Feedforward Delay and Echo

VCarrara

Definition

The Delay effect is achieved by recording the audio signal and then playing it back after a short time, mixed with the live audio. The resulting sound is perceived as a small reverberation room. The process can be repeated multiple times, by means of feedback, giving an impression of a decaying echo[1]. When multiple copies are added to the original audio, saturation in amplitude (volume) may occur. The natural way to overcome this situation is decrease the gain in the feedback signal, so the resulting audio seems to fade away. On the other hand this approach limits the number of audible copies when small gains are used, or still can be unstable if the gain is too high. Neither the live audio nor the recorded copies are modified by any sort of modulation, as can be seen in Table 1, although some designs may apply low pass filter in the delayed signals.

Table 1 – Effect composition and applied modulation

Effect	Dry		Wet		
	Output	Amplitude modulation	Number of delayed signals	Pitch modulation	Amplitude modulation
Chorus	✓		≥1	✓	✓
Vibrato	×		1	✓	×
Delay & Echo	✓	×	≥1	×	×
Reverber	✓	×	>>1	×	×
Flanger	✓	×	1	×	×
Tremolo	✓	✓	0	×	×

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A possible solution to keep the desired number of copies and still avoid saturation is to add a previously selected number of repetitions to the original sound, without feedback. This can be done by mixing a fixed number of delayed copies in a feedforward loop, as can be seen in Figure 1, resulting in a sort of FIR (Finite Impulse Response) filter. The amplitude of the input signal is initially changed by the gain *b*, and then each delayed copy is added to it, resulting for the Z transform of output

$$Y = (b + a\,z^{-k} + a^2\,z^{-2k} + \cdots + a^n\,z^{-nk})\,X\,,$$

in which *a* is the feedforward gain, *k* is the number of samples in the delayed time interval, and *n* is the number of delayed copies. By expressing the output in time domain, it yields

$$y(i) = b[x(i) + a\,x(i-k) + a^2\,x(i-2k) + \cdots + a^n\,x(i-nk)]\,.$$

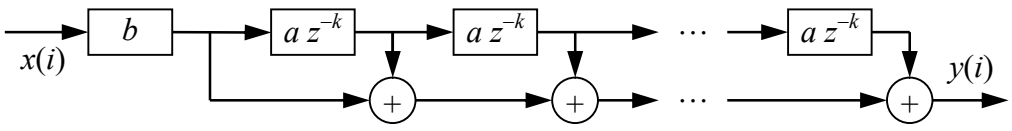

Fig. 1 – Block diagram in Z transform of the Feedforward Delay and Echo.

This expression can be used for both Delay and Echo effects, depending on the time delay k. For a sample rate of 44.1 kHz, the minimum number of delayed samples is around 800 (0.2 ms), while the maximum k shall be limited to 4400 (100 ms). The Echo is constrained by a minimum of 2200 samples (50 ms), but the only limit for the maximum value is the available memory.

The main advantage of the Feedforward Echo is to play multiple identical copies of a single note, for high values of the feedforward gain a, and long delay times, above 0.4 s. Pink Floyd used similar effect in The Wall, as well as Brian May's build up chords by striking a single note and combining them in the returning echo.

The parameters for the Feedforward Delay are, therefore, the input gain b, the feedforward gain a, the number of repetitions n, and the delay time δ_{dt}, from which the number of samples k can be obtained:

$$k = f_{sr}\ \delta_{dt}\ ,$$

where f_{sr} is the audio sampling rate.

References

[1] Wikipedia. Delay (Audio Effect). Available at: < https://en.wikipedia.org/wiki/Delay_(audio_effect)>, 2023.