



LUNAR MODULATOR

INTERGALACTIC MODULATION STATION

Lunar Modulator

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User Manual

Open firmware for the M-VAVE FM-1

Nothing in this manual runs on an FM-1 yet. It describes the browser simulator, the desktop tools and what is planned for the device. Do not try to install anything on an FM-1; chapter 1 explains why.

Generated on 2026-10-07 from commit [64209e3](#).

About this manual

This manual describes Lunar Modulator, open firmware for the M-VAVE FM-1. It is generated from the project's sources: the reference tables come from the code that the firmware is built from, so they change when the code does.

Nothing in it runs on an FM-1 yet. Every function carries a status that says where it works today:

- **In the simulator** Works today in the browser simulator.
- **On the desktop** Works today in the desktop tools (fm1-render, fm1-seq).
- ♦ **Planned for the device** Designed; not built for the FM-1 yet.

Chapter 1 explains why nothing is offered for the device until it can be restored safely, and chapter 2 shows how to play the simulator in a browser.

Generated on 2026-10-07 from commit [64209e3](#). The newest edition is online at <https://ip2k.github.io/lunar-modulator/manual/>.

Trademarks and licences

Lunar Modulator is an independent project. It is not made, endorsed or supported by M-VAVE or Cuvave; “FM-1” names the instrument the firmware is written for. Mutable Instruments module names identify where code came from; they are not product names here. Chapter 13 credits every source and licence.

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Contents

- 1 Welcome and safety. 7**
 - 1.1 What you can use today 7
 - 1.2 Features at a glance 8
 - 1.3 The one rule. 8
 - 1.4 Safety and care 9
 - 1.5 About this manual. 10
- 2 Getting started 12**
 - 2.1 The browser simulator 12
 - 2.2 A first session 16
 - 2.3 The desktop tools 17
 - 2.4 What runs on the FM-1 today 21
- 3 Panel tour 23**
 - 3.1 Knobs 24
 - 3.2 Buttons 25
 - 3.3 Keys. 28
 - 3.4 Screen. 29
 - 3.5 Connections. 34
- 4 Playing. 36**
 - 4.1 Keys and voices 36
 - 4.2 Glide and voice modes 37
 - 4.3 Velocity 39
 - 4.4 Octave and transpose. 40
 - 4.5 How notes end. 41
 - 4.6 Pitch bend 42
 - 4.7 Playing from MIDI. 42
 - 4.8 Arpeggiator 43
- 5 Sound engines 49**
 - 5.1 Choosing an engine. 51
 - 5.2 Four sounds at once 52
 - 5.3 Macro 54
 - 5.4 Macro Heavy 59
 - 5.5 Six-Op FM. 63
 - 5.6 FM6 67
 - 5.7 Shapes 71

5.8	Sophie.....	77
5.9	Drums.....	80
5.10	Acid Bass.....	83
5.11	Comet Kit.....	86
5.12	Crater Kit.....	90
5.13	Drawbar, Trio and Phase Bend.....	93
5.14	Test Sine.....	102
6	Effects.....	103
6.1	The effect chain.....	105
6.2	Plate.....	109
6.3	Ensemble.....	110
6.4	Diffuse.....	111
6.5	PSX Verb.....	112
6.6	Crush.....	114
6.7	Fold.....	115
6.8	Drive.....	117
6.9	Echo.....	119
6.10	Filter.....	121
6.11	Comb.....	124
6.12	Comp.....	125
6.13	Limiter.....	128
6.14	DJ Filter.....	130
6.15	Tilt.....	132
6.16	Master Sat.....	134
6.17	Isolator.....	136
6.18	EQ.....	138
6.19	Room.....	140
6.20	Hall.....	141
6.21	Gate.....	143
6.22	Squash.....	146
6.23	Transient.....	149
6.24	Test Gain.....	150
6.25	Test Ext.....	151
6.26	The limiter.....	152
7	Sequencer.....	153
7.1	How a pattern is organised.....	154
7.2	Steps and notes.....	157
7.3	Parameter locks.....	160

7.4	Conditions and probability.....	163
7.5	Swing and quantise.....	165
7.6	Clips	166
7.7	Scenes and song.....	168
7.8	Recording.....	171
7.9	Capture.....	174
7.10	Tracks and routing	176
7.11	Transport and clock	177
7.12	The Set, Clip and Track pages.....	179
7.13	Memory.....	179
7.14	Controls at a glance	180
7.15	Scripts on the desktop.....	182
8	Modulation	190
8.1	How modulation works	190
8.2	The gesture: making a cable with a knob	194
8.3	The rack	194
8.4	The matrix	195
8.5	Per voice.....	197
8.6	Chains.....	199
8.7	Recipes.....	200
8.8	What the pages show	201
8.9	The modules	201
8.10	Modulation on the desktop	204
9	MIDI.....	205
9.1	In the simulator.....	205
9.2	From the sequencer	206
9.3	Implementation chart	207
9.4	On the FM-1.....	209
10	Settings and storage	210
10.1	The global page.....	210
10.2	Projects, sounds and other files	212
10.3	Sequencer sets	216
10.4	Backing up	218
11	Updating and recovery.....	219
11.1	The one rule, again	219
11.2	Why the FM-1 needs a way back	219
11.3	The recovery dongle.....	219

11.4	Installing Lunar Modulator.....	221
11.5	The firmware your FM-1 has now.....	222
12	Troubleshooting	224
12.1	The simulator.....	224
12.2	The desktop tools	228
12.3	The FM-1	229
12.4	Reporting a problem.....	230
13	Specifications	231
13.1	The instrument	231
13.2	Lunar Modulator	232
13.3	The simulator.....	235
13.4	The desktop tools	236
13.5	Still to be measured on the device.....	236
14	Credits and licences.....	237
14.1	Sound engines and effects	237
14.2	The sequencer.....	241
14.3	The arpeggiator	241
14.4	Modulation.....	242
14.5	Research this project builds on.....	242
14.6	The simulator, the art and the manual.....	243
14.7	Licences	244
14.8	Trademarks	244
15	The advanced editor	245
15.1	Opening the editor	245
15.2	The outline, the Flow and the sounds	247
15.3	Choosing and moving effects	248
15.4	Modulation: the table	249
15.5	Modulation: the Map.....	250
15.6	Files, the library and links	253
15.7	Compare, Memory and Undo.....	254
15.8	Keys, the keyboard and screen readers.....	255
15.9	Phones and tablets.....	255
15.10	Browsers	255
	Glossary.....	257
	Index of controls	264

CHAPTER 1

Welcome and safety

Thank you for trying Lunar Modulator. It is open firmware being written for the M-VAVE FM-1, the pocket six-operator FM synthesizer with 27 keys, eight knobs and a 240×240 colour screen. It is designed to give the FM-1 a choice of synthesis engines, up to four sounds at once with effects of their own, a rack of modulation and a sequencer with parameter locks, and every line of its own code is open under the MIT licence.

Lunar Modulator runs today in a web browser and on computers. It does not run on the FM-1 yet. This manual describes what it does, how to play it, and where each part of it stands. Please read this chapter before anything else: it explains what you can use now, and why nothing is offered for the FM-1 itself yet.

1.1 What you can use today

Lunar Modulator is built and tested on computers first, and each function in this manual carries a status that says where it works today:

- **In the simulator** Works today in the browser simulator.
- **On the desktop** Works today in the desktop tools (fm1-render, fm1-seq).
- ◆ **Planned for the device** Designed; not built for the FM-1 yet.

- **The browser simulator** is a virtual FM-1. The firmware's engines and effects run in your browser, behind a to-scale drawing of the front panel with the firmware's own 240×240 screen. Play it with the mouse, a touch screen, the computer keyboard or a MIDI keyboard. It is the front page of the project's website, ip2k.github.io/lunar-modulator, and [chapter 2](#) shows how to use it.
- **The desktop tools** play the same engines, effects, modulation and sequencer into audio files from the command line. They are how the firmware is tested, and the only place a few of the sequencer's functions (clips, scenes and songs) run so far.

- **The FM-1 itself** runs none of it yet. Everything marked *Planned for the device* is designed and documented, and waits for the rule described below.

1.2 Features at a glance

Function	Where it works today	Chapter
Eight sound engines: Macro, Macro Heavy, Six-Op FM, FM6, Shapes, Sophie, Drums and Test Sine, up to four sounds at once	Simulator, desktop	5
Twenty-four effects: two inserts on each sound and two on the master bus, followed by a limiter	Simulator, desktop	6
The front panel: the knobs, the keys, the screen and every button but 	Simulator	3
Octave, transpose, velocity and pitch bend	Simulator; velocity and bend also on the desktop	4
Notes from a MIDI keyboard	Simulator	9
Sequencer: steps, parameter locks, conditions, recording, Capture, eight tracks	Simulator, desktop	7
Sequencer clips, scenes and songs	Desktop	7
Modulation: LFOs, envelopes and fourteen more modules, cabled to any parameter	Simulator, desktop	8
Sequencer sets saved and loaded as text files	Desktop	10
Any of the above on the FM-1	Planned	11

1.3 The one rule

Nothing is installed on, or written to, an FM-1 until two things have been shown on that very unit: a complete copy of its memory has been read out, and that copy has been written back so that the unit is byte for byte as it was.

The reason is that an FM-1 has no safety net. Its firmware lives in a single bank of memory, and the board has no recovery button and no test connector. The FM-1's own update method runs inside the firmware that is already installed: it can replace a working firmware, but it cannot rescue one that no longer starts. Owners of other

FM-1s have reported reading out and writing their units' memory with a small USB dongle, but this project has not yet done so itself. Until a way back has been shown to work on the unit in question, a failed install could leave the instrument permanently unusable.

■ There is nothing to install on your FM-1 yet

There is no Lunar Modulator firmware for the FM-1 yet, and this project will not offer one until the one rule is met. Be wary of any file that claims to be Lunar Modulator for the device: it is not from this project. To try Lunar Modulator, use the browser simulator.

The one rule also limits what this project sends to an FM-1 while the work goes on: a read-only query that asks the unit which version of its firmware it runs, and passive listening, nothing else. [Chapter 11](#) describes the recovery work under way and what will change once it succeeds.

1.4 Safety and care

Lunar Modulator does not change how the FM-1 is built or powered. M-VAVE's instructions for the battery, charging and care of the instrument still apply; follow M-VAVE's manual for them.

■ Protect your hearing

Synthesizer engines can produce loud, sudden or piercing sounds, particularly when you turn a parameter quickly, raise a feedback or resonance control, or play many notes at once. Start with the volume low, on headphones and on speakers alike, and raise it while you play. In the simulator, **MASTER** sets the output level and the firmware's limiter holds the output just below full scale, but your computer's own volume still applies on top of both.

■ Do not open the case

Nothing in this manual asks you to open your FM-1. The recovery dongle described in [chapter 11](#) is designed to plug into the USB socket from outside.

● **Your FM-1 is unchanged**

Using the simulator or the desktop tools sends nothing to an FM-1, even one connected to the same computer. The simulator reads MIDI from a keyboard you connect; it sends no MIDI at all.

1.5 About this manual

- **Controls** are written as the panel prints them: `SELECT`, `KNOB1`, `PLAY/STOP`. Sequencer functions that are still to be given a key are drawn with a dashed outline, such as `LOOP`.
- **Statuses**. The status line under a heading says where the function described below it works today, using the three labels above.
- **Notes** add detail and **tips** suggest a way of working. **Cautions** protect your hearing and your data; **warnings** protect your instrument.
- **Note names**. Middle C, MIDI note 60, is C4. The FM-1’s lowest key, F3, is MIDI note 53.
- **Generated reference**. The parameter tables, value lists and sequencer tables are generated from the firmware’s code each time the manual is built, so they always match the build named below.
- **Online and in print**. The newest edition is on the project’s website, with a PDF of the whole manual beside it. Corrections are welcome as issues on the [project’s repository](#).

This edition	
Generated on	2026-10-07
From commit	64209e3
Sound engines in the build	Macro, Shapes, Macro Heavy, Six-Op FM, FM6, Sophie, Drums, Acid Bass, Comet Kit, Crater Kit, Drawbar, Trio, Phase Bend, Test Sine
Effects in the build	Plate, Ensemble, Diffuse, PSX Verb, Crush, Fold, Drive, Echo, Filter, Comb, Comp, Limiter, DJ Filter, Tilt, Master Sat, Isolator, EQ, Room, Hall, Gate, Squash, Transient, Test Gain, Test Ext
Sequencer in the build	yes

Browser simulator published with it	yes
Tools	Python-Markdown 3.11

CHAPTER 2

Getting started

There are two ways to use Lunar Modulator today: play it in a web browser, or render its sounds with the desktop tools. This chapter sets up both, takes you through a first session, and ends with what still has to happen before Lunar Modulator can run on an FM-1.

2.1 The browser simulator

STATUS:  In the simulator

The simulator is a virtual FM-1 on a web page. The firmware's engines and effects run inside your browser, behind a to-scale drawing of the front panel. The screen in the drawing is the firmware's own 240 × 240 display, drawn by the code that is meant to draw the FM-1's.

2.1.1 What you need

- A desktop or laptop computer with a current web browser. The simulator needs WebAssembly and the Web Audio API's AudioWorklet, and the page must come from an `https://` address or from your own computer.
- Headphones or speakers.
- Optionally, a MIDI keyboard connected to the computer, and a browser with Web MIDI.

The simulator is tested in Chromium, the engine behind Chrome and Edge. Firefox, Safari, phones and tablets with real touch screens, and real MIDI hardware have not been tested yet.

Nothing is installed. The page loads only its own files, from its own website, and sends nothing anywhere.

2.1.2 Turning it on

1. Open the project's website, ip2k.github.io/lunar-modulator. The simulator is its front page; this manual is in its *manual* section.

2. Click **Power on**. Browsers allow a page to make sound only after a click, so the simulator waits for this one. Clicking the **POWER** switch drawn on the top edge of the case does the same.
3. Play the keys.

The simulator starts with the Macro engine as Sound 1 (Sounds 2 to 4 empty), the Plate reverb in the first master effect slot, the second slot empty, a one-bar demo pattern on sequencer track 1, the modulation rack's default modules, and **MASTER** at three quarters. Press **PLAY/STOP**, or Space, to hear the pattern. The status line under the controls reports the sample rate, the block size, the delay your computer adds to the output, how much of the FM-1's memory the sounds and effects take, in percent, and the sequencer's tempo and whether it plays.

To stop, click **Power off** or the **POWER** switch. The simulator keeps nothing: it starts from the same settings every time, and DX7 voices you loaded into FM6 ([chapter 5](#)) go with the power.

● When an engine refuses to start

The simulator asks your browser for 44,100 samples a second, close to the 44,118 reported for the FM-1. If the browser insists on a faster rate, such as 48,000, the four engines built from Plaits' code (Macro, Macro Heavy, Six-Op FM and Drums) cannot run. The simulator then starts with Shapes, steps over those four when you turn **PRESETS**, and says why on its screen and in the status line. The other engines, FM6 among them, run at any of these rates. Set your computer's audio output to 44.1 kHz and reload the page to get them back.

2.1.3 Playing with the mouse or a touch screen

- **Keys.** Click or touch a key to play it, and hold it for as long as the note should last. Where you press sets how hard the note is played: near the top of a key for the softest note (velocity 30), at the bottom edge for the loudest (127).
- **Knobs.** Drag up to turn a knob clockwise and down to turn it anticlockwise, or scroll over it with the mouse wheel or trackpad. Each 6 pixels of dragging is one step of an encoder.
- **Buttons.** Click or touch.

On a narrow screen the panel keeps its size, so that the keys stay large enough to play, and scrolls sideways in its own box: drag the case, not a control, to see the rest,

or turn the phone to landscape. The screen then also appears enlarged below the panel.

2.1.4 Playing from the computer keyboard

The letter keys play the first 19 keys of the panel, F3 to B4, laid out like a piano: the middle row of letters plays the white keys, and the row above it the black keys. Notes from the computer keyboard play at velocity 100.

Computer keys	What they do
A S D F G H J K L ; ' W E R Y U O P [	The white keys F3, G3, A3, B3, C4, D4, E4, F4, G4, A4 and B4
Z / X	 / 
← →	Turn  : the page, or in FX mode the effect slot and its pages
↑ ↓	Turn  : the sound engine
- =	Turn  : the engine's main list, or in FX mode the effect in the slot
Space	 : starts and stops the sequencer
1 to 8, C V B N M , . /	In SEQ mode, white keys 1 to 16: the sequencer's steps (chapter 7)
Shift	In SEQ mode, holds  , the sequencer's SHIFT
Tab	Move between the knobs and buttons of the drawing. With a knob chosen, the arrow keys turn it; with a button chosen, Enter or Space presses it
Esc	Release every note

 to  and  have no letter of their own: choose them with Tab, or use the mouse.

◆ Keys that seem stuck

If you switch to another window or tab while holding a key, the simulator lets go of everything you were holding. If a note still hangs, press Esc.

2.1.5 Playing from a MIDI keyboard

1. Connect the keyboard to the computer.
2. Click **Connect MIDI input** under the panel, and allow the browser to use MIDI devices when it asks.
3. The button now names the keyboards it found. Play.

The simulator listens on every MIDI channel. It plays notes with their velocity, bends sounding notes by up to two semitones either way, follows control change 7 as **MASTER** and control change 123 as *all notes off*, and ignores everything else. It sends no MIDI. [Chapter 9](#) has the full list.

2.1.6 The controls under the panel

Control	What it does
Sound (PRESETS)	Chooses the current sound’s engine directly, as turning PRESETS does. The label names the current sound, such as <i>Sound 2 (PRESETS)</i> ; Sounds 2 to 4 can be <i>(none)</i>
Effect 1, Effect 2	Choose the effect in each master slot, or <i>(none)</i> to empty it
Connect MIDI input	Asks the browser for your MIDI keyboards (above)
Open..., Save..., Copy link	Load and save projects, sounds and other files, and share a project as a link (chapter 10). Files can also be dropped on the page
Screen ×2	Shows a second, larger copy of the screen below the panel. On by default in a narrow window
Power off	Stops the sound

A choice in one of the lists hands the computer keyboard straight back to the instrument, so the next letter you type plays a note.

The page remembers your project in the browser as you work: come back later, press **Power on**, and it is as you left it. To start from an example, open *Saved in this browser*, *Recent and examples* under the status line and load *First orbit*, the guide’s first song.

2.1.7 The advanced editor

The switch at the top of the page, **Panel**, **Workbench** and **Editor**, opens the advanced editor beside the panel or in its place. It shows every value of a sound at once,

grouped by the panel's own pages, and changes the same simulator the panel plays: turn a knob on the panel and its row lights in the editor; move a slider in the editor and the panel opens that page. It also draws the signal flow, the modulation rack and its cables (as a table or as a patch bay), and says what each choice would cost in memory before you make it. [Chapter 15](#) describes it.

2.1.8 Running the simulator from your own copy

To run the simulator without the website, for example from a copy of the project you have changed, serve its folder from your own computer. You need Git and Python 3.9 or newer.

```
git clone https://github.com/ip2k/lunar-modulator
cd lunar-modulator/sim/web/www
python3 -m http.server 8000
```

Then open `http://localhost:8000/` in the browser. Opening `index.html` straight from the disk does not work: browsers allow the simulator's audio only on a web address.

2.2 A first session

STATUS:  In the simulator

This short tour plays notes from the computer keyboard and turns the four parameter knobs and the buttons with the mouse. Start with the volume low.

1. Click **Power on**.
2. Hold A, D and G together: an F major chord on the Macro engine, through the Plate reverb. Each key's light comes on while you hold it.
3. Press = four times. **ALGORITHM** steps Macro's Model from VA+Filter to VA Pair, and the screen shows the new model for a moment.
4. Hold the chord again and drag **KNOB3** slowly upwards. **KNOB3** is Timbre on the first page: watch its bar move on the screen as the sound changes.
5. Press →. **SELECT** turns to the second page: Decay, Colour and Volume. Drag **KNOB1** up to raise Decay, and the notes ring on after you let go of the keys.

6. Click **FX**. The screen shows the effect chain, with M1, the first master slot, chosen: Plate is there, and **KNOB1** is now Plate's Mix.
7. Press → twice, past Plate's second page (Freeze), to move to M2, the second master slot, empty, then = twice: Ensemble, a chorus, fills it.
8. To put Ensemble before Plate, click **SEL**, press ←, and click **SEL** again.
9. Click **HOME** to return to the sound, then press ↑ to turn **PRESETS** to the next engine, Shapes.
10. Press Space: the demo pattern plays on Shapes. Click **SEQ** to see it: the white keys' lights follow the steps, and a tap on a white key adds or removes a note. Press Space again to stop.

Chapter 3 describes every control, chapters 5 and 6 every engine and effect, chapter 7 the sequencer and chapter 8 modulation.

● Changing the engine starts it afresh

Each time you choose a sound engine or an effect, it starts with its default settings. The simulator does not keep sounds yet; saving them is planned (chapter 10).

2.3 The desktop tools

STATUS: ■ On the desktop

The desktop tools build the same engine, effect and sequencer code that the firmware will use, and play it into a WAV file. They are the reference the simulator is checked against, and the way to hear a change before it reaches the simulator.

2.3.1 Building them

You need Git, `make` and a C and C++ compiler that supports C++11: on macOS the Xcode command-line tools, on Linux a package such as `build-essential`.

```
git clone https://github.com/ip2k/lunar-modulator
cd lunar-modulator
make -C engines # builds engines/build/fm1-render
engines/build/fm1-render --list # every engine, effect and parameter, as JSON
```

2.3.2 Rendering a sound

`fm1-render` plays a list of notes through one sound engine and any number of effects, then through the same limiter as the firmware, and writes the result as a 16-bit stereo WAV file at 44,118 samples a second.

```
engines/build/fm1-render --engine macro --param Model=4 \
  --note 0:57:100:1 --note 0:60:100:1 --note 0:64:100:1 \
  --fx ensemble --fx plate --fx-param Mix=0.3 \
  --seconds 3 --out chord.wav
```

This plays an A minor chord on Macro's VA Pair model, through Ensemble and then Plate, with Plate's Mix at 0.3.

- **A note** is written `start:key:velocity:length`, with the start and length in seconds, the key as a MIDI note number (60 is middle C) and the velocity from 1 to 127.
- **Parameter names** are the ones in this manual's tables, in any mix of capitals. A list parameter takes the number of its value, not its name: `Model=4` is VA Pair.
- **Effects** run in the order you give them, and each `--fx-param` sets a parameter of the `--fx` just before it.
- **Events** take effect at the start of the next block of 64 samples, every 1.45 ms.

After each render the tool prints one line of figures, among them the peak level before and after the limiter.

More examples:

```
# FM6's tine electric piano, a C major chord, through Ensemble and
Plate
engines/build/fm1-render --engine dx7 --param Patch=0 \
    --note 0:60:90:1 --note 0:64:90:1 --note 0:67:90:1 \
    --fx ensemble --fx plate --seconds 3 --out tines.wav

# FM6 playing the eighth voice of a 32-voice bank of your own, a .syx
file
engines/build/fm1-render --engine dx7 --sysex mybank.syx --param
Patch=39 \
    --note 0:48:100:2 --seconds 3 --out mine.wav

# Six-Op FM's first electric piano, a C major chord, through Ensemble
and Plate
engines/build/fm1-render --engine sixop --param Patch=32 \
    --note 0:60:90:1 --note 0:64:90:1 --note 0:67:90:1 \
    --fx ensemble --fx plate --seconds 3 --out piano.wav

# Macro's 2-op FM model, with Timbre turned up after one second and
down after two
engines/build/fm1-render --engine macro --param Model=6 --note
0:45:100:3 \
    --param-at 1:Timbre=0.9 --param-at 2:Timbre=0.1 --seconds 4 --out
fm.wav

# A low note through Filter's diode ladder, its cutoff opened after
half a second
engines/build/fm1-render --engine macro --param Model=0 --note
0:36:110:2 \
    --fx filter --fx-param Type=2 --fx-param Cutoff=300 --fx-param
Resonance=0.8 \
    --fx-param-at 0.5:1:Cutoff=1500 --seconds 2.5 --out acid.wav

# Sophie's kick, closed hi-hat and snare, through PSX Verb's Room
engines/build/fm1-render --engine sw-sophie \
    --note 0:36:110:0.5 --note 0.25:42:90:0.2 --note 0.5:38:100:0.2 \
    --fx sw-psxverb --fx-param Model=0 --seconds 2 --out kit.wav
```

2.3.3 Options

Option	What it does
<code>--list</code>	Prints every engine and effect with its parameters, ranges, defaults and value names, as JSON
<code>--engine ID</code>	The sound engine: <code>macro</code> , <code>macro-heavy</code> , <code>sixop</code> , <code>dx7</code> (FM6), <code>shapes</code> , <code>sw-sophie</code> , <code>drums</code> or <code>test-sine</code> . Each engine's identifier is under its table in chapter 5
<code>--param NAME=VALUE</code>	Sets one of the engine's parameters before the first note
<code>--note T:KEY:VEL:LEN</code>	Plays a note (above)
<code>--param-at T:NAME=VALUE</code>	Sets one of the engine's parameters at time <i>T</i> , in seconds
<code>--bend T:SEMITONES</code>	Bends every note from time <i>T</i> , by up to 48 semitones either way. Sophie has no pitch bend and refuses it
<code>--fx ID</code>	Adds an effect to the chain: <code>plate</code> , <code>ensemble</code> , <code>diffuse</code> , <code>sw-psxverb</code> , <code>crush</code> , <code>fold</code> , <code>drive</code> , <code>echo</code> , <code>filter</code> , <code>comb</code> , <code>comp</code> , <code>limit</code> , <code>djfilter</code> , <code>tilt</code> , <code>sat</code> , <code>isolator</code> , <code>eq</code> , <code>room</code> , <code>hall</code> , <code>gate</code> , <code>test-gain</code> or <code>test-ext</code> . With the multi-sound options below, the first two are the master effects
<code>--fx-param NAME=VALUE</code>	Sets a parameter of the effect before it
<code>--fx-param-at T:K:NAME=VALUE</code>	Sets a parameter of the <i>K</i> -th effect (the first <code>--fx</code> is 1) at time <i>T</i> , in seconds
<code>--seconds S</code>	The length of the file, 2 seconds unless you say otherwise
<code>--rate HZ</code>	The sample rate, 44,118 unless you say otherwise. Macro, Macro Heavy, Six-Op FM and Drums refuse rates above 47,872; Shapes runs from 24,000 to 96,000; FM6 from 16,385 to 384,000
<code>--sysex FILE.syx</code>	Loads DX7 voices from a SysEx file into FM6's user slots (<code>--engine dx7</code>): a bank fills User 1 to 32, single voices go to User 1, 2 and on, in the order given (chapter 5)
<code>--frames N</code>	The block size, 64 unless you say otherwise
<code>--tempo BPM</code>	The tempo the effects hear when no sequencer plays, from 20 to 300; 120 unless you say otherwise. Of the effects, only Test Ext listens to it so far
<code>--out FILE.wav</code>	Where to write the sound

Option	What it does
<code>--sound K:ID , --insert K:ID , --level K:PCT , --sound-note K:T:KEY:VEL:LEN , --slots</code>	Several sounds at once, as in the simulator: sound <i>K</i> (1 to 3; <code>--engine</code> is 0), an insert effect on sound <i>K</i> , its level into the mix, a note on it; <code>--slots</code> routes the sequencer’s tracks to the sounds (chapter 5)
<code>--mod FILE</code>	Modulation from a file (chapter 8)
<code>--cmd , --seq , --log- events , --route , --tracks</code>	Play the sequencer (chapter 7)

An unknown engine or parameter name, or a rate an engine cannot run at, stops the tool with a message saying so.

2.3.4 Rendering a sequence

`fm1-render` can also play the sequencer: a script of sequencer commands (`--cmd`) or a saved set (`--seq`) drives the engine, note for note and lock for lock. [Chapter 7](#) describes the sequencer and its scripts.

2.4 What runs on the FM-1 today

STATUS:

◆ Planned for the device

Nothing from this project. The FM-1 keeps whatever firmware it has: M-VAVE’s own, or a third-party firmware you chose to install yourself. [Chapter 1](#) explains the rule that holds Lunar Modulator back from the device, and [chapter 11](#) the recovery work that has to succeed first.

2.4.1 The road to the device

Each step below has to succeed before the next one starts:

1. **A way back.** Read a complete copy of an FM-1’s memory through its USB socket with the recovery dongle, write it back, and show twice that the unit is byte for byte as it was.
2. **A development board.** Run Lunar Modulator’s code on a board with the same family of processor, and show that it gives the same results as the desktop tools and the simulator.

3. **The FM-1, from memory.** Run Lunar Modulator on the FM-1 without writing anything to its permanent memory.
4. **The FM-1, installed.** Install it with a way back built in: a key held at power-up that returns the unit to its update mode, and a copy of the original firmware kept.
5. **For everyone.** Publish an installer that works over USB and can also put the original firmware back.

2.4.2 What you will need

When a device version exists, the plan is that installing it will need a computer and the FM-1's USB socket, and nothing inside the case ([chapter 11](#)). Until then, keep playing your FM-1 with the firmware it has, and play Lunar Modulator in the simulator.

CHAPTER 3

Panel tour

This chapter names every control on the FM-1 and says what Lunar Modulator does with it. The drawing is to scale and matches the simulator’s panel. Each section says which parts work in the simulator today and which are planned for the device.

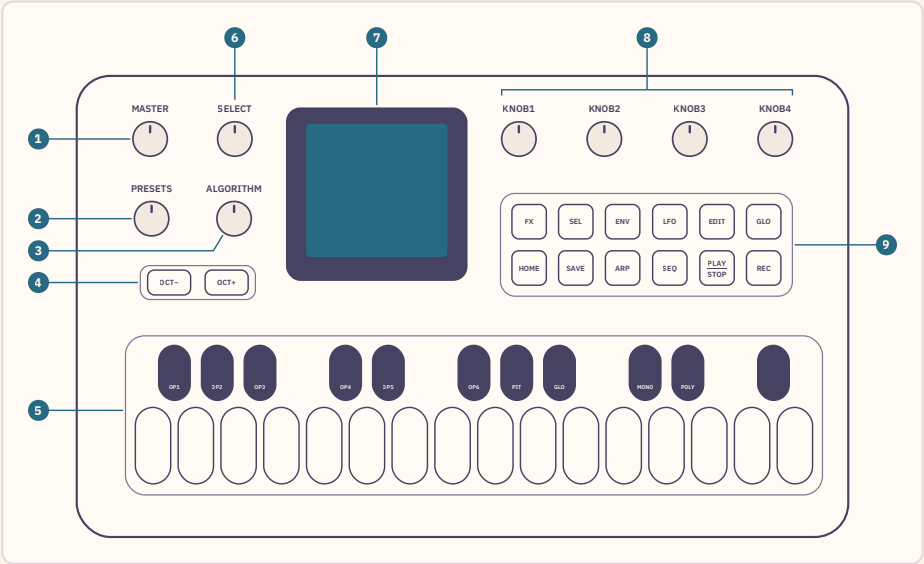


Figure 3.1 Front panel. The numbers match the table below it.

No.	Control	What it does in Lunar Modulator
1	MASTER	Output volume
2	PRESETS	Chooses the sound engine; with SEL held, which of the four sounds you play
3	ALGORITHM	Steps through the engine’s main list: its model, shape, patch or pad. In FX mode it chooses the effect in the chosen slot
4	OCT- and OCT+	Move the keyboard down or up an octave; both together reset octave and transpose
5	Keys	27 keys, F3 to G5 at the middle octave

No.	Control	What it does in Lunar Modulator
6	SELECT	Turns the page. In FX mode it moves between the effect slots and their pages
7	Screen	The 240 × 240 colour display
8	KNOB1 to KNOB4	Change the four parameters shown on the screen
9	Function buttons	Twelve buttons in two rows. All but SAVE work today

3.1 Knobs

STATUS:  In the simulator  Planned for the device

The FM-1 has eight knobs. **MASTER** is a potentiometer: it turns between two end stops, and its position is the volume. The other seven are encoders: they turn without end, in steps you can feel.

Knob	What it does
MASTER	The output volume, from silent to full. While you turn it the screen shows <i>Volume</i> and its position from 0 to 100
SELECT	On the sound's page, turns the page. In FX mode, moves through the slots of the chain and their pages. In SEQ mode and on the modulation pages it does more (chapters 7 and 8). On the global page it turns between <i>Globe</i> and <i>Key</i>
PRESETS	Chooses the current sound's engine, in this order: Macro, Shapes, Macro Heavy, Six-Op FM, FM6, Sophie, Drums, Test Sine, and round again; Sounds 2 to 4 start the list with <i>Empty</i> . With SEL held, chooses the current sound, 1 to 4 (chapter 5)
ALGORITHM	Steps through the engine's main list: Model for Macro and Macro Heavy, Shape for Shapes, Patch for Six-Op FM and FM6, Pad for Sophie and Drums. Test Sine has none. In FX mode it chooses the effect in the chosen slot. With OCT- or OCT+ held, it transposes (chapter 4)
KNOB1 to KNOB4	Change the four parameters of the current page, in the order the screen lists them. With LFO or ENV held, they make a modulation cable (chapter 8). On the global page KNOB1 and KNOB2 set the project key (chapter 10)

3.1.1 How far one step goes

- **A list parameter** (Model, Shape, Patch, Pad and the like) moves one value per step and stops at each end of its list.
- **A continuous parameter** moves a hundredth of its range per step, so 100 steps take it from one end to the other. Parameters whose range runs between whole numbers ten or more apart move in whole units instead: Sophie's Tune moves a semitone per step, and its Sweep two units.
- **A frequency or a time** on an effect (a cutoff, a crossover, a delay or a release) also takes 100 steps from end to end, but each step multiplies it by the same ratio, so every step is the same musical interval, at the low end as at the high: on a cutoff from 20 Hz to 18 kHz, about a semitone ([chapter 6](#)).
- **PRESETS**, and **ALGORITHM** in FX mode, go round: after the last choice comes the first.
- **Speed makes no difference.** Every step is the same size however fast you turn; there is no acceleration.

MASTER is not linear: half way round gives a quarter of full level, about 12 dB down.

3.1.2 Turning knobs in the simulator

Drag a knob up or down, or scroll over it. Dragging 6 pixels turns an encoder one step; **MASTER** goes from silent to full over 180 pixels. Scrolling turns an encoder one step at the start of each scroll, then one step for every 60 pixels the page would have scrolled, and **MASTER** 2 % per step. From the computer keyboard, choose a knob with Tab and turn it with the arrow keys ([chapter 2](#)).

3.1.3 On the FM-1

The FM-1's knobs are planned to work as they do in the simulator. Other open firmware for the FM-1 reports that its processor reads all seven encoders through its key scanning, and **MASTER** as an analogue input; this project has still to check that on a unit. It does not change what the knobs do.

3.2 Buttons

STATUS:  In the simulator  Planned for the device

The FM-1 has fourteen buttons, each with a light. **OCT-** and **OCT+** sit at the left, under **ALGORITHM**. The other twelve, the function buttons, sit in two rows of six under **Knob1** to **Knob4**: **FX**, **SEL**, **ENV**, **LFO**, **EDIT**, **GLO** on top, and **HOME**, **SAVE**, **ARP**, **SEQ**, **PLAY/STOP**, **REC** below.

Button	In the simulator	Planned for the device
OCT- , OCT+	Move the keyboard an octave down or up, three octaves at most either way. Press both together to return to the middle octave and cancel any transpose. Hold one and turn ALGORITHM to transpose	The same (chapter 4)
FX	Shows the effect chain (chapter 6). Press it again to return to the sound's page	The same
SEL	In FX mode, picks up the chosen effect so that SELECT swaps it with its neighbour; press SEL again to put it down. Everywhere else it is SHIFT, the sequencer's second function key: held, it changes what the keys, knobs and buttons do (chapter 7); with PRESETS it chooses the current sound. In the modulation pages it picks up a module, or opens a cable's chain (chapter 8)	The same
ENV , LFO	A tap shows the modulation rack at an envelope or an LFO; held while you turn a knob, they make a cable to that knob's parameter (chapter 8)	The same
EDIT	Shows the modulation matrix, the list of cables; press it again to leave (chapter 8)	The same
GLO	Shows the global page, with the project key on its second page; press it again to leave	The global page, with settings (chapter 10)
HOME	Returns to the sound's page from any mode	The same
SEQ	Shows the sequencer's steps, SEQ mode, from any mode; held with a white key 1 to 8, focuses that track (chapter 7)	The same
PLAY/STOP	Starts and stops the sequencer, in any mode	The same
REC	Records into the focused track; held in SEQ mode while stopped, step recording; with SEL , Capture (chapter 7)	The same

Button	In the simulator	Planned for the device
	Keeps the project in the browser, where <i>Saved in this browser</i> lists it (chapter 10)	Saving projects, after the one rule
	A tap switches the current sound's arpeggiator on, and opens its pages, or off; held, it latches; with  , it opens the pages (chapter 4)	The same

3.2.1 Button lights

Light	What it means
 or 	How far the keyboard is from the middle octave, on the button for that direction: off at the middle octave, a slow blink one octave away, a fast blink two away, steady three away
	On in FX mode
	On while an effect or a module is picked up, while you hold it as SHIFT, and in a cable's chain
	On while the global page is shown
	On in SEQ mode
	On while the sequencer plays
	On while recording; a fast blink during a count-in or while a first take waits for its bar; a slow blink while Capture holds notes you could keep
 , 	On while the rack shows one of their modules
	On in the matrix and the chain
	On while the current sound's arpeggiator is on; a blink once a second while it latches
Any other button	On while you hold it

3.2.2 Functions still to be given a key

The sequencer needs more functions than the panel has free buttons. In SEQ mode the black keys take some of them ([Keys](#)) and  is SHIFT. A few are still to be

assigned a key; this manual draws them with a dashed outline: `COPY`, `LOOP`, `SESSION` and `UNDO`. [Chapter 7](#) describes what each one does.

3.3 Keys

STATUS: • In the simulator ♦ Planned for the device

The FM-1 has 27 keys, from F3 to G5 at the middle octave: 16 white and 11 black, each with a light. The lowest key plays MIDI note 53. `OCT-` and `OCT+` move the whole keyboard by octaves, and `ALGORITHM` with one of them held moves it by semitones ([chapter 4](#)).

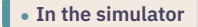
- **How hard you play.** In the simulator, the place you press a key sets its velocity: softest at the top of the key, loudest at the bottom. Whether the FM-1's own keys can sense how hard they are played has not been measured yet.
- **Key lights.** A key's light is on while its note is held, whether you hold the key or a MIDI keyboard plays that note. With a drum kit as the sound, a white key lights while its pad's note is held.
- **Drum kits' pads.** With Sophie or Drums as the current sound, the 16 white keys play the kit's 16 pads at any octave, and the black keys play nothing ([chapter 5](#)).

The FM-1 prints labels under its black keys for M-VAVE's own firmware: from the lowest black key upwards, `OP1` to `OP6`, `PIT`, `GLO`, `MONO` and `POLY`; the highest black key has none. This manual uses them to name the black keys. Outside SEQ mode, `SEL` held with `MONO` or `POLY` sets the current sound's Voice Mode ([chapter 4](#)).

● The keys and the sequencer

The keys have two jobs. Outside SEQ mode they play notes, as usual. In SEQ mode (`SEQ`) the sixteen white keys are the sixteen steps of a bar, and the black keys are sequencer controls: `OP1` and `OP3` change bar, `OP5` clears, `OP6` mutes, `MONO` and `POLY` change track. [Chapter 7](#) describes them.

3.4 Screen

STATUS:  

The screen has three parts: a bar along the top, the current mode in the middle, and a bar along the bottom. The code that draws it is meant to carry over to the FM-1, so the device's screen is planned to look as the simulator's does.

3.4.1 The top and bottom bars

- **Top bar.** The name of the sound engine (with two or more sounds in use, the current sound's number first, such as *S2 Shapes*), and at the right a level meter. The meter shows the output from silent (−48 dB) to full scale, before **MASTER**. It turns red when the output comes close to full scale, where the limiter is holding it down (chapter 6).
- **Bottom bar, left.** The page you are on and how many there are, such as *1/2*, and the mode: *Sound*, an effect slot such as *M1* or *S1 In2*, *Mix*, *Seq*, *Globe* or *Key* on the global page, or a modulation page.
- **Bottom bar, right.** The memory meter: a bar and the share, in percent, of the FM-1's memory the sounds, effects, sequencer and modulation would take. 100 % is the room M-VAVE's firmware leaves free on the FM-1, the simulator's estimate of what Lunar Modulator will have there (chapter 13). Whatever would take it past 100 % is refused (chapter 6).

3.4.2 The sound's page

The simulator starts on this page, and **HOME** returns to it.

- **The main list.** Under the top bar, in rose and a smaller type, the current value of the engine's main list by its full name (*Phase Distortion*, which the row below shortens to *PhaseDist*): the model, shape, patch or pad. On the right, its place in the list, such as *2/8*. Test Sine has no list, so the line is left empty.
- **Four rows.** One row for each parameter on the page, in knob order: **KNOB1** at the top, **KNOB4** at the bottom. Each row shows the name and the value, with a bar beneath.
- **Bars.** A bar fills from the left for most parameters. For a parameter that runs from negative to positive, such as Sophie's Tune, it fills from a centre mark. For a list parameter, a short marker shows where the value sits in the list. For a frequency or

a time, the bar shows where the knob is, which is not the same share of the value's range.

- **Modulation.** A parameter that a modulation cable reaches has its name in the modulation colour and a bracket of that colour on its bar ([chapter 8](#)).
- **Oscilloscope.** A strip at the bottom shows the waveform of the output. It is scaled to fill the strip, so quiet sounds show up too. On a page with fewer than four parameters it grows into the empty rows.

With no engine in the current sound (Sounds 2 to 4 can be empty) the page says *Empty sound: turn PRESETS*.

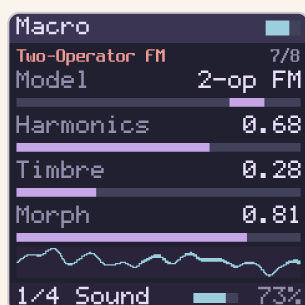


Figure 3.2 The sound's page: Macro on its 2-op FM model, page 1 of 3, after turning KNOB1 to KNOB4. The level meter is at the top right, the memory meter at the bottom right.

3.4.3 The effects page

FX shows the effect chain:

- **The chain**, on the first line: the current sound (*S1*), its two inserts (*In1*, *In2*), the Mix page and the two master slots (*M1*, *M2*). The chosen one is highlighted, in gold while you have its effect picked up with **SEL**. The sound's number and its inserts that hold an effect are in the sound's own colour (below); an empty slot is dim.
- **The chosen slot's effect**, in rose, by its full name (*Compressor* for *Comp*), and on the right what the slot is: *insert*, *master* or *mix*. An empty slot reads *Empty*.
- **The chosen effect's parameters**, as rows and bars like the sound's page. An empty slot says *Empty slot: turn ALGORITHM* instead. The Mix page shows the four sounds' levels, each name and bar in that sound's colour; an empty sound's bar is left unfilled.

- The **bottom bar** shows the page and the slot, such as *1/2 M2*, or *1/2 S1 In1* for an insert.

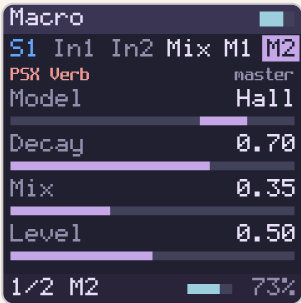


Figure 3.3 FX mode: Plate in M1 and PSX Verb in M2, chosen, with its first page on the knobs.

Each of the four sounds has a colour of its own wherever it is named: Sound 1 blue, Sound 2 orange, Sound 3 green and Sound 4 yellow-green, in the top bar's S2, the chain, the Mix page, the list of sounds, the sequencer's tracks and the modulation pages. The number always goes with the colour.

3.4.4 What the colours mean

Each colour on the screen means one thing, wherever it appears:

Colour	Means	Where you see it
Lilac	What is chosen, and the value you edit	Value bars, notes in the sequencer's grid, the highlighted row of a list or the matrix, the chosen slot in FX mode
Gold	Held or locked	Steps you hold, parameter locks and lanes, a module or effect picked up with SEL , REC during a count-in, a latched arpeggiator
Blue-green	A live signal, or modulation	The oscilloscope, the meters, PLAY, a modulated parameter's name and bracket, the matrix's sources
Rose	Where you are	The line under the top bar (the model, <i>Step 7</i> , <i>Lock step 6</i>) and a list's title
Red	Refused, recording, or over the limit	A message that refuses something, REC and STEP, a refused cable, the meters at their limit

Colour	Means	Where you see it
Grey	Labels and things at rest	Parameter names, a list's place, <i>Empty</i> , STOP
Blue, orange, green, yellow-green	Sounds 1 to 4	Beside the sound's number (above)

3.4.5 The sequencer, modulation and arpeggiator pages

SEQ shows the sequencer's steps, **LFO**, **ENV** and **EDIT** the modulation pages, and **ARP** the arpeggiator's. Chapters 7, 8 and 4 describe them.

3.4.6 The global page

GLO shows the sample rate, the block size, the share of the FM-1's free memory the sounds and effects take, in percent, the current sound's number of voices, the names of the two master effects (*M1* and *M2*), and the octave and transpose. The bottom bar reads *Globe*, the name M-VAVE's firmware gives this page. **SELECT** turns to a second page, *Key*, where **KNOB1** and **KNOB2** set the project key's root and scale, each opening its list as you turn it; they do so from *Globe* too, which then turns to *Key*. Chapter 10 describes both.

3.4.7 Lists

When you turn through a list, the list appears over the middle of the screen until about a second after your last turn: its name in rose at the top left, the chosen entry's place at the top right (such as 34/96), and its entries, the chosen one highlighted. A long list shows eight entries at a time in a smaller type; the four sounds, the quantize values and Capture's tempos and the arpeggiator's presets show all of theirs in the main type. The chosen entry sits on the third row, with the two before it above and the rest after it below; at either end of the list the rows stop moving and the highlight goes to the first or last row. A small triangle above the entries means the list goes on above them, one below them that it goes on below. *Empty* and *Empty slot* are dim. Entries go by their full names: where an engine's own name is short, the list spells it out (*Phase Distortion* for PhaseDist, *Triple Saw* for 3x Saw, *Compressor* for Comp).

