The Educational DIY Synth Thing

Projects – v0.1 – Nov 2024

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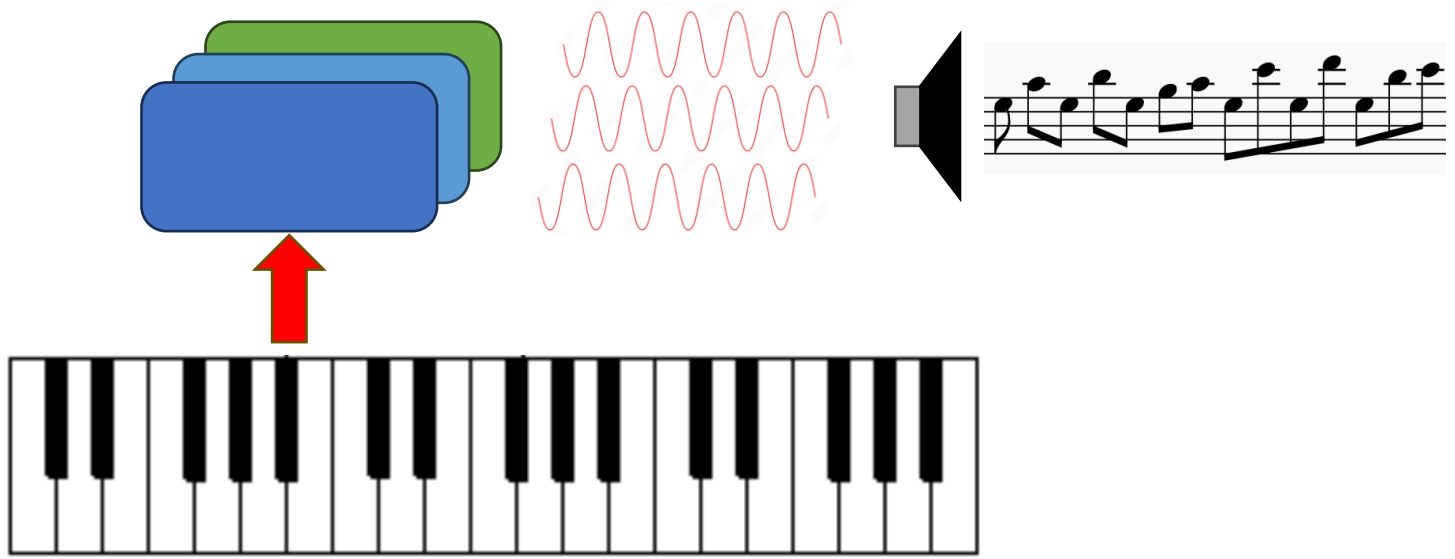
https://diyelectromusic.com/2024/05/07/educational-diy-synth-thing/

Ch 1 - Introduction

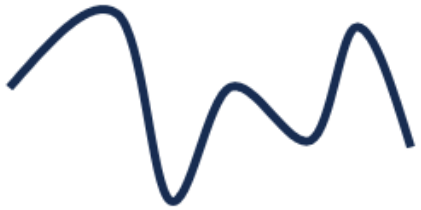
Introduction to Analog Synthesis

- Key Principles:
  - Audio Signals
  - Voltage Control
  - Gate and Trigger Signals
- Other Principles:
  - Envelopes
  - Modules
  - Monophonic
  - Polyphonic

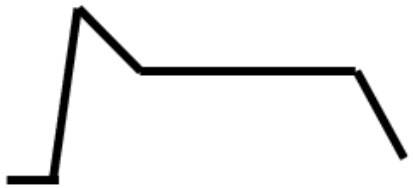


Key Principles

- Audio Signals
  - Produce the sounds.

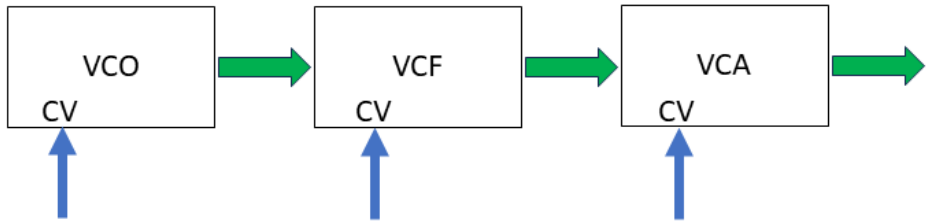


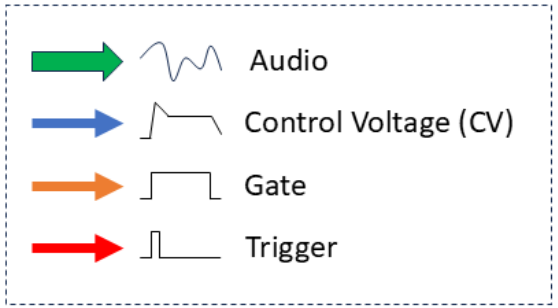
- Control Voltages
  - Everything is controlled by voltage levels.
  - Can be constant or changing.
  - Can be continuous or with a start and end.



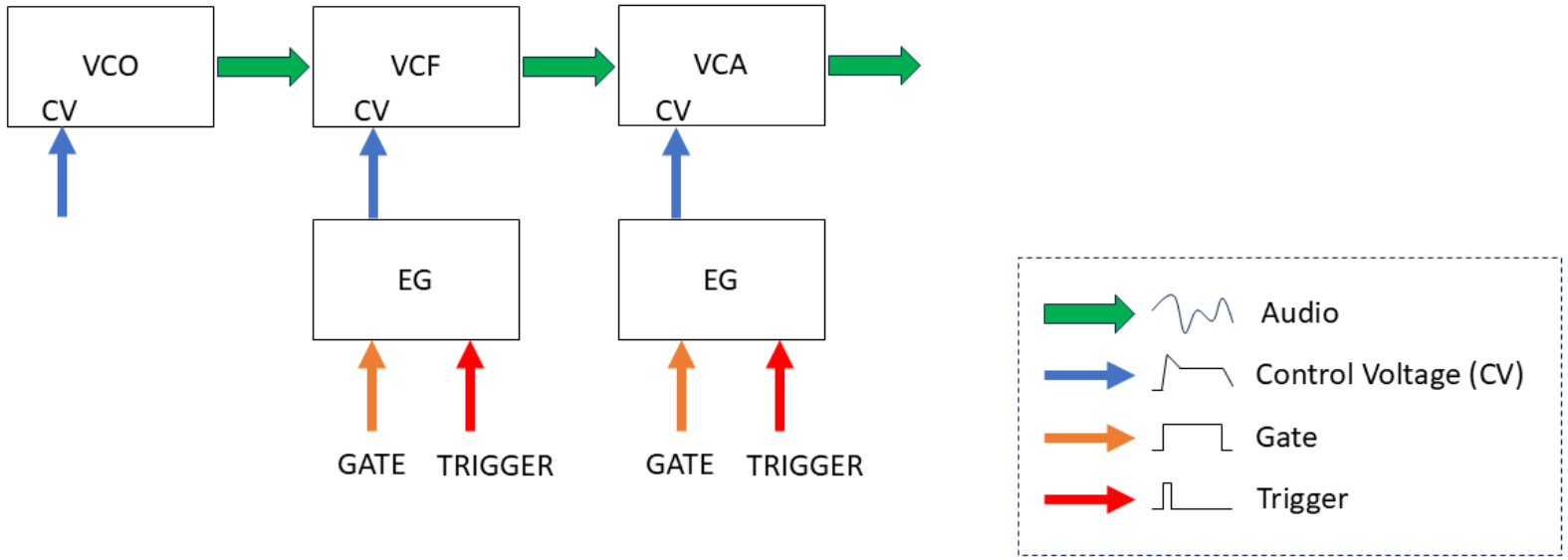
- Gates and Triggers
  - Start and stop sounds.

Basic Structure of an Analog Synthesizer



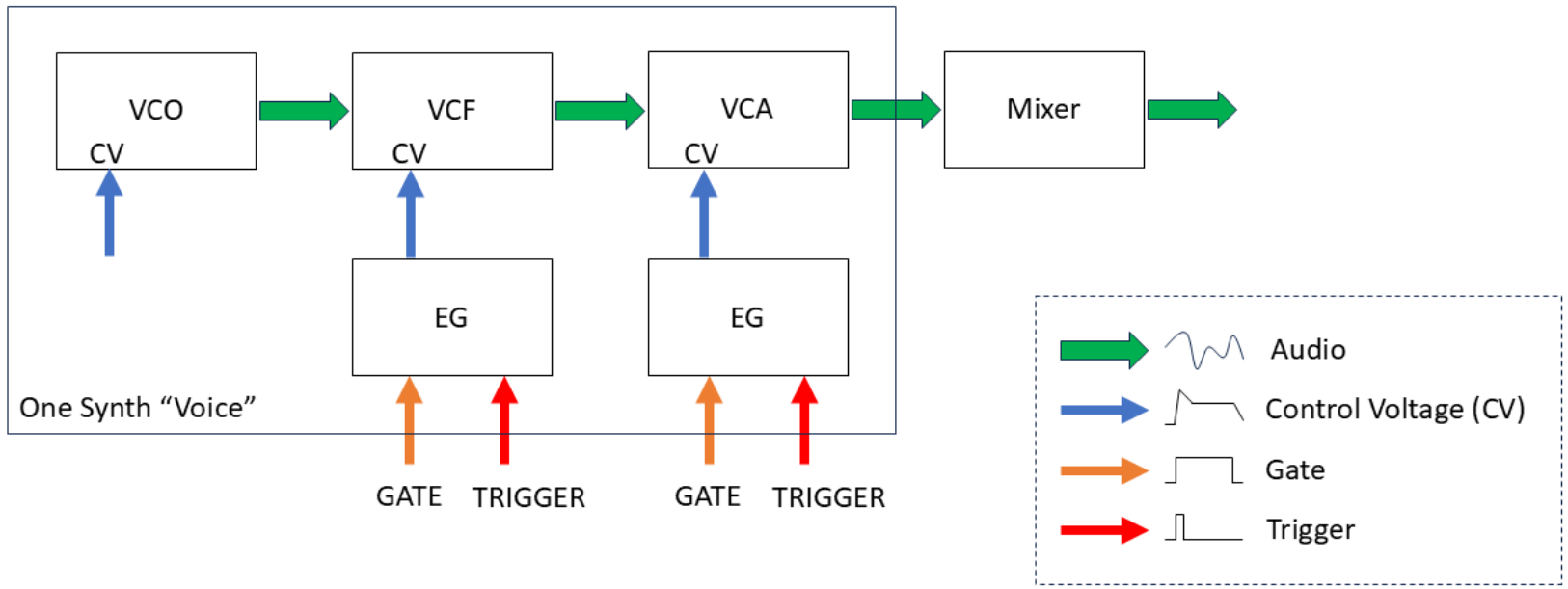


Basic Structure of an Analog Synthesizer



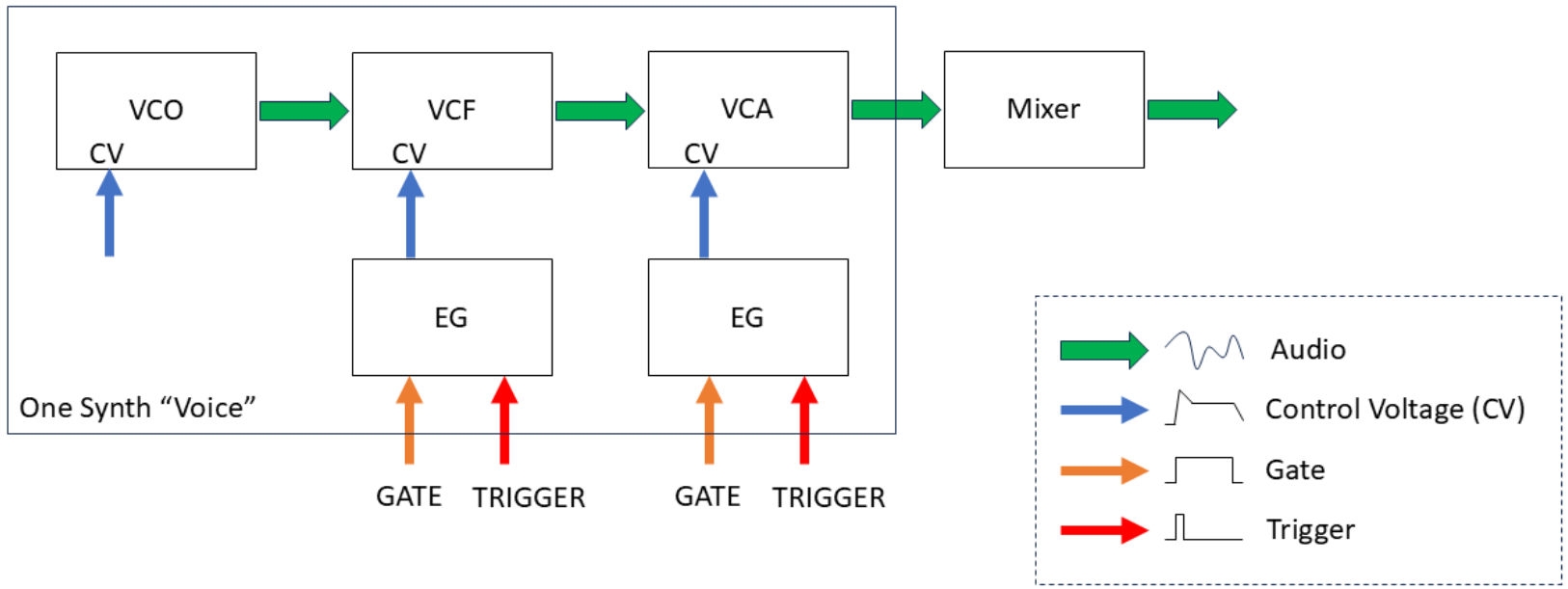
One Voice = Monophonic

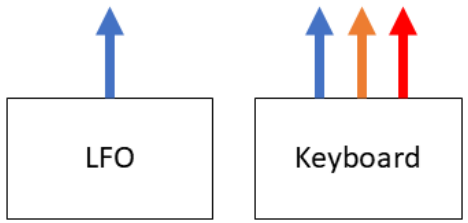
Basic Structure of an Analog Synthesizer



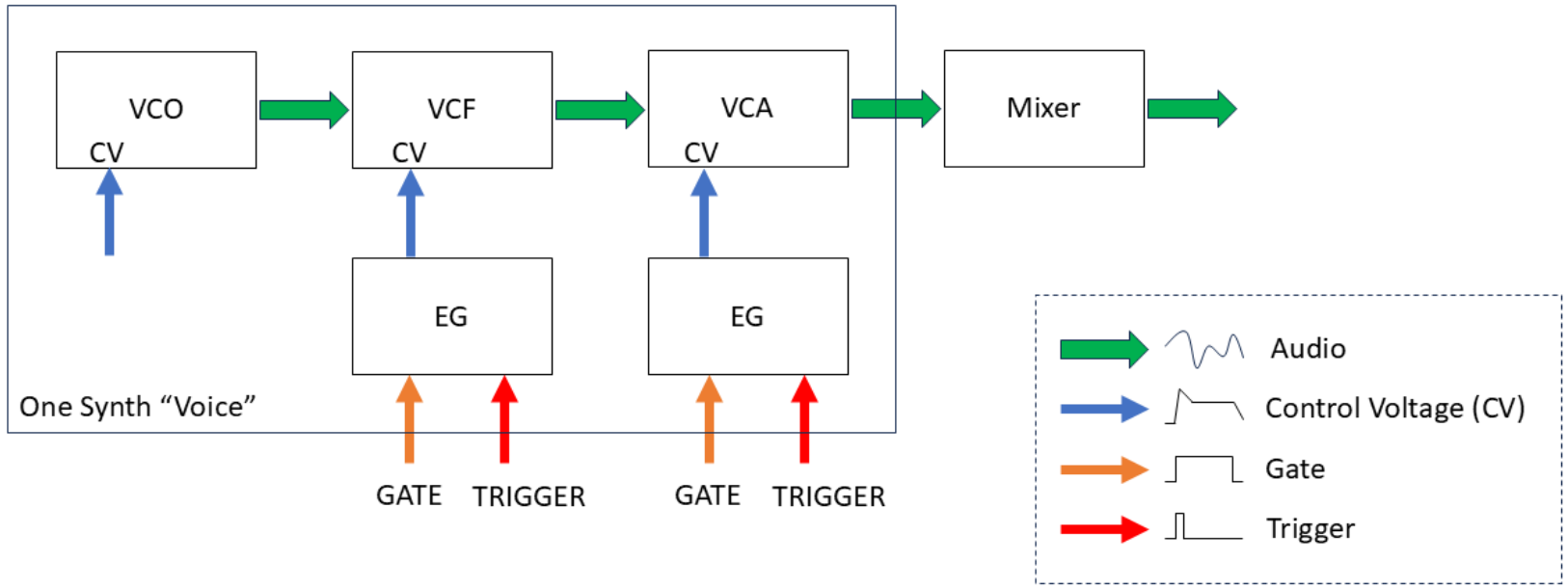
Many Voices = Polyphonic

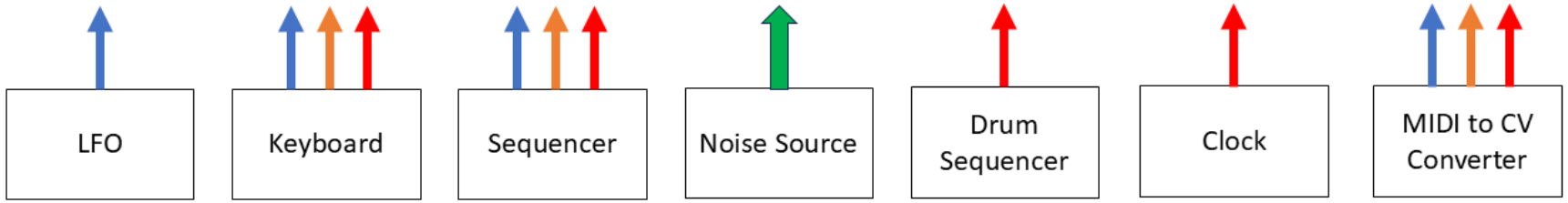
Basic Structure of an Analog Synthesizer



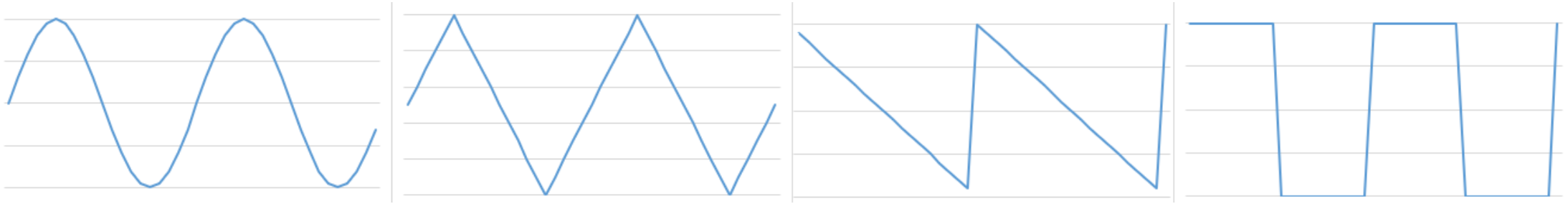


Basic Structure of an Analog Synthesizer



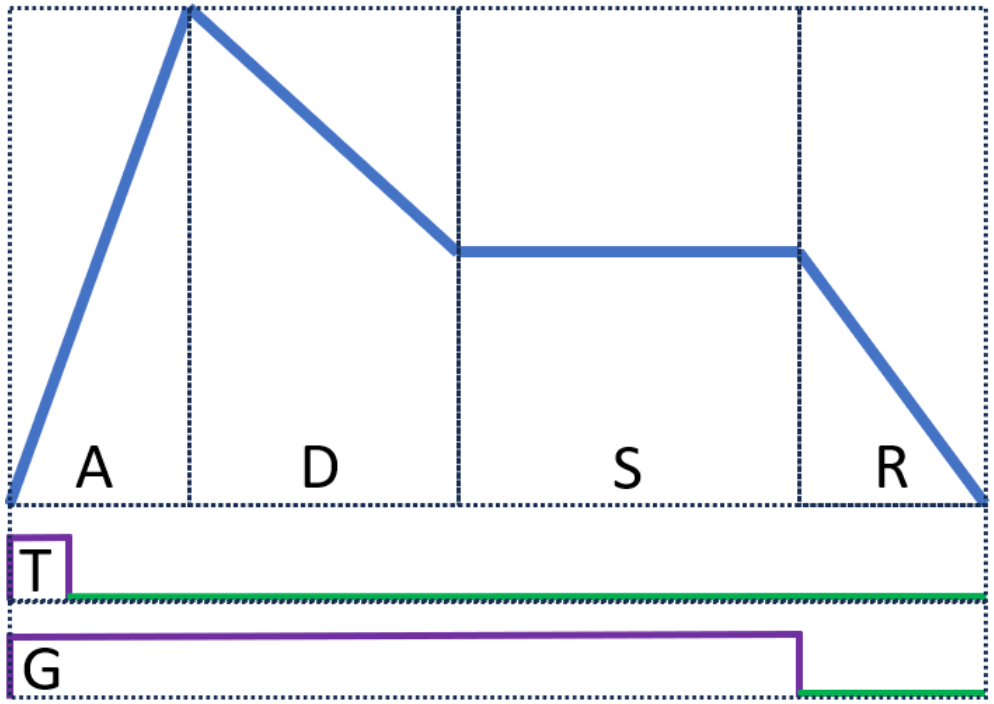


Waveforms



Sine Triangle Saw Square

Envelopes



- Attack (A)
- Decay (D)
- Sustain (S)
- Release (R)

< Trigger

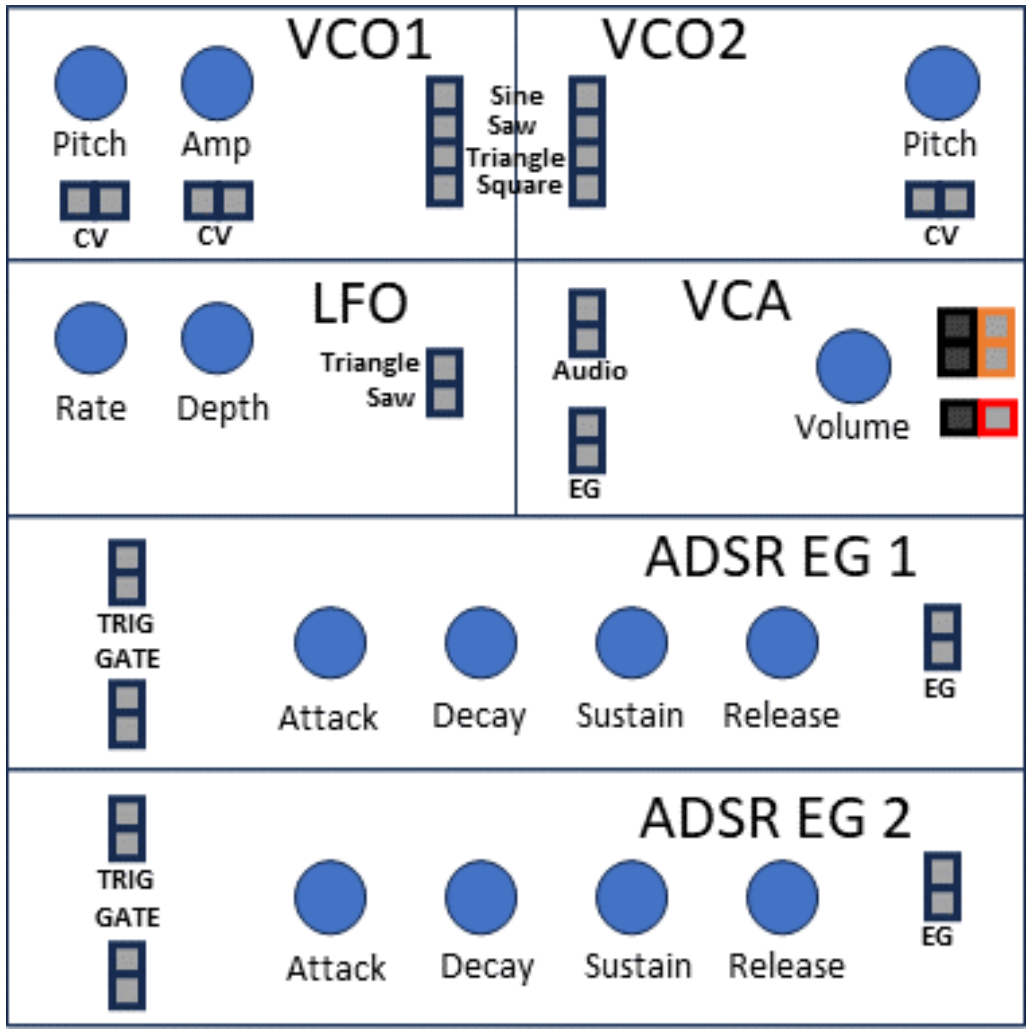
< Gate

Key Points of Analog, Modular Synths

- (Pretty much) Everything can be voltage controlled.
- (Pretty much) Any signal can be a control voltage!

The Synth Thing

The Synth Thing

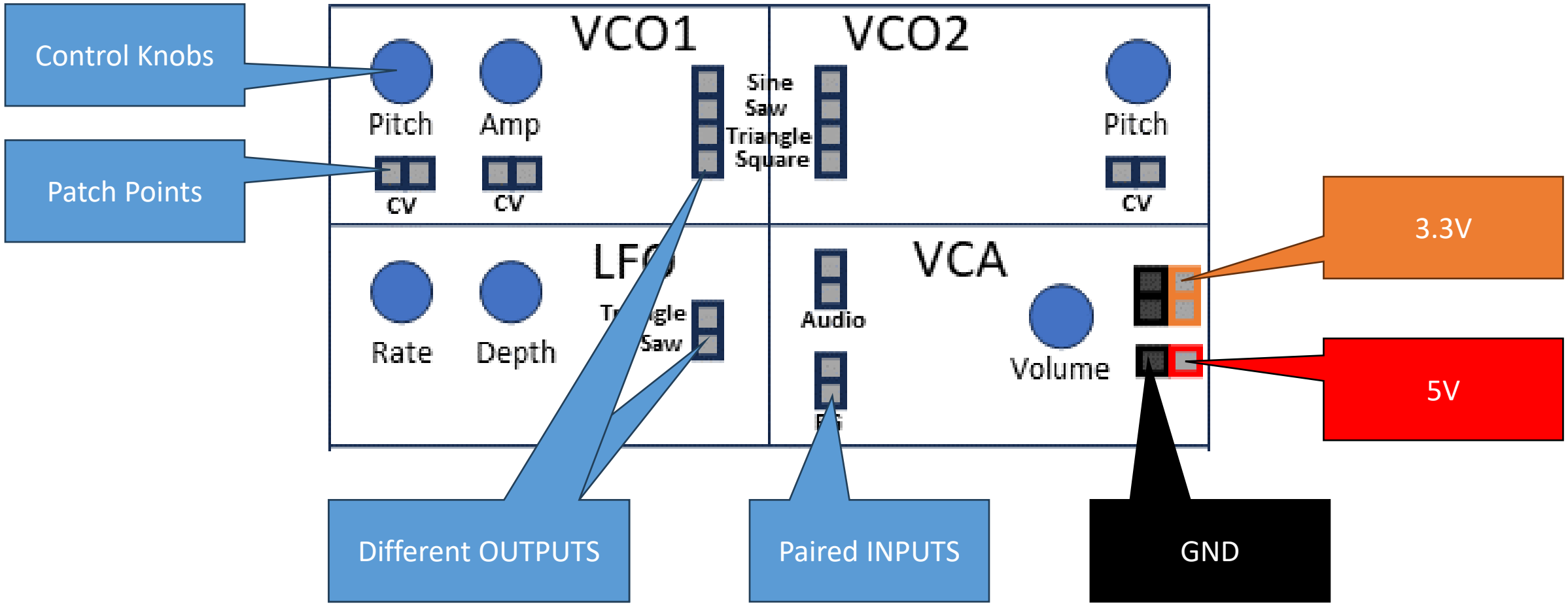


Modules:

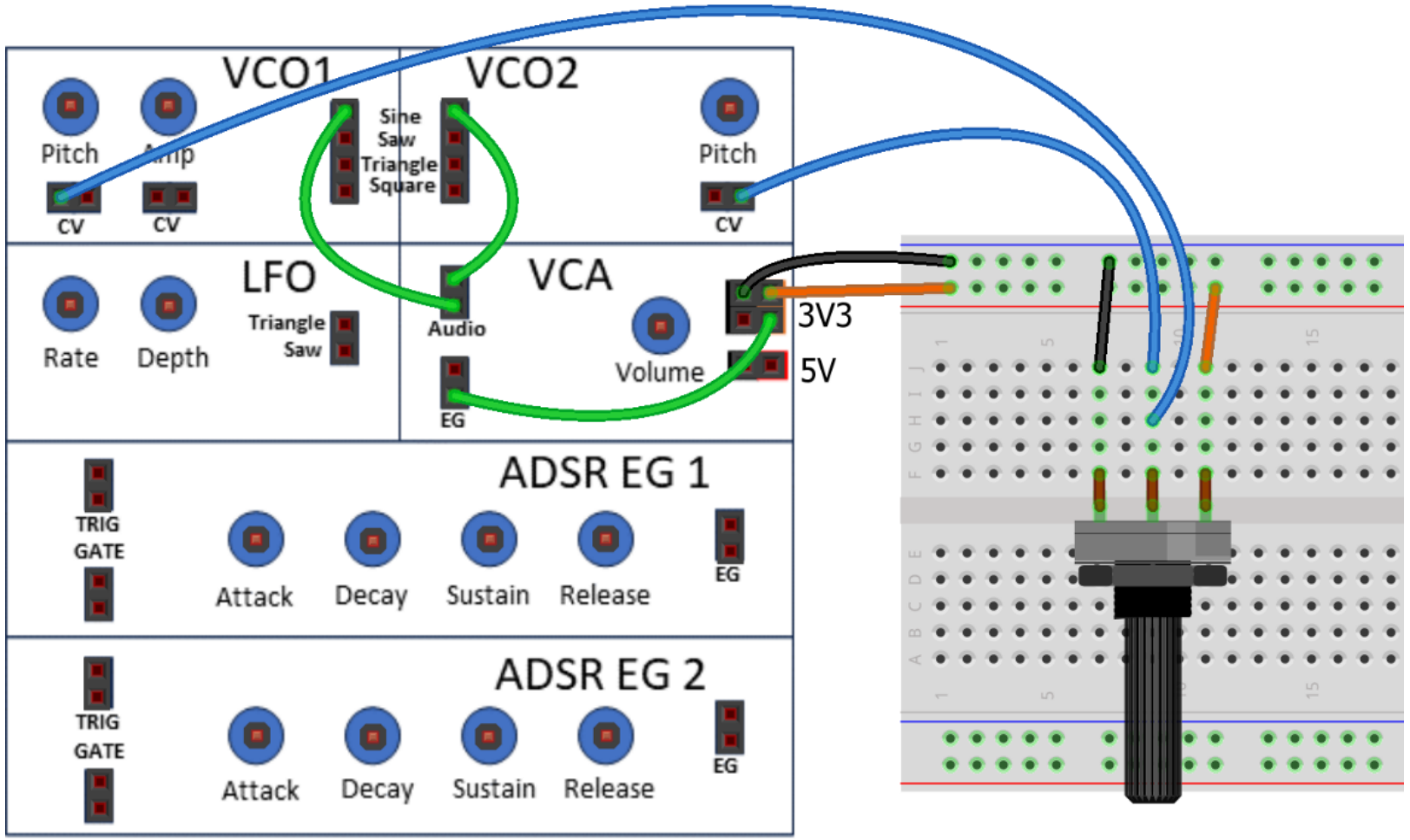
- 2x Voltage Controlled Oscillators.
  - 4x VCO waveforms.
- 1x Low-Frequency Oscillator.
  - 2x LFO waveforms.
- 1x Voltage-Controlled Amplifier.
  - Audio output.
- 2x Envelope Generators.
  - ADSR.

