ELECTRONIC AUDIO EXPERIMENTS

Technical Manual

Prismatic Wall

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Foreword

In February 2012, my friends and I made an EP at a studio in North Andover, MA called The Office Recording. It was my first time in a proper recording studio, and Mike Moschetto, the engineer (and later my good friend) demonstrated a level of professionalism that caught our scrappy basement band by surprise. At one point, to add some color to the mix, Mike placed a cinder block on the sustain pedal of a piano in the live room and aimed a microphone inside the body. Loud sounds nearby excited the strings, producing a ghostly, chromatic reverberation that stuck with me many years later.

I do not know how or where this technique originated. It feels very old—after all, the piano predates the recording studio, and sympathetic strings are older still. Perhaps that is why I found the sound so compelling. For years I sought ways to capture sympathetic string vibrations as a sound design tool, eventually studying how they are modeled and synthesized.

Resonators are by no means a new idea. Simple analog resonators using bandpass filters and tuned analog delay lines have existed since the 1970s. In 1983, Kevin Karplus and Alex Strong publishing their eponymous string synthesis algorithm, kicking off the field of physical modeling synthesis as we know it. Today, physical modeling is a popular sound design tool in plugin and eurorack form. However, I noticed two things missing. First, I became aware of a conspicuous lack of resonators in a pedal format. Second, I was dissatisfied with existing hardware options for processing external audio, particularly amplified instruments. And thus I found a niche. Many months of research, exploration, prototyping, failure, and joy culminated in a resonator of our own: Prismatic Wall.

Many kind people offered their wisdom and insights on this project. The digital control system would not have been possible without our firmware engineer Kyle Gardner, who translated my harebrained ideas into code and made numerous essential contributions of his own. Hawker from Asheville Music Tools joined me for multiple design reviews, providing sage advice throughout. Matthew Farrow and Dan Pechacek helped me decipher the finer quirks of the DSP platform.

I must also thank Mike Moschetto for initially planting the idea in my head, Andy Pitcher for being a champion of the concept from the very beginning, Charlie Carbiener for being a sounding board throughout the entire dev process, and Jaak Jensen for sanity checking the esoterica of resonators. Our friend Eden Rayz was the one to suggest neutral thirds as a possible tuning mode, which genuinely tied it all together. And I'm especially thankful to the shop team: Brad, Miranda, and Jasper tolerated many awful sounds emanating from my workbench, and they also shared my enthusiasm when the ideas finally worked. I also owe a huge thanks to our graphic designer Bryan Aiken for making this pedal look as good as it sounds!

Finally: to the reader, thanks for engaging with our work. It is incredibly fulfilling to make these devices and to hear the sounds you create with them.

John Snyder
June 2024

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1 Introduction

Thank you for purchasing the Electronic Audio Experiments Prismatic Wall. This manual is an in-depth guide for properly understanding, using, and enjoying your pedal.

Prismatic Wall is a sympathetic string resonator. It is designed to behave like an illusory bank of tuned strings that vibrate in response to incoming sounds. It's part reverb and part synthesizer, but with an uncannily familiar physicality not typically found in either. Within you will find sounds resembling third bridge overtones, fingers raking the strings of a piano, sitar and hurdy gurdy drones, and more. Of course, it's capable of subtlety too—it is well suited to adding harmonic enhancement, a sense of acoustic space, or comb-filtered modulation textures to your playing.

This is our weirdest and deepest device yet, with many layers to traverse. While this manual is a good reference, it is no substitute for experimentation. This document is divided into digestible sections, so feel free to skip around as you like. First we'll go over the controls and basic functions. Then we can dive into more advanced functions such as the alternate functions, the LFO and mod matrix, morphing and expression control, and MIDI. Later we discuss the deeper underpinnings of the sound and functions, including a primer on physical modeling synthesis and some insights into how we approached the sound design. We also included some suggested settings for you to check out. The Appendix contains information about hidden utility functions and the MIDI CC assignments.

So, read on and enjoy. We're excited to hear the sounds you make with Prismatic Wall.

2 Setup

2.1 Power

To power your Prismatic Wall, please use a standard, reliable 9VDC center-negative power supply with a 2.1x5.5mm barrel tip. This pedal has a current draw of up to 120mA when active. To accommodate startup surges, we recommend a power supply rated for 200mA minimum. When using Prismatic Wall with other pedals, we also recommend the use of an isolated supply. We have had the greatest success with Cioks™, Truetone™, and Voodoo Lab™power supplies.

Prismatic Wall will function on a daisy chain power supply provided the maximum current of the 9V source is not exceeded. If using a daisy chain, please note that there may be additional noise in your signal chain due to spurious interactions between multiple pedals. Try as we might, we can't control for all of them.

The power input is protected against over-voltage and reverse polarity conditions up to $\pm$20V in either direction. The unit will quickly shut itself off (or simply not turn on) if an incorrect power supply is used. In this event, check that you are using the correct supply.

If Prismatic Wall is not receiving enough current, it may spontaneously shut down. If this occurs, unplug the pedal, wait for 30 seconds, and try again with a higher current power supply.

Finally, please note that EAE products are not designed to use batteries.

2.2 Signal I/O

Prismatic Wall has three 1/4" audio jacks along the top face:

$\bigtriangledown$ **(Input):** unbalanced, mono 1/4" audio input with high input impedance

$\bigtriangleup$ **(Output):** unbalanced, mono 1/4" audio output with low output impedance

CTRL: Multi-function jack that can be used for expression, CV, or MIDI. For more information refer to Sections 3.6 and 4.

Use standard shielded 1/4" mono cables to patch Prismatic Wall into a signal chain. It can be used with amplified instruments, synthesizers, or any line level signal. Note that the bypass signal is always buffered, so the pedal requires power to pass a signal.

3 Controls

3.1 Main Controls

This section contains an overview of the front panel controls. The user interface is designed so that you can dive right in and come back to the advanced functions later. You can even skip right to the suggested settings in Section 6. We also have a quick reference guide available on our site.