List	When
<i>Engine</i> : the sound engines, after <i>Empty</i> on Sounds 2 to 4 (<i>S2 engine</i> and the like while more than one sound is in use)	You turn PRESETS
The engine's main list, such as <i>Model</i> or <i>Patch</i>	You turn ALGORITHM
A parameter's list, such as <i>Patch</i> , <i>Shape</i> or <i>Pad</i>	You turn the knob of a list parameter with five entries or more; a shorter one, such as <i>Off</i> and <i>On</i> , changes on its row
<i>Master 1 effect</i> , <i>S1 insert 1 effect</i> and the like: <i>Empty slot</i> , then every effect	You turn ALGORITHM in FX mode
<i>Current sound</i> : the four sounds and what each holds, each in its colour	You turn PRESETS with SEL held
<i>Mod3 kind</i> and the like: <i>Empty</i> , then the sixteen kinds	You turn ALGORITHM in the rack (chapter 8)
<i>Destination</i> : every parameter a cable can reach	You turn KNOB2 in the matrix (chapter 8)
<i>Clip quantize</i> : 0 %, the set's default and 100 %	You press white key 16 with SEL held in SEQ mode (chapter 7)
<i>Capture tempo</i> : the tempos a phrase fits	You capture while the sequencer is stopped (chapter 7)
<i>Arp preset</i> : the stock FM-1's six arpeggio modes	You turn ALGORITHM on the ARP pages (chapter 4)

3.4.8 Messages

Short messages appear for about a second. One that fits a line, such as *Volume 75* or *Metronome on*, is a band across the bottom of the page, which stays in view; a longer one covers the middle of the screen. A message that refuses something always covers the middle, its reason in red:

Message	When
<i>Volume 75</i>	You turn MASTER
<i>Octave +1</i>	You press OCT- or OCT+
<i>Transpose -2</i>	You turn ALGORITHM with OCT- or OCT+ held

Message	When
<i>Octave 0, Transpose 0</i>	You press OCT- and OCT+ together
An engine's name and <i>refuses 48000 Hz</i>	That engine cannot run at the sample rate the browser chose (chapter 2)
An engine's or effect's name, <i>does not fit</i> and what the chain would need, such as <i>needs 112% of RAM</i>	It would take the chain past the FM-1's memory (chapter 6)
A track, <i>Captured, Metronome on</i> and the like	The sequencer did something you asked (chapter 7)
A cable and its amount, such as <i>LFO1 > S2 Color +12%</i>	You make a cable (chapter 8)
<i>SAVED</i> and the project's name	You press SAVE : the project is kept in the browser
<i>NOT SAVED</i> and why	The page could not keep the project. Where the browser blocks storage, SAVE keeps it for this visit only, and the page says so

◆ A larger screen

Under the panel, **Screen ×2** shows a second copy of the screen at twice the size.

3.5 Connections

STATUS: ◆ Planned for the device

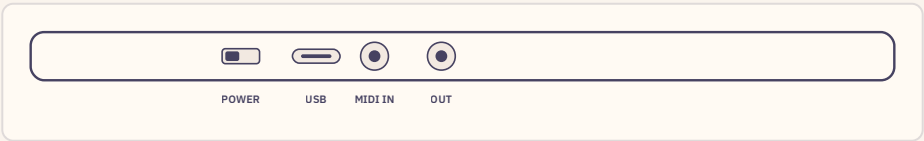


Figure 3.4 The top edge, seen from above with the keys towards you.

The connectors are on the edge above the screen. From left to right, seen from above with the keys towards you:

Connector	What it is	With Lunar Modulator
POWER	The power slide switch. While it is off, a computer does not see the FM-1 over USB	Unchanged. In the simulator, clicking the drawn switch turns the simulator on and off
USB	USB-C. With M-VAVE's firmware it charges the battery and carries MIDI and two channels of audio each way between the FM-1 and a computer	Planned: MIDI in and out, and the way Lunar Modulator will be installed (chapter 11). Whether it will also carry audio is not decided yet
MIDI IN	MIDI input on a 3.5 mm TRS jack. It receives only	Planned: MIDI input (chapter 9). Which kind of TRS adapter it expects has not been measured yet
OUT	Stereo audio output on a 3.5 mm jack, for headphones, an amplifier or a mixer	The instrument's output

The FM-1 also has a speaker of its own inside the case. For the battery and charging, follow M-VAVE's manual: Lunar Modulator changes neither.

CHAPTER 4

Playing

This chapter covers playing notes: the keys and how many notes sound at once, gliding between notes and playing one voice at a time, how hard you play, the octave and transpose controls, how notes end, pitch bend, and notes that arrive from a MIDI keyboard.

4.1 Keys and voices

STATUS: • In the simulator ■ On the desktop ◆ Planned for the device

Each key plays one note on the current sound for as long as you hold it ([chapter 5](#)); a note you hold keeps playing on its sound even if you choose another. Outside SEQ mode the notes also go to the sequencer’s focused track, for recording and Capture ([chapter 7](#)); chapter 5 draws the whole path from the keys to the output ([Four sounds at once](#)). A *voice* is one sounding note, and each engine has a fixed number of them, for each sound it plays:

Engine	Voices
Macro, FM6, Shapes, Sophie, Drums, Test Sine	12
Six-Op FM	8
Macro Heavy	4

A note keeps its voice while it fades out after you let go, so a fast run of notes can use more voices than the keys you are holding.

4.1.1 When every voice is busy

When you play a note and no voice is free, the engine takes one over:

- **Macro, Macro Heavy, Six-Op FM, FM6 and Shapes** take a voice whose key has already been let go, choosing the one whose note started first. If every key is still held, they take the note that started first.
- **Sophie** takes the hit that started longest ago.

- **Drums** takes the quietest hit, so an old cymbal that still rings loud keeps going. It first takes a hit that a hi-hat is cutting short.
- **Test Sine** ignores the new note until a voice is free.

On Macro, Macro Heavy, Six-Op FM, FM6 and Shapes, playing a key again while its note is still fading restarts that note in the same voice. On Sophie each hit gets a voice of its own. On Drums a pad struck again while it rings is struck again in its own voice, as a drum is.

● **Many notes at once**

Twelve voices playing loudly together can add up to more than the output can carry. The limiter after the effects turns the sum down so that it never clips (chapter 6).

4.2 Glide and voice modes

STATUS:  **In the simulator**  **On the desktop**  **Planned for the device**

Macro, Macro Heavy, Six-Op FM, FM6 and Shapes can slide from one note to the next, and can play one voice at a time, like a monophonic synthesizer. Four parameters do it, together on the engine's last page: page 4 of Macro and Macro Heavy, page 3 of the others.

Glide Mode chooses which notes slide:

Glide Mode	What slides
Off (the default)	Nothing. The engine plays exactly as it does without glide
Legato	Only a note you play while you hold another key: it starts at the pitch of the note you are holding and slides to its own. A note you play with no key held starts on its own pitch
Always	Every note: it starts at the pitch of the last note you played, held or not, and slides to its own. This is the stock FM-1's full-time portamento

The notes of a chord you strike together never slide from each other: each slides from the note before the chord. The very first note you play starts on its own pitch.

Glide sets how long the slide takes, from 1 ms to 5 seconds; the default is 100 ms. Turning it during a slide changes its speed for the rest of the way. **Time Mode** chooses what Glide means:

Time Mode	A slide takes
Time (the default)	The Glide time, whether the notes are a semitone or two octaves apart
Rate	The Glide time for each octave it covers: two octaves take twice as long as one, a fifth a little over half as long

Either way the slide moves evenly through the semitones.

Voice Mode chooses how notes take voices:

Voice Mode	A key you play while holding another	When you let go of the key that sounds while others are held
Poly (the default)	Plays as a note of its own, as usual; it slides as Glide Mode says	That note ends as usual
Mono	Takes over the one voice, which plays the new key and starts its sound again from the beginning	The voice goes back to the last key you are still holding, without starting again
Legato	Takes over the one voice without starting anything again: the note carries on at the new pitch, at the first note's loudness	As Mono

With Glide Mode on Legato or Always, every change of key in Mono and Legato slides, back to a held key included.

In the simulator, hold **SEL** and press **MONO** to choose Mono, and **MONO** again for Legato; **SEL** and **POLY** choose Poly. The screen names the mode, and while **SEL** is held **MONO** lights on Mono or Legato and **POLY** on Poly. In SEQ mode the two keys change track instead ([chapter 7](#)).

Changing any of the three modes never ends a note that is sounding, and a slide under way finishes as it began; the new setting applies from the next key you play or let go.

◆ **A classic mono lead**

Choose Voice Mode Legato, Glide Mode Legato and a Glide of about 100 ms, and play with overlapping notes: each overlap slides, and a detached note starts afresh. For the stock FM-1's portamento, where every note slides, choose Glide Mode Always instead.

The sequencer and modulation can change all four: a lock on any of them applies from its step, and a modulation route can sweep Glide's time ([chapter 7](#), [chapter 8](#)). Sophie and Drums have none of them: their keys play pads, each a sound of its own, rather than pitches.

4.3 Velocity

STATUS: ● In the simulator ■ On the desktop ◆ Planned for the device

Every note carries a velocity from 1 to 127 that says how hard it was played.

Where the note comes from	Its velocity
A key of the simulator, with the mouse or a touch screen	From 30 at the top of the key to 127 at its bottom edge
The computer keyboard	Always 100
A MIDI keyboard	The keyboard's own
The desktop tools	The velocity written in each --note

What velocity changes depends on the engine:

Engine	What a harder note does
Macro, Macro Heavy	Louder and brighter: velocity opens the low-pass gate further. The range is gentle, so soft notes stay clearly audible. On the models that sound by themselves (String, Modal and the drums) it sets how hard the sound is struck, and on spoken words how loud they are
Six-Op FM, FM6	Whatever the patch was programmed to do with velocity: depending on the patch, louder, brighter, both, or neither

Engine	What a harder note does
Shapes, Sophie, Test Sine	Louder
Drums	Louder and harder: how much, Accent sets

Whether the FM-1’s own keys can sense how hard they are played has not been measured yet.

4.4 Octave and transpose

STATUS:  In the simulator  Planned for the device

At the middle octave the keys play F3 to G5. You can move the keyboard by octaves, three at most either way, and transpose it by semitones, twelve at most either way.

To move the keyboard by an octave: press **OCT-** or **OCT+**. The screen shows the new octave, such as *Octave +1*.

To transpose: hold **OCT-** or **OCT+** and turn **ALGORITHM**. Each step is a semitone, and the screen shows the total, such as *Transpose -2*.

To return to the middle octave and cancel the transpose: press **OCT-** and **OCT+** together.

● Pressing an octave button to transpose

The octave changes as soon as you press **OCT-** or **OCT+**, so holding one to transpose also moves the keyboard an octave. Let go, then press the other button once to move the octave back: the transpose stays.

The note a key plays is

$$53 + \text{the key's position} + 12 \times \text{the octave} + \text{the transpose},$$

counting the lowest key as position 0. For example, at octave +1 with a transpose of -2, the lowest key plays $53 + 0 + 12 - 2 = 63$, D#4, instead of F3.

The lights in **OCT-** and **OCT+** show the octave: the button for the direction you moved lights up, with a slow blink one octave from the middle, a fast blink two away and a steady light three away. The transpose has no light; the global page (**GLO**) shows both the octave and the transpose.

A key you are holding keeps its note when you change the octave or the transpose: the change applies to the next key you press. The octave and transpose move the panel’s keys only; notes from a MIDI keyboard play as they arrive.

4.5 How notes end

STATUS:  In the simulator  On the desktop  Planned for the device

When you let go of a key, each engine ends the note in its own way:

Engine	While you hold the key	After you let go
Macro	The note sustains, through Plaits’ low-pass gate	It fades out as the gate closes; Decay sets how long that takes, Colour how much darker it gets as it fades
Macro Heavy, most models	As Macro	As Macro
Macro Heavy, String, Modal, the drums and spoken words	The sound rings or speaks by itself, and may end before you let go	Any sound still ringing fades out, over a time set by Decay and Colour
Six-Op FM	The patch’s own envelopes, scaled by Envelope	The patch’s release, scaled by Envelope
FM6	The voice’s own envelopes, run faster or slower by Env Time	The voice’s release, likewise. A voice whose release holds above silence (its last envelope level above 0) sounds until a new note takes its voice, as on the keyboards
Shapes	The note rises over the Attack time and then holds. The struck shapes, such as Pluck, Bell and Drum, also die away by themselves	It fades over the Release time
Sophie	Each hit rings for its pad’s Decay	Letting go changes nothing

Engine	While you hold the key	After you let go
Drums	Each hit rings for its pad’s decay; a closed or pedal hi-hat cuts the open one short	Letting go changes nothing
Test Sine	The note holds	It fades in 5 ms

Chapter 5 describes each of these controls.

4.5.1 Releasing every note

If a note keeps sounding, release everything at once:

- in the simulator, press Esc;
- from a MIDI keyboard, send control change 123, *all notes off*.

Every note then ends as if you had let go of its key, with its normal release, the sequencer’s notes on every sound included. Choosing another sound engine ends every note of that sound.

4.6 Pitch bend

STATUS:  In the simulator  On the desktop  Planned for the device

Pitch bend moves the pitch of every sounding note, and of notes played while it is held, up or down.

- **In the simulator**, the pitch-bend wheel of a MIDI keyboard bends the current sound by up to two semitones either way.
- **In the desktop tools**, `--bend T:SEMITONES` sets the bend from time *T*, by up to 48 semitones either way ([chapter 2](#)).
- **Sophie** ignores pitch bend; every other engine follows it.

The FM-1 has no pitch wheel, so on the device bend is planned to arrive over MIDI.

4.7 Playing from MIDI

STATUS:  In the simulator  Planned for the device

Notes, velocity and pitch bend from a MIDI keyboard play the current sound as the panel's keys do, and you can play both at once. Notes from MIDI also go to the sequencer, in every mode: in SEQ mode a note adds its pitch to the steps you hold ([chapter 7](#)). The simulator listens on every MIDI channel; control change 7 sets the volume like **MASTER**, and control change 123 releases every note. [Chapter 9](#) lists everything the simulator receives.

On the FM-1, Lunar Modulator is planned to receive MIDI over USB and at the 3.5 mm **MIDI IN** jack. The FM-1 also has Bluetooth, which M-VAVE's firmware uses for MIDI; whether Lunar Modulator will use it is not decided yet.

4.8 Arpeggiator

STATUS:  In the simulator  On the desktop  Planned for the device

The arpeggiator plays the notes you hold one after another, in time with the sequencer's tempo. Each of the four sounds has its own; **ARP** works on the current sound.

- **Tap** **ARP** to switch it on. Its pages open, and its light comes on. Tap it again on its pages to switch it off; the pages close, and the notes it was playing stop at once.
- **Hold** **ARP** for half a second to latch: the notes keep playing after you let go of the keys, and the next chord you play replaces them. Notes added while you still hold keys join the chord. Hold **ARP** again to stop latching. Holding it also switches the arpeggiator on, latched. While it latches, its light blinks once a second.
- **SEL** and **ARP** opens its pages without switching it.

Notes from the keys, from MIDI and from the sequencer's tracks that play this sound all go through the arpeggiator while it is on. A note you were holding before you switched it on goes on sounding until you let go.

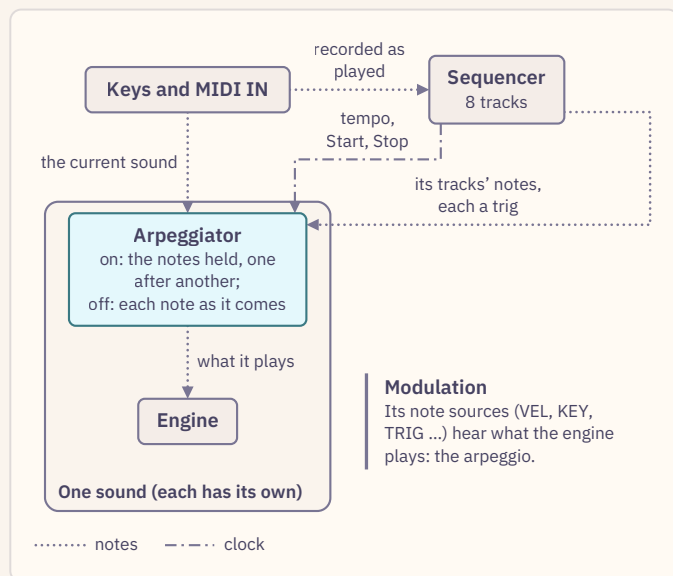


Figure 4.1 Where the arpeggiator sits. While it is on it takes every note headed for its sound, from the keys, MIDI IN and the sequencer, and plays the arpeggio on the sound's tempo; the sequencer records the keys as you played them.

The arpeggiator remembers where each note came from: your hands (the keys and MIDI) or the sequencer. While it latches, the two latch apart. A new chord of yours replaces the chord you latched, and a new note from the sequencer replaces the sequencer's; the arpeggiator plays both together.

4.8.1 The ARP pages

Turn **SELECT** for the page. **KNOB1** to **KNOB4** set the four values on it, and **ALGORITHM** steps through the stock FM-1's arpeggio modes: Up, Down, Up/Down, Down/Up, Random and Played.

The line under the top bar says *Arp on* (rose), *Arp latched* (gold, the colour of what is held) or *Arp off* (grey), with the stock mode the settings make on the right, such as *Up*, when they make one. **ALGORITHM** shows the six modes as a list, and turning the knob of Mode, Rate, Pattern, Oct Mode or Repeat shows that value's list ([chapter 3](#)).

Page	KNOB1	KNOB2	KNOB3	KNOB4
1 PLAY	Mode: the order of the notes	Rate: how long a step is, 1/32 triplet to a whole note, or TRG	Gate: how long each note sounds, 1 to 200 % of the step	Octaves: 1 to 4
2 RHYTHM	Pattern: every step, or one of 22 rhythms	Fill: the beats of a Euclidean rhythm	Rotate: where it starts	Length: the Euclidean rhythm's steps; 0 uses Pattern
3 CHANCE	Chance: how likely a step is to play	Ratchet: notes inside a step, 1 to 4	Vel Spread: random velocity, up and down	Loop: after this many steps the chances repeat; 0 never
4 FEEL	Oct Mode: how the octaves combine with the mode	Velocity: as played, or fixed	Join: keys added to a playing chord join now, or at the next pass	
5 MORE	Order: notes sorted by pitch, as played, or reversed	Repeat: steps per note	Chord %: how likely a step is to play the whole chord	Oct Jump: how likely a note is an octave up
6 KEYS	Latch	Sync: the first key restarts the pattern, or the pattern runs on	Ratchet %: how likely a step is to ratchet	Gate Sprd: random gate length
7 SEED	Seed: which random choices the chances make			

The modes are Up, Down, Up-Down, Down-Up, Up&Down and Down&Up (which play the top and bottom notes twice), Converge and Diverge, Converge-Diverge (Conv-Div on the page), Thumb and Pinky (the lowest or highest note between the others), four modes that add octaves to some notes only, Crawl, Random, Shuffle (each note once per pass, in a new order), Walk (a random step to a neighbour) and Chord. The same Seed makes the same choices every time, so a random arpeggio repeats exactly.

TRG (Trigger in Rate's list), at the left end of Rate, plays one step each time the sequencer starts notes on this sound (a trig), however far apart the trigs are. The keys

alone do not step it. Its first note lasts until the next trig; after that, Gate is a share of the time between the last two.

4.8.2 With the sequencer

The arpeggiator follows the sequencer’s tempo whether the sequencer plays or not.

- **On the beat.** While the sequencer plays, the arpeggiator’s steps fall on the sequencer’s beat: at 1/16, on every sixteenth note of the bar, counted from **PLAY/STOP**. A key you press between two steps waits for the next one, and so does an arpeggiator you switch on in the middle of a bar. Triplet steps fall on the triplets of the beat, and the set’s swing delays every second step on the same grid. A dotted rate, such as 1/16D, finds the bar line again after a few bars (1/16D after three).
- **Stopped.** While the sequencer is stopped, the arpeggiator runs from its own steps at the sequencer’s tempo, and a first key starts it at once.
- **Swing.** The arpeggiator has no swing of its own: it swings with the set, by the Swing on the sequencer’s Set page ([chapter 7](#)), playing or stopped. A file saved before it followed the set loads as before; its old arpeggiator Swing value is kept in the file’s data but no longer does anything.
- **PLAY/STOP** restarts the pattern on the first beat.
- **When the sequencer stops**, it takes back what it gave the arpeggiator: its notes leave the chord, latched or not, and a note they were playing stops at once. The notes you play or latched by hand go on playing.

Sync, on the KEYS page, says what a first key, one played into an empty chord, does to the pattern’s place: where its rhythm, its Loop and its chances are. Either way the new chord’s notes start from the first.

Sync	While the sequencer plays	While it is stopped
Key	The pattern starts again at the next step on the beat	The pattern starts again at once
Free	The pattern runs on from PLAY/STOP , and the key joins it at the next step on the beat, so a rhythm such as a Euclidean pattern stays on the bar. An arpeggiator switched on after PLAY/STOP keeps its own count of the pattern, which need not match the bar, until the next PLAY/STOP	The pattern runs on from its own last step, and the key waits for the next of them

The arpeggiator does not use the project key, which the global page sets ([chapter 10](#)); it is there for the MIDI effects to come.

The sequencer records the notes you play, not the arpeggio. A part recorded with the arpeggiator on plays back through it again, so you can change the arpeggio afterwards, or switch it off and hear the notes as you played them.

The arpeggiator takes memory only while it is on. When the sounds and effects leave too little, **(ARP)** says *does not fit* and what the chain would need with it, such as *needs 101% of RAM*.

4.8.3 Acid Gen

STATUS:  In the simulator  On the desktop  Planned for the device

Acid Gen writes acid basslines: it is TB-3PO, the line generator of fm1-x0x, Charles Vestal's firmware for the FM-1, after the TB_3PO applet of the Phazerville Hemisphere Suite ([chapter 14](#)). It takes the arpeggiator's place: on the ARP pages, turn **(ALGORITHM)** past the stock modes to *Acid Gen*; turning back to a mode brings the arpeggiator back. **(ARP)** then switches Acid Gen on and off, and holding it latches, as for the arpeggiator. It is made for [Acid Bass](#) and plays any sound.

● In builds with the GPL switch on

Acid Gen's code is published under the GNU General Public License, so it is there only while the firmware's GPL switch is on: in the simulator while we test ([chapter 14](#)).

- **Hold a key** and a line plays, sixteenths in A minor to begin with, starting from the key you hold: hold another key and the line moves there. Let go and it stops, unless Latch is on.
- Each line comes from a **seed**: the same Seed and settings always play the same line, so a song keeps it. Turn **Seed** for a new one. **Mutations** changes about a quarter of the steps, once for each step of the knob; **Mut Every** does that by itself every so many passes.
- **Density** sets how many steps play, **Accent** how many are accented, **Slide** how many slide into the next note.
- Accented notes are played at velocity 118, the others at 72, and a slide holds its note into the next one, so Acid Bass accents and slides them.

Page	KNOB1	KNOB2	KNOB3	KNOB4
1 LINE	Density	Accent	Slide	Octaves: how far the notes spread, 1 to 3
2 KEY	Root: the key, or Project to follow the project's	Scale: Minor, Phrygian, Harm Minor, Min Pent, Dorian or Major, or Project	Octave: where the root sits	Keys: Transpose (hold a key to play) or Run (play while the sequencer plays)
3 PLAY	Rate: 1/16, 1/16T, 1/32 or 1/8T	Length: 1 to 32 steps	Direction: Forward, Reverse, Ping-Pong or Random	Latch
4 SEED	Seed	Mutations	Mut Every: passes between automatic mutations, or 0	

With Keys at **Run**, the line plays from its first step when the sequencer starts and stops with it; a key you hold, or a note the sequencer plays on this sound, moves it to that note while it sounds.

4.8.4 In the desktop tools

`--mfx K:arp` puts the arpeggiator in front of sound *K* (0 is `--engine`), and `--mfx-param K:NAME=VALUE` sets a value; a list's value is its position, from 0. `--mfx-on-at K:T:0` switches it off at time *T*, and `:1` on; `--mfx-param-at K:T:NAME=VALUE` changes a value then. `--log-mfx FILE` writes every note it plays ([chapter 2](#)). `--mfx K:acid-gen` puts Acid Gen there instead, and `--key ROOT:SCALE` sets the project key it follows (*ROOT* 0 for C to 11 for B, *SCALE* 0 major or 1 minor).

CHAPTER 5

Sound engines

A sound engine is the part of the firmware that makes the notes. Lunar Modulator has several, each a different kind of synthesis, and up to four sounds, each with an engine of its own, play at once ([Four sounds at once](#)). You choose the current sound’s engine with **PRESETS**. The knobs then play that engine’s parameters, four to a page: **SELECT** turns the page and **ALGORITHM** steps through the engine’s main list.

Sound engines in this build				
Name	Voices	Parameters	Chosen from a list	Built from
Macro	12	15	Model, LPG, Voice Mode, Glide Mode, Time Mode	Engines from Mutable Instruments Plaits by Emilie Gillet (MIT)
Shapes	12	10	Shape, Voice Mode, Glide Mode, Time Mode	Macro-oscillator from Mutable Instruments Braids by Emilie Gillet (MIT)
Macro Heavy	4	16	Model, LPG, Voice Mode, Glide Mode, Time Mode	Heavy engines from Mutable Instruments Plaits by Emilie Gillet (MIT)
Six-Op FM	8	8	Patch, Voice Mode, Glide Mode, Time Mode	Six-operator FM engine from Mutable Instruments Plaits by Emilie Gillet (MIT); DX7 patch banks as distributed with Plaits
FM6	12	9	Patch, Voice Mode, Glide Mode, Time Mode	Six-operator FM on msfa, the FM core of Google's music-synthesizer-for-android (Google, Apache-2.0); named after Felucca's FM6 engine (hugelton), both borrowed with thanks; reads DX7 voice data (a Yamaha trademark; not affiliated); built-in voices our own
Sophie	12	8	Pad, Model	Sophie by Matt Estela (github.com/mestela/schwung-sophie, MIT), via the Schwung v2 shim (Schwung plugin ABI by Charles Vestal, MIT)

Name	Voices	Parameters	Chosen from a list	Built from
Drums	12	14	Pad, Model, Kit, Choke	Kick, tom, snare and hi-hat voices from Mutable Instruments Plaits by Emilie Gillet (MIT); rim, clap, cowbell and cymbal from this repository (MIT), after Werner, Abel and Smith's TR-808 cowbell and cymbal models
Acid Bass	1	12	Wave, Drive Type	A bass after the TB-303: fm1-x0x's 303 by Charles Vestal (GPL-3.0), ported from schwung-303: Open303 by Robin Schmidt (MIT), Devilfish ranges after jc303 by midilab (GPL-3.0), RAT drive after dm-Rat by Dave Mollen (GPL-3.0)
Comet Kit	11	13	Pad, Drive Type, Kit	A kit after the TR-909: fm1-x0x's 909 by Charles Vestal (GPL-3.0), ported from 9W9 by athousanddetails (GPL-3.0), which grew out of ER-99 by Matthew Cieplak (GPL-3.0); hi-hat, crash and ride recordings from ER-99 (GPL-3.0)
Crater Kit	13	11	Pad, Dist, Choke	A kit after the TR-808: fm1-x0x's 808 by Charles Vestal (GPL-3.0), ported from 8W8 by athousanddetails (GPL-3.0): circuit models after the TR-808 service notes and Werner, Abel and Smith; the rim shot after sc808 by Yoshinosuke Horiuchi and Sam Aaron (MIT)
Drawbar	8	13	Drawbars, Perc, Rotor	Felucca by Leo Kuroshita (@kurogedelic), Hugelton Instruments (GPL-3.0): its WHEEL engine, a tonewheel-style organ of its own design
Trio	8	14	Wave, Mode	Felucca by Leo Kuroshita (@kurogedelic), Hugelton Instruments (GPL-3.0): its TRIO engine, three oscillators and a filter in the style of 8-bit sound chips

Name	Voices	Parameters	Chosen from a list	Built from
Phase Bend	8	16	Wave, Wave 2, Line, Voice Mode, Glide Mode, Time Mode	Felucca by Leo Kuroshita (@kurogedelic), Hugelton Instruments (GPL-3.0): its PHASE engine, a port of the phase-distortion oscillator of CrispyZebra by the same author (GPL-3.0)
Test Sine	12	1	—	This repository (MIT)

Four of the engines are built from the code of Mutable Instruments’ modules, written by Emilie Gillet and published under the MIT licence, and Drums takes its kicks, toms, snares and hi-hats from it; FM6 comes from msfa, the FM synthesizer core Google published under the Apache licence; Sophie comes from the Schwung community. Their names here are this project’s own, and [chapter 14](#) credits each source.

● **How to read the tables**

The tables in this chapter are generated from the firmware’s code. *Where* says on which page, and under which knob, a parameter sits: page 1, KNOB2 is the second knob on the first page. A *list* parameter steps through named values, numbered from 0; a *continuous* one moves smoothly across its range. The default is the value an engine starts with. The screen rounds what it shows: two decimals for a range of up to 2, one decimal up to 20, whole numbers beyond.

5.1 Choosing an engine

STATUS:  In the simulator  Planned for the device

To choose an engine: turn **PRESETS**. The engines come in this order: Macro, Shapes, Macro Heavy, Six-Op FM, FM6, Sophie, Drums, Acid Bass, Comet Kit, Crater Kit, Drawbar, Trio, Phase Bend, Test Sine, and round again. Acid Bass, Comet Kit, Crater Kit, Drawbar, Trio and Phase Bend are there only in builds with the GPL switch on, as the simulator is while we test ([Acid Bass](#), [Comet Kit](#), [Crater Kit](#), [Drawbar](#), [Trio](#) and [Phase Bend](#)). While you turn, the screen lists the engines, eight at a time, with the new one highlighted ([chapter 3](#)). In the simulator you can also pick one from the **Sound (PRESETS)** list under the panel.

When you choose an engine:

- every note that was sounding on that sound ends; the other sounds play on;
- the new engine starts with its default settings, so changes you made to the previous engine are not kept;
- the effects keep their settings;
- the screen stays on the same page if the new engine has that many pages, and goes to its last page otherwise.

Every engine but Sophie has a **Volume** parameter, its own output level, on its second page (on Drums, its fourth; on Comet Kit and Crater Kit, their third). It is separate from **MASTER**, which sets the level of everything. Macro, Macro Heavy, Six-Op FM, FM6 and Shapes also have **Glide**, **Voice Mode**, **Glide Mode** and **Time Mode**, together on their last page, for sliding between notes and playing one voice at a time ([chapter 4](#)).

● Engines that need the FM-1's sample rate

Macro, Macro Heavy, Six-Op FM and Drums run Plaits' code at its own rate, 47,872 samples a second, and convert the result to the output's rate. They cannot run when the output is faster than that. If your browser runs the simulator at 48,000 samples a second, **PRESETS** steps over those four and the screen names the one it skipped ([chapter 2](#)). Crater Kit, Drawbar, Trio and Phase Bend, built for 44,100 samples a second, run only near that rate (Crater Kit from 44,000 to 44,200, the other three within a quarter of a percent), and are stepped over at others in the same way.

5.2 Four sounds at once

STATUS: ● In the simulator ■ On the desktop ◆ Planned for the device

Up to four sounds play at once, each an engine of its own with two insert effects and a level into the mix; the mix then goes through the two master effects ([chapter 6](#)). Sound 1 always holds an engine; Sounds 2 to 4 can be empty, as they are when the simulator starts. The sequencer's tracks play whichever sound their route names ([chapter 7](#)).

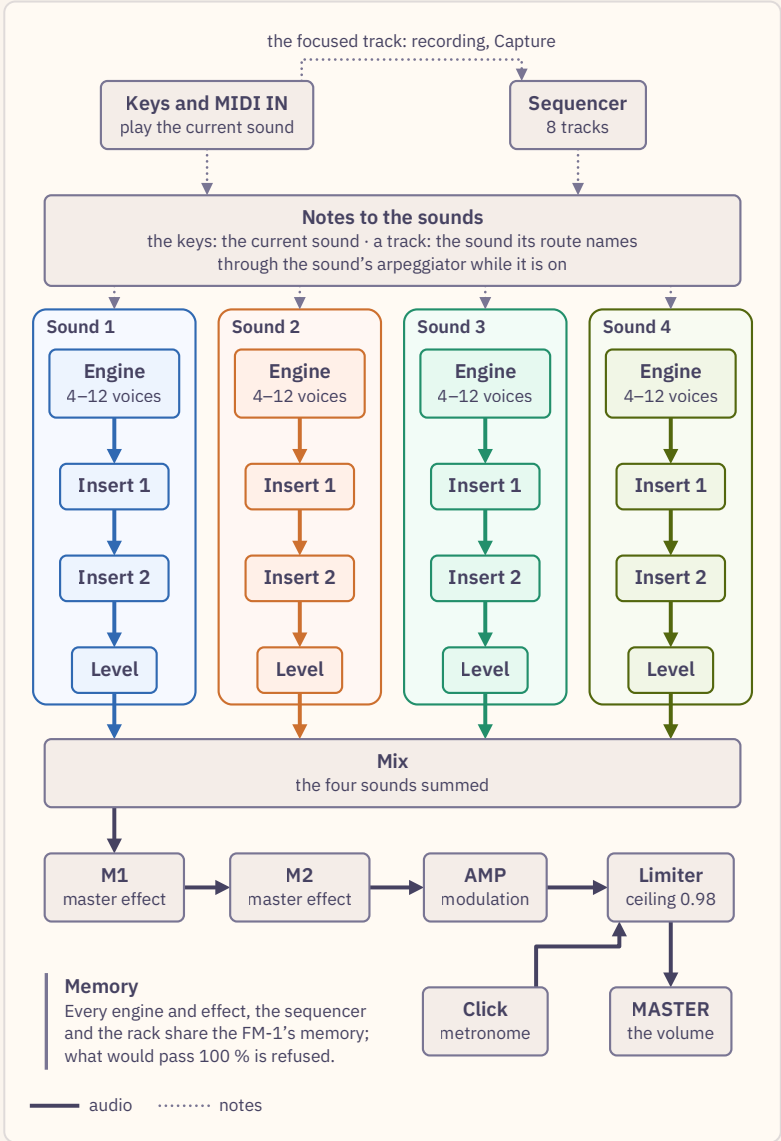


Figure 5.1 Where notes go and how the sound comes out: the keys, MIDI IN and the sequencer's eight tracks play the four sounds, through each sound's arpeggiator while it is on; each sound runs through its two inserts and its level into the mix, then the two master effects, AMP, the limiter and MASTER.

The **current sound** is the one the keys and **MIDI IN** play, and the one the sound's page, **PRESETS**, **ALGORITHM** and the knobs edit.

- **To choose it:** hold **SEL** and turn **PRESETS**: Sound 1 to 4. The screen lists the four sounds and the engine each holds, such as *S2 Shapes* or *S3 Empty*, with the current one highlighted. **SEL** has this job everywhere but in FX mode, where it picks up effects.
- **To give it an engine:** turn **PRESETS**. On Sounds 2 to 4 the list starts with *Empty*, which unloads that sound.
- Once a second sound is in use, the top bar names the current one, such as *S2 Shapes*.
- Focusing a sequencer track makes the sound it plays the current one ([chapter 7](#)); you can choose another afterwards.
- A key you hold, or a note at **MIDI IN**, is released on the sound it started on, even after you choose another.
- In the simulator, the **Sound (PRESETS)** list under the panel is the current sound's, and its label names it.

Each sound's level, from 0 to 100 %, is on the Mix page in FX mode ([chapter 6](#)). Every sound counts against the FM-1's memory, and a sound that would not fit is refused ([chapter 6](#)): *Shapes* twice, for one, does not fit.

In the desktop tools, `--sound K:ID` loads sound *K*, `--sound-note` plays a note on it and `--level K:PCT` sets its level ([chapter 2](#)).

5.3 Macro

STATUS:  **In the simulator**  **On the desktop**  **Planned for the device**

Macro is eight synthesizers in one, from Mutable Instruments Plaits: a virtual-analogue voice with a filter, phase distortion, wave terrain, a chiptune voice, a pair of analogue oscillators, a waveshaper, two-operator FM and a wavetable. Each note passes through Plaits' low-pass gate, which ties the note's brightness to its level, so that it darkens as it fades, as acoustic instruments do.

- **Model** chooses one of the eight. **ALGORITHM** steps through them, and so does **KNOB1** on page 1. Changing the model ends the notes that are sounding.

- **Harmonics, Timbre** and **Morph** are Plaits’ three sound controls. What each one does depends on the model (below).
- **Decay** sets how long a note takes to fade after you let go of the key. While you hold a key, the note sustains.
- **Colour** sets how much the low-pass gate darkens the note as it fades: at the left the tone closes down with the level, like a plucked string; at the right only the level falls.
- **Volume** is the engine’s output level.
- Playing harder makes a note louder and brighter.
- Page 3 holds Plaits’ own envelope, which every note restarts and Decay shortens or lengthens:
- **Env Pitch, Env Timbre** and **Env Morph** set how far it moves the note, Timbre and Morph, from nothing in the middle to the most at either end, to the right upwards and to the left downwards. A short Decay with some Env Pitch gives a falling zap or a drum-like thump. On Chip, Env Timbre sets the arpeggio’s own fade instead: the further from the middle, the shorter each note.
- **LPG** chooses how the low-pass gate plays: **Gate** follows the key, as described above; **Ping** strikes the gate at each key press and lets it close over the Decay time even if you hold the key, like a plucked or struck sound; **Off** takes the gate out, so the note keeps its full brightness and only its level fades after you let go.
- Page 4 holds **Glide, Voice Mode, Glide Mode** and **Time Mode**: how notes slide from one to the next, and one-voice playing ([chapter 4](#)).

Model	Harmonics	Timbre	Morph
VA+Filter: an analogue-style waveform through a resonant low-pass filter	The filter’s character: a steeper slope on the left, a gentler one on the right, and more resonance the further from the middle	The filter’s cutoff	The waveform: sawtooth on the left, square in the middle, a narrowing pulse towards the right; near either end a sub-oscillator an octave down joins in
PhaseDist: phase-distortion synthesis	The frequency of the distortion, in steps of musical ratios	The amount of distortion	The asymmetry of the distortion
Terrain: the waveform is read along a circular path over a surface	Which of eight terrains, blending between neighbours	The size of the path	Where the path sits on the terrain

Model	Harmonics	Timbre	Morph
Chip: a chiptune voice with an arpeggiator	The chord the arpeggiator plays	The arpeggio: up, down, up and down, or random, over one, two or four octaves	Below the middle, a pulse-width effect; above it, hard sync
VA Pair: two classic oscillators	The detuning between them	The first oscillator: from a narrow pulse to a square, then hard-sync formants	The second oscillator: from a triangle to a sawtooth with a widening notch
Shaper: a waveshaper and wavefolder	The waveshaper's curve	How much the wave is folded	The waveform's asymmetry, from triangle to sawtooth
2-op FM: two operators, one modulating the other	The frequency ratio between them	The modulation amount	Feedback: towards the right the second operator modulates itself, for a rough tone; towards the left it feeds back into the first, for chaotic tones; none in the middle
Wavetable: banks of waveforms on an 8 × 8 grid	Which bank. In the first half of its range the waves blend smoothly; in the second they step from one to the next, for a grainier sound	The row in the bank	The column in the bank

● **Chip, the arpeggiating model**

Each key press on Chip plays the next note of the arpeggio, a chord built on the key you press. Strike one key repeatedly and the notes walk through the chord. Each voice keeps its own place in the pattern, so the first notes of a chord played across several keys may start at different places.

◆ **Starting points**

- **Bass:** VA+Filter with Morph at the left, a sawtooth with its sub-oscillator, Timbre low and Decay low.
- **Pads:** VA Pair with Decay high, and Ensemble then Plate in the effect slots (chapter 6).

Macro’s output is mono; the effects spread it in stereo. 2-op FM is the heaviest of its models for the processor, and the others are light.

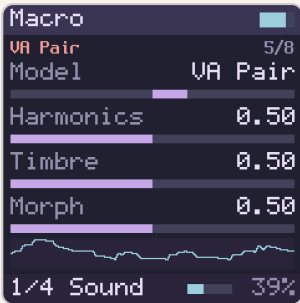


Figure 5.2 Macro on its VA Pair model, page 1, while a chord sounds.

Macro: what the four knobs do on each page				
	Knob1	Knob2	Knob3	Knob4
Page 1	Model	Harmonics	Timbre	Morph
Page 2	Decay	Colour	Volume	–
Page 3	Env Pitch	Env Timbre	Env Morph	LPG
Page 4	Glide	Voice Mode	Glide Mode	Time Mode

Macro parameters				
Parameter	Where	Type	Range	Default
Model	Page 1 · Knob1	List, 8 values	0 – 7	0 VA+Filter
Harmonics	Page 1 · Knob2	Continuous	0 – 1	0.5
Timbre	Page 1 · Knob3	Continuous	0 – 1	0.5

Parameter	Where	Type	Range	Default
Morph	Page 1 · KNOB4	Continuous	0 – 1	0.5
Decay	Page 2 · KNOB1	Continuous	0 – 1	0.5
Colour	Page 2 · KNOB2	Continuous	0 – 1	0.5
Volume	Page 2 · KNOB3	Continuous	0 – 1	0.7
Env Pitch	Page 3 · KNOB1	Continuous	-1 – 1	0
Env Timbre	Page 3 · KNOB2	Continuous	-1 – 1	0
Env Morph	Page 3 · KNOB3	Continuous	-1 – 1	0
LPG	Page 3 · KNOB4	List, 3 values	0 – 2	0 Gate
Glide	Page 4 · KNOB1	Continuous, logarithmic	1 – 5000 ms	100 ms
Voice Mode	Page 4 · KNOB2	List, 3 values	0 – 2	0 Poly
Glide Mode	Page 4 · KNOB3	List, 3 values	0 – 2	0 Off
Time Mode	Page 4 · KNOB4	List, 2 values	0 – 1	0 Time

Model values

- 0 VA+Filter

1 PhaseDist

2 Terrain
- 3 Chip

4 VA Pair

5 Shaper
- 6 2-op FM

7 Wavetable

LPG values

- 0 Gate
- 1 Ping
- 2 Off

Voice Mode values

- 0 Poly
- 1 Mono
- 2 Legato

Glide Mode values

- 0 Off
- 1 Legato
- 2 Always

Time Mode values

0 Time

1 Rate

12 voices · Identifier `macro` · Engines from Mutable Instruments Plaits by Emilie Gillet (MIT)

5.4 Macro Heavy

STATUS: • In the simulator ■ On the desktop ◆ Planned for the device

Macro Heavy holds the larger Plaits models: a string machine, chords, speech, formants, additive synthesis, a swarm of oscillators, filtered noise, particles, a modelled string, a modal resonator and three drums. Each voice needs much more memory than Macro's, so Macro Heavy plays four notes at once.

- **Model, Harmonics, Timbre, Morph, Decay, Colour** and **Volume** work as in Macro. Changing the model ends the notes that are sounding.
- **Word Speed**, on page 2, sets how fast the Speech model says its words: from a quarter of the normal speed at the left, through normal at 0, to four times as fast at the right.
- Page 3 works as in Macro. On Speech, Env Pitch also lets a spoken word's own pitch contour through. With LPG on Ping, String, Modal and the drums ring out after you let go, instead of fading.
- Page 4, **Glide, Voice Mode, Glide Mode** and **Time Mode**, works as in Macro. On Legato a string, a modal sound or a drum is not struck again when you play over a held key, and a word goes on; on Mono it is.
- **String, Modal, Bass Drum, Snare and Hi-Hat** sound by themselves: a key press strikes them, and they ring for as long as Morph sets. Speech, when it says words, says one word per key press. When you let go of the key, Decay and Colour set how quickly whatever is still sounding fades.
- Str Machine plays in stereo. The other models are mono.

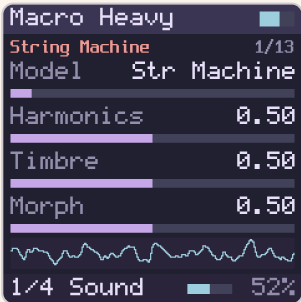


Figure 5.3 Macro Heavy on Str Machine, page 1.

Model	Harmonics	Timbre	Morph
Str Machine: a string machine playing a chord on each key, through a filter and an ensemble	The chord	Brightness, with more ensemble towards either end	The registration: sawtooth footages on the left, square ones on the right
Chords: a chord on each key	The chord	Inversion and transposition	On the left half, mixes of square and sawtooth harmonics, like an organ or a string machine; on the right half, waveforms from a wavetable
Speech: vowels and words	Formant vowels, then early computer-speech vowels, then LPC vowels; above about 0.44, banks of spoken words	The size of the voice, from deep to squeaky	The vowel, or which word of the bank
Formant: two formants over a carrier	The ratio between the two formants	The formant frequency	The formants' width and shape
Additive: a spectrum of harmonics	How many bumps the spectrum has	Which harmonic is strongest	The shape of the bumps, from flat and wide to peaked and narrow
Swarm: a cloud of enveloped sawtooth grains	How far the grains' pitches scatter	How dense the cloud is	The grains' length and overlap

Model	Harmonics	Timbre	Morph
Filt Noise: noise through a resonant filter	The filter’s response: low-pass, band-pass, high-pass	The noise’s clock rate	The resonance
Particle: random clicks through filters	How far the particles’ pitches scatter	How dense the particles are	Below the middle a reverberating diffuser; above it, increasingly resonant band-pass filters
String: a plucked, inharmonic string	Inharmonicity, or the material	The brightness of the excitation, and the amount of dust in it	How long it rings
Modal: a struck resonator, such as a bar, a bell or a plate	Inharmonicity, or the material	The brightness of the excitation, and the amount of dust in it	How long it rings
Bass Drum: an analogue-style kick	How sharp the attack is, and how much overdrive	Brightness	How long it rings
Snare: an analogue-style snare	The balance of tone and noise	The balance between the drum’s modes	How long it rings
Hi-Hat: an analogue-style hi-hat	The balance of metallic tone and noise	The cutoff of its high-pass filter	How long it rings

◆ **Speaking a word**

Set Speech’s Harmonics above the middle to choose a bank of words, and Morph to choose the word. Each key press says it once, on the key’s pitch. Word Speed makes it faster or slower without changing its pitch.

◆ **Drums on a keyboard**

The drums, String and Modal ring by themselves while you hold the key, and fade over the Decay time when you let go. For short taps that still ring out, raise Decay. With four voices, a fifth note takes over one that is already sounding.

Macro Heavy: what the four knobs do on each page				
	Knob1	Knob2	Knob3	Knob4
Page 1	Model	Harmonics	Timbre	Morph
Page 2	Decay	Colour	Volume	Word Speed
Page 3	Env Pitch	Env Timbre	Env Morph	LPG
Page 4	Glide	Voice Mode	Glide Mode	Time Mode

Macro Heavy parameters				
Parameter	Where	Type	Range	Default
Model	Page 1 · Knob1	List, 13 values	0 – 12	0 Str Machine
Harmonics	Page 1 · Knob2	Continuous	0 – 1	0.5
Timbre	Page 1 · Knob3	Continuous	0 – 1	0.5
Morph	Page 1 · Knob4	Continuous	0 – 1	0.5
Decay	Page 2 · Knob1	Continuous	0 – 1	0.5
Colour	Page 2 · Knob2	Continuous	0 – 1	0.5
Volume	Page 2 · Knob3	Continuous	0 – 1	0.7
Word Speed	Page 2 · Knob4	Continuous	-1 – 1	0
Env Pitch	Page 3 · Knob1	Continuous	-1 – 1	0
Env Timbre	Page 3 · Knob2	Continuous	-1 – 1	0
Env Morph	Page 3 · Knob3	Continuous	-1 – 1	0
LPG	Page 3 · Knob4	List, 3 values	0 – 2	0 Gate
Glide	Page 4 · Knob1	Continuous, logarithmic	1 – 5000 ms	100 ms
Voice Mode	Page 4 · Knob2	List, 3 values	0 – 2	0 Poly
Glide Mode	Page 4 · Knob3	List, 3 values	0 – 2	0 Off
Time Mode	Page 4 · Knob4	List, 2 values	0 – 1	0 Time

Model values		
0 Str Machine	2 Speech	4 Additive
1 Chords	3 Formant	5 Swarm

6 Filt Noise
7 Particle
8 String

9 Modal
10 Bass Drum
11 Snare

12 Hi-Hat

LPG values

0 Gate

1 Ping

2 Off

Voice Mode values

0 Poly

1 Mono

2 Legato

Glide Mode values

0 Off

1 Legato

2 Always

Time Mode values

0 Time

1 Rate

4 voices · Identifier `macro-heavy` · Heavy engines from Mutable Instruments Plaits by Emilie Gillet (MIT)

5.5 Six-Op FM

STATUS: • In the simulator ■ On the desktop ◆ Planned for the device

Six-Op FM is a six-operator FM synthesizer in the tradition of the classic 1980s FM keyboards, from Plaits' six-operator engine, with the 96 patches that Plaits ships in three banks of 32. Each patch is a complete sound with its own algorithm, envelopes and velocity response. **ALGORITHM** steps through the patches, and the knobs adjust the one you have chosen.

