The Science of Wah Pedals

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Introduction

I first became interested in effects pedals after attending Adrian Belew's performance at the Elnora guitar festival. It was a one man show where Belew, armed with a guitar, various gadgets, and foot pedals, played a set of modern yet expressive pieces. The performance left an impression on me as an aspiring jazz pianist. In the middle of trying to electrify and expand my own sound, the freedom and flexibility afforded Belew by his various accessories inspired me to take a greater look into the science and use of electronic effects.

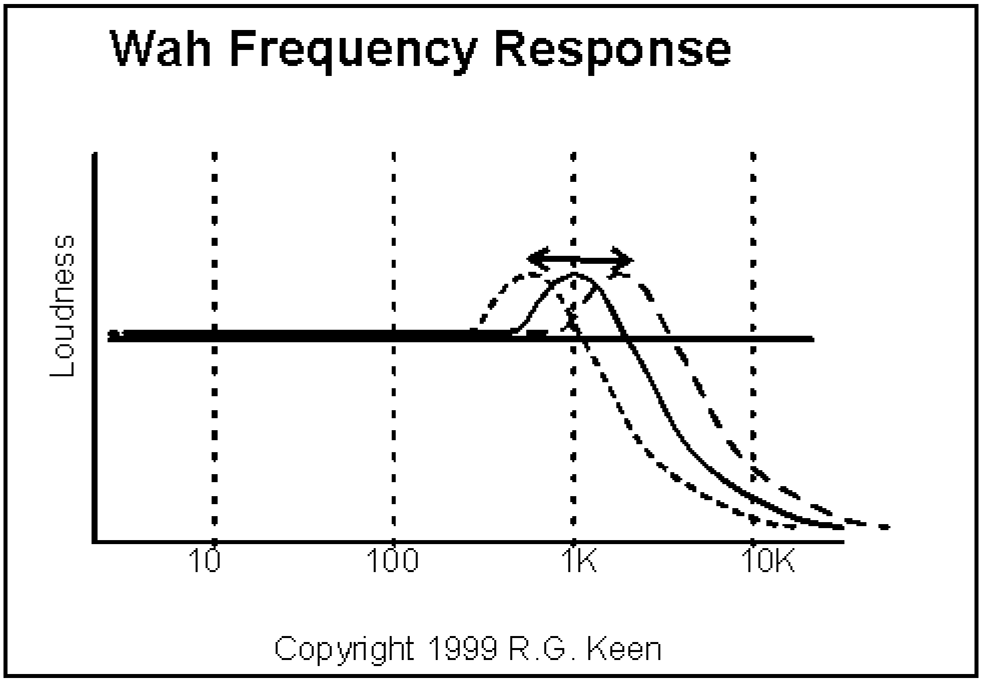
Overview

Stomps, wahs, and other effects serve to increase the range of tonal and articulate expression on various instruments. They are especially effective when used with guitar or keys because of the instruments' very limited control of tone and expression. While guitars have some capacity for shakes and other ornaments on notes, keys are almost wholly incapable of enjoying the expressiveness of other instruments. Effective use of wahs by these instrument types can open up whole new dimensions to their play.

All effects pedals follow the same basic path. An electrical signal travels through a wire into the pedal. Once in the pedal, a circuit carries out any number of operations on the source wave. These can change frequency, wavelength, wavenumber, amplitude, intensity, speed and direction of the source wave. Once done the pedal will then send the wave on to more effects or the resulting sound source. Changes in the sound's waveform can then be observed by the listener. Varying the harmonic content with effects is analogous to vocalists or wind players being able to vary tone and expression. The only difference is that instead of physically changing the behavior of a vibrating membrane and its resulting sound wave, effects pedals use circuits to perform operations on electronic waves.

Enter the Wah

After much deliberation, I decided to build a wah-wah. Wahs work as either band pass or low pass filters. Band pass filters filter out signals outside of a certain range while the low pass filter is over coupled, exhibiting a resonant peak just at its low pass roll off frequency. The resonance can be swept across a range of frequencies by depressing or raising the pedal to make the signature wah sound.



