Plucked String

Delay line: swiss army knife of soudtools

Karplus-Strong

In the sixties and seventies of the last century Manfred Schroeder publishes on time delays and their application as basic building blocks in artificial reverberation. Alex Strong and Kevin Karplus describe in 1983 their Karplus-Strong algorithm. A digital delay line, with a noise burst as input, and adjustable feedback, with a low pass filter in the feedback loop. This circuit is a virtual example of a plucked string: the first scientific description of a time delay as a harmonic resonator.

With well-known applications for effects such as flanging, vibrato, doppler shifts, comb filtering, delay and echoes, the audio delay line is rightly the Swiss army knife of sound tools.

1993 Yamaha's VP-1 physical modeling synthesizer

This instrument was - and is - the only one that is entirely based on the Karplus-Strong synthesis model in extensive form. (listen on: [https://soundcloud.com/yasunari-takahashi)](https://soundcloud.com/yasunari-takahashi). With a price tag of about 50,000 US you got 4 parts multimbrality with a maximum polyphony of 16 voices.

`MONOCHORD-X.pch2` is a VP-1 inspired instrument simulation of one plucked string consisting of a pick, string, wahwah and FX delay/echo.
The heart of this patch, the pick and the string, are both formed by a Karplus-Strong circuit. Also the location where the string is plucked and the placement of the pick up are formed by such a Karplus-Strong algorithm.

The place of picking and pick up position

The place where the string is struck determines which harmonics are actually occur. If we strike exactly in the middle, the odd harmonics are maximally activated in addition to the fundamental tone. Because for the odd harmonics the string in the middle shows a vibrating maximum, a so called anti node For the even harmonics, this middle forms a resting point, a so-called node. For example, on a quarter of the length of both ends, we find a anti node for the second harmonic.

It can be guessed that the place of picking on the one hand determines the strength ratio between the even and odd harmonics and on the other hand the volume ratio between the fundamental and higher harmonics. The basic rule is that the fundamental frequency has a maximum amplitude when the string is excitated in at the mid point. At this point there a nodes for all even harmoinics so only odd harmonics will be generated.

Bringing the string into vibration close to one of the ends, for example at the bridge, means that the fundamental will sound weaker and harmonics louder. In addition to the many possibilities for sound forming in this way, the material with which you strike a string also plays a role. The basic rule is:

the harder the material and the stronger the attack, the stronger the overtones. That attack can be regarded as a noise burst. If we look at the spectrum of such a vibrating string, we see a comb filter-like spectrum, the distance of the teeth of the comb being dependent on the point of picking. It all becomes a lot clearer when you start the following interactive Java applet: www.till.com/articles/PickupResponseDemo/.

In this demo you see that the location of 'monitoring' the position of the element plays a similar role as the place of attack. Again, when the element is placed exactly in the middle, the root is the strongest and mainly the odd harmonics are picked up. The element near the comb then produces a weak ground note and relatively strong high harmonics.

MONOCHORD-X.pch2

Excitator

Now that the term comb filter has fallen, it should come as no surprise that we end up on the string for the synthesis solution of the anchor point with a time delay module with extension. The extension here stands for a mixture of the stopping noise pulse with a time-delayed and phase-reversed version of itself. The output of this now forms a noise burst with a comb filter structure.

We see the implementation of this in the yellow modules, which generate the excitation signal. The OscString is used here as a delay, which has the advantage that we can directly enter the pitch value instead of the delay time, without first having to convert from time to frequency again (T = 1 / f).

This OscString module also has a low pass filter at the exit, which we can use as a loop filter. We are expanding the basic comb filter patch with an external feedback loop. Instead of the internal feedback (Decay), we use a separate crossfade module plus a mixer with invert option. By multiplying the feedback signal by -1, we can thus generate a comb filter structure whose peaks in the spectrum are at odd harmonic proportions (see G2 patch, `BasicTD formulas.pch2`).

These peaks in the spectrum can then be further enhanced by making the feedback value (crossfad value) greater than 50%. If we generate an excitation signal in this way according to the fundamental pitch of the resonator, only the fundamental and odd harmonics will be heard in the final signal.

By varying the 'pitch' of the excitation signal with respect to the resonator pitch, we simulate variation in the end points on the string. Especially in Variations 1, 2 and 6 you can hear this beautifully. Because with a high feedback value in the position delay the clotting time of the comb filter naturally increases, this signal is fed into an en-developed module, with which the paging time can be shortened if desired, but while maintaining the sound character.

Resonator
The virtual string is also formed by an OscString module, of which the internal feedback is applied. This is controlled with the Decay parameter, which represents the internal damping of the string. The Damp parameter, an internal low pass filter, represents the external damping at the end of the string on the bridge.

Pick-Up, Wah-Wah, Monitoring and Delay FX
The implementation of the oick up placement is found in the turqoise modules. The heart of this is a Delay module whose output is mixed one-to-one with the signal from the virtual string. The delay time can be modulated, among other things, by a LFO which enables chorus and flanging effects.

In addition Monochord-X is completed with a Wah-Wah module, which can also be modulated with the aforementioned LFO. In the monitoring block the signals from Excitator, Resonator, pick-up and WahWah can be listened separately or combined. The whole is again rounded off by the FX Delay / Echo.

Attention
In addition to the `MONOCHORD-X.pch2` patch, you will also find separate sub-patches for the pick, pick up placement and eMusician. To complete the whole, you will also find a theory patch, `BasicTD Formulas.pch2`. These patches give you a more detailed explanation and insight into the operation of `MONOCHORD-X.pch2`.
Watch and listen for real plucks, taps and slaps Enver Izmailov and Greg Howard.

Ernst Bonis

This article was originally published in Dutch as ‘Monochord’ in Interface 96 March 2006.

Literature

Schroeder, Manfred R.
Natural Sounding Artificial Reverberation
JAES Volume 10 Issue 3 pp. 219-223; July 1962

Kevin Karplus, Alex Strong (1983).
"Digital Synthesis of Plucked String and Drum Timbres".
Computer Music Journal (MIT Press) 7 (2): 43-55

Charles R. Sullivan,
'Extending the Karplus-Strong Algorithm to Synthesize Electric Guitar Timing with Distortion and Feedback', Computer Music Journal, Vol. 14, Number 3,

Fall 1990

internet
streaming video string vibrations
http://hyperphysics.phy-astr.gsu.edu/hbase/sound/stawav.html#c1

interactive Java applet for element-placement
www.till.com/articles/PickupResponseDemo/

Karplus-Strong
http://en.wikipedia.org/wiki/Karplus-Strong_algorithm

Enver Izmailov, two hands tapping on electric guitar
https://www.youtube.com/watch?v=prdA1LXI50s
https://www.youtube.com/watch?v=dVdQBpVXYHQ
https://www.youtube.com/watch?v=0yLCJ1EQdus
https://www.youtube.com/watch?v=rCTk3NU2zsc

Greg Howard, streaming video, Chapman Stick tapping
https://www.youtube.com/watch?v=vxZsOMqsayI