- *Every patch point is a real signal!*

Patch Points: control, audio, power

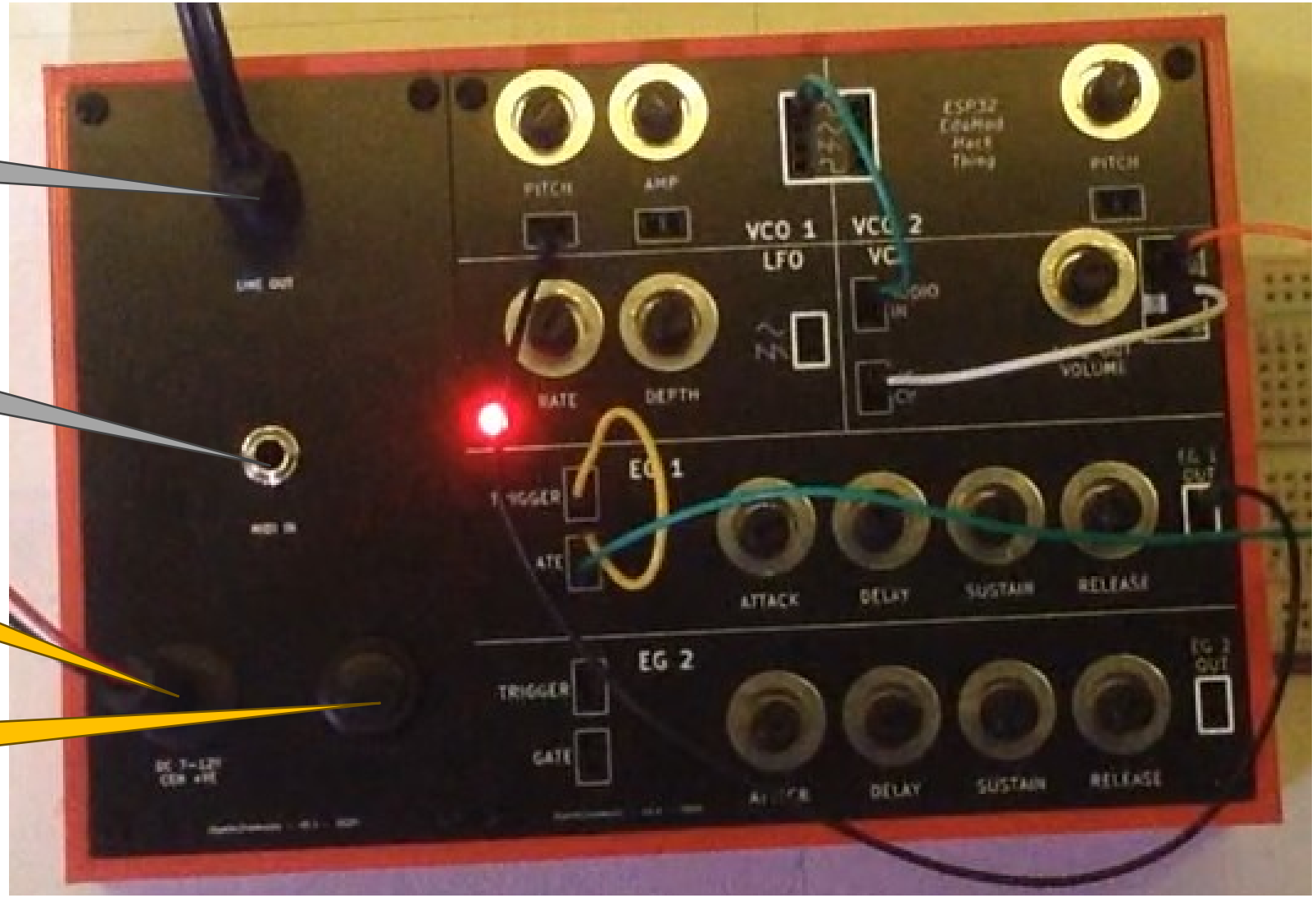


Patch Diagrams

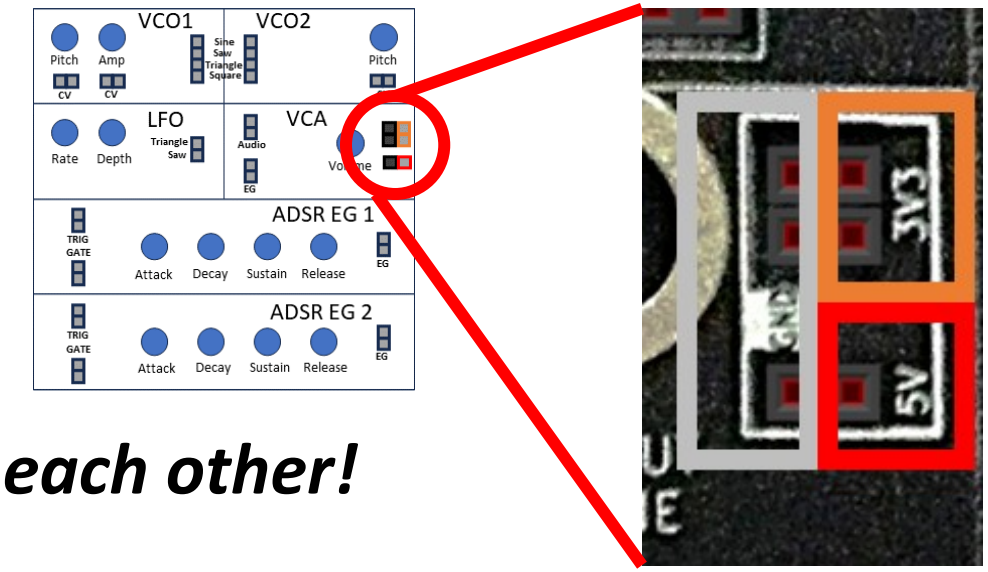


- Green: Internal Links
- Blue: External Links
- Black: GND
- Orange: 3.3V
- Red: 5V

Extra Connections



Basic Dos and Don’ts



Don’ts:

- ***DO NOT CONNECT 3V3 or 5V or GND to each other!***

Dos:

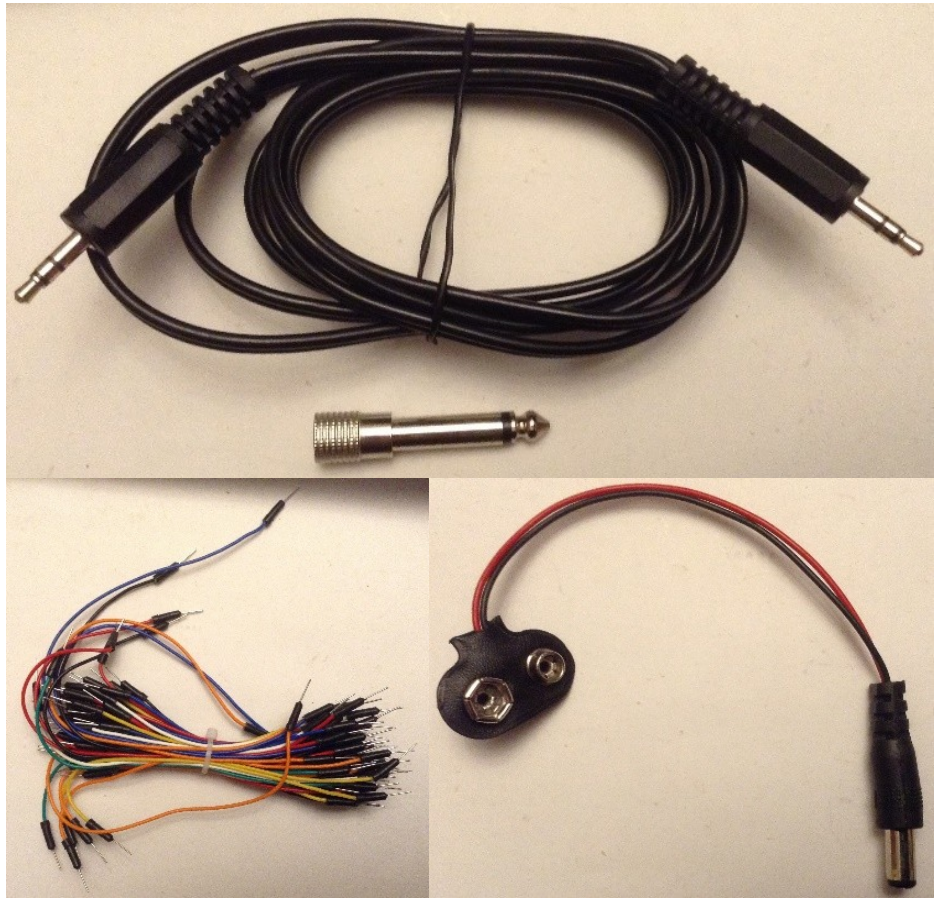
- Experiment with the different signals!
- Link to a solderless breadboard to make new circuits.
- Look at signals with an oscilloscope.
- Use MIDI.

Ch 2 - Starter Projects

Getting Started

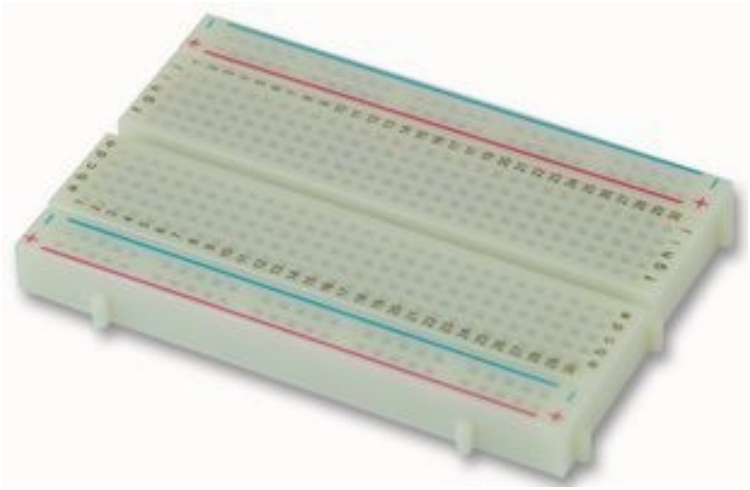
3.5mm
STEREO
AUDIO OUT

7-12V
DC IN

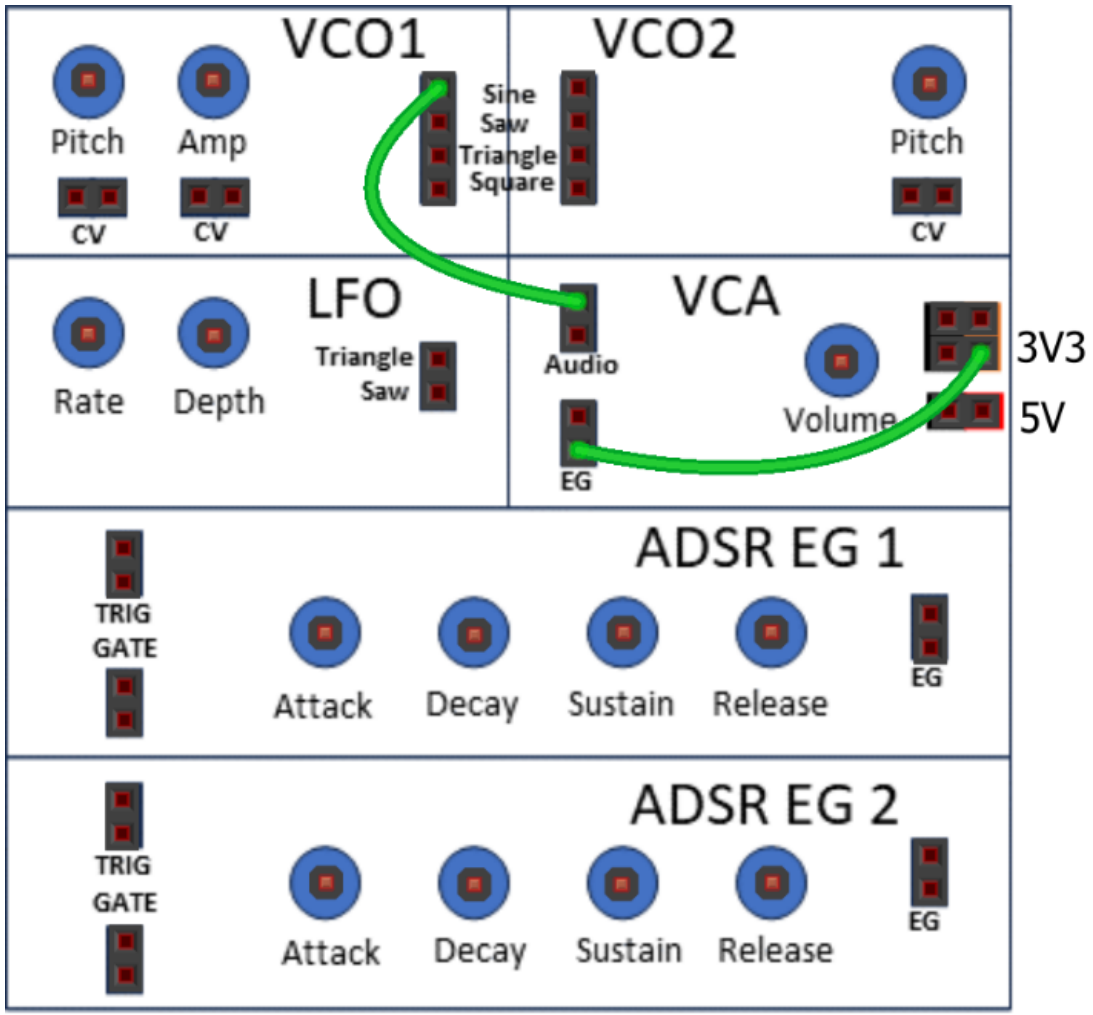


Other Equipment

- Optional: Oscilloscope
- Solderless breadboard
- Potentiometer (10K to 100K)
- Button
- (Cheap/Old) Amplification



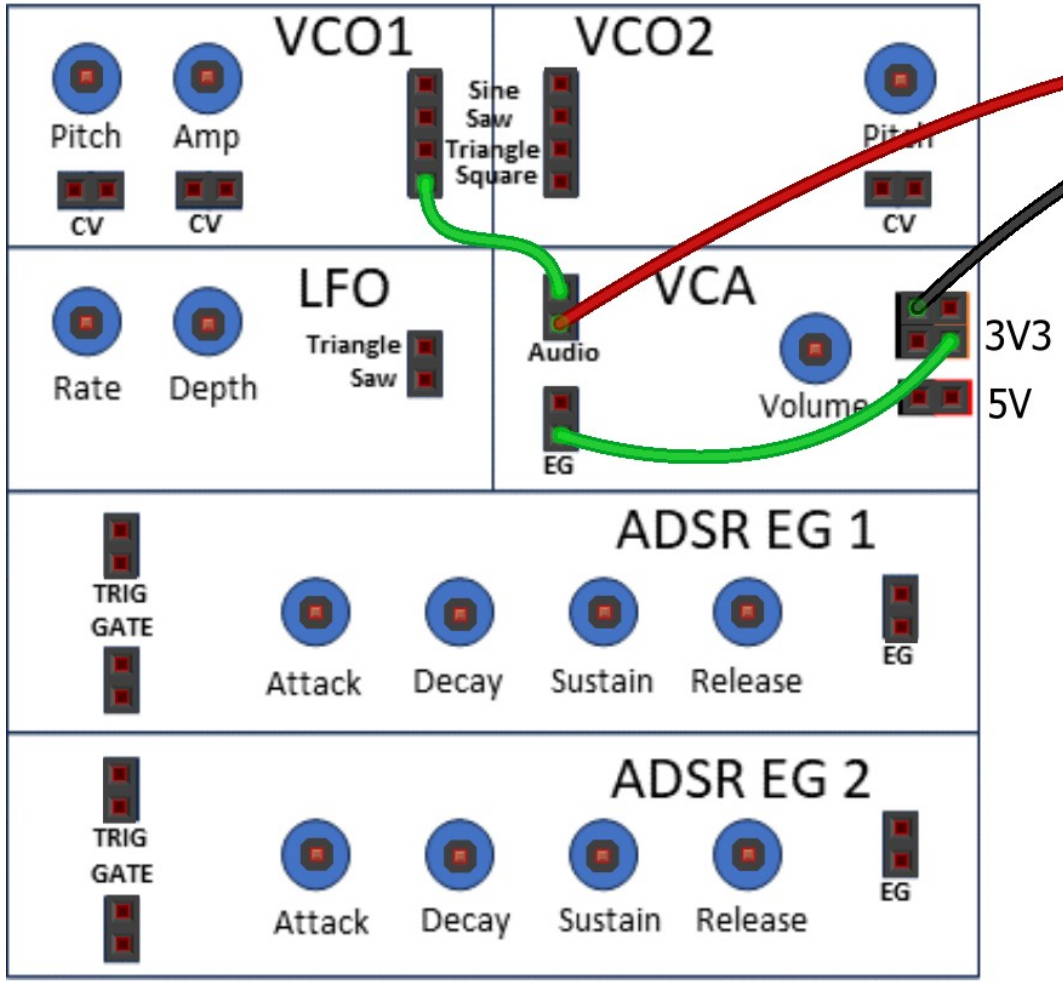
1. Basic Oscillator (VCO) Output



- VCA EG fixed at 3V3.
- Turn up VCA Volume.
- Experiment with:
  - VCO1 Amp.
  - VCO1 Pitch.

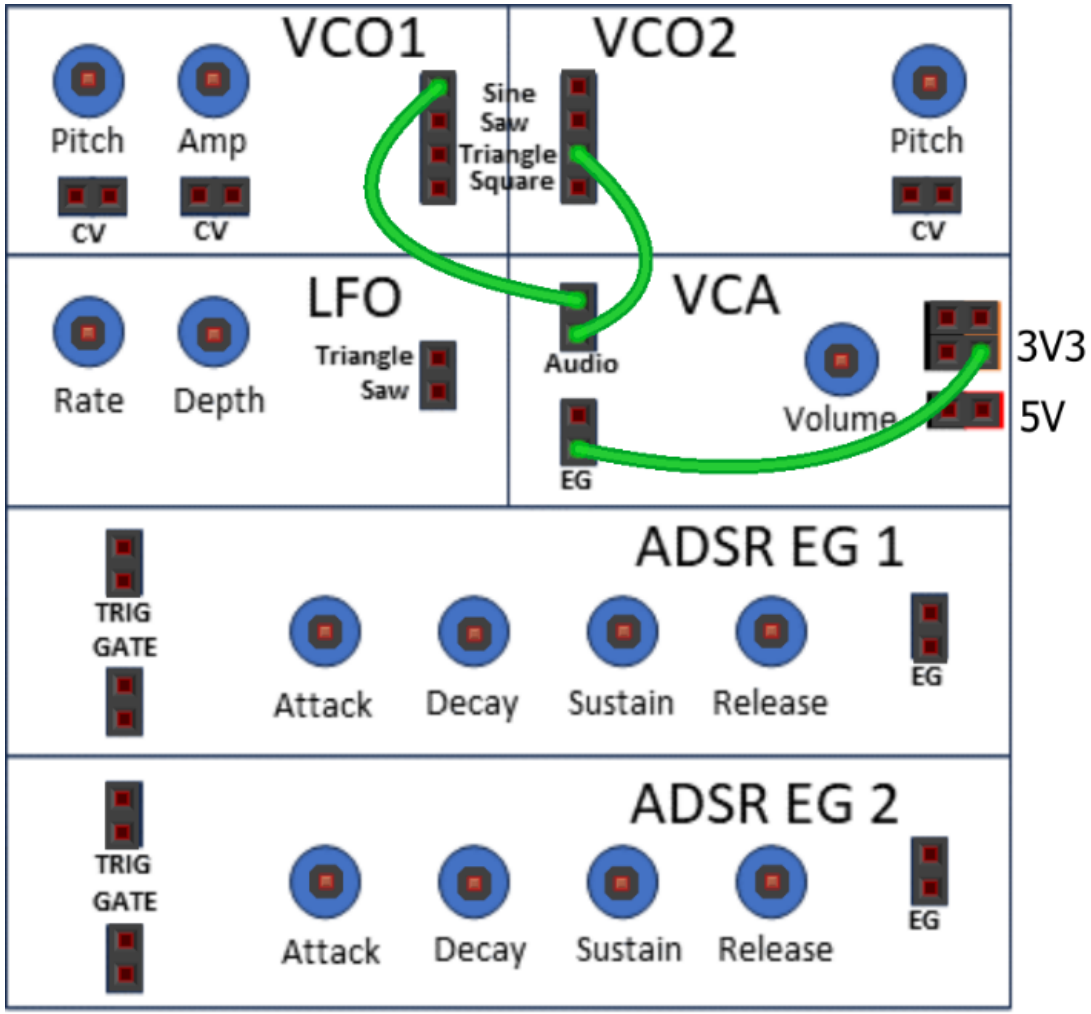
- What are the highest and lowest frequencies?

2. VCO Waveform on an Oscilloscope



- **Note: Needs a GND connection.**
- Try all four VCO1 waveforms.
- Change the VCO1 Amp and Pitch.
- Measure highest and lowest frequencies.

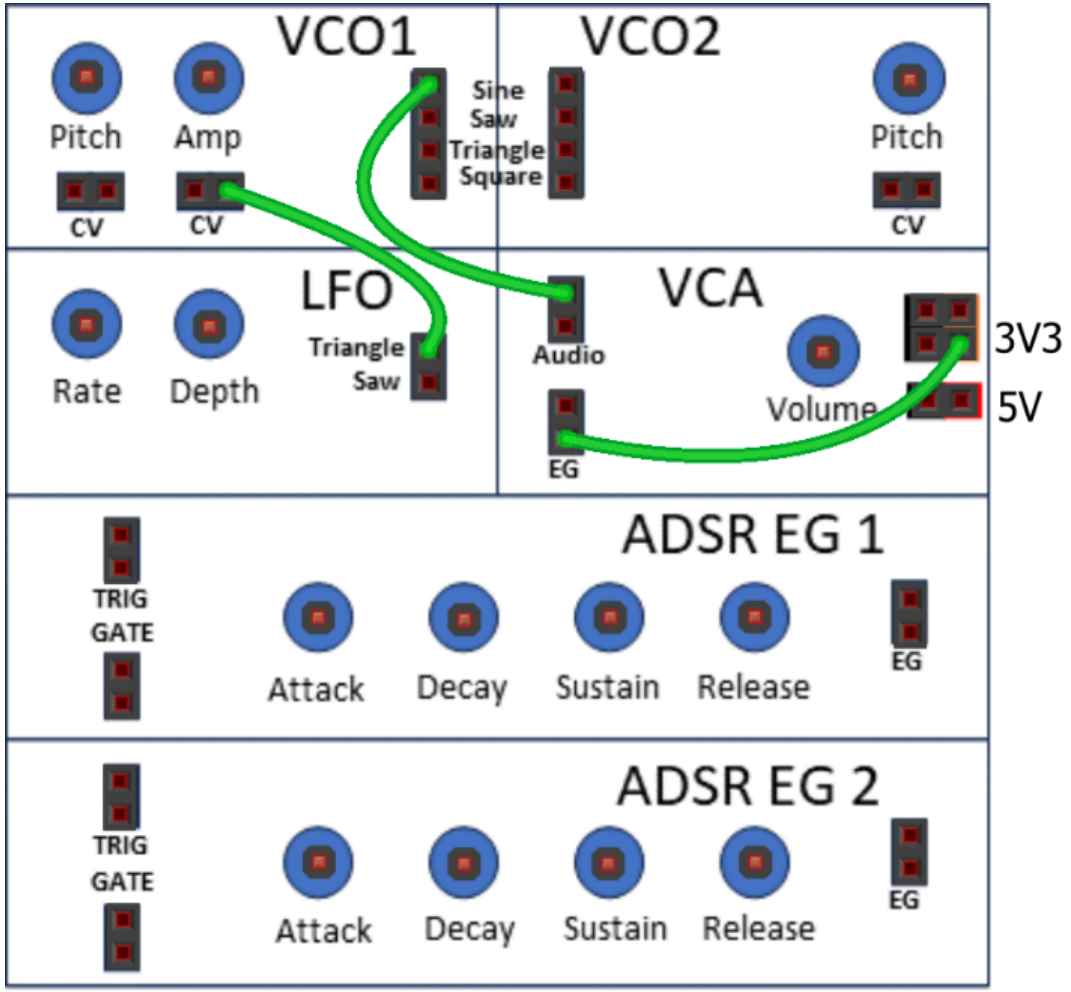
Dual Oscillator Output



- Change:
  - VCO1 and VCO2 Pitch.
  - VCO1 Amp.
  - VCO1 and VCO2 Waveforms.

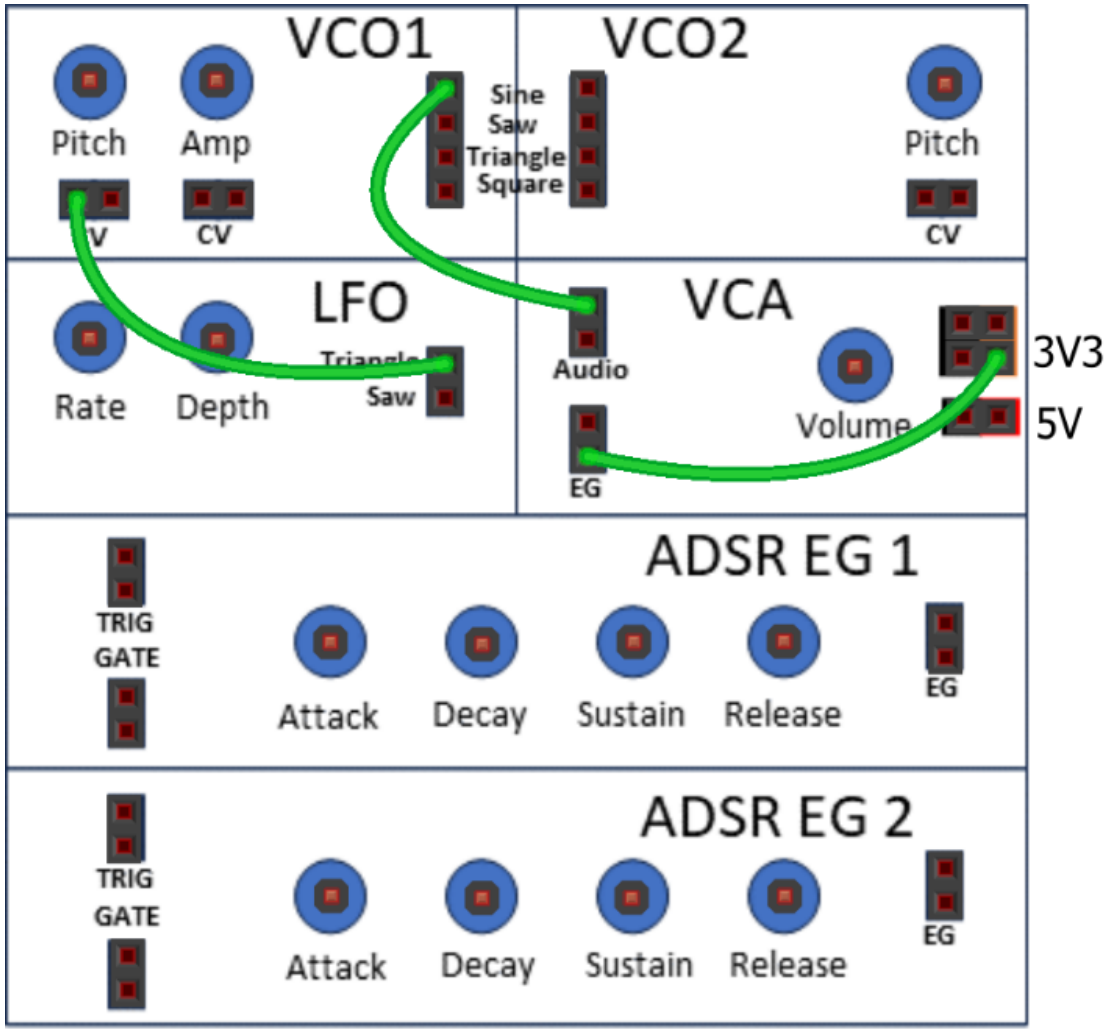
- Experiments:
  - Tune to same pitch.
  - Detune one slightly.
  - Tune to 1 octave apart.
  - Tune to 2 octaves.
  - Find other intervals.