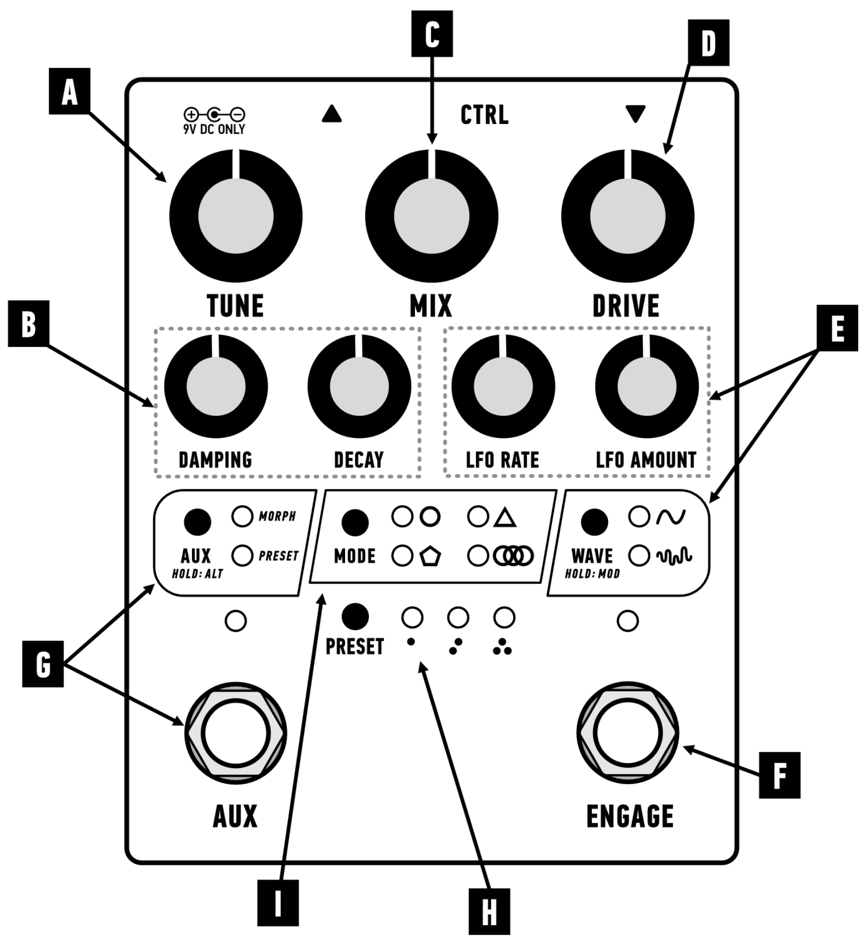


Figure 1: Prismatic Wall main panel.

A) The **Tune** control is the heart of the pedal. It changes the pitch of the entire resonator bank across a four octave range. This also changes the tonality of the resonators: higher pitches are brighter, and lower pitches are naturally darker. The pitch can be tailored to specific instruments, pickup positions, amplifiers, etc. This control works by changing the sample rate of the DSP, which will cause the audio quality to naturally degrade at lower pitch settings. This control and its implications are discussed in more detail in Section 5.1.

B) The **Damping** and **Decay** knobs change the sustain and timbre of the resonator. The Damping control changes the sustain for high frequencies, ranging from muted to metallic. The resulting brightness is scaled by the Tune setting. The Decay control changes the sustain for all frequencies. At higher settings, it adds analog feedback to produce infinite drones and noise.

C) **Mix** sets the blend between the input signal and the output of the resonators, from fully dry to fully effected.

D) **Drive** is the input gain of the resonator bank. Use to adjust the sensitivity of the resonators, or turn up to add analog saturation.

E) The **LFO** (low frequency oscillator) modulates the Tune control to create pitch bending effects. Use the Rate and Amount controls to adjust the speed and intensity, respectively. The Wave button selects between periodic and randomized waveforms. The wave can be modified into a variety of shapes, and the LFO can also be assigned to other controls. For details refer to Section 3.4.

F) The **Engage footswitch** activates the pedal. Long press to toggle between standard (buffered) bypass and trails bypass mode. The Engage LED will briefly flash to acknowledge the change. In trails mode, the resonators will ring out naturally when disengaged.

G) The **Aux footswitch** is a multi-function performance tool. Its behavior is selected using the Aux button. In Morph mode, the Aux footswitch allows for ramping between two control states with intelligent momentary/latching behavior and fully adjustable rise/fall times. For more info about morphing, refer to Section 3.5. In Preset mode, the Aux footswitch can be used to step through saved presets. To learn more, refer to Section 3.3.

H) The **Mode** button selects the tuning and interval spacing of the resonator bank. There are four possible modes:

- ◯ Single mode: a fundamental note with four additional strings spaced in an overtone series.
- △ Stacked neutral thirds: five strings spaced in neutral 3rds (exact halfway point between a major 5th). Subtly microtonal, with a dreamlike quality.
- ⬠ Stacked fifths: five strings spaced in 5ths. Deep, expansive, and sustaining.
- ◯◯◯ Chromatic: twelve strings each spaced a semitone apart. Uses a lower fidelity string model to maximize density at the cost of some fidelity, imparting a subtle digital haze.

You can also long press Mode to toggle a +1 octave up shift for any of the above tunings. The indicator LEDs will invert while this setting is active, so the LED that is *off* will indicate the active mode.

I) The **Preset** Button is used to save and recall presets. For more information, refer to Section 3.3.

