Proceedings of CONF-SEML 2025 Symposium: Machine Learning Theory and Applications
DOI: 10.54254/2755-2721/158/2025.TJ23295

Analysis of the Systematic Procedure to Generate Percussions Based on Syn thesizers

Bolin Chen

High School Affiliated to South China Normal University, Guangzhou, China
chenbl.william2023@gdhfi.com

Abstract: The development of synthesizers is a huge leap in music production, enabling composers to generate varied sounds through non-natural means. During the evolution, the emergence of drum machines as unique synthesizers promotes the generation of percussions through synthesizers. This study mainly discusses the systematic procedure to generate percussions through synthesizers based on the outstanding features of percussions and the practical functions of synthesizers. It concludes two necessary components of percussions - attack transients and decays and emphasizes their features. In addition, it highlights that it is convenient to separate the synthesis of two components during the whole procedure. For both two parts, the combination of sinewave and noise is practical for mimicking their outstanding features and the difference is the use of effects, adjustments of envelopes, and the selection of layers. Lastly, the essay summarizes the limitations of existing methods, stating that future research should focus on raising signal processes' efficiency and incorporating different models and these processes into synthesizers through an understandable means to ensure user experiences. These results provide a guide for composers to produce percussions through synthesizers and point out directions for further improvement of synthesizers.

Keywords: Percussion synthesis, synthesizers, attack transients, decays.

1. Introduction

The invention of synthesizers can be traced back to the development of Fourier Transformation [1], which states that all the complex waveforms can be divided into regular sine waves with different amplitude and frequency. Based on the theory, the first analog synthesizer Theremin was invented and players can easily control the amplitude and frequency by changing the distance between their hands and the instrument [2]. However, since Theremin largely relies on electromagnetic fields and antennae to generate signals, the signals can be easily affected by other players around it [3]. Therefore, followed by Telharmonium, a series of analog synthesizers, such as Moog Minimoog, that use voltage signals instead of electromagnetic fields to reduce the intervention of other signals [4]. Next, the development of FM modulation is another great leap in the methods that manipulate sound, significantly expanding the capability of synthesizers [5]. Digital synthesizers, like Yamaha DX7, can use up to 6 different operators to generate waveforms and use them as either carriers or modulators. Besides the updates of the methods to adjust wavetable, the use of effect became more and more diverse as time went on. From analog synthesizers that only included filters, envelope generators, LFOs, and other basic effects, to digital synthesizers that included reverb, delay, chorus, and more advanced effects, humans achieved great progress in generating non-natural sounds.

DOI: 10.54254/2755-2721/158/2025.TJ23295

Until now, with the popularity of computers, software synthesizers, like Xfer Serum and Native Instruments Massive, have integrated these functions into single devices to simplify the operation of users. Although the design of the user interface remains an issue nowadays [6], the flexible results it generated have already significantly improved the experimentation and innovation in the field of music production. Due to the rise of electronic music in mid-20th century, many composers tried to use electronic devices to mimic the sounds of traditional percussion instruments. Since most of the percussions ignore the difference in pitches, the inchoate tries include the use of noise oscillators and envelop generators to mimic the basic shapes of percussions. However, this cannot imitate the subtle details in the percussion sounds. As the synthesizers started to get advanced, commercialized drum machines such as The Wurlitzer Sideman Drum Machine were utilized for accompany [7], but it could only control the level and the selection of presets. This limitation is overcome by the invention of Roland CR-78, and especially, Roland TR-808 (seen from Fig. 1) [8]. As a groundbreaking drum machine, every drum sample from TR-808 is generated from electronic circuits in real-time, leading to the dynamic control of the timbre. Although at first it is not widely used by producers, it gradually becomes widely known nowadays.

