DIGITAL IMPLEMENTATION OF VIBRATO

Adrian Clarke 306164981(SID)

Digital Audio Systems, DESC9115, Semester 1 2012
Graduate Program in Audio and Acoustics
Faculty of Architecture, Design and Planning, The University of Sydney

ABSTRACT

Digital Audio Effects are often discussed in audio production circles by their acoustical effect on an input signal [1]. As opposed to discussing *what* is happening acoustically, this report aims to delve deeper into the DSP (Digital Signal Processing) algorithms underlying an effect to explain *how* it is being created. The focus of this report is on the digital implementation of a vibrato effect.

After a short introduction outlining what vibrato is and how it has classically been achieved in the analog domain, a more in depth analysis of how vibrato can be achieved digitally is presented. This analysis focuses on furthering an understanding of what a time-delay based effect is and the parameters used to control such effects, especially the influence of a low frequency oscillator (LFO) for modulating delay time.

1 VIBRATO

Vibrato can be defined as a periodic variation in time of pitch, above and below the fundamental frequency of a sound. Its purpose is to add warmth and expression to a sound and can be heard as a harmonious wavering [2][3]. An example of how this has classically been achieved with acoustic instruments such as a violin or guitar, is through a wiggling of the finger being used to press the string on the fingerboard. The two fundamental parameters of vibrato are the amount of pitch variation and the rate at which the pitch is varied. For most acoustic instruments the amount the pitch is varied by is typically much less than one semitone and the rate at which it is varied is usually between 5 to 14Hz [4][5][6].

On many string instruments, vibrato has the acoustical effect of causing the emitted sound to be highly directional. This is particularly apparent at higher frequencies and can be heard as a shimmer to the sound [6].

1.1 Analog Vibrato

Electronic analog vibrato effects units can be seen appearing in the early 1950's. These units were sometimes incorporated into guitar amps such as those made by Magna Electronics Inc. or as stand-alone units such as the Gibson GA-V1 Vibrato Box. These early devices relied on complex circuitry and required at least two tube pre-amps, as such they were costly and difficult to implement. Many manufacturers used a far simpler and cheaper tremolo circuit and labeled it as vibrato. To this day there are many instances of equipment manufacturers incorrectly labeling tremolo as vibrato and vice versa. Tremolo differs in that it is a periodic variation of amplitude as opposed to pitch, a visual representation of vibrato is shown in Figure 1. [3][7].

With the rise of solid-state equipment, analog vibrato units became easier and cheaper to make. There are now a wide variety of different analog vibrato units available for relatively cheap. As technology has advanced further with the rise of digital audio, vibrato can now be created quite easily in the digital domain.

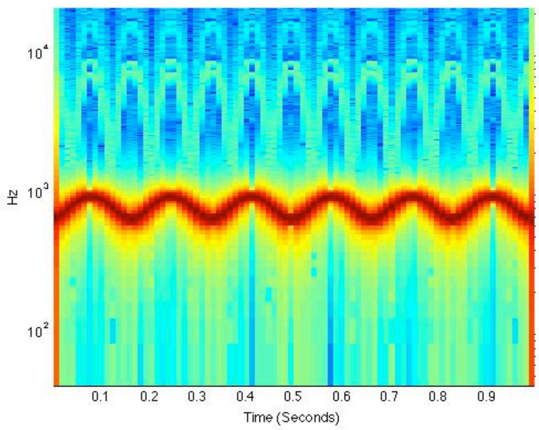

Figure 1. *Spectrogram illustrating modulation of frequency over time of a vibrato effect.*

2 DIGITAL VIBRATO

2.1 Delay Based Effects

Digital vibrato can be catagorised as a delay based effect. Other examples of effects which fall into this category are flanging, chorus, slapback and echo. These effects are a combination of an input signal with one or more delayed copies of that signal. The main difference between these effects and vibrato is that vibrato is solely the delayed (or 'wet') signal, and is not mixed with the original input. Other differences between these effects are the delay time (an echo for example having a much greater delay time than vibrato) and the number of delayed signals (chorus for example being many different copies of the input sound at different delay times). What gives vibrato its character sound is that the amount of time by which the input signal is delayed is being constantly varied by an LFO.

Correlation can be made between the well known Doppler effect and vibrato. The pitch variation we hear due to the Doppler effect is caused by a change in the distance between the sound source and the observer. Varying the distance in this case can be considered directly equivalent to the varying of time delay in the case of vibrato [5].

2.2 Digital Vibrato Parameters

The parameters used to control digital vibrato are similar to those used to describe the vibrato effect as created by an acoustic instrument. In the case of digital vibrato the pitch variation can be equated to the delay time, typically an average of between 5-10ms and again causing a variation of less than a semitone. The rate of vibrato mentioned earlier is directly equated in the digital domain to the frequency of the LFO, again typically 5-14Hz.

When these parameters greatly exceed the values typically associated with vibrato, the vibrato effect is lost completely and new effects are created.