3.2 Alt Functions

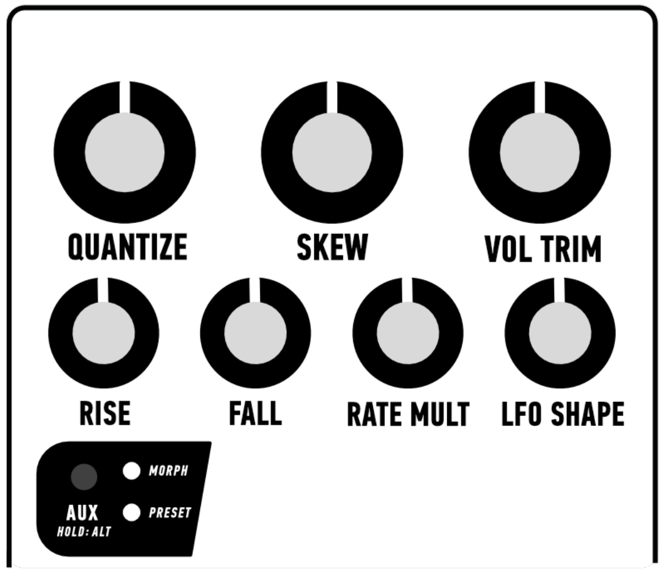


Figure 2: Prismatic Wall alt functions.

Prismatic Wall contains a handful of useful "set and forget" utility functions. To access them, long press the Aux button until the nearby LEDs begin to blink. This grants access to the following controls:

- **Quantize:** turn right past center to enable. This quantizes the Tune knob in semitone steps, to easily dial in exact pitches.
- **LFO Skew:** Gradually shapes the LFO into an upwards (clockwise) or downward (counterclockwise) ramp. In the middle, the waveform is unaffected.
- **Level Trim:** Turn from center to fine tune the resonator output volume by ±3dB.
- **Morph Rise:** Rise time for the Morph function. Turn clockwise to increase the ramp time, or turn counterclockwise to decrease.
- **Morph Fall:** Fall time for the Morph function. Turn clockwise to increase the ramp time, or turn counterclockwise to decrease.
- **Rate Multiplier:** sets the range of LFO Rate settings, with four zones: slow, medium, fast, and "all" which grants the Rate control the full range of the LFO.
- **LFO Shape:** Change the LFO shape. In periodic LFO mode, this changes the shape between sine, square, and triangle. In random LFO mode, it changes the smoothing of the random waveform to add steps and glitches. For more information refer to Section 3.4.

To exit the Alt menu, long press Aux again until the LEDs stop blinking. All Alt settings are saved as part of a preset. You can also reset Alt functions to their default state by holding the Aux button and then pressing Preset[1].

3.3 Presets

Prismatic Wall can store up to 16 presets. Three of these are accessible from the front panel, with the remainder via MIDI. Presets save all primary and secondary knob functions as well as the bypass mode, expression/morphing state, and any settings exclusively controlled via MIDI CC. The bypass state (engaged or bypass) is not saved, to allow for preset changes while the pedal is not active.

To save a preset, hold down the Preset button until one of the preset LEDs starts to blink. Press the Preset button to scroll to the desired slot. Then, long press to confirm the save. To load a preset, simply press Preset until you reach the desired slot. You can also use the Aux footswitch in Preset mode to load presets in a performance setting. Pressing the Aux footswitch scrolls through the first three saved presets.

If you adjust a control while a preset is active, the corresponding LED will blink to indicate it has been edited. You can save it again to include your changes, otherwise the preset will load in its originally saved state. This allows you to use presets as starting points without changing or losing them.

Presets can also be saved and recalled using MIDI PC messages. Refer to Section 4 for more information.

3.4 LFO and Mod Matrix

The onboard LFO can be used to add movement to the resonator bank. By default, it wiggles the Tune control to create pitch-bending effects like vibrato and divebombs. The Rate and Amount controls change the speed and intensity of this movement. These both have a wide range of subtle and extreme settings. The Wave button can toggle between periodic (i.e. consistently repeating) or random modulation.

The Shape and Skew alternate functions enable additional ways to tailor the waveform. The Shape control has different behavior in the periodic and random modes. In Periodic mode, it selects between Sine, Square, and Triangle waveforms. Sine waves have a gentler transition at the extremes, which suits pitch vibrato. Triangle waves are good for dramatic pitch bends or long, slow ramps. The Square wave setting can be used for rhythmic and glitchy sounds. In Random mode, the Shape control changes the sampling of the random waveform, producing steps and glitches in the modulation. The Skew setting can turn these into ramping waveforms, enabling repetitive upward or downward motion. At slow LFO rates, this can be quite dramatic.

[1] The default state is: Quantize off, Skew centered, Level trim centered, rise and fall time centered, LFO multiplier in medium mode, LFO shape set to sine (minimum).

The Rate Multiplier alt function can be used to more easily dial in a rate setting on the main panel. The Slow, Medium, and Fast ranges are all tapered for greater resolution within their specific ranges. If you want to traverse from glacially slow to audio rate at the cost of some precision, set the multiplier to the "All" mode.

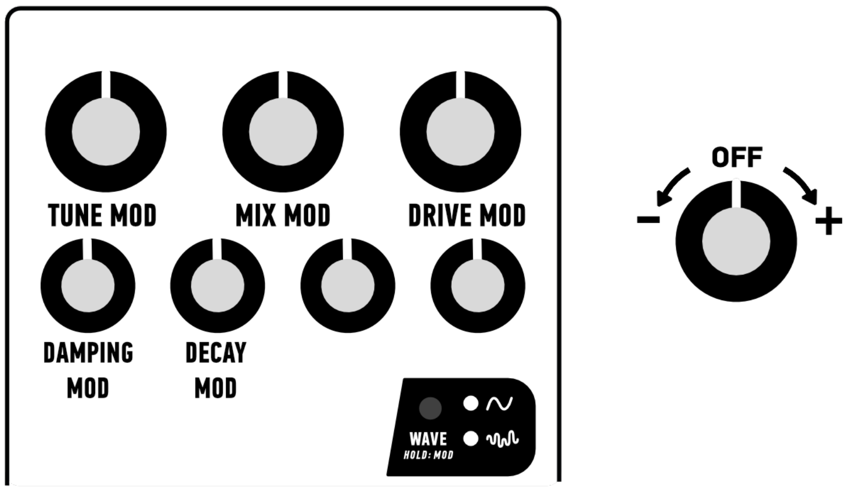


Figure 3: Prismatic Wall modulation matrix and attenuverter operation.

