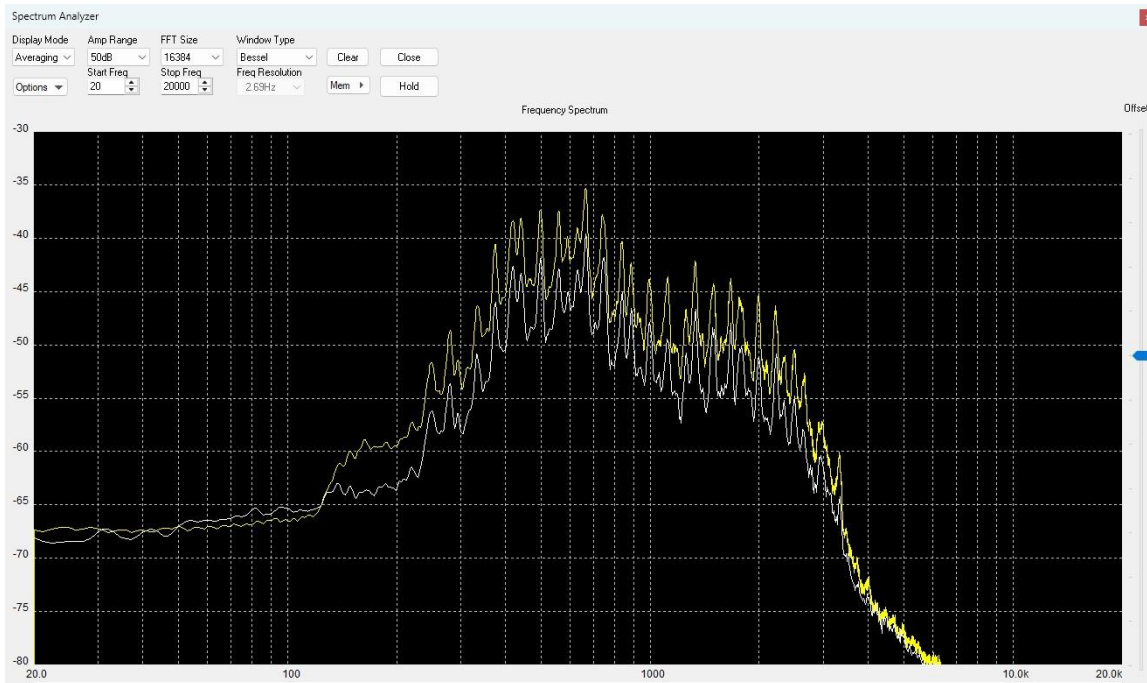


Figure 9 Clean (White) and Enhanced (Yellow)

The Statistics for the Enhanced File are in figure 10.

Start Time = 00:00.0000
 Stop Time = 03:53.1171
 Selected Region = 03:53.1171sec
 Selected Samples (Mono) = 10280468
 Sample rate = 44100Hz
 Bit Depth = 16 Bits
 RMS = 5.4k samples
 Rectified Avg = 1.9k samples
 Max Pos Peak = 31k samples
 Max Neg Peak = 32k samples
 Crest Factor = 6.09

Figure 10 Statistics for Enhanced Music File

Notice the significant decrease in the Crest Factor from the original 10.22 to 6.09 and the corresponding boost to many frequencies in the Spectrum. When this music file is heard it is close to or even better than that heard from the Edison Phonograph.

The increase in the low frequencies, below 400 Hz, now provides an opportunity to boost these frequencies and improve the overall music sound. Prior to use of equation (1), any boost to these frequencies would also increase low end noise present during the manufacture of these records. Recall from the Edison Phonograph frequency spectrum how frequencies below 300 Hz have a very limited amplitude. In the Edison recording music studio, there were significant musical energy below 300 Hz, but this was not heard during playback. How much of the low music frequencies present in the Studio that was recorded onto the initial master record cannot be known at this time; however, the Enhanced music *does indicate* some useful energy.

A final restoration to the music used the previous Enhanced file along with another use of Equation One (adding one-half of the result). The low-end frequencies benefited from a 78 RPM 250 Hz Turnover. *Baxandall* Tone Controls applied frequency boosts of low, mid, and high values. Some extra filtering was applied to remove new noise frequencies, along with a normalization to have the music amplitude fully range over the available values. This completed the restoration operation.

The resulting Restoration Music file is in figure 11 with the yellow trace, along with the original Edison Phonograph white trace. Figure 12 contains the statistics for the restored song.