Figure 1: Roland TR-808 drum machine [8]

From the 1990s to today, the techniques used to simulate drum samples significantly improved. Producers can use physical modeling [9] to simulate the vibration of drum heads and cymbals to achieve more realistic results. Also to make the results more acoustic, motion capture databases and behavioral models can be used by computers to learn the movements and gestures of drummers and study the change of timbre, velocity, and duration of results [10] (although directly using acoustic samples is also a practical method, this essay only discusses the use of synthesizers in percussion synthesis).

As the rise of electronic music goes on, percussions have already become a necessary part of music. Nevertheless, although there has already been a huge progress in using synthesizers to simulate percussions, the limitations still exist. For example, the use of behavior models in mimicking the gestures of drummers may introduce an abnormality in velocity, causing some samples to sound singularly louder than others [10]. Therefore, in order to achieve more acoustic results, it is

DOI: 10.54254/2755-2721/158/2025.TJ23295

indispensable to systematically summarize the indispensable processes of using synthesizers. In addition, existing researches often focus on the research of specific techniques and areas, ignoring the review of the whole process. Thus, this essay is focused on systematically bridging this gap, summing the critical features of percussions, summarizing the important functions of synthesizers that can be used to generate percussions, and listing the main processes of the simulation and limitations of existing measures. Through this framework, this essay seeks to point out the direction of further research for the more acoustic synthesis of percussions.

2. Features of percussions

In general, the definition of percussion sounds that have a sense of percussive impact. Percussions may sound varied in different genres. For example, the sounds of acoustic drums and percussions in experimental music have significant differences in the textures. Therefore, this essay will only summarize the main process to generate sounds that have all the features of percussions, but not further discuss how to tailor the results to make them fit different music genres.

2.1. Features of attack transients

First, the most distinguishing features of percussions are the attack transients at the beginning of the sounds. In the acoustic drum, when the drumstick hits the drum head, the energy is released in a short time and leads to an abrupt change in amplitude from loud to quiet [11]. This fast change in amplitude is the key to the punch of percussions. Besides, attack transients also include a fast change of frequency. For example, the attack transients of percussions may include high energy in high frequency and quickly decay to low frequency. This change in frequency decides the brightness of the percussions. The duration and timbre of attack transients can also affect the sounds [12]. For the duration, brief attack transients often generate shaper and aggressive sounds, like snare in the acoustic drum. In contrast, longer attack transients will generate a softer sound, such as the timpani. For timbre, the materials of the instrument will generate different rates of vibration, leading to the difference in the energy of attack transients. Some instruments are made of metal, like cymbals, the attack transients will be bright and metallic due to the fast vibration, while some drum heads are soft and floppy, like timpani, the attack transients will be low and soft due to the slow vibration.

2.2. Features of decays

Except for attack transients, decay also plays a crucial role in percussions. It stands for the part after the attack transients and the amplitude decays from high to zero. Decay directly affects the texture of percussions. On the one hand, some percussions, like a kick in an acoustic drum kit, have fast decays, making the sounds brief and punchy. On the other hand, some percussions, e.g., cymbals and timpani, have relatively longer decays, causing a strong resonance in high or low frequency and spaciousness in the stereo field. Therefore, compared to attack transients, decay is a more complex and flexible feature of percussions. Effects like reverb and delay are widely used to add depth to decays. Moreover, the sound distribution in the left and right channels widens the stereo field of percussions. Effects like ping pong delay cause the decay to sweep between left and right channels, making the amplitude of decay decrease irregularly. Some producers may even layer different decays that have varied textures to generate more unique percussions. Therefore, favorable percussion always contains a punchy attack transient to provide enough energy and a rich, special decay to provide a unique texture.