The Mod Matrix is used to assign the LFO to any and all of the main front panel parameters: Tune, Mix, Drive, Damping, and Decay. To enter this menu, long press the Wave button until the corresponding LEDs begin to blink. Each knob becomes an attenuverter, which allows you to choose the amount and the polarity of the modulation for that respective parameter. When the knob is centered, there is no modulation applied to that parameter. Turn clockwise for positive modulation, and turn counterclockwise for negative modulation. This allows you to modulate parameters in opposite directions. To exit the Mod Matrix, long press the Wave button again. You can reset the mod matrix to its default state (modulating Tune only) by holding the Aux button and then pressing Wave.

3.5 Morphing

Prismatic Wall has the ability to seamlessly morph between two groups of settings, for dynamic changes during a performance. First, press the Aux button to toggle into Morph mode. Dial in a desired sound. Then, press the Aux footswitch. While the Aux LED is lit, you can dial in a new sound. Then, pressing the Aux footswitch will smoothly jump between these two settings. The Morph function has intelligent momentary and latching behavior: short taps will toggle it on and off, while longer presses will be registered as momentary holds[2]. Morphing can be applied to all of the main panel controls and all of the Alt functions except for Quantize. (Note that Mode cannot be morphed.) The rise and fall times of the

[2] Use the utility menu to adjust the length of the hold time. For more info see Appendix A.

Morph function can be set in the Alt menu, for quick jumps or slow ramps. All morphing assignments are included as part of a preset. Finally, if you need a blank slate, you can clear the Expression values by holding Aux and pressing Mode.

3.6 CTRL Jack

The CTRL jack can accommodate a variety of inputs and automatically detects what is connected. Broadly speaking these inputs can be divided into two types: expression/CV signals and MIDI. Expression sources a physical expression controller such as an expression pedal, slider, or similar. The CTRL jack generates its own current-limited 5V supply, permitting the use of a wide range of input devices. You can also supply a control voltage source generated by a synthesizer or utility pedal. Note that in this case you must use a TRS cable with a floating ring, and be sure the voltage is in the 0-5V range. MIDI inputs are discussed in Section 4.

Expression and voltage control are closely tied to the morphing function. An expression controller or control voltage will continuously vary between the two morph states, with the main panel being the minimum/0V state and the morph assignments being the maximum/5V state. This also means that the Aux footswitch can be used to set expression values without a controller present. This is a convenient way to configure voltage control when patching from an external source. Additionally, the Expression value may be accessed via MIDI, which is useful if you have a MIDI controller hooked up to the CTRL jack but still wish to use expression control.

4 MIDI

Prismatic Wall can be controlled via MIDI, enabling external control of every function within the pedal plus additional utility functions.

4.1 Connectivity

Prismatic Wall receives MIDI through the CTRL jack. The CTRL jack automatically detects whether a MIDI cable or expression/CV source is connected, but may take a few seconds to adjust. You must use a TRS cable with a MIDI box that is set to Tip Active[3]. In other words, MIDI data is sent on the jack tip. Please refer to the manual of your MIDI Box or MIDI controller for additional instructions. Due to inconsistencies in MIDI Box standards we cannot guarantee operation with every brand, but every one we have tried so far has worked. We have had good luck with MIDI boxes from Disaster Area Designs, Chase Bliss, and Morningstar.

The default MIDI channel is 2. To assign the MIDI channel, hold down the Aux button during startup to enter Configuration Mode. Then, send a PC message on your desired channel. The pedal will automatically set itself to that channel. For more information on Configuration Mode refer to Appendix A.

[3]Note that our Sending V2 delay uses traditional Type A MIDI and does not require a MIDI box.

4.2 CC Messages

Each front panel control, secondary parameter, and footswitch state is assigned a CC number. Some parameters are capable of 14-bit MIDI where two paired CCs can be used for enhanced precision. If you are using normal MIDI, you can use the MSB (most significant bit) CC and ignore the LSB (least significant bit). All of the expression/morph parameters have their own individual CC assignments as well, so that these settings can be configured purely via MIDI. A couple bonus functions, including a MIDI clock ignore setting, also have dedicated CC numbers. For a complete list of CC assignments, refer to Appendix C.

4.3 PC Messages

Send a program change (PC) number to load that corresponding preset. The first three presets are accessible via the front panel, and MIDI enables the use of additional presets up to 16. To save settings to preset 4 and beyond, hold the Preset button until it enters the save state. The current front panel state will be saved to a channel corresponding to the next incoming PC message. You can also save a preset by sending the desired PC number plus 64. For example, to execute a save to preset slot 4, you would send PC 68. At any time, PC 0 will revert the pedal to the last state of the control panel.

4.4 MIDI Clock

If a MIDI clock is present, the LFO will sync to that clock as long as the MIDI Clock Ignore CC is not active. The Wave LEDs will flash in time with the incoming clock. The LFO Rate knob will now adjust the rhythmic subdivision of the incoming tempo. MIDI clocking is enabled by default. To ignore a MIDI clock, set CC 89 to 64 or higher.

4.5 MIDI Notes

The Tune value can also be set using MIDI notes. This enables all kinds of possibilities, including:

- Sequencing notes that change along with an incoming melody
- Creating melodies from a drum machine or sampler with a MIDI note output
- Synchronizing the pitch of the resonator bank with an incoming synthesizer
- Playing Prismatic Wall as its own instrument by turning Decay up and changing the pitch of the resulting drone tones

Prismatic Wall works across two ranges. The range C-2 to C2 plays the pitch of the Tune control across its entire range. From C3-C7, the Tune control range is repeated. In addition, the onset of a note will also trigger the Morph function, which can be configured as a triggered attack/release envelope. For example, you can set Morph to control the Damping value to serve as a pseudo VCF, or Mix to serve as a pseudo VCA. The note C8 resets the LFO phase.

5 Lore and Ephemera

5.1 About Physical Modeling Synthesis

The desire to recreate real instruments is as old as synthesis itself. For a long time these pursuits were phenomenological in nature. Early string synthesizers, drum machines, and electronic organs all used additive and subtractive synthesis techniques to mimic instruments, with limited success. But through missing the mark, these instruments developed a character of their own. Nobody considers the Roland TR-808 or Solina String Ensemble to be pinnacles of realism, but their mark on music is undeniable.[4] Limitations and art go hand in hand.