- **Patch** chooses one of the 96. Its name starts with its bank, 1 to 3. A new patch applies to the next note you play; notes already sounding keep theirs.

- **Brightness** scales the modulating operators: below the middle the sound is softer, above it brighter and harsher. In the middle the patch plays as programmed.
- **Envelope** scales the patch’s envelope times. Attacks and decays are shorter towards the left and longer towards the right, and play as programmed in the middle. Releases play as programmed a little left of the middle, at 0.3, and grow longer either side of it: at the default, 0.5, they last about three times as long as programmed.
- **Volume**, on page 2, is the engine’s output level.
- Page 3 holds **Glide**, **Voice Mode**, **Glide Mode** and **Time Mode**, which slide between notes and play one voice ([chapter 4](#)). On Legato a note played over a held one does not restart the patch’s envelopes.
- Eight notes play at once.



Figure 5.4 Six-Op FM on its default patch, 2 E.PIANO
1. Its first page has three controls.

The banks:

Bank	Patch numbers	What is in it
1	0 – 31	Basses, analogue-style synthesizers, leads, textures and effects
2	32 – 63	Electric and acoustic pianos, clavinetts, plucked strings, mallets, bells, drums and percussion
3	64 – 95	Organs, pads, textures, strings and brass

● Patch names

A few of the stored patch names are trademarks or a person’s name. Public builds show those patches under descriptive names of this project’s own; the sound is the same.

◆ Shaping a patch

Turn Envelope left for snappier attacks and quicker decays, and right to slow them into swells. Brightness works like a tone control for the whole patch.

Six-Op FM: what the four knobs do on each page

	Knob1	Knob2	Knob3	Knob4
Page 1	Patch	Brightness	Envelope	–
Page 2	Volume	–	–	–
Page 3	Glide	Voice Mode	Glide Mode	Time Mode

Six-Op FM parameters

Parameter	Where	Type	Range	Default
Patch	Page 1 · Knob1	List, 96 values	0 – 95	32 2 E.PIANO 1
Brightness	Page 1 · Knob2	Continuous	0 – 1	0.5
Envelope	Page 1 · Knob3	Continuous	0 – 1	0.5
Volume	Page 2 · Knob1	Continuous	0 – 1	0.7
Glide	Page 3 · Knob1	Continuous, logarithmic	1 – 5000 ms	100 ms
Voice Mode	Page 3 · Knob2	List, 3 values	0 – 2	0 Poly
Glide Mode	Page 3 · Knob3	List, 3 values	0 – 2	0 Off
Time Mode	Page 3 · Knob4	List, 2 values	0 – 1	0 Time

Patch values

- 0 1 SOLID BASS
- 2 1 LeaderTape
- 4 1 BASS 3
- 1 1 Fat Low
- 3 1 ACID BASS
- 5 1 PLUCK BASS

6	1 BASS 1	36	2 *Tines III	66	3 E.ORGAN 3
7	1 ELEC BASS	37	2 CLAV-E.PNO	67	3 60-S ORGAN
8	1 S.BAS 27.7	38	2 SYNTH CLAV	68	3 OPTIC 28
9	1 RESONANCES	39	2 FUNK CLAV	69	3 PIPES 1
10	1 SYN-BASS 2	40	2 PIANO 5	70	3 PIPES 3
11	1 PRC SYNTH1	41	2 GRD PIANO1	71	3 PIPES 2
12	1 PRISM 2	42	2 BIG GRAND	72	3 POLY PAD
13	1 ANALOG 4	43	2 GUIT ACOUS	73	3 SOUNDTRACK
14	1 ANALOG A	44	2 SITAR	74	3 ICE PAD 2
15	1 ANALOG 6	45	2 KOTO	75	3 LUSH PADS
16	1 POLY 80	46	2 HARPSICH 1	76	3 BAROQUE 2
17	1 INSERT 1	47	2 CLAV 3	77	3 SOFT TOUCH
18	1 SPIRAL	48	2 XYLOPHONE	78	3 *Planets
19	1 FM-TROTT	49	2 MARIMBA	79	3 CIRRUS
20	1 GASHAUS	50	2 VIBE 1	80	3 ENTRIX
21	1 RING DING	51	2 GLOKENSPL	81	3 MAL POLY
22	1 PAPAGAYO	52	2 BELL C	82	3 Textures 6
23	1 WINEGLASS	53	2 BELLS	83	3 Etherial5a
24	1 SEDATIVE	54	2 TUB BELLS	84	3 'Airy'
25	1 SAMPLER 1	55	2 GONG 2	85	3 BORON A
26	1 *Wavetbl 1	56	2 KETTLE 6	86	3 CINEMA 1
27	1 *Wavetbl 2	57	2 MID DRM 3	87	3 STRINGS C
28	1 *Sampler 3	58	2 ORI DRUM 1	88	3 STRINGS 3
29	1 *Vocoder 2	59	2 WOOD 6	89	3 STRINGS 2
30	1 *Sequence	60	2 LATN DRM 4	90	3 STRINGS 7
31	1 Bounce 4	61	2 CIMBAL	91	3 FULL STRIN
32	2 E.PIANO 1	62	2 SYNTH DRUM	92	3 SYN-ORCH
33	2 TINE EP 1	63	2 B.DRM-SNAR	93	3 BRASS 1
34	2 WINTER EP	64	3 CLICK 124	94	3 BRASS 6 BC
35	2 RS-EP C	65	3 *Drawbar 1	95	3 BR TRUMPET

Voice Mode values

0 Poly

1 Mono

2 Legato

Glide Mode values

0 Off

1 Legato

2 Always

Time Mode values

0 Time 1 Rate

8 voices · Identifier `sixop` · Six-operator FM engine from Mutable Instruments Plaits by Emilie Gillet (MIT); DX7 patch banks as distributed with Plaits

5.6 FM6

STATUS: • In the simulator ■ On the desktop ◆ Planned for the device

FM6 is a six-operator FM synthesizer that plays voices in the format of the classic 1980s FM keyboards, the DX7's: 155 parameters for six operators with their own envelopes, 32 algorithms, feedback, an LFO and a pitch envelope. Its synthesis is msfa, the FM core Google published for Android, the same core the FM-1's own firmware runs. It comes with 32 voices of this project's own, and plays voices you load from SysEx files (below). **ALGORITHM** steps through the voices, and the knobs shape the one you have chosen.

Both the engine and its name are borrowed, with thanks: the engine is Google's msfa, and the name is that of the FM engine in hugelton's Felucca, open firmware for the FM-1, whose port of the same core checks FM6's sound in this project's tests.



Figure 5.5 FM6 on its first voice, TINE EP, while a chord sounds.

- **Patch** chooses a voice: the 32 built-in ones, then User 1 to User 32, which show the names of the voices you have loaded. A new voice applies to the next note you play; notes already sounding keep theirs.

- **Brightness** moves the level of every modulating operator, up to 24 dB down at the left and up at the right. In the middle the voice plays as programmed. The carriers, and so the loudness, do not change.
- **Env Time** runs all the voice’s envelopes faster or slower, the pitch envelope’s too: up to 8 times faster at the left, 8 times slower at the right, as programmed in the middle. It acts on notes that are sounding.
- **Feedback** adds to the voice’s own feedback, from 0 to 7 in whole steps.
- **Volume**, on page 2, is the engine’s output level.
- Page 3 holds **Glide**, **Voice Mode**, **Glide Mode** and **Time Mode**, which slide between notes and play one voice ([chapter 4](#)). On Legato a note played over a held one keeps the envelopes and the LFO running.
- Twelve notes play at once.

The built-in voices:

Patch numbers	What they are
0 – 4	Keys: two electric pianos, a clavinet-like pluck, a harpsichord, a koto
5 – 10	Mallets and bells: marimba, vibraphone (with tremolo), tubular bell, glass bell, chimes, steel drum
11 – 13	Organs: drawbars, drawbars with a percussive click, a gritty rock organ
14 – 17	Brass and winds: brass, soft brass, flute, clarinet
18 – 21	Strings and pads: strings, warm pad, glass pad, a slow sweep
22 – 24	Basses: FM bass, plucked bass, saw bass
25 – 27	Leads: saw, square, a sync-like sweep
28 – 30	Drums: kick (play it low), snare, hi-hat
31	A pure sine, for tuning and tests
32 – 63	User 1 to User 32, named after the voices loaded into them

5.6.1 Loading voices from SysEx

STATUS:  

The user slots take voices from SysEx files (`.syx`), the format the DX7 and its editors save: a single voice, or a bank of 32. A bank fills User 1 to User 32; single voices go to

the user slots one after another, starting after the last one loaded. A file may hold several dumps. Values out of range are brought into range, and anything that is not a voice dump is skipped.

In the simulator ([chapter 2](#)):

1. Power on.
2. Choose **Load DX7 patches...** under the panel and pick one or more `.syx` files, or drop the files anywhere on the page.
3. The screen shows *Loaded 32 voices* (or how many there were), which user slots they went to and the first voice's name, and the status line under the panel says the same. The current sound now plays the first voice loaded: if it was another engine, it becomes FM6.
4. Turn **ALGORITHM** to step through the voices by name. Every sound you set to FM6 later has them too.

The file is read in your browser; nothing is uploaded. The simulator checks it first: a file that is empty, is not SysEx, holds SysEx of another kind, is cut short, or holds a voice dump of the wrong length loads nothing, and the status line says which. A dump whose checksum is wrong is loaded all the same, as DX7 editors load one, and the status line says the file may be damaged. Files of up to 64 KB are read. The voices stay until you power off.

On the desktop, `fm1-render --sysex FILE.syx` loads files before the first note ([chapter 2](#)), and prints the names it found.

● Voices from elsewhere

Files of DX7 voices circulate widely, Yamaha's own factory voices among them. They are not part of Lunar Modulator, and nothing here comes with them: load only files you are entitled to use.

◆ Two algorithms with a loop

Algorithms 4 and 6 feed a whole stack of operators back on itself, as the DX7 does; FM6 runs that loop, where msfa itself plays those two algorithms without feedback. The built-in SAW BASS uses it.

FM6: what the four knobs do on each page				
	Knob1	Knob2	Knob3	Knob4
Page 1	Patch	Brightness	Env Time	Feedback
Page 2	Volume	–	–	–
Page 3	Glide	Voice Mode	Glide Mode	Time Mode

FM6 parameters				
Parameter	Where	Type	Range	Default
Patch	Page 1 · Knob1	List, 64 values	0 – 63	0 TINE EP
Brightness	Page 1 · Knob2	Continuous	0 – 1	0.5
Env Time	Page 1 · Knob3	Continuous	0 – 1	0.5
Feedback	Page 1 · Knob4	Continuous	–7 – 7	0
Volume	Page 2 · Knob1	Continuous	0 – 1	0.7
Glide	Page 3 · Knob1	Continuous, logarithmic	1 – 5000 ms	100 ms
Voice Mode	Page 3 · Knob2	List, 3 values	0 – 2	0 Poly
Glide Mode	Page 3 · Knob3	List, 3 values	0 – 2	0 Off
Time Mode	Page 3 · Knob4	List, 2 values	0 – 1	0 Time

Patch values		
0 TINE EP	13 ROCK ORGAN	26 SQUARE LD
1 BARK EP	14 BRASS	27 SYNC LEAD
2 CLAV	15 SOFT BRASS	28 KICK
3 HARPSI	16 FLUTE	29 SNARE
4 KOTO	17 CLARINET	30 HI-HAT
5 MARIMBA	18 STRINGS	31 PURE SINE
6 VIBES	19 WARM PAD	32 User 1
7 TUBE BELL	20 GLASS PAD	33 User 2
8 GLASS BELL	21 SWEEP	34 User 3
9 CHIMES	22 FM BASS	35 User 4
10 STEEL DRUM	23 PLUCK BASS	36 User 5
11 ORGAN 1	24 SAW BASS	37 User 6
12 ORGAN PERC	25 SAW LEAD	38 User 7

39	User 8	48	User 17	57	User 26
40	User 9	49	User 18	58	User 27
41	User 10	50	User 19	59	User 28
42	User 11	51	User 20	60	User 29
43	User 12	52	User 21	61	User 30
44	User 13	53	User 22	62	User 31
45	User 14	54	User 23	63	User 32
46	User 15	55	User 24		
47	User 16	56	User 25		

Voice Mode values

- 0 Poly
- 1 Mono
- 2 Legato

Glide Mode values

- 0 Off
- 1 Legato
- 2 Always

Time Mode values

- 0 Time
- 1 Rate

12 voices · Identifier `dx7` · Six-operator FM on `msfa`, the FM core of Google's `music-synthesizer-for-android` (Google, Apache-2.0); named after Felucca's FM6 engine (hugelton), both borrowed with thanks; reads DX7 voice data (a Yamaha trademark; not affiliated); built-in voices our own

5.7 Shapes

STATUS:

• In the simulator

■ On the desktop

◆ Planned for the device

Shapes is the macro-oscillator from Mutable Instruments Braids: 47 shapes, from analogue waveforms and their sync and sub-oscillator versions to formants, FM, physical models of plucked, bowed and blown instruments, bells and drums,

wavetables, noise and granular textures. Each voice has its own attack and release envelope.

- **Shape** chooses one of the 47. **ALGORITHM** steps through them, and a new shape applies at once, to notes that are sounding too.
- **Timbre** and **Color** are the two controls Braids gives every shape; what they do depends on the shape (below).
- **Attack** sets how long a note takes to rise, and **Release**, on page 2, how long it takes to fade after you let go. Both run from 1 ms at the left to 4 seconds at the right.
- **Volume**, on page 2, is the engine’s output level.
- Page 3 holds **Glide**, **Voice Mode**, **Glide Mode** and **Time Mode**, which slide between notes and play one voice (chapter 4). On Legato a note played over a held one does not strike the shape again.
- Playing harder makes a note louder.

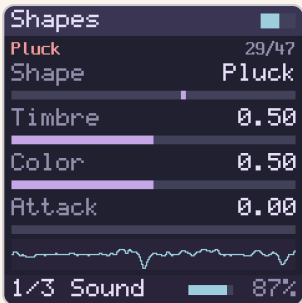


Figure 5.6 Shapes on Pluck, page 1.

No.	Shape	Timbre	Color
0	CSaw: a sawtooth with a notch	Where the notch falls	How deep it is
1	Morph: one oscillator through a filter	The waveform: triangle, sawtooth, square, then a narrowing pulse	A low-pass filter that closes, with more overdrive, as Color rises
2	Saw/Sqr	The shape of both waves	From sawtooth to square
3	Sine/Tri: a wavefolder	How much the wave is folded	From a folded sine to a folded triangle

No.	Shape	Timbre	Color
4	Buzz: a buzzy train of harmonics	How many harmonics	A second buzz voice, detuned by up to a semitone
5, 6	Sqr Sub, Saw Sub: a wave with a sub-oscillator	The pulse width, or the sawtooth's shape	The sub-oscillator: none in the middle, two octaves down towards the left, one octave down towards the right
7, 8	Sqr Sync, Saw Sync: two oscillators in hard sync	The pitch of the synced oscillator	The balance between the two
9 – 12	3x Saw, 3x Sqr, 3x Tri, 3x Sine: three oscillators	The second oscillator's interval, from two octaves down to two up, slightly detuned near the middle	The third oscillator's interval
13	3x Ring: three sines, ring-modulated	The second sine's pitch	The third sine's pitch
14	Swarm: a swarm of sawtooths	How far they are detuned	A high-pass filter
15	Comb: a sawtooth through a comb filter	The comb's pitch	The resonance, from negative on the left to positive on the right
16	Toy: a circuit-bent, low-fidelity oscillator	The sample-rate reduction	Digital bit-mangling
17 – 20	LP Flt, Peak Flt, BP Flt, HP Flt: waveforms that sound like a resonant filter	The filter's frequency	The shape of the wave under it
21	Vosim: two formants	The first formant's frequency	The second formant's frequency
22	Vowel: vowel synthesis	The vowel	The size of the voice
23	Vowel FOF: sung vowels	The vowel	The kind of voice
24	Harmonic: additive harmonics	Which harmonic is strongest	How widely the energy spreads around it
25 – 27	FM, FB FM, Chaos FM: two-operator FM, with feedback in the last two	The modulation amount	The frequency ratio

No.	Shape	Timbre	Color
28	Pluck: a plucked string	How long it rings	Where it is plucked
29	Bowed: a bowed string	The bow's friction	Where it is bowed
30	Blown: a reed instrument	The breath pressure	The instrument's body
31	Flute: a flute	The breath pressure	The mouthpiece's geometry
32	Bell: a struck bell	How long it rings	Inharmonicity
33	Drum: a struck drum	How long it rings	Brightness, from tone towards noise
34	Kick: an analogue-style kick	How long it rings	Its tone
35	Cymbal: a metallic cymbal	The filter's frequency	The balance of metal and noise
36	Snare: an analogue-style snare	The drum's tone	How much snare rattle
37	Wavetbl: wavetables	The position in the table	Which table
38	Wave Map: a map of waveforms	One coordinate on the map	The other coordinate
39	Wave Line: a line of waveforms	The position along the line	How the waves are drawn and joined, between smooth and stepped
40	Wave x4: four voices from wavetables	The position among the waves	The chord
41	Filt Noise: noise through a filter that follows the key	The resonance	The response: low-pass, band-pass, high-pass
42	Twin Peak: noise through two resonant peaks	The resonance	The second peak's frequency
43	Clk Noise: stepped noise clocked by the key's pitch	How often the random pattern repeats	How many levels it steps between, from 2 to 32
44	Granular: a cloud of sine grains	The grains' length	How far their pitches scatter

No.	Shape	Timbre	Color
45	Particle: random clicks through resonant filters	How dense the particles are	How far the filters' frequencies scatter
46	Digital: a digitally modulated carrier	The data rate	The data sent

● The struck shapes

Pluck, Bell, Drum, Kick, Cymbal and Snare are struck when you press a key and die away by themselves, however long you hold it. Release matters only if you let go before they have finished.

● Memory

Shapes is the largest engine: twelve voices take 54 % of the memory the simulator allows for everything (chapter 13). With PSX Verb and Plate together as effects it does not fit, nor as two sounds at once, and the simulator refuses what would not (chapter 6). The FM-1 build may play fewer Shapes notes at once.

● At the edges

Shapes keeps Braids within the range its code was written for. A note bent or offset above MIDI 127 sounds as the top of that range, on every shape. Comb's Timbre stops where the comb reaches its lowest pitch, which only the lowest four octaves of keys get to, and sounds the same there. The last sliver of Wave Line's Timbre (above about 98 %) plays the line's last wave.

Shapes: what the four knobs do on each page				
	Knob1	Knob2	Knob3	Knob4
Page 1	Shape	Timbre	Color	Attack
Page 2	Release	Volume	–	–
Page 3	Glide	Voice Mode	Glide Mode	Time Mode

Shapes parameters				
Parameter	Where	Type	Range	Default
Shape	Page 1 · KNOB1	List, 47 values	0 – 46	0 CSaw
Timbre	Page 1 · KNOB2	Continuous	0 – 1	0.5
Color	Page 1 · KNOB3	Continuous	0 – 1	0.5
Attack	Page 1 · KNOB4	Continuous	0 – 1	0
Release	Page 2 · KNOB1	Continuous	0 – 1	0.3
Volume	Page 2 · KNOB2	Continuous	0 – 1	0.7
Glide	Page 3 · KNOB1	Continuous, logarithmic	1 – 5000 ms	100 ms
Voice Mode	Page 3 · KNOB2	List, 3 values	0 – 2	0 Poly
Glide Mode	Page 3 · KNOB3	List, 3 values	0 – 2	0 Off
Time Mode	Page 3 · KNOB4	List, 2 values	0 – 1	0 Time

Shape values

- 0 CSaw

1 Morph

2 Saw/Sqr

3 Sine/Tri

4 Buzz

5 Sqr Sub

6 Saw Sub

7 Sqr Sync

8 Saw Sync

9 3x Saw

10 3x Sqr

11 3x Tri

12 3x Sine

13 3x Ring

14 Swarm

15 Comb
- 16 Toy

17 LP Flt

18 Peak Flt

19 BP Flt

20 HP Flt

21 Vosim

22 Vowel

23 Vowel FOF

24 Harmonic

25 FM

26 FB FM

27 Chaos FM

28 Pluck

29 Bowed

30 Blown

31 Flute
- 32 Bell

33 Drum

34 Kick

35 Cymbal

36 Snare

37 Wavetbl

38 Wave Map

39 Wave Line

40 Wave x4

41 Flt Noise

42 Twin Peak

43 Clk Noise

44 Granular

45 Particle

46 Digital

Voice Mode values

0 Poly

1 Mono

2 Legato

Glide Mode values

0 Off

1 Legato

2 Always

Time Mode values

0 Time

1 Rate

12 voices · Identifier `shapes` · Macro-oscillator from Mutable Instruments Braids by Emilie Gillet (MIT)

5.8 Sophie

STATUS: • In the simulator ■ On the desktop ◆ Planned for the device

Sophie is a sixteen-pad metallic FM percussion synthesizer by Matt Estela, from the Schwung community. Each pad is a drum sound of its own. A hit rings for its pad's Decay, whether or not you keep the key down.

- Sophie plays MIDI notes 36 to 51, one pad each, and ignores other notes. Its pads follow the General MIDI drum layout: 36 is the kick, 38 the snare, 42 the closed hi-hat and so on, so drum parts from other instruments play the right sounds.
- **Pad** chooses which pad the other knobs edit. `ALGORITHM` steps through the pads, and so does `Knob1` on page 1.
- **Tune** sets the pad's pitch in semitones, from two octaves down to two octaves up, relative to its key.
- **Decay** is how long a hit takes to die away, in seconds.
- **Model** chooses how the pad's operators are wired: *Fuse*, two modulators in series, very responsive to feedback; *Stack*, a dense stack of operators; *Split*, operators side by side with uneven modulation; and *Shard*, a coarse, stepped wave mixed with noise. On pad 1, the kick, a sine body always carries the weight, and Model adds a layer over it.

- **Color** moves the modulators' frequency ratios through inharmonic, clangorous zones.
- **Metal** sets how much the operators modulate one another: the higher, the more metallic.
- **Feedback** feeds the sound back into its own modulator, for a rougher edge.
- **Sweep** bends the start of each hit: a fast drop in pitch towards the right, a fast rise towards the left.
- Playing harder makes a hit louder. Sophie ignores pitch bend.



Figure 5.7 Sophie on pad 1, the kick, just after it was struck.

To play Sophie from the FM-1's keys: play the white keys. With a drum kit as the sound (Sophie, Drums, Comet Kit or Crater Kit), the sixteen white keys play the sixteen pads at any octave, from the kick on the lowest F up to the ride on the highest white key, and the black keys play nothing. On the computer keyboard, A is the kick, S the rim, D the snare, F the clap, J the closed hi-hat, L the pedal hi-hat and ' the open hi-hat. A MIDI keyboard plays the pads on notes 36 to 51, as a drum part from another instrument expects.

■ The values shown after you change pads

The screen cannot read a pad's settings back from Sophie. When you choose another pad, the screen keeps showing the values you last set. The first turn of a knob gives the new pad the value shown, plus that turn.

Sophie has further controls for each pad, for bit crushing, drive, level, a filter and a ring resonator, which this build does not show on the screen yet.

Sophie: what the four knobs do on each page				
	Knob1	Knob2	Knob3	Knob4
Page 1	Pad	Tune	Decay	Model
Page 2	Color	Metal	Feedback	Sweep

Sophie parameters				
Parameter	Where	Type	Range	Default
Pad	Page 1 · Knob1	List, 16 values	0 – 15	0 1 Kick
Tune	Page 1 · Knob2	Continuous	−24 – 24	−5
Decay	Page 1 · Knob3	Continuous	0.03 – 4	0.28
Model	Page 1 · Knob4	List, 4 values	0 – 3	0 Fuse
Color	Page 2 · Knob1	Continuous	0 – 100	24
Metal	Page 2 · Knob2	Continuous	0 – 100	8
Feedback	Page 2 · Knob3	Continuous	0 – 100	6
Sweep	Page 2 · Knob4	Continuous	−100 – 100	55

Pad values		
0 1 Kick	6 7 Closed HH	12 13 High-Mid
1 2 Rim	7 8 Floor Tom	13 14 Crash
2 3 Snare	8 9 Pedal HH	14 15 High Tom
3 4 Clap	9 10 Mid Tom	15 16 Ride
4 5 Snare 2	10 11 Open HH	
5 6 Low Tom	11 12 Low-Mid	

Model values	
0 Fuse	2 Split
1 Stack	3 Shard

12 voices · Identifier `sw-sophie` · Sophie by Matt Estela (github.com/mestela/schwung-sophie, MIT), via the Schwung v2 shim (Schwung plugin ABI by Charles Vestal, MIT)

5.9 Drums

STATUS: • In the simulator ■ On the desktop ◆ Planned for the device

Drums is a sixteen-pad drum kit after the classic analogue drum machines: a deep kick with a long boom, a short punchy one, two snares, a clap, closed, pedal and open hi-hats, six toms, a rim shot, a crash and a ride, and a cowbell you can put on any pad. Its kicks, toms, snares and hi-hats are Plaits' drum models; the rim shot, clap, cowbell and cymbals are this project's own, after published studies of the analogue circuits ([chapter 14](#)).

- Drums plays MIDI notes 36 to 51, one pad each, in the same order as Sophie, and ignores other notes: 36 is the kick, 38 the snare, 42 the closed hi-hat, 46 the open one, 49 the crash and 51 the ride. On the FM-1's keys the sixteen white keys play the pads ([Sophie](#) shows which key is which).
- A hit rings for its pad's decay, whether or not you keep the key down. Up to twelve hits sound at once. A pad struck again while it rings is struck again, as a drum is, rather than starting a second sound; a thirteenth pad takes over the quietest hit.
- A closed or pedal hi-hat cuts the open hi-hat short, as on the machines: the three hi-hats share a choke group in both kits. Any pads can share one (Choke, below).
- **Pad** chooses which pad the pad's knobs edit: those on pages 1 to 3. **ALGORITHM** steps through the pads, and so does **KNOB1** on page 1. Each pad keeps its own settings.
- The pad's knobs start in the middle, Tune at 0: that is the pad as the kit sets it up, and you turn from there. So until you change them the screen shows true values whichever pad you choose.
- **Tune** sets the pad's pitch, up to two octaves either way.
- **Decay** sets how long it rings.
- **Level** sets its level in the kit.
- **Tone** (page 2) makes it brighter to the right.
- **Snapp** sets the attack: the kick's click, the snare's wires, the hi-hats' noise against their metal, the clap's bursts, the rim's click, the cymbals' wash, the cowbell's first clank.
- **Sweep** sets the fall in pitch at the start of a hit, the kick's and the toms' especially. On the other sounds, above the middle the hit falls in pitch, and below it rises.
- **Drive** saturates the pad, clean at 0.

- **Model** (page 3) chooses the pad's sound. *Kit* is the kit's own choice; the others are *Analog Drum* (a deep kick or tom), *Punch Drum* (a punchy, swept kick or tom), *Snare*, *Snap Snare*, *Hat*, *Ring Hat*, *Cymbal*, *Clap*, *Rim* and *Cowbell*. A pad given another sound plays that sound as Drums sets it up, so a cowbell on a tom's pad is a cowbell.
- **Choke** (page 3) chooses the pad's choke group: a hit cuts short every pad in its group that is still ringing, within a few milliseconds. *Kit*, the default, is the kit's own choice: the three hi-hats share *Group 1* in both kits, whatever sound their pads play, and the other pads none. *None* takes the pad out of any group, and *Group 1* to *Group 4* put it in one. Put the crash and the ride in *Group 2* and each cuts the other; put a pad in *Group 1* and the hi-hats cut it.
- Page 4 is the whole kit's:
- **Kit** chooses *Deep*, the long, round kit, or *Punch*, harder and shorter, with a swept kick, a crisper snare and ring-modulated hi-hats.
- **Accent** sets how much velocity matters: at 0 every hit plays the same, at the right a soft hit is quiet and dull and a hard one loud and bright.
- **Volume** sets the kit's level.
- **Kit Decay** makes every pad ring shorter or longer at once, each from its own Decay: in the middle the kit is as set up, to the left every pad shortens towards its shortest, to the right every pad lengthens towards its longest.
- Model, Choke and Kit reach the next hit; a hit that is ringing keeps the sound and the group it started with. The other knobs move a ringing hit too.
- Pitch bend bends every pad.



Figure 5.8 Drums on pad 1, the kick of the Deep kit, just after it was struck.

■ **The values shown after you change pads**

As on Sophie, the screen cannot read a pad’s settings back. When you choose another pad, the screen keeps showing the values you last set, and the first turn of a knob gives the new pad the value shown, plus that turn.

Drums: what the four knobs do on each page				
	KNOB1	KNOB2	KNOB3	KNOB4
Page 1	Pad	Tune	Decay	Level
Page 2	Tone	Snap	Sweep	Drive
Page 3	Model	Choke	–	–
Page 4	Kit	Accent	Volume	Kit Decay

Drums parameters				
Parameter	Where	Type	Range	Default
Pad	Page 1 · KNOB1	List, 16 values	0 – 15	0 1 Kick
Tune	Page 1 · KNOB2	Continuous	–24 – 24	0
Decay	Page 1 · KNOB3	Continuous	0 – 1	0.5
Level	Page 1 · KNOB4	Continuous	0 – 1	0.8
Tone	Page 2 · KNOB1	Continuous	0 – 1	0.5
Snap	Page 2 · KNOB2	Continuous	0 – 1	0.5
Sweep	Page 2 · KNOB3	Continuous	0 – 1	0.5
Drive	Page 2 · KNOB4	Continuous	0 – 1	0
Model	Page 3 · KNOB1	List, 11 values	0 – 10	0 Kit
Choke	Page 3 · KNOB2	List, 6 values	0 – 5	0 Kit
Kit	Page 4 · KNOB1	List, 2 values	0 – 1	0 Deep
Accent	Page 4 · KNOB2	Continuous	0 – 1	0.5
Volume	Page 4 · KNOB3	Continuous	0 – 1	0.7
Kit Decay	Page 4 · KNOB4	Continuous	0 – 1	0.5

Pad values

- | | | |
|-------------|---------------|----------------|
| 0 1 Kick | 6 7 Closed HH | 12 13 High-Mid |
| 1 2 Rim | 7 8 Floor Tom | 13 14 Crash |
| 2 3 Snare | 8 9 Pedal HH | 14 15 High Tom |
| 3 4 Clap | 9 10 Mid Tom | 15 16 Ride |
| 4 5 Snare 2 | 10 11 Open HH | |
| 5 6 Low Tom | 11 12 Low-Mid | |

Model values

- | | | |
|---------------|--------------|------------|
| 0 Kit | 4 Snap Snare | 8 Clap |
| 1 Analog Drum | 5 Hat | 9 Rim |
| 2 Punch Drum | 6 Ring Hat | 10 Cowbell |
| 3 Snare | 7 Cymbal | |

Kit values

- | | |
|--------|---------|
| 0 Deep | 1 Punch |
|--------|---------|

Choke values

- | | | |
|--------|-----------|-----------|
| 0 Kit | 2 Group 1 | 4 Group 3 |
| 1 None | 3 Group 2 | 5 Group 4 |

12 voices · Identifier `drums` · Kick, tom, snare and hi-hat voices from Mutable Instruments Plaits by Emilie Gillet (MIT); rim, clap, cowbell and cymbal from this repository (MIT), after Werner, Abel and Smith's TR-808 cowbell and cymbal models

5.10 Acid Bass

STATUS: • In the simulator ■ On the desktop ◆ Planned for the device

Acid Bass is a bass after the TB-303: one voice, a sawtooth or square wave through a resonant filter swept by an envelope, with accents and slides. It is the 303 of fm1-x0x, Charles Vestal's firmware for the FM-1, which ports Robin Schmidt's Open303

with the Devilfish's longer slides and accent decays and a RAT-style drive ([chapter 14](#)).

● In builds with the GPL switch on

fm1-x0x's code is published under the GNU General Public License, so Acid Bass is built in only while the firmware's GPL switch is on: in the simulator while we test, and in firmware for the person who builds it, never in a shared build ([chapter 14](#)).

- **Accent.** A note played with a velocity of 100 or more is accented: louder, and with a harder sweep of the filter. Velocity does nothing else, as on the original, so play softer than 100 for a plain note.
- **Slide.** A key you play while holding another slides to its pitch instead of starting again: the 303's slide. Let go of the newer key while the older one is still down and the note slides back. Let go of the last key and the note ends.
- **Page 1, the filter.**
 - **Cutoff** sets how bright the note is at rest, 314 to 2,394 Hz.
 - **Resonance** adds the squelch: at the right the filter sings.
 - **Env Mod** sets how far each note opens the filter.
 - **Decay** sets how long that sweep takes to close, 200 ms to 2 s.
- **Page 2, the voice.**
 - **Accent** sets how hard an accented note hits.
 - **Wave** chooses *Saw* or *Square*.
 - **Tune** moves the pitch up to an octave either way.
 - **Volume** sets the level.
- **Page 3, drive and slides.**
 - **Drive** saturates the sound, clean at 0.
 - **Drive Type** chooses *Soft*, a warm overdrive, *RAT*, a gritty distortion pedal, or *Off*.
 - **Slide** sets how long a slide takes, 2 to 360 ms (60 ms, the original's, to begin with).
 - **Acc Decay** sets the filter sweep's decay on accented notes, 30 ms to 3 s.
- Cutoff, Resonance, Env Mod, Tune, Volume, Drive and Slide move a note that sounds. Decay, Accent and Acc Decay reach the next note, a slide included. Wave and Drive Type wait for the next note that is not a slide, so they never click in the middle of one; while nothing sounds they change at once.

- Pitch bend bends the note, slides included.
- **ALGORITHM** steps through Wave.

Some settings to start from:

Sound	Cutoff	Resonance	Env Mod	Decay	Accent	Drive
Rubber bass	500 Hz	40 %	30 %	900 ms	40 %	0
Squelch	420 Hz	92 %	85 %	300 ms	90 %	0
Acid lead (Square)	1,500 Hz	70 %	60 %	630 ms	60 %	0
Distorted acid	700 Hz	80 %	100 %	400 ms	80 %	75 %, RAT

Acid Bass: what the four knobs do on each page				
	KNOB1	KNOB2	KNOB3	KNOB4
Page 1	Cutoff	Resonance	Env Mod	Decay
Page 2	Accent	Wave	Tune	Volume
Page 3	Drive	Drive Type	Slide	Acc Decay

Acid Bass parameters				
Parameter	Where	Type	Range	Default
Cutoff	Page 1 · KNOB1	Continuous, logarithmic	314 – 2394 Hz	870 Hz
Resonance	Page 1 · KNOB2	Continuous	0 – 100	50
Env Mod	Page 1 · KNOB3	Continuous	0 – 100	50
Decay	Page 1 · KNOB4	Continuous, logarithmic	200 – 2000 ms	630 ms
Accent	Page 2 · KNOB1	Continuous	0 – 100	50
Wave	Page 2 · KNOB2	List, 2 values	0 – 1	0 Saw
Tune	Page 2 · KNOB3	Continuous	-12 – 12	0
Volume	Page 2 · KNOB4	Continuous	0 – 1	0.7
Drive	Page 3 · KNOB1	Continuous	0 – 100	0
Drive Type	Page 3 · KNOB2	List, 3 values	0 – 2	1 Soft
Slide	Page 3 · KNOB3	Continuous, logarithmic	2 – 360 ms	60 ms
Acc Decay	Page 3 · KNOB4	Continuous, logarithmic	30 – 3000 ms	200 ms

Wave values

- 0 Saw
- 1 Square

Drive Type values

- 0 Off
- 1 Soft
- 2 RAT

1 voices · Identifier `acid-bass` · A bass after the TB-303: fm1-x0x's 303 by Charles Vestal (GPL-3.0), ported from schwung-303: Open303 by Robin Schmidt (MIT), Devilfish ranges after jc303 by midilab (GPL-3.0), RAT drive after dm-Rat by Dave Mollen (GPL-3.0)

5.11 Comet Kit

STATUS:

● In the simulator

■ On the desktop

◆ Planned for the device

Comet Kit is a sixteen-pad drum kit after the TR-909: a kick with a punchy sweep and a beater click, a snare with its rattle of wires, three toms, a rim shot and a hand clap, all modelled on the machine's circuits, and hi-hats, a crash and a ride played from recordings, as the machine played its cymbals. It is the 909 kit of fm1-x0x, Charles Vestal's firmware for the FM-1, which ports 9W9 by athousanddetails, itself grown out of ER-99 by Matthew Cieplak; the cymbal recordings are ER-99's ([chapter 14](#)).

● In builds with the GPL switch on

fm1-x0x's code and ER-99's recordings are published under the GNU General Public License, so Comet Kit is built in only while the firmware's GPL switch is on, as Acid Bass is ([Acid Bass](#)). Drums stays the kit every build has.

- Comet Kit plays MIDI notes 36 to 51, one pad each, in the same order as Drums and Sophie; on the FM-1's keys the sixteen white keys play them ([Sophie](#) shows which key is which).

Note	Pad	Sound
36	1 Kick	the kick
37	2 Rim	the rim shot

Note	Pad	Sound
38	3 Snare	the snare
39	4 Clap	the hand clap
40	5 Snare 2	the snare, a little higher, with more of its wires
41, 43	6 Low Tom, 8 Floor Tom	the low tom, and the low tom tuned up
45, 47	10 Mid Tom, 12 Low-Mid	the mid tom, and the mid tom tuned up
48, 50	13 High-Mid, 15 High Tom	the high tom tuned down, and the high tom
42, 44	7 Closed HH, 9 Pedal HH	the closed hi-hat, and a longer one
46	11 Open HH	the open hi-hat
49	14 Crash	the crash
51	16 Ride	the ride

- A hit rings for its sound’s decay, whether or not you keep the key down. The kit has one voice for each of its eleven sounds, as the machine has: a sound struck again starts again, and the two pads that share a sound (the two snares, two of the toms, the closed and pedal hi-hats) cut each other. A closed or pedal hi-hat cuts the open hi-hat short.
- **Velocity** (page 3) sets how much a soft hit drops: at 100 % a hit at half velocity is half as loud; at 0 every hit plays at the Accent level. **Accent** sets the level a full-velocity hit reaches, the machine’s accent.
- **Pad** chooses which pad the pad’s knobs edit, those on pages 1 and 2 and Drive Type on page 3. **ALGORITHM** steps through the pads, and so does **KNOB1** on page 1. Each pad keeps its own settings.
- The pad’s knobs are the machine’s own knobs for that sound. They start where the kit sets the pad up: Tune, Decay, Level, Tone and Snap in the middle, Sweep and Drive at 0. Turned fully left or right, a knob is at the end of that sound’s range on the machine, so a tom cannot be tuned onto another, as on the machine.
- **Tune** sets the pitch; on the kick, how far its pitch sweeps down at the start of a hit.
- **Decay** sets how long it rings; on the clap, its room tail. The snare and the rim shot have none: their length is fixed, as on the machine.
- **Level** sets its level in the kit.
- **Tone** (page 2) sets the length of the snare’s wires; on the kick, the pitch Sweep pulls it to.

- **Snap** sets the snare’s wires against its body, and the click of the kick and of the toms.
- **Sweep** works on the kick only: at 0 the kick is the machine’s; turned up, its pitch moves towards the one Tone sets, and its sweep deepens.
- **Drive** saturates the pad.
- **Drive Type** (page 3) chooses how: *Diode*, the machine’s own soft rounding, *Clip*, *Saturate*, *Fuzz*, *Crunch*, *Fold* (a wavefolder) or *Crush* (fewer bits and a lower sample rate).
- **Kit** (page 4) chooses *Classic*, the kit as 9W9 sets it up, or *Big Beat*, fm1-x0x’s own: a shorter, harder kick and a quieter open hi-hat.
- Drive Type and Kit reach the pad’s next hit; a hit that is ringing keeps the sound it started with. The other pad knobs move a ringing hit when its sound reads them, and otherwise reach the next hit.
- Comet Kit ignores pitch bend.

■ **The values shown after you change pads**

As on Drums, the screen cannot read a pad’s settings back. When you choose another pad, the screen keeps showing the values you last set, and the first turn of a knob gives the new pad the value shown, plus that turn.

Comet Kit: what the four knobs do on each page

	KNOB1	KNOB2	KNOB3	KNOB4
Page 1	Pad	Tune	Decay	Level
Page 2	Tone	Snap	Sweep	Drive
Page 3	Drive Type	Accent	Velocity	Volume
Page 4	Kit	–	–	–

Comet Kit parameters

Parameter	Where	Type	Range	Default
Pad	Page 1 · KNOB1	List, 16 values	0 – 15	0 1 Kick
Tune	Page 1 · KNOB2	Continuous	0 – 1	0.5
Decay	Page 1 · KNOB3	Continuous	0 – 1	0.5

Parameter	Where	Type	Range	Default
Level	Page 1 · KNOB4	Continuous	0 – 1	0.5
Tone	Page 2 · KNOB1	Continuous	0 – 1	0.5
Snap	Page 2 · KNOB2	Continuous	0 – 1	0.5
Sweep	Page 2 · KNOB3	Continuous	0 – 1	0
Drive	Page 2 · KNOB4	Continuous	0 – 1	0
Drive Type	Page 3 · KNOB1	List, 7 values	0 – 6	0 Diode
Accent	Page 3 · KNOB2	Continuous	1 – 4	1.9921
Velocity	Page 3 · KNOB3	Continuous	0 – 100	100
Volume	Page 3 · KNOB4	Continuous	0 – 1	0.7
Kit	Page 4 · KNOB1	List, 2 values	0 – 1	0 Classic

Pad values

- 0

1 Kick
- 1

2 Rim
- 2

3 Snare
- 3

4 Clap
- 4

5 Snare 2
- 5

6 Low Tom
- 6

7 Closed HH
- 7

8 Floor Tom
- 8

9 Pedal HH
- 9

10 Mid Tom
- 10

11 Open HH
- 11

12 Low-Mid
- 12

13 High-Mid
- 13

14 Crash
- 14

15 High Tom
- 15

16 Ride

Drive Type values

- 0

Diode
- 1

Clip
- 2

Saturate
- 3

Fuzz
- 4

Crunch
- 5

Fold
- 6

Crush

Kit values

- 0

Classic
- 1

Big Beat

11 voices · Identifier `comet` · A kit after the TR-909: fm1-x0x's 909 by Charles Vestal (GPL-3.0), ported from 9W9 by athousanddetails (GPL-3.0), which grew out of ER-99 by Matthew Cieplak (GPL-3.0); hi-hat, crash and ride recordings from ER-99 (GPL-3.0)

5.12 Crater Kit

STATUS:

In the simulator

On the desktop

Planned for the device

Crater Kit is a sixteen-pad drum kit after the TR-808: a booming kick, a snare, three toms and three congas, a clap and maracas, a rim shot and claves, a cowbell, closed and open hi-hats and a cymbal, every one the machine’s own sound. It is the 808 of fm1-x0x, Charles Vestal’s firmware for the FM-1, which ports 8W8 by athousanddetails: fifteen of the sounds are models of the machine’s circuits, built from its service notes and published analyses, and the rim shot is sc808’s ([chapter 14](#)). Drums stays beside it: two kits of its own, any sound on any pad, in every build.

● In builds with the GPL switch on

fm1-x0x’s code is published under the GNU General Public License, so Crater Kit is built in only while the firmware’s GPL switch is on: in the simulator while we test, and in firmware for the person who builds it, never in a shared build ([chapter 14](#)).

- Crater Kit plays MIDI notes 36 to 51, one sound each, and ignores other notes; on the FM-1’s keys the sixteen white keys play them, from F3:

Note	Pad	Note	Pad	Note	Pad	Note	Pad
36	Kick	40	Claves	44	Maracas	48	High Tom
37	Rim Shot	41	Low Tom	45	Mid Tom	49	Cymbal
38	Snare	42	Closed HH	46	Open HH	50	Hi Conga
39	Clap	43	Low Conga	47	Mid Conga	51	Cowbell

- A hit rings for its sound’s decay, whether or not you keep the key down. Struck again while it rings, a sound is struck again in its own circuit, as on the machine.
- As on the machine, each conga is its tom’s circuit switched over: a low conga stops a ringing low tom, and the other way round. The rim shot and the claves, and the clap and the maracas, sound together freely.
- **Velocity** 88 is the 808’s normal hit and 127 its accent, louder and harder; between them the hit grows, and below 88 it is quieter.

- **Pad** chooses which pad the pad's knobs edit: those on pages 1 and 2. **ALGORITHM** steps through the pads, and so does **Knob1** on page 1. Each pad keeps its own settings, and starts as the 808 is set up: Tune at 0 and the other knobs in the middle, so until you change them the screen shows true values whichever pad you choose.
- **Tune** sets the pad's pitch, up to an octave either way (the toms and congas go further than the machine's, which move two semitones).
- **Decay** sets how long it rings: the kick's boom, the snare's ring, the hi-hats' and cymbal's length.
- **Level** sets its level in the kit, up to twice the 808's.
- **Tone** (page 2) shapes the kick (brighter to the right) and the snare (from its low shell to its high one); it does nothing on the other pads.
- **Snap** sets the kick's attack click, the snare's snares and the maracas' attack; it does nothing on the other pads.
- **Drive** saturates the pad, clean at 0.
- **Dist** chooses how Drive saturates: *Diode* (the machine's own rounding), *Clip*, *Sat*, *Fuzz*, *Cubic* (a biased crunch), *Fold* (a wavefolder) or *Crush* (bits and rate falling together).
- Page 3 is the whole kit's:
- **Accent** sets how far below an accent a softer hit sits: at 100 %, velocity 88 is the 808's normal hit; at 0 every hit is as loud as an accent.
- **Choke** sets which hi-hat cuts which: *Off*, *Closed*>*Open* (a closed hi-hat cuts the open one, as on the machine), or *Both*.
- **Volume** sets the kit's level.
- Tune, Decay, Tone, Snap, Accent and Choke reach the next hit; a hit that is ringing keeps what it started with. Level, Drive and Volume move a ringing hit too. Dist waits for the pad's next hit, so it never clicks in the middle of one.
- Pitch bend moves the hits you strike while you hold it, together with Tune up to an octave either way.

■ The values shown after you change pads

As on Drums, the screen cannot read a pad's settings back. When you choose another pad, the screen keeps showing the values you last set, and the first turn of a knob gives the new pad the value shown, plus that turn.

