MUMT 307 Final Project: Guitar Amplifier Simulation

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I. Introduction

The digital modeling of an analog device relies on recreating actual physical systems and their related behaviors inside a virtual paradigm. Here, a mathematical model that allows to accurately describe such systems serves as the main connection between both realms. In the specific case of the Weiner-Hammstein model, used to reference analog systems [3], these elements can be viewed as a series connection between an input linear filter, a nonlinear transfer-function, and another output linear filter. This model, also referred to as the *"fundamental paradigm of electrical guitar tone"*, has the advantage of representing the basis of a music-oriented distortion system [3]. For the present project, although system modeling and the required measurements could not be accomplished due to its complexity and a lack of the necessary tools, the same model was adopted with the intent of designing an amplifier using deliberate pre-established parameters inside the Max/MSP environment.

II. Preamp Stage

From Eicha et al.'s conference paper [3], and as explained in the introduction, one can represent the analog system of interest through the following digital block diagram:

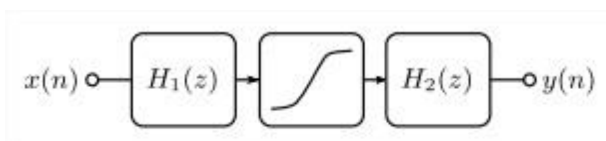

Figure 1. Block diagram of the digital model [3].

In this setup, the first filter will shape the incoming signal, thus defining which frequencies to distort, while the second stage will be the one responsible of the actual distortion; finally, the last filter will shape the already distorted sound. Here, both our linear filters will act as a pair of frequency equalization systems where certain harmonics can be cut out or added in order to shape the final output. In the present case, the first linear filter was aimed at simulating some sort of preamp sound coloration, while the last one served as the tone control of the distortion's output. Both systems were implemented using Max/MSP's preestablished filtering functions:

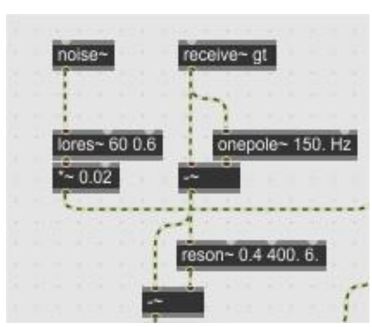

Figure 2. Preamp coloration stage.

Inside the preamp stage, we create a high pass filter at 150 Hz by running the signal through a one pole low pass filter, and then subtracting the result from the original input. The same is done in order to achieve some sort of band-stop filtering at 400 Hz through the use of a *reson~* object. Furthermore, in order to simulate the typical guitar amplifier mains “hum”, some amount of filtered white noise was added thanks to a *lores~* object at 60 Hz.

III. Distortion Stage

As shown in Figure 1., the next stage in processing was done through the application of a non-linear filter. There are several ways to accomplish this, and as explained in Ragland’s work [4], the wave-shaping technique by using lookup tables represents one of these methods. Even though this approach poses an issue because of its memoryless nonlinearity, the results obtained for this project were satisfactory enough.

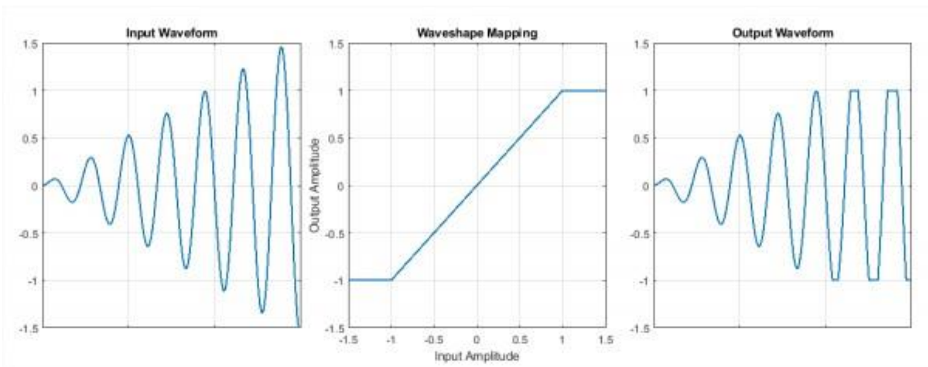

Figure 3. Wave-shaping example [4].

