Delay Line Effects

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All technical information in this report comes from Reiss and McPherson (1).

Introduction

This report will focus on effects which are implemented by using delay lines. A delay line simply stores samples in a buffer then accesses the samples after a certain amount of time then uses that sample to contribute to the output signal. In practice when the length of the delay does not align with an integer multiple of the sample period interpolation is used to estimate the value of the signal at that point. Commonly a 3rd order polynomial interpolation is used. The specific effects which will be covered are delay, vibrato, flanger, and chorus.

Delay

Basic delay simply stores audio samples in a buffer then applies some gain to the samples before adding them to the input to create the output. With sufficient delay time and appropriate gain this delay can sound like an echo. An output $y[n]$ is described as a function of an input $x[n]$ as follows :

$$y[n] = x[n] + g\,x[n-N] \tag{1}$$

and a block diagram is shown in fig 1. It is fairly simple to conclude that this system is linear and time-invariant. By taking the z-transform of (1) we get:

$$H(z) = 1 + g\,z^{-N} \text{ or } H(z) = \frac{z^N + g}{z^N} \tag{2}$$

Clearly all poles are inside the unit circle so the system will always be stable for bounded inputs.

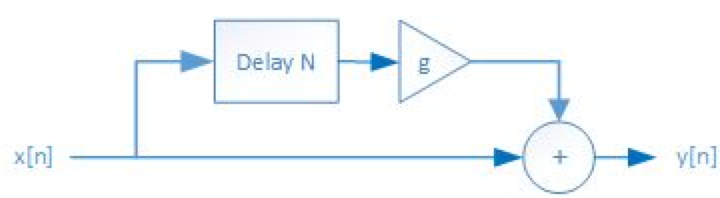

Figure 1. Basic Delay Block Diagram

Without any feedback the basic delay shown in fig.1 provides only a single echo and isn't particularly versatile. By adding feedback we get an effect which will provide many more sound possibilities. The resulting is equation is as follows

$$y[n] = x[n] + g_{FF}d[n-N] \text{ where } d[n] = x[n-N] + g_{FB}d[n-N] \tag{3}$$

Fig. 2 shows the block diagram for this effect. Note that g_{FF} and g_{FB} represent the gain of the feed forward and the gain of the feedback respectively.

Less common types of delay include multi-tap and ping pong delay. Multi-tap delay is implemented by taking multiple taps at different points along the delay line and adding those to the signal. Ping pong delay is an effect with a stereo output although it can have either a mono or a stereo input. In ping pong delay each channel has a delay line which feeds forward to that channels output and a feedback component which feeds into the other channels delay line. The effect is that the left and right channel signals bounce back and forward between one another.

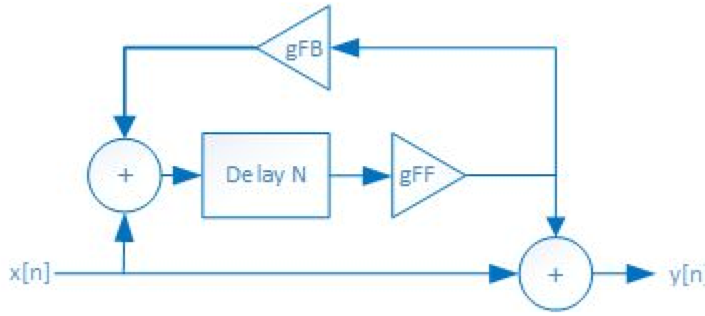

Figure 2. Delay with Feedback

Vibrato

"Vibrato is defined as a small, quasi-periodic variation in the pitch of a tone." [1] This is generally implemented as a technique rather than an effect but is presented briefly here to illustrate a concept which is necessary to understand the flanger effect and the chorus effect. Vibrato can be implemented by using a delay line whose length is modulated by a low frequency oscillator (LFO). The effect of this modulation is that the playback rate for the delay samples is always being sped up or slowed down which shifts the pitch. In a vibrato effect only the delay signal would be sent to the output.

Flanger and Chorus

The flanger effect gets its name from how it was originally implemented. Music producers would actually use their fingers to speed up and slow down a tape reel by touching the flange. This sped up and slowed down track would be dubbed back into the mix. When producers would do this the result was much closer to what we now call chorus than what we call flanger but the principle is the same. The main differences between flanger and chorus are the rate at which the speed is modulated and the width of the modulation.

In order to modify a basic delay to become a basic flanger or chorus the only change that has to be made is modulate the delay time. Making this change eq. 1 yields the difference equation for both flanger and chorus.

$$y[n] = x[n] + g\,x[n - M[n]] \tag{4}$$

Where $M[n]$ varies under control of the LFO. The transfer function is obtained by taking the z-transform.

$$H(z) = 1 + g\, z^{-M[n]} \tag{5}$$

Substituting e^{jw} yields:

$$H(e^{jw}) = 1 + ge^{-jwM[n]} = 1 + g\ cos(wM[n]) - j\ g\ sin(wM[n])$$

$$|H(e^{jw})| = \sqrt{(1 + ge^{-jwM[n]})(1 + ge^{-jwM[n]})} = \sqrt{1 + 2gcos(wM[n]) + g^2} \tag{6}$$

The frequency response is periodic and dependant on the number of samples in the delay line. This number changes as the LFO modulates the delay time. The result is a shifting and periodic filter.

When the length of the delay is relatively short on the order of 1 to 10ms the effect is called a flanger. Since the delay is well below what a human would register as an echo or a separate event (about 30 ms) and the peaks and notches of the periodic filter are further apart more closely resembling a more traditional filter. The notches of the filter move as the delay time is modulated resulting in the shifting filter sound of a flanger.

When the length of the delay is longer, on the order of 20 to 30ms the delayed signal begins to be perceived as a separate sonic event. As in the vibrato the delayed signal also undergoes some pitch shifting. When two or more individuals sing the same melody, as in a choir, there will inherently be some minute differences in timing, pitch, and timbre between individuals which gives the music a thicker sound. The pitch shifting and delay of a chorus effect cause a similar phenomenon to two people or, in the case of multi-chorus, a group of people singing the same melody. In short chorus artificially modulates pitch and timing of a copy of the input signal to emulate multiple instruments playing together.

Conclusion

Effects based on delay lines are some of the most useful guitar effects when used correctly. Delay, flanger, and chorus can be used to subtly enhance the sound of a guitar by adding depth or texture or be used to create extreme and unusual sounds. Since these effects are based around a simple circular buffer they are fairly easy to implement digitally.

References

Reiss, Joshua D., and Andrew McPherson. *Audio effects: theory, implementation and application*. CRC Press, 2014.