Some settings to start from:

Sound	Pad	Tune	Decay	Tone	Snap	Drive, Dist
Long boom kick	1 Kick	-2	0.85	0.3	0.3	0
Short punchy kick	1 Kick	+3	0.3	0.7	0.9	0.3, Sat
Crisp snare	3 Snare	+2	0.4	0.8	0.8	0
Gritty cowbell	16 Cowbell	0	0.5	-	-	0.5, Fold

Crater Kit: what the four knobs do on each page

	KNOB1	KNOB2	KNOB3	KNOB4
Page 1	Pad	Tune	Decay	Level
Page 2	Tone	Snap	Drive	Dist
Page 3	Accent	Choke	Volume	-

Crater Kit parameters

Parameter	Where	Type	Range	Default
Pad	Page 1 · KNOB1	List, 16 values	0 – 15	0 1 Kick
Tune	Page 1 · KNOB2	Continuous	-12 – 12	0
Decay	Page 1 · KNOB3	Continuous	0 – 1	0.5
Level	Page 1 · KNOB4	Continuous	0 – 1	0.5
Tone	Page 2 · KNOB1	Continuous	0 – 1	0.5
Snap	Page 2 · KNOB2	Continuous	0 – 1	0.5
Drive	Page 2 · KNOB3	Continuous	0 – 1	0
Dist	Page 2 · KNOB4	List, 7 values	0 – 6	0 Diode
Accent	Page 3 · KNOB1	Continuous	0 – 100	100
Choke	Page 3 · KNOB2	List, 3 values	0 – 2	1 Closed>Open
Volume	Page 3 · KNOB3	Continuous	0 – 1	0.7

Pad values

0 1 Kick

1 2 Rim Shot

2 3 Snare

3	4 Clap	8	9 Maracas	13	14 Cymbal
4	5 Claves	9	10 Mid Tom	14	15 Hi Conga
5	6 Low Tom	10	11 Open HH	15	16 Cowbell
6	7 Closed HH	11	12 Mid Conga		
7	8 Low Conga	12	13 High Tom		

Dist values

0	Diode	3	Fuzz	6	Crush
1	Clip	4	Cubic		
2	Sat	5	Fold		

Choke values

0	Off	1	Closed>Open	2	Both
---	-----	---	-------------	---	------

13 voices · Identifier `crater` · A kit after the TR-808: fm1-x0x's 808 by Charles Vestal (GPL-3.0), ported from 8W8 by athousanddetails (GPL-3.0); circuit models after the TR-808 service notes and Werner, Abel and Smith; the rim shot after sc808 by Yoshinosuke Horiuchi and Sam Aaron (MIT)

5.13 Drawbar, Trio and Phase Bend

STATUS:  In the simulator  On the desktop  Planned for the device

Three engines come from **Felucca**, Leo Kuroshita's open firmware for the FM-1 (Hügelton Instruments), each its own design: **Drawbar**, an organ; **Trio**, three oscillators in the style of the sound chips of the early 8-bit home computers; and **Phase Bend**, phase distortion. Their sound is Felucca's own: the firmware runs Felucca's code for them unchanged, notes, envelope and all, and plays every one of Felucca's factory sounds for them to the sample as Felucca does ([chapter 14](#)).

● In builds with the GPL switch on

Felucca is published under the GNU General Public License, so these three engines are built in only while the firmware's GPL switch is on: in the simulator while we test, and in firmware for the person who builds it, never in a shared build ([chapter 14](#)).

What the three share:

- **Eight voices.** A key struck while it sounds starts again in its own voice, from where its level is. With all eight busy, a new note takes the oldest released voice, else the oldest held one, never the lowest key held.
- **An envelope,** Felucca's: **Attack** rises to full level in its time, **Decay** falls to the **Sustain** level, and **Release** falls away after the key, each from 1 ms to 10 s in Felucca's 128 steps. Velocity sets the level, and a velocity over 110 is an accent: it opens Trio's filter and Phase Bend's bend with the envelope.
- **Volume** sets the level.
- Pitch bend bends every note.
- Notes, knobs and bends take effect at the next 0.7 ms, Felucca's control step, wherever they fall.
- They run at the FM-1's rate, 44,100 or 44,118 samples a second, and stay off the list in a browser that runs the simulator faster, as Macro does. At 44,118 they play 0.7 cent sharp, as Felucca does on the FM-1.

5.13.1 Drawbar

Drawbar is a tonewheel organ: nine sine partials at the drawbar pitches of the organs it is after, from 16' (an octave down) to 1' (three octaves up).

- **Drawbars** chooses one of sixteen drawbar settings (registrations): *Flute, Mellow, Hollow, Smooth, 3 Bar, Blues, Gospel, Rock, Tops, Clarinet, Reed, Strings, Chapel, Bright, Bass* and *Full*. **ALGORITHM** steps through them.
- **Sub, Body** and **Top** pull the setting's low bars (16' and 5 1/3'), its middle (8' and 4') and its upper five down or up, by up to eight steps of about 3 dB.
- **Perc** adds the organ's percussion, a decaying second or third harmonic, *Soft* (quieter) or *Slow* (longer), struck only on a note played while no other key is held, as on the organs. With it on, the 1' bar is silent.
- **Click** sets the key click at the start and end of each note.
- **Drive** overdrives each note.
- **Rotor** spins a rotary speaker, *Slow* or *Fast*, or stops it (*Off*); it speeds up and slows down as the real one does.
- Drawbars, Sub, Body, Top, Perc, Click, Drive and Rotor move the notes that sound, without a click.

Some of Felucca's own Drawbar sounds (Attack 1 ms, Decay 104 ms, Sustain 100 %):

Sound	Drawbars	Perc	Click	Drive	Rotor	Release
Full Organ	Full	Off	24 %	16 %	Slow	26 ms
Jazz Perc	3 Bar	3rd	39 %	6 %	Slow	18 ms
Gospel	Gospel	2nd	47 %	31.5 %	Fast	26 ms
Soft Flute	Mellow (Body –2)	Off	8 %	0	Slow	54 ms
Rock Drive	Rock	Off	55 %	79 %	Fast	18 ms

Drawbar: what the four knobs do on each page

	KNOB1	KNOB2	KNOB3	KNOB4
Page 1	Drawbars	Sub	Body	Top
Page 2	Perc	Click	Drive	Rotor
Page 3	Attack	Decay	Sustain	Release
Page 4	Volume	–	–	–

Drawbar parameters

Parameter	Where	Type	Range	Default
Drawbars	Page 1 · KNOB1	List, 16 values	0 – 15	4 3 Bar
Sub	Page 1 · KNOB2	Continuous	–8 – 8	0
Body	Page 1 · KNOB3	Continuous	–8 – 8	0
Top	Page 1 · KNOB4	Continuous	–8 – 8	0
Perc	Page 2 · KNOB1	List, 7 values	0 – 6	0 Off
Click	Page 2 · KNOB2	Continuous	0 – 100	31.5
Drive	Page 2 · KNOB3	Continuous	0 – 100	0
Rotor	Page 2 · KNOB4	List, 3 values	0 – 2	1 Slow
Attack	Page 3 · KNOB1	Continuous, logarithmic	1 – 10000 ms	1 ms
Decay	Page 3 · KNOB2	Continuous, logarithmic	1 – 10000 ms	103.6 ms
Sustain	Page 3 · KNOB3	Continuous	0 – 100	100
Release	Page 3 · KNOB4	Continuous, logarithmic	1 – 10000 ms	26.1 ms
Volume	Page 4 · KNOB1	Continuous	0 – 1	0.7

Drawbars values

0 Flute	6 Gospel	12 Chapel
1 Mellow	7 Rock	13 Bright
2 Hollow	8 Tops	14 Bass
3 Smooth	9 Clarinet	15 Full
4 3 Bar	10 Reed	
5 Blues	11 Strings	

Perc values

0 Off	3 2nd Soft	6 3rd Slow
1 2nd	4 3rd Soft	
2 3rd	5 2nd Slow	

Rotor values

0 Off	1 Slow	2 Fast
--------------	---------------	---------------

8 voices · Identifier `drawbar` · Felucca by Leo Kuroshita (@kurogedelic), Hugelton Instruments (GPL-3.0): its WHEEL engine, a tonewheel-style organ of its own design

5.13.2 Trio

Trio plays three oscillators together, each a triangle, sawtooth, pulse or pitched noise, or a mix of two of them the way the old sound chips combined waves, with ring modulation and hard sync between them, into a filter that gets gritty when you push its resonance.

- **Wave** chooses one of sixteen sets of three waves and how they interact: three saws, three pulses, a pulse pair with a triangle, the combined *Saw&Tri* and *Pulse&Saw*, *Pulse+Noise*, *Noise*, the *Sync* sets (the second oscillator restarts with the first) and the *Ring* sets (the first oscillator ring-modulated by the third). **ALGORITHM** steps through them. A note keeps the wave it started with.
- **Int 2** and **Int 3** tune the second and third oscillators up to two octaves either way, in semitones; **Detune** pulls them apart, the second up and the third down, by up to 50 cents.

- **Mode** chooses the filter: *Low-pass*, *Band-pass*, *High-pass* or *Notch*. A note keeps the mode it started with.
- **Cutoff** (30 Hz to 16 kHz) and **Resonance** set the filter; its cutoff wanders a little, as the chips' did.
- **PW** sets the pulse width of the pulse waves.
- **Env Amt** lets the envelope open (to the right) or close (to the left) the filter.

Felucca's own Trio sounds:

Sound	Wave	Int 2, Int 3	Detune	Mode	Cutoff	Resonance	PW	Env Amt	Attack, Decay, Sustain, Release
Fat Bass	Saw x3	0, -12	9	Low- pass	643 Hz	35 %	50 %	62.5 %	1 ms, 90 ms, 47 %, 6 ms
Arp Lead	Pls+Pls+Tri	+12, 0	4	Low- pass	2,326 Hz	20 %	25 %	12.5 %	1 ms, 78 ms, 71 %, 9 ms
Sync Lead	Sync	+9, 0	0	Low- pass	1,729 Hz	24 %	50 %	28.1 %	1.2 ms, 160 ms, 79 %, 18 ms
Ring Bell	Ring 3	0, +18	6	Band- pass	3,455 Hz	24 %	50 %	0	1 ms, 790 ms, 0 %, 331 ms
Chip Choir	Pulse x3	0, +12	7	Band- pass	643 Hz	75 %	31 %	46.9 %	160 ms, 683 ms, 87 %, 476 ms

Felucca plays Fat Bass and Sync Lead one note at a time; Trio has no voice mode of its own, so play them one note at a time, or let the sequencer do.

Trio: what the four knobs do on each page				
	KNOB1	KNOB2	KNOB3	KNOB4
Page 1	Wave	Int 2	Int 3	Detune
Page 2	Mode	Cutoff	Resonance	PW
Page 3	Env Amt	Attack	Decay	Sustain
Page 4	Release	Volume	–	–

Trio parameters				
Parameter	Where	Type	Range	Default
Wave	Page 1 · KNOB1	List, 16 values	0 – 15	0 Saw x3
Int 2	Page 1 · KNOB2	Continuous	–24 – 24	0
Int 3	Page 1 · KNOB3	Continuous	–24 – 24	–12
Detune	Page 1 · KNOB4	Continuous	0 – 50	6
Mode	Page 2 · KNOB1	List, 4 values	0 – 3	0 Low-pass
Cutoff	Page 2 · KNOB2	Continuous, logarithmic	30 – 16000 Hz	1566.45 Hz
Resonance	Page 2 · KNOB3	Continuous	0 – 100	31.5
PW	Page 2 · KNOB4	Continuous	0 – 100	50.3937
Env Amt	Page 3 · KNOB1	Continuous	–100 – 100	0
Attack	Page 3 · KNOB2	Continuous, logarithmic	1 – 10000 ms	2.07 ms
Decay	Page 3 · KNOB3	Continuous, logarithmic	1 – 10000 ms	160.2 ms
Sustain	Page 3 · KNOB4	Continuous	0 – 100	70.9
Release	Page 4 · KNOB1	Continuous, logarithmic	1 – 10000 ms	77.6 ms
Volume	Page 4 · KNOB2	Continuous	0 – 1	0.7

Wave values		
0 Saw x3	5 Saw&Tri	10 Sync Pulse
1 Pulse x3	6 Pulse&Saw	11 Sync 3
2 Pls+Pls+Tri	7 Pulse+Noise	12 Ring
3 Saw+Saw+Tri	8 Noise	13 Ring 3
4 Tri x3	9 Sync	14 Ring+Sync

15 Ring+Sync P

Mode values

- 0

Low-pass
- 2

High-pass
- 1

Band-pass
- 3

Notch

8 voices · Identifier `trio` · Felucca by Leo Kuroshita (@kurogedelic), Hugelton Instruments (GPL-3.0): its TRIO engine, three oscillators and a filter in the style of 8-bit sound chips

5.13.3 Phase Bend

Phase Bend is phase distortion, as on the Casio CZ: a sine read through a bent phase, whose bend turns it into a sawtooth, a square, a pulse or one of three resonant waves, a sine sweeping inside a window. It is a port of CrispyZebra, the same author’s phase-distortion oscillator.

- **Wave** chooses the wave: *Saw, Square, Pulse, Double Sine, Saw Pulse*, and the resonant *Reso Saw, Reso Tri* and *Reso Trap*. **ALGORITHM** steps through them. **Wave 2**, when not *Same*, plays on every other cycle, alternating with the first. A note keeps the waves it started with.
- **DCW** sets the bend: at 0 a plain sine; turning it up brightens the wave, or, on the resonant waves, sweeps the resonance up.
- **Env** lets the envelope bend it further as each note starts.
- **Detune** (0 to 127 cents) and **Line** add a second line, detuned, *Mixed* with the first or *Ring*-modulated with it. A note keeps the line it started with.
- **Sub** adds a sine an octave down.
- Page 4 is glide’s, as on Macro: **Glide, Voice Mode, Glide Mode** and **Time Mode** slide between notes and play one note at a time ([chapter 4](#)). Nothing slides until Glide Mode is on Legato or Always.

Felucca’s own Phase Bend sounds:

Sound	Wave, Wave 2	DCW	Env	Detune	Attack, Decay, Sustain, Release
Brass	Saw	24 %	71 %	0	1.8 ms, 160 ms, 71 %, 18 ms
Organ	Double Sine	31 %	0	0	1 ms, 10 s, 100 %, 9 ms
String	Saw, Double Sine	39 %	31.5 %	12	18 ms, 683 ms, 79 %, 160 ms

Sound	Wave, Wave 2	DCW	Env	Detune	Attack, Decay, Sustain, Release
Reso	Reso Saw	47 %	47 %	0	1 ms, 160 ms, 24 %, 78 ms
Bell	Reso Tri	63 %	39 %	0	1 ms, 982 ms, 0 %, 683 ms
Wire	Saw Pulse, Reso Tri	55 %	31.5 %	7	2.1 ms, 331 ms, 63 %, 78 ms

Phase Bend: what the four knobs do on each page

	KNOB1	KNOB2	KNOB3	KNOB4
Page 1	Wave	Wave 2	DCW	Env
Page 2	Detune	Line	Sub	Attack
Page 3	Decay	Sustain	Release	Volume
Page 4	Glide	Voice Mode	Glide Mode	Time Mode

Phase Bend parameters

Parameter	Where	Type	Range	Default
Wave	Page 1 · KNOB1	List, 8 values	0 – 7	0 Saw
Wave 2	Page 1 · KNOB2	List, 9 values	0 – 8	0 Same
DCW	Page 1 · KNOB3	Continuous	0 – 100	47.2441
Env	Page 1 · KNOB4	Continuous	0 – 100	50.4
Detune	Page 2 · KNOB1	Continuous	0 – 127	0
Line	Page 2 · KNOB2	List, 2 values	0 – 1	0 Mix
Sub	Page 2 · KNOB3	Continuous	0 – 100	0
Attack	Page 2 · KNOB4	Continuous, logarithmic	1 – 10000 ms	2.07 ms
Decay	Page 3 · KNOB1	Continuous, logarithmic	1 – 10000 ms	160.2 ms
Sustain	Page 3 · KNOB2	Continuous	0 – 100	70.9
Release	Page 3 · KNOB3	Continuous, logarithmic	1 – 10000 ms	77.6 ms
Volume	Page 3 · KNOB4	Continuous	0 – 1	0.7
Glide	Page 4 · KNOB1	Continuous, logarithmic	1 – 5000 ms	100 ms
Voice Mode	Page 4 · KNOB2	List, 3 values	0 – 2	0 Poly
Glide Mode	Page 4 · KNOB3	List, 3 values	0 – 2	0 Off

Parameter	Where	Type	Range	Default
Time Mode	Page 4 · KNOB4	List, 2 values	0 – 1	0 Time

Wave values

- | | | |
|----------|---------------|-------------|
| 0 Saw | 3 Double Sine | 6 Reso Tri |
| 1 Square | 4 Saw Pulse | 7 Reso Trap |
| 2 Pulse | 5 Reso Saw | |

Wave 2 values

- | | | |
|----------|---------------|-------------|
| 0 Same | 3 Pulse | 6 Reso Saw |
| 1 Saw | 4 Double Sine | 7 Reso Tri |
| 2 Square | 5 Saw Pulse | 8 Reso Trap |

Line values

- | | |
|-------|--------|
| 0 Mix | 1 Ring |
|-------|--------|

Voice Mode values

- | | | |
|--------|--------|----------|
| 0 Poly | 1 Mono | 2 Legato |
|--------|--------|----------|

Glide Mode values

- | | | |
|-------|----------|----------|
| 0 Off | 1 Legato | 2 Always |
|-------|----------|----------|

Time Mode values

- | | |
|--------|--------|
| 0 Time | 1 Rate |
|--------|--------|

8 voices · Identifier `phase-bend` · Felucca by Leo Kuroshita (@kurogedelic), Hugelton Instruments (GPL-3.0): its PHASE engine, a port of the phase-distortion oscillator of CrispyZebra by the same author (GPL-3.0)

5.14 Test Sine

STATUS:

• In the simulator

■ On the desktop

Test Sine plays a plain sine wave for each note, at a level set by velocity, with 5 ms fades in and out. It exists to test the firmware and the simulator, and has a single control, **Volume**. When all twelve voices are busy, it ignores further notes until one is free.

Test Sine: what the four knobs do on each page				
	Knob1	Knob2	Knob3	Knob4
Page 1	Volume	–	–	–

Test Sine parameters				
Parameter	Where	Type	Range	Default
Volume	Page 1 · Knob1	Continuous	0 – 1	0.7

12 voices · Identifier `test-sine` · This repository (MIT)

CHAPTER 6

Effects

Each sound passes through two insert effects of its own; the four sounds are then mixed, each at its own level, and the mix passes through two master effects, then the limiter, then **MASTER**. Each slot holds one effect or nothing. Every engine but Macro Heavy’s string machine plays in mono; the effects are where the sound gains its stereo width.

Effects in this build			
Name	Parameters	Chosen from a list	Built from
Plate	5	Freeze	Reverb from Mutable Instruments Rings by Emilie Gillet (MIT)
Ensemble	3	–	Ensemble from Mutable Instruments Plaits by Emilie Gillet (MIT)
Diffuse	4	–	Diffuser from Mutable Instruments Plaits by Emilie Gillet (MIT); tone filter and decorrelator from this repository (MIT)
PSX Verb	5	Model	PSX Verb by Charles Vestal (github.com/charlesvestal/schwung-psxverb , MIT), via the Schwung v2 shim (Schwung plugin ABI by Charles Vestal, MIT)
Crush	6	–	This repository (MIT); after DaisySP's Decimator and Bitcrush (Electro-Smith, MIT), no code copied
Fold	6	–	This repository (MIT): a wavefolder after the Serge and Buchla folders and the folding in Mutable Instruments Warps and Plaits (Emilie Gillet), no code taken; anti-aliasing after Parker, Zavalishin and Le Bivic (DAFx-16)
Drive	8	Type, Auto	This repository (MIT): overdrive and saturation curves written here; anti-aliasing after Parker, Zavalishin and Le Bivic (DAFx-16)
Echo	7	–	This repository (MIT). Ping-pong topology after Zoelzer's DAFX; 16-bit delay words after Emilie Gillet's FxEngine (Mutable Instruments, MIT)

Name	Parameters	Chosen from a list	Built from
Filter	8	Type	This repository (MIT): zero-delay-feedback filters after Zavalishin's The Art of VA Filter Design, Simper's (Cytomic) SVF, Huovilainen's ladder, the Korg35, diode-ladder and Steiner-Parker circuits; vowels from Peterson and Barney (1952). No code taken
Comb	7	—	This repository (MIT): Zoelzer's universal comb (DAFX, ch. 2), with the Filter's saturating loop. No code taken
Comp	10	Character, Auto Rel, Auto Gain	This repository (MIT): a feed-forward compressor after Giannoulis, Massberg and Reiss, "Digital Dynamic Range Compressor Design" (JAES 2012); no code taken
Limiter	7	Mode	This repository (MIT): a look-ahead limiter after Geraint Luff's "Designing a straightforward limiter" (SignalSmith Audio, 2022), no code taken; Mode Round ports Airwindows ClipOnly2 (Chris Johnson, MIT)
DJ Filter	6	Slope	This repository (MIT): a trapezoidal state-variable filter after Andrew Simper (Cytomic) and Vadim Zavalishin, in the form of stmlib's SvF (Emilie Gillet, MIT); no code taken
Tilt	4	Curve	This repository (MIT): a tilt equaliser of first-order sections, bilinear and prewarped at the pivot; the idea after Airwindows ToneSlant (MIT) and Faust's spectral_tilt (STK-4.3), no code taken
Master Sat	8	Shape	This repository (MIT): band-limited bus saturation; curve coefficients from Airwindows PurestSaturation and TapeHack2 (Chris Johnson, MIT, notice in the source); Glue after Airwindows Compresaturator, no code taken
Isolator	6	Kill	This repository (MIT): a three-band kill EQ with Linkwitz-Riley crossovers, the band tree after Faust's crossover3LR4 (filters.lib, STK-4.3), no code taken; TPT state-variable filters after Zavalishin and Simper (Cytomic)

Name	Parameters	Chosen from a list	Built from
EQ	10	–	This repository (MIT): low shelf, bell and high shelf on the trapezoidal state-variable filter in the form Andrew Simper (Cytomic) published (public domain), no code taken; tested against the RBJ Audio EQ Cookbook
Room	6	–	Reverb and diffuser from Mutable Instruments Clouds by Emilie Gillet (MIT); Width and the rate rule from this repository (MIT)
Hall	10	Freeze	This repository (MIT): a feedback delay network after Jot and Chaigne (1991), structure after schwung-work's Voidspace and Geraint Luff's Signalsmith basics (MIT), no code taken; input all-passes after Schroeder and Dattorro; 16-bit delay words after Emilie Gillet's FxEngine (Mutable Instruments, MIT)
Gate	13	Mode, Listen, Link	This repository (MIT): a noise gate with controls after the Drawmer DS201 and DS301 manuals; algorithm ours, no code taken
Squash	12	Type	Airwindows (Chris Johnson), MIT: Pop3, Pressure4 and ButterComp2, ported to single precision without libm by this repository (MIT)
Transient	6	–	This repository (MIT): a transient shaper on the differential-envelope principle (a fast and a slow follower), our own arithmetic; no code taken
Test Gain	1	–	This repository (MIT)
Test Ext	3	Probe, Listen	This repository (MIT)

6.1 The effect chain

STATUS:  In the simulator  On the desktop  Planned for the device

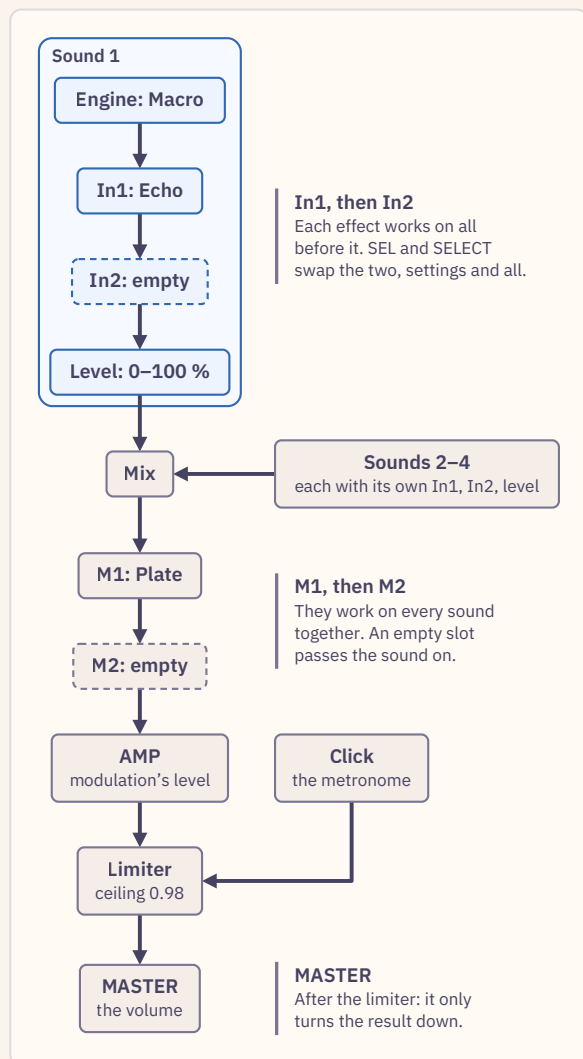


Figure 6.1 One sound's chain and the master bus, with Echo in Sound 1's first insert and Plate in M1 as an example. An empty slot passes the sound on; the limiter keeps the sum below full scale, and MASTER turns the result down.

The simulator starts with Plate in M1, the first master slot, and every other slot empty. An effect processes everything before it: a sound's inserts work on that sound alone, the master effects on everything. A reverb after a chorus sounds different from a chorus after a reverb.

To see the chain: press **[FX]**. The first line of the screen lists the current sound (such as *S1*), its two inserts *In1* and *In2*, the *Mix* page and the master slots *M1* and *M2*, with the chosen one highlighted; the line under it names the chosen slot's effect and says whether the slot is an insert or a master slot. The chosen effect's parameters are on **[KNOB1]** to **[KNOB4]**. FX mode first opens on *M1*. Press **[FX]** again, or **[HOME]**, to return to the sound.

To choose a slot: turn **[SELECT]**. It moves through *In1*'s pages, then *In2*'s, the *Mix* page, *M1*'s and *M2*'s. The bottom bar shows where you are, such as *1/2 M2*: page 1 of 2, the second master slot, or *1/1 S1 In1*. The inserts are the current sound's: to reach another sound's inserts, choose that sound first ([chapter 5](#)).

To put an effect in the chosen slot: turn **[ALGORITHM]**. It steps through *Empty slot*, *Plate*, *Ensemble*, *Diffuse*, *PSX Verb*, *Crush*, *Fold*, *Drive*, *Echo*, *Filter*, *Comb*, *Comp*, *Limiter*, *DJ Filter*, *Tilt*, *Master Sat*, *Isolator*, *EQ*, *Room*, *Hall*, *Gate*, *Squash*, *Transient*, *Test Gain* and *Test Ext*, and round again, stepping over an effect that would not fit the memory (below). The list on the screen spells the short names out: *Compressor*, *Master Saturation*, *Equaliser*, *Transient Shaper*. In the simulator you can also use the **Effect 1** and **Effect 2** lists under the panel for the two master slots.

To empty a slot: turn **[ALGORITHM]** to *Empty slot*, one step before *Plate*, or choose (*none*) in the list.

To swap two effects: press **[SEL]** to pick up the chosen effect (its arrow turns into an asterisk and **[SEL]** lights), turn **[SELECT]** to move it, and press **[SEL]** again to put it down. The two inserts swap with each other, and the two master effects with each other. The effects move with their settings.

- An effect you put in a slot starts with its default settings, and the old effect's tail stops at once.
- **Knobs for frequencies and times turn in ratios.** A cutoff, a crossover, a delay time or a release moves by the same musical step wherever it is: each click of the knob multiplies it, so 20 to 40 Hz takes as many clicks as 5 to 10 kHz, and a hundred clicks go from one end to the other. The screen still shows hertz and milliseconds, with more decimals at the low end, and the bar shows where the knob is. The sequencer's locks will store them the same way once they reach the effects ([chapter 7](#)), and modulation moves them in octaves: a source that follows the note you play, at full amount, makes a cutoff follow the keyboard exactly.
- The same effect can sit in several slots, each with its own settings.

- **Modulation reaches the effects' parameters**, in the inserts and the master slots (chapter 8). The sequencer's parameter locks reach only the sounds' parameters so far; locks on the effects are planned (chapter 7).
- Changing a sound's engine keeps its inserts and the master effects, and their settings.

In the desktop tools, `--fx` adds effects in the order you give them, and each `--fx-param` sets a parameter of the effect before it (chapter 2). There you can chain more than two. With the multi-sound options, `--insert K:ID` adds an insert to sound *K* and the first two `--fx` are the master effects.

6.1.1 The Mix page

Between the inserts and the master slots, the Mix page shows the four sounds, each with its engine (or *Empty*) and its level into the mix, from 0 to 100 %. **Knob1** to **Knob4** set the levels of Sounds 1 to 4, 1 % a click. Every sound starts at 100 %.

6.1.2 Memory

Every sound, effect and module, the sequencer and modulation have to fit in the FM-1's memory. The simulator measures them against the room M-VAVE's firmware leaves free on the FM-1, as an estimate of what Lunar Modulator will have there (chapter 13), and shows memory only as a share of that room: 100 % is all of it. The meter in the screen's bottom bar shows how much the whole chain takes, as a bar and a percentage, and the global page the same percentage.

Whatever would take the chain past 100 % is refused, whether you choose it with **PRESETS**, **ALGORITHM** or a list under the panel: the screen names it, says *does not fit* and what the chain would need with it, such as *needs 112% of RAM*, and the slot keeps what it had. **PRESETS** and **ALGORITHM** step on to the next choice that fits. Most chains fit; Shapes twice, or Shapes with PSX Verb and Plate, do not. So whatever plays in the simulator would fit the FM-1.

● Rates

The effects run at the output's rate. They were written for rates of about 48,000 samples a second, so at the FM-1's 44,118 their delays come out about 9 % longer, a slightly larger room, and their slow modulation about 8 % slower. Their decay times are corrected, and stay within a few per cent of the originals'. Room, from Clouds, was written for 32,000, so its room comes out about a quarter smaller and its slow modulation faster; its decay is corrected the same way, though its shortest settings ring a little shorter than on Clouds. Crush, Fold, Drive, Echo, Filter, Comb, Comp, Limiter, DJ Filter, Tilt, Master Sat, Isolator, EQ, Hall, Gate, Squash and Transient, written or rewritten for Lunar Modulator, work out their frequencies and times from the output's rate, so they need no correction.

6.2 Plate

STATUS:  In the simulator  On the desktop  Planned for the device

A plate reverb, from Mutable Instruments Rings: a dense, smooth tail that sits behind the sound. It takes the sum of both channels in and returns a stereo tail.

- **Mix** fades from the dry sound at the left to the reverb alone at the right.
- **Decay** sets how long the tail lasts.
- **Damping** darkens the tail as it decays: the higher, the darker.
- **Diffusion** smears the echoes into a smooth wash; lower values leave more distinct reflections. The default, 0.5, is the setting Rings itself uses.
- **Freeze**, on page 2, holds the tail at the level it has and lets nothing new in, as Mutable Instruments Elements does with this reverb: play over a frozen chord, and Mix still blends in what you play. Decay and Damping wait until you turn it off. It switches over 5 milliseconds, so it does not click, and modulation can turn it on and off in time. The hold is long but not endless: the highs fade over seconds and the body over minutes, and a quiet tail runs out sooner (about 25 seconds at -39 dBFS, nearly 3 minutes at -19 dBFS).

◆ **Starting points**

- **A small room:** Decay low, Mix about 0.2.
- **A long plate for pads:** Decay high, Damping low, Mix about 0.4.
- **A dark wash:** Decay high, Damping high, Mix towards the right.
- **A held chord:** play a chord, turn Freeze on, then play over it.

Plate: what the four knobs do on each page				
	KNOB1	KNOB2	KNOB3	KNOB4
Page 1	Mix	Decay	Damping	Diffusion
Page 2	Freeze	–	–	–

Plate parameters				
Parameter	Where	Type	Range	Default
Mix	Page 1 • KNOB1	Continuous	0 – 1	0.3
Decay	Page 1 • KNOB2	Continuous	0 – 1	0.5
Damping	Page 1 • KNOB3	Continuous	0 – 1	0.3
Diffusion	Page 1 • KNOB4	Continuous	0 – 1	0.5
Freeze	Page 2 • KNOB1	List, 2 values	0 – 1	0 Off

Freeze values	
0 Off	1 On

Effect • Identifier `plate` • Reverb from Mutable Instruments Rings by Emilie Gillet (MIT)

6.3 Ensemble

STATUS: ● In the simulator ■ On the desktop ◆ Planned for the device

The ensemble from Plaits’ string machine: a rich, swirling chorus that turns one voice into many. It mixes three moving copies of the sound, swept by a slow and a fast modulation.

- **Mix** blends in the effect. The dry sound never drops below half, so even at the right the original is still there.
- **Depth** sets how far the copies drift.
- **Width** spreads the effect across the stereo field. At the left both sides are the same, as in the original module; turn it up to widen a mono engine.

Ensemble has no tail: when the sound stops, so does the effect.

◆ **Strings and pads**

Put Ensemble before Plate for string-machine pads, and keep Depth low for a subtle thickening of single notes.

Ensemble: what the four knobs do on each page

	Knob1	Knob2	Knob3	Knob4
Page 1	Mix	Depth	Width	–

Ensemble parameters

Parameter	Where	Type	Range	Default
Mix	Page 1 · Knob1	Continuous	0 – 1	0.5
Depth	Page 1 · Knob2	Continuous	0 – 1	0.5
Width	Page 1 · Knob3	Continuous	0 – 1	1

Effect · Identifier `ensemble` · Ensemble from Mutable Instruments Plaits by Emilie Gillet (MIT)

6.4 Diffuse

STATUS: • In the simulator ■ On the desktop ◆ Planned for the device

The diffuser from Plaits’ particle model: a short, grainy reverb that blurs attacks. It takes the sum of both channels in and returns a stereo result.

- **Mix** fades from the dry sound at the left to the effect alone at the right.
- **Time** sets how long the blur lasts.
- **Tone** darkens the effect: at the left only the lows remain, and at the right almost nothing is filtered. The default lets through everything up to about 9.5 kHz.
- **Width** spreads the effect across the stereo field. At the left both sides are the same.

◆ **Softening attacks**

Use Diffuse on percussion such as Sophie or Macro Heavy’s drums, and in front of Plate to soften the start of each note before the long tail.

Diffuse: what the four knobs do on each page

	Knob1	Knob2	Knob3	Knob4
Page 1	Mix	Time	Tone	Width

Diffuse parameters

Parameter	Where	Type	Range	Default
Mix	Page 1 · Knob1	Continuous	0 – 1	0.5
Time	Page 1 · Knob2	Continuous	0 – 1	0.5
Tone	Page 1 · Knob3	Continuous	0 – 1	0.75
Width	Page 1 · Knob4	Continuous	0 – 1	1

Effect · Identifier `diffuse` · Diffuser from Mutable Instruments Plaits by Emilie Gillet (MIT); tone filter and decorrelator from this repository (MIT)

6.5 PSX Verb

STATUS: • In the simulator ■ On the desktop ◆ Planned for the device

A reverb modelled on the sound chip of a well-known 1990s games console, by Charles Vestal, from the Schwung community. Its six models range from a small room to a hall and Space Echo.

- **Model** chooses the room: *Room*, *Studio S*, *Studio M*, *Studio L*, *Hall* or *Space Echo*. The default is Hall.
- **Decay** sets the length of the tail. In the middle it matches the original chip; to the left it is shorter, to the right longer.
- **Mix** fades from the dry sound at the left to the reverb alone at the right.
- **Level** sets how loud the reverb itself is.
- **Input**, on page 2, sets how hard the reverb is driven.

● **Choosing the model**

In FX mode, **ALGORITHM** changes the effect in the slot, not PSX Verb’s model. To change the model, turn **KNOB1** on page 1.

PSX Verb takes 35 % of the memory, the most of any effect.

PSX Verb: what the four knobs do on each page

	KNOB1	KNOB2	KNOB3	KNOB4
Page 1	Model	Decay	Mix	Level
Page 2	Input	–	–	–

PSX Verb parameters

Parameter	Where	Type	Range	Default
Model	Page 1 · KNOB1	List, 6 values	0 – 5	4 Hall
Decay	Page 1 · KNOB2	Continuous	0 – 1	0.7
Mix	Page 1 · KNOB3	Continuous	0 – 1	0.35
Level	Page 1 · KNOB4	Continuous	0 – 1	0.5
Input	Page 2 · KNOB1	Continuous	0 – 1	0.5

Model values

0 Room	2 Studio M	4 Hall
1 Studio S	3 Studio L	5 Space Echo

Effect · Identifier `sw-psxverb` · PSX Verb by Charles Vestal (github.com/charlesvestal/schwung-psxverb, MIT), via the Schwung v2 shim (Schwung plugin ABI by Charles Vestal, MIT)

6.6 Crush

STATUS:  In the simulator  On the desktop  Planned for the device

A bitcrusher and sample-rate reducer, for the grit of early samplers and game consoles. It holds each sample for a while and rounds it to a coarse step, so the sound loses its top end in a shower of aliasing and its quiet detail in buzz. Both channels are held at the same moments.

- **Bits** sets how fine the steps are, from 16, all but untouched, down to 1. It turns smoothly between whole numbers, so it can sweep. Silence stays silent at any setting, but at very low Bits quiet sounds fall under the first step and drop out: at 1 bit only full-scale sound comes through.
- **Rate** sets how often a new sample is taken, from 100 times a second at the left to every sample at the right; the default is about 9,600. The scale is even in pitch, so each step of the knob sounds alike.
- **Jitter** makes each hold a little longer or shorter at random, which roughens the tone and smears the aliasing into noise. At the left every hold is the same length. The randomness repeats exactly each time the effect starts.
- **Mix** fades from the dry sound at the left to the crushed sound alone at the right, the default.
- **Tone**, on page 2, darkens the crushed sound: at the right nothing is filtered, at the left only the lows below about 150 Hz remain.
- **Level**, on page 2, sets how loud the crushed sound is, up to twice its level.

◆ **Starting points**

- **Old sampler:** Bits 12, Rate about 0.8, Tone about 0.8.
- **Broken game console:** Bits 4, Rate about 0.5, Jitter a little.
- **Radio static:** Bits 2 to 3, Rate low, Jitter high, Mix about 0.5.
- Turn the engine up rather than Level when low Bits makes a quiet sound vanish: the steps are fixed against full scale.

Crush: what the four knobs do on each page

	Knob1	Knob2	Knob3	Knob4
Page 1	Bits	Rate	Jitter	Mix
Page 2	Tone	Level	–	–

Crush parameters

Parameter	Where	Type	Range	Default
Bits	Page 1 · Knob1	Continuous	1 – 16	8
Rate	Page 1 · Knob2	Continuous	0 – 1	0.75
Jitter	Page 1 · Knob3	Continuous	0 – 1	0
Mix	Page 1 · Knob4	Continuous	0 – 1	1
Tone	Page 2 · Knob1	Continuous	0 – 1	1
Level	Page 2 · Knob2	Continuous	0 – 2	1

Effect · Identifier `crush` · This repository (MIT); after DaisySP's Decimator and Bitcrush (Electro-Smith, MIT), no code copied

6.7 Fold

STATUS: • In the simulator ■ On the desktop ◆ Planned for the device

A wavefolder, written for Lunar Modulator, after the folders of Serge and Buchla synthesizers. It turns the sound up into a fold point and folds whatever passes it back

on itself, again and again, so a plain wave grows bright, hollow, ringing overtones that move as the level changes. Each channel is folded on its own.

- **Fold** sets how hard the sound is driven into the folds, from not at all at the left (a sound within full scale passes unfolded) to sixteen times at the right. The louder the note, the more it folds, so velocity and the engine’s envelope shape the tone.
- **Symmetry** shifts the sound before it is folded. In the middle the folds are even; away from it they are lopsided and add a hollow, reedy colour, and at either end a quiet sound is folded on one side only.
- **Shape** chooses the fold: at the left sharp corners, bright and buzzy; at the right rounded ones, softer; in between a blend.
- **Mix** fades from the dry sound at the left to the folded sound alone at the right, the default.
- **Tone**, on page 2, darkens the folded sound, from about 200 Hz at the left to almost nothing filtered at the right.
- **Level**, on page 2, sets how loud the folded sound is.

Silence stays silent at any setting, and the knobs glide over a few milliseconds, so turning them does not click. Fold is built to keep the harsh, unrelated tones of a digital folder low, and it has no tail: when the sound stops, so does the effect.

◆ **Starting points**

- **West-coast lead:** a sine from Shapes or Macro, Fold about 0.6, Shape about 0.5, and play with velocity.
- **Reedy bass:** Fold about 0.4, Symmetry about 0.4, Tone about 0.6.
- **Movement:** put Ensemble or Echo after Fold, and sweep Fold slowly by hand while a note holds.

Fold: what the four knobs do on each page				
	Knob1	Knob2	Knob3	Knob4
Page 1	Fold	Symmetry	Shape	Mix
Page 2	Tone	Level	—	—

Fold parameters				
Parameter	Where	Type	Range	Default
Fold	Page 1 · KNOB1	Continuous	0 – 1	0.4
Symmetry	Page 1 · KNOB2	Continuous	–1 – 1	0
Shape	Page 1 · KNOB3	Continuous	0 – 1	0
Mix	Page 1 · KNOB4	Continuous	0 – 1	1
Tone	Page 2 · KNOB1	Continuous	0 – 1	0.8
Level	Page 2 · KNOB2	Continuous	0 – 1	0.7

Effect · Identifier `fold` · This repository (MIT): a wavefolder after the Serge and Buchla folders and the folding in Mutable Instruments Warps and Plaits (Emilie Gillet), no code taken; anti-aliasing after Parker, Zavalishin and Le Bivic (DAFx-16)

6.8 Drive

STATUS:  In the simulator  On the desktop  Planned for the device

Overdrive and saturation, written for Lunar Modulator: the sound is turned up into a curve that flattens its peaks, from a gentle warmth to a buzzing fuzz. Each channel is shaped on its own.

- **Type** chooses the curve. Changing it fades from one to the next in a few milliseconds, so it does not click, even when modulation changes it on every step.
 - **Soft:** smooth, rounded saturation, the most even-tempered.
 - **Tube:** lopsided, so it adds a warm second harmonic even when barely driven, and squashes one side of the wave before the other.
 - **Diode:** clean up to a point, then a firmer knee, like the clipping diodes in an overdrive pedal.
 - **Fuzz:** a hard clip with corners, lopsided and with a little gate of its own, so decaying notes break up and sputter.
 - **Tape:** gentle, with more headroom; loud high notes and bright sounds saturate first and come out softened.

- **Drive** sets how hard the sound is driven, from -12 dB at the left (nearly clean) to +36 dB at the right. Louder notes are driven harder, so velocity and the engine’s envelope change the tone.
- **Tone** tilts the driven sound: in the middle it is left alone, to the left the highs are cut (darker, less fizz), to the right the lows (thinner, brighter).
- **Mix** fades from the dry sound at the left to the driven sound alone at the right, the default. In between, the dry sound keeps its punch under the drive.
- **Bias**, on page 2, makes the clipping uneven, which adds a hollow, reedy colour; in the middle the curve is used as it is.
- **Gate**, on page 2, makes the quietest part of each wave drop out, from nothing at the left to a lot at the right: a crackle on every Type, and on Fuzz the starved, sputtering sound of a fuzz with a dying battery. More Drive lets more of the sound through.
- **Level**, on page 2, sets how loud the driven sound is, from -24 to +12 dB.
- **Auto**, on page 2, is on by default: it keeps the driven sound about as loud as the dry sound whatever Drive and Type are, so turning Drive changes the character and not the volume. Turn it off to let Drive make the sound louder too, as on a pedal.

Silence stays silent at any setting, and the knobs glide over a few milliseconds, so turning them does not click. Drive is built to keep the harsh, unrelated tones of a digital clipper low, and it has no tail: when the sound stops, so does the effect.

◆ **Starting points**

- **Warm bass:** Tube, Drive about +12 dB, Tone a little left of the middle.
- **Lead:** Diode, Drive +24 dB, Tone about 0.4, then a little Echo.
- **Broken fuzz:** Fuzz, Drive +24 dB, Gate about 0.4, Bias a little off the middle, and play notes that decay.
- **Tape glue:** Tape, Drive about +18 dB, Mix about 0.6, on chords.

Drive: what the four knobs do on each page				
	KNOB1	KNOB2	KNOB3	KNOB4
Page 1	Type	Drive	Tone	Mix
Page 2	Bias	Gate	Level	Auto

Drive parameters				
Parameter	Where	Type	Range	Default
Type	Page 1 · KNOB1	List, 5 values	0 – 4	0 Soft
Drive	Page 1 · KNOB2	Continuous	–12 – 36 dB	12 dB
Tone	Page 1 · KNOB3	Continuous	0 – 1	0.5
Mix	Page 1 · KNOB4	Continuous	0 – 1	1
Bias	Page 2 · KNOB1	Continuous	–1 – 1	0
Gate	Page 2 · KNOB2	Continuous	0 – 1	0
Level	Page 2 · KNOB3	Continuous	–24 – 12 dB	0 dB
Auto	Page 2 · KNOB4	List, 2 values	0 – 1	1 On

Type values

- 0 Soft
- 1 Tube
- 2 Diode
- 3 Fuzz
- 4 Tape

Auto values

- 0 Off
- 1 On

Effect · Identifier `drive` · This repository (MIT): overdrive and saturation curves written here; anti-aliasing after Parker, Zavalishin and Le Bivic (DAFx-16)

6.9 Echo

STATUS:

In the simulator

On the desktop

Planned for the device

A stereo echo, written for Lunar Modulator, whose repeats can bounce from one side to the other. Up to about a third of a second the echoes are clean copies; longer ones

grow darker with each repeat, like those of an old analogue echo pedal, so that the effect keeps to 17 % of the memory however long the time.

- **Time** sets the delay, from 10 milliseconds at the left to one second at the right; the default is 300. Turning it while echoes sound bends their pitch, like changing a tape echo’s speed.
- **Feedback** sets how many times the sound repeats, from a single echo at the left to a long, slowly fading trail at the right. It never runs away.
- **Ping-pong** at the right, the default, sends the repeats left, right, left; at the left each side echoes on its own side.
- **Mix** fades from the dry sound to the echoes. The dry sound stays at full level up to the middle and the echoes are at full level from the middle on, so the middle has both at full level.
- **Tone**, on page 2, darkens each repeat a little more than the one before: at the left the trail turns dull quickly, at the right it stays bright.
- **Wow**, on page 2, adds a slow wobble to the delay, like a worn tape; it sounds the same every time you play.
- **Level**, on page 2, sets how much of the sound goes into the echo. Turn it down to let the echoes ring on while what you play next stays dry.

◆ **Starting points**

- **Slapback:** Time about 100, Feedback low, Ping-pong at the left, Mix about 0.3.
- **Wide bounce:** Time about 300, Feedback about 0.5, Ping-pong at the right.
- **Dub trail:** Time about 600, Feedback high, Tone about 0.3, Wow about 0.3.

Echo does not yet follow the sequencer’s tempo; set Time by ear.

Echo: what the four knobs do on each page				
	Knob1	Knob2	Knob3	Knob4
Page 1	Time	Feedback	Ping-pong	Mix
Page 2	Tone	Wow	Level	–

Echo parameters				
Parameter	Where	Type	Range	Default
Time	Page 1 · KNOB1	Continuous, logarithmic	10 – 1000 ms	300 ms
Feedback	Page 1 · KNOB2	Continuous	0 – 1	0.4
Ping-pong	Page 1 · KNOB3	Continuous	0 – 1	1
Mix	Page 1 · KNOB4	Continuous	0 – 1	0.35
Tone	Page 2 · KNOB1	Continuous	0 – 1	0.6
Wow	Page 2 · KNOB2	Continuous	0 – 1	0.1
Level	Page 2 · KNOB3	Continuous	0 – 1	1

Effect · Identifier `echo` · This repository (MIT). Ping-pong topology after Zoelzer's DAFX; 16-bit delay words after Emilie Gillet's FxEngine (Mutable Instruments, MIT)

6.10 Filter

STATUS: ● In the simulator ■ On the desktop ◆ Planned for the device

A filter with six characters in one, written for Lunar Modulator. It takes away part of the sound's spectrum, the highs, the lows or a band, and as Resonance rises it rings at the cutoff, up to a whistle of its own. Each channel is filtered on its own, so Morph can pull them apart.

