INITIAL TECHNOLOGY REVIEW: THE IMPLEMENTATION OF A ROTARY LOUDSPEAKER EFFECT AS A DIGITAL SIGNAL PROCESSOR ALGORITHM

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ABSTRACT

The effective creation of rotary speaker digital audio effects has long been a sought-after design goal for DSP implementation. Due to the expense and difficulty in producing, recording, and reproducing a rotary speaker (such as Leslie or Motion Sound speakers) it is highly desirable to create efficient and believable virtual rotary speaker effects. Although the actual behaviour of such a speaker is relatively straight-forward, detailed emulation of the subtle characteristics of this effect is essential to make it attractive to the end-user.

This review will analyse the principles of a rotary loudspeaker and propose the basic signal processing algorithms necessary to recreate its effect on an input signal.

1. INTRODUCTION

A rotary loudspeaker is a loudspeaker (and, usually, amplifier) combination originally designed for use with electric organs. These speakers were designed to add richness, interest, a sense of movement, and a sense of space to the sound of the organ. Much of this desired sound was a result of electric organs being used in churches, as they attempted to simulate large reverberant pipe organs. With the rise of popular music, rotary loudspeakers took on new importance and prominence, being used from anything from guitars, basses, vocals, electric pianos, and so forth.[1] The popularity and common recognition of this sound is what makes it an attractive effect to simulate as a DSP algorithm.

Many DSP simulators exist with varying degrees of user control. Common developers and manufacturers of such simulators are the Voce V5, the Native Instruments B4, the Guitar Rig Rotary Speaker device, and several others. Some of these are linked stubbornly to virtual instruments (organs generally) and others, such as the Guitar Rig device, allow the input of any signal. All of these devices have limited user control and often don't allow for careful manipulation of parameters to suit all possible effects. In designing and implementing an algorithm, it is the author's goal to explain and, ultimately, implement a rotary speaker effect with full user control of all parameters.

1.1. Basic Principles

A rotary loudspeaker consists of one or more rotating loudspeaker drivers. Larger units consist of two independently rotating drivers (one for low frequencies and one for high), while smaller units will consist of one rotating element, usually mid- to broadband in frequency response. These drivers are usually concealed within a cabinet with vents or slots cut to allow the sound to exit the cabinet in at least two or more directions. Figure 1 details the basic construction of a typical rotary loudspeaker.

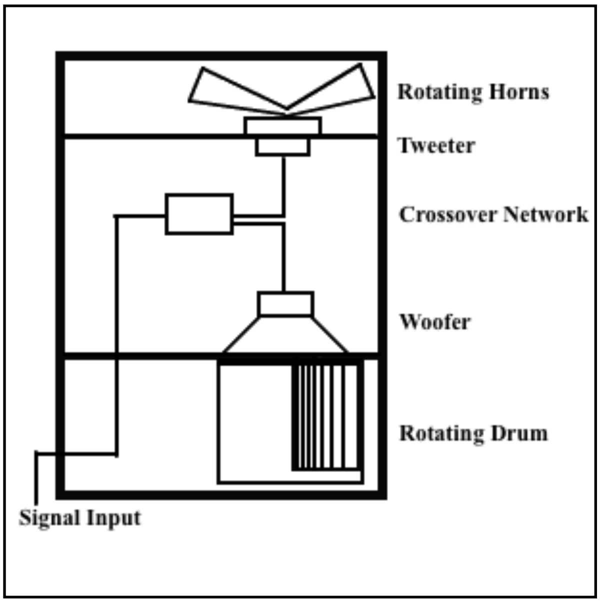

Figure 1. *The typical construction of a rotary speaker cabinet. A crossover network splits the signal into high frequency and low frequency bandwidths. The user has control of the rotation of both the horn and drum components.*

As dictated by common recording practise, these loudspeakers are typically recorded and reproduced in stereo, but sometimes are reproduced as mono recordings. Additionally, the speed of the rotation is often controllable on these units. Single-driver units may include two speeds as well as stop (no rotation) while two-driver units typically have two speeds for the tweeter (in addition to stop), and one continuously slow speed for the woofer.