By looking at Max/MSP’s documentation [1, 2], a straightforward implementation of the wave-shaping technique can be found. Here, distortion was accomplished through the use of the previously mentioned lookup tables defined inside a 512-sample buffer. Furthermore, the process was separated into three different frequency ranges by using the *svf~* object in order to process low, mid and high harmonics in a different manner.

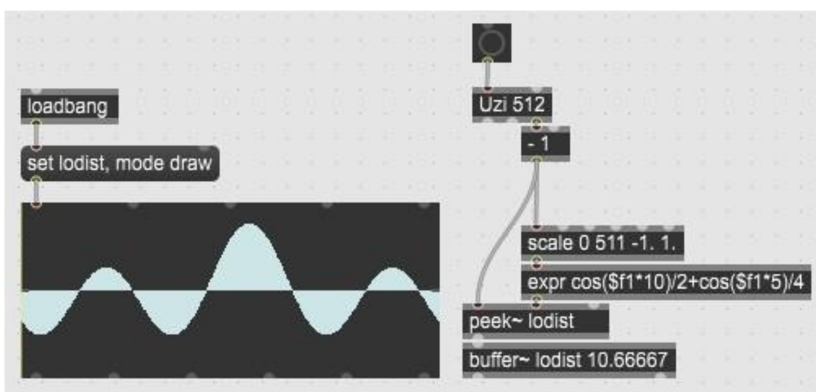

Figure 4. Low frequency distortion lookup table.

The distortion equations of each one of the sections were defined by trial and error until the desired sound was obtained.

Equation 1. Low frequency distortion

$$y = \frac{\cos(10x)}{2} + \frac{\cos(5x)}{4}$$

Equation 2. Mid frequency distortion

$$y = \frac{\tan^{-1}(25x)\sin(10x)}{5}$$

Equation 3. High frequency distortion

$$y = \frac{\tan(x)\cos(4x)}{2}$$

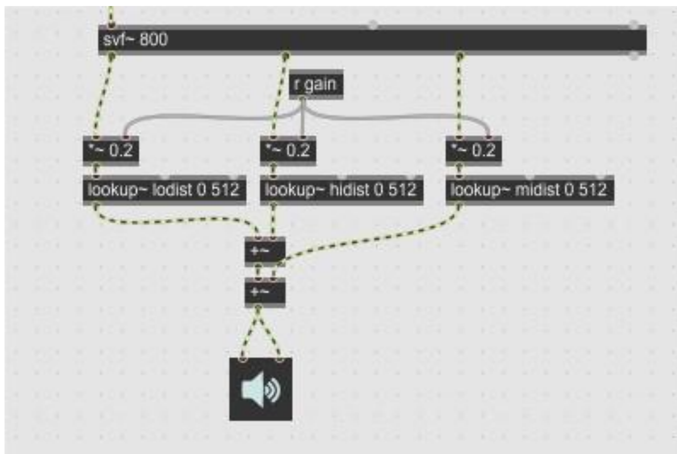

Figure 5. Distortion section.

IV. Tone Control Stage

This stage represents the last of the linear filters inside the Weiner-Hammstein model. Here, three knobs allow the user to control the amount of low, high and mid output frequencies consisting of high-shelf, low-shelf and peak notch filtering implemented by using cascaded *biquad*~ objects inside Max/MSP. The actual filter definition was obtained thanks to the *filtercoeff*~ and the *filterdetail* objects, which allowed for a visual representation of the modifiable parameters.

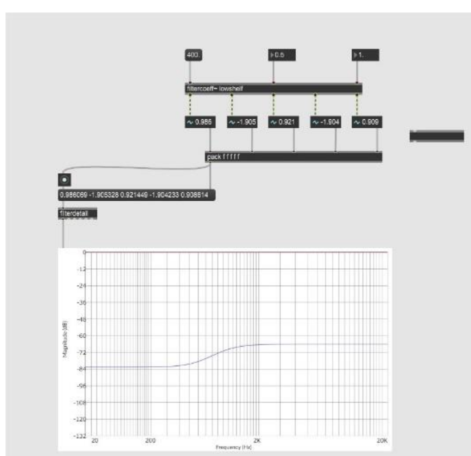

Figure 5. Filter definition.