- **Type** chooses the filter. Changing it starts the new one quietly in the background, then fades over to it, all within about 10 milliseconds, so it does not click, even when modulation changes it on every step.
 - **SVF**: a clean state-variable filter. Mode picks low-pass, band-pass, high-pass or notch.
 - **Ladder**: the classic four-stage ladder, the default: round and thick, and its bass holds as Resonance rises. Mode picks how steep it is, from 24 dB per octave down to 6.
 - **Diode**: a diode ladder in the style of the TB-303: rubbery and squelchy at high Resonance. Mode as for Ladder.

- **Sallen-Key:** a Sallen-Key filter, after the Korg-35 filter of the later MS-20: bright and aggressive, it screams as Resonance rises. Mode picks low-pass, band-pass, high-pass or notch.
 - **SK Mixed:** a mixed-input Sallen-Key, after the Steiner-Parker Synthacon's filter: gritty and uneven. Mode picks which input the sound goes into: low-pass, band-pass, high-pass, or a notch.
 - **Formant:** the vowels A, E, I, O and U, as a voice shapes them. Morph sweeps through the vowels; Mode picks the voice, a man's at the left, a woman's in the middle, a child's at the right; Cutoff shifts the vowels up or down; Resonance makes them narrower and more vocal.
- **Cutoff** sets where the filter works, from 20 Hz to 18 kHz; the default is 2 kHz. When a filter rings on its own, it rings at this pitch. Each click moves it about a semitone, the same at any height.
 - **Resonance** emphasises the sound around Cutoff. Near the right, from about 0.93, SVF, Ladder, Diode, Sallen-Key and SK Mixed whistle on their own, in tune with Cutoff (SK Mixed a little flat). On Formant it sets how narrow the vowels are.
 - **Drive** pushes the sound into the filter's saturation: quiet sounds come up to 12 dB louder, loud ones thicken and grit.
 - **Mode**, on page 2, changes the response as each Type above describes. It turns smoothly: between two positions you hear a blend of both.
 - **Morph**, on page 2, spreads the two channels for SVF, Ladder, Diode, Sallen-Key and SK Mixed: at the right, the left channel's cutoff is up to an octave lower and the right's an octave higher. On Formant it sweeps the vowels.
 - **Mix**, on page 2, fades from the dry sound at the left to the filtered sound alone at the right, the default.
 - **Level**, on page 2, sets the filtered sound's level, up to twice (6 dB) at the right.

Silence stays silent at any setting, even with a filter ringing, and the knobs glide over a few milliseconds, so turning them does not click.

◆ **Starting points**

- **Acid bass:** Diode, Cutoff about 400 Hz, Resonance about 0.8, Drive about 0.5, low notes, and turn Cutoff while they play.
- **Talking pad:** Formant, Resonance about 0.6, and sweep Morph slowly.
- **Screaming lead:** Sallen-Key, Resonance about 0.9, Drive about 0.3.
- **Wide sweep:** Ladder, Morph about 0.3, and sweep Cutoff.

The comb filter that was the seventh Type until October 2026 is an effect of its own now: [Comb](#).

Filter: what the four knobs do on each page				
	KNOB1	KNOB2	KNOB3	KNOB4
Page 1	Type	Cutoff	Resonance	Drive
Page 2	Mode	Morph	Mix	Level

Filter parameters				
Parameter	Where	Type	Range	Default
Type	Page 1 • KNOB1	List, 6 values	0 – 5	1 Ladder
Cutoff	Page 1 • KNOB2	Continuous, logarithmic	20 – 18000 Hz	2000 Hz
Resonance	Page 1 • KNOB3	Continuous	0 – 1	0.25
Drive	Page 1 • KNOB4	Continuous	0 – 1	0
Mode	Page 2 • KNOB1	Continuous	0 – 3	0
Morph	Page 2 • KNOB2	Continuous	0 – 1	0
Mix	Page 2 • KNOB3	Continuous	0 – 1	1
Level	Page 2 • KNOB4	Continuous	0 – 2	1

Type values

- | | | |
|----------|--------------|------------|
| 0 SVF | 2 Diode | 4 SK Mixed |
| 1 Ladder | 3 Sallen-Key | 5 Formant |

Effect · Identifier `filter` · This repository (MIT): zero-delay-feedback filters after Zavalishin's The Art of VA Filter Design, Simper's (Cytomic) SVF, Huovilainen's ladder, the Korg35, diode-ladder and Steiner-Parker circuits; vowels from Peterson and Barney (1952). No code taken

6.11 Comb

STATUS: • In the simulator ■ On the desktop ◆ Planned for the device

A comb filter, written for Lunar Modulator: a very short echo tuned by Cutoff, which makes metallic, flanger-like peaks or notches at the multiples of that pitch. It was one of Filter's types until October 2026; on its own, Filter no longer carries its memory.

- **Cutoff** tunes the comb, from 20 Hz to 18 kHz; the default is 2 kHz. Set it on the note you play and the sound rings at that pitch. Like Filter's, each click moves it about a semitone.
- **Resonance** sets how long the echo rings, from a short colour at the left to a long, singing ring at the right.
- **Drive** pushes the sound into the comb's saturation: quiet sounds come up louder, loud ones thicken.
- **Mode**, on page 2, goes from peaks at the left (the echo fed back) to notches at the right (the echo added once), blending between.
- **Morph**, on page 2, sets the polarity: at the left the peaks sit on Cutoff's harmonics; in the middle the comb does nothing; at the right the sound turns hollow and an octave lower.
- **Mix**, on page 2, fades from the dry sound at the left to the comb alone at the right, the default.
- **Level**, on page 2, sets the comb's level, up to twice (6 dB).

Silence stays silent at any setting, and the knobs glide, so turning them does not click.

◆ Starting points

- **Metallic ring:** Cutoff on the note you play, Resonance about 0.8.
- **Hollow tube:** Morph at the right, Resonance about 0.6, Cutoff an octave above the note.
- **Flanger:** Mode about 2, Mix about 0.5, and modulate Cutoff with a slow LFO.

Comb: what the four knobs do on each page				
	KNOB1	KNOB2	KNOB3	KNOB4
Page 1	Cutoff	Resonance	Drive	–
Page 2	Mode	Morph	Mix	Level

Comb parameters				
Parameter	Where	Type	Range	Default
Cutoff	Page 1 · KNOB1	Continuous, logarithmic	20 – 18000 Hz	2000 Hz
Resonance	Page 1 · KNOB2	Continuous	0 – 1	0.25
Drive	Page 1 · KNOB3	Continuous	0 – 1	0
Mode	Page 2 · KNOB1	Continuous	0 – 3	0
Morph	Page 2 · KNOB2	Continuous	0 – 1	0
Mix	Page 2 · KNOB3	Continuous	0 – 1	1
Level	Page 2 · KNOB4	Continuous	0 – 2	1

Effect · Identifier `comb` · This repository (MIT): [Zoelzer's universal comb \(DAFX, ch. 2\)](#), with the Filter's saturating loop. No code taken

6.12 Comp

STATUS: • In the simulator ■ On the desktop ◆ Planned for the device

A compressor, written for Lunar Modulator. When the sound gets louder than a threshold, Comp turns it down, so loud and quiet notes sit closer together: drums hit harder and hang together, chords sustain evenly, a bass line stays steady. Both channels are turned down together, so the stereo picture does not move.

- **Threshold** sets the level above which Comp starts to work, from –60 dB at the left to 0 dB, full scale, at the right. The lower it is, the more of the sound is compressed.
- **Ratio** sets how hard. At 4, the default, every 4 dB that the sound rises past the threshold comes out as 1 dB. It goes from 1 (no compression) to 20, and at 21, the far right, nothing gets past the threshold at all: Comp becomes a limiter.

- **Attack** sets how quickly Comp reacts, from at once at 0 to 100 milliseconds. A slower attack lets the start of each note or hit through before the sound is turned down, which keeps it punchy.
- **Release** sets how quickly the sound comes back up once it gets quieter, from 10 milliseconds to 2 seconds. Short releases pump with the rhythm; long ones hold the level steady.
- **Knee**, on page 2, softens the threshold. At 0 the compression starts all at once; the higher the knee, the more gently it eases in, over that many dB around the threshold.
- **Makeup**, on page 2, turns the result up, or down, by up to 24 dB, to win back the level the compression took.
- **Mix**, on page 2, blends the untouched sound back in. At the right, the default, you hear only the compressed sound; in between is parallel compression, where the dry sound's hits ride on the compressed sound's body.
- **Character**, on page 2, chooses how Comp listens and reacts:
 - **Peak** reacts to every peak: precise, for taming hits and for limiting.
 - **RMS** reacts to the average loudness, which is gentler and closer to how loud the sound seems.
 - **Glue** listens like RMS, but more slowly, lets go more smoothly and has a softer knee: for holding chords or a whole part together.
 - **Punch** reacts to peaks but eases into each one, so the front of every hit gets through before Comp clamps down.
- **Auto Rel**, on page 3, makes the release follow the music. After a short peak the sound comes back quickly; after a long loud passage, slowly. Short hits leave no holes and long notes do not pump.
- **Auto Gain**, on page 3, sets the makeup for you, so that a sound at full scale stays at full scale however Threshold, Ratio and Knee are set, up to 24 dB of it: past that, at very low thresholds and high ratios, the sound comes out quieter. It never pushes a sound past full scale, and it touches nothing else: only a moment that its makeup would push past full scale, such as the start of a hit before Attack has caught up, is held at full scale, so a sound that does not pass full scale on the way in does not pass it on the way out, and everything under full scale, steady notes included, sounds exactly as with the same makeup set by hand. Where it holds a peak it clips it, so with a slow Attack the starts of loud notes can sound slightly gritty; a shorter Attack, or the Limiter for a clean ceiling, avoids it. Makeup then

adds to it or takes from it; with Makeup above 0 the output can pass full scale by that much.

Silence stays silent at any setting, and the knobs glide over a few milliseconds, so turning them does not click; changing Character, Auto Rel or Auto Gain while Comp is working does not jump either, so modulation can change them on every step.

◆ **Starting points**

- **Tighter drums:** Peak, Threshold about -20, Ratio 4, Attack about 10, Release about 100, Auto Gain on.
- **Smooth pad:** Glue, Threshold about -24, Ratio 2 to 3, Attack about 30, Release about 400, Auto Rel on.
- **Parallel punch:** Punch, Threshold about -35, Ratio 8, Mix about 0.5, then Makeup to taste.
- **Brick wall:** Peak, Ratio 21, Attack 0, Release about 50, the threshold just under the loudest peaks.

Comp listens only to the sound passing through it. Making one sound duck under another (a sidechain) may come later.

Comp: what the four knobs do on each page				
	Knob1	Knob2	Knob3	Knob4
Page 1	Threshold	Ratio	Attack	Release
Page 2	Knee	Makeup	Mix	Character
Page 3	Auto Rel	Auto Gain	—	—

Comp parameters				
Parameter	Where	Type	Range	Default
Threshold	Page 1 • Knob1	Continuous	-60 – 0 dB	-18 dB
Ratio	Page 1 • Knob2	Continuous	1 – 21	4
Attack	Page 1 • Knob3	Continuous	0 – 100 ms	10 ms
Release	Page 1 • Knob4	Continuous, logarithmic	10 – 2000 ms	150 ms
Knee	Page 2 • Knob1	Continuous	0 – 24 dB	6 dB

Parameter	Where	Type	Range	Default
Makeup	Page 2 • KNOB2	Continuous	−12 – 24 dB	0 dB
Mix	Page 2 • KNOB3	Continuous	0 – 1	1
Character	Page 2 • KNOB4	List, 4 values	0 – 3	0 Peak
Auto Rel	Page 3 • KNOB1	List, 2 values	0 – 1	0 Off
Auto Gain	Page 3 • KNOB2	List, 2 values	0 – 1	0 Off

Character values

- 0

 Peak
- 1

 RMS
- 2

 Glue
- 3

 Punch

Auto Rel values

- 0

 Off
- 1

 On

Auto Gain values

- 0

 Off
- 1

 On

Effect • Identifier `comp` • This repository (MIT): a feed-forward compressor after Giannoulis, Massberg and Reiss, "Digital Dynamic Range Compressor Design" (JAES 2012); no code taken

6.13 Limiter

STATUS:

In the simulator

On the desktop

Planned for the device

A look-ahead brickwall limiter, written for Lunar Modulator, for the whole sound (in M2, the second master slot) or to tame one effect’s peaks. It sees peaks a few milliseconds before they arrive and turns the sound down just in time, so nothing passes its ceiling, and it leaves anything quieter untouched.

- **Ceiling** is the most the output reaches, from −24 dB at the left to 0 dB, full scale, at the right; the default is −1 dB.

- **Drive** turns the sound up into the limiter, by up to 24 dB, for a louder, denser sound; to the left of 0 it turns the sound down.
- **Release** sets how quickly the sound comes back up after a peak, from 1 millisecond to 1 second; the default is 100 milliseconds. Short releases are louder but can pump or distort low notes; long ones are smoother.
- **Lookahead** sets how far ahead the limiter looks, from 0 to 5 milliseconds; the default is 2. The sound is delayed by as much. At 0 there is no delay, and the limiter catches the front of each peak with a gentle soft clip instead.
- **Mode**, on page 2, chooses how peaks are handled:
 - **Brickwall** turns them down, so nothing passes the ceiling and nothing below it is changed.
 - **Soft Clip** lets them run into a curve that rounds them off just under the ceiling: louder and warmer, with some added harmonics.
 - **Round** lets peaks up to 3 dB over the ceiling through to a gentle final clip that rounds each one off between its neighbours and the ceiling, and turns down only what goes further. Everything under the ceiling passes untouched. Louder than Brickwall, with a little edge on the loudest peaks; after the Airwindows ClipOnly2 clipper ([chapter 14](#)). The 3 dB is meant: the limiter leaves the top 3 dB of each peak to the clip, which is where Round's loudness and edge come from, and the output still never goes past the ceiling.
- **Link**, on page 2, at the right, the default, turns both channels down together, so the stereo picture holds. At the left each channel is limited on its own: louder, but a peak on one side can shift the picture.
- **Mix**, on page 2, blends the untouched sound back in (parallel limiting). Below the right end, the output can pass the ceiling.

Turning Lookahead fades from the old delay to the new, and switching Mode fades too, so neither clicks, even when modulation changes them on every step; the ceiling holds throughout. The other knobs glide over a few milliseconds.

◆ Starting points

- **Safety on the whole sound:** in M2, Ceiling -1 dB, the rest at their defaults.
- **Louder:** Drive +6 to +9 dB, Release about 60 milliseconds.
- **Warm and loud:** Soft Clip, Drive about +6 dB, Lookahead 0.
- **Loud, only the tips touched:** Round, Drive about +3 dB, Ceiling -1 dB.

The limiter at the very end of the chain ([below](#)) stays in place. With Ceiling at -0.2 dB or lower and nothing louder after it, it has nothing left to do.

Limiter: what the four knobs do on each page				
	KNOB1	KNOB2	KNOB3	KNOB4
Page 1	Ceiling	Drive	Release	Lookahead
Page 2	Mode	Link	Mix	–

Limiter parameters				
Parameter	Where	Type	Range	Default
Ceiling	Page 1 · KNOB1	Continuous	$-24 - 0\text{ dB}$	-1 dB
Drive	Page 1 · KNOB2	Continuous	$-12 - 24\text{ dB}$	0 dB
Release	Page 1 · KNOB3	Continuous, logarithmic	$1 - 1000\text{ ms}$	100 ms
Lookahead	Page 1 · KNOB4	Continuous	$0 - 5\text{ ms}$	2 ms
Mode	Page 2 · KNOB1	List, 3 values	$0 - 2$	0 Brickwall
Link	Page 2 · KNOB2	Continuous	$0 - 1$	1
Mix	Page 2 · KNOB3	Continuous	$0 - 1$	1

Mode values		
0	Brickwall	1 Soft Clip
		2 Round

Effect · Identifier `limit` · This repository (MIT): a look-ahead limiter after Geraint Luff's "Designing a straightforward limiter" (SignalSmith Audio, 2022), no code taken; Mode Round ports Airwindows ClipOnly2 (Chris Johnson, MIT)

6.14 DJ Filter

STATUS: ● In the simulator ■ On the desktop ◆ Planned for the device

A one-knob filter of the kind on a DJ mixer, written for Lunar Modulator. Turned left of the middle it takes away the highs, turned right it takes away the lows, and around the

middle it leaves the sound alone. It suits a master slot, M2 at the end, where it works on everything before it, for build-ups and breakdowns.

- **Sweep** moves the filter. From the middle to the left, a low-pass closes from 20 kHz down to 60 Hz until only the bass is left; from the middle to the right, a high-pass opens from 20 Hz up to 8 kHz until only the top is left. Equal turns move it by equal musical steps. Around the middle the sound passes through untouched.
- **Resonance** adds a peak at the filter’s frequency. It is strongest halfway along each side and fades out towards both ends, so the open end never whistles and the far end never booms.
- **Slope** chooses how steeply the filter cuts: 12 dB per octave, the default, or 24 dB for a deeper cut. Changing it fades from one to the other in a few milliseconds, so it can be switched while playing.
- **Mix** fades from the dry sound at the left to the filtered sound alone at the right, the default.
- **Dead Zone**, on page 2, sets how wide the untouched middle is, from none to a fifth of the way to either end; the default is 0.05.
- **Range**, on page 2, shortens the sweep for gentler moves. At 1, the default, the knob reaches the whole sweep; at 0.5 the low-pass stops at about 1.1 kHz and the high-pass at about 400 Hz.

Sweeps are smooth whether you turn the knob or modulate it, and crossing from one side to the other neither clicks nor thumps.

◆ **Starting points**

- **Breakdown:** turn Sweep slowly to about -0.7 with Resonance about 0.3, and back to the middle on the drop.
- **Thin build-up:** Slope 24 dB, Resonance about 0.5, and turn Sweep to the right over a few bars.
- **Gentle moves:** Range about 0.5, so the whole knob covers only the middle of the sweep.

DJ Filter: what the four knobs do on each page

	Knob1	Knob2	Knob3	Knob4
Page 1	Sweep	Resonance	Slope	Mix

	Knob1	Knob2	Knob3	Knob4
Page 2	Dead Zone	Range	–	–

DJ Filter parameters				
Parameter	Where	Type	Range	Default
Sweep	Page 1 · Knob1	Continuous	–1 – 1	0
Resonance	Page 1 · Knob2	Continuous	0 – 1	0.2
Slope	Page 1 · Knob3	List, 2 values	0 – 1	0 12 dB
Mix	Page 1 · Knob4	Continuous	0 – 1	1
Dead Zone	Page 2 · Knob1	Continuous	0 – 0.2	0.05
Range	Page 2 · Knob2	Continuous	0.1 – 1	1

Slope values

0 12 dB

1 24 dB

Effect · Identifier `djfilter` · This repository (MIT): a trapezoidal state-variable filter after Andrew Simper (Cytomic) and Vadim Zavalishin, in the form of stm32lib's SvF (Emilie Gillet, MIT); no code taken

6.15 Tilt

STATUS:

• In the simulator

■ On the desktop

◆ Planned for the device

A tilt equaliser, written for Lunar Modulator: one knob turns the whole sound darker or brighter. Turned right, the highs rise and the lows fall by the same amount; turned left, the reverse. One frequency, the pivot, keeps its level, so the sound changes colour without getting much louder or quieter. It suits the end of the chain, M2, where it shapes everything before it.

- **Tilt** sets how far, up to 9 dB either way. In the middle, the default, the sound passes through untouched.
- **Pivot** sets the frequency that stays put, from 200 Hz to 5 kHz; the default is 1 kHz. Lower it to brighten or darken mostly the body of the sound, raise it to work mostly on the air at the top.

- **Curve** chooses the shape. *Shelf*, the default, turns quickly around the pivot and then levels off, like the treble and bass controls of an amplifier turned in opposite directions. *Slope* turns more gently and evenly across the whole range, for a subtler change of colour.
- **Level** sets the output level, from -24 dB to $+12$ dB, to make up for what a strong tilt adds or takes away.

Every control, Curve included, moves smoothly when you turn it, so Tilt can be swept or modulated without clicks.

◆ **Starting points**

- **Warm up a bright mix:** Tilt about -3 , Curve Slope.
- **Lift a dull pad:** Tilt about $+4$, Pivot about 2 kHz.
- **Telephone-thin, for a break:** Tilt at the right, Pivot about 3 kHz, Level down a few dB.

Tilt: what the four knobs do on each page

	Knob1	Knob2	Knob3	Knob4
Page 1	Tilt	Pivot	Curve	Level

Tilt parameters

Parameter	Where	Type	Range	Default
Tilt	Page 1 • Knob1	Continuous	$-9 - 9$ dB	0 dB
Pivot	Page 1 • Knob2	Continuous, logarithmic	200 – 5000 Hz	1000 Hz
Curve	Page 1 • Knob3	List, 2 values	0 – 1	0 Shelf
Level	Page 1 • Knob4	Continuous	$-24 - 12$ dB	0 dB

Curve values

0 Shelf

1 Slope

Effect • Identifier `tilt` • This repository (MIT): a tilt equaliser of first-order sections, bilinear and prewarped at the pivot; the idea after Airwindows ToneSlant (MIT) and Faust's spectral_tilt (STK-4.3), no code taken

6.16 Master Sat

STATUS:  In the simulator  On the desktop  Planned for the device

Gentle saturation for the whole mix, written for Lunar Modulator: the warmth and density of a signal pushed a little too hard through analogue gear, meant to be left on. Quiet passages pass through unchanged and only the loud parts are rounded off. The bass and the top end can be kept out of it, so the low end stays tight and the highs stay clear. It starts with **Mix** at the left, where it changes nothing at all: turn Mix up to hear it.

- **Drive** sets how early the sound starts to bend, from barely, only the loudest peaks, at the left to well into it at the right. It does not make the sound louder: quiet notes keep their level.
- **Clean Lo** keeps the bass below it out of the saturation, from 20 Hz to 300 Hz. Higher settings keep the kick and the bass line clean and stop them from muddying everything else, and Glue does not react to them.
- **Glue** turns the whole sound down a little when the saturation works hard, up to about 6 dB, and lets it back up over a fraction of a second, like a bus compressor. It holds a mix together and keeps loud passages from turning harsh. At the left it does nothing.
- **Mix** fades from the dry sound at the left, the default, to the saturated sound alone at the right.
- **Shape**, on page 2, chooses the curve: Smooth, the default, bends gradually; Dense bends sooner and holds the peaks lower, for a thicker, more compressed sound. Changing it fades from one to the other in a few milliseconds, so it can be switched while playing.
- **Asymmetry**, on page 2, makes one side of the wave bend before the other, which adds a warmer, rounder colour of even harmonics. In the middle, the default, both sides bend alike.
- **Clean Hi**, on page 2, keeps the highs above it out of the saturation, from 1 kHz to 20 kHz; the default is 6 kHz. Lower settings keep cymbals and the top of the sound crisp; at the right almost everything is saturated.
- **Level**, on page 2, sets how loud the saturated sound is, from 12 dB down to 12 dB up.

Silence stays silent at any setting, and the knobs glide over a few milliseconds, so turning them does not click. Master Sat is built to keep the harsh, unrelated tones of digital distortion very low at moderate settings; with Drive near the right, Clean Hi is what keeps them down.

Left with Mix at the left for two seconds, Master Sat rests: it stops working and costs the FM-1 almost nothing. Turn Mix up after a rest and the sound starts to change about a fifth of a second later, while it warms up without a click; within two seconds of the last change it answers at once. A Mix lock shorter than that fifth of a second, after a rest, is not heard: for a single short lock, park Mix a little above the left instead. Master Sat never rests while a sequencer lock or a modulation cable reaches any of its knobs, even a cable set to zero, so a cable or a lock is always heard at once.

◆ **Starting points**

- **Warmth:** Mix at the right, Drive about 6, Glue about 0.25.
- **Glue a mix together:** Drive about 9, Glue about 0.6, Clean Lo about 120, Clean Hi about 5,000.
- **Driven and dense:** Shape Dense, Drive about 14, Asymmetry about 0.4, and Level up a little to make up for Glue.
- Master Sat belongs last, in M2, or just before a reverb.

Master Sat: what the four knobs do on each page

	Knob1	Knob2	Knob3	Knob4
Page 1	Drive	Clean Lo	Glue	Mix
Page 2	Shape	Asymmetry	Clean Hi	Level

Master Sat parameters

Parameter	Where	Type	Range	Default
Drive	Page 1 • Knob1	Continuous	0 – 18 dB	6 dB
Clean Lo	Page 1 • Knob2	Continuous, logarithmic	20 – 300 Hz	100 Hz
Glue	Page 1 • Knob3	Continuous	0 – 1	0.25
Mix	Page 1 • Knob4	Continuous	0 – 1	0
Shape	Page 2 • Knob1	List, 2 values	0 – 1	0 Smooth

Parameter	Where	Type	Range	Default
Asymmetry	Page 2 · KNOB2	Continuous	-1 – 1	0
Clean Hi	Page 2 · KNOB3	Continuous, logarithmic	1000 – 20000 Hz	6000 Hz
Level	Page 2 · KNOB4	Continuous	-12 – 12 dB	0 dB

Shape values

0 Smooth

1 Dense

Effect · Identifier `sat` · This repository (MIT): band-limited bus saturation; curve coefficients from Airwindows PurestSaturation and TapeHack2 (Chris Johnson, MIT, notice in the source); Glue after Airwindows Compresaturator, no code taken

6.17 Isolator

STATUS: ● In the simulator ■ On the desktop ◆ Planned for the device

A three-band kill EQ, as on a DJ mixer, written for Lunar Modulator. It splits the sound into lows, mids and highs, each with its own knob, and can drop any of them out completely, for the classic bass-out, bass-back-in moves. At its defaults it passes the sound through untouched.

- **Low, Mid and High** set each band’s level. At the left the band is gone altogether; at three quarters of the way, the default, it is left as it is; at the right it is 6 dB louder. Halfway down, at 0.375, the band is about 18 dB quieter.
- **Kill** drops bands out at once, whatever their knobs say: None, the default, Low, Mid, Low+Mid, High, Low+High, Mid+High or All. Back at None, each band returns to its knob’s level. A kill fades in a few milliseconds, so it does not click, and modulation can switch it in time.
- **Low Xover**, on page 2, sets where the lows end and the mids begin, from 80 to 400 Hz; the default is 250 Hz.
- **High Xover**, on page 2, sets where the mids end and the highs begin, from 1,500 to 5,000 Hz; the default is 2,500 Hz.

The bands are split with steep filters, so a killed low or high band is really gone, and with all three knobs at their defaults the bands add back up to the sound you started

with. The mid band is wide, so a killed mid still lets a little through near the two crossovers. Every knob glides, so turning them does not click.

Left at its defaults for two seconds (the crossovers can be anywhere), Isolator rests: it stops working and costs the FM-1 almost nothing. The first move after a rest comes in about 10 ms late, 35 ms with Low Xover at the left, while its filters warm up without a click (a kill shorter than that, after a rest, is not heard); a kill and back within two seconds is never delayed. Isolator never rests while a sequencer lock or a modulation cable reaches any of its knobs.

◆ **Starting points**

- **Bass out for the break:** Kill Low, then back to None on the drop.
- **Telephone:** Kill Low+High.
- **Kick and hats:** Kill Mid, with High a little above three quarters.

Isolator: what the four knobs do on each page

	KNOB1	KNOB2	KNOB3	KNOB4
Page 1	Low	Mid	High	Kill
Page 2	Low Xover	High Xover	–	–

Isolator parameters

Parameter	Where	Type	Range	Default
Low	Page 1 • KNOB1	Continuous	0 – 1	0.75
Mid	Page 1 • KNOB2	Continuous	0 – 1	0.75
High	Page 1 • KNOB3	Continuous	0 – 1	0.75
Kill	Page 1 • KNOB4	List, 8 values	0 – 7	0 None
Low Xover	Page 2 • KNOB1	Continuous, logarithmic	80 – 400 Hz	250 Hz
High Xover	Page 2 • KNOB2	Continuous, logarithmic	1500 – 5000 Hz	2500 Hz

Kill values

- | | | |
|--------|-----------|------------|
| 0 None | 2 Mid | 4 High |
| 1 Low | 3 Low+Mid | 5 Low+High |

6 Mid+High

7 All

Effect · Identifier `isolator` · This repository (MIT): a three-band kill EQ with Linkwitz-Riley crossovers, the band tree after Faust's crossover3LR4 (filters.lib, STK-4.3), no code taken; TPT state-variable filters after Zavalishin and Simper (Cytomic)

6.18 EQ

STATUS:  In the simulator  On the desktop  Planned for the device

A three-band equaliser, written for Lunar Modulator: a low shelf, a bell in the middle and a high shelf, one page each, then an output level. Use it to shape one sound as an insert, or in M2 as a tone control for everything before it. The bands run one after the other, on both channels alike.

- **Low Freq, Low Gain** and **Low Q** shape the bass. Low Gain raises or lowers everything below Low Freq, by up to 15 dB either way; at Low Freq itself the change is half as much. Low Q sets how sharply the shelf turns: at 0.71, the default, as steeply as it can without overshooting; higher, a bump and a dip appear either side of Low Freq; lower, the change spreads over a wider range.
- **Mid Freq, Mid Gain** and **Mid Q**, on page 2, boost or cut a band around Mid Freq, anywhere from 20 Hz to 18 kHz. Mid Gain is the change at Mid Freq itself. Mid Q sets the width, from wide at the left to narrow at the right; a cut is as narrow as a boost.
- **High Freq, High Gain** and **High Q**, on page 3, do for the treble, above High Freq (1 to 18 kHz), what the Low knobs do for the bass.
- **Level**, on page 3, raises or lowers the result by up to 15 dB, to make up for boosts and cuts.

With every Gain and Level at 0, the default, EQ leaves the sound exactly as it is. The knobs glide over a few milliseconds and the bands are built to be swept, so turning a knob does not click, even quickly. EQ has no tail beyond the ring of a narrow band.

Left that way for two seconds, EQ rests: it stops working and costs the FM-1 almost nothing. The first Gain turned after a rest comes in a moment late while its band warms up, without a click: a few milliseconds for the Mid and High bands, about 30 ms for Low at 100 Hz, up to a tenth of a second for the lowest settings. Level answers

at once. EQ never rests while a sequencer lock or a modulation cable reaches any of its knobs, so those answer at once.

◆ **Starting points**

- **Warmth:** Low Freq about 120, Low Gain about +4.
- **Presence:** Mid Freq about 3,000, Mid Gain about +4, Mid Q about 1.
- **Air:** High Freq about 10,000, High Gain about +5.
- **Find a ring:** Mid Gain at +15 and Mid Q near 10, sweep Mid Freq until the ring jumps out, then turn Mid Gain down to about -10.

EQ: what the four knobs do on each page				
	KNOB1	KNOB2	KNOB3	KNOB4
Page 1	Low Freq	Low Gain	Low Q	–
Page 2	Mid Freq	Mid Gain	Mid Q	–
Page 3	High Freq	High Gain	High Q	Level

EQ parameters				
Parameter	Where	Type	Range	Default
Low Freq	Page 1 · KNOB1	Continuous, logarithmic	20 – 1000 Hz	100 Hz
Low Gain	Page 1 · KNOB2	Continuous	–15 – 15 dB	0 dB
Low Q	Page 1 · KNOB3	Continuous	0.3 – 2	0.7071
Mid Freq	Page 2 · KNOB1	Continuous, logarithmic	20 – 18000 Hz	1000 Hz
Mid Gain	Page 2 · KNOB2	Continuous	–15 – 15 dB	0 dB
Mid Q	Page 2 · KNOB3	Continuous	0.3 – 10	1
High Freq	Page 3 · KNOB1	Continuous, logarithmic	1000 – 18000 Hz	8000 Hz
High Gain	Page 3 · KNOB2	Continuous	–15 – 15 dB	0 dB
High Q	Page 3 · KNOB3	Continuous	0.3 – 2	0.7071
Level	Page 3 · KNOB4	Continuous	–15 – 15 dB	0 dB

Effect · Identifier `eq` · This repository (MIT): low shelf, bell and high shelf on the trapezoidal state-variable filter in the form Andrew Simper (Cytomic) published (public domain), no code taken; tested against the RBJ Audio EQ Cookbook

6.19 Room

STATUS:  In the simulator  On the desktop  Planned for the device

A room reverb, from Mutable Instruments Clouds: smaller and denser than Plate, with Clouds' diffuser in front of it to smear each attack before it enters the room. It takes 11 % of the memory, under two thirds of Plate's.

- **Mix** fades from the dry sound at the left to the reverb alone at the right; the default is 0.3. At the left the sound passes untouched.
- **Decay** sets how long the room rings: under a second at the left, about 1.2 seconds at the default, 0.5, about 2.4 seconds at 0.75, and a tail of 15 seconds or more at the right.
- **Damping** darkens the tail as it decays: at the left it stays bright, and the higher, the darker it turns.
- **Diffusion** at the left lets the first reflections through as separate echoes; at the right they blur into a smooth wash. The default, 0.8, is the setting Clouds itself uses.
- **Blur**, on page 2, sends the sound through the diffuser before the room: the attack of each note is smeared and its start thickens. It changes only the reverb, never the dry sound.
- **Width**, on page 2, narrows the reverb from wide stereo at the right, the default, to mono at the left.

Every knob glides, so turning one while the room rings does not click, and silence stays silent.

◆ Starting points

- **A small, tight room:** Decay about 0.2, Diffusion about 0.5, Mix about 0.25.
- **Soft attacks:** Blur at the right, Decay about 0.6, Mix about 0.4.
- **After Plate:** Plate in M1 with a little Mix, Room in M2 with Decay low, for depth without a longer tail.

Room: what the four knobs do on each page				
	KNOB1	KNOB2	KNOB3	KNOB4
Page 1	Mix	Decay	Damping	Diffusion
Page 2	Blur	Width	–	–

Room parameters				
Parameter	Where	Type	Range	Default
Mix	Page 1 · KNOB1	Continuous	0 – 1	0.3
Decay	Page 1 · KNOB2	Continuous	0 – 1	0.5
Damping	Page 1 · KNOB3	Continuous	0 – 1	0.4
Diffusion	Page 1 · KNOB4	Continuous	0 – 1	0.8
Blur	Page 2 · KNOB1	Continuous	0 – 1	0.5
Width	Page 2 · KNOB2	Continuous	0 – 1	1

Effect · Identifier `room` · Reverb and diffuser from Mutable Instruments Clouds by Emilie Gillet (MIT); Width and the rate rule from this repository (MIT)

6.20 Hall

STATUS: • In the simulator ■ On the desktop ◆ Planned for the device

A stereo hall reverb, written for Lunar Modulator: a large, smooth space whose tail can ring from a fraction of a second to twenty seconds, or be frozen and held. It takes 13 % of the memory, three quarters of Plate’s.

- **Decay** sets how long the reverb rings, from 0.2 seconds at the left to 20 seconds at the right; the default, 2 seconds, is a concert hall. Size does not change it.
- **Size** sets how large the hall is: at the left a small room whose first reflections come quickly, at the right a large hall. Turning it while the reverb rings bends the pitch of the tail.
- **Damping** makes the high frequencies die away faster than the low ones, as they do in a real room: at the left the tail stays bright, at the right it turns dark quickly.
- **Mix** fades from the dry sound to the reverb. The dry sound stays at full level up to the middle and the reverb is at full level from the middle on.

- **Pre-delay**, on page 2, waits up to 150 milliseconds before the reverb starts, which keeps the attack of a note clear of it; the default is 20.
- **Diffusion**, on page 2, at the left lets the first reflections through as separate echoes; at the right they blur into a smooth wash.
- **Mod**, on page 2, gently moves the reverb’s internal delays, like a slow chorus. It keeps long tails from sounding metallic; turn it down for a stiller, purer tail. It sounds the same every time you play.
- **Freeze**, on page 2, holds the reverb as it is and lets nothing new in: play over a frozen chord. The hold lasts minutes, fading by about a decibel a minute. Off lets it fade away. It switches without a click, so modulation can turn it on and off in time.
- **Width**, on page 3, narrows the reverb from wide stereo at the right to mono at the left.
- **Low Cut**, on page 3, keeps the bass out of the reverb, so a bass line or a kick stays tight while everything else rings.

◆ **Starting points**

- **Concert hall:** the defaults.
- **Big, dark ambience:** Decay about 0.8, Size at the right, Damping about 0.7, Mod about 0.5, Mix about 0.5.
- **Small, bright room:** Decay about 0.2, Size at the left, Damping low, Diffusion at the right.
- **Drone pad:** play a chord, turn Freeze on, then play over it.

Hall: what the four knobs do on each page

	Knob1	Knob2	Knob3	Knob4
Page 1	Decay	Size	Damping	Mix
Page 2	Pre-delay	Diffusion	Mod	Freeze
Page 3	Width	Low Cut	–	–

Hall parameters

Parameter	Where	Type	Range	Default
Decay	Page 1 · Knob1	Continuous	0 – 1	0.5
Size	Page 1 · Knob2	Continuous	0 – 1	0.7

- **Decay** sets how fast it closes once Hold is over, from 2 milliseconds to 4 seconds; the default is 150.
- **Range**, on page 2, sets how far down a closed gate turns the sound, from not at all at the right (0 dB) to silence at the left (−90 dB); the default is −80 dB. A little range, −10 to −20 dB, makes a sound breathe instead of cutting it off.
- **Return**, on page 2, makes the gate wait until the sound falls this many dB below the threshold before it starts to close, so a sound that hovers around the threshold does not make it chatter; the default is 4.
- **Mode**, on page 2, chooses **Gate**, or **Duck**, which turns the sound down to Range while it is loud and lets it back up over Decay once it is quiet. The change fades over 5 milliseconds.
- **Key HP** and **Key LP**, on page 3, filter only what the gate listens to, not what you hear: Key HP keeps low notes from opening it, Key LP high ones. At 20 Hz and 20,000 Hz, the defaults, they are out.
- **Listen**, on page 3, set to Key, lets you hear what the gate listens to, the sound through Key HP and Key LP, while you set them. Set it back to Off to hear the gated sound.
- **Lockout**, on page 4, stops the gate from opening again for this long after it opens, up to 5 seconds, so a ringing sound or a flam does not set it off twice; the default, 0, is off.
- **Lookahead**, on page 4, delays the sound by up to 5 milliseconds, so the gate has opened before the note that opens it arrives and its attack comes through whole; the default, 0, adds no delay.
- **Link**, on page 4, sets what the gate listens to in a stereo sound: **Max**, the louder channel, the default; **Sum**, both together; or **Left**, the left channel only.

Mode, Listen, Link and Lookahead change without a click, so modulation can change them on every step. The other knobs glide or take effect at once. With Range at 0 dB, the sound passes untouched.

◆ **Starting points**

- **Gated reverb:** Plate in M1 with Mix and Decay high, Gate in M2 with Threshold about -30, Hold about 60, Decay about 40 and Range at the left. On one sound alone, put the two in its inserts instead.
- **A tighter tail:** Threshold just above the noise, Hold about 20, Decay about 100.
- **Breathing pad:** Range about -15, Attack about 50, Decay about 400.

For now the gate listens only to the sound passing through it. Opening it from another sound or from the sequencer may come later.

Gate: what the four knobs do on each page				
	Knob1	Knob2	Knob3	Knob4
Page 1	Threshold	Attack	Hold	Decay
Page 2	Range	Return	Mode	—
Page 3	Key HP	Key LP	Listen	—
Page 4	Lockout	Lookahead	Link	—

Gate parameters				
Parameter	Where	Type	Range	Default
Threshold	Page 1 • Knob1	Continuous	-80 – 0 dB	-40 dB
Attack	Page 1 • Knob2	Continuous	0 – 1000 ms	0.5 ms
Hold	Page 1 • Knob3	Continuous, logarithmic	2 – 2000 ms	50 ms
Decay	Page 1 • Knob4	Continuous, logarithmic	2 – 4000 ms	150 ms
Range	Page 2 • Knob1	Continuous	-90 – 0 dB	-80 dB
Return	Page 2 • Knob2	Continuous	0 – 12 dB	4 dB
Mode	Page 2 • Knob3	List, 2 values	0 – 1	0 Gate
Key HP	Page 3 • Knob1	Continuous, logarithmic	20 – 10000 Hz	20 Hz
Key LP	Page 3 • Knob2	Continuous, logarithmic	200 – 20000 Hz	20000 Hz
Listen	Page 3 • Knob3	List, 2 values	0 – 1	0 Off

- **Mu** is a smooth leveller in the style of a valve compressor: the louder a passage, the longer it takes to recover, so it blooms back after loud parts rather than pumping. As you turn Squash up past the middle it turns the level back up by itself, partly: a drum kit or a chord stays at about the same loudness up to three quarters of the way, so Squash mostly changes the sound's character. Quiet passages come up with it, by up to 24 dB at the right end, where loud sounds still come out much quieter. The lift never pushes a sound past full scale: when a loud note starts, before Mu has turned it down, the lift gives way. It uses Squash, Release, Shape, Output and Mix.
- **Split** treats the top and bottom of the wave separately and has no timing knobs: it recovers more slowly while the sound is loud, which glues a mix together. It uses Squash, Output and Mix, and lifts quiet sounds a little.

Changing Type while the sound plays starts the new one at the level the old one had reached and fades between them, so modulation can change it on every step. -

Squash sets how hard it works, from not at all at the left to the most at the right; the default is half-way. - **Attack** (Snap) sets how quickly it turns the sound down, from 1 millisecond to 200; the default is 25.5. - **Release** sets how quickly the sound comes back up, from 1 millisecond to 3 seconds. For Mu it is how fast it recovers once the sound is quiet; after a loud passage it is slower. The default is 46.8. - **Ratio** (Snap), on page 2, sets how far the sound is turned down, from not at all at the left to all the way at the right. - **Shape** (Mu), on page 2, bends Mu's response: towards the right it clamps down harder on loud sounds, towards the left it is gentler. The default is the right end. - **Output**, on page 2, turns the result up or down by up to 24 dB. - **Mix**, on page 2, blends the untouched sound back in, for parallel compression. - **Gate** (Snap), on page 3, is the level a sound must reach to open Snap's gate, from -80 dB at the left, where the gate is off, to 0 dB. - **Gate Depth** (Snap), on page 3, sets how far a closed gate turns the sound down, up to silence at the right. - **Hold** (Snap), on page 3, keeps the gate open longer after the sound falls below Gate. - **Gate Rel** (Snap), on page 3, sets how slowly it closes, from 10 milliseconds to 12 seconds; the default is 365.6.

Silence stays silent, and the knobs glide over a few milliseconds.

◆ **Starting points**

- **Punchy, tight drums:** Snap, Squash about 0.6, Attack about 10, Release about 60, Gate about -40 with Gate Depth 0.8 to cut the ringing between hits.
- **Smooth vocal-like lead or pad:** Mu, Squash about 0.5, Release about 500, Output up 6 to 10 dB.
- **Glue on the whole mix:** Split in M1, Squash about 0.3, Mix about 0.7.

Squash: what the four knobs do on each page

	Knob1	Knob2	Knob3	Knob4
Page 1	Type	Squash	Attack	Release
Page 2	Ratio	Shape	Output	Mix
Page 3	Gate	Gate Depth	Hold	Gate Rel

Squash parameters

Parameter	Where	Type	Range	Default
Type	Page 1 · Knob1	List, 3 values	0 – 2	0 Snap
Squash	Page 1 · Knob2	Continuous	0 – 1	0.5
Attack	Page 1 · Knob3	Continuous, logarithmic	1 – 200 ms	25.5 ms
Release	Page 1 · Knob4	Continuous, logarithmic	1 – 3000 ms	46.8 ms
Ratio	Page 2 · Knob1	Continuous	0 – 1	0.5
Shape	Page 2 · Knob2	Continuous	-1 – 1	1
Output	Page 2 · Knob3	Continuous	-24 – 24 dB	0 dB
Mix	Page 2 · Knob4	Continuous	0 – 1	1
Gate	Page 3 · Knob1	Continuous	-80 – 0 dB	-80 dB
Gate Depth	Page 3 · Knob2	Continuous	0 – 1	0.5
Hold	Page 3 · Knob3	Continuous	0 – 1	0.5
Gate Rel	Page 3 · Knob4	Continuous, logarithmic	10 – 12000 ms	365.6 ms

Type values

0 Snap

1 Mu

2 Split

Effect · Identifier `squash` · Airwindows (Chris Johnson), MIT: Pop3, Pressure4 and ButterComp2, ported to single precision without libm by this repository (MIT)

6.23 Transient

STATUS: • In the simulator ■ On the desktop ◆ Planned for the device

A transient shaper, written for Lunar Modulator: it changes the attack and the sustain of each note or hit, whatever its level. Turn up **Attack** for a harder, clickier start, down to soften it; turn **Sustain** up to bring out the body and the ring of a sound, down to make it short and dry. It works by comparing a quick and a slow follower of the level, so it reacts to how the sound changes, not to how loud it is. Both channels move together. It takes under 1 % of the memory.

- **Attack** lifts the start of each note, by up to 12 dB at +100 %, or softens it down to -100 %, where a note rises no faster than Window.
- **Sustain** lifts what follows the start, by up to 12 dB at +100 %, where a sound fades as slowly as Tail, or cuts it at the left, where it fades about twice as fast.
- **Window** sets how long the start of a note counts as its attack, from 5 to 100 milliseconds; the default is 20.
- **Tail** sets how long a fading sound counts as its sustain, from 50 milliseconds to 2 seconds; the default is 400.
- **Output**, on page 2, turns the result up or down.
- **Mix**, on page 2, blends the untouched sound back in.

With Attack and Sustain at 0 and Output at 0 dB, the sound passes exactly untouched. A steady note changes by well under a decibel at any setting; very low notes can pick up a slight roughness at the extremes. The knobs glide over a few milliseconds.

◆ **Starting points**

- **Snappier drums:** Attack +60 %, Sustain –30 %.
- **Longer, roomier hits:** Sustain +70 %, Tail about 800.
- **Softer plucks:** Attack –60 %, Window about 40.

Transient: what the four knobs do on each page				
	Knob1	Knob2	Knob3	Knob4
Page 1	Attack	Sustain	Window	Tail
Page 2	Output	Mix	–	–

Transient parameters				
Parameter	Where	Type	Range	Default
Attack	Page 1 · Knob1	Continuous	–100 – 100	0
Sustain	Page 1 · Knob2	Continuous	–100 – 100	0
Window	Page 1 · Knob3	Continuous, logarithmic	5 – 100 ms	20 ms
Tail	Page 1 · Knob4	Continuous, logarithmic	50 – 2000 ms	400 ms
Output	Page 2 · Knob1	Continuous	–24 – 12 dB	0 dB
Mix	Page 2 · Knob2	Continuous	0 – 1	1

Effect · Identifier `shaper` · This repository (MIT): a transient shaper on the differential-envelope principle (a fast and a slow follower), our own arithmetic; no code taken

6.24 Test Gain

STATUS: ☒ In the simulator ☐ On the desktop

Test Gain multiplies the sound by **Gain**, from silence at 0 through unchanged at 1 to twice the level, 6 dB up, at 2. It exists to test the effect chain and the limiter.

Test Gain: what the four knobs do on each page				
	Knob1	Knob2	Knob3	Knob4
Page 1	Gain	–	–	–

Test Gain parameters				
Parameter	Where	Type	Range	Default
Gain	Page 1 · Knob1	Continuous	0 – 2	1

Effect · Identifier `test-gain` · This repository (MIT)

6.25 Test Ext

STATUS:

In the simulator

On the desktop

Test Ext passes the sound through and marks what the firmware tells an effect about the sequencer with single clicks: one when it starts, one on each beat (louder on every fourth) and a negative one when it stops. **Probe** set to Tempo adds a small offset that shows the tempo it hears; **Listen** set to Key plays the effect’s key input in place of its sound (today that is its own sound). It exists to test that wiring, which delays and gates synced to the tempo will use.