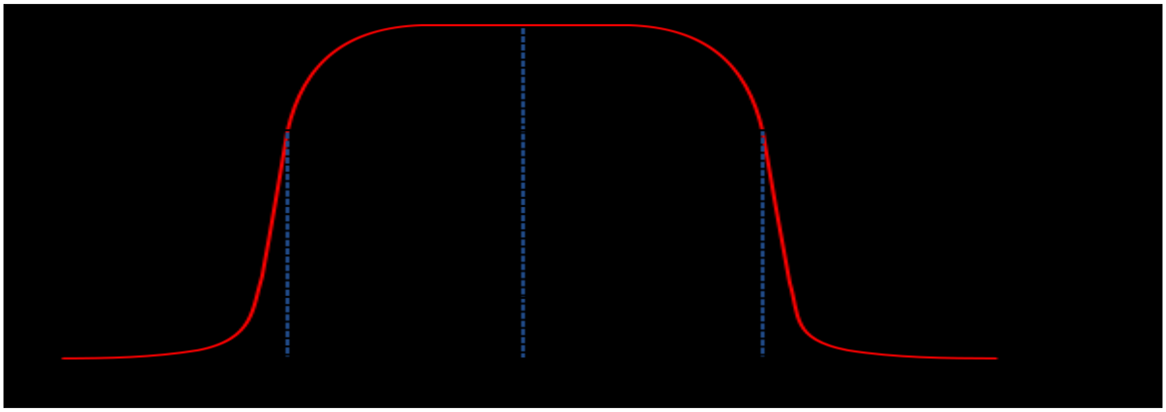
The effect most resembles a trumpet player's use of a plunger mute. Plunger mutes physically filter frequencies by covering the horn's bell. Performers can then move the filtered frequency up or down by changing how open or closed the bell is.

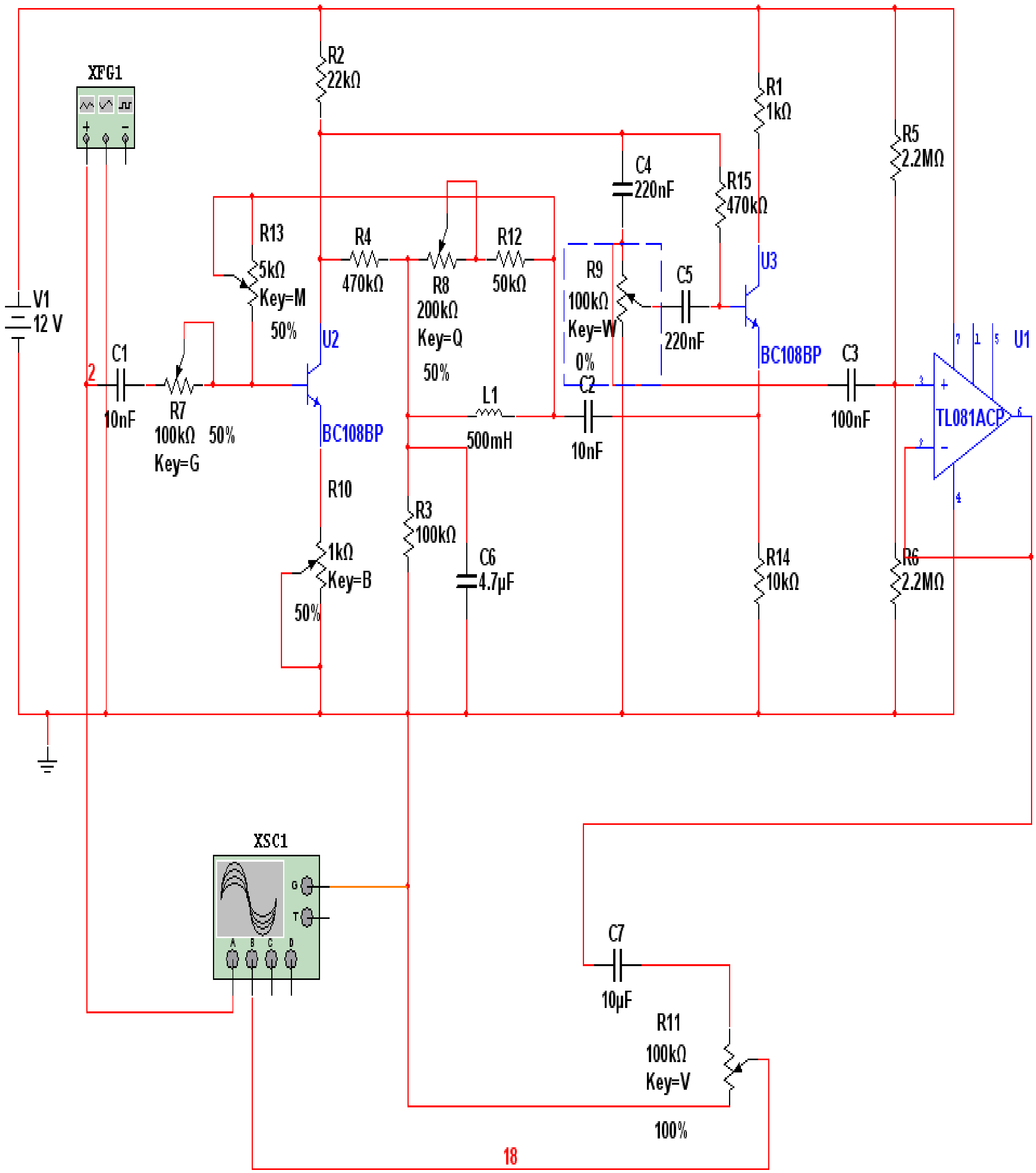
Ironically, when the wah wah was first happened upon by a vox employee the first reaction was to market it as a horn effect. If not for a number of individuals seeing its potential as an accessory to the guitar, it may not have become the iconic piece of gear it is today.