4. LFO Amplitude Modulation



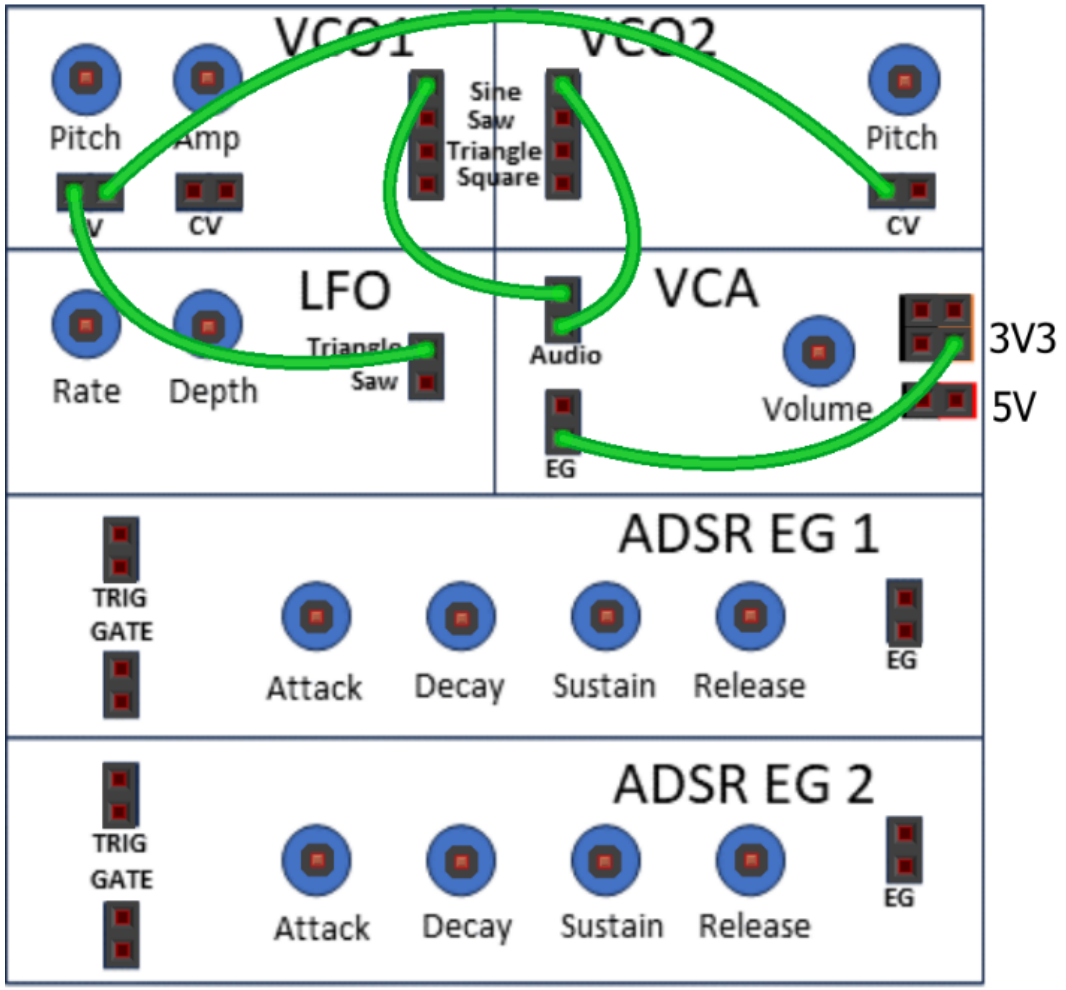
- VCO1 Amp must be turned down.
- Try LFO Rate and Depth.
- Try both LFO waveforms.

5. LFO Pitch Modulation



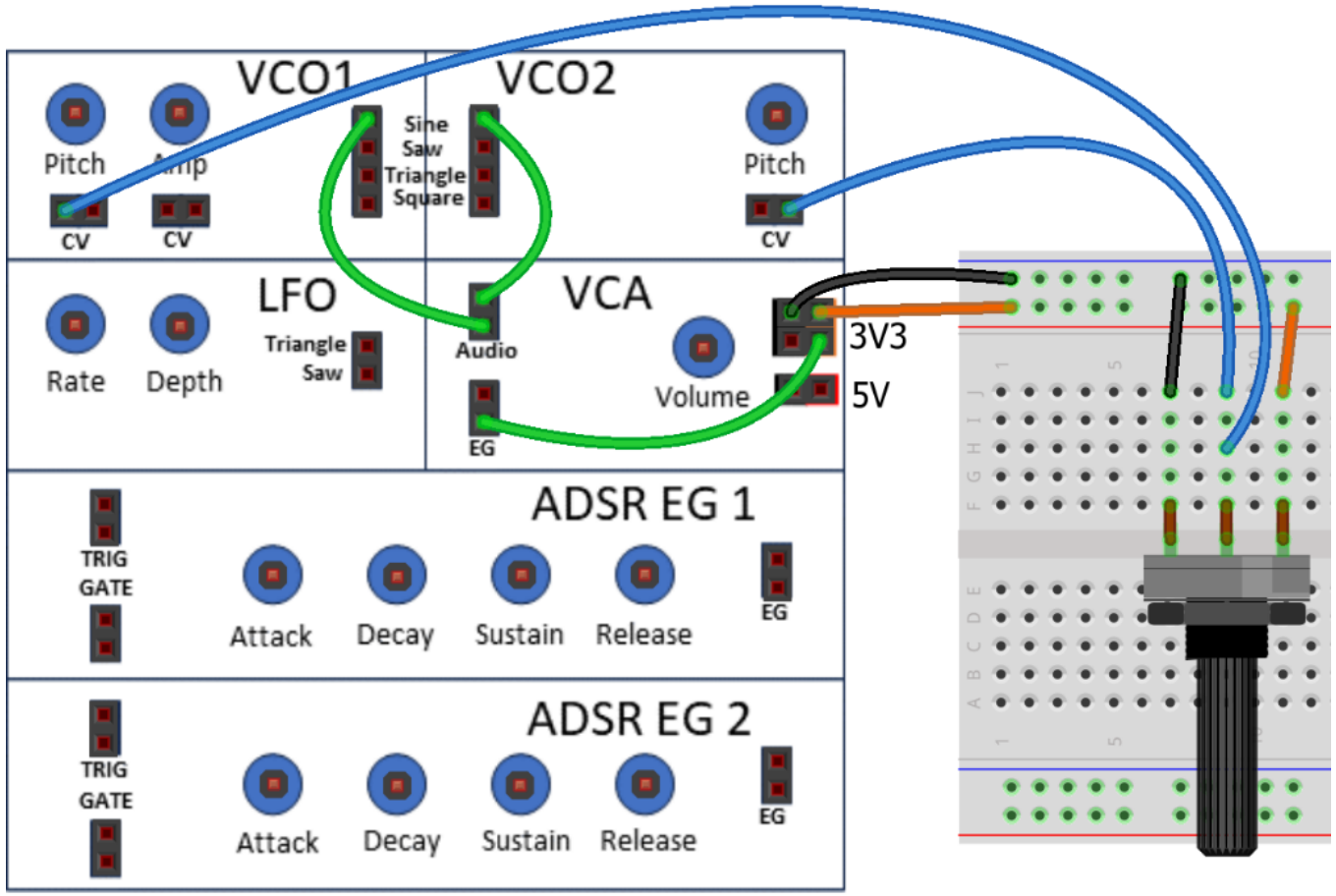
- Turn VCO1 Amp up.
- Try LFO Rate and Depth.
- Try both LFO waveforms.
- Combine Pitch and Amp modulation using both LFO waveforms at the same time.

6. Dual VCO+LFO Pitch Modulation



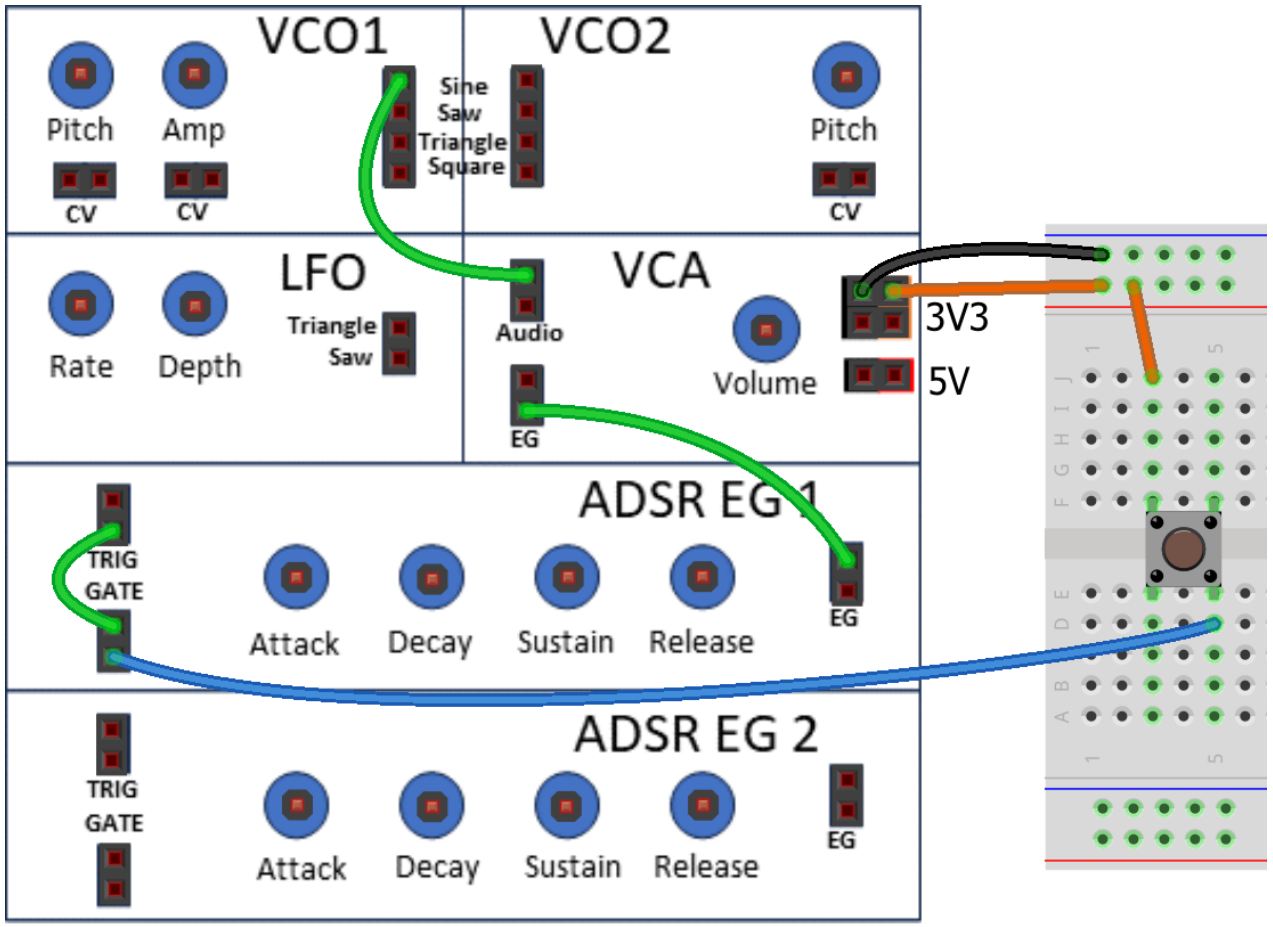
- Links VCO1 and VCO2 CVs.
- Turn LFO off and tune VCOs to 1 octave.
- Try LFO Rate and Depth.
- Try LFO waveforms.
- Connect one LFO waveform to VCO1 and one to VCO2.

7. External Dual VCO Pitch Control



- 3V3 and GND to breadboard.
- Potentiometer to VCO1 and VCO2 CVs.
- Detune one VCO.
- Try:
  - Tune to one octave or different intervals.
  - Different waveforms.
  - Add LFO to amplitude modulate VCO1.

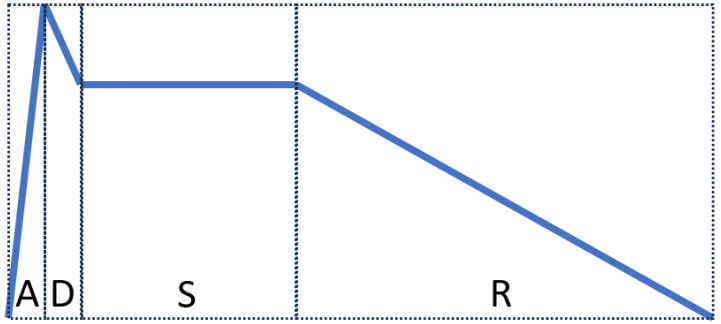
8. ADSR Envelope Generator



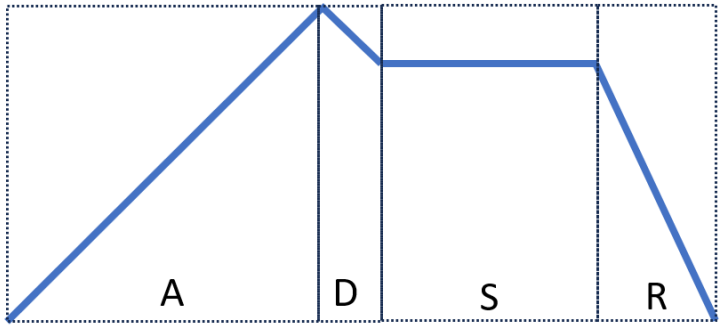
- 3V3 and GND to breadboard.
- ADSR EG1 EG to VCA.
- EG1 TRIG and GATE linked.
- Start with:
  - A: almost full anti-clockwise.
  - D: almost full anti-clockwise.
  - S: fully clockwise.
  - R: in the middle.
- Try different A, D, S, R settings.

9. ADSR Envelope Generator – Part 2

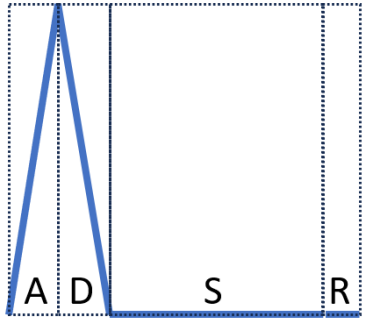
- Attempt to create the following envelopes:



Short attack.
Short decay.
High sustain.
Long release.

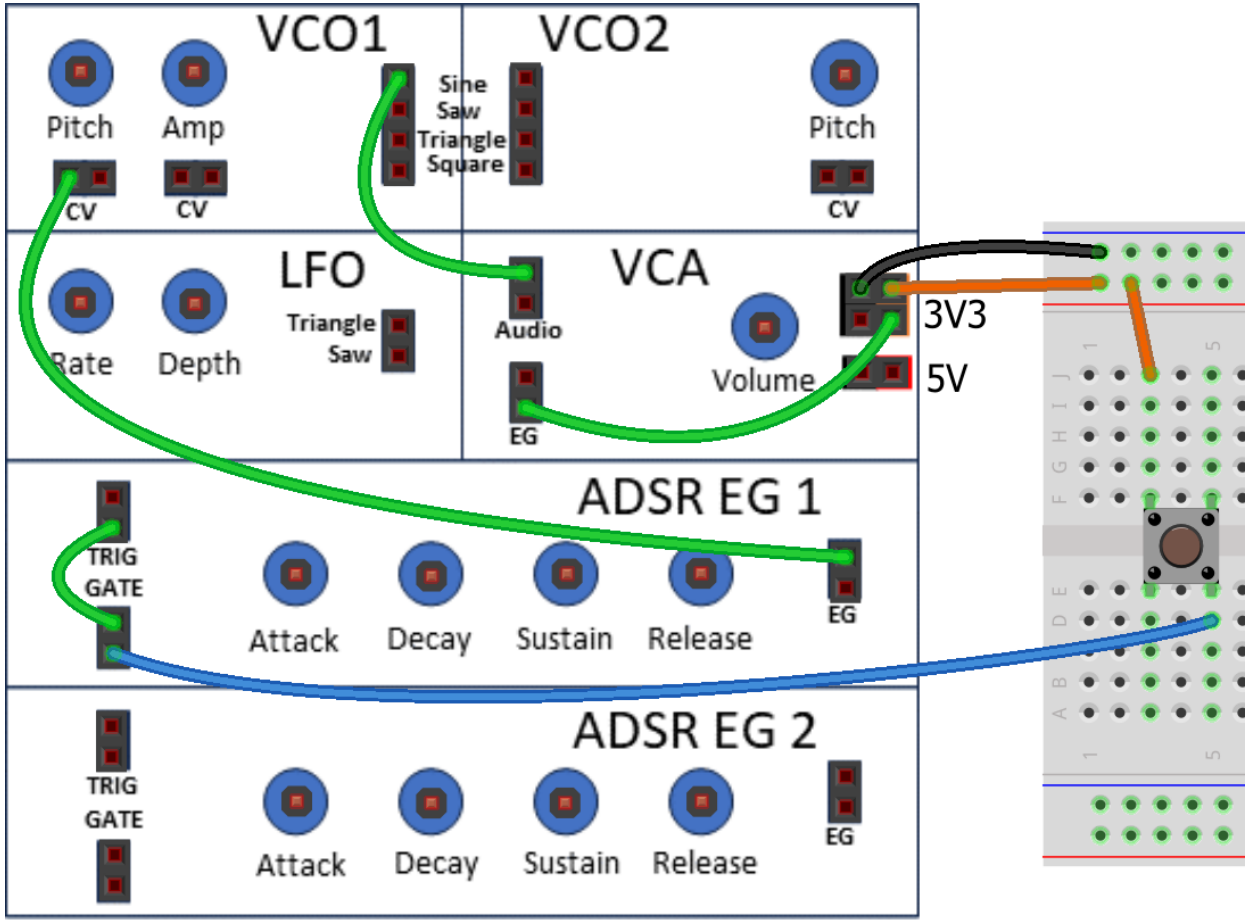


Long attack.
Short Decay.
High sustain.
Short release.



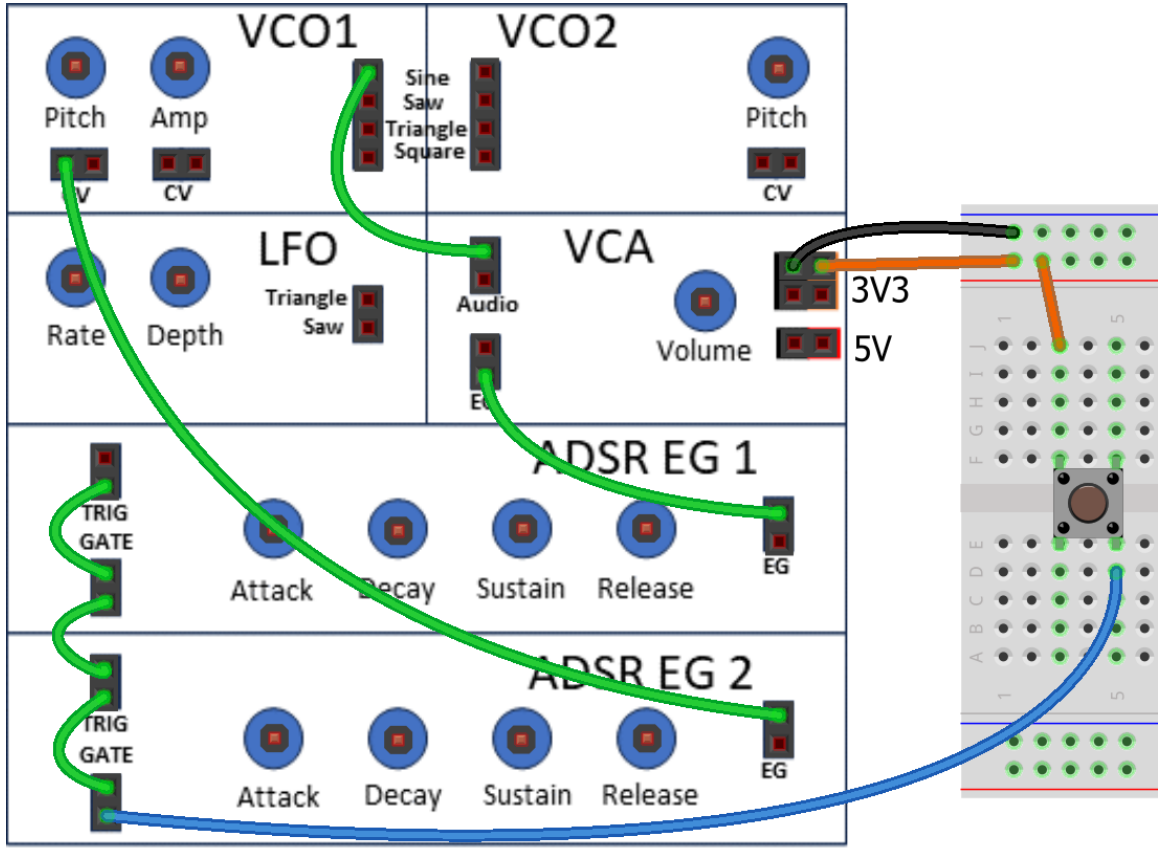
Short attack.
Short decay.
No sustain.
No release.

10. ADSR Envelope Generator for Pitch



- VCA EG to 3V3 again.
- EG1 to VCO1 Pitch.
- Try different A, D, R timings.
- Try different S level.

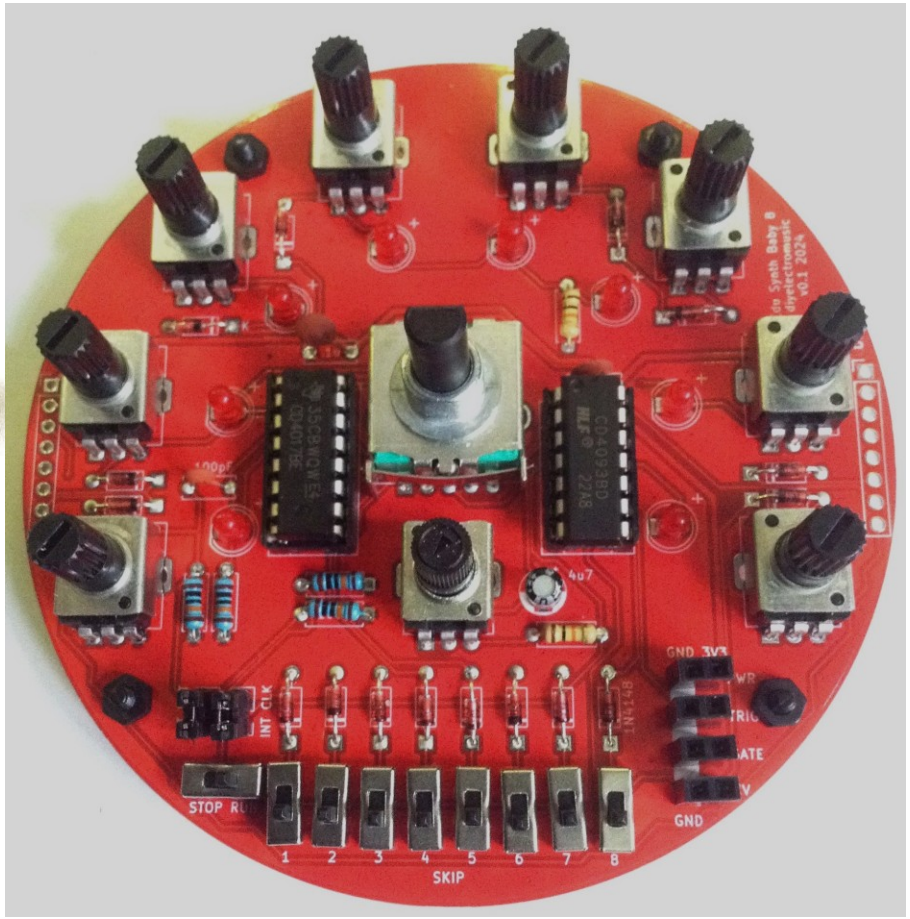
11. ADSR Envelope Generator for Amplitude and Pitch



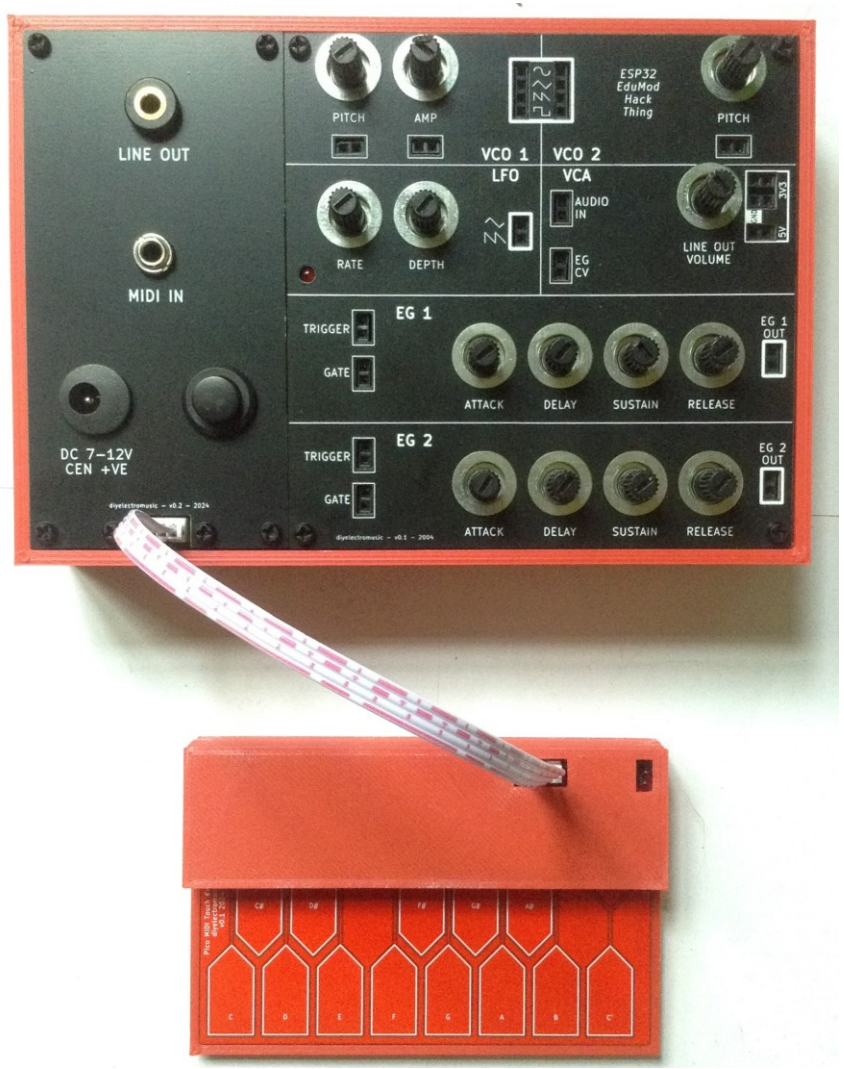
- EG1 back to controlling VCA.
- EG2 now controlling VCO Pitch.
- Try different A, D, S, R settings for both amplitude and pitch.

Ch 3 - Add-on Projects

Keyboard and Sequencer

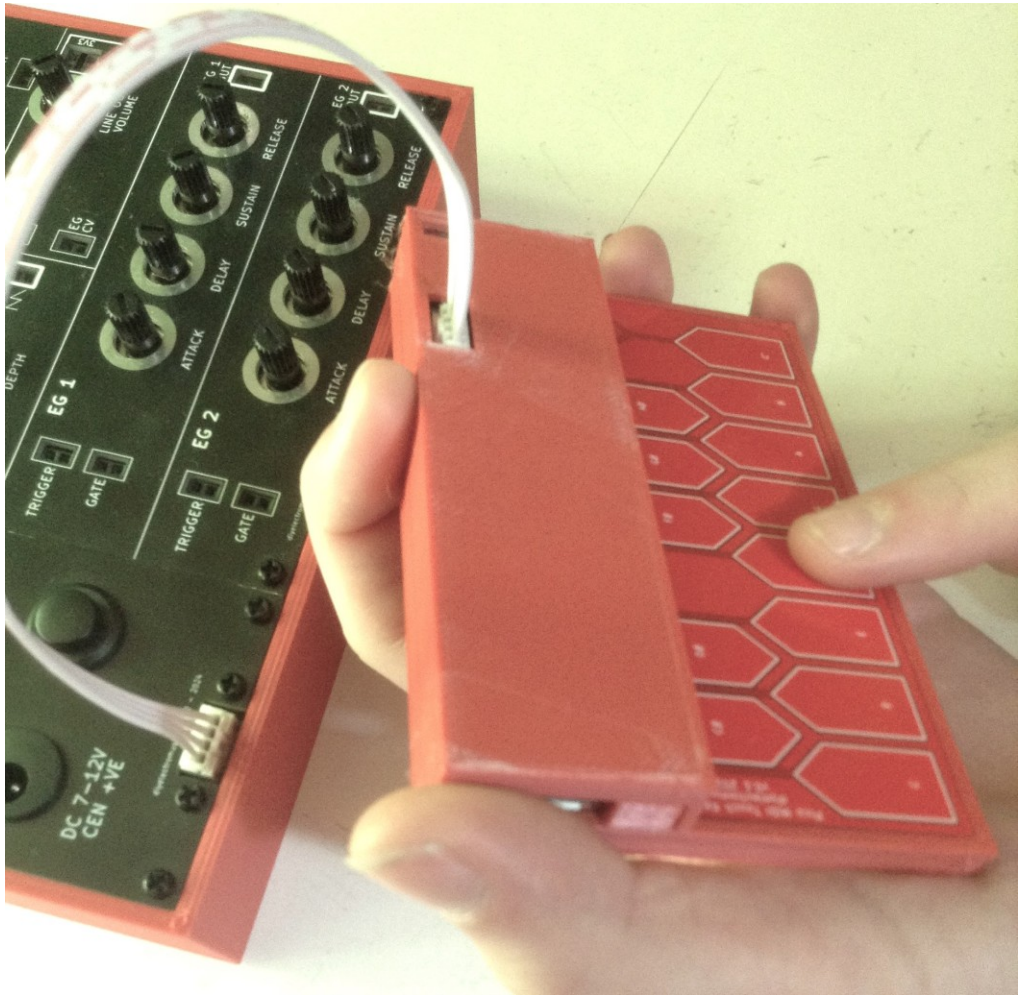


Adding a Touch Keyboard

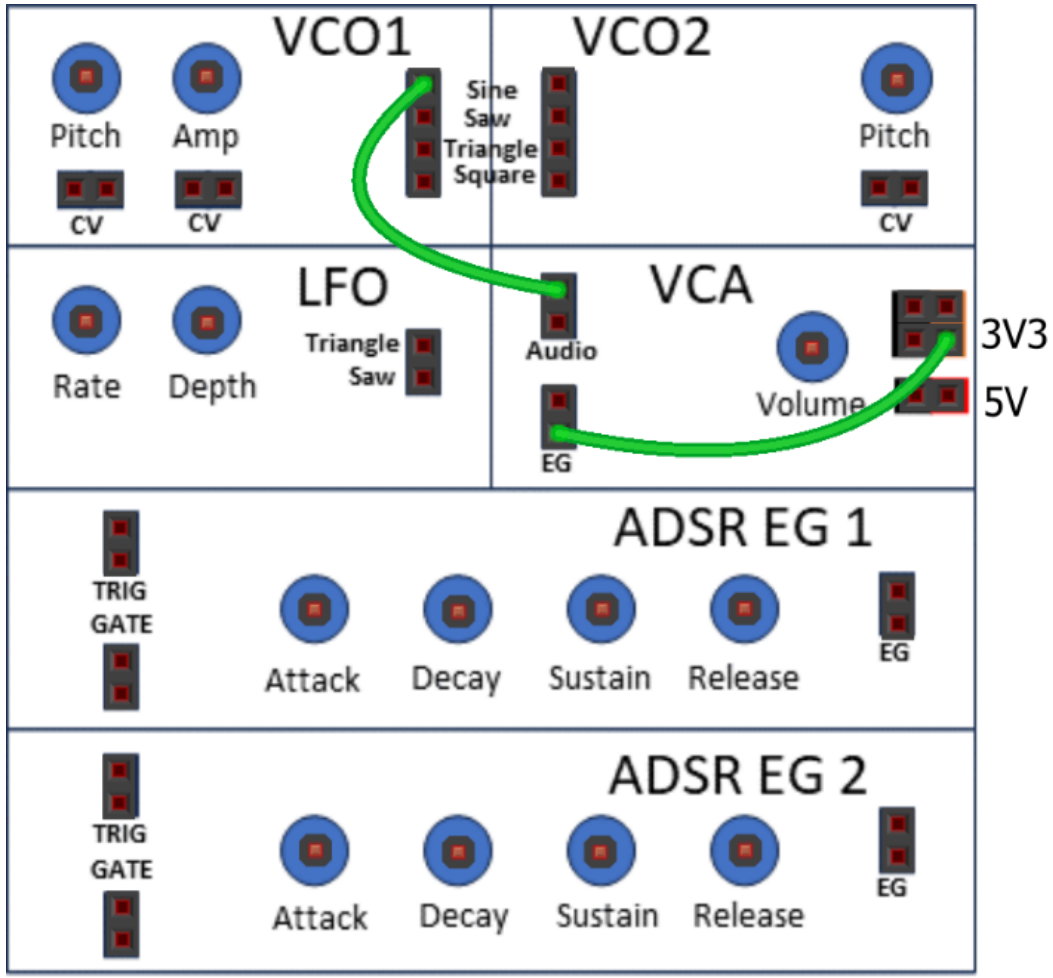


GND Point.