Test Ext: what the four knobs do on each page				
	Knob1	Knob2	Knob3	Knob4
Page 1	Click	Probe	Listen	–

Test Ext parameters				
Parameter	Where	Type	Range	Default
Click	Page 1 · Knob1	Continuous	0 – 1	0.5
Probe	Page 1 · Knob2	List, 2 values	0 – 1	0 Off
Listen	Page 1 · Knob3	List, 2 values	0 – 1	0 Off

Probe values

0 Off

1 Tempo

Listen values

0 Off

1 Key

Effect · Identifier `test-ext` · This repository (MIT)

6.26 The limiter

STATUS:  In the simulator  On the desktop  Planned for the device

Last in the chain, the limiter keeps the output just below full scale, so a twelve-note chord cannot clip however its notes add up.

- A single voice passes untouched.
- When the sum gets louder than 0.98 of full scale, about 0.2 dB below it, the limiter turns it down at once, and lets it recover over about a tenth of a second.
- It also protects your ears and equipment from faults: a sample that is not a number becomes silence, and a wildly large one is clamped and holds the output down briefly instead of passing through.

For a ceiling of your own, lookahead or a softer clip, put the **Limiter** effect in a slot.

MASTER comes after the limiter and only turns the result down. The level meter in the screen's top bar shows the output before **MASTER**, and turns red when the limiter is close to working.

◆ When you can hear the limiter

Dense chords at a high engine Volume can make the limiter duck: the whole sound dips as new notes come in and swells back. If the level meter turns red often, lower the engine's Volume, not **MASTER**.

CHAPTER 7

Sequencer

Lunar Modulator’s sequencer records and plays patterns of notes and parameter changes. Its design follows Moby, the sequencer megadake wrote for the Ableton Move: tracks of clips, sixteen steps to a bar, parameter locks on any step, conditions and probability, swing, non-destructive quantise, scenes and a song mode, and Capture, which keeps what you just played even when you were not recording.

The sequencer runs in the browser simulator, on the panel, and in the desktop tools, where it is tested note for note against Moby’s own code. On the FM-1 it is planned, with the same controls. In the simulator you can enter steps, edit and lock them, record, step record and capture, and work with eight tracks, their mute, their routing to the four sounds (chapter 5) and their pages. Launching clips and scenes, songs, the loop view, copying, undo and drum tracks are in the desktop tools only so far; this chapter says so where they come up.

● **Reading this chapter**

- In SEQ mode the black keys take on sequencer jobs, which the screen names. The keys are called here by the labels printed under them, such as **OP1** and **OP5**.
- **SEL** is the sequencer’s SHIFT everywhere but in FX mode.
- Controls drawn with a dashed outline, such as **LOOP** and **COPY**, are functions still to be given a key. They are not in the simulator yet; the index of controls lists them apart.
- Steps, tracks, slots and scenes are numbered from 1 here, as the screen shows them. Scripts for the desktop tools count from 0 ([Scripts on the desktop](#)).

The sequencer at a glance

Item	Value	Notes
Clock resolution	96 ticks per quarter note	MIDI clock out is 24 per quarter note
Step	24 ticks, a sixteenth note	16 steps to a 4/4 bar
Clip length	1 – 256 steps	up to 16 bars

Item	Value	Notes
Tracks	up to 16	the FM-1 build is planned with 4 to 8
Clip slots	8 per track	a scene is one slot on every track
Parameter-lock lanes	8 per track	each lane drives one parameter
Lock values	0 – 127	scaled onto the parameter’s own range
Notes on one step	up to 12 at once	a chord
Tempo	20 – 300 BPM	in steps of 0.01 BPM

7.1 How a pattern is organised

STATUS:  In the simulator  On the desktop  Planned for the device

Everything the sequencer holds is a **set**: the tempo, the swing, a song, and every track with its clips.

- A **track** plays one sound: one of the four sounds, or an instrument on a MIDI channel. The simulator has eight tracks, as the FM-1 build will.
- Each track has eight **clip slots**. A **clip** is a loop of 1 to 256 steps, up to sixteen bars, holding notes, parameter locks and step conditions. One clip per track plays at a time.
- A **step** is a sixteenth note. Sixteen steps make a bar of 4/4.
- A **scene** is one slot number across every track: launching scene 3 launches slot 3 on each track. A **song** is a list of scenes played in order.

Example set	Slot 1	Slot 2	Slot 3	Slot 4	Slot 5	Slot 6	Slot 7	Slot 8
Track 1	plays	clip	clip					
Track 2	plays	clip						
Track 3	clip	plays	clip					
Track 4			clip					

In this set, tracks 1 and 2 play their first clip, track 3 its second, and track 4 is silent. Launching scene 3 would start slot 3 on tracks 1, 3 and 4 at the next bar, and stop track 2, which has nothing in slot 3.

In the simulator each track plays its first slot; launching other slots and scenes is in the desktop tools so far (Clips).

◆ The demo pattern

When the simulator starts, track 1 holds a one-bar pattern in C minor at 120 BPM. Press **PLAY/STOP**, or Space on the computer keyboard, to hear it; tap its steps away to start your own.

7.1.1 SEQ mode and the keys

The keys have two jobs:

- **Outside SEQ mode** (the sound’s page, FX mode, the global page) the keys play notes, as in chapter 4. The notes also go to the focused track: they are what you record, and what Capture hears.
- **In SEQ mode** the 16 white keys are the 16 steps of the bar shown on the screen, numbered 1 to 16 from the left, and they play nothing. Press **SEQ** to enter SEQ mode from any mode; **HOME**, **FX** and **GLO** leave it. The sequencer keeps playing in every mode.

In SEQ mode the black keys are the sequencer’s controls:

Key	In SEQ mode
OP1 (F#3)	◀: the previous bar. With steps held, nudges them earlier. In step recording, a step back
OP3 (A#3)	▶: the next bar. With steps held, nudges them later. In step recording, a rest or a tie
OP2 (G#3)	LOOP: with SEL (SHIFT), the song page. Held in the session view, white keys 1 to 8 are scenes
OP4 (C#4)	COPY: held in the session view, copies and pastes clips
OP5 (D#4)	CLEAR: with steps held, clears their locks; held, a knob clears that parameter’s locks from the track. A tap deletes the clip, after a question
OP6 (F#4)	MUTE: a tap mutes or unmutes the track; held, white keys 1 to 8 mute and unmute tracks 1 to 8
MONO (C#5), POLY (D#5)	The previous and the next track

Key	In SEQ mode
PIT	Nothing yet. It is planned for UNDO

SEL is **SHIFT** in every mode but FX mode, where it keeps its job of picking up an effect ([chapter 6](#)). Its light is on while you hold it. Hold it with no step held and the screen lists the shortcuts below ([The Set, Clip and Track pages](#)).

On a computer keyboard, 1 to 8 and C V B N M , . / are steps 1 to 16 in SEQ mode, Shift is SHIFT there, and Space is PLAY/STOP in every mode, unless a button on the page has the focus.

7.1.2 What the screen shows

In SEQ mode the screen shows the focused track:

- **The status line:** the tempo (*120 BPM*; decimals only when it has them, such as *120.5 BPM*), the eight tracks and PLAY, STOP, REC (gold during a count-in, or while a take waits for its bar) or STEP (step recording). Each track is a small tile with the number of the sound it plays (*1* to *4*), in that sound’s colour; *M* on grey is MIDI out. The focused track’s tile is taller than the others. A muted track’s tile goes dark and leaves its number in the sound’s colour (the focused one keeps a bar above and below it).
- **The grid:** four bars around the bar on the keys, 16 steps a row. A step with notes is filled, a step outside the loop is outlined (its notes as a dim bar), the playhead is inverted, a step with a condition, probability or invert has a tick under it, a step with a lock a gold dot in its corner, and held steps are framed in gold. A mark at both ends shows the bar on the keys. A muted track’s notes are dim. With SHIFT held, the shortcuts take the grid’s place.
- **The knob strip:** four bars for KNOB1 to KNOB4 on the sound’s current page; while you turn a knob, the other three dim.
- **The hint line:** the knob you turned, its name and value, for two seconds; the bar the keys moved to; in step recording, the step under the record head; otherwise the sound’s model, in rose like every page’s heading.
- **The bottom bar:** the page, the mode and the track, such as *1/3 Seq T1*, and the memory meter ([chapter 6](#)).

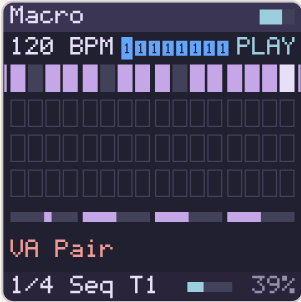


Figure 7.1 SEQ mode while the demo pattern plays: the status line, the grid with the playhead (the light step), the knob strip and the hint line.

7.1.3 The key lights

Key light in SEQ mode	Meaning
On	The step has notes
Off	The step is empty, or outside the loop
Inverted: off on a step with notes, on on an empty one	The playhead is on this step
Slow blink	The step lies under the note of the step you are holding
Fast blink	The record head of step recording
OP1, OP3 on	There is a bar to go to, or held steps to nudge
OP5 on	The track has a lock lane
OP6 on	No step is held: a tap mutes
MONO, POLY on	There is a track before or after this one

Held, OP6 lights white keys 1 to 8 for the tracks that sound; held, SEQ lights the focused track’s key. Outside SEQ mode the sequencer’s notes light no key.

7.2 Steps and notes

STATUS: ● In the simulator ■ On the desktop ◆ Planned for the device

7.2.1 To put notes on a step

1. In SEQ mode, show the bar with **OP1** and **OP3**.
2. Tap the step's white key. The key lights.

The step gets the last chord you played on the keys outside SEQ mode, or at **MIDI IN**, each note at the velocity you played it; if you have played nothing yet, C4 at velocity 100. A tap places up to twelve notes, each one step long.

A step changes when you release its key, so a key you hold to edit the step (below) never switches it on or off. Tap a step that has notes to remove them; its parameter locks stay.

The first note in an empty clip makes a one-bar clip. **OP3** shows one empty bar past the end of the pattern; a note there lengthens the clip to the end of that bar.

● Editing a clip that is not playing

If you add notes to a clip that is not playing while the sequencer runs, that clip starts playing on its track at the next bar.

7.2.2 To add a pitch to a step

1. Hold the step's white key.
2. Hold **SEL** (SHIFT). While it is down, the white keys are pitches in the current octave.
3. Press a white key to add its pitch to every step you hold.

A note at **MIDI IN** adds its pitch to the held steps too; that is how sharps go in. A pitch added this way takes the length of the notes already on the step. To remove pitches, clear the step and enter it again.

With a drum kit as the sound (Sophie or Drums), a white key adds the pad it plays, as it does in step recording.

7.2.3 The step pages

Hold a step for about 300 ms and the screen opens the step pages, with the step's own settings on the knobs. Turn **SELECT** to change page.

Page	KNOB1	KNOB2	KNOB3	KNOB4
Step 1/2	Velocity	Length	Prob	Condition
Step 2/2	Invert	Nudge (shown)	Note (shown)	

Setting	What it sets	Range
Velocity	The velocity of the step's notes, 4 a click	1 to 127
Length	How long the step's notes last; ... when they differ	1/32 to 16 bars, up to the end of the loop
Prob	The chance that the step plays	100 % down to 10 %
Condition	On which passes of the clip the step plays	36 conditions, 1:1 to 8:8
Invert	Turns the condition round	Off or on

The first line names the held step (*Step 7*, or *Step 7 +2* with two more held), and the strip under the rows shows the bar, the held steps in gold. Holding several steps edits them all, from the first one's values. Past Step 2/2, **SELECT** goes on to the sound's own pages, where the knobs lock ([Parameter locks](#)).

[Conditions and probability](#) explains Prob, Condition and Invert.

7.2.4 To set the length of notes

- Hold the step and tap a later step: the held step's notes now last until the end of that step. Tap it again for its start.
- Or set Length on the step page.

A note never lasts past the next note of the same pitch, nor past the end of the loop.

7.2.5 To nudge notes

Hold one or more steps and press **OP1** or **OP3**: their notes move 2 ticks earlier or later. Hold **SEL** (SHIFT) as well to move them 1 tick. A tick is 1/24 of a step, and a note stays within one step of the step it belongs to. Step page 2 shows the nudge.

◆ **Nudges and quantise**

Quantise pulls nudged notes back towards the grid too. At 100 % a nudge has no effect; at 0 % you hear it in full (*Swing and quantise*).

7.2.6 To change velocity or pitch

Hold one or more steps, then:

- turn Velocity on the step page to set the velocity of their notes;
- press **OCT-** or **OCT+** to move every note on them a semitone down or up, or an octave with **SEL** (SHIFT) held.

7.2.7 Full velocity

SEL (SHIFT) and white key 10 enter every step, and play the keys, at full velocity until you press them again. A message says which.

7.2.8 To clear steps

To clear	Do this
A step's notes	Tap the step
The notes of held steps	Hold the steps and tap SEL (SHIFT) on its own
The locks of held steps	Hold the steps and press OP5 (CLEAR)
A step's notes and locks	Hold OP5 (CLEAR) and press the step: planned

7.3 Parameter locks

STATUS: ● In the simulator ■ On the desktop ◆ Planned for the device

A parameter lock gives one step its own value for one parameter: a brighter note on step 5, a longer decay on step 13. You lock the parameters of the sound the track plays, as [chapter 5](#)'s tables list them; locks on the effects' parameters are planned.

7.3.1 To lock a parameter on a step

1. Hold the step's white key.
2. Turn **SELECT** past the two step pages. The pages that follow are the sound's own, as on the sound's page, and the first line reads *Lock step 5*.
3. Turn the parameter's knob. The value is stored on that step, and shows in gold over the dim value the parameter has on other steps.
4. Release the key.

You do not hear a lock while you set it on a held step; you hear it when the step plays. Locks are made with one step held: with two or more steps held, the sound's pages change the sound itself, with no lock.

A step does not need notes to carry a lock. A lock on an empty step changes the sound under notes that are still ringing, and the value then holds until a step with notes resets it (below).

Each track has eight lock lanes, so it can lock up to eight different parameters at once. A parameter takes a lane the first time you lock it, and gives it back when its last lock on the track, in any of its clips, is cleared. A ninth parameter says *8 lanes used*.

- A step with locks has a gold dot in the grid.
- On the lock pages a dot after a parameter's bar marks a lane, filled where the held step has a lock.
- A lock goes to the sound the track plays, even when the keys play another sound; the first line then names it, such as *Lock step 5 S2*.

7.3.2 How a lock plays

When the playhead reaches a step, each locked parameter on the track takes:

1. the step's lock, if it has one;
2. otherwise, if the step has notes, the parameter's base value;
3. otherwise, the value it already has.

A value is sent only when it changes, and a step's locks are sent just before its notes, so each note starts with its locked sound. In this example the parameter runs from 0 to 1 and its base value is 0.40:

Step	1	2	3	4	5	6	7	8
Notes	yes		yes		yes		yes	
Lock			0.80			0.20		
Value	0.40	0.40	0.80	0.80	0.40	0.20	0.40	0.40

● **Locks keep running**

Locks follow the steps even when the track is muted or a condition keeps a step's notes silent, so the sound is ready when the notes come back.

7.3.3 Base values

Each locked parameter has a base value, the value that steps with notes but no lock return to: the knob's value. Turning the knob with no step held changes the parameter as usual, in the 128 steps a lock uses, and every lane on it follows, so what you hear between locks, and after a stop, is what the knob shows.

7.3.4 Recording knob moves

While the track records, turning a knob writes its moves into the steps as they play, and you hear them as you turn ([Recording](#)).

7.3.5 When the sequencer stops

When you stop the sequencer, every locked parameter that was left at a locked value goes back to its base value, after the notes have ended. The same happens to a track that stops at the bar, and to a parameter when you clear its last lock. A sound never stays at a value that no step asked for.

7.3.6 To clear locks

To clear	Do this
One lock	Hold the step, hold SEL (SHIFT), and turn the parameter's knob on its lock page
Every lock on the held steps	Hold the steps and press OP5 (CLEAR)

To clear	Do this
Every lock of one parameter on the track	Hold OP5 (CLEAR) and turn the parameter’s knob one click

7.3.7 Values and list parameters

- A lock stores one of 128 values spread evenly across the parameter’s range, and the screen shows it in the parameter’s own units. On a frequency or a time (a cutoff, a delay, a release: the effects have them, and locks on the effects are planned), they are spread evenly in ratio, as the knob turns, so each step is the same musical interval: from 20 Hz to 18 kHz, a little under a semitone a step.
- On a list parameter, such as Model, Shape, Patch or Pad, the 128 values are divided evenly between the entries.
- Parameters that disturb every sounding note when they change refuse locks: Macro’s and Macro Heavy’s Model, which cut the notes, and Shapes’ Shape, which strikes them again. Their lock pages say *no lock*, and a turn says the parameter cannot be locked. A lock on Six-Op FM’s Patch or on Sophie’s Model changes the sound of that step’s notes only, as those engines read it when a note starts.
- Continuous parameters glide to a locked value over a few milliseconds, so a lock under a ringing note does not click.
- The sound engine itself cannot be locked. To change engine on a step, put the notes on a track that plays another sound.

7.4 Conditions and probability

STATUS:  In the simulator  On the desktop  Planned for the device

A step can play only on some passes of its clip, or only by chance. Set both on the step page.

7.4.1 Conditions

A condition A:B plays the step on the A-th pass of every B passes of its clip. Passes are counted for each track from 1, starting when its clip starts: when you press Play, or when the clip is launched.

Condition	Plays on passes
1:1	Every pass (the default)
1:2	1, 3, 5, 7 ...
2:2	2, 4, 6, 8 ...
1:4	1, 5, 9, 13 ...
3:4	3, 7, 11, 15 ...
4:4	4, 8, 12, 16 ...

Condition on the step page offers the 36 conditions with A and B up to 8 and A no greater than B, from 1:1 to 8:8. Scripts accept A and B up to 64.

7.4.2 Probability

Prob gives a step a chance to play each time it comes round, from 100 % (always) down to 10 %. Scripts accept any value from 0 to 100 %.

The chance comes from a fixed random sequence that starts afresh when the sequencer starts up, so the desktop tools render the same script the same way every time.

7.4.3 Invert

Invert turns a condition round: the step plays on exactly the passes the condition would skip. 1:4 inverted plays on passes 2, 3, 4, 6, 7, 8 and so on.

7.4.4 How they combine

- The condition comes first. The chance is tried only on the passes the condition lets through.
- All the notes on a step share one decision: a chord plays whole, or not at all.
- One note of a step can also have a condition and a chance of its own, which then decide for that note alone. The desktop tools set them with a pitch; the FM-1 is planned to offer them on drum tracks.

7.5 Swing and quantise

STATUS: ● In the simulator ■ On the desktop ◆ Planned for the device

7.5.1 Swing

Swing delays every second sixteenth note to give a pattern a shuffle. It is set for the whole set, on the Set page, from 50 % (straight) to 80 %:

Swing	Off-beat sixteenths play late by
50 %	Nothing: straight
60 %	4 ticks, 1/6 of a step
66 %	6 ticks, 1/4 of a step
70 %	8 ticks, 1/3 of a step
80 %	12 ticks, half a step

The arpeggiator swings with the set too: it has no swing of its own ([chapter 4](#)).

Swing follows the tempo, not the clip. In a clip playing at 2X it delays the steps that land on the tempo's off-beat sixteenths, steps 3, 7, 11 and 15 of each bar of the clip, so that the clip swings with the others. A clip at half speed or slower is not swung, because none of its steps lands on an off-beat sixteenth.

7.5.2 Quantise

Quantise pulls recorded notes towards their steps, from 0 % (as played) to 100 % (exactly on the step). It is non-destructive: each note keeps the timing you played, and quantise only changes where it sounds, so you can change it again at any time.

- Each clip has its own quantise, on the Clip page. SEL (SHIFT) and white key 16 step it through 0 %, the set's default and 100 %.
- New clips start with the set's default quantise, on the Set page, which is 0 % until you change it.
- Notes you place by tapping steps are already on the grid; quantise matters for notes you record, capture or nudge.

7.6 Clips

STATUS:  In the simulator  On the desktop  Planned for the device

In the simulator each track plays the clip in its first slot, and the Clip page edits it. Choosing and launching other slots, Double Loop, copying, deleting clips and undo are in the desktop tools, and planned for the simulator and the FM-1 with the session view.

7.6.1 The Clip page

Press **SEL** (SHIFT) and white key 3 to open the Clip page of the focused track's clip:

Setting	What it sets	Range
Speed	The clip's speed against the tempo: at 2X its steps are 32nd notes, at 1/2X eighth notes	1/8X to 4X
Length	The clip's length; – when the track has no clip	1 to 256 steps
Transpose	Moves every note of the clip up or down without changing the stored notes; not on drum tracks	–36 to +36 semitones
Quantize	How far recorded notes are pulled to their steps	0 to 100 %

7.6.2 Length and the loop window

A new clip is one bar long. You can change its length on the Clip page, from 1 to 256 steps, or set its loop window with **LOOP** (planned):

1. Press **LOOP**. The white keys now stand for bars 1 to 16.
2. Press the first bar of the loop, then the last.

To loop a single bar, double-tap it instead. To make the loop longer or shorter afterwards, hold **LOOP** and turn **SELECT**.

A loop window starts at the beginning of a bar and is at least one bar long. Notes outside it stay in the clip, silent, until the window includes them again. The grid outlines them.

7.6.3 To choose and launch a clip

STATUS:  In the simulator  On the desktop  Planned for the device

In the session view, keys 1 to 8 launch slots 1 to 8 of the focused track ([Scenes](#) and [song](#)).

- A launch takes effect at the next bar, so clips change in time.
- Launching a clip while the sequencer is stopped starts the sequencer. Tracks that were playing when you stopped start again with it.
- Launching an empty slot stops the track at the next bar.
- Launching a clip by hand while a song plays stops following the song, but the song keeps its list ([Song](#)).

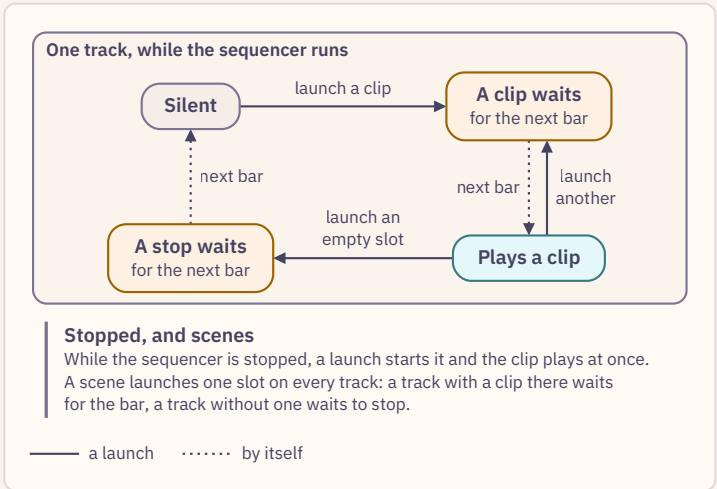


Figure 7.2 What a launch does to one track while the sequencer runs, in the desktop tools so far. A launch waits for the next bar, so clips change in time; launching a scene does the same on every track at once.

7.6.4 Double Loop

STATUS: ■ On the desktop ◆ Planned for the device

SEL (SHIFT) and white key 15 are planned to double the clip's length and copy its notes into the new half: a one-bar idea becomes two bars to develop. Locks and conditions are not copied. A clip that would grow past sixteen bars is left as it is.

7.6.5 To copy steps and clips

STATUS:  In the simulator  On the desktop  Planned for the device

In the session view:

1. Hold **OP4** (COPY).
2. Press the key of a slot with a clip: it is copied.
3. Press the key of each slot to paste it to.

A copied clip takes everything with it: notes, locks, conditions and its settings.

Copying single steps in the track view, and duplicating a clip into the next empty slot, are planned; the desktop tools have their commands already.

7.6.6 To delete a clip

STATUS:  In the simulator  On the desktop  Planned for the device

- In the track view, tap **OP5** (CLEAR) with no step held.
- In the session view, hold **OP5** (CLEAR) and press the slot's key.

The screen asks, for example, *Delete T2 clip 3?*. Press **OP5** again to delete the clip.

Any other key or button only closes the question, and does nothing else. The question stays until you press something; the knobs do nothing while it shows, and the sequencer keeps playing.

7.6.7 Undo

STATUS:  Planned for the device

UNDO takes back your last gesture, and **SEL** (SHIFT) with **UNDO** brings it back. A gesture is one action, such as a step tap or one turn of a knob: a turn counts as finished when you leave the knob for 0.6 s. The desktop tools accept its commands and ignore them.

7.7 Scenes and song

STATUS:  In the simulator  On the desktop  Planned for the device

A **scene** is a column of slots: scene 3 is slot 3 of every track. A **song** is a list of scenes that plays by itself, for an arrangement that runs hands-free.

7.7.1 The session view

Press **SEQ** while in SEQ mode to switch between the track view and the session view; **SEQ** blinks slowly in the session view. It shows the eight slots of every track, one row a track, with the scene numbers above and the song along the bottom.

- Keys 1 to 8 launch the focused track's slots. Keys 9 to 16 focus tracks 1 to 8.
- A slot with a clip has an edge in its track's sound colour. A playing clip is filled, with a bar along its bottom for how far it has played. A clip waiting for the next bar flashes, and so does one about to stop. The clip each track edits is outlined. A muted track is grey.
- The key lights: keys 1 to 8 are lit for a clip, flash fast for one waiting and slowly for the one playing; keys 9 to 16 are lit for each track, slowly flashing for the focused one.
- Hold **OP6** (MUTE) and press keys 1 to 8 to mute tracks, as in the track view. **OP4** (COPY) and **OP5** (CLEAR) work on slots ([To copy steps and clips](#), [To delete a clip](#)).

7.7.2 To launch a scene

In the session view, hold **OP2** (LOOP) and press white keys 1 to 8 for scenes 1 to 8.

- The scene starts at the next bar: every track with a clip in that slot plays it, and the others stop. While the sequencer is stopped, launching a scene starts it.
- **One scene** in a hold launches it and nothing else. A song you have keeps its list, but is no longer followed.
- **Two or more scenes** in one hold make a new song of them, in the order you press them: the first plays at once, and the others follow. Press a key twice in a row to play its scene twice as long.
- While **OP2** is held, keys 1 to 8 show the scenes. With a song: lit for the scene playing, flashing fast for the next one, slowly for the others the song uses. Without one: lit where the column has a clip.

7.7.3 Song

The song plays its scenes one after the other, each for as long as its longest clip, rounded up to whole bars, times its repeats.

- **PLAY/STOP** plays the song from its first entry. Stopped and started again, it always starts from the top.
- The next scene is launched a bar ahead, so it starts exactly on time. In that last bar the track view's hint line says what comes next.
- The status line says **SONG** while the song plays, and **END** once it has finished in Park.
- A scene with no clips at all stops every track and ends the song there.
- A song holds up to 64 presses: an entry played three times is three.
- Launching a clip, or a single scene, by hand stops following the song, so you can play live over an arrangement. The song keeps its list: stop and play again, or **SEL** (SHIFT) with **PLAY/STOP** on the song page, to follow it again.

The band at the bottom of the session view shows the song: an entry per scene, 3x2 for scene 3 played twice, the playing one framed and the next one flashing in its last bar. *END* or *STOP* after the last entry say what the song does there; < and > mean there is more to either side.

7.7.4 The song page

SEL (SHIFT) with **OP2** (LOOP) opens the song page from the track view or the session view, and the same again goes back. **SEQ** goes to the track view.

Each row is one entry: its number, its scene and the scene's name, how many times it plays, its length in bars and the time it starts at the current tempo. The last row, + *add*, is where new entries go. The top line has the song's length, what it does at its end, and the entry you are on. While the song plays, the playing entry has a play triangle (▶), its repeats show the pass (2/4) and its bars the bar of that pass (13/16); the cursor follows it until you move the cursor away.

Control	On the song page
SELECT , or OP1 / OP3	The cursor, up and down the entries and + <i>add</i>

Control	On the song page
SEL + OP1 / OP3	Moves the entry up or down
White keys 1 to 8	Add a scene after the entry, or at the end from + <i>add</i> . The entry's own scene plays once more instead
White keys 9 to 16	The entry plays 1 to 8 times
KNOB1	The entry's scene, 1 to 8. A scene with no clips shows (<i>end</i>)
KNOB2	How many times it plays, up to what the 64 presses leave
KNOB3	The scene's name: Intro, Verse, Pre, Chorus, Drop, Break, Build, Bridge, Fill, Outro, or none
KNOB4	What the song does at its end: Loop starts again, Park stops every track but keeps the sequencer running, Stop stops the sequencer
OP5 (CLEAR)	Deletes the entry
SEL + OP5	Clears the whole song, after a question
PLAY/STOP	Plays or stops, from the top
SEL + PLAY/STOP	Plays from the entry. While playing, it starts on the next bar, from its beginning

To build a song from nothing, open the song page and, on + *add*, press the scenes' keys in order: 1, 2, 2, 3 makes scene 1, scene 2 twice, then scene 3. Two entries of the same scene side by side become one, with their repeats added, and the screen says *Joined*.

You can edit while the song plays. The list changes at once and the sound follows at the next bar; deleting or changing the playing entry brings in what takes its place at the next bar.

7.8 Recording

STATUS:

In the simulator

On the desktop

Planned for the device

PLAY/STOP

 and

REC

 move the sequencer between the states below; the rest of this section and the next, [Capture](#), go through each.

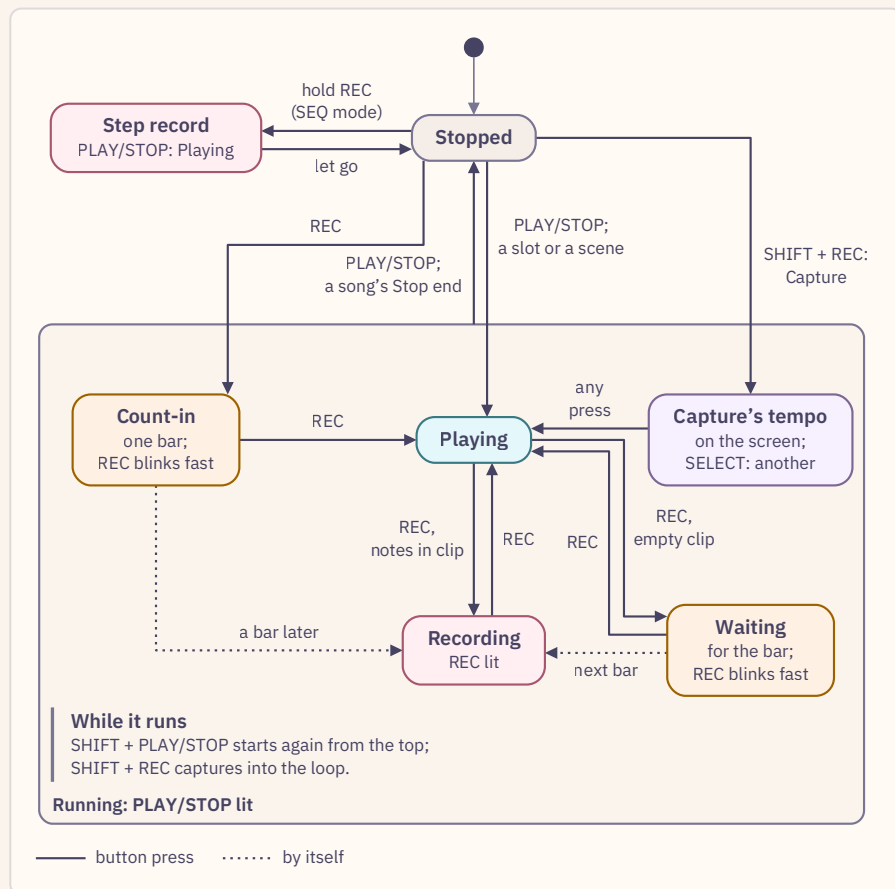


Figure 7.3 What PLAY/STOP and REC do. Every state inside the frame is the sequencer running; PLAY/STOP stops it from any of them but Capture's tempo, which any press only closes. When Capture finds a single tempo for an empty clip it plays at once, without the tempo on the screen.

7.8.1 To record

1. Focus the track to record on (**Tracks and routing**).
2. Press **REC**. Its light is on while it records.
3. Play, on the keys outside SEQ mode or on a keyboard at **MIDI IN**.
4. Press **REC** again to stop recording. The sequencer keeps playing; **PLAY/STOP** stops both.

If the sequencer was stopped, it starts with a one-bar count-in, during which **REC** blinks fast; recording begins on the bar after it. With the metronome on, the count-in clicks.

In SEQ mode while the sequencer is stopped, **REC** acts when you let go of it, because holding it starts step recording (below): tap it.

7.8.2 First take and overdub

- **Into an empty clip** (a first take) recording starts on the next bar, and **REC** blinks fast until then. The clip grows a bar at a time for as long as you keep recording, up to sixteen bars. When you stop recording, it keeps every bar it has reached and loops.
- **Into a clip with notes** (an overdub) recording starts at once and adds to the notes there. The clip keeps its length.

7.8.3 How played notes are placed

- Each note goes to the nearest step, swing included, and keeps the timing you played, so quantise can pull it in later.
- A note played up to half a step before recording starts lands on the first step.
- A note you hold across the end of the loop keeps growing, up to the length of the clip.
- A note you have just recorded does not play again until the loop comes round, so you never hear it twice.
- Up to 16 notes held at the same time are recorded.

7.8.4 Turning knobs while recording

Turning a knob while you record locks the parameter on the step that is playing, and you hear the change as you turn ([Parameter locks](#)).

7.8.5 Metronome

Press **SEL** (SHIFT) and white key 6 to turn the metronome on or off, or set Metronome on the Set page. It clicks on every beat and accents the first beat of each bar, and a count-in clicks too. In the desktop tools the clicks sound in the rendered audio and are written to the event log.

7.8.6 Step recording

Step recording enters notes one step at a time, without the clock running.

1. Stop the sequencer and press **SEQ**.
2. Hold **REC**. The screen shows STEP, and a red frame, the record head, on the first step; its key blinks fast.
3. Play white keys: each one sounds and goes onto the step under the head, and the head moves on when you let go. Keys held together make a chord. Notes at **MIDI IN** go in too; that is how sharps go in. With a drum kit as the sound (Sophie or Drums), a white key enters the pad it plays.
4. Let go of **REC** when you are done.

While you hold **REC**:

- **OP3** leaves a rest, or, with keys held, ties them into the next step;
- **OP1** steps back, or unties;
- **SEL** (SHIFT) and a white key move the head to that step and clear it.

On an empty track the pattern grows to what you play; on a pattern the head wraps at its end.

7.9 Capture

STATUS: • In the simulator ■ On the desktop ◆ Planned for the device

Capture keeps listening while you are not recording. If you played something you like, capture it afterwards and it becomes a clip: press **SEL** (SHIFT) and **REC**. While something is waiting to be kept, **REC** blinks slowly.

● Capture in the desktop tools

`fm1-seq` and `fm1-render` run with Capture on and 256 events, as the simulator does and as planned for the FM-1. In compat mode, which reproduces Movy exactly, they keep 512 like Movy. `fm1-seq --capture 0` runs without it.

7.9.1 What Capture keeps

- The notes you play on the keys or at **MIDI IN**, for the focused track, unless you are recording on it, and not during a count-in.
- Your last phrase: up to eight bars at the current tempo and up to 256 note events. Each note takes two, its start and its end, so that is about 128 notes.
- A pause longer than two bars starts a new phrase. At fast tempos the pause must still last more than 2 seconds, and at slow ones 8 seconds is always enough.
- While the sequencer plays, Capture keeps your latest pass of the loop: when you play again at a point you played on an earlier pass, it starts afresh from there.

■ Capture empties itself

Starting or stopping the sequencer empties Capture, and so do most edits: a step, a lock, a clip setting, a launch, a recording, or focusing another track (the screen says so). Capture straight after the phrase you want to keep.

7.9.2 To capture while stopped

1. With the sequencer stopped, play your phrase.
2. Press **SEL** (SHIFT) and **REC**.

Into an empty clip, Capture works out the tempo you played at, between 40 and 250 BPM, from three or more notes; with fewer it keeps the current tempo. It sets the sequencer to that tempo, writes the notes into the clip, rounded up to whole bars and at most sixteen, and starts playing it.

Into a clip with notes, or while the sequencer follows an external clock, the tempo stays as it is and your phrase is fitted to it. Into a clip with notes, the phrase is added into the clip's loop. The sequencer then starts playing, and the screen says which tempo the phrase was fitted to; any press closes the message.

7.9.3 Choosing a tempo

A phrase often fits more than one tempo, typically one and its half or double. Capture then shows up to three, slowest first, with its best guess chosen. Turn **SELECT** (or **KNOB1**) to try another: the clip is rewritten at that tempo, and you hear it at once. Any other press keeps the one you hear and closes the choice. Capture does not listen while the choice is open.

7.9.4 To capture while playing

Press **SEL** (SHIFT) and **REC** while the sequencer plays, and the notes go where you played them in the loop, into the focused track's clip, which keeps playing; the screen says *Captured*. If that clip is empty, Capture makes a new clip as long as your phrase in whole bars, starting where in the bar you started, and launches it at the next bar. With nothing to keep, the screen says *Nothing to capture*.

7.10 Tracks and routing

STATUS:  In the simulator  On the desktop  Planned for the device

The track you work on is the **focused track**: the steps, **REC**, Capture and what you play all go to it, and its sound becomes the one the keys play and the sound's page edits.

7.10.1 To focus a track

- Hold **SEQ** and press white key 1 to 8, in any mode. If you were outside SEQ mode, you are back there when you let go of **SEQ**.
- In SEQ mode, **MONO** and **POLY** focus the previous and the next track.

The screen names the track. Focusing another track empties what Capture holds, and the screen says that too.

7.10.2 To mute a track

- In SEQ mode, tap **OP6** (MUTE) to mute or unmute the focused track.
- Hold **OP6** and press white keys 1 to 8 to mute and unmute tracks 1 to 8; their lights show which are playing.

The track tiles at the top of the screen show a muted track as its number alone, without its tile. Muting a track ends its sounding notes at once. Its parameter locks keep running ([Parameter locks](#)). Solo is planned for later.

7.10.3 Routing

Each track plays one of the four sounds, or an instrument on a USB-MIDI channel from 1 to 16. Set it on the Track page ([below](#)): Route chooses *Sound* or *MIDI out*, and the next knob the sound (*1 Macro*, *3 Empty*) or the channel. A set keeps its routing.

- In the simulator every track plays Sound 1 until you route it elsewhere.
- A track routed to an empty sound plays nothing.
- The simulator sends no MIDI: a track on MIDI out is silent there.
- Moving a playing track elsewhere lets go of the note it holds where it was sounding.

In the desktop tools, track 1 plays the sound engine when nothing else is routed, and MIDI-routed tracks are written to the event log rather than played ([Scripts on the desktop](#)).

7.10.4 Drum tracks

STATUS:  On the desktop  Planned for the device

A track can be made a drum track. Its clips' transpose then does not apply, so each note keeps its drum, and you can mute up to 16 single drum notes on it, or solo one. Drum tracks are in the sequencer already; their controls are planned for later.

7.11 Transport and clock

STATUS:  In the simulator  On the desktop  Planned for the device

7.11.1 Play and stop

Press **PLAY/STOP**, in any mode, to start the sequencer; its light is on while it plays. Play always starts from the beginning: a song from its first scene, otherwise each track's chosen clip.

Press **PLAY/STOP** again to stop. Notes end, recording ends, locked parameters return to their base values, and a song goes back to its start. Each track keeps its chosen clip.

SEL (SHIFT) and **PLAY/STOP** while playing restart from the beginning. In scripts, a `play` while the sequencer plays restarts it too.

7.11.2 Tempo

The tempo runs from 20 to 300 BPM in steps of 0.01 BPM, and is 120 BPM when the sequencer starts up. Set it on the Set page: 1 BPM a click, 0.1 with **SEL** (SHIFT) held. The tempo, the swing and the default quantise belong to the set as a whole. The status line under the simulator's panel shows the tempo and the transport.

7.11.3 MIDI clock out

STATUS:  On the desktop  Planned for the device

While it plays, the sequencer sends MIDI clock: Start when it starts, 24 pulses per quarter note, and Stop when it stops. A restart sends Stop and then Start, so devices that follow stay in time. On the FM-1 the clock is planned on USB-MIDI; the desktop tools write it to the event log, and the simulator sends no MIDI.

7.11.4 Following an external clock

STATUS:  On the desktop  Planned for the device

When MIDI clock arrives while the sequencer plays, the sequencer follows it:

- It waits for the next bar of the incoming clock, counted from its first pulse, then plays in step with it.
- It takes its tempo from the pulses, smoothing out small changes.
- It stops sending clock of its own while it follows.
- A MIDI Start restarts it from the beginning.
- If the pulses stop for half a second, or a MIDI Stop arrives, it carries on by itself at the last tempo, and sends Start to its own followers at the next bar.

In the desktop tools, a MIDI Start or Stop also starts or stops the sequencer itself, but only while the set's `link` setting is on: `link 1` in a script, or a set saved with it on. It is off otherwise. The simulator does not read MIDI clock yet. On the FM-1, Continue and Song Position are planned as well ([chapter 9](#)).

7.12 The Set, Clip and Track pages

STATUS: • In the simulator ◆ Planned for the device

The sequencer’s settings are on three pages of SEQ mode, in rows like the sound’s page. Hold **SEL** (SHIFT) with no step held to see the shortcuts, then press a white key:

SEL (SHIFT) and white key	Does
2	Opens the Track page
3	Opens the Clip page (Clips)
5, 7 or 9	Opens the Set page
6	Turns the metronome on or off
10	Full velocity on or off
16	Steps the clip’s quantise: 0 %, the set’s default, 100 %

SELECT also walks on from the sound’s last page to the Set, Clip and Track pages.
SEQ goes back to the steps.

Page	KNOB1	KNOB2	KNOB3	KNOB4
Set (<i>Set: all tracks</i>)	Tempo	Swing, 50 to 80 %	Def quant, the quantise new clips get	Metronome
Clip (<i>Clip: track 1</i>)	Speed	Length	Transpose	Quantize
Track (<i>Track 1 of 8</i>)	Route: <i>Sound</i> or <i>MIDI out</i>	Sound, or Channel 1 to 16	Mute	

Track page 2 (turn **SELECT**) lists the focused track’s eight lock lanes: each parameter’s name and its base value from 0 to 127, an unused lane as –. On Track page 1 the sound is in its colour, as on the status line.

7.13 Memory

STATUS: • In the simulator ■ On the desktop ◆ Planned for the device

The FM-1 has no room to spare, so the sequencer keeps its notes, locks and step conditions in fixed pools that every clip of the set draws from, and reserves all its memory when it starts. A full pool never corrupts a set: an edit that does not fit is refused whole, never half done. The simulator’s sequencer is the FM-1 build, and its memory counts in the meter on the screen (chapter 6).

The FM-1's memory the sequencer takes, by number of tracks		
Tracks	Without Capture	With a 256-event Capture
4	4 %	5 %
6	6 %	7 %
8	8 %	9 %
16	15 %	16 %

Pool	For each track	Notes
Notes	192	One clip can hold up to 512
Parameter locks	192	One clip can hold up to 1,024
Step conditions and probabilities	32	One clip can hold up to 1,024

The pools are shared, so one busy clip can use what quieter tracks leave free. Besides them the set has room for 64 notes sounding at once (when all are in use, the oldest ends to make room), a song of 64 entries, and 16 notes held at once while recording.

7.14 Controls at a glance

STATUS:  In the simulator  Planned for the device

In SEQ mode unless the gesture says otherwise. The last rows are planned and not in the simulator yet.

Gesture	What it does	See
	Opens SEQ mode from any mode	SEQ mode and the keys
Tap a white key	Puts notes on the step, or removes them	Steps and notes

Gesture	What it does	See
Hold a step for 300 ms	Opens the step pages	The step pages
Hold a step, press a later step	Sets the length of the held step's notes	Steps and notes
Hold a step and SEL (SHIFT), press white keys	Adds pitches to the step	Steps and notes
Hold steps, tap SEL (SHIFT)	Clears their notes	Steps and notes
Hold steps, press OP1 or OP3	Nudges their notes 2 ticks; with SHIFT, 1 tick	Steps and notes
Hold steps, press OCT- or OCT+	Transposes them a semitone; with SHIFT, an octave	Steps and notes
OP1 , OP3	The previous and the next bar	Steps and notes
Hold a step, SELECT past the step pages, turn a knob	Locks the parameter on the step	Parameter locks
Hold a step and SEL (SHIFT), turn a knob	Clears that lock	Parameter locks
Hold steps, press OP5 (CLEAR)	Clears their locks	Parameter locks
Hold OP5 (CLEAR), turn a knob one click	Clears that parameter's locks on the track	Parameter locks
PLAY/STOP , in any mode	Starts from the beginning, or stops; with SHIFT while playing, restarts	Transport and clock
REC , in any mode	Starts or stops recording	Recording
Hold REC , stopped, in SEQ mode	Step recording	Recording
SEL (SHIFT) and REC	Capture	Capture
Hold SEQ , press white key 1 to 8, in any mode	Focuses that track	Tracks and routing
MONO , POLY	The previous and the next track	Tracks and routing
Tap OP6 (MUTE); hold it and press white keys 1 to 8	Mutes the track; mutes and unmutes tracks 1 to 8	Tracks and routing

Gesture	What it does	See
SEL (SHIFT) and white key 2, 3, or 5, 7, 9	The Track, Clip and Set pages	The Set, Clip and Track pages
SEL (SHIFT) and white key 6, 10, 16	Metronome, full velocity, the clip's quantise	The Set, Clip and Track pages
LOOP , then two bars; LOOP and SELECT	Sets the loop window; makes it longer or shorter (planned)	Clips
Hold COPY , press a step, then others	Copies the step to the others (planned)	Clips
SEL (SHIFT) and white key 15	Double Loop (planned)	Clips
SESSION	Shows every track and slot (planned)	Scenes and song
UNDO ; SEL (SHIFT) and UNDO	Undo; redo (planned)	Clips

7.15 Scripts on the desktop

STATUS: ■ On the desktop

The desktop tools drive the sequencer from a text script: one command per line, each a time, a verb and its arguments. `fm1-seq` runs the sequencer on its own and writes every event it produces; `fm1-render` plays the same script through a sound engine into a WAV file.

7.15.1 The script format

```
#!/ rate=44118 block=64 tracks=4 end=264708
# A one-bar pattern on track 0 with a brighter second note, then play.
@0 bpm 12000
@0 tog 0 0 48 100; tog 0 4 55 90; tog 0 8 60 100; tog 0 12 55 90
@0 alabel 0 0 synth:Timbre; abaseq 0 0 40
@0 aset 0 0 4 110 1
@0 play
```

- The first line, `#!`, sets the sample rate (default 44,118 Hz), the block size in frames (default 128), the number of tracks (default 8) and, with `end`, how many frames to run. Without `end` the run stops just after the last command.
- Each command line starts with `@` and the frame at which it applies, in samples at the script's rate. Several commands can share a line, separated by `;`.
- Lines starting with `#` are comments.
- Tracks, steps, slots and scenes count from 0. Tempos are in hundredths of a BPM, and lock values run from 0 to 127.
- A line `@<frame> rt F8` delivers a MIDI clock pulse to the sequencer; `FA`, `FB` and `FC` are Start, Continue and Stop.