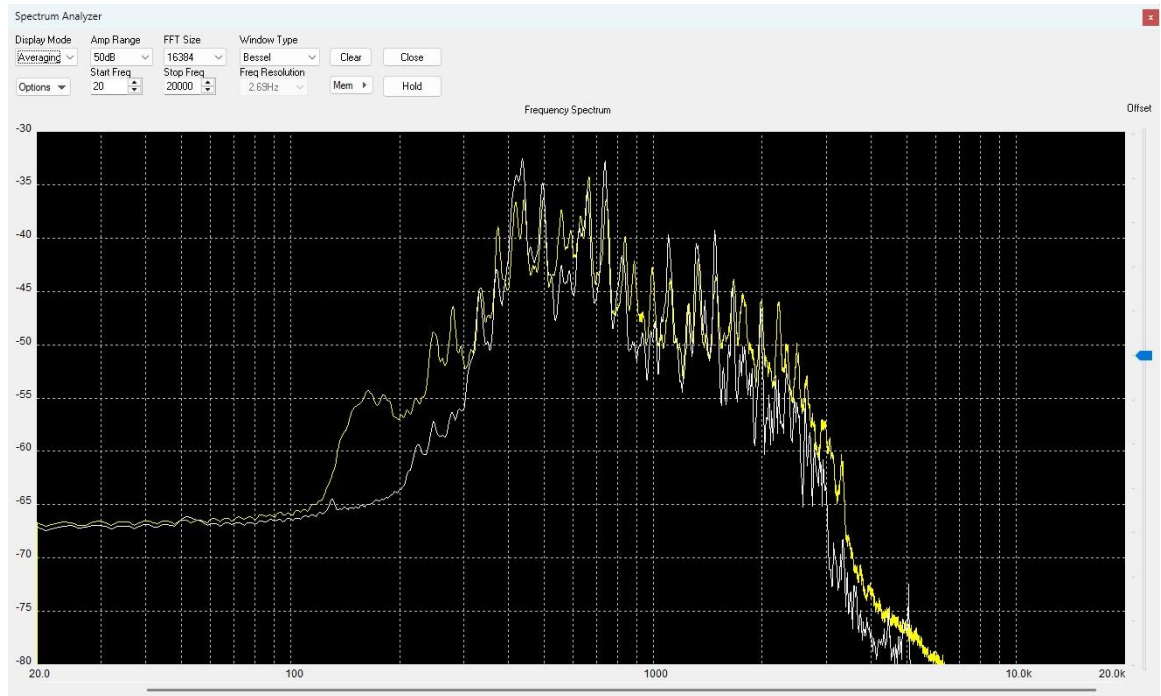


Figure 11 Restored Yellow Trace with Edison Phonograph White Trace

Start Time = 00:00.0000
 Stop Time = 03:53.1171
 Selected Region = 03:53.1171sec
 Selected Samples (Mono) = 10280468
 Sample rate = 44100Hz
 Bit Depth = 16 Bits
 RMS = 5.9k samples
 Rectified Avg = 2.2k samples
 Max Pos Peak = 31k samples
 Max Neg Peak = 32k samples
 Crest Factor = 5.53

Figure 12 Statistics of the Restored Music

The crest factor is now slightly less than the result from the Edison Phonograph. The music is very pleasant to hear and provides an ability to hear the music close to the way it was heard in the recording studio.

Implementation

This implementation will use software algorithms within DC Forensics 11.08 and is a *starting point* for this enhancement to the Acoustic Era Music. While the results yield a significant improvement in the Music, further refinements are possible.

The input digital music file has sample values 44.1 kHz and 16 bits. The file is monaural and has been transcribed from an Edison Diamond Disc or Other Record Manufacture. Noise from the record grooves has been removed with no significant modification to the frequency content. The amplitude has been normalized to 0.0 dB. The process will be described by using screen shots from the Diamond Cut Productions software and consists of using Two Multifilters along with the Normalization Algorithm.

Step One is to apply a Multifilter that limits noise and boosts low amplitude values via the Polynomial Curve. Refer to Figures 13-16.