Touch when in use for better accuracy and reliability…



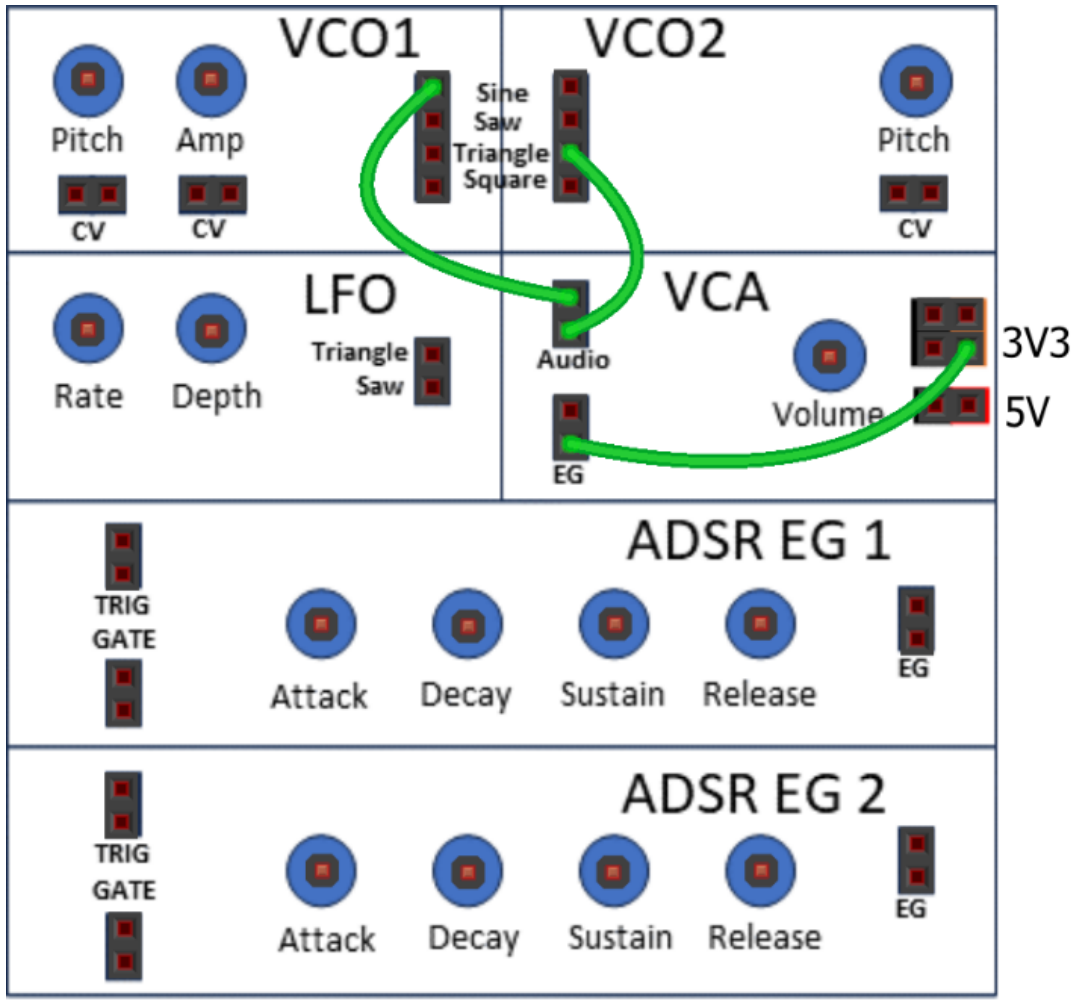
1. Basic Oscillator (VCO) Circuit



- VCA EG Fixed at 3V3.
- Turn up VCA Volume.
- Turn down VCO1 Pitch.
- Play some notes.

- Experiment with:
  - VCO1 Amp.
  - VCO1 Pitch.

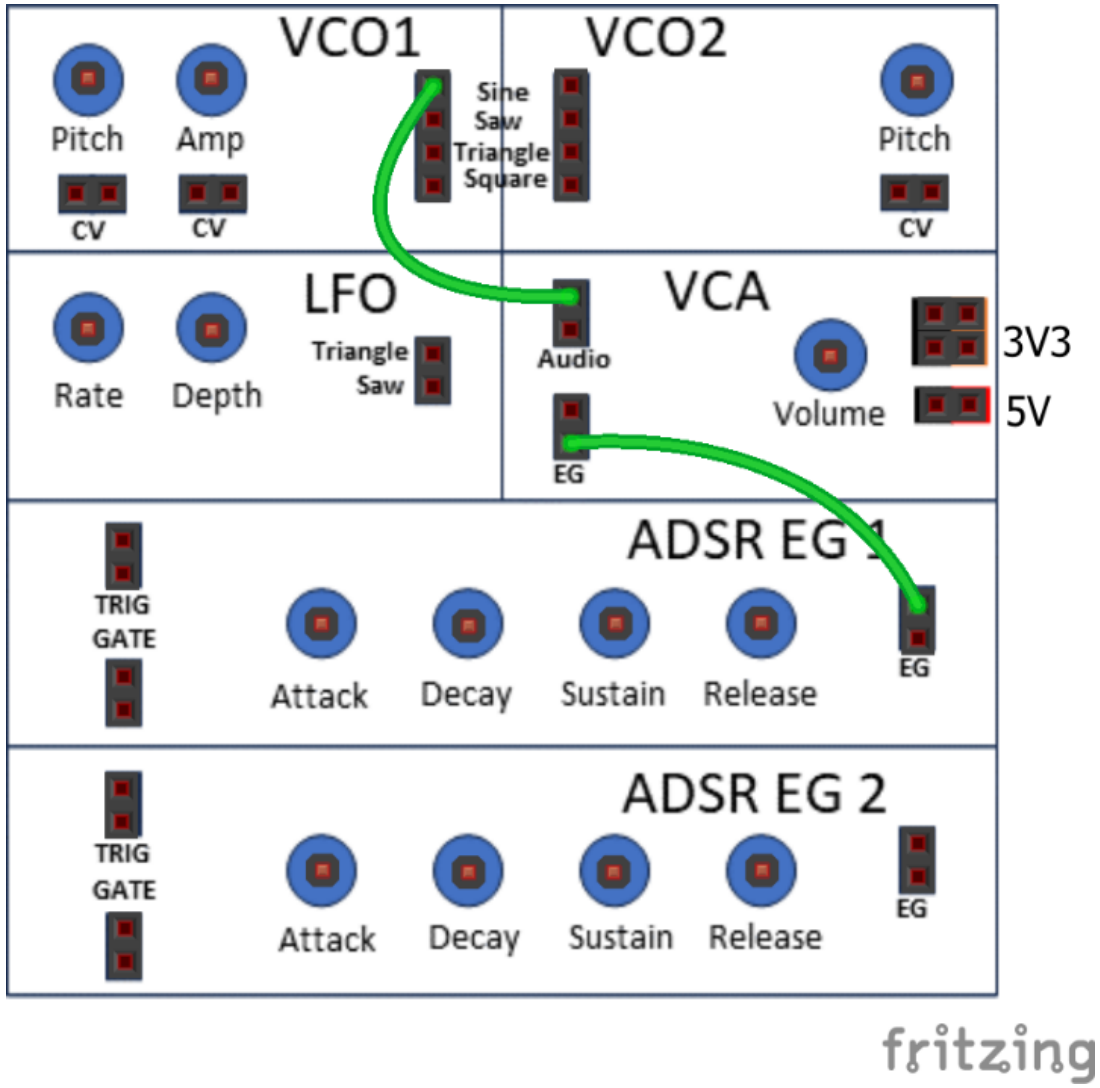
2. Dual Oscillator Circuit



- Turn down VCO1 and VCO2 Pitch.
- Turn up VCO1 Amp and VCA Volume.
- Play some notes.

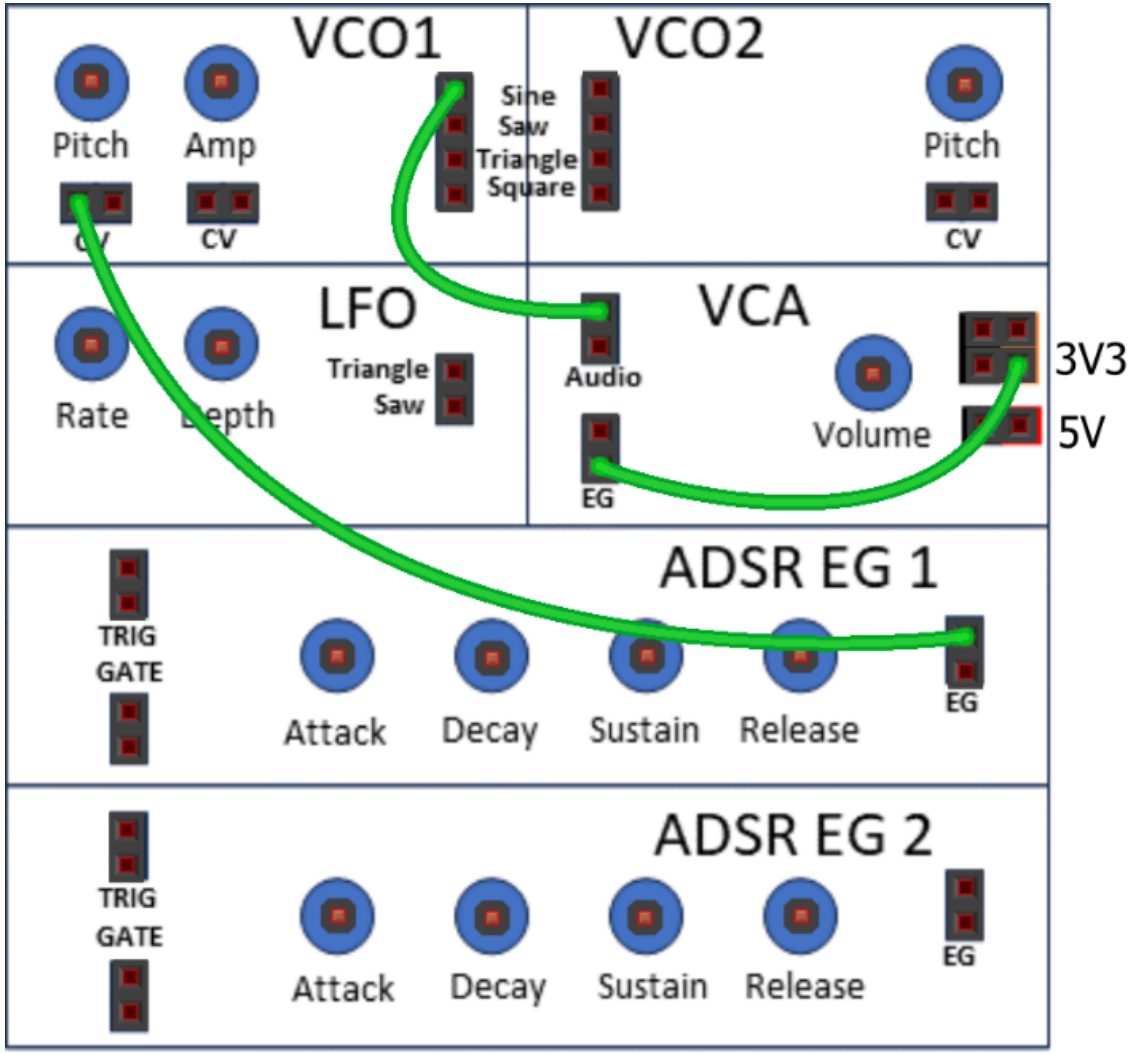
- Experiment with:
  - Changing VCO2 Pitch to detune.
  - Different Waveforms.
  - Changing VCO1 and VCO2 Pitch.

3. ADSR Envelope Generator



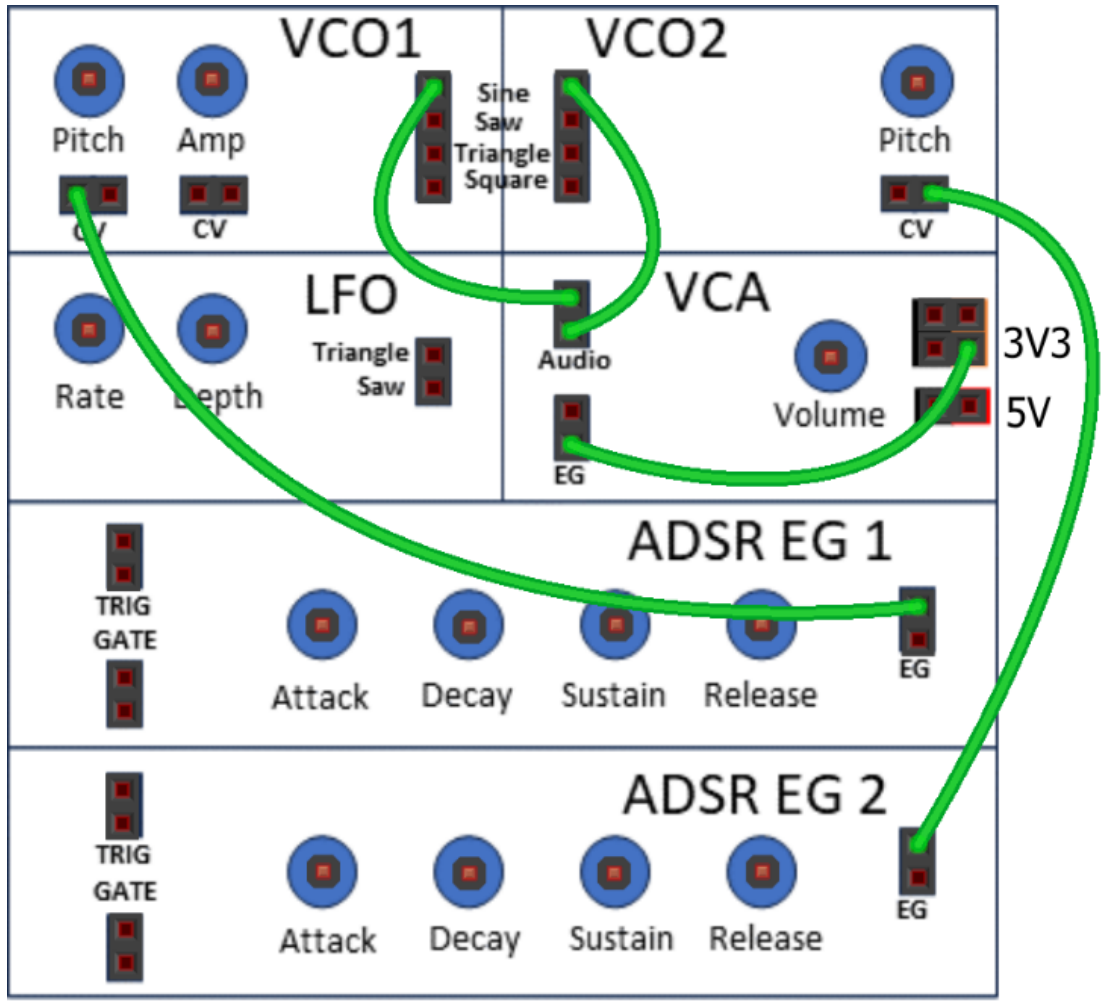
- VCA is now connected to EG1.
- Start with:
  - VCO1 Pitch right down.
  - VCO1 Amp and VCA Volume right up.
  - A: almost full anti-clockwise.
  - D: almost full anti-clockwise.
  - S: fully clockwise.
  - R: in the middle.
- Play some notes.
- Experiment with different ADSR settings.

4. ADSR Generator for Pitch



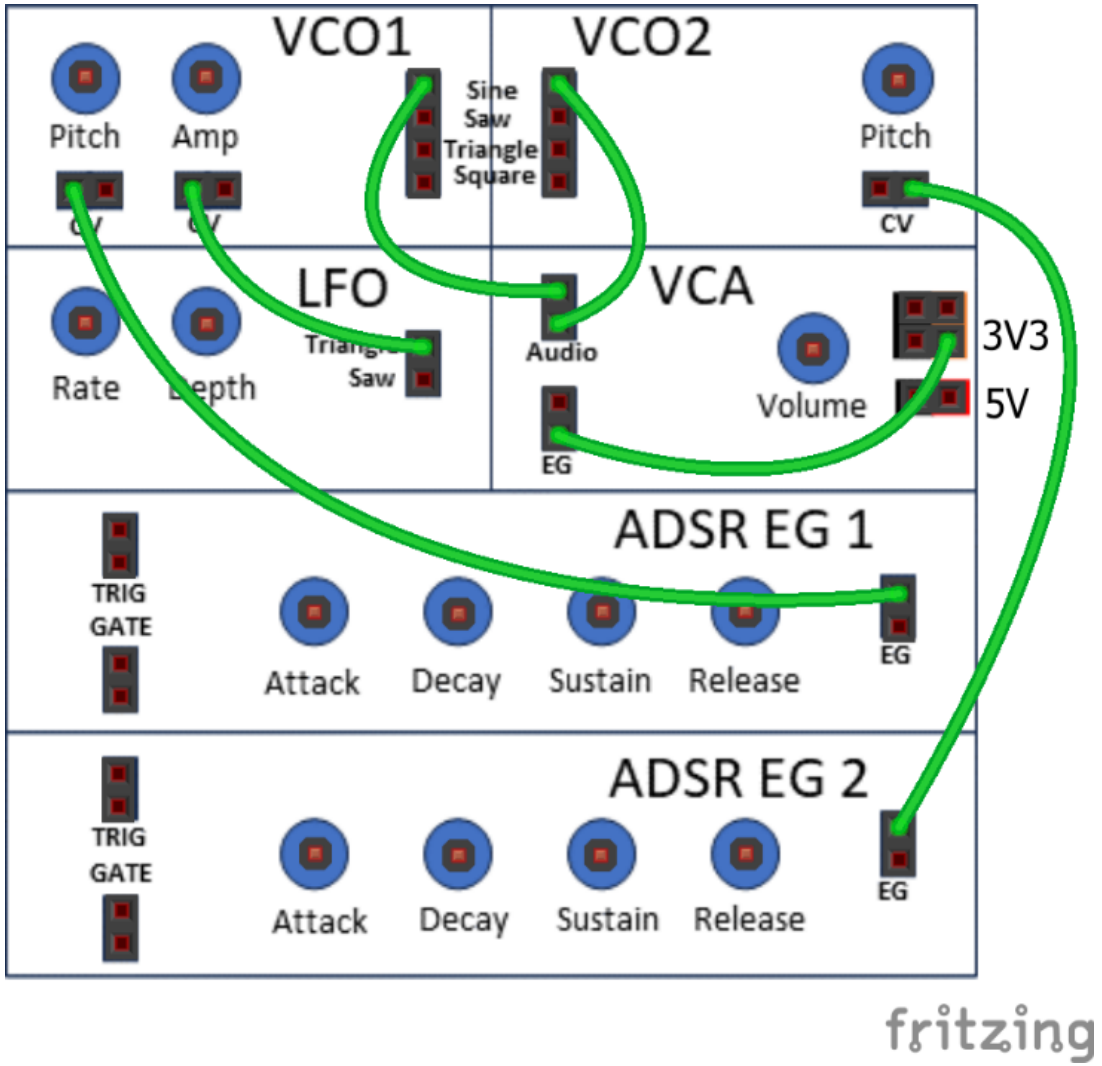
- VCA is back to constant 3V3 CV.
- Start with:
  - VCO1 Pitch turned right down.
  - Fairly low Sustain.
  - VCO1 Amp and VCA Volume turned up.
- Play some notes.
- Experiment with:
  - Different ADSR settings.
  - VCO1 Pitch control.

5. ADSR Envelope Generator – Dual Pitch



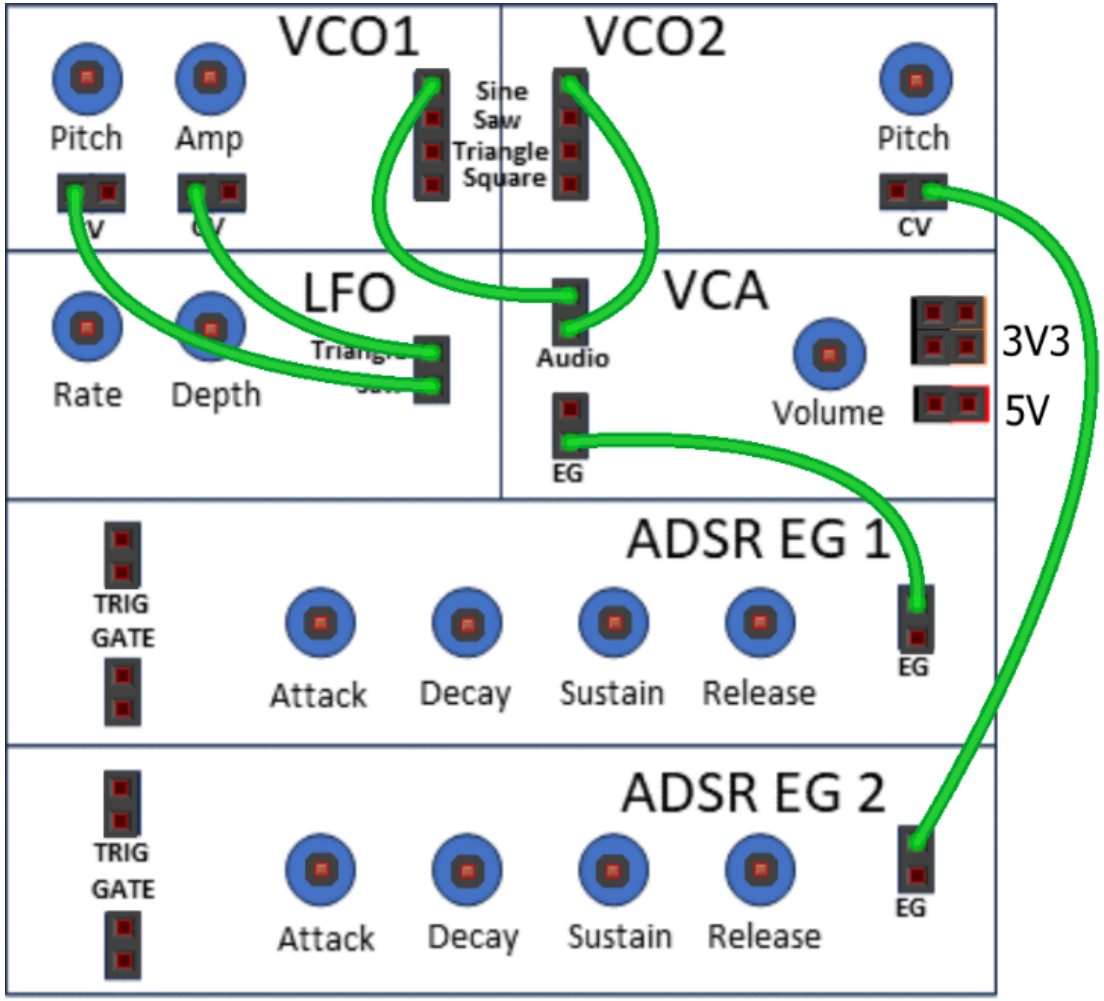
- Start with:
  - Both Pitch controls turned right down.
  - Low Sustain (S) level on each EG.
- Play some notes.
- Experiment with:
  - Both sets of ADSR Settings.
  - Detuning VCO2.
  - Setting VCOs an octave apart.
  - Different waveforms.

6. Include the LFO



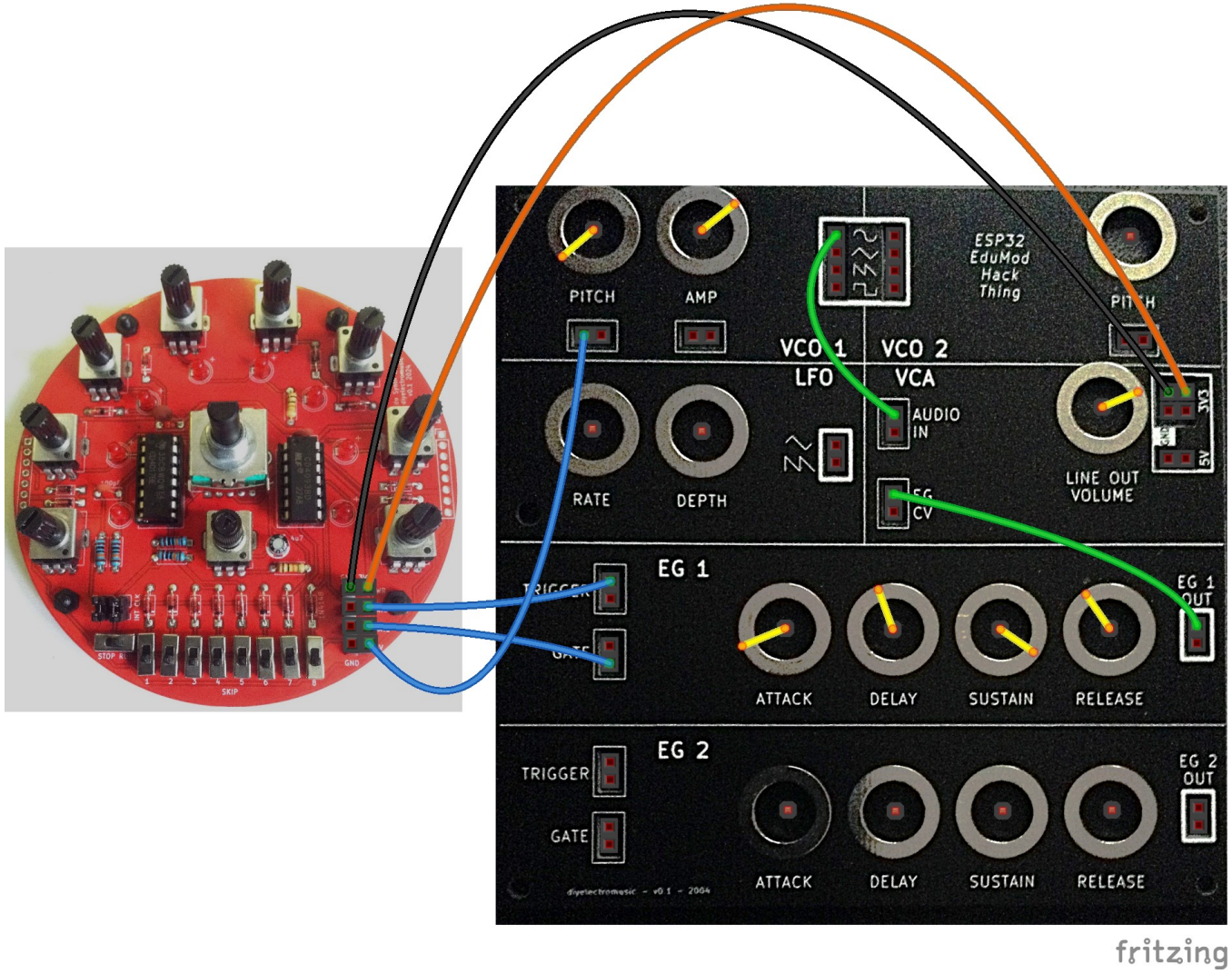
- Start with:
  - Both VCO Pitch turned down.
  - VCO1 Amp turned down.
  - VCA Volume turned up.
  - Sustain (S) pretty low or even disconnect EGs to start with.
- Experiment with:
  - LFO Rate and Depth.
  - LFO Waveforms.
  - ADSR for both EGs.
  - VCO Pitch controls.
  - VCO Waveforms.