There are many ways to build a filter for a wah but I eventually settled on an inductor design similar to the one first made by the Vox Corporation. The design creates a band pass filter using a variable inductor-capacitor circuit. A simple LC circuit has a specific resonance because charge is periodically discharging from the capacitor, traveling through the inductor, collecting on the other side of the capacitor, and then repeating the process in reverse. The resonant frequency of the simple inductor capacitor circuit can be given with the expression.

$$f = 1/(2\pi\sqrt{LC})$$

Below is also a visualization of a simple LC band pass filter around its resonant peak.

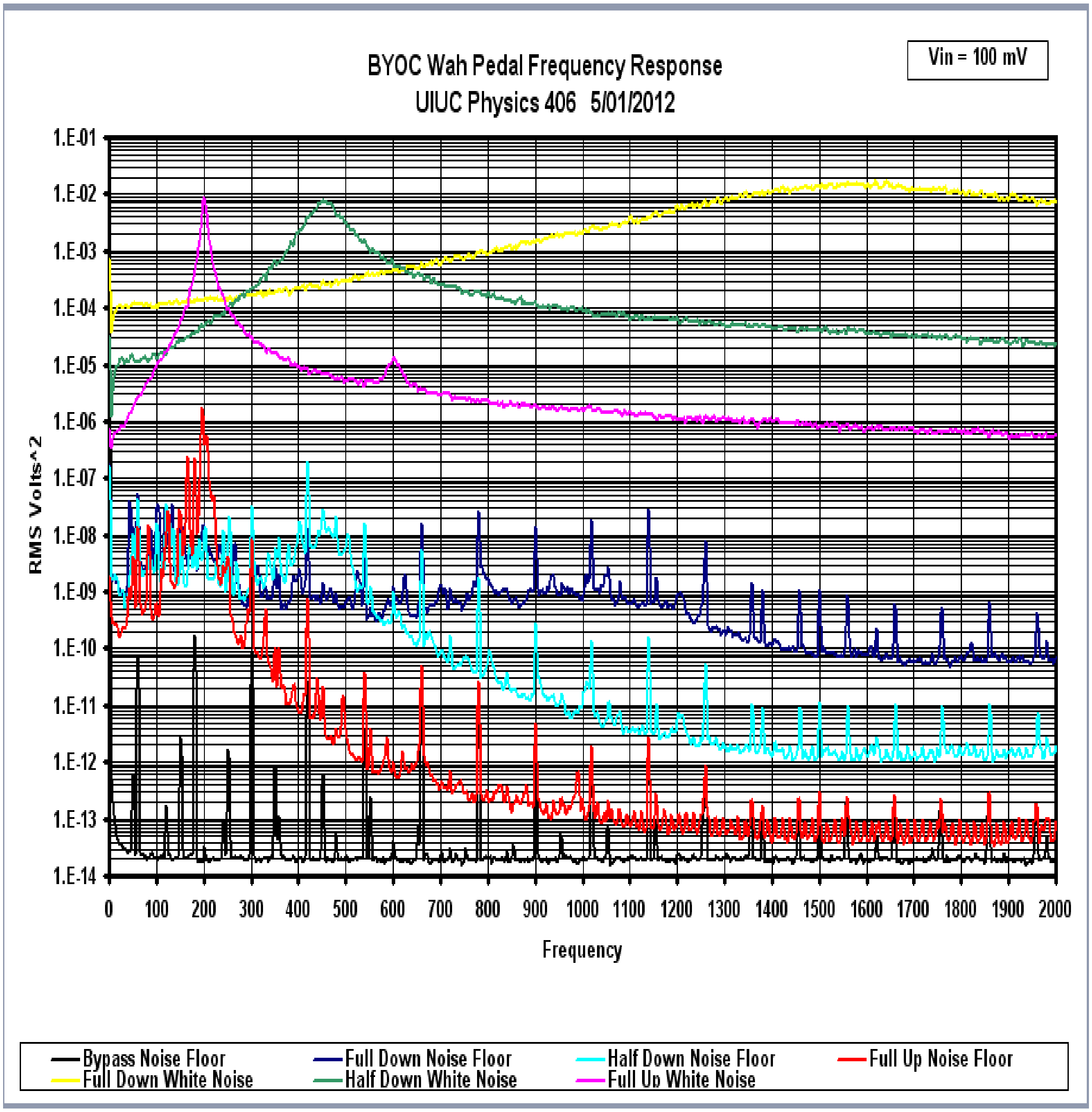



XFG1
R2
22kΩ
R1
1kΩ
R5
2.2MΩ
C4
220nF
R15
470kΩ
R13
5kΩ
Key=M
50%
R4
470kΩ
R8
200kΩ
Key=Q
50%
R12
50kΩ
R9
100kΩ
Key=W
0%
C5
220nF
U3
BC108BP
U2
BC108BP
V1
12 V
C1
10nF
2
R7
100kΩ
50%
Key=G
L1
500mH
C2
10nF
C3
100nF
U1
TL081ACP
R10
1kΩ
Key=B
50%
R3
100kΩ
C6
4.7µF
R14
10kΩ
R6
2.2MΩ
XSC1
C7
10µF
R11
100kΩ
Key=V
100%
18

Wah wahs get their signature sound by varying where this resonant peak is. Upon looking at my schematic, I began to ask questions. How does a wah with only some fixed capacitors and a fixed inductor vary its resonant frequency? To the inductor, the second transistor appears grounded through the 4.7uF capacitor. The capacitor also appears grounded to the inductor because its far side is connected to the emitter of the second transistor. The second transistor's emitter has a low output impedance and therefore looks like "ground" if you ignore the signal coming out of the emitter. Current passing through the capacitor is determined by the voltage across the inductor/capacitor and the voltage driving its apparently grounded side. That voltage is increased or decreased by the position of the foot controlled pot. If the wah pot setting increases, the capacitor will let more signal current through because the voltage driving the second transistor is bigger. If the wah pot setting decreases, the capacitor will let in less signal current. Changing the current through the capacitor can make it look larger or smaller than it really is. The variable potentiometer effectively makes a variable capacitor with the circuit.