1.2. Summary of Electroacoustic Characteristics

The main sonic characteristics of this loudspeaker type are related to both the crossover network as well the rotation of the horn and drum. These effects can be summarised as follows:

Horn Characteristics:

- High frequency content (~1kHz – ~10kHz)
- Amplitude modulation (sinusoidal rotation)
- Doppler effect (sinusoidal modulation)

Woofer Characteristics:

- Low frequency content (~40Hz – ~1kHz)

- Amplitude modulation (sinusoidal rotation)

1.2.1. Electroacoustic Characteristics as Design Goals

For clarity and simplicity of description, this review will explore the relevant signal processing algorithms of a rotary speaker with the following specifications:

- Mono input source
- Stereo output
- Two-speed horn, one-speed woofer drum

1.3. Aims

The goal of research included in this review is to present the DSP algorithms that are relevant and necessary to complete the stated Design Goals. With clear, methodical description of each component of the algorithm, it should be clear how the code comes together to build the final output signal.

Including the use of diagrams for clarity, the following process will be demonstrated and explained:

- The input signal will be split into three components (horn left, horn right, and drum)
- The two horn signals will be amplitude and frequency modulated inverse to one another to create the rotating stereo effect
- The drum component will be amplitude modulated at a different rate than the horn components
- All three signals will then be added in small proportion to one another to create a summed output to simulate crosstalk between the left and right channels

2. METHOD

The first step in understanding the process needed is to create a vibrato algorithm to simulate the Doppler effect of the rotating horn. This must be divided into two signals (as the horn must have a stereo output). The signals must also be amplitude modulated to create the alternating level changes between the channels. Both modulations must be done with sinusoidal oscillation inverse to one another to recreate the circular rotating effect.

The input signal must also be made into a third variable to simulate the rotating drum. Due to its low frequency content and slower rotation speed, it won't be necessary to Doppler this variable, but only to amplitude modulate it, as shown in Figure 2.

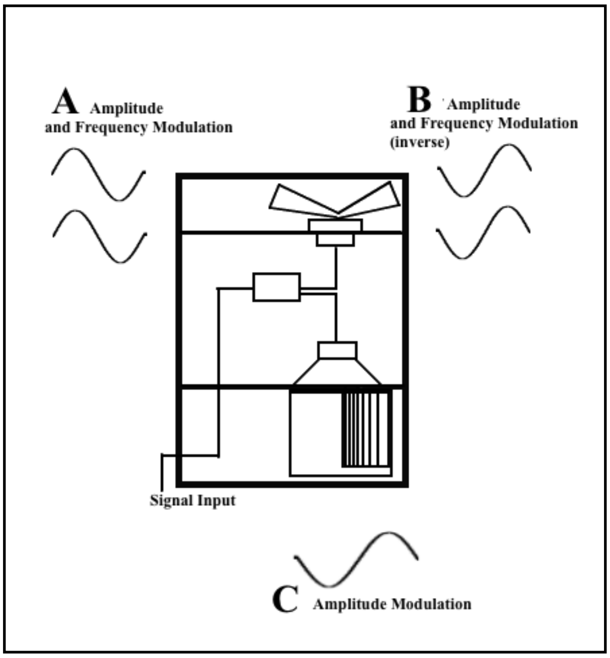

Figure 2. *The three main signal components of the rotary loudspeaker effect referenced to the loudspeaker being simulated.*

To accomplish the desired effect, the following process must be followed. A sin for frequency modulation (vibrato, or Doppler effect) must be created at an appropriate frequency. The "A" and "B" signals must have their sample rates multiplied by this sine (and inverse sine, respectively). This will create the inversely oscillating pitches. The next step is to multiply the amplitude of these signals by the same sine and inverse sine (so the signals have matching amplitude and pitch modulation frequency and phase.