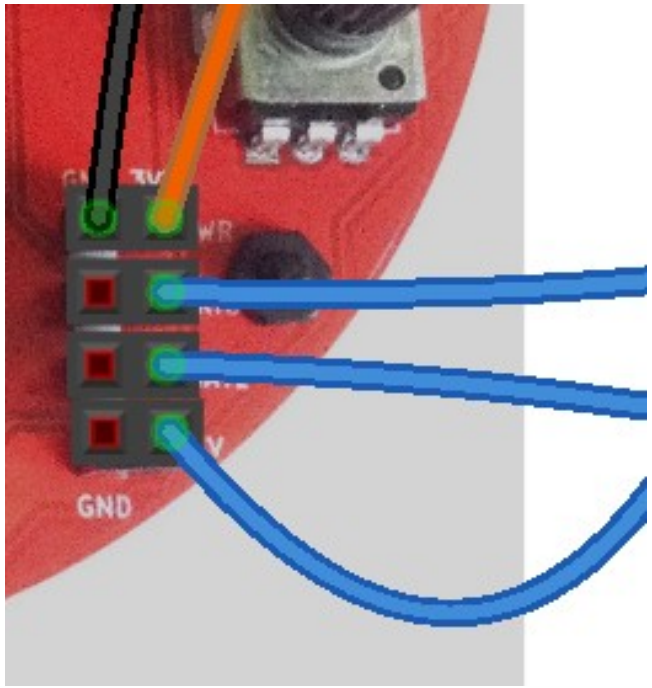
7. Final Keyboard Patch



- Complete keyboard patch:
  - EG1 controls VCA.
  - LFO controls both Pitch and Amp for VCO1.
  - EG2 controls VCO2.
- Experiment with:
  - Rate and Depth of LFO.
  - Different links between LFO and VCO1.
  - VCO waveforms.
  - EG1 ADSR.
  - EG2 ADSR.

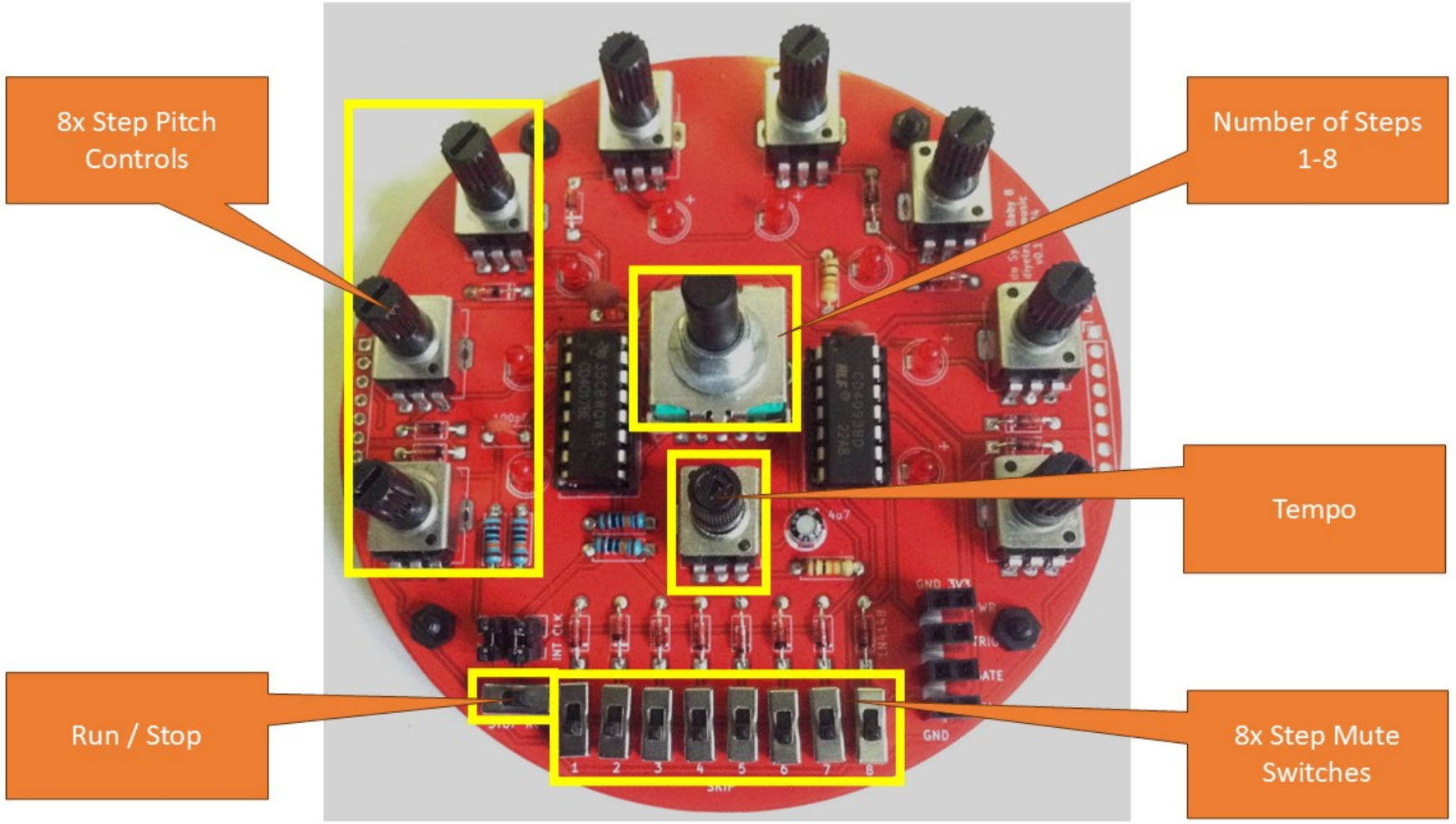
Adding a Baby-8 Sequencer



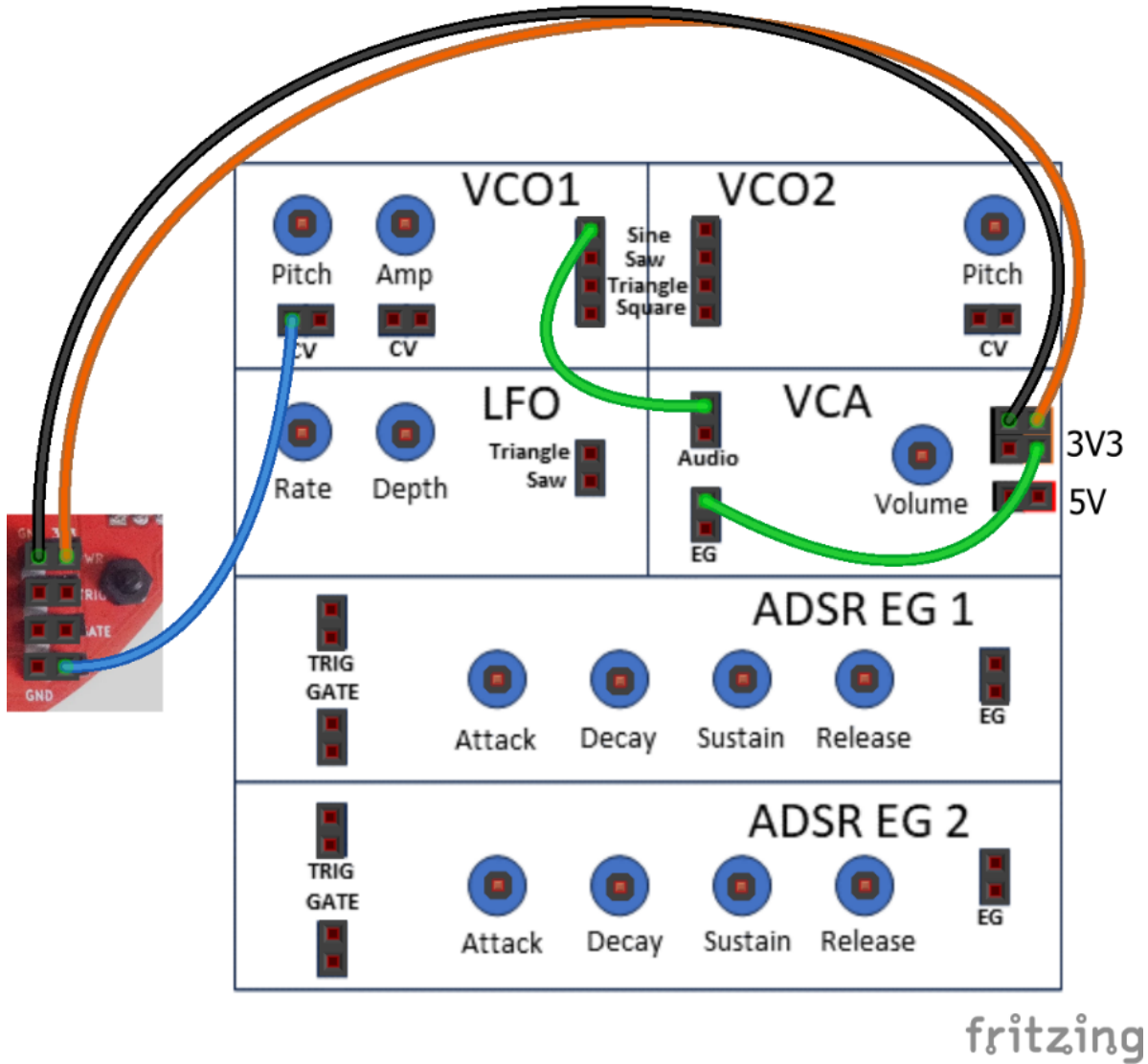


IN: GND and 3V3 Power
OUT: TRIGGER
OUT: GATE
OUT: Control Voltage (CV)

Basic Controls

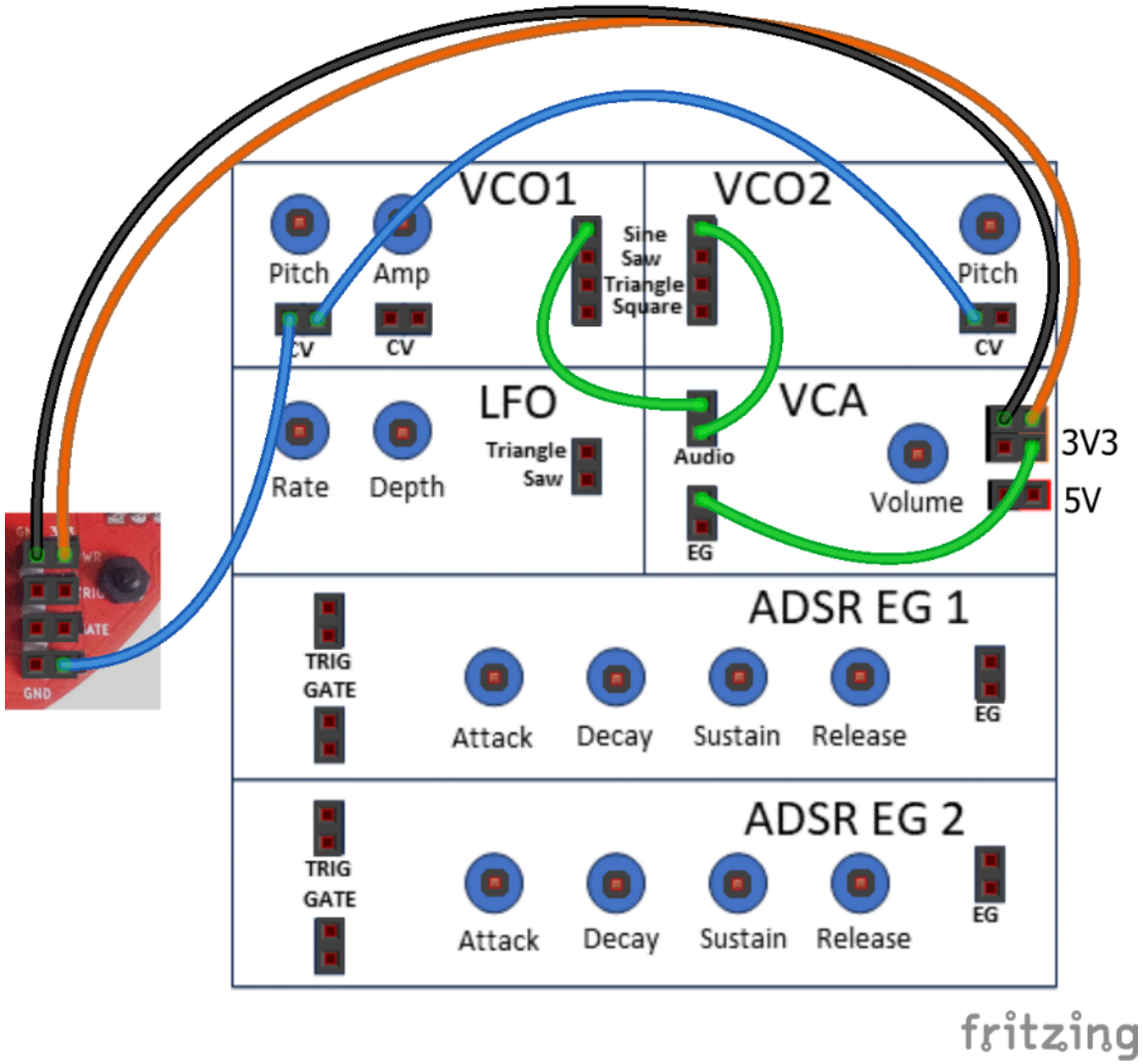


1. Simple Pitch Sequence



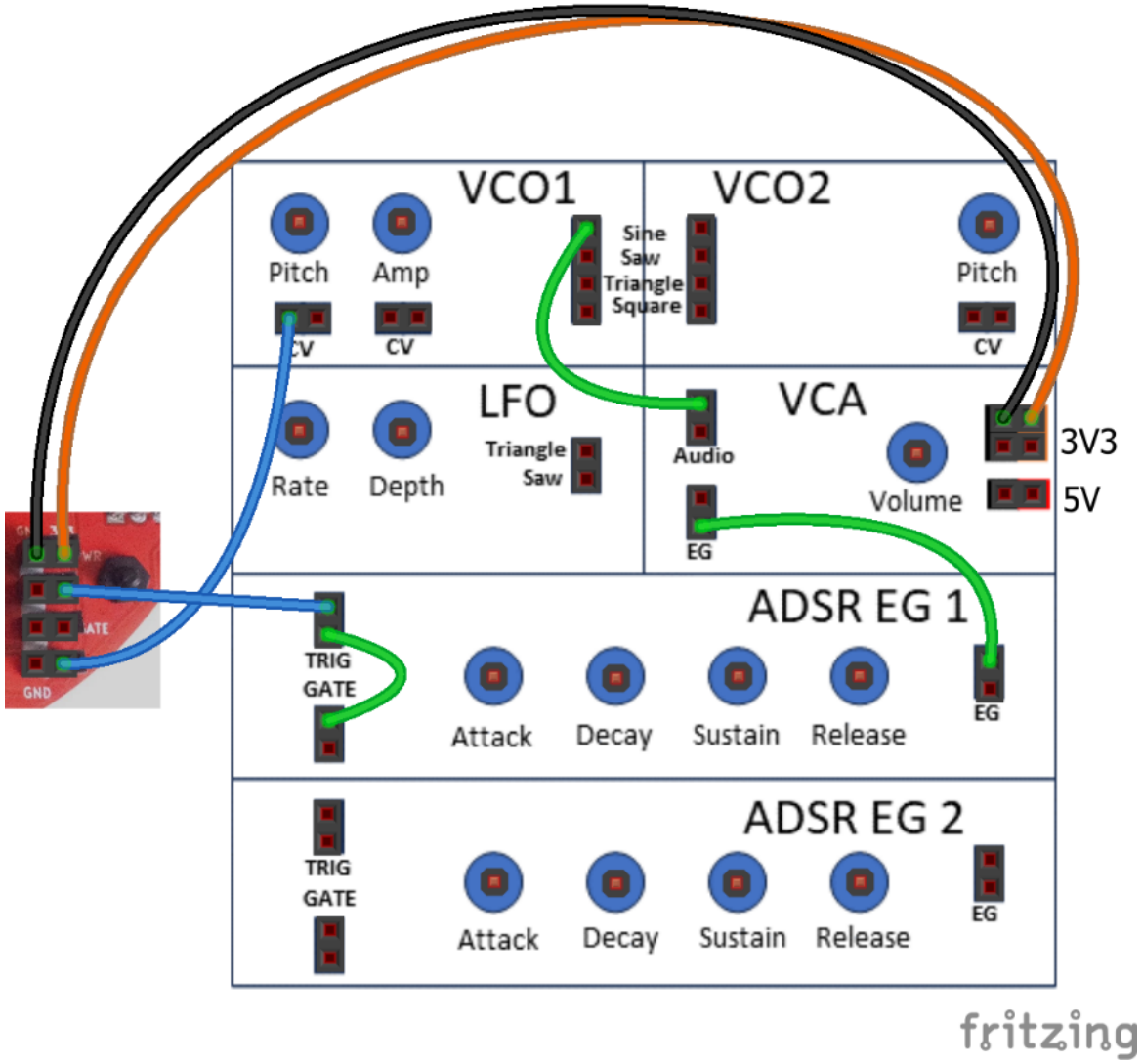
- VCA EG Fixed at 3V3.
- Start with:
  - Turn down VCO1 Pitch.
  - Turn up VCO1 Amp and VCA Volume.
  - Baby 8 Steps fully clockwise (8 steps).
  - Baby 8 Run/Stop -> Run (to the right).
- Experiment with:
  - All 8 Baby 8 step Pitch controls.
  - Baby 8 Tempo.
  - Baby 8 Number of Steps.
  - Baby 8 Run/Stop.

2. Dual Pitch Sequence



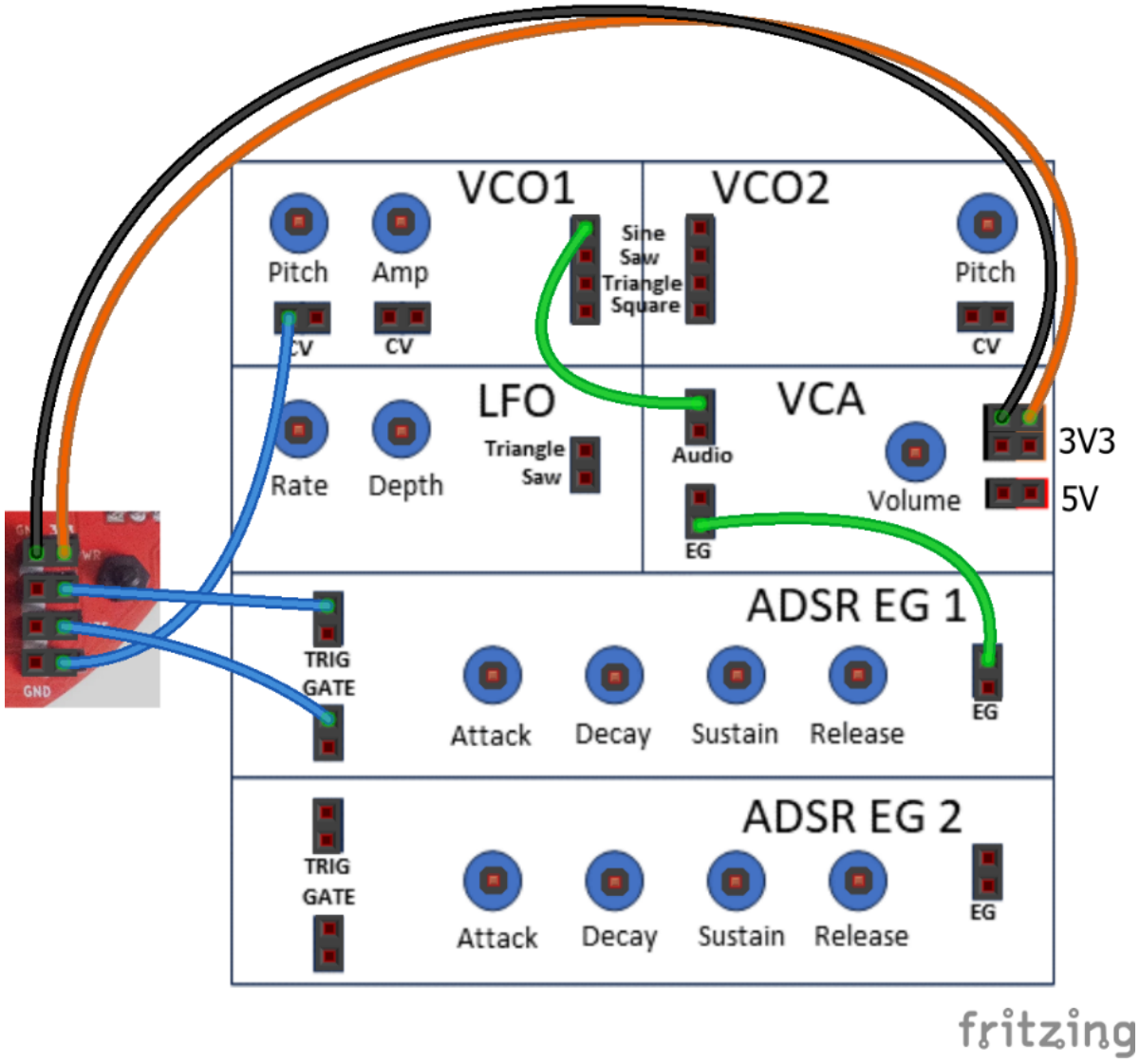
- Both VCOs connected.
- Start with:
  - VCO Pitch controls turned right down.
  - VCO1 Amp and VCA Volume right up.
  - Baby 8 steps fully clockwise (8 steps).
  - Baby 8 Run/Stop -> Run (to the right).
- Experiment with:
  - Detune VCO2.
  - Different Waveforms.
  - Different Pitch controls.
  - Adjust the sequence.

3. Baby 8 Trigger



- More useful Baby 8 EG Option
- Start with:
  - VCO1 Pitch right down.
  - VCO1 Amp and VCA Volume right up.
  - A: almost full anti-clockwise.
  - D: almost full anti-clockwise.
  - S: fully clockwise.
  - R: in the middle.
  - Baby 8 slow Tempo (anti-clockwise).
- Experiment with:
  - Adjust ADSR settings.
  - Baby 8 mute switches.
  - Baby 8 Tempo.

4. Baby 8 Trigger and Gate

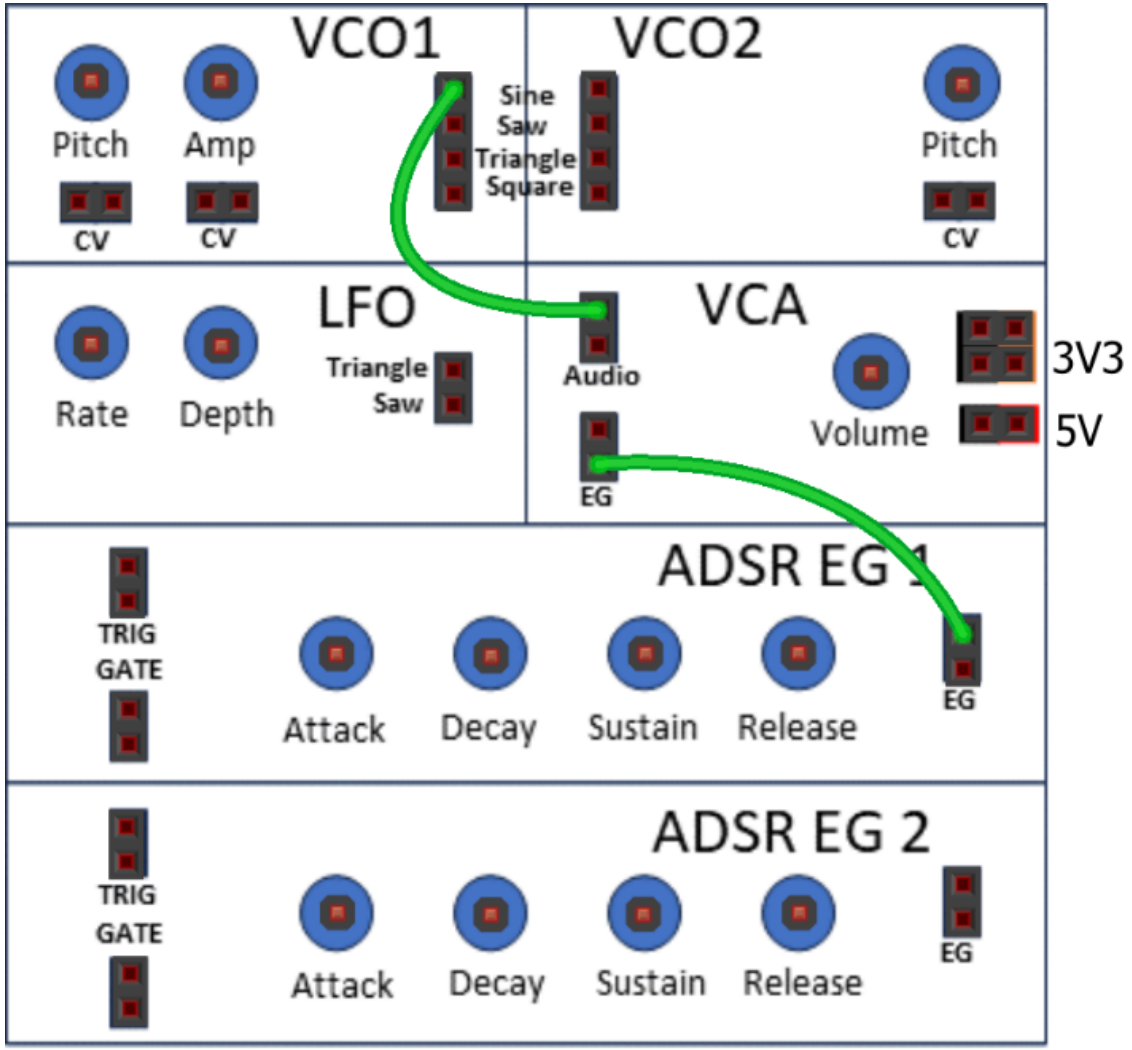


- The less useful (more complex) option!
- Start – as previous experiment.
- Try muting steps 2, 4, 6 and 8.
- Experiment with ADSR settings.

MIDI


3.5mm
STEREO
AUDIO OUT
3.5mm
TRS Type A
MIDI IN
7-12V
DC IN
LINE OUT
MIDI IN
DC 7–12V
CEN +VE
PITCH
AMP
VCO 1
VCO 2
ESP32
EduMod
Hack
Thing
PITCH
LFO
VCA
RATE
DEPTH
AUDIO
IN
EG
CV
LINE OUT
VOLUME
3V3
5V
EG 1
TRIGGER
GATE
ATTACK
DELAY
SUSTAIN
RELEASE
EG 1
OUT
EG 2
TRIGGER
GATE
ATTACK
DELAY
SUSTAIN
RELEASE
EG 2
OUT

Basic MIDI Patch



- MIDI Channel 1. Mapped to:
  - Both VCO Pitch CVs.
  - Both EG TRIG and GATE.
- Start with:
  - VCO1 Pitch turned right down.
  - VCO1 Amp and VCA Volume turned right up.
  - EG1: Short A, Short D, High S, Medium R.
- Experiment with:
  - Pitch range available through MIDI.
  - Adding second VCO.
  - ADSR settings.
  - Adding LFO.
  - Adding second EG2.

Ch 4 – Oscilloscope Use

Oscilloscope Controls - Operation

DSO-152

Probe Connector

Menu Selector

Automatic Configuration

AUTO/ Normal/Single

USB-C Charger

RUN/STOP

On/Off

Oscilloscope Controls - Display

DSO-152

Left/Right

Selected “Active” item is highlighted in blue.

Up/Down cursor keys adjust setting.