DOI: 10.54254/2755-2721/158/2025.TJ23295

3. Practical functions of mainstream synthesizers

3.1. FM modulation

FM modulation is one of the most important functions in synthesizers to expand the possibility of sound design. A carrier waveform and a modulation waveform are required to achieve FM modulation [6]. The formula of FM Modulation:

$$s(t) = A_c \cos(2\pi f_c t + 2\pi k \int_0^t m(\tau), d\tau) \tag{1}$$

From the formula, it is clear that the key point is to use the modulation waveform to affect the phase of the carrier waveform in order to control the frequency of the carrier waveform. Therefore, the amplitude of the modulation waveform will have a positive correlation with the frequency of the carrier waveform, making it widely used in the control of pitch. From previous discussions of the features of percussions, creating the decay of metallic percussions like cymbals and snares needs a rich resonance. Therefore, it is effective to use FM modulation to achieve it. Specifically, the modulation waveform must be a waveform with frequency, to make the carrier wave extremely high pitch and shape. This is the main process of achieving metallic feelings.

3.2. Envelope generator

The envelope generator is a function to control the change of certain attributes of a signal, such as pitch, amplitude, phase, and wavetable position. The core principle of the envelope generator is to use four different stages to describe the change - attack, decay, sustain, and release - and users can adjust the duration of each stage [13]. Attack is the change of the attribute at the beginning from zero to the maximal level; decay is the change of the attribute from the maximal level to the sustain level; sustain is the stage that the attribute remains on the sustain level; Release is the change of attribute from sustain level back to zero. Using these four stages, users can generate varied shapes of envelopes to control the attributes. Envelope generators full cycle is given in Fig. 2. The envelop generators are useful in synthesizing percussions. In designing the attack transients and decay, producers need to control the amplitude of the signal to increase and decrease in a certain shape. Therefore, it is always practical to use envelop generators to achieve this purpose. Also, the attack transients require an abrupt change of frequency from high to low. Although FM modulation can also be used to achieve it, it is more convenient to use envelope generators. Producers only need to set attack, sustain, and release to zero, decay from the maximal value to zero, and adjust the pitch of the original signal by using this envelope. This will create a laser-like attack transient for the percussions.

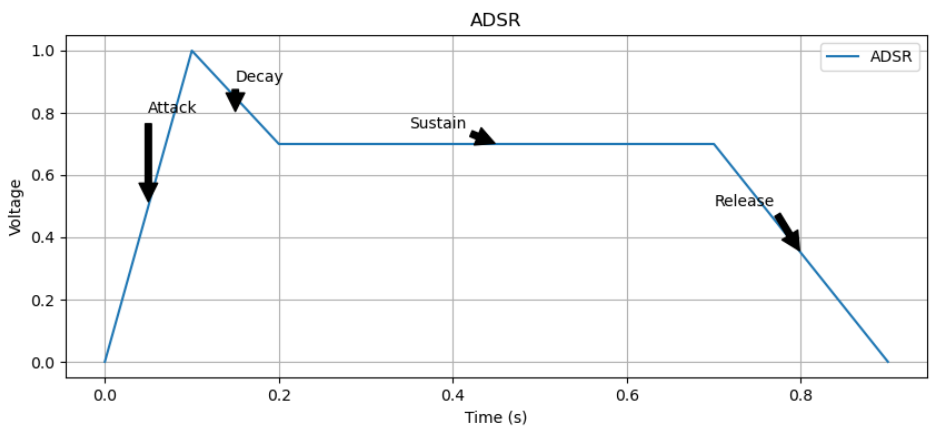

Figure 2: Envelope generators full cycle (photo/picture credit: original)

DOI: 10.54254/2755-2721/158/2025.TJ23295

3.3. Effect

As the synthesizer develops, the type of effect producers can use nowadays is distinctly expanded. Mastery of using effect will significantly improve the percussions after using envelope generators and FM modulation to mold the basic shape of percussions. Filter is one of the most commonly used effects in sound design. The core principle is to enhance some frequency while weakening some frequency, which is very simple among all the effects. Common filters include Low-Pass Filters, High-Pass Filters, Band-Pass Filters, Notch Filters, and so on, while producers also can adjust the shape of the filter to enhance or reduce certain frequencies as they want.In creating percussions, filters can be used to adjust and eliminate the frequencies that are noisy and harsh to make the percussions cleaner. Also, filters can also be used to enhance some frequency of percussions - especially the attack transients - to make the percussions stronger and punchier.

