WOW WAH

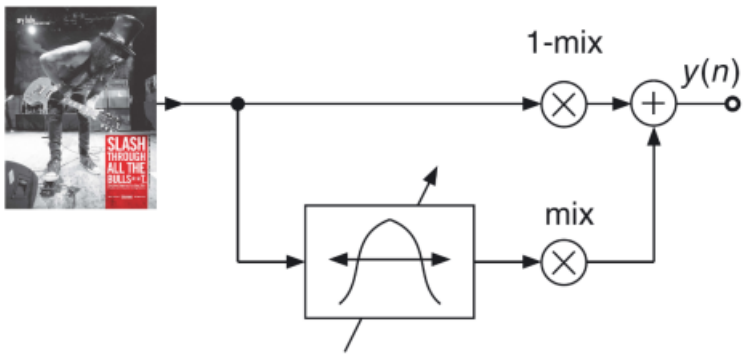
Wah effect with Juce

Link GitHub: https://github.com/polimi-cmls-22/group12-hw-Juce-Ratatouille

Wah pedal overview

Wah-wah electric guitar effects pedals are one of the most common stomp boxes used by players today, found in everything from funk, metal and more.
On a practical level, the standard Wah pedal exploits a mechanical connection between the foot impulse and the opening/closing of the sound effect.
Since its first implementation, in the second half of the twentieth century, the famous onomatopoeic pedal has gained numerous innovative features, created by manipulating the foot-controlled signal.

The Wah effect can be obtained by engaging a “moving” filter, with a variable resonant peak. Players’ foot action allows the movement of the resonant frequency peak up and down among a defined range. This effect leads to a spectrum shaping similar to speech and produces a speech like “wah-wah” sound.

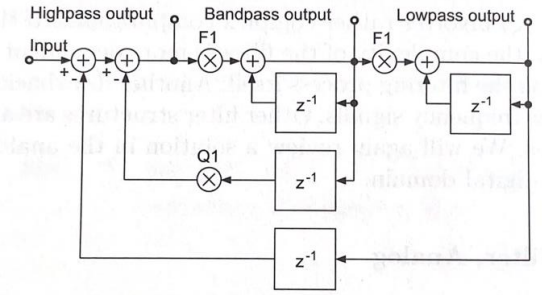


The basic block diagram above schematically shows how the input is filtered by a resonant filter and then summed back with the original dry signal.

WOW WAH algorithm

To generate a code that actually described the wah-wah effect we chose a state variable filter to produce all three filter responses (Low Pass, High Pass and Band Pass) simultaneously.
Briefly, the LP filter selects low frequencies up to the cut-off frequency f_c and attenuates frequencies higher than fc; the HP selects frequencies higher than fc and attenuates frequencies below f_c and the BP selects frequencies between a lower cut-off frequency f_{cl} and a higher cut-off frequency f_{ch}. Frequencies below f_{cl} and above f_{ch} are attenuated.

This course of action also allows the time-varying control of the main filter parameters.
The digital implementation of the state variable filter is at the heart of our code, and can be represented as shown in the image below:



The difference equations describing for the output signal are the following ones:

$$y_l(n) = F_1 y_b(n) + y_l(n-1)$$
$$y_b(n) = F_1 y_h(n) + y_b(n-1)$$
$$y_h(n) = x(n) - y_l(n-1) - Q_1 y_b(n-1)$$

where F_1 and Q_1 are tuning parameters, respectively described by these formulas:

$$F_1 = 2\sin\left(\frac{\pi f_c}{f_s}\right)$$

$$Q_1 = 2\zeta$$

The simple relations between control parameters and tuning coefficients warrants particular efficiency to this filter, especially for musical applications where the tuning frequencies are small compared to the sampling one, and the damping factor is usually set to small values.

For the development of the *WOW WAH* we took as reference several Wahs currently on the market, such as the Boss AW-3. In addition to the classic parameter of most of the Wah pedals, the AW-3 allows the switch between the tempo (auto-wah) and classical (dynamic) modes.
The core of our project consists of the characterization and implementation of these two features since they represent a valid alternative to the common stompbox.

WOW WAH **GUI**

WOW WAH's GUI presents a simple and intuitive interface, divided into three separate sections, which allow the user to simultaneously visualize all the adjustable parameters.
Because of the wide variety of results achievable by simply modifying the major parameters, we decided to provide labels and visible values for all the commands, so that the user can easily understand how a determined sound is obtained.
The left part of *WOW WAH* interface is entirely dedicated to the mode settings.

Tempo mode:

The tempo mode allows the user to select a defined rate for the filter sweeping, among a time interval between 200ms and 4s.
This particular effect is obtained with the use of a sinusoidal Low Frequency Oscillator, adopted to change the center frequency.
The frequency of the LFO determines the periodicity of the Wah sound, regardless of the audio track the effect is applied on.