Zero Line

Trigger Level

V/Div
Vertical Scale

Probe X1/X10

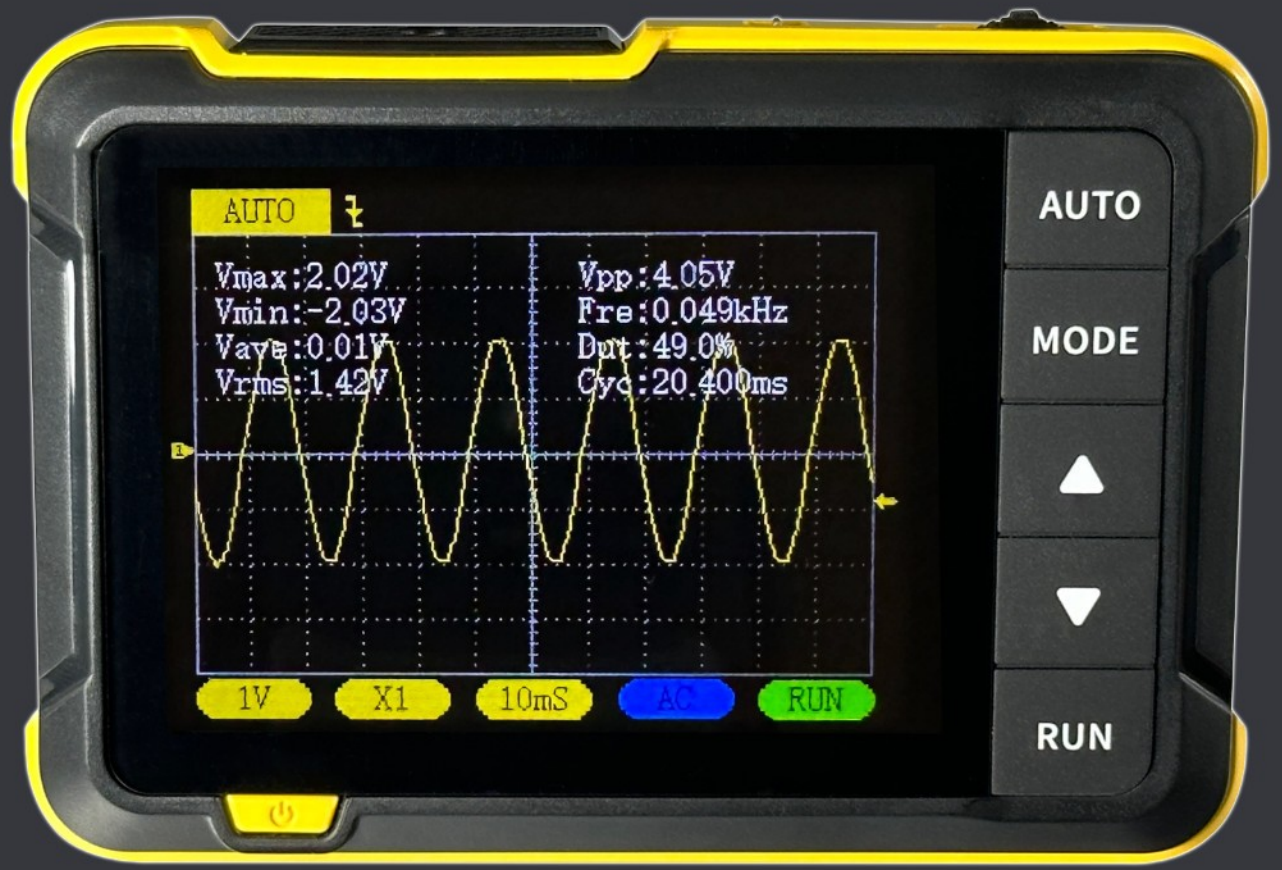
Timebase
Horizontal Scale

AC/DC Coupling

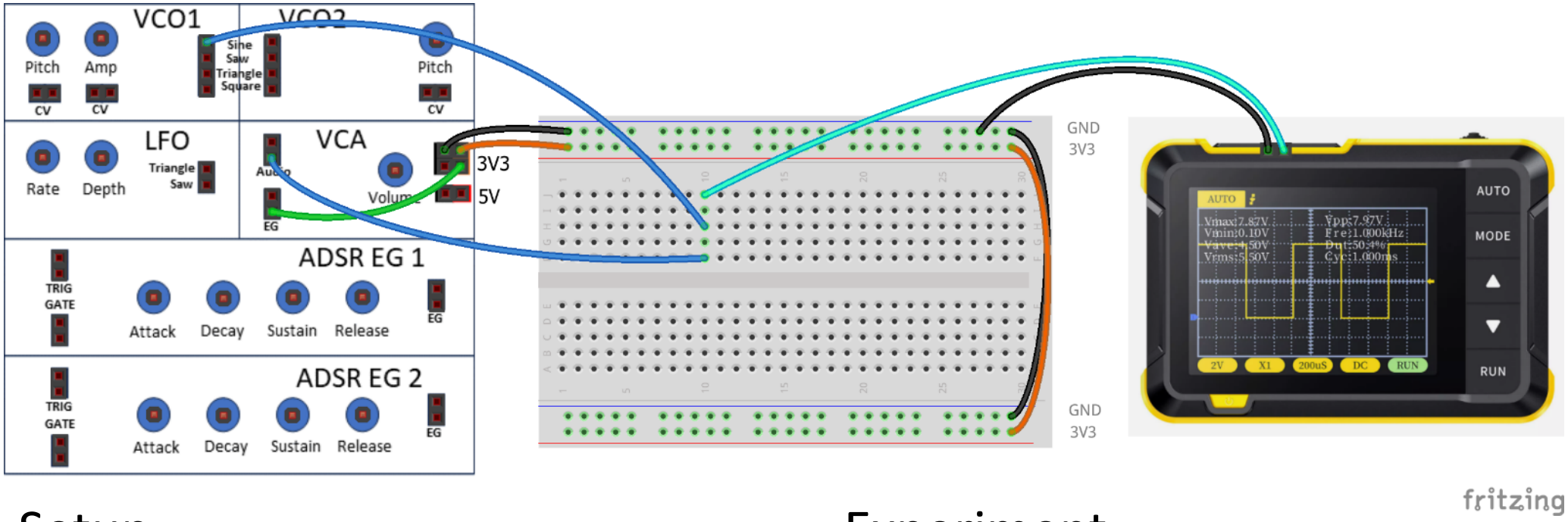
KEY FUNCTION

BUTTON	OPERATION	FUNCTION
	Short press	Control parameters function selection
	Short press	Exit auto calibration (Auto calibration page)
	Long press	Enter the automatic calibration page
	Short press	Control parameters function selection
AUTO	Short press	Automatic adjustment (frequency below 45Hz cannot be calibrated correctly)
MODE	Short press	AUTO/Single/Normal switching
	Long press	Rising edge/falling edge switching

BUTTON	OPERATION	FUNCTION
▲	Short press	Parameter addition adjustment
▼	Short press	Parameter subtraction adjustment
RUN	Short press	Run/pause waveforms (other pages) Enter auto calibration (Auto calibration page)
	Long press	Show/close detailed parameters
⏻	Short press	On
	Long press	OFF



1. Oscilloscope and Breadboard



Setup:

- VCO1 Amp and VCA Amp turned fully clockwise.
- VCO1 Pitch half-way.
- Press “AUTO” on the oscilloscope.

Experiment:

- Try all four waveform outputs.
- Switch back to Sine.

2. Oscilloscope Detailed Parameters

DSO-152

Setup

- Same circuit as before
- Push and hold “RUN” for detailed parameters.

Experiment

- Change VCO1 Pitch – watch Freq value
- Change VCO1 Amp – watch Vmax and Vpp values.

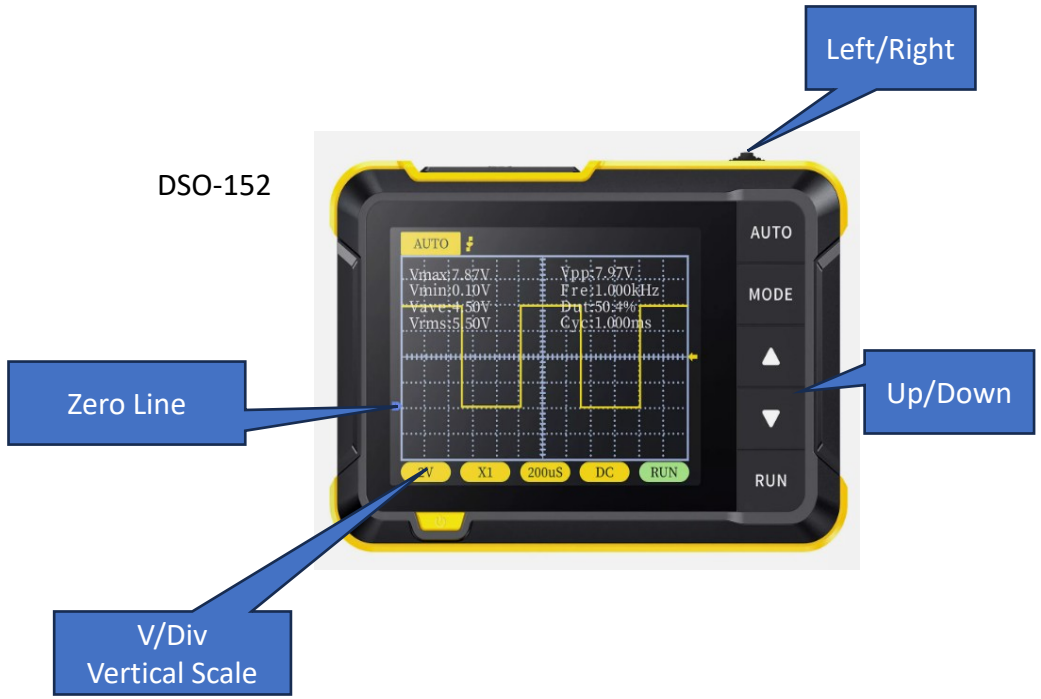
3. Oscilloscope Horizonal Scale

DSO-152

Use same circuit as before.

- Try to set the pitch to close to 440Hz.
- Use the left/right and up/down buttons to select 2mS as the timebase.
- Observe how each wave pattern is close to being a single box wide.
- Experiment with different timebase settings and see how the display changes.

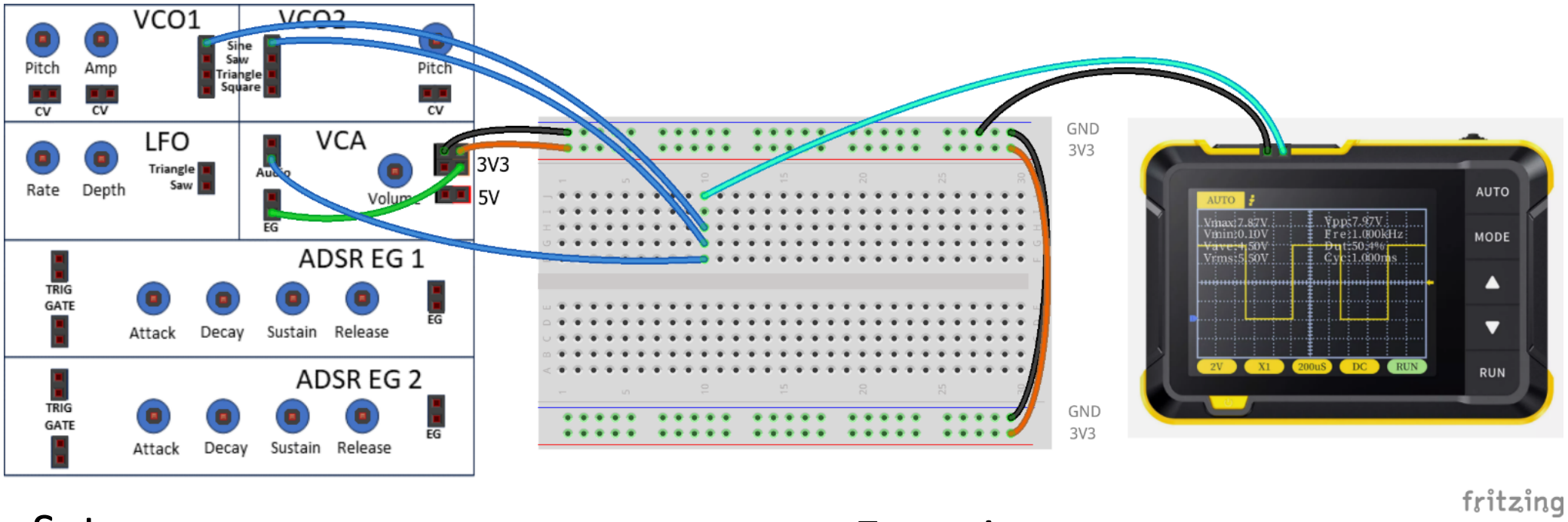
4. Oscilloscope Vertical Scale



Use same circuit as before.

- VCO1 Amp fully clockwise.
- Use the left/right and up/down buttons to select 1V.
- Observe how the waveform should now span around two and a half boxes on the display.
- Adjust V/Div to 500mV – it is now possible the top of the wave is off the top of the display!
- Use the left/right and up/down buttons to select the “zero line” and move it downwards.
- Experiment with the VCO1 Amp control to change the level.

5. Dual Oscillators and Oscilloscope



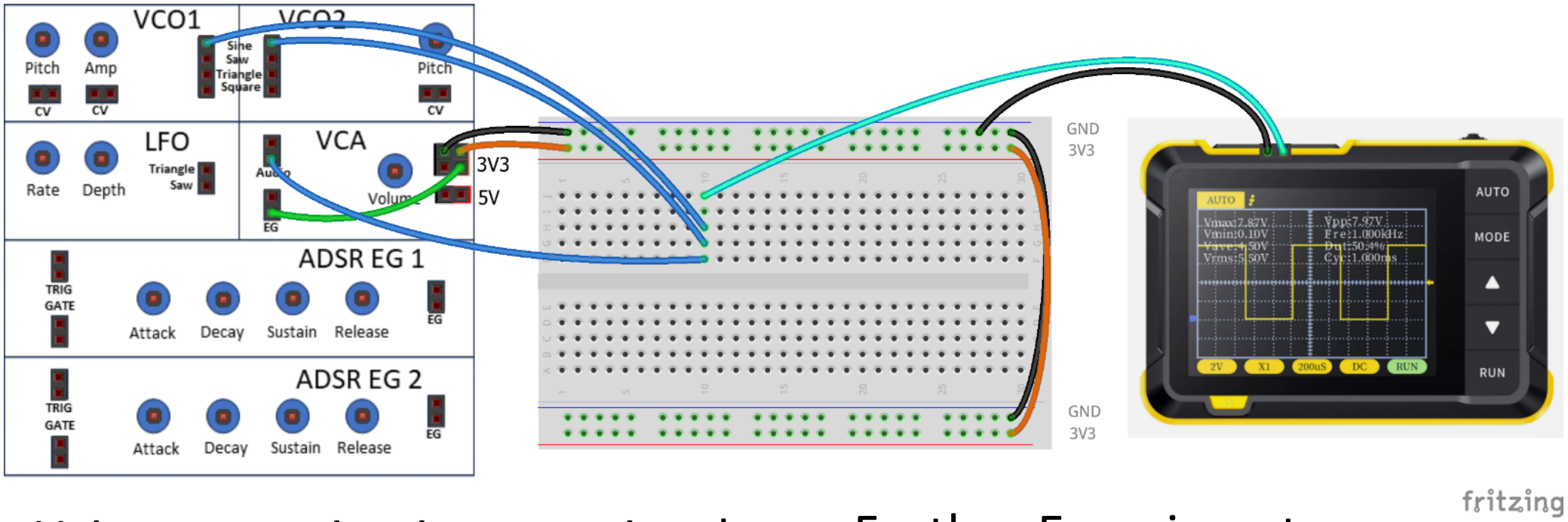
Setup:

- VCA Amp turned fully clockwise.
- VCO1 Amp fully anticlockwise (off).
- VCO1 and VCO2 Pitch half-way.
- Use both Sine outputs.

Experiment:

- Slowly increase VCO1 Amp.
- Tune both VCOs to same Pitch.
- Watch how the waveform slowly changes.

6. Dual Oscillators – Complex Waveforms



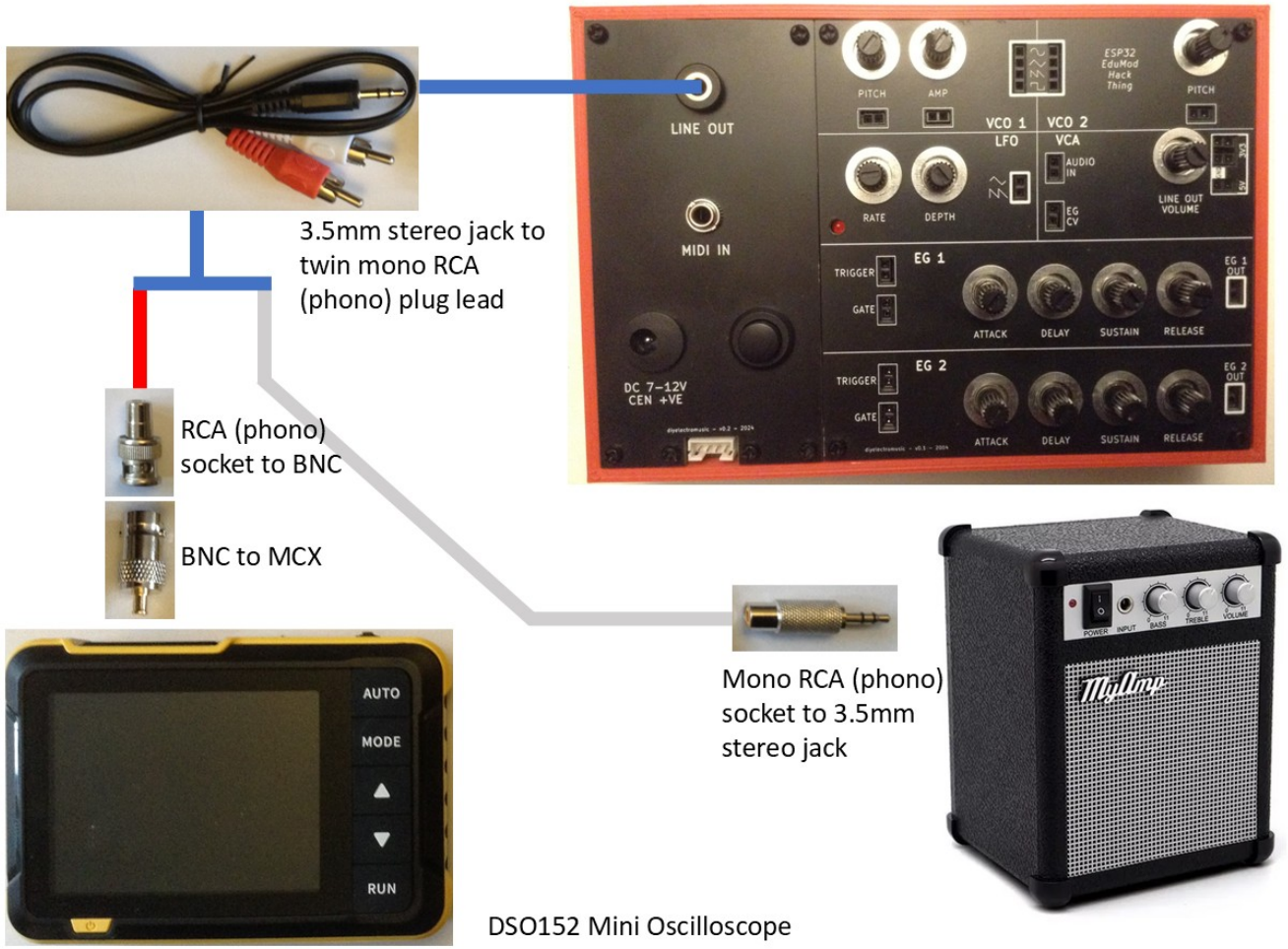
Using same circuit as previously

- Adjust VCO2 to be just below VCO1
- Set VCO2 to be almost the same as VCO1
- Set VCO2 to be just above VCO1.

Further Experiments

- Tune VCO1 and VCO2 to be one octave apart.
- Experiment with different intervals.
- Experiment with different waveforms.

7. Oscilloscope and Audio Output



The oscilloscope can be patched into the Audio output (line out) path from the Synth Thing to an amp as shown here.

This is using a jack-to-phono “splitter” cable and various adaptors.

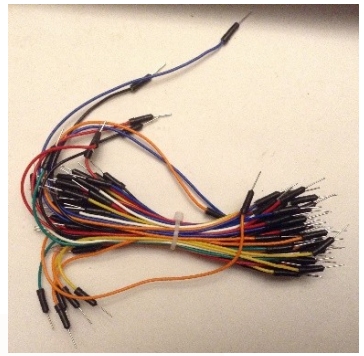
The oscilloscope can now be used to capture the final output of the Synth Thing – including the use of envelopes or any external circuitry - which will be useful later!

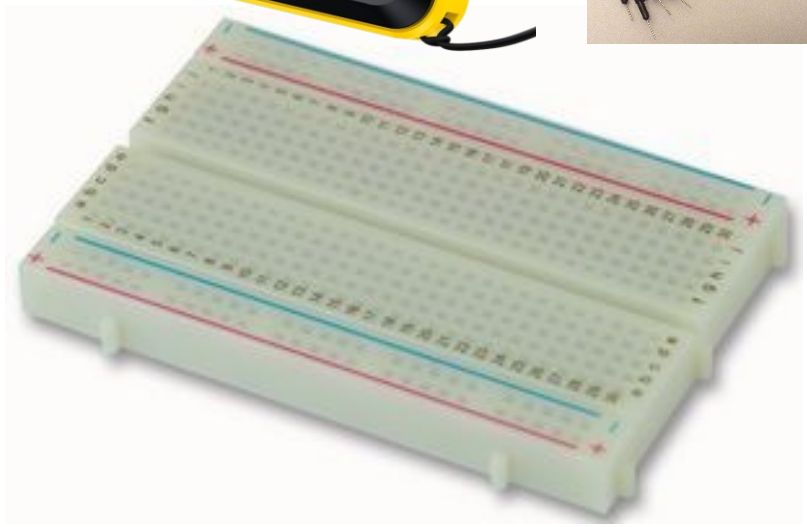
Ch 5 - External Passive Circuits

Basic Set-up

3.5mm
STEREO
AUDIO OUT

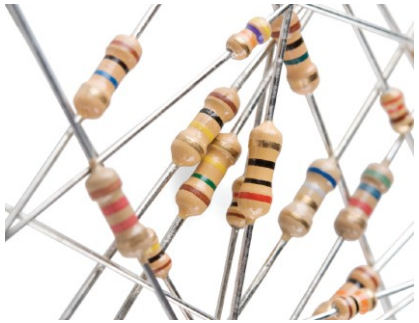
7-12V
DC IN

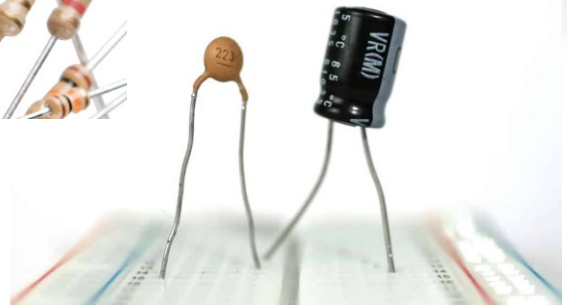




Components

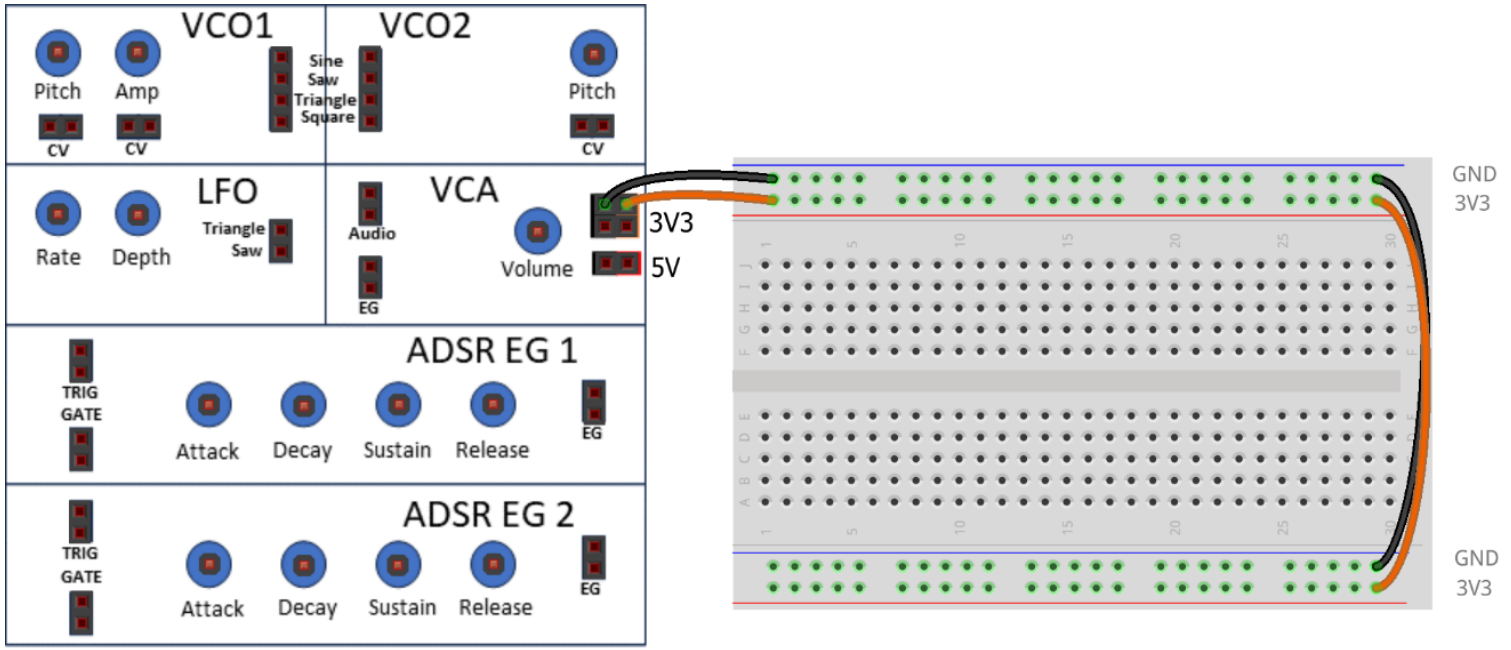
- Resistors
- Potentiometers
- Capacitors
- LEDS



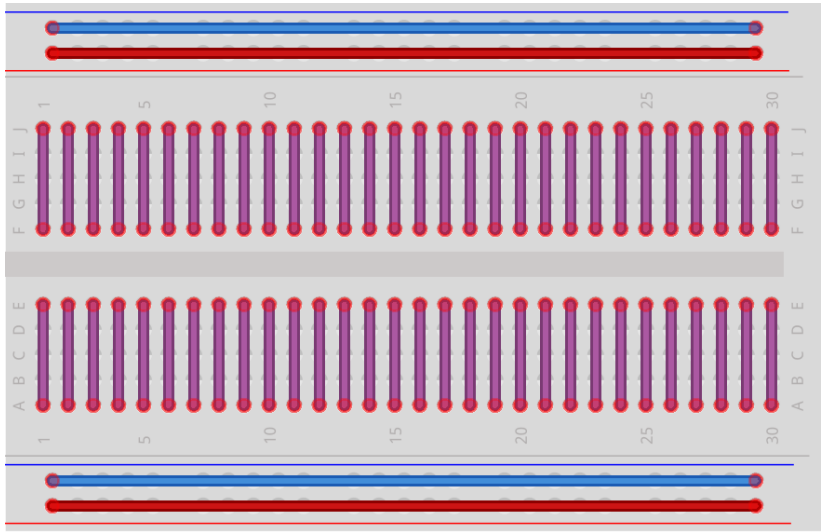


- Two-way “thumb” joystick.
- Light-dependant resistor (LDR).
- Force sensitive resistor (FSR).

Basic Connections



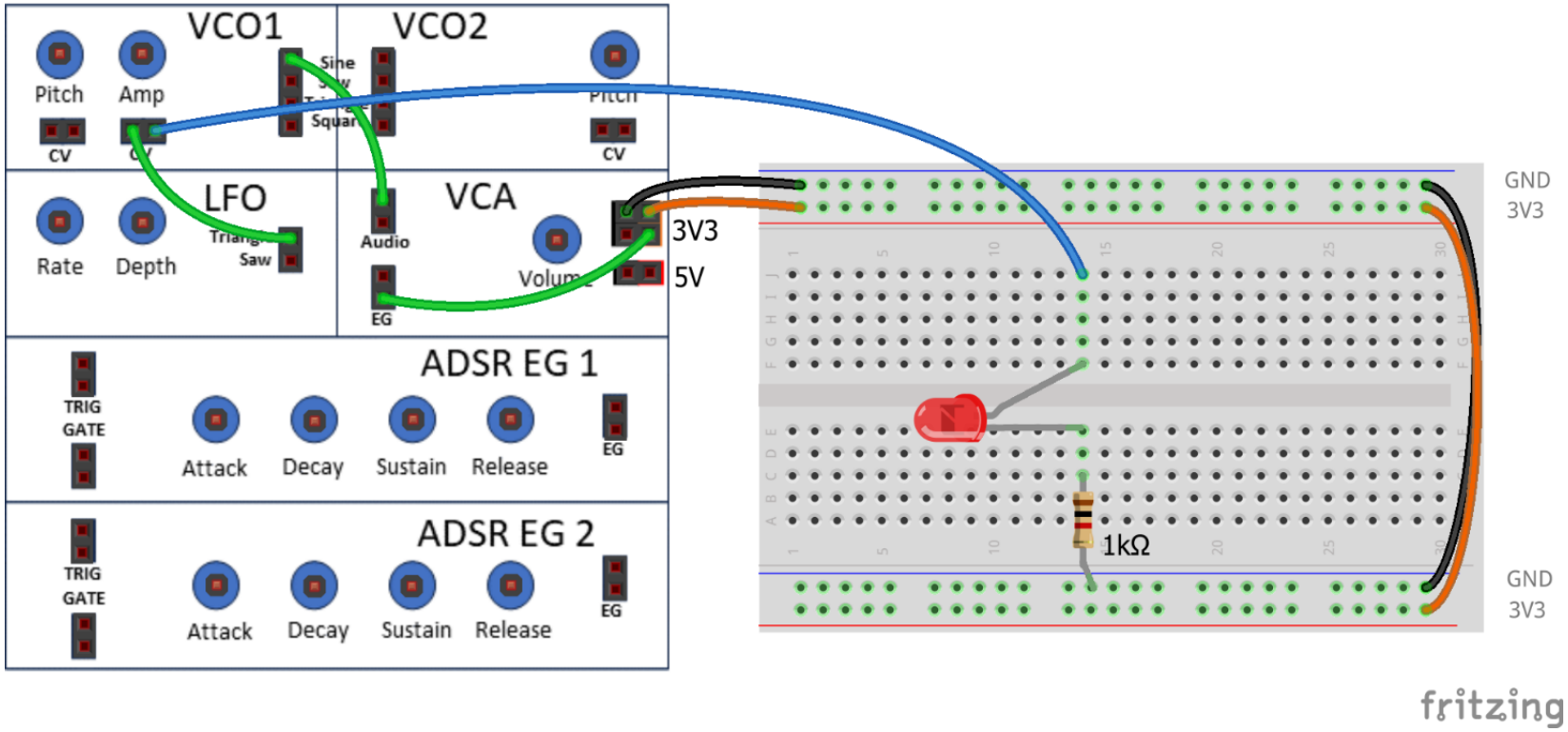
- GND and 3V3
- Use “power rails”



- Green – internal connections between patch points on the Synth Thing.
- Blue – external connections between the Synth Thing and the breadboard.
- Black – GND connections.
- Orange – 3V3 connections.
- Red – 5V connections.
- Other Colours – other connections on the breadboard as required.