As digital signal processing emerged and computers became more advanced, so did these attempts at electronic mimicry. In the early 1980s Kevin Karplus and Alexander Strong published their eponymous algorithm, which recreates the sound of a vibrating string[5]. The algorithm was subsequently shown by Julius O. Smith III[6] to be a special case of *digital waveguide synthesis*, which more generally describes how acoustic waves behave in objects. This development kicked off the field of physical modeling synthesis as we know it, and while commercial applications didn't immediately land, modern physical modeling is a popular sound design tool capable of astounding realism.

I suppose at this point I should clarify what we mean by modeling. (It's such a broad concept, with some particular connotations in the guitar realm.) A model is a way to describe the world and make predictions based on that description. To make a physical modeling synthesizer, we need to construct a model of an instrument.

The physical makeup of an instrument can be broken down into two main components. First is an exciter: whatever bows, picks, plucks, strikes, or moves air. Second is a resonator, which is a vibrating element such as a string, a wooden body or cavity, a pipe, a drum head—the list goes on. Many such elements aren't directly played at all, but their resonances are what give an instrument its characteristic overtones and sustain. Sometimes resonators are used in a more intentional and prominent fashion: consider drone strings on a sitar or hurdy gurdy, the metal cone of a resonator guitar, or the membrane of a banjo. Now, modeling an instrument means modeling these constitutent parts and their interactions.

With some background out of the way, let's return to Prismatic Wall, which originated out of a desire to emulate resonating metal strings. Accordingly, we chose the classic Karplus-Strong model as a starting point. At its most basic, the model consists of a delay line with filtered feedback as shown in Figure 4. (Note that this is more or less a feedback comb filter.) The length of the delay line represents the length of the string. As length increases, the pitch decreases. The filter represents the decaying vibrations of the string—in other

[4]The designers of these devices used some clever techniques! I am especially compelled by the usage of tuned filter banks to achieve the resonances of a vocal tract or the body of an instrument. The resonator section of the Polymoog is a good example of this. Of course, modal/formant synthesis is a whole field of its own so I am really getting off topic now.

[5]Here's a nice primer: `https://ccrma.stanford.edu/~jos/pasp/Karplus_Strong_Algorithm.html`. Honestly, this whole site is a gold mine.

[6]The fellow responsible for the incredible Stanford website!

words, the rate at which its vibrational energy is dissipated. This filter represents basic material properties of the string, but it can be expanded to account for other factors such as string stiffness. This filter can also be used to help tune the pitch of the string and account for sample rate limitations by interpolating adjacent samples.

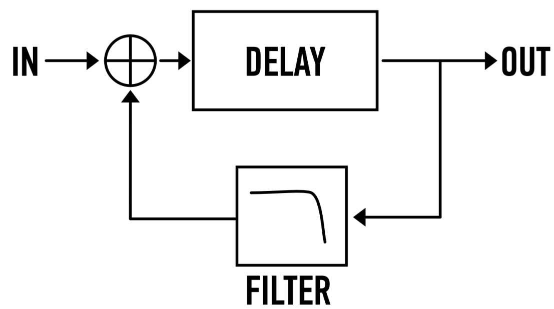


Figure 4: Basic implementation of the Karplus-Strong algorithm.

The traditional Karplus-Strong input is some kind of signal that represents a pick attack, like a short burst of noise. Filtering or ramping this burst of noise can replicate fingerpicking or bowing as well. Since we wish to create a sympathetic resonator that responds to outside stimuli, we can use our own input signal in lieu of the typical input. More importantly, with a model in hand, we can set our sights on artfully breaking it. More on that below.

5.2 Resonators as a Musical Tool

As mentioned previously, resonators are by no means a new idea. There has not been a serious attempt to make them available and accessible to guitarists in pedal format, likely because physical modeling is perceived more as a sound generation tool than as an effect for existing sounds. Given the relative uncharted nature of this category of effect, I think it is worth discussing the sounds in greater detail.

There is undeniable overlap between resonators and reverb. Both create a sustaining sound, after all. Traditional reverb seeks sustain without resonance. Mechanical reverbs using springs and plates relied on the inherent inharmonic character and dispersion of metal objects to be effectively pitch-neutral, and the pioneers of digital reverberation took care in their algorithms to avoid the buildup of specific resonant tones. Prismatic Wall turns that concept on its head—what if the resonances were intentionally selected pitches that could be manipulated? Even if we ignore the finer points of physical modeling, this gives us an intuitive understanding of this effect: it's like a reverb that contains an abundance of tonal information, expanding the harmonic complexity of sounds fed into it while using resonant decay to add a sense of space.

Where resonators differ most from reverbs is the stark differences in response for transient versus sustained inputs. This difference is best highlighted in Prismatic Wall's Single mode. Try dialing in a particular note using the Tune knob, then play that note a few ways: first with a pick, then fingerpicked, then by swelling or bending into the note. Matching the pitch will always induce sympathetic vibrations at that pitch. Then, try again with other notes. You can observe that the nature of the attack also has a significant impact. Pick attacks, string slides, fret noise, and other percussive content will "strike" the whole resonator, exciting every string in tandem even if not matched in pitch. This is the core reason why a resonator feels so different from a reverb. They are also highly sensitive to playing dynamics, which is also the primary reason why we included a Drive control to directly change the input sensitivity.

The Tune knob and Mode selector globally control the resonator's pitch and character, with the Tune knob setting the fundamental frequency across a four octave range. The electric guitar itself spans about five octaves (give or take a few depending on how many frets you have), so when you factor in the span of the resonator bank, this represents quite a large range. Selecting a resonant frequency is much like choosing the register in which to play, and is entirely context-dependent. Put another way, the EQ profile and pitch are closely linked. To sit properly in a more traditional mix, Prismatic Wall typically should match the register of the instrument that it is processing. Of course, anything goes for more general sound design purposes.