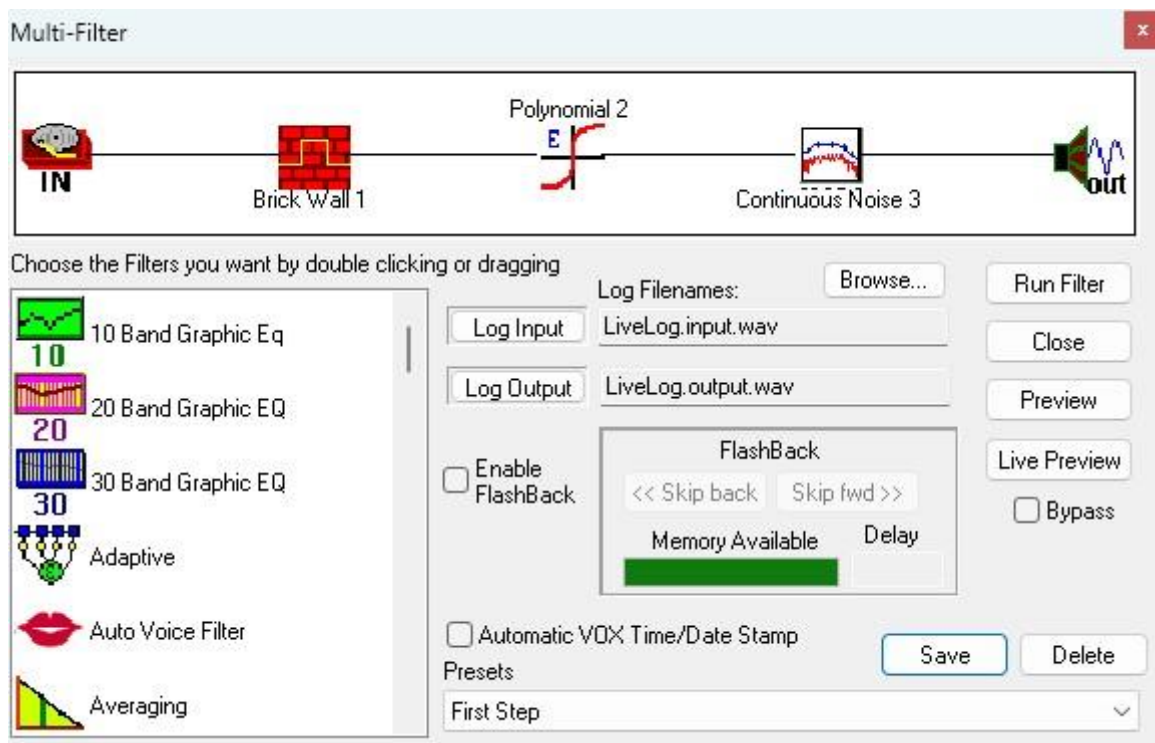


Figure 13 First Step Multifilter

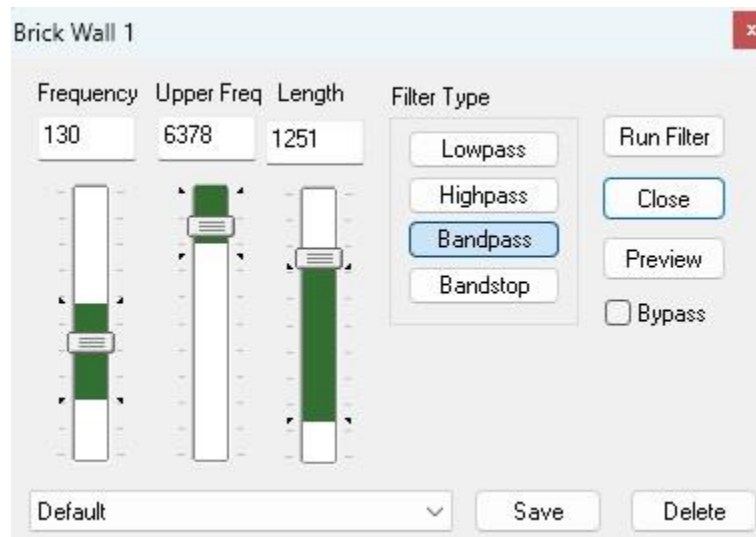


Figure 14 First Step Multifilter (Part One)

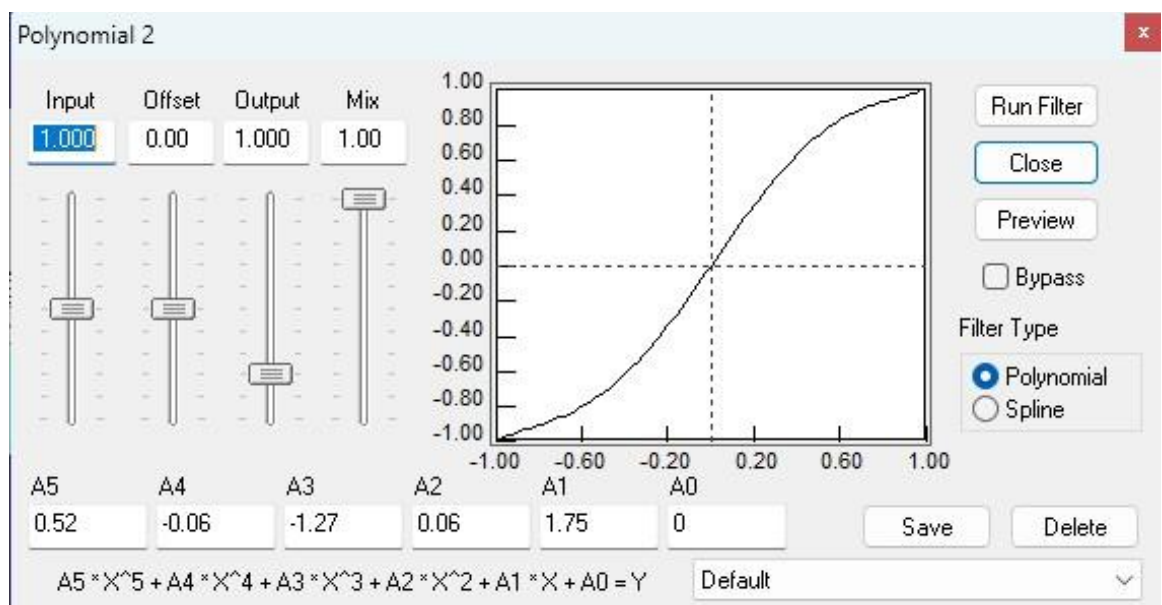


Figure 15 First Step Multifilter Part (Two)

