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A Digital Model of the Boss PS-2

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ABSTRACT
The Boss PS-2 is a digital delay / pitch shifting guitar pedal produced by Boss/Roland from 1987 to 1994. It is one of the rarer Boss pedals and currently has a growing cult following. With its ability to pitch shift up to ±1 octave and produce digital delays up to 2 secs the pedal has many tonal capabilities. It can produce a variety of effects from straight ahead pitch shifting, digital delay, chorus, and many other experimental tones. The pedal has a distinct 'lo-fi' sound which is why it is still a collectible even after being discontinued for over 25 years. The motivation behind creating a digital model is to make an authentic and more accessible way for contemporary engineers and musicians to gain the tones from the PS-2.

1 Introduction

The PS-2 was a first for Boss in a couple of ways: it was their first dual board circuit in a small pedal enclosure, and it was their first digital pitch shifter. The pedal has a 12-bit digital board with a 12 kHz sampling rate. In addition, early production models of the PS-2 had an issue with high-frequency noise that caused the feedback loop of the delay to become unstable. This allowed the pedal to self-oscillate in a unique way. To hear this effect, listen to the last 40 seconds of the song *Souvlaki Space Station* by *Slowdive*. This engineering "flaw" is why vintage gear collectors seek out early serial number versions of the PS-2.

Figure 1. The Boss PS-2

2 Reverse Engineering Methods

For the most part, this pedal does its effects processing on a DSP chip. Therefore, in order to model the PS-2, I had to reverse engineer the sound by ear and with the limited information about the schematic provided in the service manual.

Additional features were also added to the model, such as using the pitch shifter in series with the digital delay and allowing for pitch shifting in the feedback loop. To test and design my DSP I used the Software RackAFX in conjunction with C++.

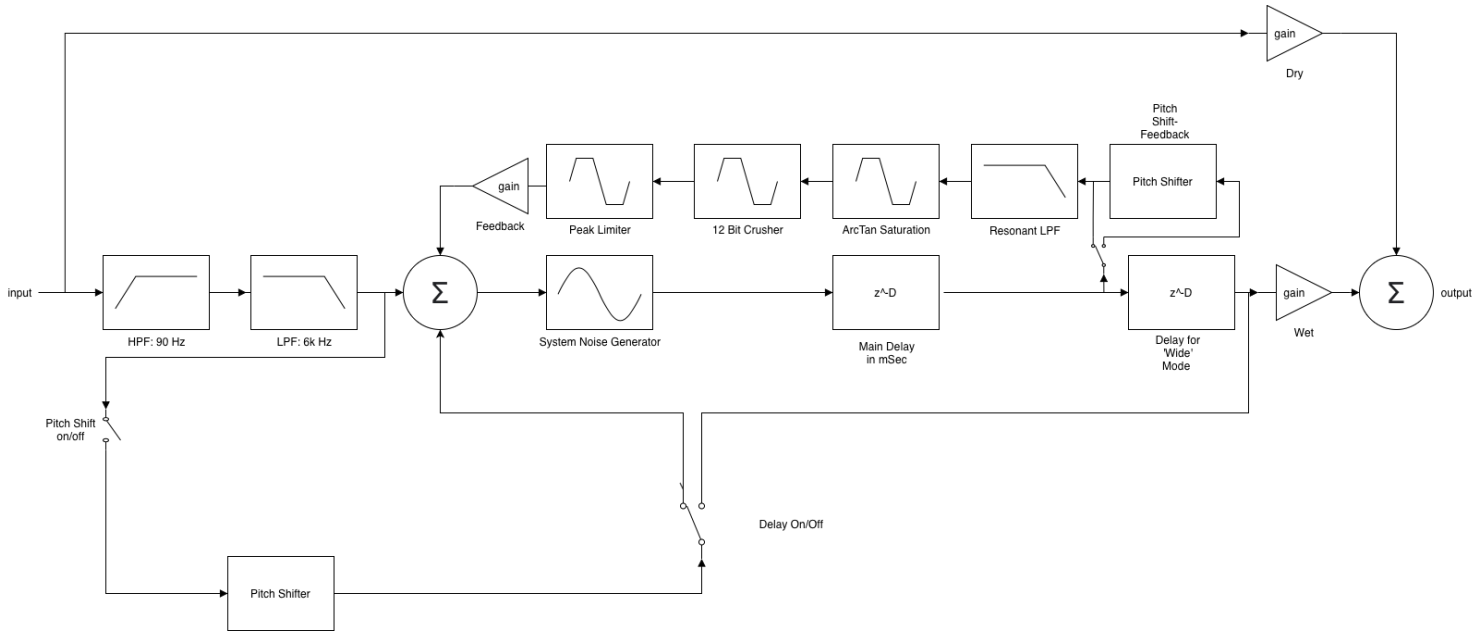

Figure 2: The full PS-2 Model

3 Modeling the Digital Delay

The signal flow architecture of the PS-2 model is shown in Fig. 2. Simply put the signal is split at the input for the wet/dry gain controls. The input signal is then filtered and fed into a delay line with a variety of filters, bit-depth reduction, and non-linear components in the delay's feedback loop. Finally, there are various switches to control how the pitch shifter is implemented.

3.1 Input Filters and System Nosie

Now we will look at the specific choices made in the modeling architecture.

First the signal is passed through two filters, a 2nd order high-pass filter with a cutoff at 80 Hz and a 2nd order low-pass filter with a cutoff at 6 kHz. These cutoff frequencies match the frequency bandwidth of the 'effect' signal path stated in the manual, 80 Hz to 6 kHz.