The Mode selector changes the musical interval spacing of individual strings in the resonator bank. There are four different tunings in two different octave ranges, for a total of eight modes. The interval determines the harmonic character of the mode as well as the overall span between the lowest and highest strings. Below we go into greater detail about each mode.

Single This mode consists of a fundamental pitch accompanied by its first four harmonic partials, for especially strong overtones. It is ideal for exploring specific sympathetic tones that accentuate (or deliberately conflict) a piece of music. It is also a gateway to more traditional comb filter modulation effects via the LFO.

Stacked Neutral Third This mode is a strange one, and was the last mode we finished. The neutral third is the exact halfway point between a major and a minor third, and also the halfway point between two notes that are a perfect fifth apart. It has an ambiguous, dreamy character that can mesh with a wide variety of inputs.

Stacked Fifth This mode is grandiose. Stacked fifths have an inherently rich sound, and this mode doubles down by also having the widest octave coverage and longest sustain compared to the others. [7]

Chromatic This mode is the closest to the original concept of a "pianoverb" thanks to its tight clustering of semitones. Any note that is played will resonate something, and percussive content will exaggerate its piano-like nature. This mode has reduced fi-

[7] This mode always reminds me of *La cathédrale engloutie* (The Sunken Cathedral) by Claude Debussy. My brother learned this one when we were younger, and it's a favorite of mine.

delity, with blurry, hazy artifacts that are especially noticeable at longer Decay times. This is due to tradeoffs between the number of strings and the complexity of the string model which we will discuss below.

Brief aside about the chromatic mode: we originally planned for this to be the core of the pedal. As the string model became more sophisticated, we realized we could only fit 5-6 strings instead of the 12 needed to cover an octave of semitones. Thus, we decided to split the chromatic configuration into its own mode and have additional modes that committed to specific tuning choices. However, we did not want to limit ourselves to a traditional major/minor dichotomy. So, other than the single pitch mode, the options we selected were chosen specifically for their harmonic ambiguity, allowing them to intertwine with a wide variety of source material regardless of the key signature.

The octave shift (achieved by long pressing the Mode button) was a relatively late addition, motivated by a particular tradeoff between the sample rate and the resonator pitch that influenced the overall timbre. For a given sample rate, any frequencies above half the sample rate (a parameter called the Nyquist frequency) will not be accurately reproduced. In our system, we filter them out. This means that a lower-pitched resonator is going to have more overtones because the distance between its resonant frequency and the Nyquist frequency is larger. For a higher-pitched resonator, there is less room for overtones before reaching the Nyquist frequency. Therefore, the lower octave modes will be more harmonically rich and higher octave modes will have a simpler timbre. In addition, the octave up shift changes the buildup of low frequencies and is useful for avoiding overly boomy bass resonances.

5.3 Design Notes

For our Karplus-Strong implementation, we decided to pair relatively primitive DSP technology with extensive analog processing. We used the popular Spin FV-1 processor, which is comparable to a 1980s rack reverb in terms of its processing power and performance. It owes much of its enduring popularity to a unique design choice: the entire processor can be externally clocked. With some additional circuitry, the sample rate of the system can be changed on the fly. Many pedals make use of a “clock” knob of some sort. But in our case, it gives us a tool to parametrically re-tune a bank of several strings. Since the pitch of a Karplus-Strong resonator is based on delay time, and delay time is based on sample rate, we can tune the strings together by changing the clock frequency! Furthermore, the digital clock oscillator we developed for our Sending V2 analog delay is perfectly suited to this application because it can be smoothly modulated—an uncommon element in digital oscillators. This enables natural pitch changes including pitch vibrato.

In addition to the variable clock we also included analog gain, filtering, and noise reduction. All things considered, we are treating the FV-1 more like a bucket brigade device than we are like a traditional DSP. Like a BBD system, the tools used to mitigate the flaws of the system impart their own coloration, forming a cohesive whole.

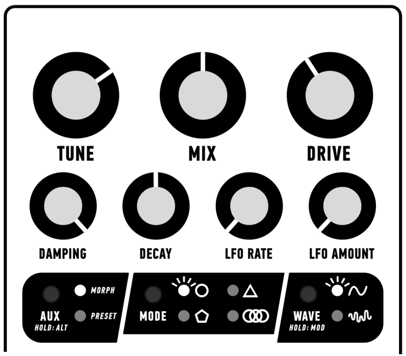
Working in the analog domain lets us do a few things particularly well. The analog input preamp (a calling card of ours, by now) allows us to add saturation to signals before they hit the DSP input. There are some interesting interactions here. Of course, we have control over the reactivity of the resonators. Though more interestingly, the harmonics produced by the overdriven preamp circuit are beyond the sampling rate of the resonator bank, especially when tuned to a lower pitch. This allows for more aliasing products to form, adding a high frequency edge to the resonators. To balance this out, the fixed analog filters provide fixed points to alleviate noise within the system.

The digital limitations of the processor are also a factor in the sound quality. Because we were operating several strings in parallel, any complexity in the model was multiplicative! We dealt with two major limitations: a finite sample rate and low headroom. The finite sample rate meant we could not exactly tune the pitch of each string. This required us to implement tuning correction, which introduces its own filtering to change the resonator behavior and sound. Headroom considerations were trickier. A resonator, by definition, concentrates amplitude at a particular frequency. There is an exceedingly narrow line between enough resonance to sustain indefinitely, and the amount of resonance that introduces undesirable hard clipping. Thus we had to include individual limiters in each feedback loop to instead ensure softer, more natural clipping.

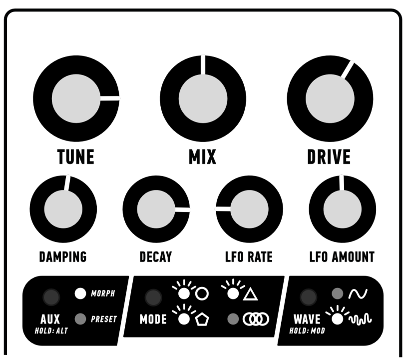
The aforementioned processor limitations are also why chromatic mode has its own timbre. To fit enough extra strings to cover an octave's worth of semitones, we had to use a simplified version of the model. The most significant change is that the damping filter is not part of the feedback network, and is instead a basic low pass filter at the output. We also had to implement a simpler limiting scheme which means that chromatic mode has slightly harsher clipping when hit hard. The reduced fidelity makes for a compelling contrast against the other modes, so we opted to embrace it.

