Two notes are better than one: A chord-generating pre-amp

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ABSTRACT

The guitar pedal has been used since the 1950's to amplify, modulate, delay, and otherwise modify the sound of a guitar to create interesting sound effects. Today, there are literally hundreds of guitar pedals on the market that can do compression, wah-wah, overdrive, chorus, flanger, phase-shift, time-delay, and reverberation sound effects. In particular, there is a class of effects in which the pitch is shifted in order to create intervals. However, many of the guitar pedals currently available can only make the same interval for each pitch--even though music theory tells us that in a key, not all chords are harmonized the same way. Thus, we designed a pre-amp that will harmonize a note depending on the chosen key. First, we sampled at 44.1 kHz, a frequency greater than the Nyquist frequency and the standard for sampling music. Then, we employed the FFT to anaylyze the signal in the frequency domain. Third, we identified the pitch. Fourth, we modulated the pitch by a major third or a minor third depending on the pitch. Fifth, we combined the modified signal and the original signal to create the harmonized signal. Last, we took the IFFT and sent the new signal to the amplifier.

BACKGROUND & THE PROBLEM

History of Guitar Pedals

Technology is amazing. For example, when I wake up in the morning, I reach for my smartphone and turn-on some music to start my day. And yes, those are basically the opening lyrics to "More than a Feeling" by Boston, you can put your smartphone away now.

Barry Goudreau, Tom Scholz, Sib Hashian, Brad Delp, Fran Sheehan, in 1977.

But what you may not know is that Tom Scholz, the founding member of Boston and its primary songwriter, attended MIT and actually invented a guitar pedal to use to help make Boston's distinctive sound.

Guitar Pedal Effects

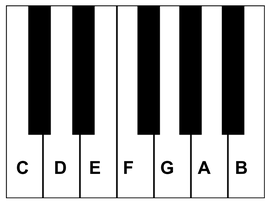
There is a "signal chain" where the electrical guitar is connected to the "guitar pedal" which is then connected to the large amplifier. The effects can be split into three main areas: volume and dynamic effects, modulation effects, and time-based effects. Modulation effects include those pedals which can output musical intervals of primarily octaves.

The Problem

Currently, guitar pedals which change the tone can only do so in fixed intervals--which allows for incomplete harmonization. We wanted to design a guitar pedal which could harmonize different notes in the key with a different invterval--which allows for better harmonization.

THEORY: MUSIC AND MATH

Music Theory



One octave of a piano: the white notes make the key of C. The black notes are C#/Db, D#/Eb, F#/Gb, G#/Ab, and A#/Bb and are used in other keys.

In western music, the octave is split into twelve "semitones," with a key consisting of a collection of 8 notes. On a piano, the key of C are the "white notes." A quick glance will verify that C to E is separated by 4 semitones, while E to G is separated by only 3. Thus, to stay in the key of C, different notes must be harmonized by different amounts.

Math Theory

$$X_k = \sum_{n=0}^{N-1} x_n * e^{-2\pi * k \frac{n}{N}}$$

$$n = 1200 * log_2(\frac{f2}{f1})$$

$$x_n = \frac{1}{N} \sum_{k=0}^{N-1} X_k * e^{j2\pi k \frac{n}{N}}$$

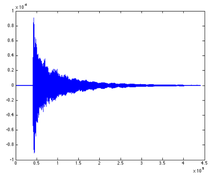
First, we must convert our input guitar signal into the frequency domain.

Cents are defined as n. Cents partition an octave into 1200 equal intervals.

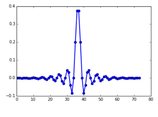
In order to output a note, we take take the inverse Fourier Transform of f_2.

Filter Response

Time Domain Guitar



Filter Coef.



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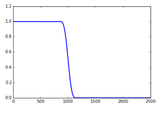
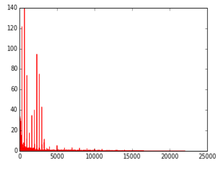


Freq. Domain Guitar



IMPLEMENTATION

Overview and Signal Sequence

Electric Guitar:
Produces an analog signal

Behringer U-Control UCA-222:
ADC that samples at 44.1 kHz

Laptop:
Low-Pass Filter, FFT, harmonize, IFFT, send signal.

Behringer U-Control UCA-222:
DAC of harmonized signal

Amplifier:
Outputs harmonized notes.

Design Choices

For the prototype,we had two "presets" for how device would harmonize each key. For the key of C, the first preset has C, F, G major, D, E, A minor, and B diminished. The second preset has C, F, G minor, D, E, A, major, and B diminished. It does not harmonize notes not in the key.

CONCLUSIONS

In the future, we can extend this idea to:
1. Presets of more chords such as Dominant, Major, Minor, Augmented, and Diminished Seventh Chords
2. Allow for a "manual" mode where the user can specify specific intervals for each scale-degree.
4. Use a "plucked-string" algorithm or synthesizer to make the harmonics sound as if they were played by different instruments.

We want to thank Dr. Baraniuk for teaching the four types of Fourier Transforms and saying the words "Daft Punk." We also want to thank Jeff Lievense and Nancy Jia for their work as TA's.

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