Accessories and Indicators

1. LED Indicator

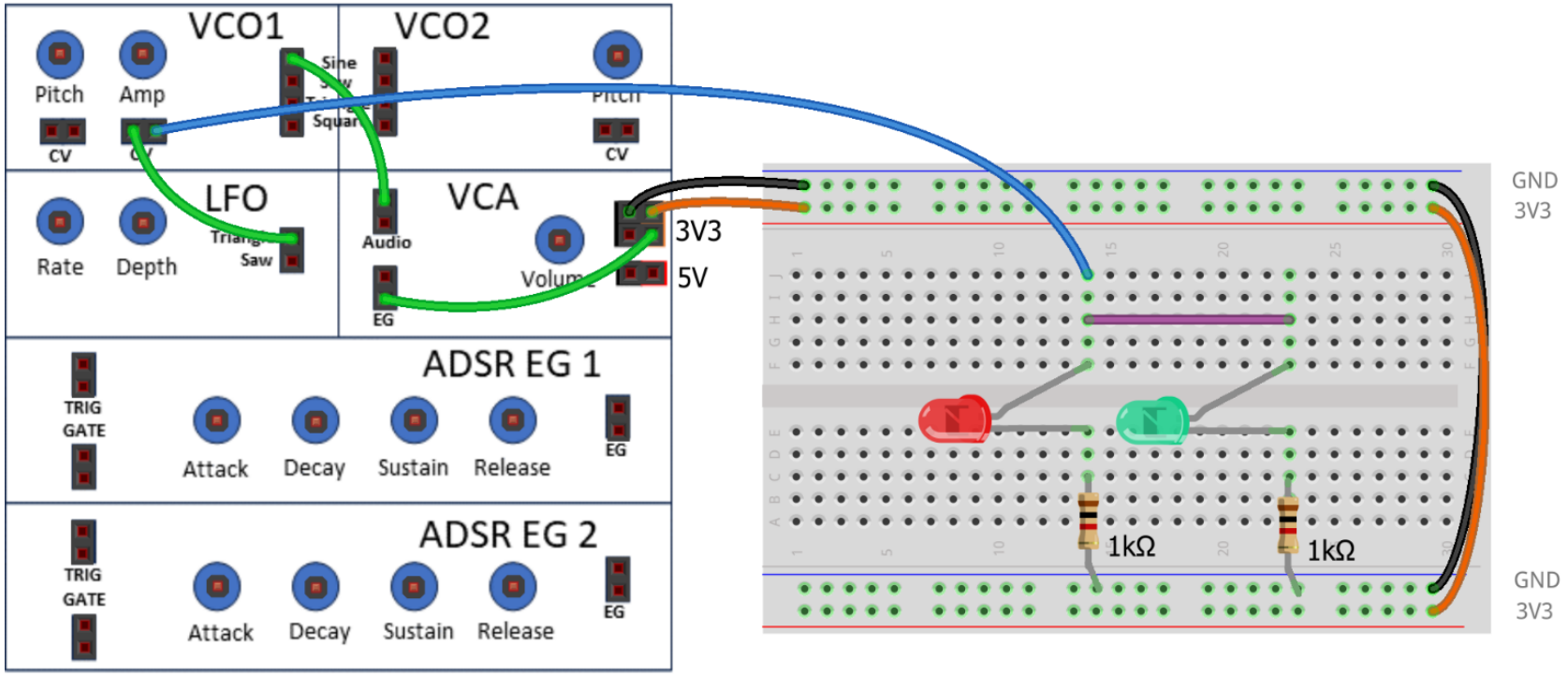


- Experiment with:
  - LFO Rate
  - LFO Depth
  - LFO Waveform
- Contrast fast rate with very slow rate.

Setup

- VCO1 Amp fully anti-clockwise (“off”).
- VCO1 Pitch half-way.
- LFO Depth half-way.
- LFO Rate fully anti-clockwise (“slow”).

2. Dual LED Indicator

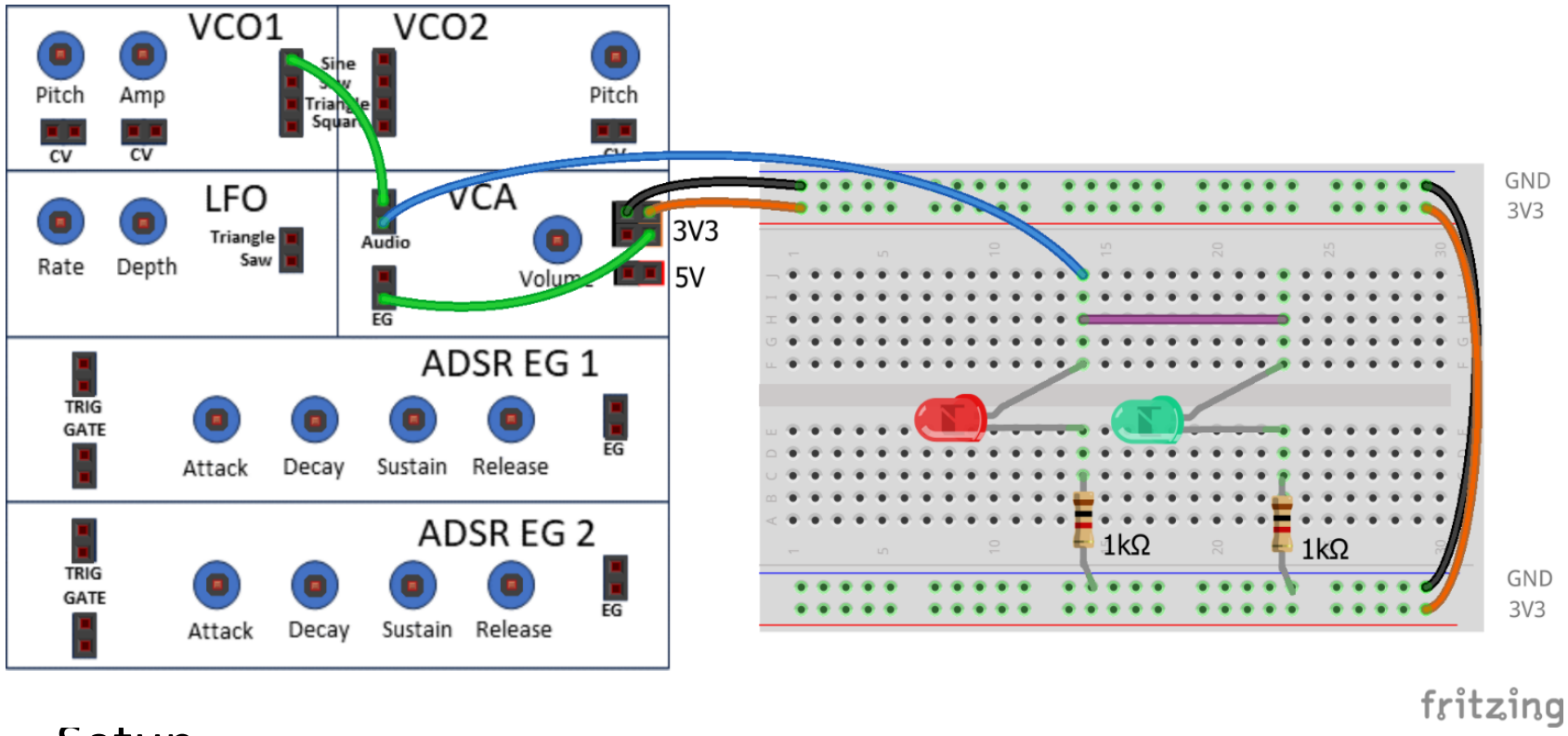


- Slowly increase LFO depth.
- Which LED comes on first?
- Which LED goes off first?
- Can you find a Depth where just one of the LEDs comes on?
- If you have an oscilloscope connected, then measure the voltages at which each LED comes on.

Setup

- VCO1 Amp fully anti-clockwise (“off”).
- VCO1 Pitch half-way.
- LFO Depth fully anti-clockwise (“off”).
- LFO Rate almost fully anti-clockwise (“slow”).

3. Audio Level Meter

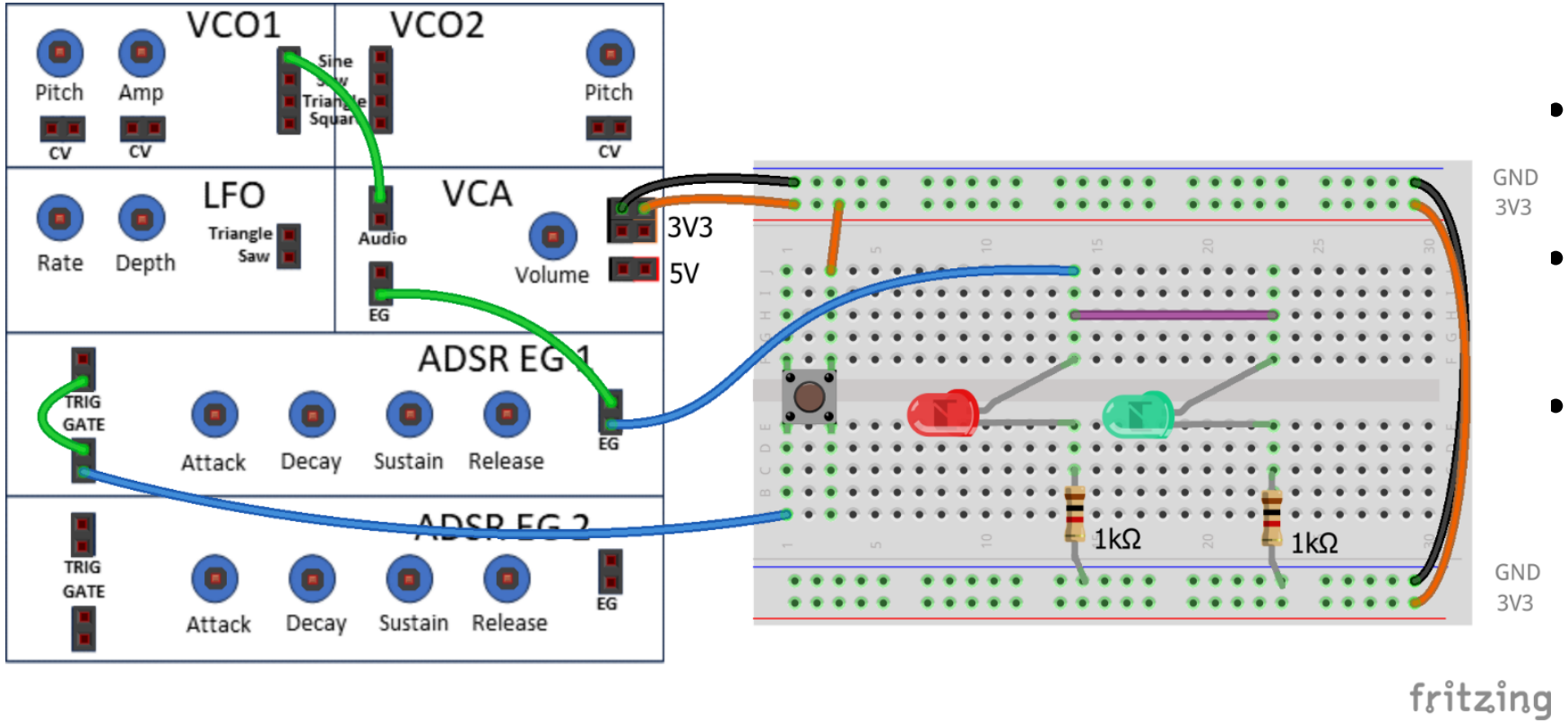


- Slowing increase VCO1 Amp until one LED lights up.
- Increase it further until both LEDs light up.
- Experiment with:
  - VCO1 Pitch.
  - VCO1 Waveform.

Setup

- VCA Volume fully clockwise.
- VCO1 Amp fully anticlockwise.
- VCO1 Pitch half-way.

4. Audio Level Meter with EG



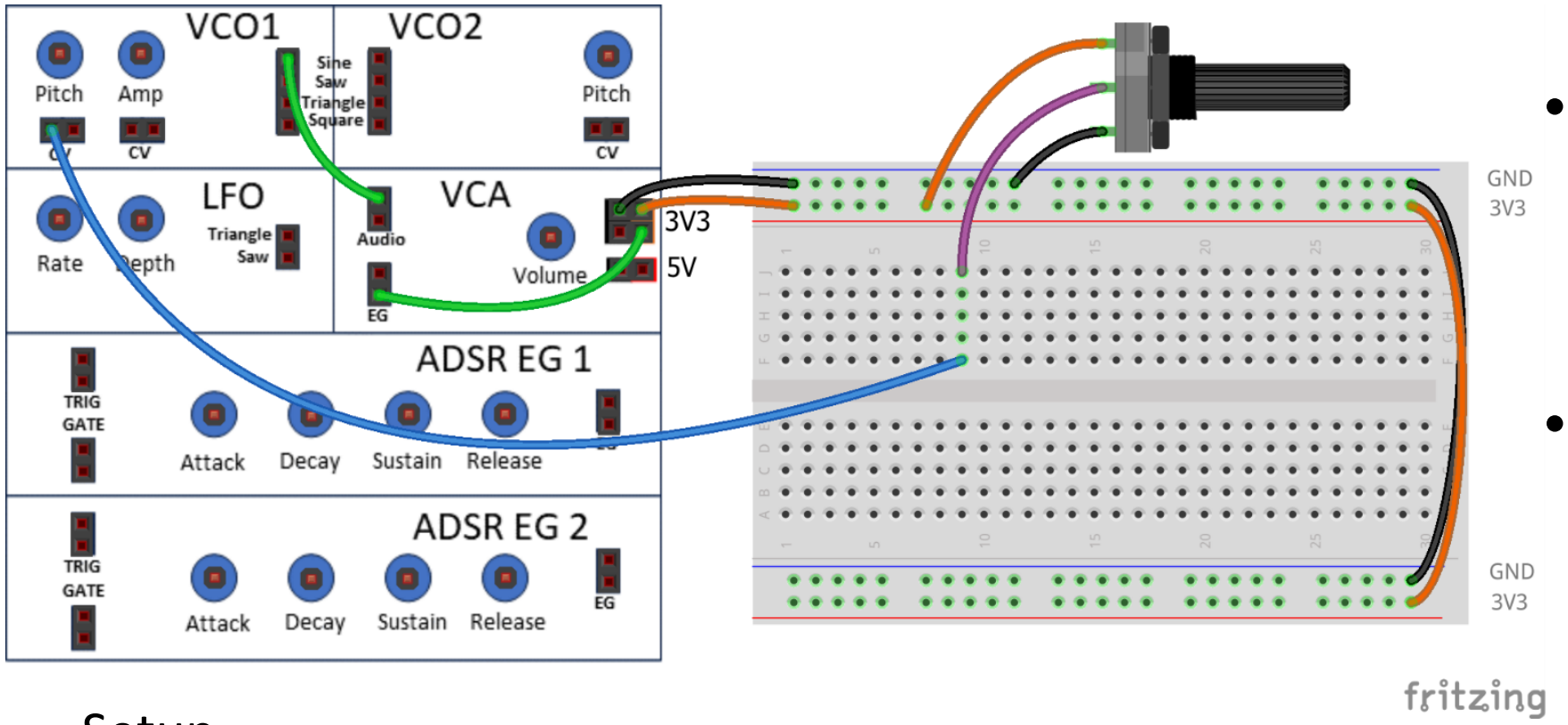
- Trigger the envelope with the button.
- Experiment with EG1 Sustain level.
- Can you make both LEDs come on at the start, but then leave just one on until the button is released?

Setup

- VCO1 Amp and VCA Volume fully clockwise.
- VCO1 Pitch half-way.
- ADSR EG1 as follows: Attack – almost fully anticlockwise; Decay – almost fully anticlockwise; Sustain – fully clockwise; Release – half-way.

Sensor Voltage Controllers

1. Potentiometer Control

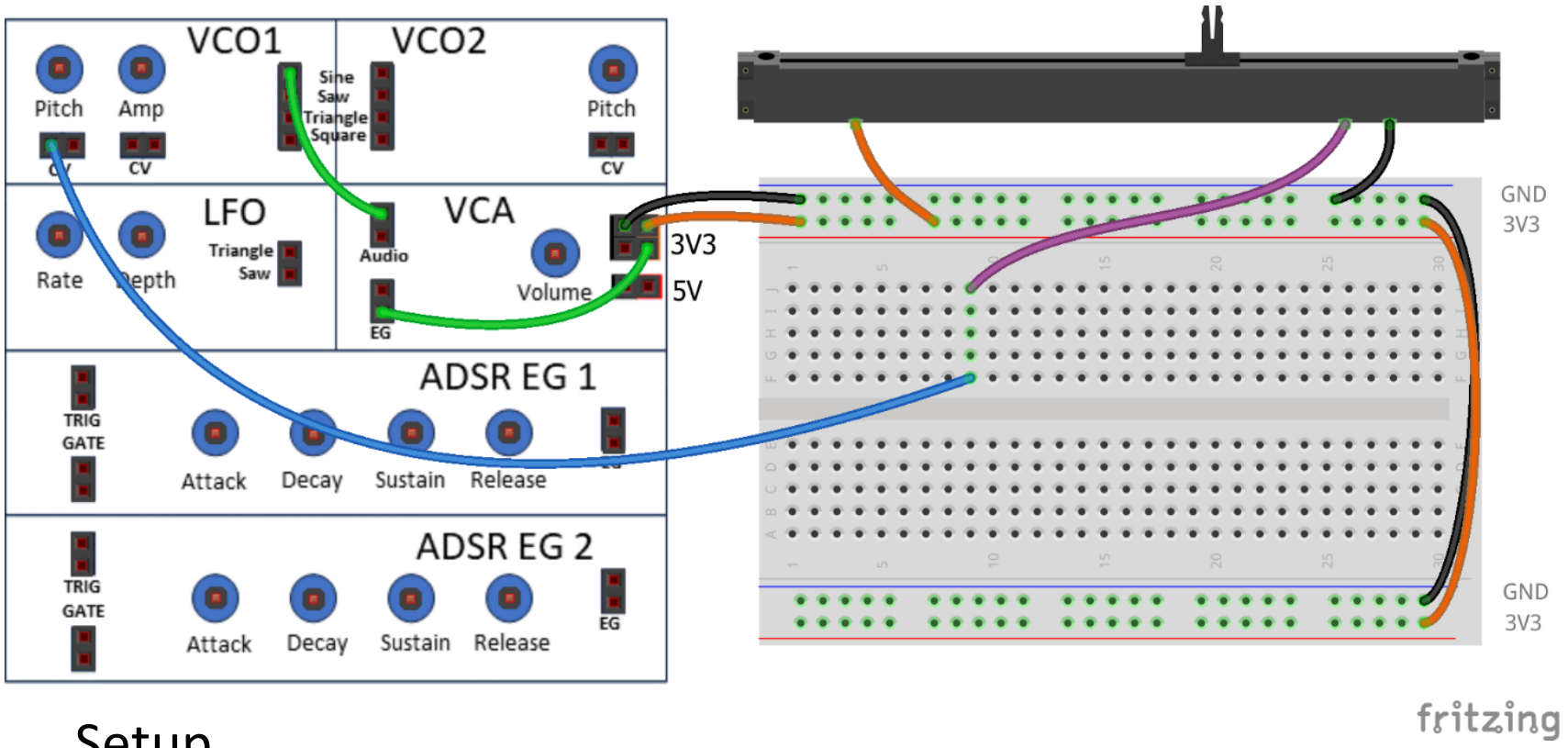


- Experiment with:
  - VCO1 Pitch
  - Pot Control
- Notice how the two add to each other…

Setup

- Pot between 3V3 and GND.
- VCO1 Amp and VCA Vol fully clockwise.

2. Linear Potentiometer Control

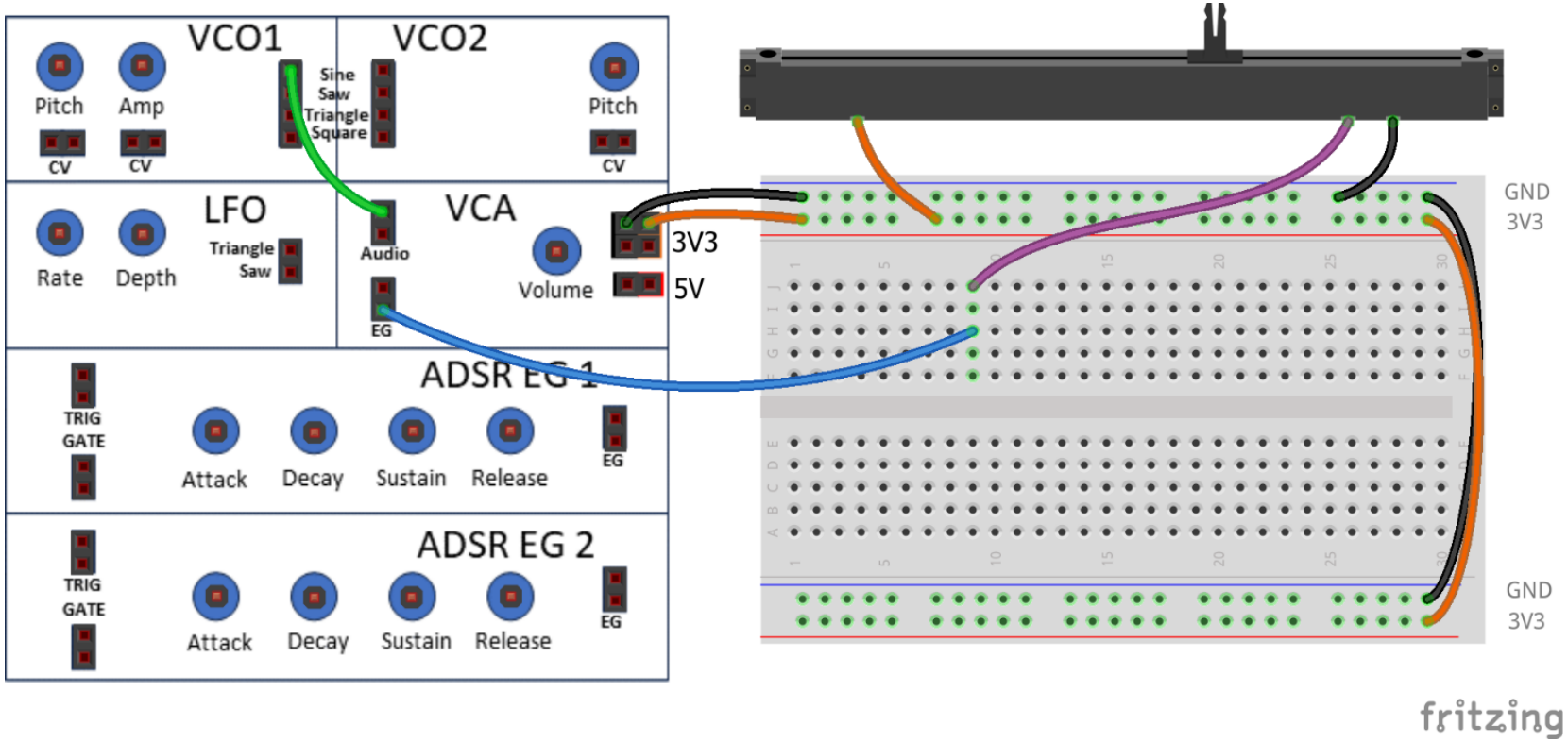


- Experiment with:
  - VCO1 Pitch
  - Linear Pot Control
- Notice how the two add to each other…

Setup

- Pot between 3V3 and GND.
- VCO1 Amp and VCA Vol fully clockwise.

3. Linear Potentiometer Volume Fader

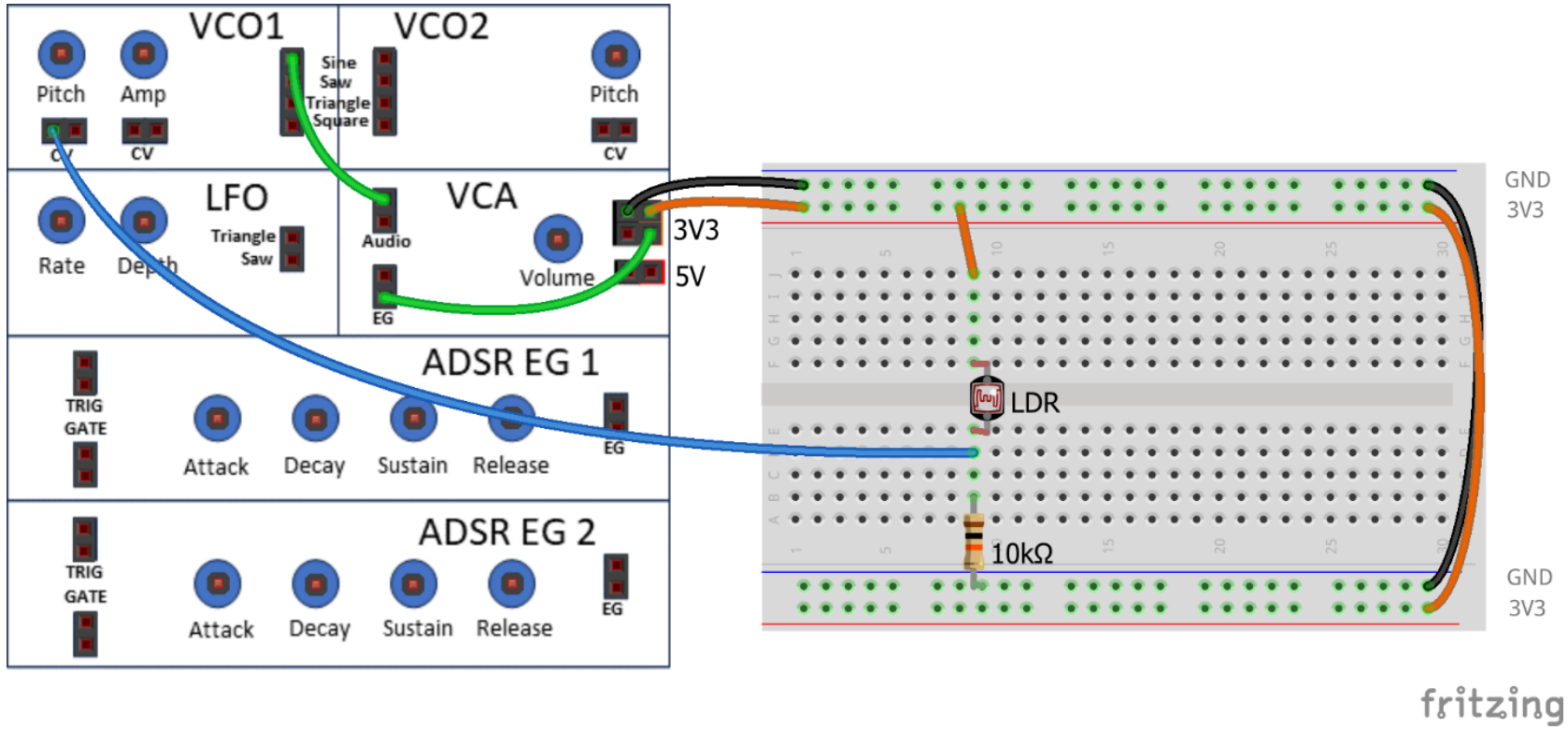


- Experiment with:
  - Linear Pot Control
- Now acts as a “master fader” for the Synth Thing.

Setup

- Pot between 3V3 and GND.
- VCO1 Amp and VCA Vol fully clockwise.

4. Light Dependant Resistor Control

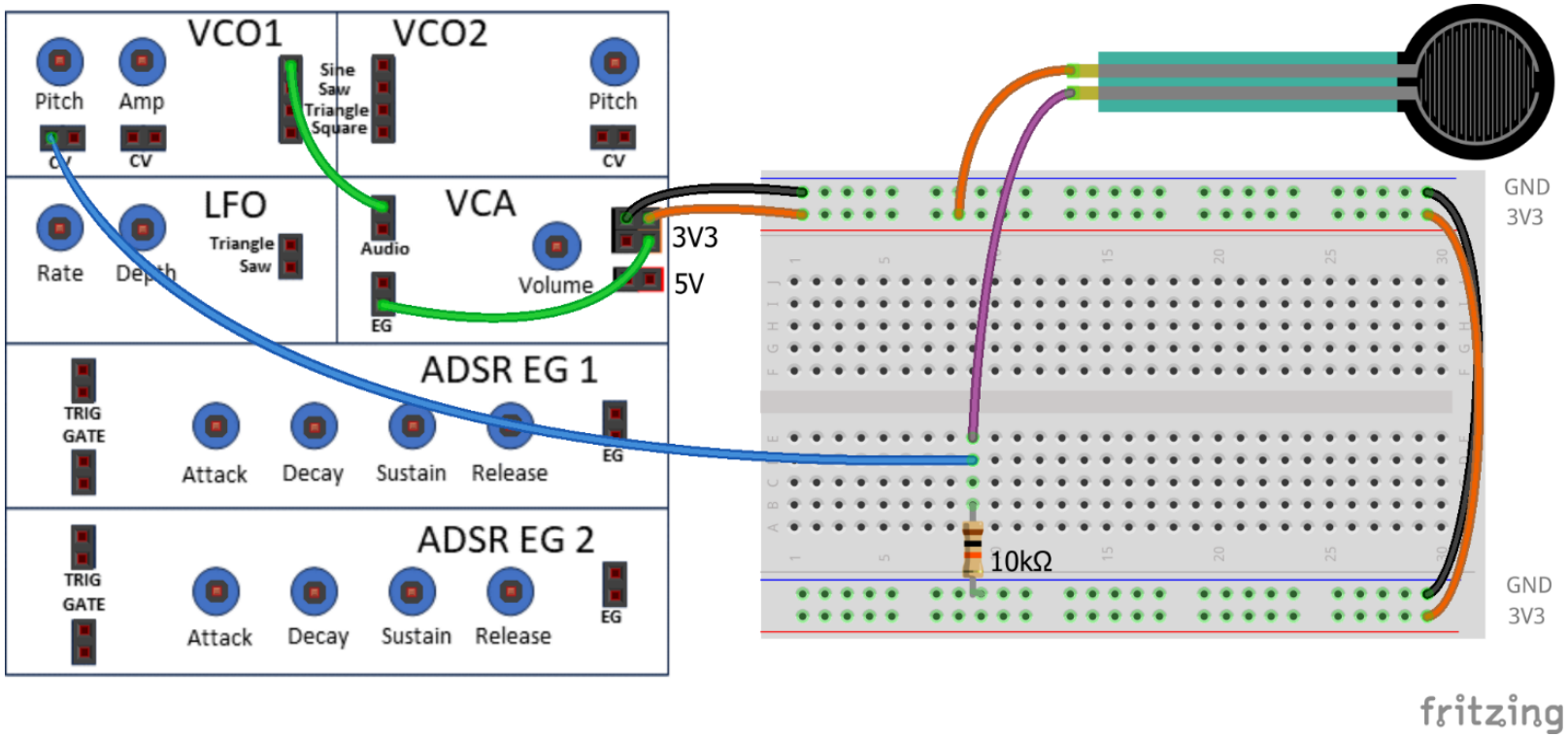


- Move hand over the LDR.
- Experiment with different positions from fully covered to fully open.
- This simulates an instrument called a “Theremin”.

Setup

- VCO1 Pitch half-way.
- VCO1 Amp and VCA Vol fully clockwise.