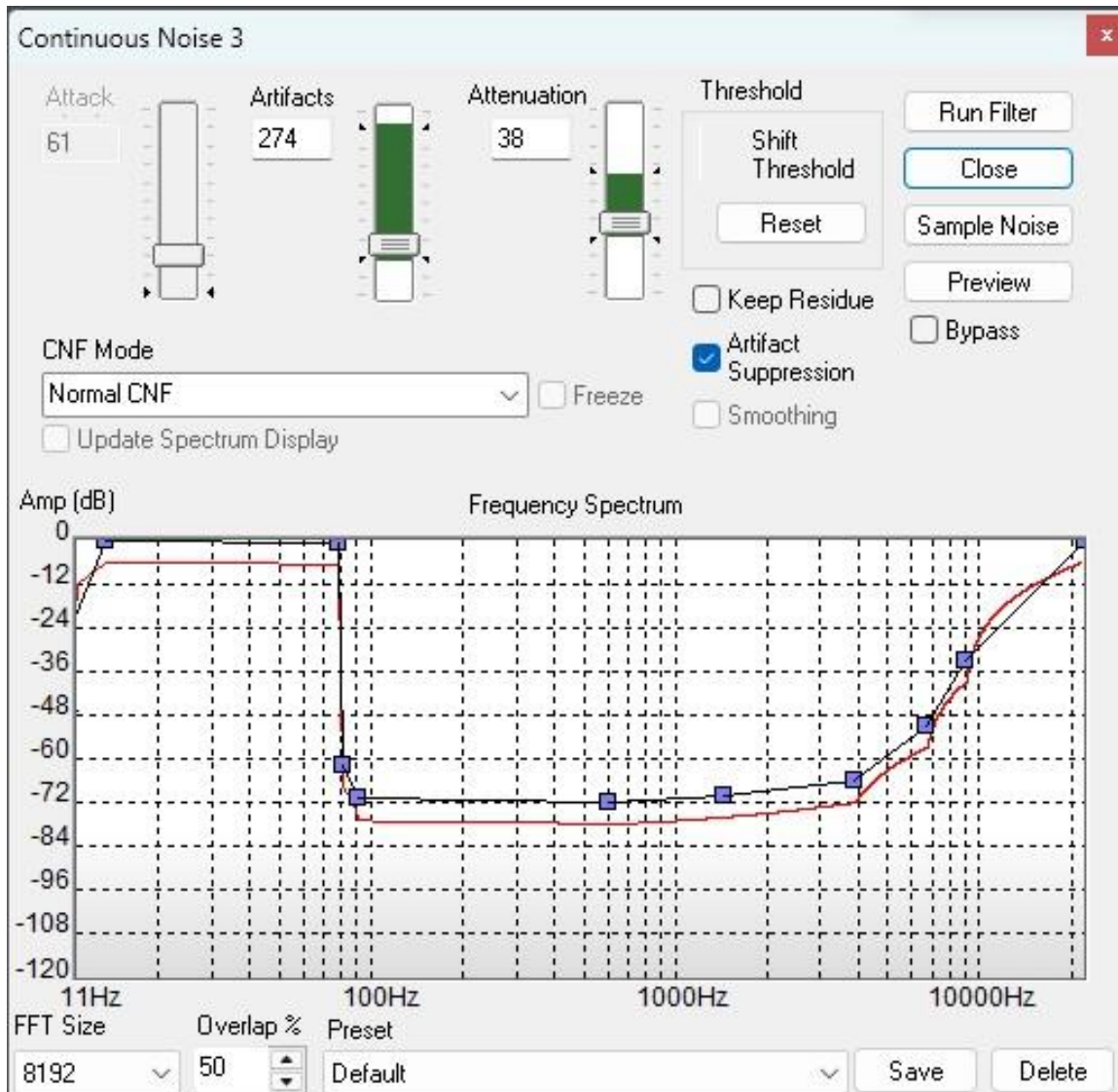


Figure 16 First Step Multifilter Part (Three)

Step Two is to apply Various Frequency Modifications to the Step One output results. After this multifilter is used, the amplitude should be normalized to 0.0 dB. The Step Two Multifilter is in Figure 17, and the various Parts are in Figures 18-22.

This completes the implementation of the process for Acoustic Records. Future refinements in the values used and techniques are possible and should be persuaded.