Distortion is an effect that is used to distort the signal to create from subtle overdrive to an aggressive boost [14]. The core principle behind it is the use of clipping and gain adjustment. First of all, producers will set a threshold for distortion, when the amplitude of the original signal is over this threshold, the redundant part will be clipped and level out, creating harmonic distortion. Because the peak of the original signal is leveled out, the average amplitude of the signal is reduced. Therefore, to maintain the loudness, producers then will adjust the gain of the signals until achieve a favorable result. Since distortion can make the sounds more aggressive and powerful, it is widely used in molding and enhancing the attack transients of percussions. It can offer enhancement from more harmonic distortion to extreme aggression (like percussions in hardstyle music) to the attack transients.

Reverb and delay are two effects that are used to create atmosphere in sound design. While reverb simulates the reflection of sounds in spaces like halls and small rooms, delay can create the feeling of echo, adding extra textures to the sound. Both the reverb and delay can deepen the stereo perception, enhancing the depth of sounds. In synthesizing percussions, reverb and delay can be used to lengthen the decay of percussions, adding extra textures to them. Some percussions, like woodblock, are often played in empty places. Therefore, using reverb and delay can create the atmosphere for these percussions, making them more realistic. Also, it is practical to combine the reverb and delay together to strengthen the effect, creating a deeper stereo perception for the percussions.

4. Compulsory procedure for percussion synthesis

As mentioned before, two necessary features of percussions are attack transients and decays. Therefore, to achieve more favorable results, it’s practical to separate the synthesis into two parts, focusing on synthesizing attack transients and decays respectively. Then, adjust the crossfade between two parts to smoothly connect two parts together.

4.1. Attack transients synthesis

The first step is to determine the wavetables that are used. The attack transients’ spectrum mainly contains non-harmonic parts instead of regular harmonic components [15]. Therefore, plenty of wavetables, like square waves and triangular waves, with strong harmonic characteristics are not practical for attack transient synthesis. Also, research from Tim Kirby and Mark Sandler highlights that the attack components can be modeled as a series of sinusoidal peaks [15]. Hence, using sinewave as the base wavetable to synthesize the attack transients is practical. Besides, since the attack transients contain mainly high-frequency components which are also so random and complicated that can hardly be simulated by only sinewave [15, 16].

