I. Overview

In today’s world of abundant computation, musicians have many options when they wish to produce effects or alter the sound of their instruments; however, digital signal processing requires large overhead and the audio signal must be sampled and converted into digital form which can degrade quality and add unwanted distortions. The features of analog signal processing, namely lower power consumption, minimal perceptible delay and preservation of fidelity, make it a clearly preferable to the digital route for the highest quality.

In our project, we will attempt to have a customizable and modular analog effects bank for the bass guitar that will focus on the freedom of the user to choose how to modulate their audio. Our system will include a variety of interconnectable passive, active, and adjustable modules that the user can select and combine to achieve their desired overall effect. The design will output the modulated sound through a speaker using a conventional amplifier design. Since the design is intrinsically modular, we expect to keep expanding the functionality of this device to include a wider range of effect options.

II. Modules

The effects bank will consist of a pre-amplification stage, 5 audio effects modules plus an output stage depicted in the figure below. All of the effects stages will be buffered and have a max output of 5Vp-p in order to ensure ample room for processing with ±15V rails. With this design paradigm, the modules can be placed in any order and any combination the user desires without any consideration other than what sound will be produced.

1. Pre-amp (Israel)

Electric instruments, in particular Bass guitars, require a pre-amp stage in order to increase their signal strength. Without this stage noise on the signal line can become a major issue and negatively affect the sound of the instrument. The amplification can be accomplished with a two stage inverting JFET amplifier with adjustable gain that will output a maximum of
5Vp-p. JFETs are chosen over other transistors because they are highly linear and introduce little unwanted distortion. As a stretch goal, we will add a 3-5 band equalizer as a third stage.

![Diagram of the project workflow.](image)

*Figure 1. Workflow diagram. This project is inherently modular, thus some stages may be interweaved differently. The above diagram shows one possible set up.*

2. Auto-Wah (Israel)

The auto wah effect produces a wavering sound that is controlled by the playing dynamic. The effect is made by shifting the cutoff frequency of a filter to accentuate certain frequencies being played based on voltage that corresponds to playing dynamic. The control voltage will be supplied by a diode rectifier functioning as an envelope follower to determine the signal level and fed into a voltage controlled state variable filter which can be constructed with op-amps, transconductance amplifiers, passives, and BJTs.

3. Phaser (Israel)

The Phaser module produces a subtle shimmering effect that has a somewhat otherworldly feeling. The effect is achieved by splitting the signal into two feed-forward paths, one of which is treated with n all-pass filters, thereby altering the phase of the waveform, and is then added back into the original, resulting in n/2 notches, or disturbances in the original signal’s frequency spectrum. The hardware of this module is fairly simple and can be realized with op-amps and passives. As a stretch goal it is possible to make the phase shift of the all-pass filters voltage controlled and swept through with a low frequency oscillator for an additional effect.
4. Flanging (Mark)

The flanger functions effectively like a comb filter and creates a thicker swooshing or shimmering effect. This filter can be implemented by feeding back a time delayed version of the signal and mixing it with the original audio signal. A common approach to analog delay is the bucket brigade, which is essentially a chain of capacitors and MOSFETS, each storing a voltage and passing it along the chain. The propagation time of the waveform in this long chain of sample and hold blocks corresponds to the time delay.

At the circuit level, the input audio will be split in two, one of which will undergo analog delay through the bucket brigade. The signal, with a delay from 5ms ~ 20ms, will then be passed through an all-pass filter with a voltage controlled phase shift. The final processed signal will be added back to the original audio waveform to produce a definitive flanging effect.

5. Bitcrusher (Mark)

Bitcrushing turns the normal sound of an instrument into the “8-bit” type of music typically heard in the first video games. The effect is achieved by altering the voltage resolution and the sampling rate of the audio signal. In operation a smooth waveform is sampled and held at a certain frequency and with a output voltage of only predefined increments creating a series of steps that approximate the signal.

The operation of the bitcrusher can be implemented with two main circuit stages, the sample and hold and an analog to digital converter (ADC). The sample and hold is made by an intervallic charging of a hold capacitor, whose period is set by a clock circuit with an adjustable frequency and duty cycle, which allows us to adjust the sampling rate. Then the held value is fed into a 3-bit direct-conversion ADC. The ADC rounds the sampled audio signal to a set constant value, thus setting the resolution. As a stretch goal, more resolution to the ADC will be added, since the number of comparators needed for this type of ADC increases as $2^N - 1$, where $N =$ number of bits.

6. Overdrive (Mark)

Overdrive introduces new even and odd harmonics, which can make the sound either warmer or harsher and is responsible for the heavy distortion heard in Rock and Metal.. Overdrive is a “gain” effect, which is achieved through methods involving amplification of the original signal. When a sinusoid passes through an audio amplifier with large enough gain, the
waveform will hit the rails of the amplifier and undergo a nonlinear transformation called clipping. When a waveform clips, it introduces new even and odd harmonics, which are responsible for the alteration of the sound profile.

This is realized at the circuit level by cascading various amplifier stages with variable gain. The adjustable gain varies how harsh the overdrive is by varying the degree of waveform clipping. As a stretch goal, circuitry enabling soft clipping will be employed. Soft clipping is when the top of a waveform is not completely cut off, but instead the gain above a certain voltage will be compressed. This makes the waveform rounder on top and is less harsh than the regular overdrive with hard clipping.

7. Audio Amp

The audio amplifier is not a focus for this project and the surface mounted amplifier board built in the class will be used.

III. Integration and Testing schedule

By April 11: Ordered parts, designed schematic for preamp stage (Israel), schematic and working implementation of bitcrusher (Mark)
By April 18: schematic of auto wah done, working implementation of preamp stage (Israel), schematic of flanger (or am modulation) and working implementation (Mark)
By April 25: schematic of phaser, working implementation of phaser (Israel), working implementation of overdrive (Mark)
By May 2: fully integrate modules and circuit debugged (Israel/Mark)

All modules will be initially tested with the function generator at relevant frequencies; then, once working alone, they will be tested together with other modules and with a real live bass guitar.

IV. Components List

To achieve the flexible control of effects desired in our design, adjustable R and C values will be needed since things like gain, corner frequencies and oscillation frequencies need to be user controlled. Time delay is a non-trivial component that requires hundreds of stages that are infeasible to build by hand so bucket brigade ICs will be utilized. At least 5 SPDT switches will be needed to interweave the modules, allowing the user to interconnect different modules. To demonstrate our project, we will be operating on the lab kit’s +/- 15V power supply.

- LM356 operational amplifiers
- 3904 and 3906 BJTs
V. Conclusion

Although many musicians now turn to digital signal processing of audio for its flexibility, analog circuitry will always be a mainstay for those in need of quality of sound and accurate reproduction. The final result of our project is a flexible and inherently modular audio effect bank, where our implementation of difficult effects such as the auto-wah and the flanger will hold their own compared against production effects pedals. Through our diverse collection of effects modules, our final project demonstrates a wide variety of analog circuitry and has great potential for expansion and improvement.