The C signal needs to have its amplitude multiplied by another, slower sine. To make this more interesting and realistic, I suggest the frequency of this modulation sine not be an even harmonic or octave of the others.

To simulate crosstalk between the channels and create a believable stereo image, it will be necessary to combine the A and B signals with one another to a small percent (70% used in this example). Finally, the C signal will be added to both A and B (I have chosen 40% in my example as this will emphasise the A and B signals more). Figure 3 below outlines the basic mathematical approach to accomplishing the algorithm, with reference to Chapter 4 of the DAFX book. [2]

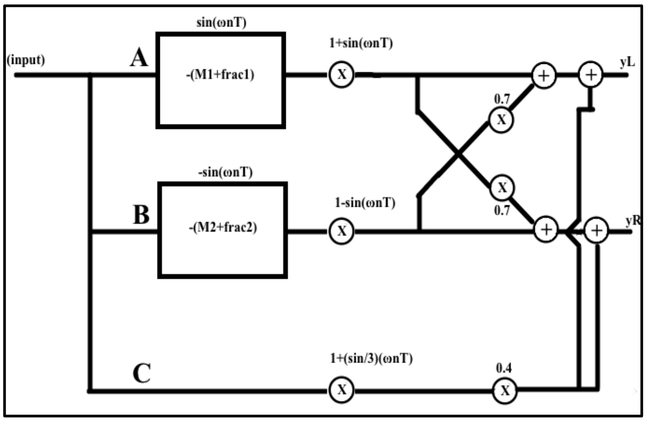

Figure 3. *Signal flow diagram of the complete rotary loudspeaker algorithm, based on a diagram by Zolzer [2], with the addition of the C component.*

In Figure 3 above, the input (x) is modulated by a delay line (expressed as M1+frac1 and M2+frac2), to derive A and B, respectively. This delay is based on sinusoidal and inverse sinusoidal frequency at a set width and depth (expressed as ω and T). Each signal is then multiplied by the sine/inverse sine to create the amplitude modulation required. Finally, these signals are added to each other at a ratio of 0.7 to create the crosstalk/center image. For signal C (the "drum"), an additional line is derived to multiplied by 1/3 of the original sine (to create a slower rate). This is then simply multiplied by 0.4 before being added to the A and B signals.

3. RESULTS

The final output of this algorithm will include the modulating A and B signals with the slower amplitude modulating signal of C, to create a realistic and easily customisable stereo rotary speaker effect, as outlined in section 1.3.

4. DISCUSSION

While this method will provide a modulating delay line to simulate a rotary speaker with some easy flexibility, there are more complex approaches that would be needed to alter and improve the effect.

It doesn't include crossover filters between the different signal components (as acknowledged in section 1.2). The design of an accurate filter would include not only the algorithms involved in creating high-pass and low-pass filters, but also adjusting the frequency response to match that of a true rotary speaker via IIR or FIR filters. For the purposes of this research the results are sufficient to demonstrate the core processing involved in simulating the main characteristic behaviours of the loudspeaker.

A mono version could easily be implemented by omitting the B component or by fully adding the A, B, and C components to produce a single mono output.

5. CONCLUSION

In conclusion, the design goal suggested in section 1.2.1 is fulfilled by this DSP strategy. Achieving synchronized amplitude and frequency modulation between components A and B, with the addition of a slower C component effectively process a mono audio input as a stereo output with the attributes of a rotary loudspeaker..

6. AKNOWLEDGMENTS

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7. REFERENCES

[1] C. A. Henrickson. *Unearthing the Mysteries of the Leslie Cabinet*: Recording Engineer/Producer Magazine, April 1981. http://theatreorgans.com/hammond/faq/mystery/mystery.html.

[2] U. Zolzer, *DAFX: Digital Audio Effects*. John Wiley & Sons, 2002.

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