DOI: 10.54254/2755-2721/158/2025.TJ23295

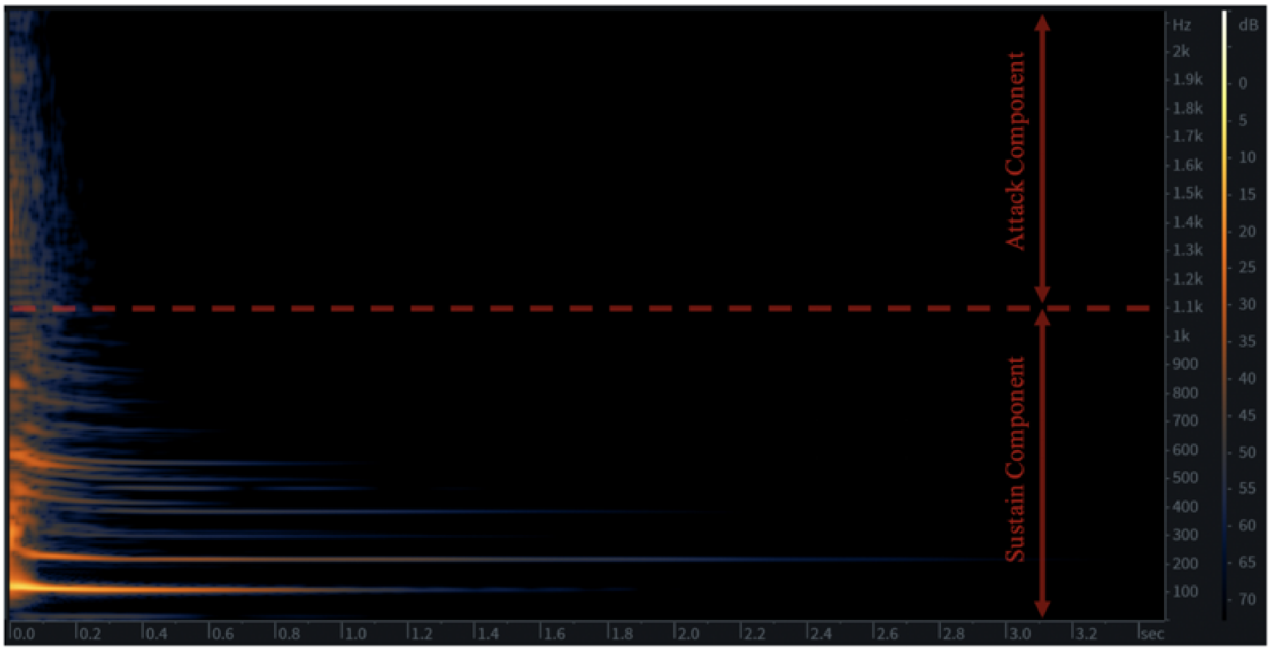

Figure 3: A typical result of spectrograms [17]

Consequently, to simulate the high-frequency components, it is necessary to introduce noise and combine it with sinewave to synthesize the attack transients. Granted, there are more effective methods like the S+N+T model to generate complicated non-harmonic sounds like the attack transients nowadays (seen from Fig. 3) [17]. However, these methods either directly use the original attack transients from samples or use complicated signal processes like Wavelet Transform which cannot achieved by common synthesizers and are outside the scope of this essay as well [17]. In addition, the S+N model which utilized the combination of sinewave and noise proved to be effective enough to simulate many simple percussions [17]. Therefore, using the combination of sinewave and noise is the most convenient and effective method to generate percussions through synthesizers.

After loading a sinwave for the base, because the attack transients contain fast changes in both frequency and amplitude as mentioned previously and these changes are always from high value to low value at the beginning of the percussion, it is practical to use an envelope generator to control these attributes. For the shape of the envelope, one can set the attack, sustain, and release all to zero, and offer a very short decay.

By doing so, the frequency and amplitude will drop from a high value to zero in an extremely short period. A similar process can also be applied to the noise layer to fit it to the sinewave. In addition, some percussions, like timpani and many unique percussions in IDM, have a specific tonal at the beginning. Therefore, composers can add different tonal layers as noise layers as they expect to offer tonality and extra textures to the attack transients. The next step is to process the stack of layers. For this step, effects like distortion, filters, and limiters can be used. First of all, filters can be used to eliminate and reduce many unwanted sounds, and distortion can be used to enhance the attack transients and glue all the components together. Finally, to achieve a smooth transition between attack transients and decays, using a limiter or compressor can set the amplitude of the results under a certain threshold, which is practical for achieving the transition. Still, besides these common effects, there are still a large number of effects that can be used to process the percussions. As long as the connection between attack transients and decays is smooth as composers expected, the use of these effects is appropriate.

4.2. Decays synthesis

According to the figure of spectrum above, the decays of the tom samples in the research have a small pitch glide at the start and energy concentrate in a certain frequency (around 100-200 Hz). In fact, not just tom, many percussion decays have energy concentrated in certain frequencies (mostly around low-mid frequency) and visible pitch glide due to the reflection of a two-dimensional traveling wave produced by the vibration of the drumhead [15, 16]. Therefore, the S+N model is exactly the method that can be used to emulate this tonal component since it can easily produce sounds with stable frequency and amplitude [17].