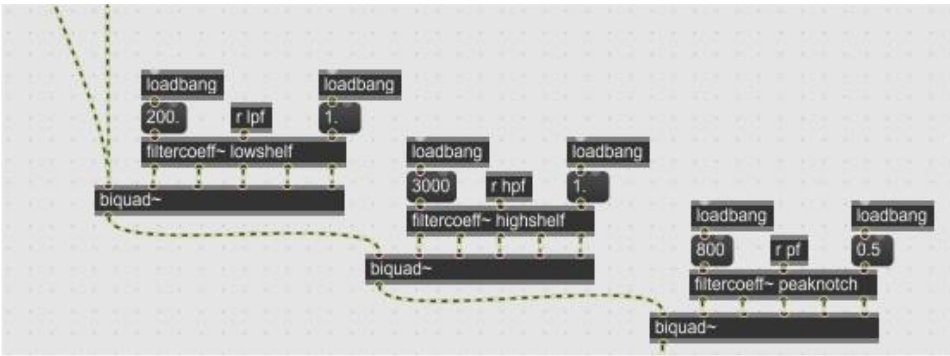

Figure 6. Tone control section.

V. Reverberation

In this final step, some reverberation was added in order to actually place our virtual amplifier inside a "digital" room. This effect was based on the Schroeder Reverberator model [5] and it gives the user the freedom of choosing the desired amount of reverb. The implementation of the actual filter proved to be challenging due to some cancelation issues inside the output matrix. Nonetheless, acceptable results were obtained by slightly modifying the filter's output.

Figure 7. Reverb implementation.

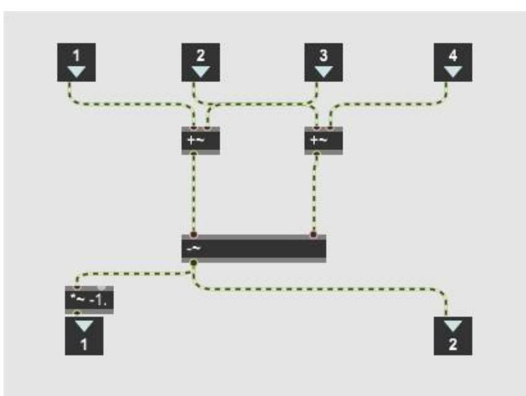

Figure 8. Output matrix of the reverberation.

VI. Conclusions

To conclude, it is important to note that even though the results from the distortion were acceptable, in order to actually model analog amplifier systems, the use of other techniques other than wave-shaping is of utmost importance. This is because the physical components that are built into such systems usually consist of time-dependent elements whose representation could benefit from algorithms containing some sort of memory.

References:

[1] Cycling ’74. (n.d.-a). *Dynamics Tutorial 3: Distortion - Max 7 Documentation*. Cycling ’74 Website. https://docs.cycling74.com/max7/tutorials/09_dynamicschapter03

[2] Cycling ’74. (n.d.-b). *MSP Tutorial 12: Waveshaping*. Cycling ’74 Website. https://docs.cycling74.com/max5/tutorials/msp-tut/mspchapter12.html

[3] Eichas, F., & Zölzer, U. (2018). *Virtual Analog Modeling of Guitar Amplifiers with Wiener-Hammerstein Models*. 44th Annual Convention on Acoustics (DAGA 2018), Munich, Germany. https://www.researchgate.net/publication/324720061_Virtual_Analog_Modeling_of_Guitar_Amplifiers_with_Wiener-Hammerstein_Models

[4] Ragland, J. (2020). *Digital Simulation and Recreation of a Vacuum Tube Guitar Amp*. https://etd.auburn.edu/bitstream/handle/10415/7112/Digital%20Simulation%20and%20Recreation%20of%20a%20Vacuum%20Tube%20Guitar%20Amp.pdf?sequence=2

[5] Smith, J. O. (2010). *“Schroeder Reverberators”, in Physical Audio Signal Processing*. CCRMA Website. https://ccrma.stanford.edu/%7Ejos/pasp/Schroeder_Reverberators.html