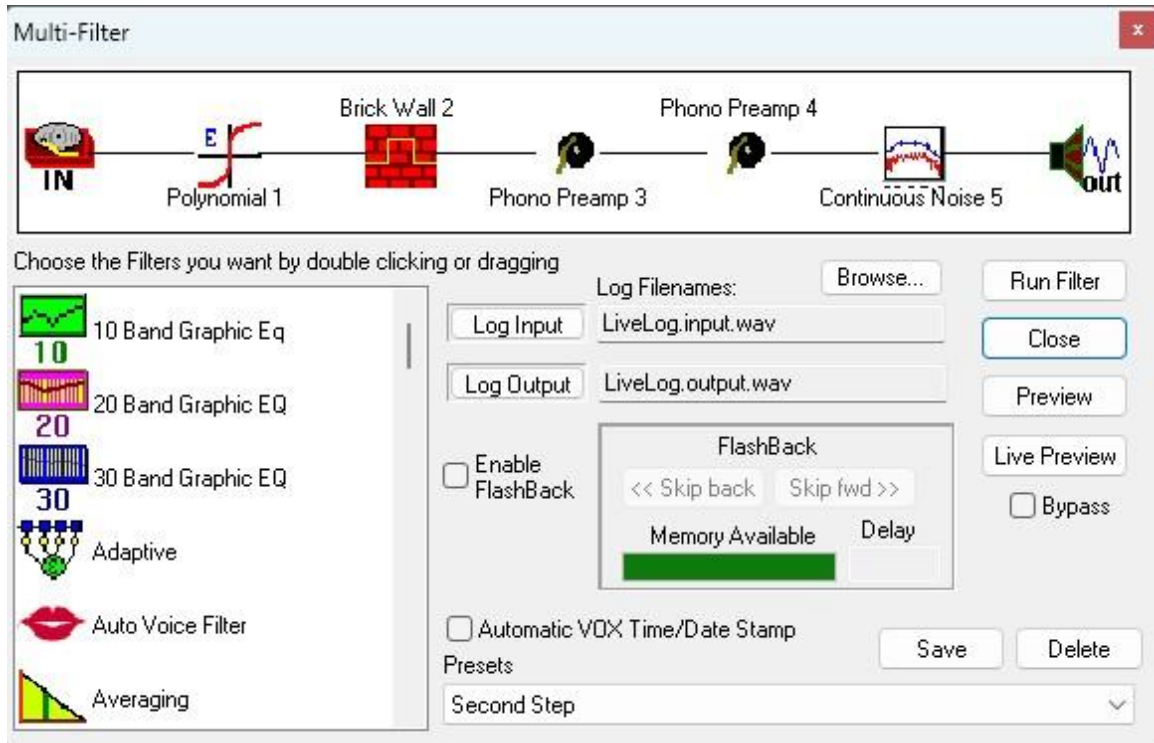


Figure 17 Second Step Multifilter

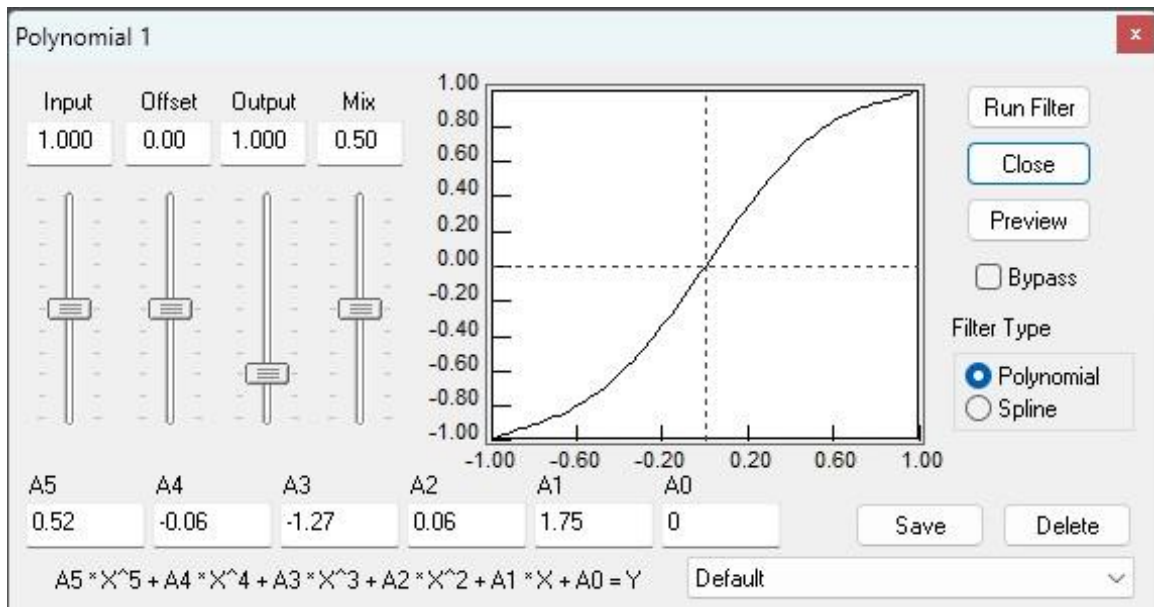


Figure 18 Second Step Multifilter Part (1)