For decay synthesis, the first step is to determine the frequency of the decay after the glide at the beginning. For most of the percussions, this frequency usually ranges around 200-500 hz. However, for some percussions made of metals like cymbals and hi-hats, the decays contain a large amount of overtone in high frequency which is difficult to only use noise and sinewave to emulate. To solve this problem, FM modulation, specifically higher-order frequency modulation, can be introduced to generate sounds with overtone. When the modulation index (the ratio of the amplitude and frequency of the modulation wave) of FM modulation is large, the result will contain more high-frequency content that fits the synthesis of overtone in many percussions [18]. Therefore, by using multiple modulation waves and adjusting the modulation index, FM modulation can be used to synthesize the decays of cymbals.

The next step is to use an envelope generator to control the amplitude and produce a pitch glide. Similar to the synthesis of attack transients, the envelope is used to control the frequency and amplitude of the decays. However, for decays, the shape of the envelope is varied. As long as it can connect smoothly with the attack transients, the envelope is appropriate. For this purpose, composers may need to specifically adjust the attack of the envelope. Also, the duration of percussions also depends on decays. Therefore, the decay of the envelope will need to be adjusted as well to achieve fit to the expected duration. Lastly, the use of effects for decays is very similar to the attack transients. Distortion, filters, limiter and other effects can be applied to the decays to tailor the decays as composers expected.

4.3. Final process

After successfully designing the attack transients and the decays, the composers can put them together and then fine-tune the result to achieve a smooth transition between the two components. For example, the fine-tuning of the envelope of two components may be crucial for the results. Finally, effects like compressor and limiter can be used to glue everything together and make the attack transients pop out in the results. Finally, adding reverb and delay to the sounds can widen the stereo to create a more immersive sound. By doing all these steps, composers can use synthesizers to generate punchy and generic percussions that can be used in varied genres.

5. Limitations and prospects

Based on previous sections, percussion synthesis by using synthesizers doesn’t require a complicated process. As synthesizers develop, users can produce favorable percussions based on only a few steps. However, the limitations of the percussion synthesis still exist. First, although composers can already generate punchy attack transients by using primarily sinewave and noise, the quality of transients still has space for improvement. Nowadays, signal processes like Wavelet Transform and Frequency-Domain LPC in the S+N+T model can be used to achieve more realistic attack transients for percussions [17]. However, due to the complexity of these processes, common synthesizers for composers cannot accommodate them. Although people can still access these processes by using platforms like Reaktor or MaxMSP, it requires the users to master programming and signal processes,

DOI: 10.54254/2755-2721/158/2025.TJ23295

which obviously is uncommon among composers. Therefore, the lack of complicated signal process methods is the first limitation of percussion synthesis by using synthesizers.

In addition, the results generated by synthesizers are static but not dynamic, meaning that the attributes of percussions, like volume and timbre, remain the same unless users adjust the parameters. Although nowadays many synthesizers incorporate random functions to provide randomness, they still hardly cannot mimic human actions as physic models do. Thus, if the composers want to mimic the acoustic drums played by a professional drummer by using synthesizers, it still takes a lot of effort to adjust parameters and fine-tune the results, which is not convenient and practical enough.

Consequently, future research may focus on incorporating complicated methods and processes into synthesizers to further improve the quality of percussions. For example, researches can focus on how to raise the efficiency of algorithms of synthesizers to speed up processes like Wavelet Transform and Frequency-Domain LPC and reduce the latency. Also, the combination between synthesizers and physic models, or even AI models, is also a possible direction that is worth researching. Because the results produced by synthesizers are static, physic models or AI models can be used to learn human behaviors and capture the subtle difference between every percussion to help synthesizers generate more realistic sounds and mimic acoustic drums. Finally, as technology improves, the experiences of users should always be placed in the first place. Since these processes and models are difficult to understand from a synthesizer amateur's perspective who has no knowledge of programming and modeling. Even without these functions, synthesizers nowadays are still difficult to master based on surveys and research [6]. Therefore, whether it is an improvement in synthesizers' efficiency or potential, these benefits should be accessible to the users and the experiences of users should be put at the top priority.