6 Suggested Settings

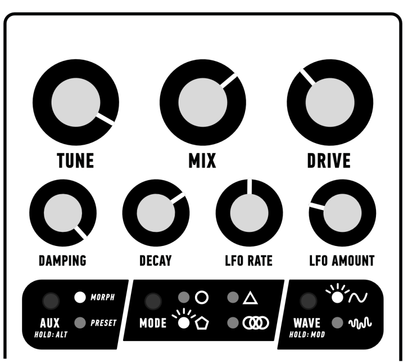
These settings provide a variety of starting points to get familiar with the available sounds. Once you've broken down the user interface, try more sophisticated morphing and LFO assignments. We'll make some suggestions below.



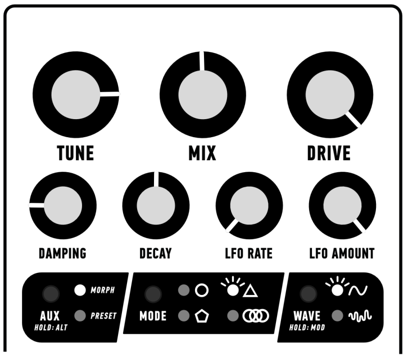
Resonant Echo. Here's a nice starting point. Using the single comb mode, explore the interations of a monophonic string resonator with your playing. Try adjusting the Tune control to get a feel for how the pitch and timbre change in tandem. With Damping at max, you get a bright sustain with a metallic edge. Use Drive to control how hard the resonator is pushed by the attack of your instrument. This is also a perfect blank slate for trying out different morphing and mod matrix assignments.



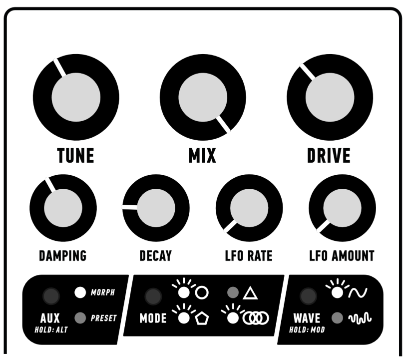
Pianoverb. A good example of the roots of this pedal. The octave up chromatic mode (accessed via long press) is bright and present. For more warmth and a smoother decay, try the standard chromatic mode. The LFO adds subtle random motion and vibrato. For a more intense effect, try turning up Mix and Damping.



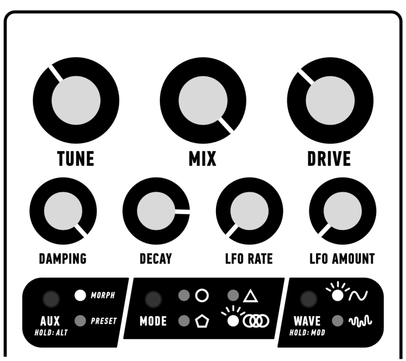
Cave of 5ths. A massive, reverberating resonance with a long sustain. Has far more bandwidth for a typical guitar, making for a grandiose soundscape. For an alternate version with less low frequency mass, try an octave shift. Try using the Morph function to increase the Decay for pads of feedback.



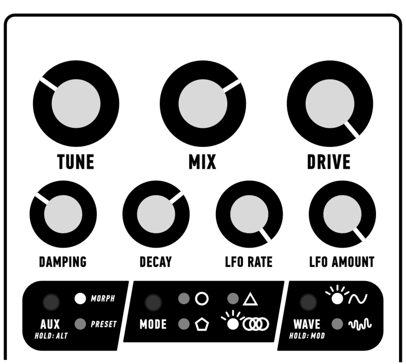
Yup, it's a modulation effect. At lower decay and damping sounds, Prismatic Wall can behave much more like a traditional modulation effect. Here we use a long, dramatic LFO sweep to get a flanger-like texture. With the Drive at max, the comb filtering of the string resonator produces a lush swirl. Try increasing the Rate and decreasing the Amount for a different flavor. (Also, Brad really wanted to call this one Flangey Pants and I just needed to get that off my chest.)



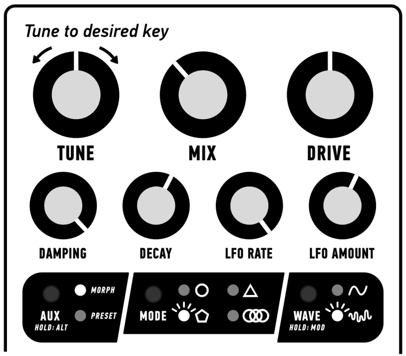
Body Resonance. When Decay and Damping are both set low, the resonator timbre is more wooden than metallic. This setting will supplement your instrument with a rich resonance akin to a cello or upright bass.



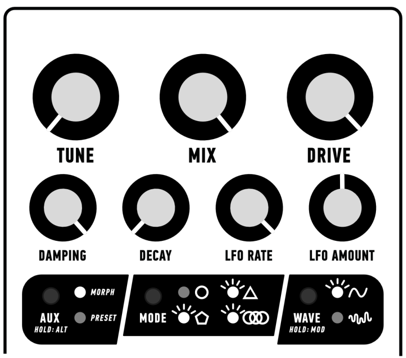
Warm Chromaticism. Revisit the chromatic mode but this time, tuned on the darker side. The piano strings fade into a formless, encompassing void of sound. Try more subtle Mix settings on sparse clean guitar parts.