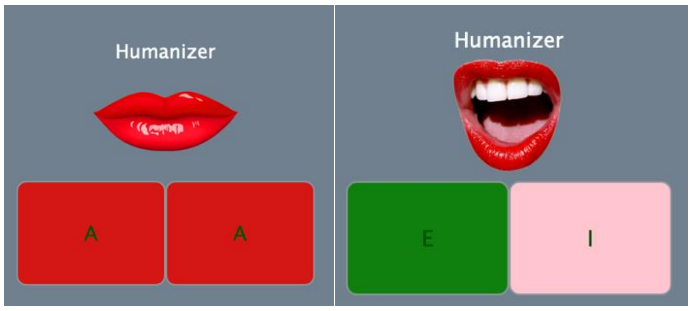
Dynamic Mode:

The dynamic mode represents a more sensitive usage of applications of the Wah effect. In this case, the effect is applied accordingly to the "profile" of the audio track. For this second mode, a further relation between the envelope of the signal and the pass filter is established. In the AW-3 this behavior is obtained thanks to a connection which links the guitar picking to the Wah range: the stronger the player plucks the string the wider will be the opening of the effect.
To obtain a similar result, due to the lack of the physical pedal control, we implemented a second filter that maps the ADSR of the audio track and controls the movement of the resonant filters.

In addition to these two switchable modes, we realized a combobox to allow the user to choose the desired type of pass filter (LP. HP and BP).

In addition to the switch between the dynamic and tempo mode, we also implemented a further feature, the so called "humanizer"

Humanizer:



Humanizer is inactive *Humanizer is active*

The "Humanizer" effect creates human voice-type vowel sounds, by varying the sweeping interval of the filter. The mouth-like bottom turns this feature on and off, while the two lower ones set the two vowels which characterize the frequency range.

The humanizer effect is given by the superposition of two state variable filters acting respectively on the first and the second formant of the desired vowels.

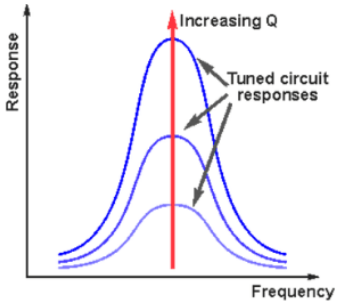
The five sliders that make up the bottom row of *WOW WAH* GUI are used to set the basic parameters of most of the existing Wah pedals.

- Depth: Moving this slider the user can change the maximum cutoff frequency of the selected pass filter. In case of Low Pass and High Pass, since there's only one f_c, the action of the slider is straightforward, while it's slightly less intuitive for the BP case. In this last scenario, the modifiable frequency is the higher one, while the lower one is fixed. By changing f_{ch}, the frequency range can be noticeably reduced, generating a consistent sound variety.

- Q-factor: the Q or quality factor affects the sharpness of the resonant frequency. Higher Q values make the resonant boost narrower and produce a sharper, more aggressive sound. Lower Q values widen the resonant boost and bring up more of the surrounding frequencies, resulting in a smoother sound.

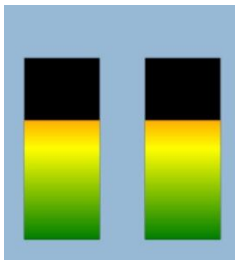
- Dry/Wet: This slider adjusts the amount of Wah effect that is applied in response to the input level. The further you turn this knob clockwise, the stronger the Wah effect applied, even with a smoother envelope.

- Decay/Attack: These two sliders allow the control of the envelope detector filter, when the dynamic mode is switched on. As a result, they modify the time over which the Wah effect acts. For example, the decay slider determines how quickly the envelope will clamp back down as the note fades out. When set very low this offers a quick plucky sound. When turned up, it allows things to ring out a little longer which can be quite helpful for chords or slower passages.



In general, the application of a filter on an audio track depends on the overall level of the input signal. The filter might produce the right effect, but the result might be useless because the incoming track is too weak. In order to avoid similar side effects, without the implementation of a normalization method (characterized by remarkable computational effort), we disposed two vertical

level meters which move accordingly to the RMS value of the signal and warn the user about the possible drawback.
If the result is too loud, the circular gain knob allows the user to fix the inconvenience and vice versa.

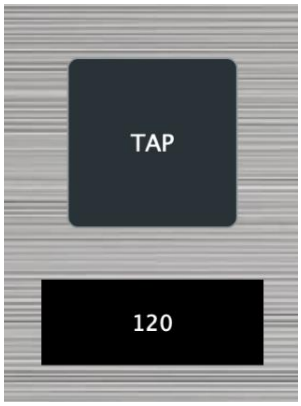


Level meters

Gain knob

TapTempo:

When the TEMPO mode is selected, it's possible for the user to manually set the rate of the oscillation, by clicking repeatedly on the corresponding button. The resulting BPM rate is shown in real time in the label below.



Tap Tempo at 120 BPM

Conclusions

Within the *WOW WAH* project we focused on the implementation of the most common used parameters of most of the Wah pedals; the main problem we had to face was the coordination between the effect and the audio track in the dynamic mode, as if to emulate the guitar picking input.
This required the digital implementation and the superposition of multiple filters, each of them characterized by several variable parameters. The choice to use an algebraic approach instead of relying on the DSP module is due to the necessity of having a more direct control on these last parameters, to get a clearer idea of the working principle of an auto-wah.
During the designing phase, we also tried to implement an additional second order low pass filter, aimed to obtain wider variety of sounds and a more accurate control over the audio input signal. This second filter thus had a disruptive impact on the overall gain and compelled us to only the state variable filter described above.
A possible future improvement of *WOW WAH* could be the realization of a specific section dedicated to the tremolo effect, achievable by simply combining the effect with a low-frequency amplitude variation.
Another additional possible implementation could be based on compiling a precise normalization method, to have an exact control on the gain due to the presence of the filter.