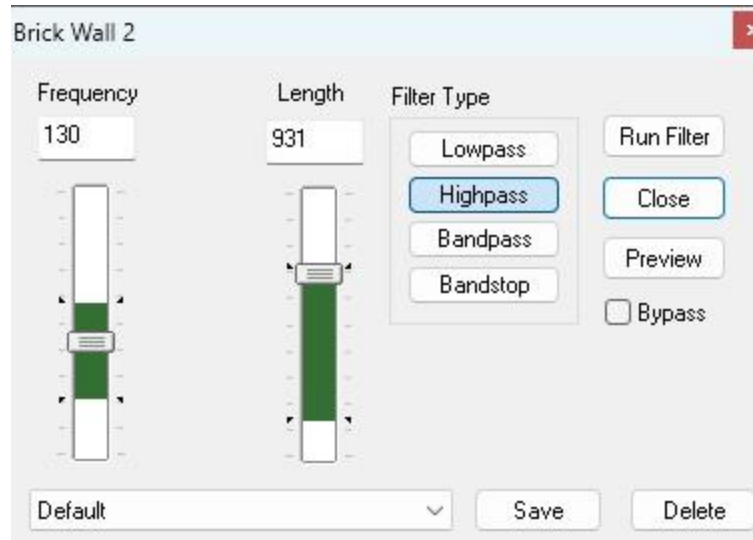


Figure 19 Second Step Multifilter Part (2)

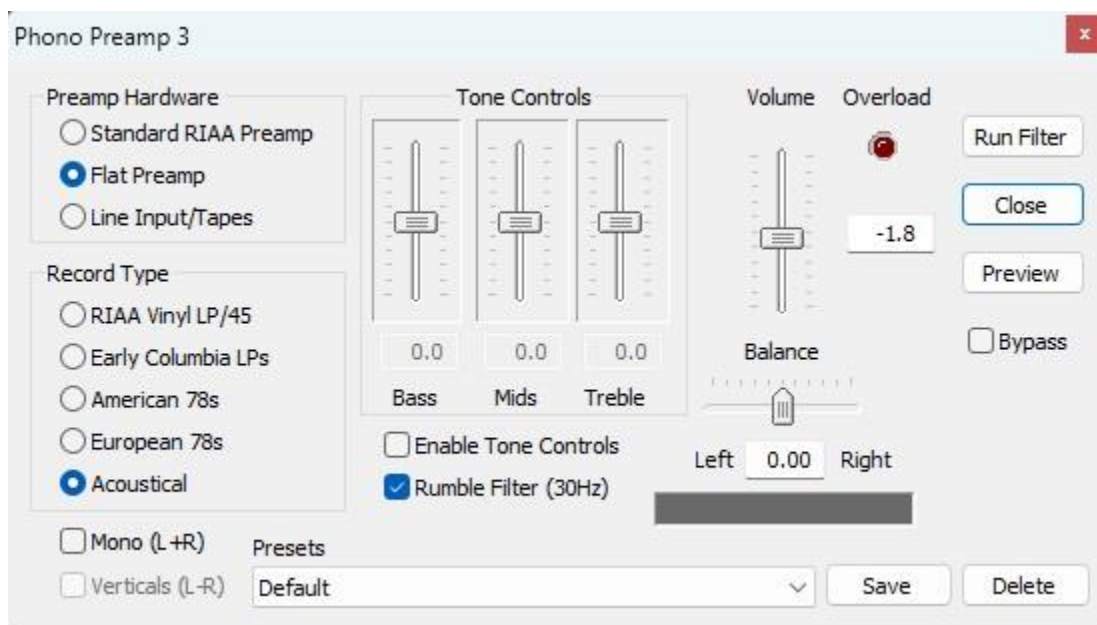


Figure 20 Second Step Multifilter Part (3)