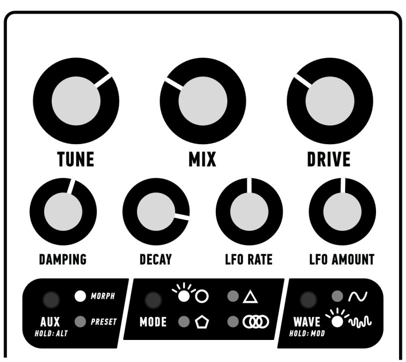
Sardaukar War Chant. Add more Drive, darken up the resonator, and dial in aggressive frequency modulation via the LFO to produce a formidable, inorganic rumble. Different LFO Rate multiplier settings can take you deeper into the audio rate/FM range. Even more scary on bass.



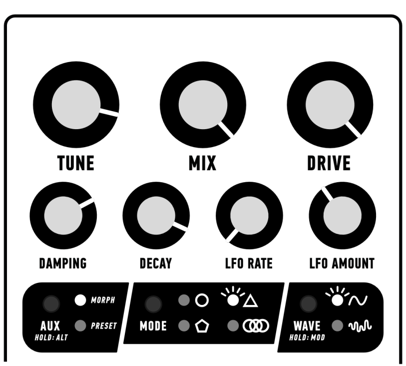
Dramatic Sigh. A different, more melodic take on an FM-forward sound. Dial in a pitch that meshes with your playing and use Morph to jump between intervals. Quite dramatic indeed.



8 Bit Dungeon. Delve into the edge cases of multiple settings simultaneously. Within this digital oubliette resides an aliased, warbling miasma. Try it with other octave-shifted string settings as well—though this one has the most prominent artifacts of the DSP breaking down.



Unstable Drone. Dial the Decay control to the edge of feedback. The LFO will jump around randomly, finding new resonances to latch onto. If necesary, the Damping control can tame the intensity of the analog feedback loop. Try using the Morph function to push Decay over the edge.



Infernal Violins. The higher frequency content of the stacked third mode can be pushed into a wailing, screeching feedback drone. You have been warned. (This is a good setting to morph into for on-demand noise blasts.)

A Configuration Mode

Configuration Mode is used for global utility functions as well as factory debugging. To enter this mode, apply power while holding down the Aux button. Keep it held until the LEDs begin to blink. In Configuration Mode you may perform the following actions:

- **Set MIDI Channel:** Send a PC message on a desired MIDI channel, and the pedal will update automatically to that channel. This is a global setting saved in system memory.
- **Morph Hold Time:** Turn the Decay knob to set the footswitch hold time for morphing, ranging from 125ms to 625ms.
- **Toggle LED Brightness:** Hold the Preset button to toggle the LED brightness between two brightness levels. The lower brightness level is the default.
- **Volume calibration:** Use the Drive knob to fine tune the volume of the dry path. This is factory calibrated to 0dB, so do not adjust it unless you have a good reason.
- **Debug Presets:** Scrolling through presets 1-3 will activate presets used for debugging the hardware. Preset 1 passes signal through the dry path only. Preset 2 passes the signal through the DSP only. Preset 3 passes signal through the DSP with the Drive control at max. All other controls are disabled in this mode.

To exit Configuration Mode, hold down Aux until the LEDs return to normal.

B Firmware Updates

The firmware may be updated through the use of MIDI System Exclusive ("Sysex") messages via our portal at `electronicaudioexperiments.com`. All you need is a USB to MIDI source and a MIDI box. To enter Boot Mode, apply power while holding the Aux Footswitch. Hold it down until the Aux and Bypass LEDs begin to blink. In this state, the unit is ready to accept updates. Detailed instructions will be available via the portal.

C MIDI CC Assignments

Table 1: MIDI CC assignments.

CC	Parameter	Values
1	14 Bit Expression MSB	0-127
12	Drive	0-127
13	Mix	0-127
14	Damping	0-127
15	Decay	0-127
16	LFO Rate	0-127
17	LFO Amount	0-127
18	Tune	0-127
19	Mode	0-15 = Single 16-31 = Stacked Neutral 3rd 32-47 = Stacked 5th 48-63 = Chromatic 64-79 = Single+1 80-95 = Stacked Neutral 3rd+1 96-111 = Stacked 5th+1 112-128 = Chromatic+1
20	Level Trim	0-127
21	LFO Skew	0-127
22	Morph Rise	0-127
23	Morph Fall	0-127
24	LFO Rate Multiplier	0-127
25	LFO Shape	0-42 = sine, 43-85 = square, 86-127 = triangle
26	Quantize	0-63 = free, 64-127 = quantized
27	LFO Mode	0-63 = normal, 64-127 = random
28	Drive Mod ±	0-127, 63 = no modulation
29	Mix Mod ±	0-127, 63 = no modulation
30	Damping Mod ±	0-127, 63 = no modulation
31	Decay Mod ±	0-127, 63 = no modulation
32	Tune Mod ±	0-127, 63 = no modulation
33	14 Bit Expression LSB	0-127
34	Drive Exp MSB	0-127

Continued on next page

35	Mix Exp MSB	0-127
36	Damping Exp MSB	0-127
37	Decay Exp MSB	0-127
38	Rate Exp MSB	0-127
39	Amount Exp MSB	0-127
40	Tune Exp MSB	0-127
41	Vol Trim Exp	0-127
42	LFO Skew Exp	0-127
43	LFO Shape Exp	0-127
44	Drive LSB	0-127
45	Mix LSB	0-127
46	Damping LSB	0-127
47	Decay LSB	0-127
48	LFO Rate LSB	0-127
49	LFO Amount LSB	0-127
50	Tune LSB	0-127
66	Drive Exp LSB	0-127
67	Mix Exp LSB	0-127
68	Damping Exp LSB	0-127
69	Decay Exp LSB	0-127
70	LFO Rate Exp LSB	0-127
71	LFO Amount Exp MSB	0-127
72	Tune Exp LSB	0-127
89	MIDI Clock Ignore	0-63 = normal, 64-127 = ignore clock
97	Aux Footswitch	0-63 = off, 64-127 = on
100	Expression	0-127
102	Bypass	0-63 = bypass, 64-127 = active
103	Bypass Mode	0-63 = standard, 64-127 = trails
107	MIDI pitchbend range	0-127

Document Revision History

Revision	Changes
A	Original Release