In the example, `tog` puts four notes on steps 0, 4, 8 and 12 of track 0. `alabel` assigns lock lane 0 to the parameter Timbre, `abaseq` sets its base value to 40 without sending it, and `aset` locks the value 110 on step 4, quietly.

7.15.2 To render a script and keep the set

```
engines/build/fm1-render --engine macro --cmd pattern.txt \
    --log-events pattern.jsonl --out pattern.wav
engines/build/fm1-seq --cmd pattern.txt --export pattern.movy1
engines/build/fm1-render --engine macro --seq pattern.movy1 \
    --seconds 8 --out set.wav
```

- The first line plays the script through Macro into `pattern.wav` and logs every event.
- The second runs it through the sequencer alone and saves the resulting set as text, in Movy's `movy1` format ([chapter 10](#)).
- The third loads that set and plays it from the beginning for eight seconds.

7.15.3 Routing and the event log

- A lock lane’s label names the engine parameter it drives: the part after the last `:`, such as `Timbre` in `synth:Timbre`, matched without regard to case. A label that names no parameter of the engine does nothing.
- With no routing given, track 0 plays the engine. `--route 1:engine` sends track 1 to the engine as well, and `--route 2:midi:3` sends track 2 to MIDI channel 3, which the event log records but nothing plays.
- With `--slots`, or any of the multi-sound options (`--sound`, `--insert`, `--level`), a track routed to the engine plays the sound its route names, as in the simulator: `route 1 1 2` sends track 1 to Sound 3.
- The event log has one line per event, in JSON: the block, the frame, the tick, the kind (`on`, `off`, `cc`, `clock`, `start`, `stop` or `click`), the track and two values. A lock is logged as kind `cc`, controller 102 plus its lane.
- `fm1-render`’s summary line reports `seq_refused`: edits that did not fit the sequencer’s memory.

7.15.4 Commands

Sequencer commands for scripts		
Verb	Arguments	What it does
TRANSPORT AND TEMPO		
<code>play</code>	<code>-</code>	Starts from the beginning: the song from its first scene, or each track’s chosen clip. While playing, restarts, sending Stop and then Start to MIDI clock followers.
<code>stop</code>	<code>-</code>	Stops. Ends recording, ends every sounding note and returns locked parameters to their base values.
<code>link</code>	<code><0 1></code>	Movy’s link to the Move’s own transport. Here, while it is 1, an incoming MIDI Start also starts a stopped sequencer and a MIDI Stop stops it. Off by default; kept in a saved set.
<code>bpm</code>	<code><bpm×100></code>	Sets the tempo in hundredths of a beat per minute, 2000 to 30000 (20 to 300 BPM).
<code>swing</code>	<code><percent></code>	Sets the swing, 50 (straight) to 80.
<code>metro</code>	<code><0 1></code>	Turns the metronome click off or on.

Verb	Arguments	What it does
key	<root> <scale>	Lunar Modulator's own verb: the project key, kept in a saved set with the tempo. Root 0 (C) to 11 (B); scale 0 major, 1 minor, 2 chromatic, 3 Dorian, 4 Phrygian, 5 Lydian, 6 Mixolydian, 7 Locrian. Out of range, nothing changes. The sequencer plays the same in any key; the MIDI effects get it.
STEPS AND NOTES		
tog	<track> <step> [<pitch> <velocity>]...	Toggles a step in the track's chosen clip, with up to 12 pitch and velocity pairs (a chord).
evel	<track> <from> <to> <pitch> <change>	Changes the velocity of the notes on a range of steps by the given amount.
elen	<track> <from> <to> <pitch> <change>	Changes the length of the notes on a range of steps, in ticks.
enudge	<track> <from> <to> <pitch> <change>	Moves the notes on a range of steps earlier or later, in ticks, within a step of where they belong.
etrn	<track> <from> <to> <pitch> <change>	Transposes the notes on a range of steps by semitones.
hold	<track> <step -1>	Tells the sequencer which step is held, so that locks set while holding it are not sounded at once; -1 releases it.
slen	<track> <from> <to> <pitch> <ticks>	Sets the length of the notes on a range of steps, in ticks (at least 1).
del	<track> <from> <to> <pitch>	Deletes notes on a range of steps: one pitch, or all with -1.
addp	<track> <from> <to> <pitch> <velocity>	Adds a pitch to every step from one step to another, where the step does not have it yet.
ltog	<track> <step> <pitch> <velocity>	Toggles one pitch on a step, leaving the step's other notes.
CONDITIONS AND PROBABILITY		

Verb	Arguments	What it does
eprob	<code><track> <from> <to> <pitch> <percent></code>	Sets the probability, 0 to 100 %, of a range of steps or of one pitch on them.
econd	<code><track> <from> <to> <pitch> <A> </code>	Sets the condition A:B (each 1 to 64): play on the A-th pass of every B.
einv	<code><track> <from> <to> <pitch> <0 1></code>	Inverts the condition, so the step plays on the passes it would skip.
CLIPS		
clen	<code><track> <steps></code>	Sets the chosen clip's length in steps.
csc1	<code><track> <numerator> <denominator></code>	Sets the chosen clip's speed as a fraction of the tempo, from 1/8 to 4.
ctr	<code><track> <semitones></code>	Transposes the chosen clip, -36 to +36 semitones, without changing its notes.
cq	<code><track> <percent></code>	Sets the chosen clip's quantise, 0 (as played) to 100 (on the grid).
dq	<code><percent></code>	Sets the quantise new clips start with.
clipdup	<code><track></code>	Duplicates the chosen clip into the next empty slot and chooses the copy.
clipdel	<code><track></code>	Deletes the chosen clip.
clipsel	<code><track> <slot></code>	Chooses which of the track's eight slots the edits apply to.
clipcopy	<code><track> <slot></code>	Copies a clip to the clip clipboard.
clippaste	<code><track> <slot></code>	Pastes the clip clipboard into a slot and chooses it.
clipdelat	<code><track> <slot></code>	Deletes the clip in a slot.
cpy	<code><track> <from> <to></code>	Copies a range of steps, notes and locks, to the step clipboard.
pst	<code><track> <step></code>	Pastes the step clipboard from the given step on.
cpyclr	<code>-</code>	Empties the step clipboard.
loop	<code><track> <start> <length></code>	Sets the chosen clip's loop window: its first step and its length.

Verb	Arguments	What it does
dbl	<track>	Double Loop: doubles the chosen clip's length and copies the notes in its loop window into the new half. Locks and conditions are not copied.
LAUNCHING, SCENES AND SONG		
launch	<track> <slot>	Launches a clip on the next bar; starts playback if stopped. An empty slot stops the track. A song stops being followed but keeps its list (Movy deletes it).
song	<scene>	Starts a new song with this scene and launches it.
songadd	<scene>	Adds a scene to the end of the song.
stoptrk	<track>	Stops a track on the next bar.
sgins	<entry> <scene> [<repeats>]	Lunar Modulator's own verb: inserts a scene, played once or more, before an entry of the song (the number of entries adds it at the end). Makes a song if there is none, without launching anything. A song holds 64 scene plays at most.
sgdel	<entry>	Lunar Modulator's own verb: deletes an entry of the song. If it is playing, the next entry plays from the next bar.
sgset	<entry> <scene> <repeats>	Lunar Modulator's own verb: changes an entry's scene and how many times it plays. Two entries of one scene side by side join into one.
sgmov	<entry> <places>	Lunar Modulator's own verb: moves an entry later in the song, or earlier with a negative number.
sgclr	–	Lunar Modulator's own verb: clears the song. What is playing keeps playing.
sgend	<0 1 2>	Lunar Modulator's own verb: what happens after the song's last entry: 0 back to the first (Movy's way), 1 every track stops while the clock runs on, 2 playback stops.
sgjump	<entry>	Lunar Modulator's own verb: plays the song from an entry. While playing, it starts on the next bar; when stopped, the next play starts there.
scene	<scene>	Lunar Modulator's own verb: launches a scene by hand on the next bar, or at once when stopped. A song stops being followed but keeps its list.

Verb	Arguments	What it does
sgnew	<scene>	Lunar Modulator's own verb: makes a new song of this scene, followed from where it already plays or is queued, without launching it again (the second scene of a LOOP hold).
sgname	<scene> <0-10>	Lunar Modulator's own verb: names a scene: 1 Intro, 2 Verse, 3 Pre, 4 Chorus, 5 Drop, 6 Break, 7 Build, 8 Bridge, 9 Fill, 10 Outro; 0 removes the name.
RECORDING AND CAPTURE		
watch	<track>	Chooses the track Capture listens to, and empties what it holds.
wlane	<pitch -1>	The drum note the step editor works on, or -1 for whole steps.
rec	<track>	Starts or stops recording on a track: with a one-bar count-in when stopped, at once (overdub) or on the next bar (first take) when playing.
cap	<track>	Capture: turns what was just played into a clip on the track. When stopped, it first offers tempos to choose from.
capclr	-	Empties what Capture holds.
capsel	<candidate>	Chooses one of the tempos Capture offers.
capdone	-	Accepts the chosen tempo and closes Capture's choice.
non	<track> <pitch> <velocity>	A note played live, for recording and Capture.
nof	<track> <pitch>	The end of a note played live.
TRACKS AND ROUTING		
tdrum	<track> <0 1>	Makes a track a drum track: clip transpose does not apply, and single drum notes can be muted or soloed.
mute	<track> <0 1>	Mutes or unmutes a track; muting ends its sounding notes.
pmute	<track> <pitch> <0 1>	Mutes or unmutes one drum note on a track.
psolo	<track> <pitch>	Solos one drum note on a track; a value outside 0 to 127 ends the solo.

Verb	Arguments	What it does
route	<track> <0 1> <channel slot>	Lunar Modulator's own verb: 0 sends the track to a USB-MIDI channel (1 to 16), 1 to a sound engine slot.
PARAMETER LOCKS		
alabel	<track> <lane> <label>	Assigns a lock lane (0 to 7) to a parameter by name, such as synth:Timbre.
abase	<track> <lane> <value>	Sets a lane's base value, 0 to 127, and sends it at once if the lane is assigned.
abaseq	<track> <lane> <value>	Sets a lane's base value without sending it.
aset	<track> <lane> <step> <value> [<quiet>]	Locks a value on a step and sends it at once, unless a fifth argument other than 0 asks for quiet.
aclr	<track> <lane>	Clears a lane in every clip of the track and frees it; the parameter returns to its base.
aclrs	<track> <lane> <step>	Clears one lock; a lane with no locks left is freed.
aclrstep	<track> <step>	Clears every lock on a step.
asetr	<track> <lane> <from> <to> <value> [<quiet>]	Locks the same value on a range of steps.
UNDO		
usnap	-	Accepted and ignored for now: undo comes with the FM-1's interface.
uswap	-	Accepted and ignored for now.
ucommit	-	Accepted and ignored for now.
udrop	-	Accepted and ignored for now.
uclr	-	Accepted and ignored for now.
MOVY ON THE MOVE ONLY		
minject	<0 1>	Movy's note injection on the Move. Stored; no effect in Lunar Modulator.

CHAPTER 8

Modulation

Modulation moves parameters for you while you play. A rack of up to eight modules, such as LFOs, envelopes and random sources, makes control signals, and up to 32 cables carry them to the parameters of any sound, any effect, the instrument's pitch and level, or another module. Every note can restart an envelope; an LFO can sweep a filter in time with the sequencer; a random source can vary each note a little. A cable can also run **per voice**: each note of a chord then has an envelope or an LFO of its own, which moves that note alone.

The rack works like a small modular synthesizer. Most of its modules are Lunar Modulator's own code after published designs, chiefly Mutable Instruments' Peaks and Braids (Emilie Gillet), Schwung's LFO (Charles Vestal), DaisySP's sample and hold (Electrosmith) and Music Thing Modular's Turing Machine and Workshop System cards (Tom Whitwell, Matt Allison); three are ports of Peaks' and Braids' code, under the MIT licence ([chapter 14](#)).

● In the simulator

The rack, the cables and their pages run in the browser simulator and in the desktop tools, and are planned for the FM-1 with the same controls. Modulation per voice reaches the sounds that keep a value for each note: Macro, Macro Heavy, Shapes, Six-Op FM, FM6 and Drums ([Per voice](#)).

8.1 How modulation works

STATUS:  In the simulator  On the desktop  Planned for the device

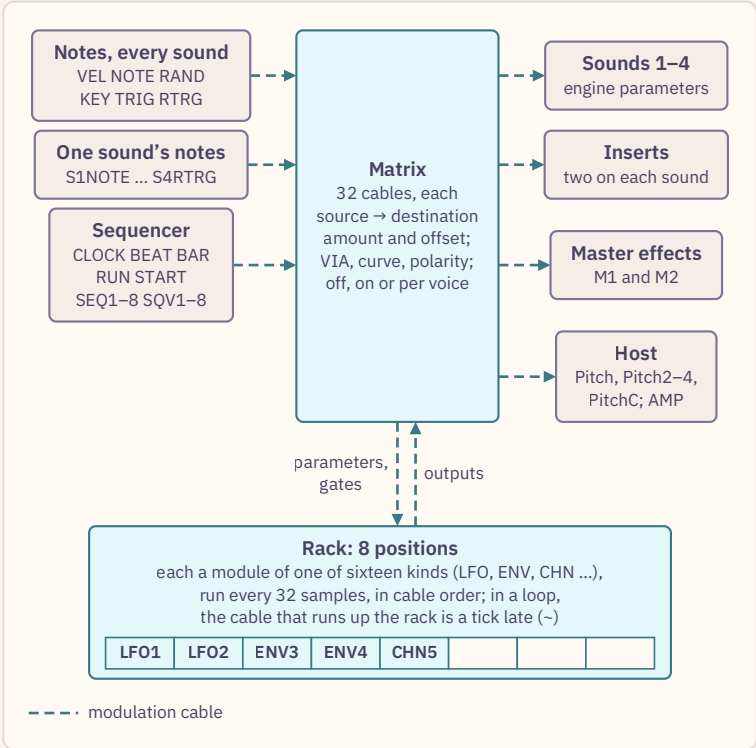


Figure 8.1 How modulation is wired: the notes, the sequencer and the rack's modules are sources; the matrix's 32 cables carry them to the sounds, the effects, the host's pitches and AMP, or back into the rack.

8.1.1 The rack

The rack has eight positions. Each holds a module or nothing. A module is named by the abbreviation of its kind and its position: *LFO1* is an LFO in position 1, *ENV3* an envelope in position 3, *CHN5* a Chance module in position 5.

The simulator starts with this rack:

Position	1	2	3	4	5	6	7	8
Module	LFO1	LFO2	ENV3	ENV4	CHN5 (Chance)			

and two cables: the note gate *RTRG* into the GATE of both envelopes, so every note, on any sound, restarts them. Re-patch or delete those cables as you like ([The matrix](#)); an envelope with no cable into its GATE restarts at every note too.

8.1.2 Cables

A cable runs from a **source** to a **destination**:

- **Sources** are the modules’ outputs (*LFO1*, *ENV3*, *CHN5.2* for its second output), the notes and the sequencer:

Source	What it gives
VEL, NOTE, RAND	The last note’s velocity and pitch, and a random value drawn at each note
KEY, TRIG, RTRG	High while a note is held; a short pulse at each note; KEY that drops and rises again at each new note
CLOCK, BEAT, BAR	A pulse at each sequencer step, beat and bar
RUN, START	High while the sequencer plays; a pulse when it starts
SEQ1 to SEQ8, SQV1 to SQV8	High while sequencer track 1 to 8 sounds a note; its last velocity
S1NOTE to S4RTRG	NOTE, VEL, KEY, TRIG and RTRG for the notes of one sound only: <i>S2KEY</i> is high while Sound 2 holds a note, <i>S1VEL</i> is Sound 1’s last velocity

The plain note sources follow the notes of every sound, from the keys, MIDI and the sequencer; the ones that start with a sound’s number follow that sound’s notes alone.

- **Destinations** are the parameters of the four sounds that take modulation, their insert effects, the two master effects, the host’s pitches and AMP (the level before the limiter), and the parameters and gate inputs of the modules. The host has a pitch for each sound, *Pitch* for Sound 1 and *Pitch2* to *Pitch4*, each added to that sound’s pitch bend, and *PitchC*, which bends whichever sound is current: choose another sound and the cable follows it.

A cable has an **amount** from –100 % to +100 % of the destination’s range, and an **offset** added to the source first. Page B of the matrix adds a **VIA** source that scales the amount (a second LFO varying the depth of the first, say), a **curve** (*lin*, *square*, *cube*, *root*, *cbrr*, *exp*, *log* or *s*), a **polarity** (*auto*, *uni*, *bi* or *inv*) and its state: off, on, or on per voice.

8.1.3 What you hear

Each parameter has a **base**: the value its knob, or a parameter lock ([chapter 7](#)), sets. Modulation adds what its cables give to the base, and the sum stays inside the parameter's range. Turning the knob moves the base; the cables keep moving around it.

- A list parameter, such as an LFO's Shape, moves from entry to entry.
- A frequency or a time on an effect, such as a cutoff or a delay, moves in octaves, as its knob turns in ratios ([chapter 6](#)): a cable at 100 % can take it across its whole range, and NOTE at +100 % into a cutoff makes it follow the keyboard exactly, twice the frequency for a note an octave higher.
- Parameters that cannot take modulation say so: those that cut or restart every sounding note when they change, such as Macro's Model.
- A parameter with no cable is never touched, so a sound with no cables sounds exactly as it would without modulation.
- Modulation is worked out every 32 samples, about 1,400 times a second, and the effects follow it within each block.

8.1.4 Gates

Some inputs are **gates**: an envelope's GATE, an LFO's RESET, a Chance module's TRIG. A gate is high or low, and its edges, its rises and falls, start things. A gate input with no cable listens to the notes: an envelope's GATE follows RTRG, so every note restarts it, and an LFO's RESET follows TRIG. A cable into it replaces that: from KEY, an envelope plays legato, rising once for overlapping notes.

- A continuous source into a gate rises at half way and falls below a quarter.
- A gate cable at less than 100 % lets each rise through with that probability: a chance of a trigger.
- Several cables into one gate combine: the gate is high while any is.

8.1.5 Loops

A module can modulate another, and cables can run in a loop. The rack works through its modules in an order that lets a chain of modules arrive in one step; inside a loop, the cable that runs up the rack reads its source's value from the step before. The matrix and the rack mark such a cable with ~.

8.2 The gesture: making a cable with a knob

STATUS: • In the simulator ◆ Planned for the device

The quickest way to modulate a parameter:

1. Show the parameter on the screen: the sound's page, an effect's page in FX mode ([chapter 6](#)), or a module's page in the rack.
2. Hold **LFO** (or **ENV**).
3. Turn the parameter's knob, **Knob1** to **Knob4**. A cable now runs from the LFO (or envelope) the rack last showed, LFO1 or ENV3 at first, to that parameter, and its amount follows the turn, 1 % a click. The screen names the cable and its amount in a band at the bottom, such as *LFO1 > S2 Color +12%*.
4. Let go of **LFO**.

Turn the knob again while you hold **LFO** to change the same cable's amount; turn it back to 0 % to silence it. On the sound's page the parameter is the current sound's ([chapter 5](#)). Released without a turn, **LFO** or **ENV** is a tap, which opens the rack (below).

◆ With a mouse

In the simulator, press Tab until **LFO** has the focus, hold Enter, and scroll over the knob.

8.3 The rack

STATUS: • In the simulator ◆ Planned for the device

The screen calls the rack RACK. Tap **LFO** or **ENV** to show the rack at the LFO or envelope it showed last (LFO1 and ENV3 at first); tap it again to step to the next module of that kind. The button lights while the rack shows one of its modules. **HOME**, **FX** and **GLO** leave the rack.

The screen shows:

- **The rack:** eight cells, each filled to its module's first output, an empty position hollow; a bar under a cell marks the one shown (gold while you move it).

- **The module's line**, such as *ENV3 2 out 1 in 1 late*: the module, its cables out and in, and those that run a step late; *3 voices* at the end says the module runs per voice, three voices now ([Per voice](#)).
- **Four rows** for the module's parameters on **Knob1** to **Knob4**, as on the sound's page.
- **The bottom bar**, such as *1/2 Mod3*: the page and the position.

Control	In the rack
SELECT	Walks every page of every position
Knob1 to Knob4	Change the module's parameters
ALGORITHM	Opens the kind picker, such as <i>Mod3 kind: Empty</i> , then the sixteen kinds, the Resonator last, eight at a time (chapter 3). The choice takes effect a second after your last turn, or at once when you use another control
SEL	Picks up the module (the light and an asterisk show it), so that SELECT moves it along the rack; press again to put it down

Changing a module's kind switches off the cables that touch it, and remembers them: change it back and they switch on again, those whose other end is still there.

8.4 The matrix

STATUS:

• In the simulator

♦ Planned for the device

Press **EDIT** to show the matrix (MATRIX on the screen), the list of the 32 cables, nine at a time; press it again to go back to the sound's page. **EDIT** is lit there.

Each row reads like this, the source in the modulation colour, the mark grey, the destination and the amount white, and a sound's *S1* to *S4* in that sound's colour, in a source such as *S2RTRG* too:

LF01	>S1 Timbre	+40	the source, > (or ~ a step late), the destination, the amount
SEQ8	-M2 Ping-pong	-100	- a cable switched off, ! one refused
ENV3	vS1 Timbre	+60	v a cable per voice
ENV3	>S2 In1 Mix	+50	Sound 2's first insert
LF02.2	>ENV3 Gate	+100	a module's input

On the screen the mark stands a little apart from the source and from the destination, so a six-letter source such as *S2RTRG* never runs into it. A destination too long for its column keeps the parameter's full name after a shorter tag, such as *S1I2 High Xover*. A switched-off row is grey and a refused one red, whole. Page B names the VIA source, the curve and the polarity in full (*square, auto*).

SELECT chooses the row. The hint line names the field you turned last, for two seconds, and otherwise the row's destination in full; it is red while the chosen cable is refused.

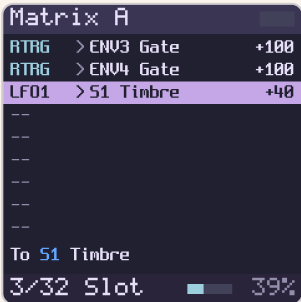


Figure 8.2 The matrix: the default rack's two cables, and a third from LF01 to Sound 1's Timbre at +40 %, chosen.

Page	KNOB1	KNOB2	KNOB3	KNOB4
A	Source; – empties the cable	Destination	Amount	Offset
B	VIA	Curve	Polarity	Off, on, or on per voice

ALGORITHM turns between the two pages. Amount and offset move 1 % a click.

- A new cable starts on, at 0 %, from the LFO the rack shows, unless you chose a source with **KNOB1** first.

- **The destination picker.** **KNOB2** opens a list, *Destination*, of the destinations in full, such as *S1 Timbre*, *S2 In1 Mix*, *M1 Mix*, *Host Amp* or *ENV3 Gate*, eight at a time with the chosen one highlighted and each sound's *S1* to *S4* in that sound's colour (chapter 3). Destinations come in groups: each sound, its two inserts, the master effects, the host, and each module; a unit that is empty is left out. While the list is open, **ALGORITHM** jumps from group to group. On an empty cable the list opens at the current sound. The choice takes effect a second after your last turn, or at once when you use another control.
- **When a sound's engine changes**, each cable into it moves to the new engine's parameter of the same name: a cable into Timbre stays on Timbre from Macro to Shapes. When the new engine has no parameter of that name, the cable switches off and keeps its old destination, shown with -, until you choose an engine that has it again; then it comes back on. The same holds for the effects.

8.5 Per voice

STATUS:  In the simulator  On the desktop  Planned for the device

A sound plays several notes at once, each on a voice of its own. A cable switched **on per voice** (**KNOB4** on page B of the matrix, turned past *On*) runs once for every voice:

- its note sources are that note's own: VEL its velocity, NOTE its pitch, RAND a random value of its own, KEY and RTRG its gate (high from its note-on to its note-off), TRIG a pulse at its note-on, and the same for the note's own sound's sources (*S1VEL* on Sound 1's notes, say; another sound's, such as *S2VEL* there, is that sound's last note);
- an Envelope, an LFO or a Chance module it reads runs once for every voice, starting at that note: each note of a chord has its own envelope, in its own attack, decay or release. Its gate, with no cable, is the note's own;
- it moves that note alone: a parameter the sound keeps for each note (its Timbre or Color, say), or the note's own pitch through *Pitch* to *Pitch4* and *PitchC*.

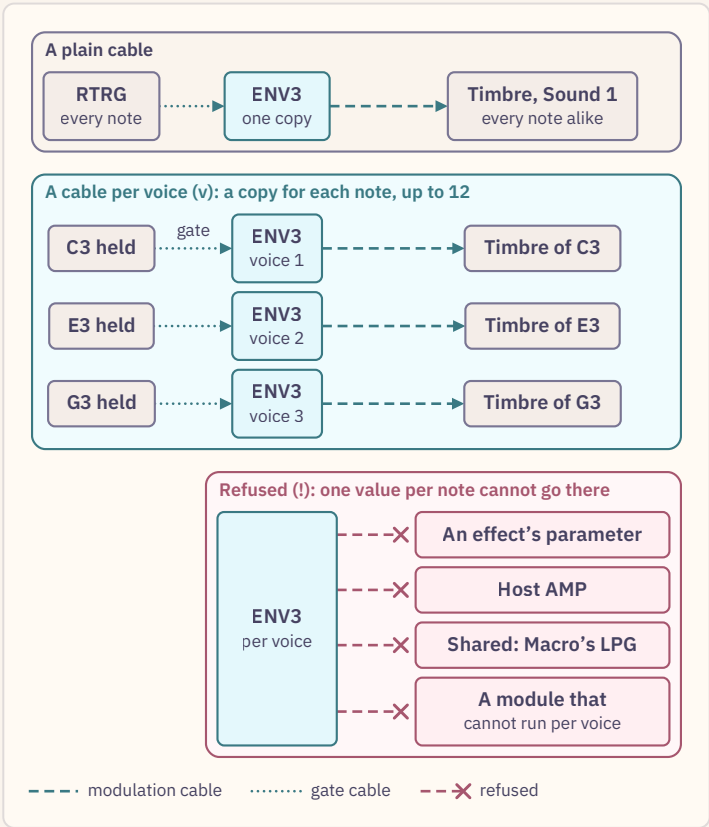


Figure 8.3 A plain cable and a cable per voice. A plain cable moves every note alike; a cable per voice gives each note its own copy of the module, started and gated by that note. What one note does cannot go to a place every note shares, so such a cable is refused.

The row shows *v*. A cable per voice into something that is not kept for each note, such as an effect, the host's AMP, a parameter that every note shares (Macro's LPG) or a module that cannot run per voice, is refused and shows *!*: what each voice does cannot be sent to one place. A plain cable into a module that runs per voice moves every voice's copy alike.

Sound	Parameters each note keeps
Macro, Macro Heavy	Every continuous parameter (Speech keeps Harmonics shared)
Shapes	Timbre, Color, Attack, Release, Volume

Sound	Parameters each note keeps
Six-Op FM	Brightness, Envelope, Volume
FM6	Brightness, Env Time, Feedback, Volume
Drums	Tune, Decay, Level, Tone, Snap, Sweep, Drive, Accent, Volume

The rack follows up to twelve voices at once, the sounds’ own polyphony, shared by every sound that has a cable per voice; a thirteenth note takes the voice that was released longest ago, or else the oldest, and the note it came from keeps its last values. A voice runs on after its note-off, through its envelope’s release, and stops when its modules stop moving. Notes already held when you make a cable per voice join it at their next note-on. With many modules per voice the rack’s memory holds fewer voices; a note that loses its voice that way goes back to the values without the cable.

◆ **An envelope for each note**

Hold **ENV** and turn **KNOB3** on Macro’s first page: a cable from ENV3 into Timbre. Press **EDIT** (the matrix opens on it), turn **ALGORITHM** to page B and **KNOB4** one click right: *On per voice*. Play a chord, one key after another: each note opens and closes on its own.

8.6 Chains

STATUS: ● In the simulator ◆ Planned for the device

In the matrix, press **SEL** to see the chain (CHAIN) through the chosen cable: the longest path of modules and cables it belongs to, one line for each module and one for each cable, such as *LFO2 Wrap +1* and *+100 >ENV3 Gate*, in the matrix’s colours. The chosen cable is highlighted, *+N* counts a module’s other cables and *~* marks a cable that runs a step late; a refused cable is not followed. **SELECT** steps along the chain, and **SEL** goes back to the matrix. **SEL** and **EDIT** are lit in the chain.

8.7 Recipes

STATUS: • In the simulator ■ On the desktop ◆ Planned for the device

Each patch below is a few ordinary cables in the matrix ([The matrix](#)): the source on **Knob1**, the destination on **Knob2**, the amount on **Knob3**. A module's parameters take cables like a sound's, so modules can drive each other.

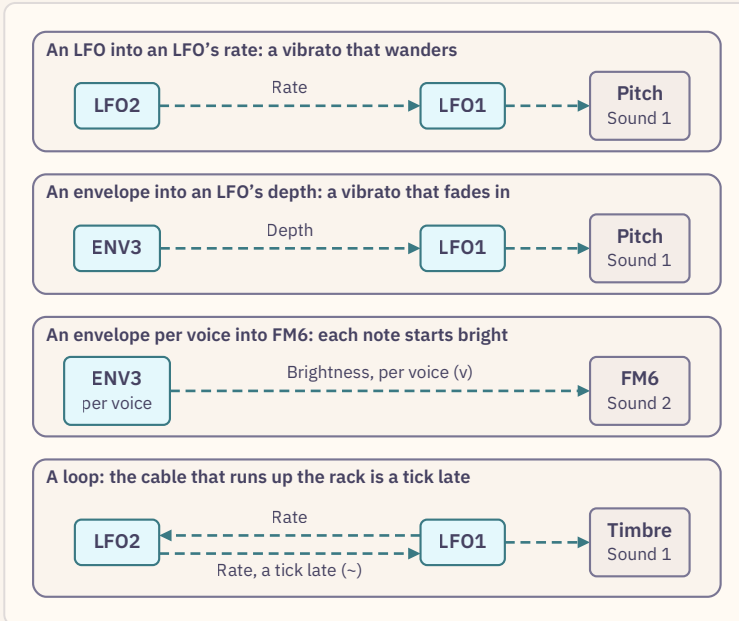


Figure 8.4 Four patches made of cables. A module's parameters take cables like any other: an LFO can speed another up, an envelope can open an LFO's depth (its knob at 0), an envelope per voice can shape each FM6 note, and two LFOs can drive each other in a loop.

- **A vibrato that wanders.** Cable LFO1 into *Host Pitch* at +1 % (Pitch spans 96 semitones, so 1 % is about a semitone; LFO1's Depth narrows it), then LFO2 into LFO1 Rate at +20 %: LFO2 now speeds LFO1 up and slows it down.
- **A vibrato that fades in.** Turn LFO1's Depth to 0. Cable ENV3 into LFO1 Depth at +50 % and LFO1 into *Host Pitch* at +1 %. Every note restarts ENV3, whose attack opens the vibrato.

- **Each FM6 note starts bright.** With FM6 on Sound 2, cable ENV3 into *S2 Brightness* at +50 % and turn **Knob4** on page B to *On per voice* (*Per voice*): each note gets an envelope of its own, so a new note starts bright while the older ones have already darkened.
- **A loop.** Cable LFO1 into *LFO2 Rate* and LFO2 into *LFO1 Rate*, each at +30 %, and LFO1 into *S1 Timbre*: the two LFOs speed each other up and slow each other down. LFO2 sits further down the rack, so its cable back to LFO1 reads LFO2 a tick late and shows ~ (*Loops*).

8.8 What the pages show

STATUS:  In the simulator  Planned for the device

On every parameter page (the sound’s, an effect’s in FX mode, and a module’s in the rack) a parameter that cables reach shows:

- its name in the modulation colour (the light blue-green of the oscilloscope);
- a bracket in that colour on its bar, the base plus and minus the cables’ depth;
- a white tick at the value it has now, which moves as you listen.

8.9 The modules

STATUS:  In the simulator  On the desktop  Planned for the device

Sixteen kinds of module are available. The default rack uses the first three, which can also run per voice (*Per voice*).

Kind	Name	What it does	Outputs
LFO	LFO	A low-frequency oscillator: eight shapes, free or restarted by notes, or in time with the sequencer	OUT; WRAP, a pulse at each cycle
Envelope	ENV	Attack, decay, sustain and release on a gate, or a looping or triggered shape	ENV; EOC at its end; ACT while it runs
Chance	CHN	Sample and hold, track and hold, a smooth random line, or a drift	HELD; SMTH, slewed; STEP at each new value

Kind	Name	What it does	Outputs
Function	FUN	A rise and a fall: an envelope, a cycling LFO or a slew to a target	OUT and five more
Bounce	BNC	A bouncing ball, dropped by each trigger	OUT; HIT at each bounce
Register	REG	A looping random shift register, from locked to random	CV; BIT; PITCH
Coin	COI	Sends each trigger to A or B, by chance	A, B
Divide	DIV	Divides, multiplies, swings or thins out a clock; Euclidean rhythms	OUT1, OUT2
Burst	BST	Ratchets, delays and random repeats of a trigger	OUT, GATE, DONE
Slew	SLW	Smooths a signal, linear or exponential	OUT and five more
Quantize	QNT	Rounds a pitch to one of 49 scales	PITCH; CHG when it changes
Compare	CMP	Gates from comparing two signals, or a signal's slope	GATE and six more
Logic	LOG	AND, OR, XOR and their opposites, flip-flops and a toggle on two gates	OUT, NOT
Calc	CLC	Arithmetic on two signals	OUT, INV
Mix	MIX	Mixes up to four signals	SUM, AVG, INV
Resonator	RES	A resonant filter for control signals, which a trigger can strike into a wobble	OUT, LP, BP, HP

8.9.1 LFO

Parameter	What it does	Range
Rate	Speed, on an exponential scale; 0.5 is 1 Hz	0.01 to 100 Hz
Shape	Sine, Triangle, Saw Up, Saw Down, Square, Smooth, S&H, Walk	A list
Depth	Scales the output	–1 to 1
Mode	Free; Trig restarts at each RESET; Hold samples at RESET; One and Half run one or half a cycle after each RESET	A list
Phase	Where a restart starts	0 to 1

Parameter	What it does	Range
Sync	Off, or a division of the sequencer's tempo from 4 bars to 1/32, with triplets and dotted values; the sequencer's Start restarts it	A list
Width	The square's pulse width	0 to 1

Its RESET gate follows TRIG, each note, until a cable reaches it.

8.9.2 Envelope

Parameter	What it does	Range
Attack, Decay, Release	Times	0.5 ms to 8 s
Sustain	The level held while the gate is high	0 to 1
Curve	Linear, Expo or Quartic	A list
Loop	Off, or repeats AD or ADR while the gate is high	A list
Mode	Gate: an ADSR on the gate. Trigger: each rise starts an attack and decay	A list
Level	Scales the output	0 to 1

Its GATE follows RTRG until a cable reaches it, so each new note restarts the envelope even when the last one is still held; in the default rack, a cable from RTRG holds it. Run per voice, its GATE is its note's.

8.9.3 Chance

Parameter	What it does	Range
Mode	S&H: a new value at each clock. T&H: follows its input while TRIG is high. Smooth: glides to each new value. Drift: a random walk	A list
Rate	Its own clock while nothing reaches TRIG	0.01 to 100 Hz
Slew	The glide of SMTH	Off, or 0.5 ms to 8 s
Level	Scales HELD	-1 to 1
Walk	Drift's largest step	0 to 1
In	The signal to sample; random values when nothing reaches it	An input

8.10 Modulation on the desktop

STATUS: ■ On the desktop

`fm1-render --mod FILE` plays a modulation file with a render: one line for each module and cable, and lines with `@` and a frame for changes during the render.

```
rack default
slot 1 rtrg > env3:gate amt=100
slot 2 lfo1 > snd:Timbre amt=40
slot 3 env3 > host:amp amt=50
slot 4 env4 > snd:Morph amt=60 voice
@44118 slot 2 lfo1 > snd:Timbre amt=80
```

```
engines/build/fm1-render --engine macro --note 0:57:100:2 --seconds 3
\
--mod pattern.mod --out swept.wav
```

`rack default` places the simulator's five modules, without its cables; each `slot` line makes a cable, or replaces the one in that slot, so the last line turns LFO1's depth up after one second (frame 44,118). `voice` makes a cable per voice, and `current 2` makes Sound 2 the current sound for *PitchC* (`host:pitchc`; the other pitches are `host:pitch` and `host:pitch2` to `host:pitch4`). `engines/build/fm1-render --list-mod` lists every kind with its parameters and ports.

CHAPTER 9

MIDI

This chapter lists the MIDI messages Lunar Modulator receives and sends. Today the browser simulator receives MIDI from a keyboard connected to your computer, and the sequencer in the desktop tools writes down the MIDI its tracks would send; the simulator sends none. On the FM-1, MIDI over USB and the 3.5 mm input is planned.

9.1 In the simulator

STATUS:  In the simulator

The simulator receives MIDI on every channel and sends nothing.

9.1.1 To connect a MIDI keyboard

1. Connect the keyboard to your computer.
2. In the simulator, click **Connect MIDI input** under the panel and allow the browser to use MIDI devices when it asks.
3. The button now reads **MIDI:** followed by the names of the inputs it listens to, or **MIDI: no inputs** if it found none.

The simulator listens to every input the browser offers, and picks up a keyboard you connect later without another click. Notes from a keyboard and from the panel's keys play together.

9.1.2 What the simulator receives

Message	Received	What it does
Note on, note off	Yes, any channel	Plays the current sound, with velocity 1 to 127, and goes to the sequencer's focused track for recording and Capture. A note on with velocity 0 is a note off
Pitch bend	Yes	Bends the current sound's notes, up to 2 semitones up or down
Control change 7	Yes	Sets the volume, as MASTER does

Message	Received	What it does
Control change 123	Yes	All notes off
Other control changes	No	Ignored, including modulation (CC 1) and sustain (CC 64)
Program change	No	Ignored
Aftertouch	No	Ignored, channel and polyphonic
System exclusive	No	Ignored
Clock, Start, Stop	No	Ignored: the simulator's sequencer runs on its own clock

● **Notes the keys cannot reach**

A MIDI keyboard can play any note from 0 to 127, beyond the 27 keys' reach. Sophie and Drums answer only notes 36 to 51 ([chapter 5](#)); on the panel their pads are the white keys.

9.2 From the sequencer

STATUS:  **On the desktop**  **Planned for the device**

A sequencer track routed to MIDI sends its notes on its own channel, 1 to 16; unless you route it otherwise, track 1 uses channel 1, track 2 channel 2, and so on ([chapter 7](#)).

What the track does	Message sent
A note starts	Note on, with the note's velocity
A note ends	Note off
A parameter lock changes a value	Control change 102 to 109, one per lock lane: lane 1 is CC 102, lane 8 CC 109, with the value 0 to 127

While it plays, the sequencer also sends MIDI clock for the whole set: Start when it starts, 24 clock pulses per quarter note, and Stop when it stops. A restart sends Stop and then Start.

In the desktop tools these messages go to the event log instead of a MIDI port (chapter 7). In the simulator a track routed to MIDI is silent: it sends nothing. On the FM-1 they are planned on USB-MIDI. The controller numbers are Movy's, which the FM-1 build is planned to keep as the default for MIDI tracks.

9.2.1 Following an external clock

The sequencer can follow MIDI clock from another instrument or a computer:

Message	What the sequencer does
Clock (F8)	Follows the tempo of the pulses, smoothing out small changes. If the pulses arrive while the sequencer plays, it joins at the next bar of the incoming clock, counted from its first pulse
Start (FA)	Restarts the sequencer from the beginning, if it is playing. With the set's <code>link</code> setting on, it also starts a stopped sequencer
Stop (FC)	Stops following: the sequencer carries on at the last tempo. With <code>link</code> on, it stops the sequencer
Continue (FB)	Resumes following
No pulses for half a second	Stops following, as Stop does

While it follows a clock, the sequencer sends no clock of its own. When it stops following, it plays on at the tempo it last measured and sends Start to its own followers at the next bar.

This is how the sequencer behaves in the desktop tools today. The `link` setting is off unless a script turns it on with `link 1`, or a set was saved with it on. For the FM-1 the plan adds Song Position and a Continue that resumes where the music stopped, as part of the MIDI implementation below.

9.3 Implementation chart

STATUS: • In the simulator ■ On the desktop ◆ Planned for the device

The chart sums up Lunar Modulator’s MIDI as it is built today. *Sent* describes the sequencer in the desktop tools, whose messages go to the event log; *received* describes the browser simulator. The FM-1’s MIDI is planned and follows in the next section.

Function	Sent	Received	Remarks
Basic channel	1 to 16	All	One channel per sequencer track; the simulator listens on every channel
Mode	—	Omni, poly	
Note number	0 to 127	0 to 127	Engines may answer fewer notes
Velocity, note on	1 to 127	1 to 127	A note on with velocity 0 counts as a note off
Velocity, note off	No	No	
Aftertouch, key and channel	No	No	
Pitch bend	No	Yes	Received: ± 2 semitones
Control change	102 to 109	7, 123	Sent: parameter locks on MIDI tracks. Received: volume, all notes off
Program change	No	No	
System exclusive	No	No	Planned for saving and loading sequencer sets (chapter 10)
System common: song position, song select, tune request	No	No	Song position is planned for following a clock on the FM-1
System real time: clock	Yes	Sequencer only	Sent at 24 pulses per quarter note while playing
System real time: Start, Continue, Stop	Start, Stop	Sequencer only	See <i>Following an external clock</i>
All notes off	No	Yes	Control change 123
Active sensing, reset, local on/off	No	No	

9.4 On the FM-1

STATUS:  **Planned for the device**

Lunar Modulator’s MIDI on the FM-1 is planned and not yet designed in every detail. What is settled so far:

- **Ports.** USB-MIDI, in and out, through the USB-C socket. The 3.5 mm **MIDI IN** jack receives only: the FM-1 has no MIDI output jack. Whether Bluetooth MIDI, which M-VAVE’s firmware offers, will be supported is still open.
- **The adapter for MIDI IN.** The 3.5 mm input is wired for one of the two kinds of TRS-to-DIN adapter, type A or type B. Which one has not been measured yet.
- **The sequencer** sends notes, parameter locks and clock as described above, on USB-MIDI.
- **Sets over MIDI.** Sequencer sets are planned to be saved to a computer and loaded from one as system exclusive messages, carrying the set as text ([chapter 10](#)).
- **Still open:** the channel the sound engine listens on, a pitch bend range, and how the instrument answers Start, Continue and Stop.

9.4.1 If you know M-VAVE’s MIDI map

M-VAVE’s firmware has a MIDI map of its own. Lunar Modulator’s engines and effects are different, so that map does not carry over:

In M-VAVE’s firmware	In Lunar Modulator today
Program change chooses one of 128 presets	Not received
An effects channel, channel 2 by default, with control changes 0 to 23 for its filter, reverb, delay, distortion, chorus and phaser	Not received; Lunar Modulator’s effects are those of chapter 6
Modulation, sustain and other control changes	Not received
DX7-style system exclusive for voices and banks	Not received over MIDI. FM6 reads the same dumps from files: in the simulator (Load DX7 patches...) and on the desktop renderer (chapter 5)
Channel aftertouch	Not received

CHAPTER 10

Settings and storage

This chapter covers the global page, where Lunar Modulator shows what applies to the whole instrument and sets the project key, and how projects, sounds and sequencer sets are kept in files.

■ **Nothing is stored on the FM-1**

Lunar Modulator writes nothing to an FM-1’s memory, and will not until the one rule is met ([chapter 1](#)). The sounds, patterns and settings your FM-1 holds now stay as they are.

10.1 The global page

STATUS: ● In the simulator ◆ Planned for the device

10.1.1 To open the global page

Press **GLO**. Press **GLO** again, or **HOME**, to leave it. It has two pages: turn **SELECT** for *1/2 Globe*, what the instrument runs, and *2/2 Key*, the project key. The bottom bar names the page.

10.1.2 What it shows

Line	What it means
Rate	The sample rate the firmware runs at, such as 44118 Hz
Block	How many samples the firmware computes at a time: 64
RAM	The share of the FM-1’s free memory the sounds, effects, sequencer and modulation take, in percent, the same figure as the memory meter in the bottom bar (of which the sequencer takes 10 % and modulation 7 %, playing or not). It is red past 100 % (chapter 6)
Voices	How many notes the current sound’s engine plays at once
M1, M2	The effect in each master slot by its name, such as <i>Plate</i> , spelled out where the line has room (<i>Compressor</i> for Comp), or -- for an empty slot

Line	What it means
Octave	The keyboard’s octave, from -3 to +3 (chapter 4)
Transpose	The transpose in semitones, from -12 to +12

On *Globe* **KNOB1** and **KNOB2** set the project key, and the page turns to *Key* to show it; **KNOB3** and **KNOB4** change nothing.

10.1.3 The project key

STATUS: ☒ In the simulator ☐ On the desktop

One key for the whole project: a root, C to B, and a scale.

Knob	What it sets
KNOB1	The root: C, C#, D and so on to B
KNOB2	The scale: Major, Minor, Dorian, Phrygian, Lydian, Mixolydian, Locrian or Chromatic

Each knob shows its list while you turn it, the chosen entry marked. The line under the top bar says the key in words, such as *D Minor*. It starts at C Major.

- **What it is for.** Every MIDI effect is told the key. The arpeggiator does not use it; the scale and chord effects planned next will. The sound engines and the sequencer play the same in any key.
- **Where it is kept.** The key belongs to the sequencer’s set, beside the tempo and the swing (*what a set keeps*). Loading a set brings its key; a set from Movy, or one saved in C Major, has none and loads in C Major. A project file also shows the key near its top, in `session`, for anyone reading the file; that copy is written from the set’s and is never loaded, so editing it changes nothing.
- **In the desktop tools.** The sequencer’s `key` command sets it in a script, such as `key 2 1` for D Minor (chapter 7).

◆ Will it fit on the FM-1?

The simulator refuses any sound or effect that would take the figure past 100 %, so whatever it plays would fit on the FM-1. To make room, choose a smaller engine or effect, or empty a sound or a slot (chapter 6).

10.1.4 Settings

STATUS: • In the simulator ■ On the desktop

Four settings belong to the instrument, not to a project. They are kept in a settings file of their own, never in a project, so loading a project leaves them as they are.

Setting	What it does
Metronome	The click while the sequencer plays (chapter 7)
Full velocity	Every step entered at full velocity (SEL + key 10 in SEQ mode)
Count-in click	Whether the count-in clicks (kept for the stage that adds it)
MIDI IN channel	The channel MIDI IN listens on, or every channel (kept for the stage that adds it)

MASTER is not a setting: the page remembers its position in the browser.

10.2 Projects, sounds and other files

STATUS: • In the simulator ■ On the desktop

Everything the simulator holds can be saved to a file and loaded back. A saved file loaded again gives the same state, and saving it once more gives the same file, byte for byte.