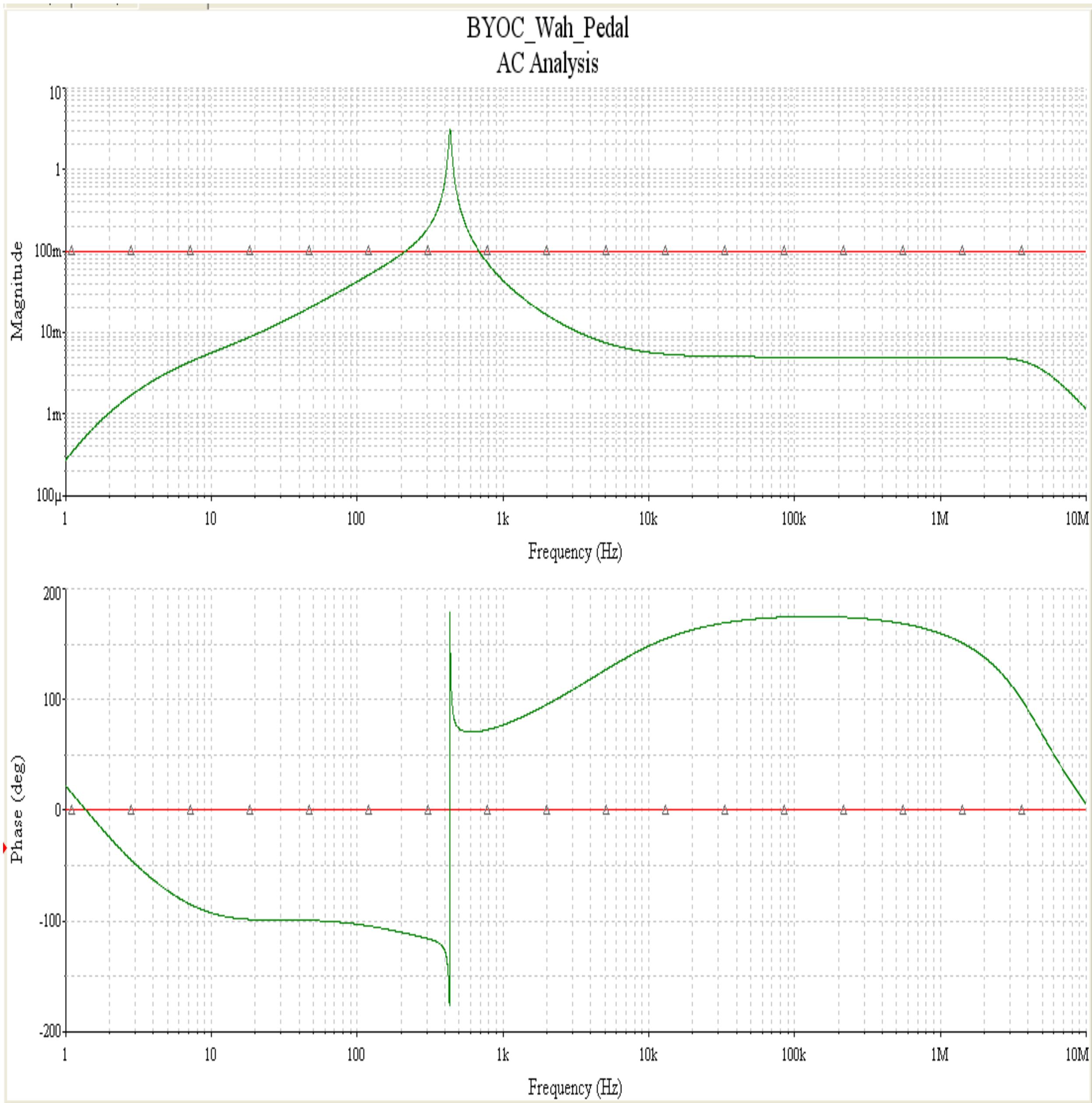
I bought components and an enclosure off of buildyourownclone.com. The price point was a little steep but I was in a rush after a botched attempt at another circuit design. All that was required was some light solder and assembly work. The wah's first run was a dud. I opened up the guts and decided to redo all the wire connections. After that slight modification it sang with a nice full tone but a whole lot of gain. I put it down for a few days only to find a perturbing clicking sound mid-sweep. The input and output jacks had come loose and after retightening them it returned to its original tone.

One thing I particularly enjoyed about the pedal was its responsiveness when swept. It had a nice smooth sound over a pretty decent range. In an effort to quantify my observations, we made both experimental and simulated measurements of the pedal itself using both matlab and electronics work bench.