2.3 Delay Lines

Most delay based digital audio effects are created through use of what is known as a delay line. "The delay is implemented in integer multiples of the unit delay. If the delay is greater than one unit delay, the chain of unit delays is referred to as a delay line" [1]. In his text *DAFX – Digital Audio Effects,* Udo Zolzer provides a detailed explanation of an FIR (Finite Impulse Response) Comb Filter and an IIR (Infinite Impulse Response) Comb Filter which are the two basic building blocks for implementing a delay line for a digital audio effect. Figure 2 shows the signal flow of FIR Comb Filter. This is explained by equation (1) where *x(n)* is the input signal, *M* is the amount of delay in samples, *g* is the amount of gain applied to the delayed signal and *y(n)* is the output. The FIR Comb Filter is also known as feed forward delay as the delayed signal is fed forward to be mixed with the input signal.

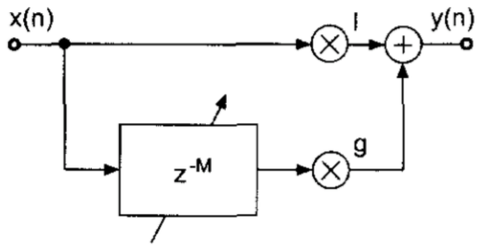

Figure 2. *FIR Comb Filter (Udo Zolzer, "DAFX – Digital Audio Effects").*

$$y(n) = x(n) + gx(n - M) \tag{1}$$

An IIR Comb Filter differs in that the delayed signal is fed back and can thus be referred to as a feed-back delay. The result of this is that *g* must now act as an attenuator to stop the delayed signal building upon itself exponentially.

The signal flow of a vibrato effect can be seen in Figure 3. As is shown vibrato is basically a FIR Comb Filter without the delayed signal being mixed back with the input. The output is purely the input *x(n)* being delayed by *M* samples to create the output *y(n)* as shown in equation (2).

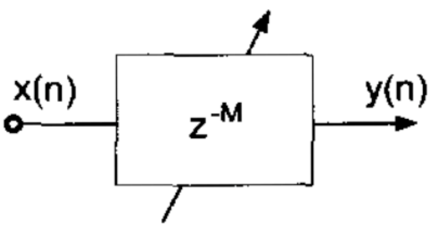

Figure 3. *Vibrato (Udo Zolzer, "DAFX – Digital Audio Effects" [5]).*

$$y(n) = x(n - M) \tag{2}$$

2.4 Variable Delay Lines

As mentioned earlier vibrato is given its characteristic sound by the fact that its delay time (which can be equated to pitch variation) is being constantly varied. Disch and Zolzer state that "the variation of the delay length is a phase modulation (PM) and its dynamic component is perceived as a frequency modulation." [1] While it is true that a variation of the delay length is a phase modulation, in the case of vibrato we only perceive a modulation of frequency as the output is solely the affected signal and not a mix of the dry input with one or more delayed copies of the input.

The way we achieve a variation in the delay length is by modulating the delay length with an LFO. By modulating the delay length the value of *M* as specified in equation (2) is constantly varying creating our vibrato effect. Figure 4 shows a processed vibrato signal in blue plotted over its input in red. The input was a 1kHz sine tone put through a vibrato function in Matlab with 5ms delay time modulated at a rate of 10Hz by an LFO. The 0 point on the x axis of this graph is actually sample 250 which is where the delayed output begins.

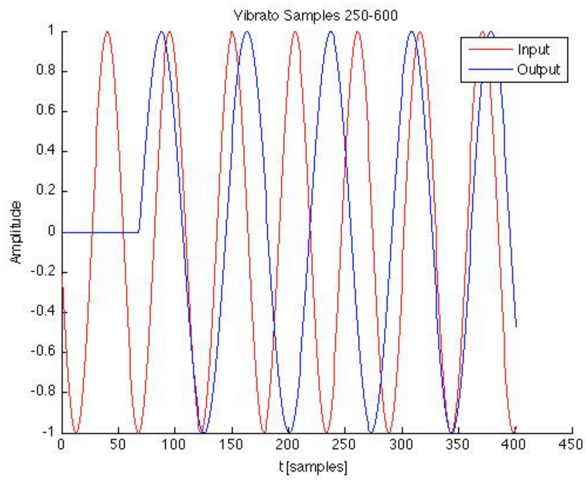

Figure 4. *Input sine wave with output vibrato.*

Notice in Figure 4 that the wavelength for the blue output signal is noticeably shifting, albeit subtly, over a small period of time.

2.5 Interpolation of Non-Integer Delay Lines

Due to the fact that we are using an LFO to modulate our delay length over time, non-integer values of the sampling interval will be created as delay lengths [5]. If we think of our unit delay as being one sample and our delay length *M* as an integer multiple of the unit delay, then by modulating *M* with an LFO we are creating a value of *M* which is a non-integer multiple of the unit delay. The way we are able to implement these non-integer delay lengths is to use interpolation techniques.

There are numerous methods that can be used to interpolate these non-integer values such as linear interpolation, allpass interpolation, sinc interpolation, spline interpolation etc. While all these forms of interpolation use a different method they will all give similar results in computing the "output sample *y(n)*, which lies in between two samples at time instants *M* and *M + 1*" [5].

3 CONCLUSION

All variants of vibrato, be they acoustic, analog or digital are far easier to comprehend once we understand the principles used to create them. Once we understand these principles we can apply this knowledge to other similar delay based effects and it is then not a large stretch to understanding the inner workings of these effects too. What at first may seem daunting, once broken down into essential components can be understood with ease. By doing this we have gained understanding of how a delay line is created and the effect on vibrato of other parameters such as delay length and LFO Frequency.

4 REFERENCES

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