5. Force Sensitive Resistor Control

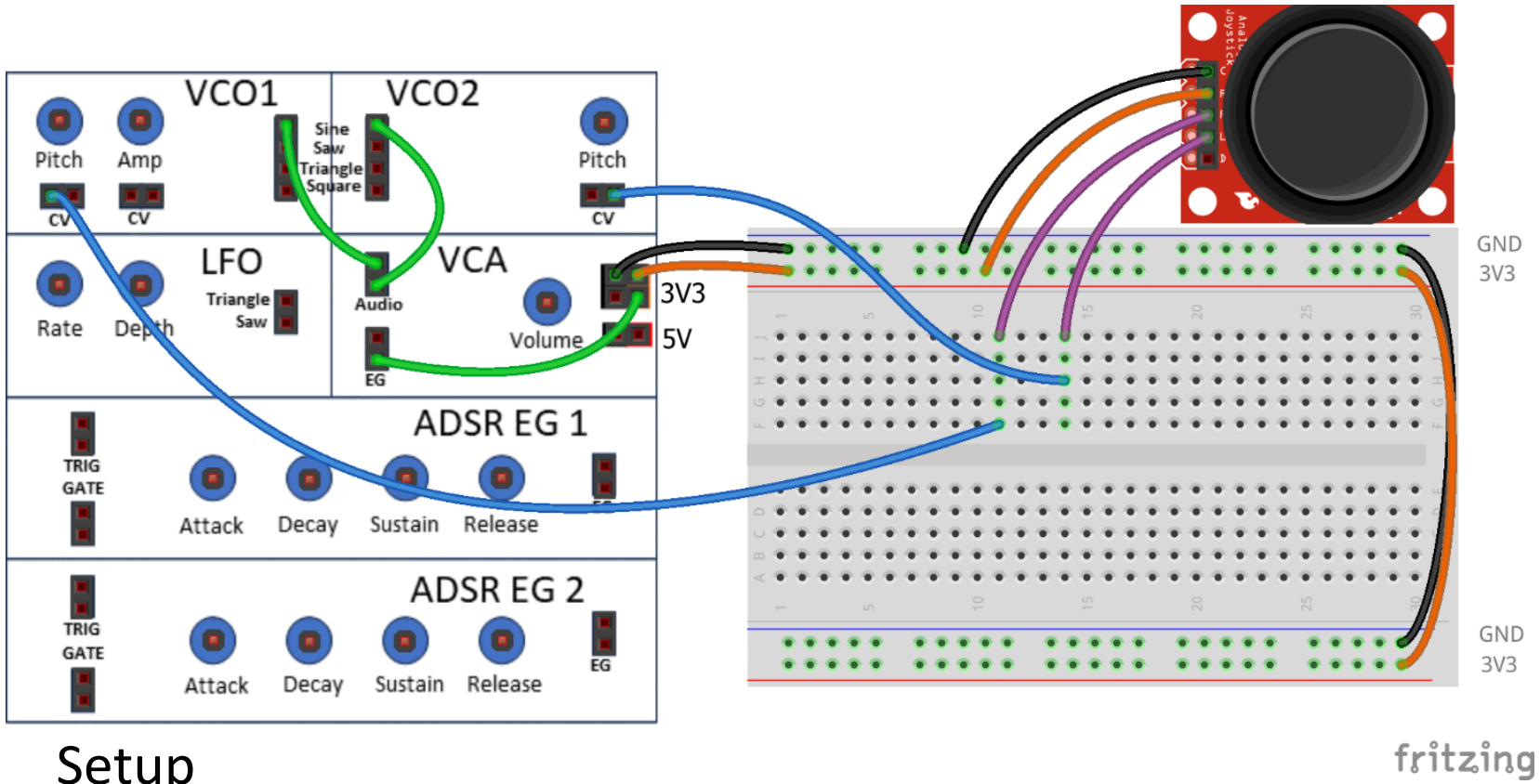


- Apply Pressure to the FSR…
- Now acts as a “pitch bend” for the Synth Thing.

Setup

- FSR between 3V3 and via 10KΩ resistor to GND.
- VCO1 Amp and VCA Vol fully clockwise.
- VCO1 Pitch half-way.

6. “Thumb” Joystick Control



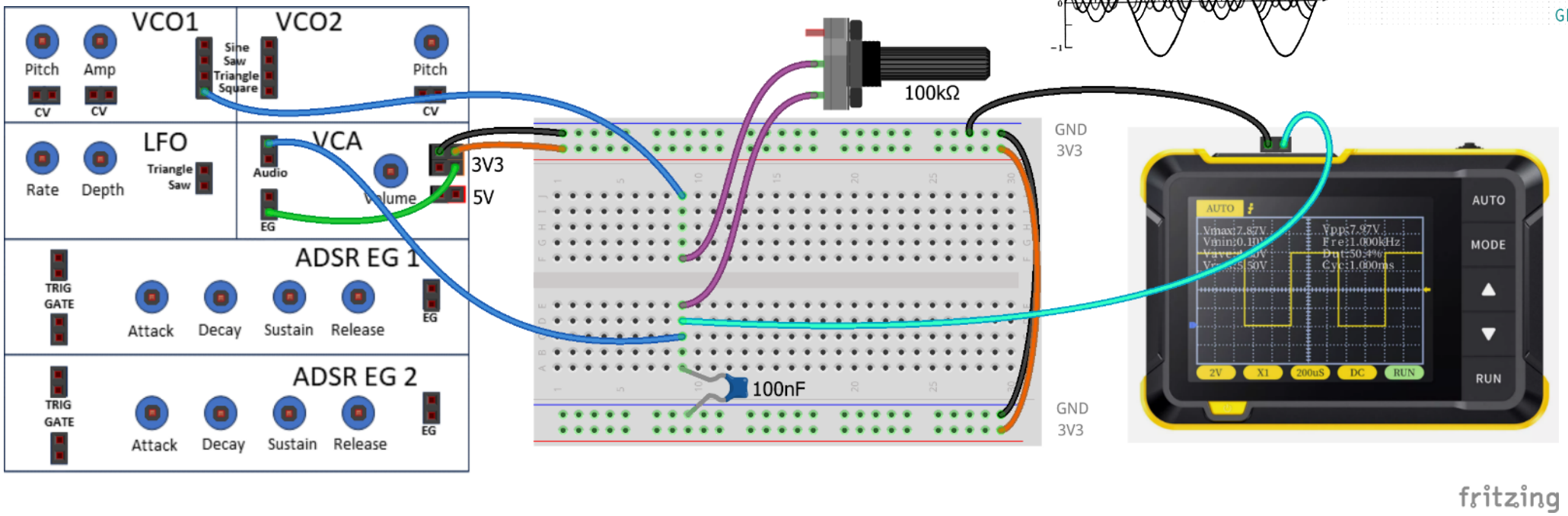
- Joystick is two potentiometers.
- Experiment with different directions.
- This now acts as a simple “dual pitch bend” for the Synth Thing.

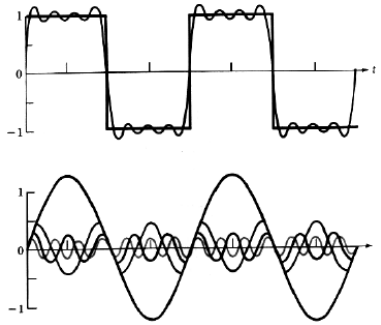
Setup

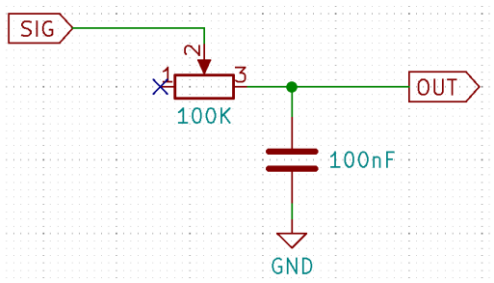
- “X” output to VCO1 CV, “Y” output to VCO2 CV.
- Double check wiring of the joystick module.
- VCO1 Amp and VCA Vol fully clockwise.
- VCO1 and VCO2 Pitch half-way.

Simple Passive Filters

1. Adjustable Low-pass Filter





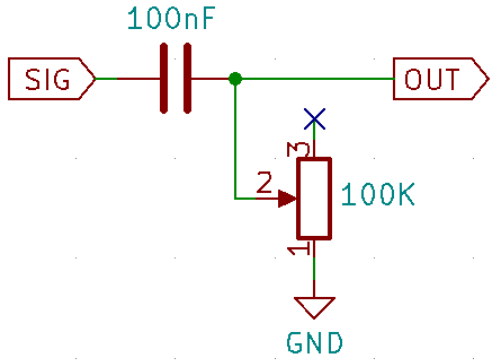


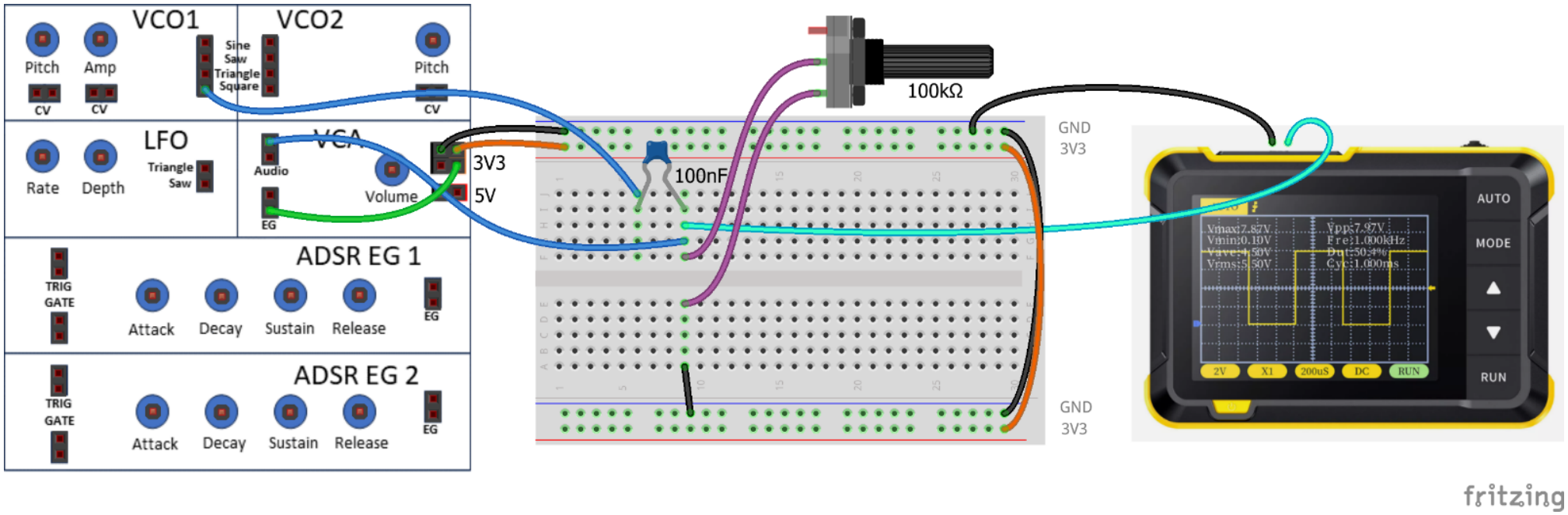
Setup

- VCO1 Amp and VCA Amp fully clockwise.
- VCO1 Pitch half-way.
- Use the VCO1 square wave output.

- Turn the external potentiometer either fully clockwise or fully anti-clockwise until a square wave can be seen on the oscilloscope.
- Gradually turn the external potentiometer and note what happens to the resulting waveform – both by listening and by looking at the oscilloscope.
- Repeat the experiment with the saw, triangle and sine waves in that order.

2. Adjustable High-pass Filter





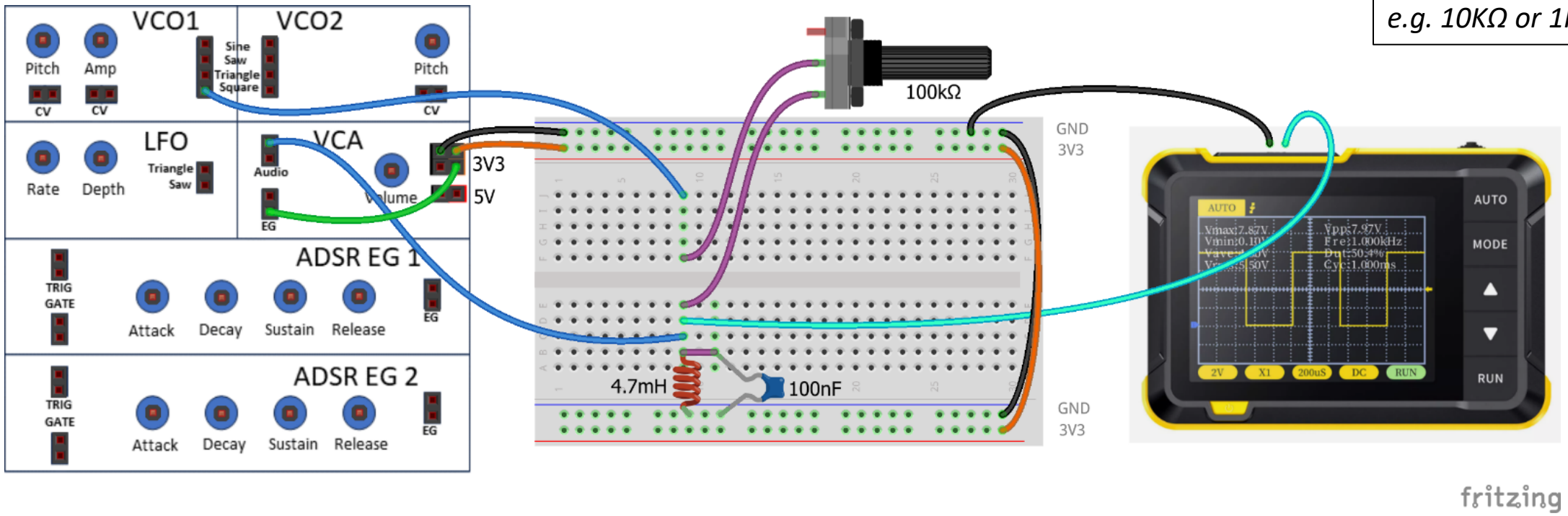
Setup

- VCO1 Amp and VCA Amp fully clockwise.
- VCO1 Pitch half-way.
- Use the VCO1 square wave output.

- Turn the external potentiometer either fully clockwise or fully anti-clockwise until a square wave can be seen on the oscilloscope.
- Gradually turn the external potentiometer and note what happens to the resulting waveform – both by listening and by looking at the oscilloscope.
- Repeat the experiment with the saw, triangle and sine waves in that order.

3. Low-pass Filter with Resonance

Use 4.7mH inductor or higher…
A lower value pot can help with the control too: e.g. 10KΩ or 1KΩ



Setup

- VCO1 Amp and VCA Amp fully clockwise.
- VCO1 Pitch half-way.
- Use the VCO1 square wave output.
- *This one is hard to hear – it really needs an oscilloscope to see the effect…*

- Turn the external potentiometer either fully clockwise or fully anti-clockwise until a square wave can be seen on the oscilloscope.
- Gradually turn the external potentiometer and note what happens to the resulting waveform – both by listening and by looking at the oscilloscope.
- Repeat the experiment with the saw, triangle and sine waves in that order.

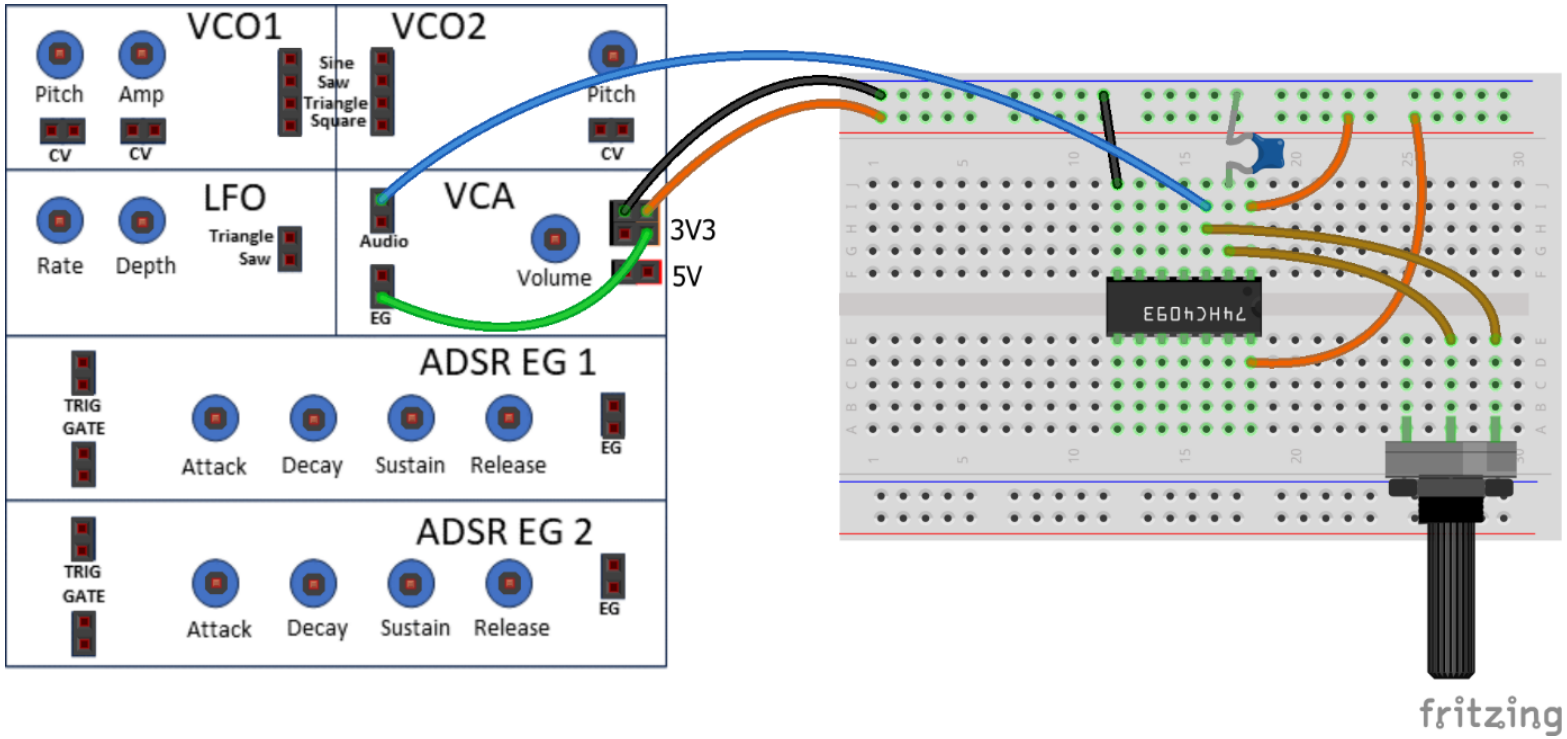
Ch 6 - External Active Circuits

Basic Set-up
Components
Basic Connections

All as per the previous chapter

Oscillators

1. NAND Schmitt Trigger Oscillator

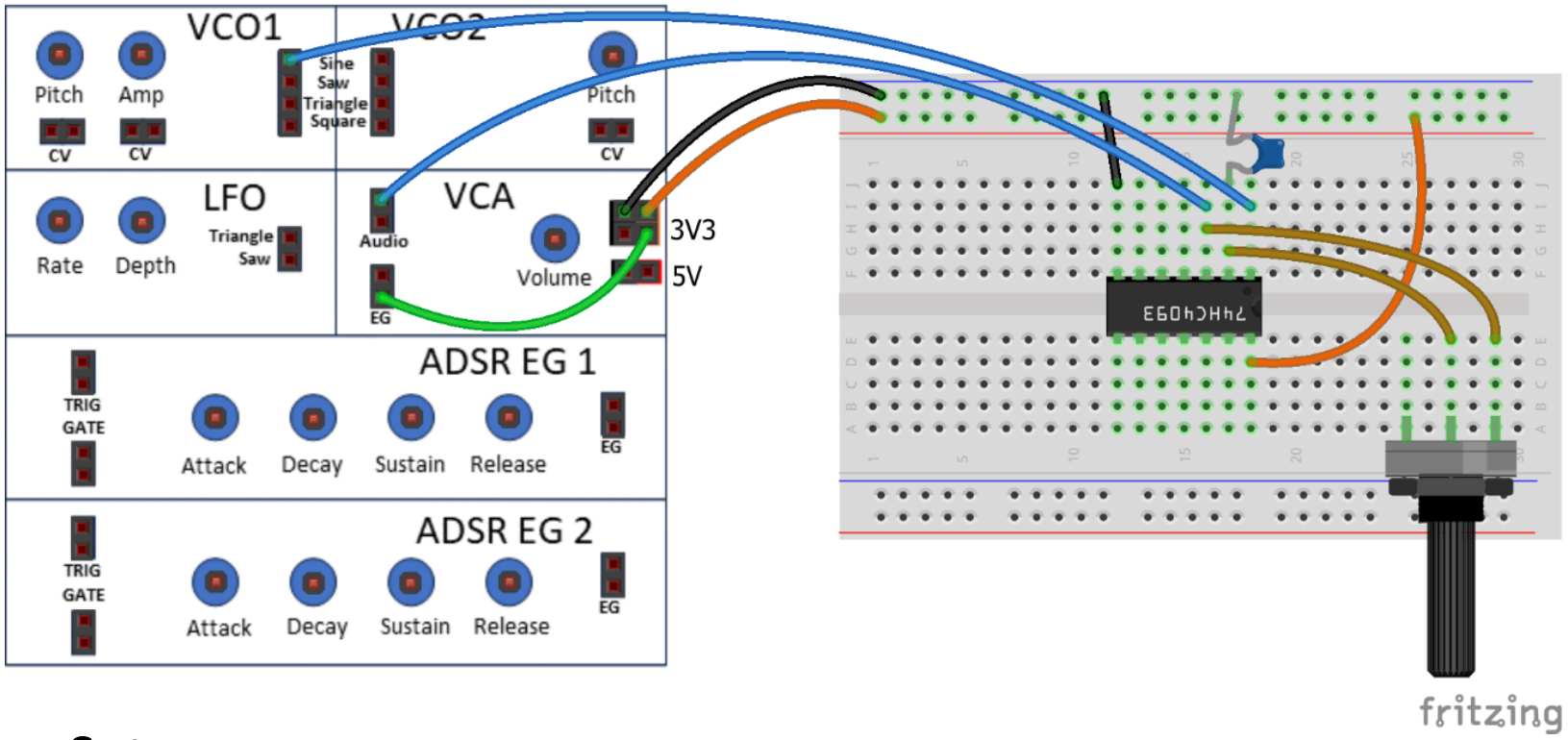


- This produces a square wave.
- Adjust the potentiometer to change the frequency of the oscillator.
- Try different value capacitors and potentiometer for different frequency ranges.

Setup

- Use 100nF capacitor and 10K or 100K potentiometer
- VCA Vol fully clockwise.

1b. NAND Schmitt Trigger Oscillator + VCO

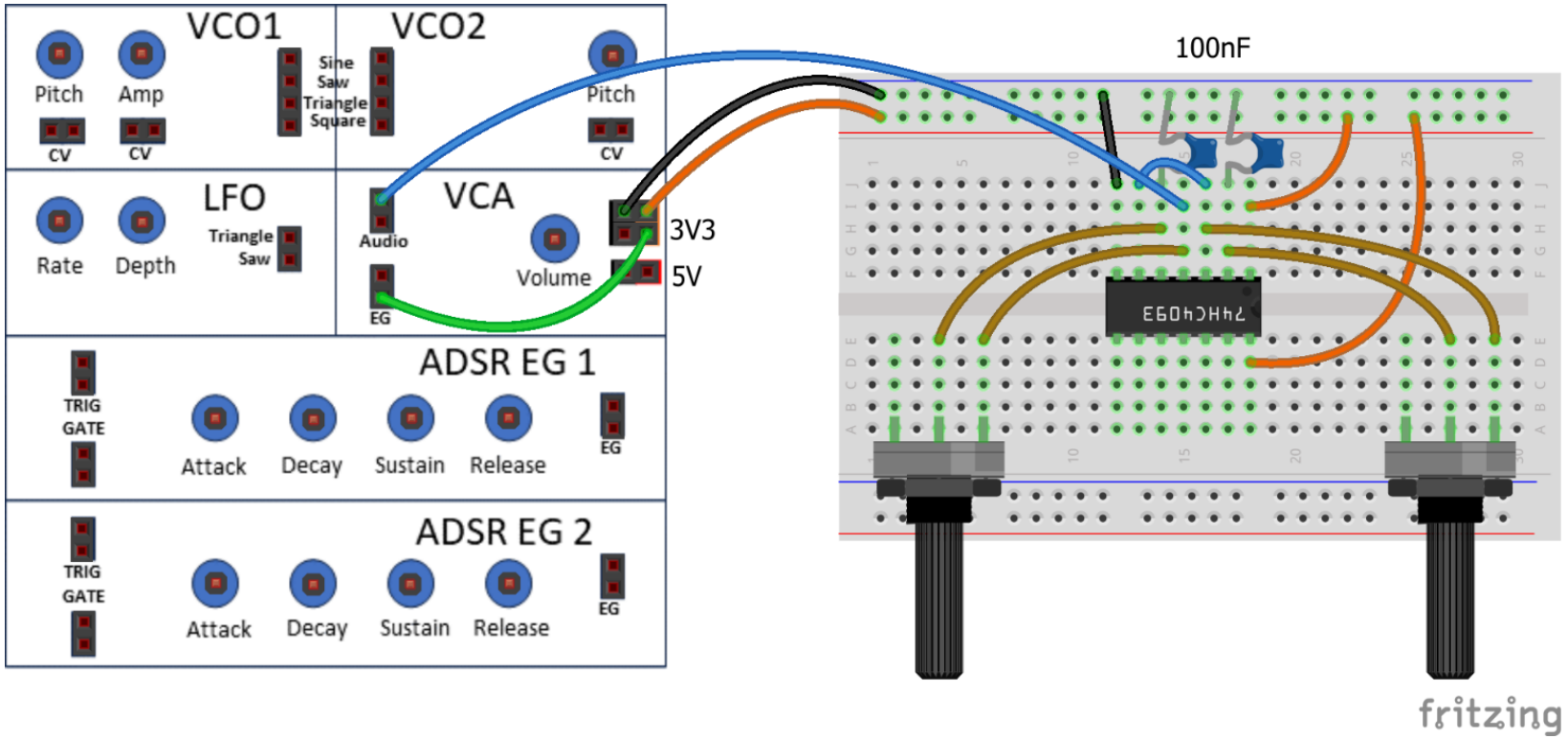


- Adjust VCO 1 Pitch and the potentiometer.
- Try different VCO 1 Amp.
- Try different VCO 1 waveforms.
- Switch to the LFO instead of VCO 1.

Setup

- Use 100nF capacitor and 10K or 100K potentiometer.
- Link NAND input to VCO1 output.
- VCO1 Amp and VCA Vol fully clockwise.

2. Dual NAND Schmitt Trigger Oscillator

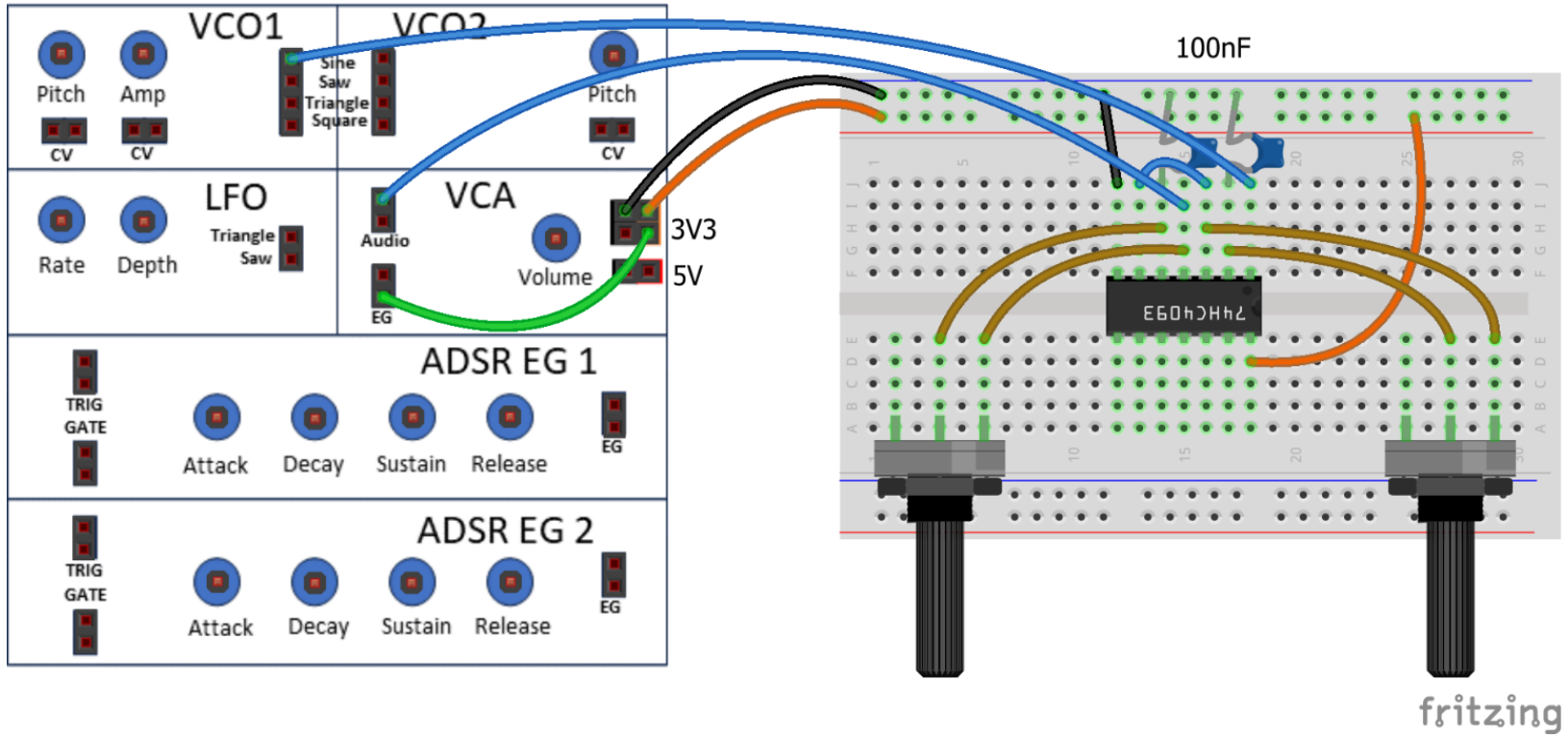


- This produces a modulated square wave.
- Adjust the potentiometers to hear how the two oscillators interact.
- Try different value capacitors and potentiometer for different frequency ranges.

Setup

- Use 100nF capacitors and 10K or 100K potentiometers
- VCA Vol fully clockwise.

2b. Dual NAND Schmitt Trigger + VCO



- Adjust VCO 1 Pitch and the potentiometers.
- Try different VCO 1 Amp.
- Try different VCO 1 waveforms.
- Switch to the LFO instead of VCO 1.

Setup

- Use 100nF capacitors and 10K or 100K potentiometers.
- Link NAND input to VCO1 output.
- VCO1 Amp and VCA Vol fully clockwise.