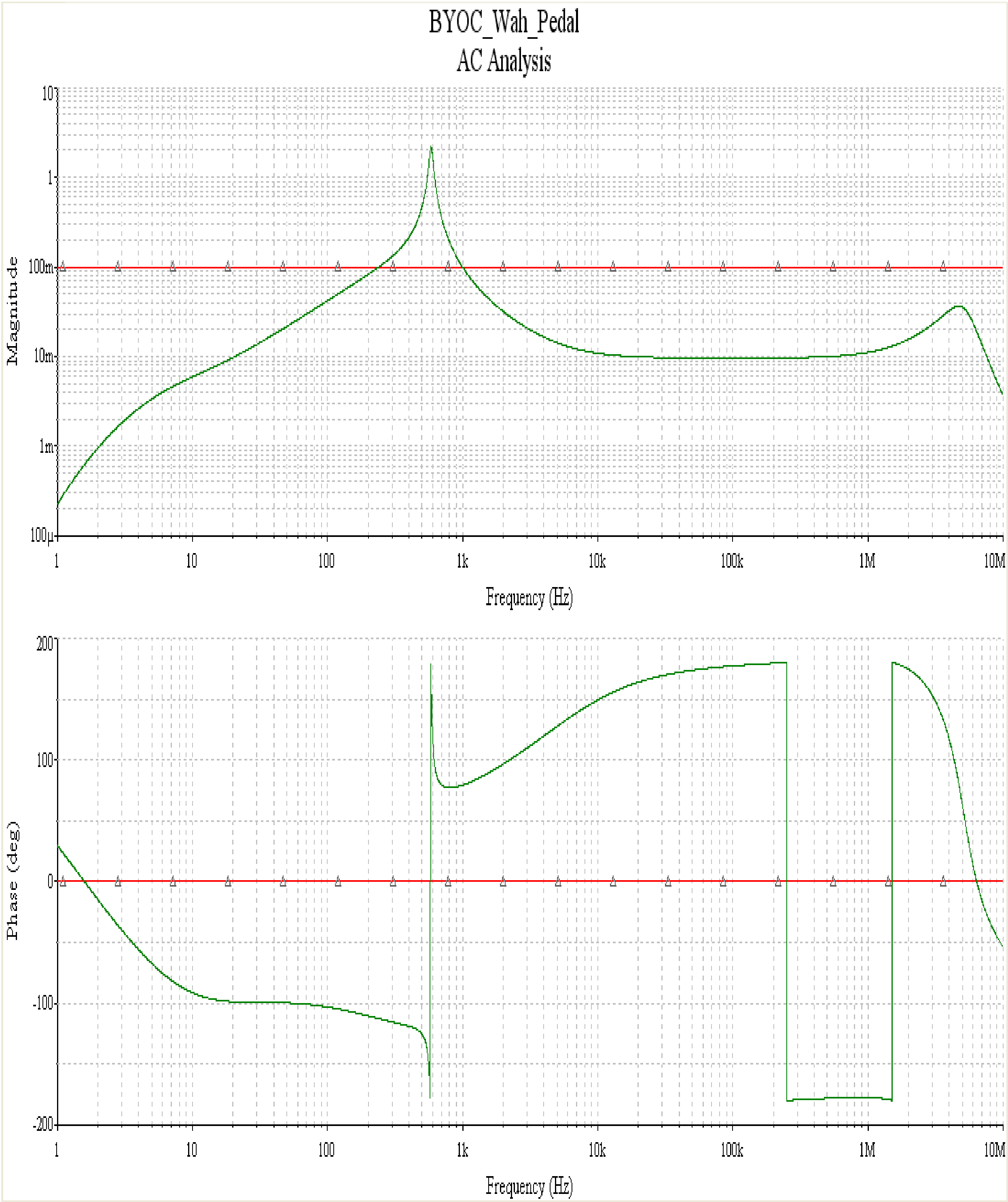


These were measured values of the wah's frequency response when pumped with white for noise and controlling for pedal depression as well as the change in the noise floor controlling bypass and pedal depression. Looking at the noise floor, one can see a good deal of gain on the signals picked up when the effect is on versus when it is bypassed. Also prevalent are the harmonics seen for 60 Hz produced by surrounding electronics. After measuring this data, we compared it to the simulated