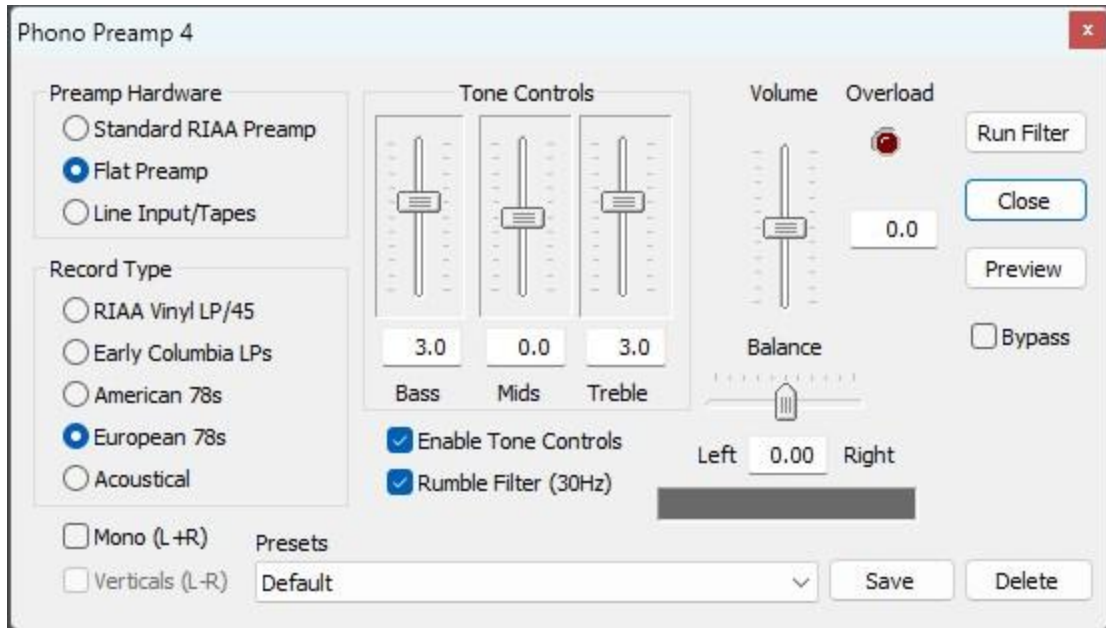


Figure 21 Second Step Multifilter Part (4)

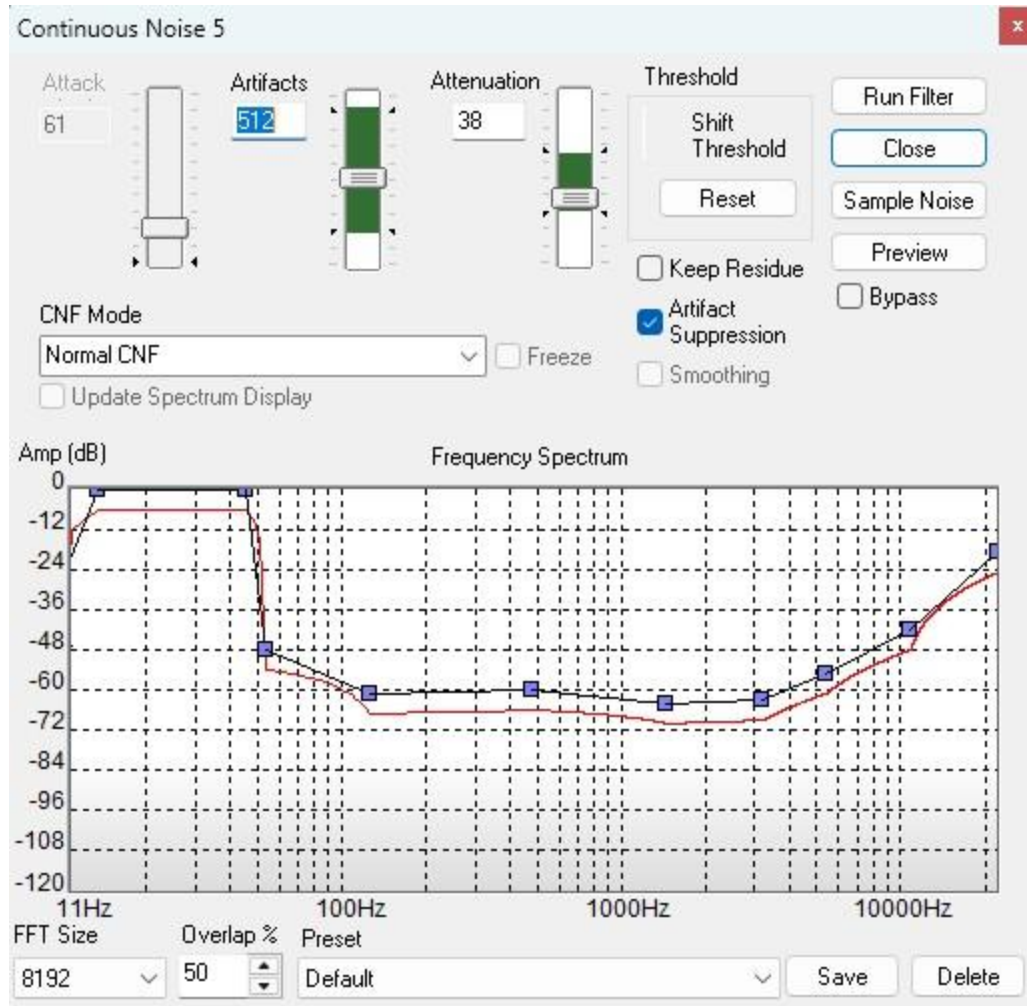


Figure 22 Step Two Multifilter Part (5)

Future Work in Audio Tone Mapping

This work represents a *beginning* to bringing back these wonderful Acoustic Recordings to *Sound the Way they were Recorded*. Values in Equation (1) can be improved along with the possible use of other mathematical relationships to bring up the lost music in the shadows. By reviewing the software tools available in Photography opens the development of an audio version of the *Raw Data Histogram Chart* that is useful in Photography.

This is a very useful Photography tool that produces a Histogram (number of occurrences verses amplitude) of the *Raw* or unprocessed digital data from the Camera's electrical light sensor. Camera sensor data goes through many conversions before it becomes an image that can be seen or printed. By performing a Histogram operation on the original or raw digital data from the camera you can observe the total range of the picture and readily see if you have an optimum light exposure for the scene. The data ranges from Dark to Shadows, then Mid-Range and finally the Highlights. Various scales can be applied to the data that help to emulate the human eyes response and exposure settings (EV units).