The original unit had a sampling rate of 12 kHz. Meaning it operates with a Nyquist frequency at 6 kHz; this explains the limited frequency bandwidth stated in the manual.

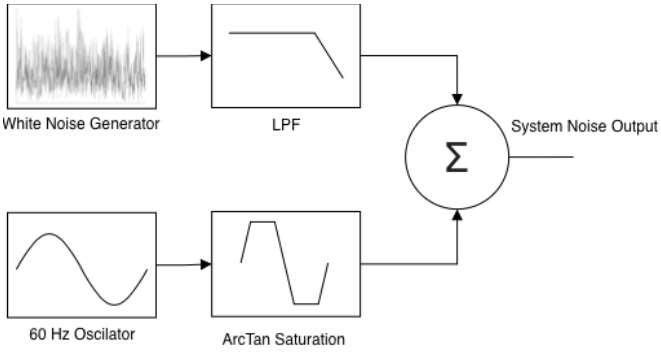

Figure 3: System Noise Generator

Next, as the signal enters the delay line there is a System Noise Generator object. This object mimics the noise floor found in the Boss PS-2. This constant noise floor also allows the delay to self- oscillate even when there is no input signal present. See Fig 3 for the System Noise Generator architecture. It is made up of two noise signals, a 60 Hz oscillator to mimic the noise from the unit's power supply, and a

white noise oscillator to mimic the mid and high frequency noise present in the pedal. In addition, the 60 Hz signal is sent through a wave shaper saturation object to add additional harmonics. This simulates the sound of aged capacitors commonly found in vintage gear. Finally, the white noise is sent through a low-pass filter to control the intensity of the noise.

3.2 The Feedback Loop

As mentioned before, the device's feedback loop can become instable allowing the unit to self-oscillate. To achieve this digitally, a combination of a resonant low-pass filter, bit-depth reduction, and nonlinear components were used.

The first object in the feedback loop is a resonant low-pass filter. This was object was critical in modeling the engineering "flaw" that caused the unit to self-oscillate. There are a few helpful hints in the unit's service manual that explain why the self-oscillation occurred. The service manual reads, "NOISE (high frequency) ... REASON: Pre-emphasis and De-emphasis circuits cannot reduce high-frequency noise."

At the time it was standard for Boss pedals to have Pre-Emphasis and De-Emphasis circuits in their pedals. The idea behind these circuits was by boosting high-frequencies of the input signal, Pre-Emphasis, and then adding an identical high-frequency cut at the output, De-Emphasis, the signal would have the same tonal consistency at the output when compared to the original signal.[1] But in the case of the PS-2 these circuits did not function properly, and the added treble boost was not attenuated properly by the De-Emphasis circuit. To mimic this engineering 'flaw' I used a resonant lowpass filter in the feedback loop. This boosted the needed high frequencies while also keeping the signals bandwidth below 6 kHz, the original unit's Nyquist frequency.

The next component is a wave-shaper saturator that emulates the sound of the PS-2 clipping during self-oscillation.

Next in the feedback loop is a 12-bit bit-crusher. This is for mimicking the 12-bit depth of the original PS-2. Finally, it is all sent through a Peak Limiter to prevent the signal from digitally peaking above 0 dB-FS.

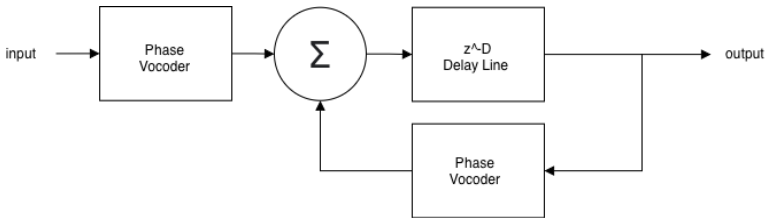

Figure 4: Pitch Shifting Architecture

4 Modeling the Pitch Shifter

The pitch shifter in the Boss PS-2 has a rather standard sound and functionality besides one control. When the pedal is put into the pitch shifting mode the feedback knob will add more pitch shifted harmonics above or below the standard pitch shifted signal. For instance, when you pitch shift +1 octave the feedback knob will begin to add octaves above the +1 octave as it is turned up. If you were pitch shifting down it would add even lower octaves. The added upper/lower harmonics are also slightly delayed from the standard pitch shifted signal.

The architecture to model this is shown in Fig 4. As the main pitch shifting algorithm, a standard phase vocoder with overlap/add processing was used to pitch shift in real time.[2] In the model I used two phase vocoders and a simple delay line with a feedback path. This will shift the pitch of the signal coming in and then depending on where the feedback gain is set the original shifted signal will be shifted again. When the delay is set with a very short delay time this effectively models the pitch shifting algorithm in the PS-2.

5 Summary

Using filters, non-linear processing, delay-lines, and a phase vocoder an effective digital model of the Boss PS-2 has been presented. It effectively captures the vintage sonic qualities of the unit and its unique self-oscillation effect. As a result of digitally

modeling the PS-2, C++ code can be constructed to create a modern audio effect plug-in for VST, AU and AAX formats. In conclusion, this allows great accessibility to the tones of the Boss PS-2.

Please check out this video for this paper:
https://youtu.be/kcoGPrmXtHg

References

[1] Electro Smash, “Boss CE-1 Analysis,” *electrosmah.com*

[2] J. Laroche, and M. Dolson, "New Phase-Vocoder Techniques are Real-Time Pitch Shifting, Chorusing, Harmonizing, and Other Exotic Audio Modifications," *J. Audio Eng. Soc.*, vol. 47, no. 11, pp. 928-936, (1999)