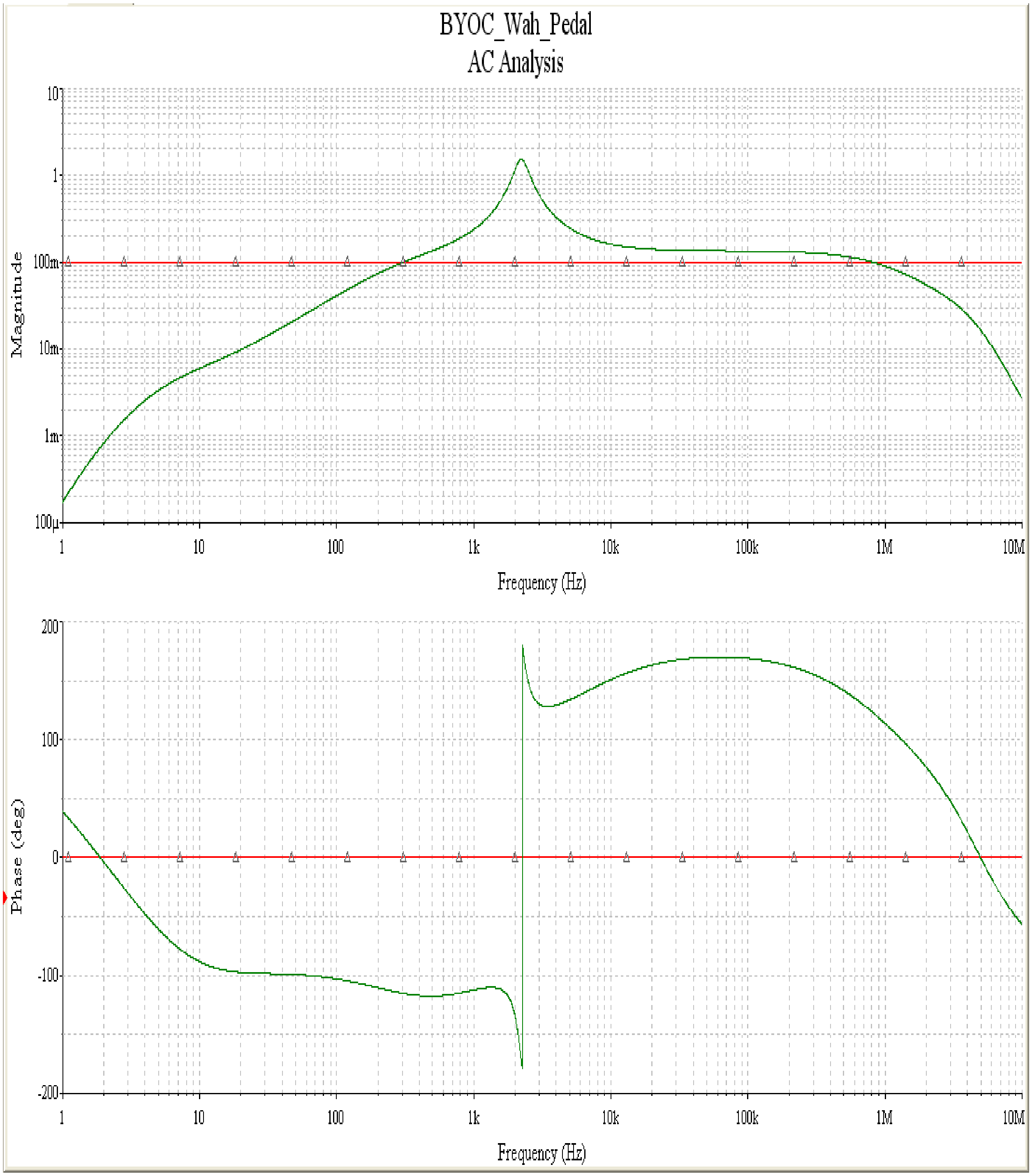
data.



Full up simulated data.



Half way down.



Fully down simulated.

Both the simulated and real circuit follow the same qualitative behavior. They sweep over similar ranges and the resonant frequency becomes wider as its frequency is increased. The simulated range is shifted a little bit higher than the measured range. We obtained measurements from

200 to about 1600 hertz for the working circuit and 430 to about 2000 hertz for the simulated circuit. Disparities probably arose because of deviations in trim pot setting. As time goes on, I am going to adjust the trim pots in an attempt to increase sweep range and change the tone.

Going forward

While I've learned and built a wah I'm still not ready to fully integrate it into my play. The build I finished is designed for a guitar which drives a lot less signal than an electric piano. I will need to step down the signal on the way in and have a preamp after the out to return the signal to line level. In addition to making this compatible with my own instruments I intend to create or procure more effects to experiment with and learn about.

Finished Wah