Figure 23 shows an example of a Photo Histogram produced using the RAWDIGGER Software, which is a very useful tool for Photography. The vertical scale is Logarithmic (simulates your vision), and the horizontal scale uses EV (Exposure Values) which relate to camera settings.

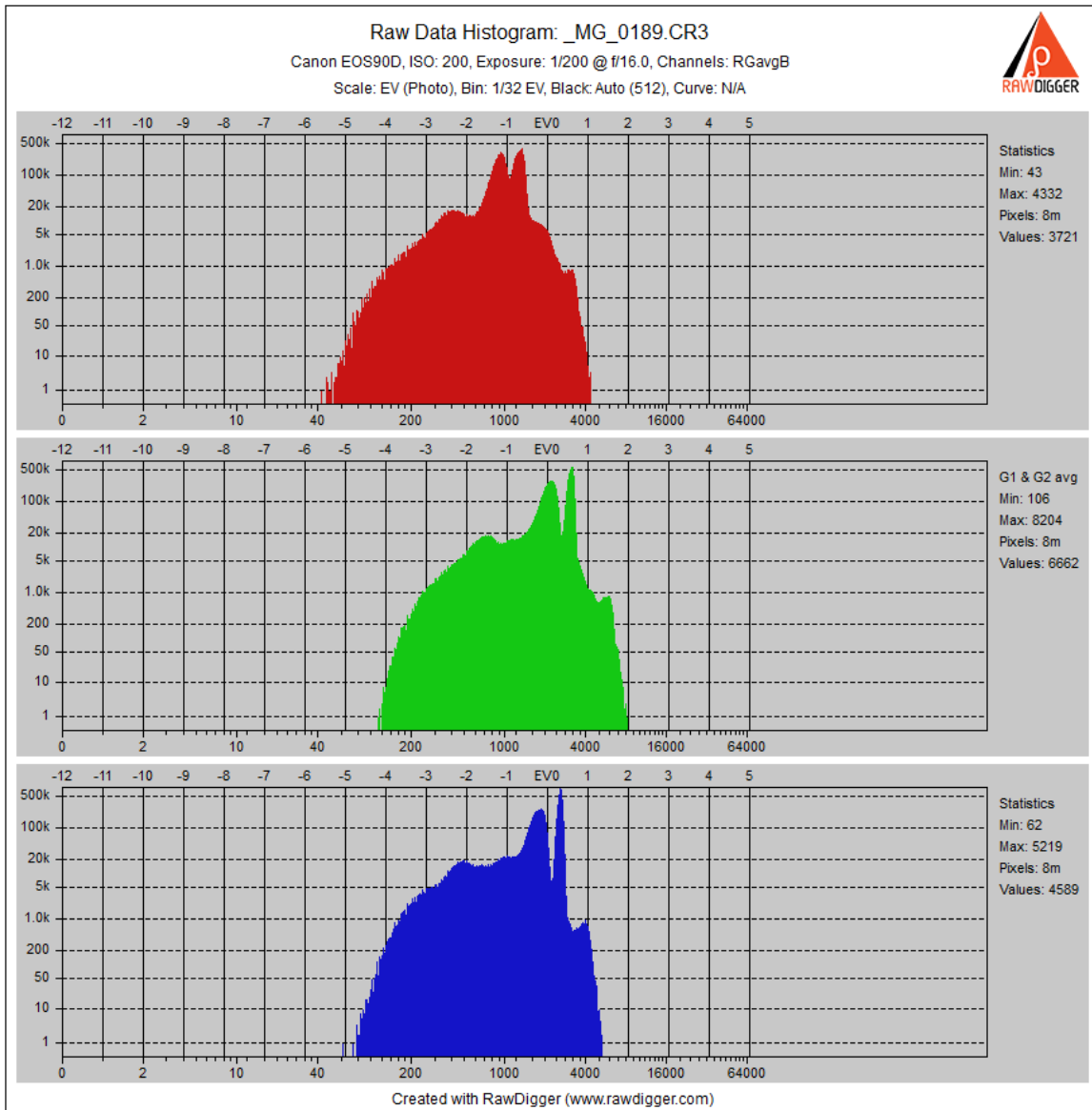


Figure 23 Photography Raw Data Histogram

A similar histogram using digital transcribed music would provide a method to visualize the music range from quiet, mid, and then loud, providing help in adjusting the various equation coefficient values. The scales in the audio histogram could be adjusted to correspond to the way that your ear hears music level changes.

Possible X axis units could be an RMS (Root Mean Square) calculation over a signal sampling interval (like the method used in the original VU meter) plotted verses number of occurrences. The resulting Histogram would display the amount of the music that is quiet verses loud or how much of the *Music is in the Shadows*.

After the use of equations like EQ (1), the resulting Histogram would show any improvements made to the overall music.

What started as a comment in the 1980's by my father regarding improvements to Acoustic music have now led to an exciting new way forward to enjoying these wonderful songs!

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