6. Conclusion

To sum up, this essay systematically summarizes the compulsory procedures of using synthesizers to produce percussions. First, it demonstrates the evolution of synthesizers. Next, it highlights the outstanding features - attack transients and decays - of percussions which are helpful in percussion synthesis. Then, it summarizes functions that are widely used in the generation of percussions, such as FM modulation, envelope generator, and many effects. Finally, the essay concludes with a step-by-step universal procedure for composers to synthesize percussions based on synthesizers and highlights the limitations of the procedure in order to demonstrate the directions for future research, including raising the efficiency of complicated signal processes, incorporating physics models or AI models, and focusing on user experiences. The implication of the essay is to provide a guide to percussion synthesis, enabling composers to simulate percussions more efficiently. In addition, the essay points out the drawbacks of existing techniques and provides directions for further research, aiming to promote further developments of synthesizers.

References

[1] *Heckbert, P. (1995) Fourier transforms and the fast Fourier transform (FFT) algorithm. Computer Graphics, 2(1995), 15-463.*

[2] *Weidenaar, R.H. (1989) The telharmonium: a history of the first music synthesizer, 1893-1918. New York University.*

[3] *Bachiller, M.C., Sastre, M.J., Ricchiuti, A., Esteban, G.H., Hernández, F.C. (2012) Study of the Interference Affecting the Performance of the Theremin. International Journal of Antennas and Propagation, 2012(1), 348151.*

[4] *Jenkins, M. (2019) Analog synthesizers: understanding, performing, buying: from the legacy of Moog to software synthesis. Routledge.*

[5] *Schottstaedt, B. (2003) An introduction to FM. Retrieved from https://ccrma. stanford. edu/software/snd/snd/fm. html.*

[6] *Rasmussen, C. (2018) Evaluating the usability of software synthesizers: An analysis and first approach (Doctoral dissertation, University of Guelph).*

DOI: 10.54254/2755-2721/158/2025.TJ23295

[7] *Medina, I. (2017) And The Beat Goes on: The Story of the Drum Machine.*

[8] *Werner, K.J., Abel, J., Smith, J. (2014) A physically-informed, circuit-bendable, digital model of the Roland TR-808 bass drum circuit. In 17th International Conference on Digital Audio Effects (DAFx-14) pp. 159-166.*

[9] *Cook, P.R. (1997) Physically Informed Sonic Modeling (PhISM): Synthesis of Percussive Sounds. Computer Music Journal, 21(3), 38–49.*

[10] *Bouënard, A., Wanderley, M.M., Gibet, S. (2009) Advantages and limitations of simulating percussion gestures for sound synthesis. ICMC, pp. 255-261.*

[11] *Thornburg, H.D., Leistikow, R.J. (2003). Analysis and resynthesis of quasi-harmonic sounds: An iterative filterbank approach. In Proc. Int. Conf. on Digital Audio Effects (DAFx-03), London, UK, pp. 129-134.*

[12] *Fletcher, N.H., Rossing, T.D. (2012) The physics of musical instruments. Springer Science & Business Media.*

[13] *Heino, M. (2022) Envelope generator for analog synthesizer.*

[14] *Mead, C., Bromham, G., Moffat, D. (2023) A History of Distortion in Music Production. In Distortion in Music Production, pp. 3-12.*

[15] *Kirby, T., Sandler, M. (2021) The evolution of drum modes with strike intensity: Analysis and synthesis using the discrete cosine transform. The Journal of the Acoustical Society of America, 150(1), 202-214.*

[16] *Kirby, T., Sandler, M. (2020) Advanced Fourier decomposition for realistic drum synthesis. Vienna, Austria, 155.*

[17] *Smith, J. O. (2020) MUS421 Lecture 9: Spectral Audio Modeling Applications. Center for Computer Research in Music and Acoustics (CCRMA), Stanford University.*

[18] *Lazzarini, V., Timoney, J. (2023) Theory and practice of higher-order frequency modulation synthesis. Journal of New Music Research, 52(2–3), 186–201.*