Kind	Holds	Loads
Project (<code>first-orbit.lunar</code>)	All four sounds with every parameter, every pad of a drum kit, their levels, inserts and arpeggiators; the master effects; FM6's user voices; the modulation rack and its cables; the sequencer's set with its song and key; the current sound, octave and transpose; and the page you were on	In place of everything
Sound (<code>deep-bass.sound.lunar</code>)	One sound, its inserts and arpeggiator, its level, the FM6 voice it plays, and the modulation that reaches only it	Into the sound you choose
Effects (<code>space-verbs.fx.lunar</code>)	One or two effects and their modulation	Into the master slots, or a sound's inserts

Kind	Holds	Loads
Mod rack (<code>wobble.mods.lunar</code>)	The rack and its cables	In place of the rack
Clip (<code>bass-a.clip.lunar</code>)	One clip, with its locks	Into a track and slot you choose
Set (<code>.movy1</code>)	The sequencer’s set, as Movy writes it	In place of the set
Settings	The four settings above	Over the settings

Files are text you can read, keep under version control or share. Each names its engines and parameters, so a file stays readable as the firmware grows.

10.2.1 What happens when you load

- **A project** replaces everything. The simulator starts afresh and builds the project’s state.
- **Every other kind** goes into its place and leaves the rest alone. A sound loaded into Sound 2 while the song plays changes Sound 2 and nothing else.
- **A sound’s modulation** goes to free places in the rack and the matrix. Its FM6 voice reuses the same voice if the bank has it, or the first empty user slot.
- **The screen** shows *LOADED*, the file’s name and the memory figure for a second, and the page says what came in: *Loaded “First orbit”: 4 sounds, 5 effects, ... It takes 69% of the FM-1’s RAM.*
- **What the load replaced** stays in the browser’s Recent list as *Before First orbit*, and **Undo load** under the message puts it back.

10.2.2 When a file does not load

A file that cannot load changes nothing. The page says why, under the panel, in the refusal colour (*“Deep space bass” was not loaded. Needs 117% of the FM-1’s RAM.*), and offers the way round when there is one, such as **Load without Rings**. In the desktop tools the screen shows *NOT LOADED* and the short form:

It says	Why	What you can do
<i>Needs 121% RAM</i>	The file would take more than the FM-1's memory. Every file is measured as the FM-1 would run it, whatever your browser's rate	Load a lighter file. This refusal has no way round it
<i>Uses Rings</i>	The file uses an engine this build does not have, or one only the GPL build has	Load it without that engine: its sound is left empty
<i>Rack is full or Matrix is full</i>	A sound's modulation has no room	Load it without its modulation, or free a place in the rack
<i>FM6 bank is full</i>	The sound's FM6 voice has no free user slot	Load it without its voice
<i>Slot holds a clip</i>	The clip's slot is not empty	Load it again and replace the clip
<i>Macro at 96 kHz</i>	The engine cannot run at your browser's sample rate	Use a browser or device at 44.1 or 48 kHz
<i>Not a Lunar file, Newer format, Bad file, File too big</i>	The file is not one this simulator reads	Check the file, or use a newer simulator

10.2.3 Tracks without a route

A project's set loads with its routes as saved: a track with no route plays nothing in the simulator. A set from Movy, where no track is routed, gets the simulator's start rule: track 1 plays Sound 1.

10.2.4 SAVE

In the simulator, **SAVE** on the panel and the page's buttons under it do the saving and loading:

On the page	What it does
Open... , or files dropped on the page	Loads <code>.lunar</code> files, a <code>.movy1</code> set or <code>.syx</code> DX7 patches, several at once. A sound, effects or a clip asks where it goes: <i>Load sound "Deep space bass" into Sound 2</i>
Save... with the list beside it	Downloads the project, the current sound, its effects, the master effects or the mod rack as a <code>.lunar</code> file, named with its kind in the middle (<code>first-orbit-s2.sound.lunar</code>), or the set as a <code>.movy1</code> file for Movy

On the page	What it does
SAVE on the panel	Keeps the whole project in this browser; the screen shows <i>SAVED</i> . Saved in this browser lists it, to load or download again
Copy link	Copies a link that holds the whole project, for anyone to open in their own browser. A link holds up to 32 KiB; a project too big for one says so, and you share the file instead

- **Autosave.** The page keeps your project in the browser as you work, a few seconds after each change and when you leave the page, and the next visit, or the next **POWER** press, starts where you left off. The message then offers **Start fresh**, which puts the start sounds and the demo pattern back (your work stays in Recent).
- **Recent** keeps the last five states a load replaced.
- **Links.** A link from the guide or a page of this manual can open a file straight into the simulator, such as `?load=examples/first-orbit.lunar`. A card names the file and what it replaces before you press **Power on and load**; your work goes to Recent first. Only files on the simulator’s own site, under its `examples/`, `guide/` and `manual/` folders, load this way.
- **On your own computer.** When you run the simulator yourself, from `localhost` or `127.0.0.1`, a link may also name a `.lunar`, `.movy1` or `.syx` file on another local server, such as `?load=http://localhost:5173/missions/first.lunar`, and a page on another local server may embed the simulator and drive it, as the guide does. The public simulator takes neither.
- **The examples** under *Saved in this browser*, *Recent* and *examples* are the guide’s files (MIT): a project, a sound, effects, a mod rack and a clip.
- **The file formats’ schemas** are published with the simulator, at `schema/1/` on its site, for editors that check `.lunar` files.

Files are read and written in your browser; nothing is uploaded, and nothing is ever sent to an FM-1. MASTER is a preference of the page, not part of a project.

10.2.5 In the desktop tools

```
sim/web/build/native/fm1-sim-render --start --save project:mine.lunar
--seconds 0
sim/web/build/native/fm1-sim-render --load mine.lunar --load s2:deep-
bass.sound.lunar --save project:mine2.lunar
engines/build/fm1-state check mine.lunar           # whether a file
fits, and what it holds
```

On the FM-1, saving sounds and projects to its flash memory waits for the one rule ([chapter 11](#)).

10.3 Sequencer sets

STATUS:  On the desktop  Planned for the device

A set is everything the sequencer holds ([chapter 7](#)).

10.3.1 What a set keeps

Kept	Not kept
The tempo, the swing, the external-clock link setting (chapter 9) and the project key	Whether the sequencer was playing
The song	The playhead's position
Each track's chosen clip, its mute, its muted or soloed drum notes, and its routing	How many times each clip has looped, which conditions count
Each track's lock lanes, with their parameters and base values	The random sequence behind probability
Every clip: its length, loop window, speed, transpose and quantise	Which tracks are drum tracks
Every note, lock, condition and probability	
The default quantise for new clips, the song's end mode and its scene names	

10.3.2 In the desktop tools

The desktop tools save and load sets as text in Movy's `movy1` format, a plain text file you can read, keep under version control or share:

```
engines/build/fm1-seq --cmd pattern.txt --export pattern.movy1    #  
save the set a script builds  
engines/build/fm1-seq --seq pattern.movy1 --export copy.movy1    #  
load a set and save it again  
engines/build/fm1-render --engine macro --seq pattern.movy1 --seconds  
8 --out set.wav
```

Movy reads these files too, and Lunar Modulator reads Movy's. The differences:

- Lunar Modulator adds a line for each track you route away from its default, and one for the project key unless it is C Major, which Movy ignores.
- It keeps what it loads within its own ranges, clip speeds of 1/8X to 4X among them.
- It leaves out what does not fit its memory: notes and locks beyond its pools, and tracks beyond the number it was started with.

10.3.3 On the FM-1

The FM-1 build is planned to keep sets in three stages:

1. **In memory.** The set lives in the instrument's working memory and is lost when you switch off.
2. **On a computer.** You save a set to a computer and load it back over USB-MIDI, as system exclusive messages carrying the same `movy1` text. A full set is about 90 KB and is sent in parts.
3. **In flash memory, last.** Sets will be written to an area of their own, apart from the areas M-VAVE's firmware uses, only when you save. Each set is kept twice, so a power cut while saving cannot lose both copies.

The third stage waits for the one rule ([chapter 11](#)).

10.4 Backing up

STATUS:  Planned for the device

10.4.1 Your work

Planned: one export that saves every sound and every set to a computer, and an import that brings them back. Until sounds and sets can be stored on the FM-1 itself, saving a set to a computer is the backup.

10.4.2 Your FM-1's own sounds and patterns

The patches, patterns and settings that M-VAVE's firmware keeps in the FM-1's flash memory stay in their own areas. Lunar Modulator is planned never to write there.

- Reading them would need their formats, which only a complete copy of the FM-1's memory can show.
- That copy is exactly what the one rule asks for first: a full read-out of the FM-1's memory, kept safe, before anything is written ([chapter 11](#)).

◆ Keep your own copies

If you use a patch editor or librarian with M-VAVE's firmware, keep your banks on your computer as well. The FM-1 accepts voices and banks over MIDI but does not send its stored banks back.

CHAPTER 11

Updating and recovery

Lunar Modulator cannot be installed on an FM-1 today. This chapter explains what has to happen first, how the project means to make installing and removing it safe, and what to do about the firmware your FM-1 has now.

11.1 The one rule, again

Nothing is installed on, or written to, an FM-1 until a complete copy of its memory has been read out and written back, byte for byte, on that unit ([chapter 1](#)). Every step below exists to meet that rule; none of them skips it.

■ No installer exists

This project publishes no firmware file for the FM-1 and no installer for one. If you find a file that claims to be Lunar Modulator for the device, do not install it.

11.2 Why the FM-1 needs a way back

The FM-1 keeps its firmware in one bank of flash memory. Its own update method runs inside the firmware that is already installed, so it can replace a working firmware but cannot rescue one that no longer starts. The board has no recovery button and no test connector. Before anything new goes on the device, there must be a way to bring it back that does not depend on the firmware at all.

11.3 The recovery dongle

STATUS: ■ On the desktop

The FM-1's processor has a recovery mode built into its read-only memory: given a special signal on the USB lines at power-up, it lets a computer read and write its memory, whatever the flash holds. A recovery dongle sends that signal through the USB-C socket, so the case stays closed.

There are two kinds:

- **The chip maker's own USB updater**, a small ready-made dongle sold for JieLi chips. The project tries this one first.
- **The project's open design**, a Raspberry Pi RP2040 board with a switch that hands the USB lines from the dongle to the computer. It reports every step it takes, which helps if the ready-made one does not work on this chip.

The open design is complete: its firmware builds, and it has been tested against a simulation of the chip's recovery mode. Neither dongle has been used on an FM-1 by this project yet.

Other FM-1 owners have reported that the route works. [czietz](#) built a simpler dongle of their own from a Raspberry Pi Pico, which brings their FM-1 into recovery mode about one power-on in two, and [masanaohayashi](#) used it to back up their FM-1's firmware and to write firmware to it. Their reports, in [issue #2](#) on the project's repository, also showed which of the two USB data lines carries the signal, and this project's dongle now tries that one first. This project has not run their dongle, and the one rule still asks for the whole procedure below on a unit before anything is written to it.

11.3.1 How it connects

The dongle sits between the computer and the FM-1:

1. Plug the dongle into the computer as its own instructions say. The ready-made one wants a USB 2.0 port on the computer itself, not a hub, a dock or a USB 3 port.
2. Connect the FM-1's USB-C socket to the dongle, with a USB-A to USB-C cable or adapter.
3. Switch the FM-1 on with **POWER** last. The chip listens for the signal only as it starts up.

■ Not the dongle maker's software

The ready-made dongle comes with Windows software that writes to the chip. Never run it against an FM-1. Reading the memory is done with open tools that the project checks step by step.

11.3.2 The procedure, once proven

The project's first goal with the dongle is to show, on one FM-1, that a unit can always be brought back:

1. Bring the FM-1 into recovery mode with the dongle.
2. Read out its whole flash memory, twice, and check that both copies are identical.
3. Keep the copies safe, with checksums.
4. Write the copy back, start the FM-1, read it out again and compare: the unit must be byte for byte as it was.
5. Do it twice. Then change one byte in a harmless place, and put it back.

Only after this has worked does anything else get written to an FM-1. The project will publish the exact procedure, with photographs, when it has.

11.3.3 What the dongle cannot do

- It cannot repair a unit that is physically damaged.
- It cannot help if the processor's recovery mode itself does not answer.
- It never needs the case opened, and changes nothing on the FM-1 by being connected.

11.4 Installing Lunar Modulator

STATUS:  Planned for the device

11.4.1 The order of work

Lunar Modulator reaches the FM-1 in stages, each with its own test:

1. **Measuring a unit, read-only.** Asking the FM-1 which firmware it runs and listening to it, without changing anything. Done in part.
2. **Recovery.** The dongle procedure above, on a unit, twice.
3. **A development board.** The firmware's code runs on a JieLi development board from the same chip family. Its output is compared, bit for bit, with the desktop tools and the browser simulator.

4. **The FM-1, from memory.** Lunar Modulator runs on an FM-1 loaded into its working memory, without writing the flash. Switching off brings back the FM-1's own firmware.
5. **Installing.** Only then is Lunar Modulator written to the flash, with the original firmware kept as a backup.

11.4.2 A way back built in

Lunar Modulator is planned with a way into update mode that does not depend on the rest of the firmware working: a key combination held while you switch on, and a counter that notices when the firmware fails to start. Both are tested before anyone is asked to install it.

11.4.3 How it will be installed

The installer is not decided. Two routes exist: the FM-1's own update method over USB-MIDI, through which third-party firmware already installs on working units, and the processor's recovery mode with a dongle. Either way the case stays closed: the first route needs a computer and a USB-C cable, the second a recovery dongle as well.

11.4.4 Updating and going back

- A newer Lunar Modulator is planned to install over an older one.
- Going back to M-VAVE's firmware is planned from the backup of your FM-1's memory, with the dongle.
- Whether M-VAVE's own updater will also be able to replace Lunar Modulator depends on whether Lunar Modulator answers that updater, which is not decided.

11.5 The firmware your FM-1 has now

M-VAVE updates the FM-1 with its own updater over USB, and publishes the firmware and the updater for macOS and Windows in the download centre of its website, m-vave.com. Third-party firmware for the FM-1 also exists and installs the same way. All of these need a working FM-1: they cannot repair one that does not start.

● **Keep your FM-1’s firmware as it is**

Nothing in Lunar Modulator requires you to change the firmware on your FM-1. If you want to try another firmware, follow its own instructions, and keep M-VAVE’s updater and a copy of the official firmware file in case you want to go back.

11.5.1 To find out which firmware your FM-1 runs

The FM-1 answers one question over USB-MIDI with its identity, a model name and a number such as `FM-1_015` . The project’s identity tool asks exactly the question M-VAVE’s updater asks when it starts, and sends nothing else:

- 1. Connect the FM-1 to your computer with USB and switch it on.
- 2. Close any other program that uses the FM-1’s MIDI port.
- 3. In a checkout of the project, with Python 3:

```
python3 -m pip install mido python-rtmidi
python3 tools/fm1_identify.py --list      # the MIDI ports your
computer sees
python3 tools/fm1_identify.py            # asks the first port named
FM-1
```

The line `identity:` in its answer is the firmware’s identity.

Identity	M-VAVE’s name for it
FM-1_009	V13
FM-1_014	V14
FM-1_015	V15

Third-party firmware reports numbers of its own.

◆ **Trust the identity, not the file name**

Version numbers in file names, in M-VAVE’s announcements and in the identity often disagree: the package called V13, for example, identifies as `FM-1_009` . When it matters which firmware you have, ask the unit.

CHAPTER 12

Troubleshooting

Find the symptom, then try the remedies in order. The simulator and the desktop tools both say what went wrong in plain words; the tables quote those messages so you can search for them.

12.1 The simulator

12.1.1 Sound and starting up

Symptom	Likely cause	What to do
No sound after Power on	The browser blocked audio, or the computer’s output is muted or set to another device	Click Power on again; check the computer’s volume and output device; turn MASTER up
Power on does nothing, and the status line still says <i>Powered off</i>	The page was opened as a file, so its scripts did not load	Open the project’s website, or serve your checkout: <code>cd sim/web/www && python3 -m http.server 8000</code> , then open <code>http://localhost:8000/</code>
The status line says <i>The browser is holding the sound back</i>	The browser has not started the sound yet, or has stopped it: on an iPhone or iPad a call, Siri or another app’s audio does this	Tap the panel or press a key
No sound on an iPhone or iPad, though the screen runs	Silent mode is on, and this version of iOS does not let a page play through it	Turn Silent mode off (the Ring/Silent switch, or the Action button), or update iOS
The status line says <i>This page needs a secure context for its audio</i>	The page was opened over plain http from another computer’s address	Open it over https, as the project’s website serves it, or from <code>http://localhost</code> on the computer that serves it
The status line says <i>Could not start audio</i>	One of the simulator’s files did not load	Reload the page; check that the whole folder is served, <code>fm1.wasm</code> included

Symptom	Likely cause	What to do
The status line says <i>This browser has no AudioWorklet</i>	The browser is too old, or lacks the audio feature the simulator needs	Use a current Chromium-based browser such as Chrome or Edge
The status line says <i>The firmware did not start</i>	The firmware’s code did not load in this browser	Reload the page; try a current Chromium-based browser
Crackles or dropouts	The computer is busy, or a phone is too slow	Close other tabs and programs; on a phone, try a computer
The status line says that <i>Macro was refused: it does not run at 48,000 Hz</i> , and the simulator started with another sound	The browser would not run audio at 44,100 Hz (the status line says <i>the browser refused 44,100 Hz</i>), and Macro, Macro Heavy, Six-Op FM and Drums need 47,872 Hz or less	Set the computer’s audio output to 44.1 kHz and reload. FM6, Shapes, Sophie and Test Sine work at 48 kHz too

12.1.2 Playing

Symptom	Likely cause	What to do
The screen says an engine <i>refuses</i> a rate, and the previous one comes back	As above: the audio runs faster than 47,872 Hz	Set the output to 44.1 kHz and reload
Sophie or Drums is silent on the black keys	With a drum kit as the current sound, the white keys play its 16 pads and the black keys nothing	Play the white keys (chapter 5)
A note keeps sounding	A key release was lost, for example when the window lost focus	Press Esc, or send CC 123 from a MIDI keyboard
The computer keys play nothing	A dropdown under the panel has the keyboard’s focus, a modifier key such as Ctrl, Alt or Cmd is down, or the page is not in front	Click the panel’s case once, release the modifier keys, then play
The computer keys play the wrong notes	The keyboard layout is not QWERTY	The keys work by position: play the keys that sit where a QWERTY keyboard has A to L and the keys after it (chapter 2)
Every note from the computer keys is equally loud	Computer keys always play at velocity 100	Click lower on a key on the panel to play louder, or use a MIDI keyboard

Symptom	Likely cause	What to do
The keys play the wrong octave	The octave or transpose is not at zero	Press OCT- and OCT+ together to reset both
Only part of the panel shows on a phone	The panel keeps its size so the keys stay playable	Drag the case sideways, or turn the phone to landscape
A file is refused with <i>Needs 117% of the FM-1's RAM</i>	It would not fit the FM-1's memory	Load a lighter file, or make room first: this refusal has no way round it (chapter 10)
Your work is not there on the next visit	The browser blocks or cleared this site's storage, or it is a private window	Keep a copy with <i>Save...</i> ; the page says when it can only keep things for the visit
PRESETS skips a sound, and the screen says <i>does not fit</i>	It would take the chain past the FM-1's memory: past 100 %, as the screen's <i>needs ...% of RAM</i> says	Empty a sound, an insert or a master effect first (chapter 6)
The keys play nothing, and the white keys' lights follow a pattern	SEQ mode is on: there the white keys are steps	Press HOME to play notes again (chapter 7)
A key plays a different sound from the one on screen, or nothing	Another sound is current, or it is empty	Hold SEL and turn PRESETS to choose the sound (chapter 5)
REC blinks slowly	Capture holds notes you played	SEL and REC keep them as a clip; otherwise ignore it (chapter 7)
A parameter moves on its own	A modulation cable reaches it: its name is in the modulation colour, with a bracket on its bar	Press EDIT and empty the cable, or turn its amount to 0 % (chapter 8)
The effect page says <i>Empty slot: turn ALGORITHM</i>	That slot holds no effect	Turn ALGORITHM to choose one

12.1.3 Loading DX7 patches

Symptom or message	Likely cause	What to do
Load DX7 patches... cannot be clicked, or the status line says <i>Power on first</i>	The simulator is off	Click Power on , then load the file

Symptom or message	Likely cause	What to do
<i>... was not loaded: it is not SysEx</i>	The file is not a SysEx file: text, a document, or patches in another program's own format	Use a <code>.syx</code> file of DX7 voices: a single voice is 163 bytes, a bank of 32 is 4,104 bytes
<i>... was not loaded: it holds SysEx, but ... of another kind</i>	The file is SysEx from another instrument, or another kind of DX7 dump	Use a file of DX7 voices; several dumps in one file are fine
<i>... was not loaded: it is cut short</i>	The file ends in the middle of a dump (a download that stopped, or a file cut by hand)	Get the file again
<i>... the wrong length</i>	A DX7 voice or bank dump with a byte missing or added	Get the file again, or try another copy
<i>... larger than the 64 KB the simulator reads</i>	The file holds more than sixteen banks, or is not a patch file	Split it into banks, or use one bank of it
The status line says a dump <i>had a wrong checksum</i>	The file was edited, or damaged on its way to you; the voices were loaded all the same	Listen to them; if one sounds wrong, get the file again
The status line says <i>the last one counts</i>	The file held several banks; each fills User 1 to 32, so only the last stays	Load the bank you want on its own
The status line says <i>the later ones replaced the earlier ones</i>	The file held more than 32 voices; they fill the user slots in turn and go round again from User 1	Load the voices you want in files of 32 or fewer

12.1.4 MIDI

Symptom	Likely cause	What to do
The status line says <i>This browser has no Web MIDI</i>	The browser does not offer MIDI to web pages	Use a Chromium-based browser for MIDI, or play the panel and the computer keys
The status line says <i>MIDI was not allowed</i>	The browser's permission was refused	Allow MIDI for the page in the browser's site settings, reload, and click Connect MIDI input again
The button reads <i>MIDI: no inputs</i>	No keyboard is connected, or another program holds it	Connect the keyboard; the simulator picks it up by itself. Close other programs that use it

Symptom	Likely cause	What to do
The keyboard plays, but the sustain pedal and modulation wheel do nothing	The simulator ignores those messages	See chapter 9 for what it receives

● Which browsers

The simulator has been tested in Chromium-based browsers on a desktop. Firefox, Safari, phones, tablets and real MIDI hardware have not been tested yet, so problems there may have causes this chapter does not list.

12.2 The desktop tools

12.2.1 Building and rendering

Symptom or message	Likely cause	What to do
<code>make -C engines</code> stops with compiler errors	No C and C++ compiler, or one without C++11	On macOS install the command-line tools (<code>xcode-select --install</code>); on Linux, your distribution's build tools package
<i>macro refused this host (rate 48000 Hz, 64 frames)</i>	Macro, Macro Heavy and Six-Op FM refuse rates above 47,872 Hz	Leave out <code>--rate</code> (the default is 44,118 Hz) or choose 44100
<i>unknown parameter for macro: Timbr</i>	The name is misspelt, or belongs to another engine	Use the names in chapter 5's tables; case does not matter. Quote names with spaces: <code>--param "Word Speed=0.5"</code>
<i>unknown, incompatible or wrong-kind engine</i>	The identifier is misspelt, or names an effect where an engine is wanted	<code>engines/build/fm1-render --list</code> prints every identifier and kind
<code>--sysex: no DX7 voice dump in FILE</code>	The file holds no single-voice or 32-voice DX7 dump, or only broken ones	Check that it is a <code>.syx</code> file of DX7 voices (163 or 4,104 bytes a dump, or 4,096 bytes of bank data alone)
<code>--sysex needs --engine dx7</code>	Only FM6 reads DX7 voices	Add <code>--engine dx7</code>
<i>sw-sophie has no pitch bend</i>	Sophie ignores pitch bend, so <code>--bend</code> is refused	Leave out <code>--bend</code> for Sophie

Symptom or message	Likely cause	What to do
<i>–bend and –param-at need –engine</i>	Those options act on a sound engine	Add <code>--engine</code>
The WAV file is silent	No <code>--note</code> , or notes outside an engine’s range	Add notes; Sophie answers only notes 36 to 51

12.2.2 The sequencer

Symptom or message	Likely cause	What to do
A script renders, but nothing plays	The script never sends <code>play</code> , or the run ends too soon	Add <code>@0 play ; set end=</code> in the <code>#!</code> line, or give <code>--seconds</code>
Notes play, but a lock changes nothing	The lane’s label names no parameter of the engine	Label the lane with the parameter’s name, as in <code>synth:Timbre</code> (chapter 7)
A track’s notes are logged but not heard	The track is routed to MIDI	Add <code>--route T:engine</code> for that track
<i>–route, –log-events, –compat and –tracks need –cmd or –seq</i>	Those options belong to sequencer renders	Add a script with <code>--cmd</code> or a set with <code>--seq</code>
<i>not a movy1 set</i>	The file does not start with the line <code>movy1</code>	Export sets with <code>fm1-seq --export</code> , or check the file
The summary reports <code>seq_refused</code> above 0	An edit did not fit the sequencer’s memory and was refused whole	Use fewer notes or locks, or fewer tracks (chapter 7)
A command seems to be ignored	Tracks, steps, slots and scenes count from 0 in scripts; an unknown verb is ignored without a message	Check the numbering and the verb’s spelling against chapter 7 ’s table of commands

12.3 The FM-1

The FM-1 does not run Lunar Modulator, so problems with the instrument itself are for M-VAVE’s manual and support. [Chapter 11](#) describes the firmware the FM-1 has now and how to find out which one it is ([chapter 11](#)).

12.4 Reporting a problem

If a remedy here does not help, open an issue on the project's repository at github.com/ip2k/lunar-modulator. Say:

- what you did, what you expected, and what happened instead;
- for the simulator: the browser and its version, the computer or phone, and the status line under the panel;
- for the desktop tools: the command, its full output, and the commit you built from;
- the edition of this manual, from the table in [chapter 1](#).

CHAPTER 13

Specifications

13.1 The instrument

These are the M-VAVE FM-1’s own specifications, as far as they matter to Lunar Modulator. The *source* column says where each figure comes from: *checked on a unit* means seen on an FM-1’s board or read from its firmware by this project; *M-VAVE* means M-VAVE’s documentation; *published analysis* means the work of others who have studied the FM-1, credited in [chapter 14](#).

Item	Specification	Source
Processor	JieLi AC791N, with a 32-bit pi32v2 core. M-VAVE’s firmware runs it at 240 MHz of a possible 320 MHz	Chip checked on a unit; clock from published analysis
Memory	578 KB of RAM on the chip, of which about 514 KB is usable; 1 MB of flash memory, probably inside the chip’s package	RAM from the chip maker’s documentation; flash from published analysis
Display	1.54-inch colour screen, 240 × 240 pixels	Published analysis and M-VAVE
Keys	27, from F3 to G5, each with a light	Count checked on a unit; range from M-VAVE
Knobs	7 encoders and 1 potentiometer (MASTER)	Checked on a unit
Buttons	14, each with a light	Checked on a unit; names from M-VAVE
Connectors	USB-C; 3.5 mm stereo audio output; 3.5 mm MIDI input (TRS, input only)	Checked on a unit; MIDI input from M-VAVE
Speaker	Built in	Checked on a unit (its connector on the board)
USB	USB 2.0 full speed. With M-VAVE’s firmware: MIDI, and two channels of audio in each direction at 44.1 kHz	Checked on a unit
Wireless	Bluetooth LE, which M-VAVE’s firmware uses for MIDI	Published analysis
Power	Lithium-polymer battery, 3.7 V, 2000 mAh (7.4 Wh), charged over USB-C; slide switch	Battery checked on a unit (cell label); charging from M-VAVE

Item	Specification	Source
Size	161.5 × 96.5 mm	M-VAVE

13.2 Lunar Modulator

STATUS: ● In the simulator ■ On the desktop

Item	Specification
Sample rate	44,118 samples a second, the rate reported for the FM-1's audio output. The simulator uses 44,100 or the computer's own rate when the browser cannot give it 44,118
Block	64 samples, 1.45 ms at 44,118
Output	Stereo
Engines' own rates	Macro, Macro Heavy, Six-Op FM and Drums run Plaits' code at 47,872 samples a second, and Shapes runs Braids' at 96,000, each converted to the output's rate, so that they sound and keep time as on the modules they come from. The four Plaits-based engines cannot run when the output is faster than 47,872. FM6 runs at the output's rate, from 16,385 samples a second up, with its envelope times kept
Sound engines	Eight; up to four sounds at once, each with its own engine (chapter 5)
Effects	Twenty-four, Test Gain and Test Ext included: two inserts on each sound, then two master effects in series after the mix (chapter 6)
Limiter	Ceiling 0.98 of full scale (−0.18 dBFS), instant attack, about 100 ms release; samples that are not numbers become silence
MASTER	After the limiter. Half way round is a quarter of full level, about −12 dB
Pitch bend	Up to ±48 semitones in the engines; ±2 semitones from MIDI in the simulator
Memory for sounds	The room M-VAVE's firmware leaves free on the FM-1, for the sounds, effects, sequencer and modulation: 100 % (379 KB) on the memory meter, which on the screen shows memory only as a share of it. The real figure for Lunar Modulator on the device will be known once it runs there
Sequencer	8 tracks in the simulator, as planned for the FM-1 (chapter 7)
Licence	MIT for Lunar Modulator's own code; code from other projects under its own licence (chapter 14)

13.2.1 Engines and effects in figures

Memory is given as the share of the FM-1's memory each engine or effect takes on its own (100 % is all the memory meter allows, 379 KB), as a 32-bit build lays it out at 44,118 samples a second, as in the simulator and on the FM-1, rounded up as the meter rounds, with the size itself in brackets (1 KB is 1,024 bytes). The screen shows the share only. The meter adds up the chain in use, with the sequencer's own, 10 % (36 KB), and modulation's, 7 % (26 KB), and is the one to trust if the two ever differ.

Engine or effect	Voices	Share of memory (size)
Macro	12	6 % (19 KB)
Macro Heavy	4	19 % (70 KB)
Six-Op FM	8	3 % (11 KB)
FM6	12	5 % (16 KB); its tables stay in flash memory
Shapes	12	54 % (202 KB)
Sophie	12	21 % (77 KB)
Drums	12	2 % (7.5 KB)
Test Sine	12	under 1 % (320 bytes)
Plate	–	17 % (64 KB)
Ensemble	–	2 % (4.6 KB)
Diffuse	–	5 % (18 KB)
PSX Verb	–	35 % (131 KB)
Crush	–	under 1 % (176 bytes)
Fold	–	under 1 % (160 bytes)
Drive	–	under 1 % (240 bytes)
Echo	–	17 % (64 KB)
Filter	–	under 1 % (656 bytes)
Comb	–	5 % (17 KB)
Comp	–	under 1 % (208 bytes)
Limiter	–	4 % (12 KB)
DJ Filter	–	under 1 % (224 bytes)

Engine or effect	Voices	Share of memory (size)
Tilt	–	under 1 % (144 bytes)
Master Sat	–	under 1 % (352 bytes)
Isolator	–	under 1 % (256 bytes)
EQ	–	under 1 % (416 bytes)
Room	–	11 % (40 KB)
Hall	–	13 % (49 KB)
Gate	–	under 1 % (2.1 KB)
Squash	–	under 1 % (416 bytes)
Transient	–	under 1 % (144 bytes)
Test Gain	–	under 1 % (24 bytes)
Test Ext	–	under 1 % (16 bytes)

13.2.2 The sequencer

STATUS: ● In the simulator ■ On the desktop ◆ Planned for the device

The sequencer at a glance		
Item	Value	Notes
Clock resolution	96 ticks per quarter note	MIDI clock out is 24 per quarter note
Step	24 ticks, a sixteenth note	16 steps to a 4/4 bar
Clip length	1 – 256 steps	up to 16 bars
Tracks	up to 16	the FM-1 build is planned with 4 to 8
Clip slots	8 per track	a scene is one slot on every track
Parameter-lock lanes	8 per track	each lane drives one parameter
Lock values	0 – 127	scaled onto the parameter's own range
Notes on one step	up to 12 at once	a chord
Tempo	20 – 300 BPM	in steps of 0.01 BPM

13.2.3 Sounds, effects and modulation

STATUS:  In the simulator  On the desktop  Planned for the device

Item	Specification
Sounds	Up to four at once, each with its own engine and a level into the mix
Effects	Two inserts on each sound, two master effects after the mix, then the limiter
Modulation	A rack of eight positions for sixteen kinds of module, 32 cables, worked out every 32 samples
Memory	Everything refused that would take the memory meter past 100 % (379 KB)

13.3 The simulator

STATUS:  In the simulator

Item	Specification
Runs in	A web browser with WebAssembly and the Web Audio API's AudioWorklet, from an https:// address or from the computer it runs on
Tested in	Chromium. Firefox, Safari, real touch screens and real MIDI hardware are not tested yet
Sample rate	Asks for 44,100 Hz. If the browser refuses, the computer's own rate, where Macro, Macro Heavy, Six-Op and Drums do not run (above 47,872 Hz); the status line says so. The memory meter counts as the FM-1 would, at 44,118 Hz
Input	Mouse, touch, the computer keyboard, and MIDI from a keyboard: notes, velocity, pitch bend, control changes 7 and 123
Output	Audio only. It sends no MIDI
Screen	The firmware's 240 × 240 screen, redrawn up to about 30 times a second while sound plays
Panel	To scale, 161.5 × 96.5 mm. On narrow screens it keeps a width of 800 pixels and scrolls sideways
Download	About 1.3 MB for the firmware, plus the page; nothing is loaded from other websites

13.4 The desktop tools

STATUS: ■ On the desktop

Item	Specification
Renderer	<code>fm1-render</code> plays notes, or the sequencer, through one engine, any number of effects and the limiter, or through up to four sounds with their inserts, levels and master effects as the simulator does, with modulation from a file, into a 16-bit stereo WAV file. Unless told otherwise: 44,118 samples a second, 64-sample blocks, 2 seconds
Sequencer tool	<code>fm1-seq</code> runs the sequencer alone, writes the events it produces, and saves and loads sets as text
Builds with	<code>make</code> and a C and C++11 compiler. The project's automatic tests build and run them on Linux and macOS

13.5 Still to be measured on the device

STATUS: ◆ Planned for the device

These figures will be added once Lunar Modulator runs on the hardware:

- the processor load of each engine and effect on the FM-1's processor, first measured on a JieLi development board;
- how many voices each engine can play on the FM-1, which memory and processor load will decide;
- battery life with Lunar Modulator;
- whether the FM-1's keys sense how hard they are played;
- which kind of TRS adapter the `MIDI IN` jack expects;
- the exact sample rate of the FM-1's audio output, so far reported, not measured, as 44,118.

CHAPTER 14

Credits and licences

Lunar Modulator stands on other people's work. This chapter names it, and the terms it is used under.

14.1 Sound engines and effects

- **Mutable Instruments**, code by **Emilie Gillet**, MIT licence. Macro, Macro Heavy and Six-Op FM are built from the engines of Plaits; Shapes from the macro-oscillator of Braids; Plate from the reverb of Rings, its Freeze after the one in Elements; Room from the reverb and diffuser of Clouds; Ensemble and Diffuse from Plaits' ensemble and diffuser. Their code is included unmodified; the wrappers that make it polyphonic and fit it to the FM-1 are this project's own, and Macro Heavy's speech model adapts one of Plaits' classes. Lunar Modulator is not affiliated with or endorsed by Mutable Instruments, and as Mutable Instruments asks of work derived from its code, the engines carry names of their own.
- **Six-Op FM's patches** are the three banks distributed with Plaits' code. Their origin is not stated there. In public builds, the twenty-three patches whose stored names are trademarks or a person's name are shown under descriptive names of this project's own.
- **msfa**, the FM synthesizer core of Google's Music Synthesizer for Android, by **Raph Levien** for **Google**, Apache License 2.0: FM6's envelopes, LFO, operators, algorithms and tables. Its code is included unmodified, its tables computed ahead of time as its own code computes them; the voice built from it, its amplitude modulation, the feedback loops of algorithms 4 and 6 and its controls are this project's own. FM6 reads voices in the format of Yamaha's DX7 and is not affiliated with or endorsed by Yamaha.
- **FM6's name** is borrowed, with thanks, from the FM engine of **Felucca** by **hugelton** (Hügelton Instruments), open firmware for the FM-1; Felucca's Apache-2.0 port of the same core checks FM6 in the tests (below).
- **FM6's built-in voices** are this project's own, written for it and under the MIT licence.
- **Sophie** by **Matt Estela**, MIT licence, included unmodified.

- **Drums:** its kicks, toms, snares and hi-hats are Plaits’ drum models by **Emilie Gillet** (Mutable Instruments, MIT licence), included unmodified, which model the circuits of Roland’s TR-808 and, in their synthetic kick and snare, borrow from the TR-909’s. Its rim shot, clap, cowbell and cymbals are this project’s own code, with three small pieces of Plaits’ hi-hat in the cowbell and cymbals (its swing VCA curve, its oscillators’ ratios and its clocked noise): the cowbell and cymbals follow the circuit models of **Kurt James Werner, Jonathan Abel and Julius O. Smith** (“More cowbell”, AES 137th Convention, 2014; “The TR-808 cymbal”, ICMC/SMC 2014, CC BY 3.0), and the clap and rim shot published descriptions of the TR-808’s circuits, among them **Baratatronix**’s. No code or text is taken from the papers or the descriptions. The two kits are inspired by those drum machines; Roland’s names appear here only as credit.
- **Acid Bass** is the 303 bass of **fm1-x0x**, open firmware for the FM-1 by **Charles Vestal**, GNU GPL version 3 (built in only with the GPL switch on; see [Licences](#)). It ports **Open303** by **Robin Schmidt** (MIT licence), with the Devilfish modifications’ ranges after **jc303** by **midilab** and a drive after **dm-Rat** by **Dave Mollen** (both GNU GPL version 3), by way of Charles Vestal’s **schwung-303**. Two small changes of this project’s let it run at the instrument’s rate and take smooth settings; the rest of its code is included unmodified. It is after Roland’s TB-303, whose name appears here only as credit.
- **Acid Gen** is TB-3PO, the line generator of **fm1-x0x** by **Charles Vestal**, GNU GPL version 3 (built in only with the GPL switch on), which ports his **schwung-tb3po** and, through it, the **TB_3PO** applet of the **Phazerville Hemisphere Suite** by **djphazer** and its contributors (GNU GPL version 3). Its code is included unmodified; playing it as an effect in front of a sound is this project’s own.
- **Comet Kit** is the 909 kit of **fm1-x0x** by **Charles Vestal**, GNU GPL version 3 (built in only with the GPL switch on). It ports **9W9** by **athousanddetails**, a drum machine for Schwung that models the TR-909’s circuits, which grew out of **ER-99** by **Matthew Cieplak** (both GNU GPL version 3); its hi-hat, ride and crash are **ER-99’s recordings**, under the same licence. Two small changes of this project’s let it run at the instrument’s rate and take smooth settings; the rest of its code, its recordings and the script that turns them into data are included unmodified. The pads, voicings of the second snare, toms and pedal hi-hat, and playing it as a pad kit are this project’s own. It is after Roland’s TR-909, whose name appears here only as credit.
- **Crater Kit** is the 808 kit of **fm1-x0x** by **Charles Vestal**, GNU GPL version 3 (built in only with the GPL switch on), which ports **8W8** by **athousanddetails** (GNU GPL

version 3). Fifteen of its sixteen sounds are models of the machine’s circuits, built from the TR-808’s service notes and the analyses of **Kurt James Werner**, **Jonathan Abel** and **Julius O. Smith**; the rim shot is **sc808**’s, by **Yoshinosuke Horiuchi**, adapted for Sonic Pi by **Sam Aaron** (MIT licence). Two small changes of this project’s let it take smooth settings and keep no shared state; the rest of its code is included unmodified. It is after Roland’s TR-808, whose name appears here only as credit.

- **Drawbar**, **Trio** and **Phase Bend** are the WHEEL, TRIO and PHASE engines of **Felucca**, open firmware for the FM-1 by **Leo Kuroshita** (@kurogedelic), **Hügelton Instruments**, GNU GPL version 3 (built in only with the GPL switch on; see [Licences](#)). Felucca’s code for them, its shared DSP and its tables are included unmodified; PHASE is a port of the oscillator of **CrispyZebra**, the same author’s (GNU GPL version 3). The code that plays them through Lunar Modulator’s engine interface is this project’s own, and the test that holds them to Felucca’s own voice code uses that code too. The engines’ names here are this project’s (“Trio” is Felucca’s own, borrowed with thanks); Felucca’s factory sounds appear in [chapter 5](#) as settings.
- **PSX Verb** by **Charles Vestal**, MIT licence, included unmodified.
- **Schwung**, Charles Vestal’s host for modules on the Ableton Move, MIT licence. Lunar Modulator includes Schwung’s plugin interface unmodified, with a compatibility layer of its own, so that Schwung modules such as Sophie and PSX Verb build from their own source. Schwung’s licence notes that it began as a fork of Move Anything by Bobby Digitales.
- **Crush** is this project’s own code. Pairing a sample-rate reducer with a bit reducer follows **DaisySP**’s Decimator and Bitcrush, by **Electro-Smith**, MIT licence; none of DaisySP’s code is used.
- **Fold** is this project’s own code, after the wavefolders of Serge and Buchla synthesizers and the folding in Mutable Instruments’ Warps and Plaits by **Emilie Gillet**; its anti-aliasing follows the method of **Parker, Zavalishin and Le Bivic** (DAFx-16). No code is taken from any of them.
- **Drive** is this project’s own code: its curves are written here, its tape emphasis follows tape’s record and replay equalisation, and its anti-aliasing follows the method of **Parker, Zavalishin and Le Bivic** (DAFx-16). No code is taken from anyone.
- **Echo** is this project’s own code. Its ping-pong layout is the textbook one, after **Udo Zölzer**’s *DAFX*, and its 16-bit delay memory follows **Emilie Gillet**’s effects engine in Rings and Clouds; none of their code is used.

- **Filter** is this project's own code: zero-delay-feedback filters after **Vadim Zavalishin's** *The Art of VA Filter Design*, **Andrew Simper's** (Cytomic) state-variable filter, **Antti Huovilainen's** ladder model (DAFx-04) and the diode-ladder circuit; its Sallen-Key type is after the Korg-35 filter of the later MS-20, and its SK Mixed type after the Steiner-Parker Synthacon's filter (their makers' names appear here only as credit); its non-linear solver follows a method **Teemu Voipio** published, and its vowels are the measurements of **Peterson and Barney** (1952). No code is taken from any of them.
- **Comb** is this project's own code: **Udo Zölzer's** universal comb (DAFX), with Filter's saturating loop. It was one of Filter's types until October 2026. No code is taken from anyone.
- **Comp** is this project's own code, after the compressor design of **Giannoulis, Massberg and Reiss** (*Journal of the Audio Engineering Society*, 2012). No code is taken from anyone.
- **Limiter** is this project's own code, after **Geraint Luff's** look-ahead limiter design (SignalSmith Audio, 2022). No code is taken from the article or from SignalSmith's library. Its Round mode ports the loop of **Airwindows** ClipOnly2, by **Chris Johnson**, MIT licence ("Copyright (c) 2016 airwindows, Airwindows uses the MIT license"; the licence is in the source tree with the effect).
- **DJ Filter** is this project's own code: the state-variable filter of **Andrew Simper** (Cytomic) and **Vadim Zavalishin**, in the form of stmllib's by **Emilie Gillet** (MIT licence). No code is taken from anyone.
- **Tilt** is this project's own code. A tilt built from first-order sections follows **Airwindows' ToneSlant** (MIT licence) and the spectral tilt of the **Faust** libraries; none of their code is used.
- **Master Sat** is this project's own code. Its two curves use the coefficients of **Airwindows** PurestSaturation and TapeHack2, by **Chris Johnson**, MIT licence ("Copyright (c) 2018 Chris Johnson"; the licence's notice is in the effect's source), and its Glue follows the idea of Airwindows Compresaturator, whose code is not used.
- **Isolator** is this project's own code. Its three bands are split as in the **Faust** libraries' three-band Linkwitz-Riley crossover, with **Andrew Simper's** (Cytomic) and **Vadim Zavalishin's** state-variable filter; none of their code is used.
- **EQ** is this project's own code. Each band is the state-variable filter in the form **Andrew Simper** (Cytomic) published, whose maths is in the public domain, and its

curves are checked against **Robert Bristow-Johnson**’s Audio EQ Cookbook. No code is taken from either.

- **Hall** is this project’s own code. It is a feedback delay network after **Jean-Marc Jot** and **Antoine Chaigne** (1991); its structure follows schwung-work’s Voidspace and **Geraint Luff**’s Signalsmith basics library (both MIT), its input diffusion **Manfred Schroeder**’s all-passes with **Jon Dattorro**’s coefficients, and its 16-bit delay memory **Emilie Gillet**’s effects engine in Rings and Clouds; none of their code is used.
- **Gate** is this project’s own code. Its controls follow the operator manuals of **Drawmer**’s DS201 and DS301 noise gates (the maker’s name appears here only as credit); its key filters are **Vadim Zavalishin**’s state-variable filter. No circuit or code is taken from anyone.
- **Squash** ports three **Airwindows** plug-ins by **Chris Johnson**, MIT licence (“Copyright (c) 2016 airwindows, Airwindows uses the MIT license”): its Snap type is Pop3, Mu is Pressure4 and Split is ButterComp2, rewritten in single precision for the FM-1, with their noise taken out and the few changes the effect’s notes list.
- **Transient** is this project’s own code, on the classic two-follower principle of transient designers, as noted from **legsmechanical**’s Bus Driver (MIT licence). No code or measurement is taken from it.

Each engine’s and effect’s credits are also built into the firmware, and are printed under its table in chapters 5 and 6.

14.2 The sequencer

- **Movy** by **megadake**, MIT licence. Lunar Modulator’s sequencer is a new implementation, written in C, of the behaviour of Movy’s sequencer core, and its design follows Movy’s. Movy’s own core, run unmodified on a computer, is used to check Lunar Modulator’s, event for event.

14.3 The arpeggiator

- The arpeggiator is this project’s own code, after published designs: its loop, rhythms, Euclidean patterns and latch follow the arpeggiator of **Mutable Instruments**’ Yarns by **Emilie Gillet** (MIT licence); its note orders and its TRG rate follow MCL’s by **Justin Mammarella** (BSD-3-Clause); its seeded, repeatable

chances follow Super Arp by **Handcrafted Media** (MIT licence). No code is taken from any of them.

- The stock FM-1's arpeggio modes, whose names the presets keep, are as **AL-255's** disassembly reads them.

14.4 Modulation

- The rack's modules are this project's own code, after published designs, chiefly those of **Mutable Instruments'** Peaks and Braids by **Emilie Gillet** (MIT licence). Three are ports of that code: Bounce from Peaks' bouncing ball, Burst from Peaks' pulse shaper and randomizer, and Quantize from Braids' quantizer and its scales.
- The LFO's shapes follow **Schwung's** LFO by **Charles Vestal** and Peaks; the envelope follows Peaks' multistage envelope; Chance follows **DaisySP's** sample and hold (**Electro-Smith**, Paul Batchelor) and **Music Thing Modular's** Workshop System Computer card 106 (**Matt Allison**); Register follows **Tom Whitwell's** Turing Machine (Music Thing Modular), **Chris Johnson's** card 20 and **Phazerville's** Turing code (**Patrick Dowling**). Divide, Burst, Compare, Logic, Calc, Slew and Mix follow Phazerville's applets (**Jason Justian** and others), and the Resonator **Andrew Simper's** (Cytomic) state-variable filter. No code is taken from any of them but the three ports above.
- Some modules follow only the published behaviour of other instruments, whose makers' names appear here only as credit: Function after Make Noise's Maths, Joranalogue's Contour 1, Serge's DUSG and Befaco's Rampage; Coin after Mutable Instruments' Branches and Marbles; the LFO's modes after Elektron's instruments; Slew, Compare and Logic after Expert Sleepers' disting and Mannequins' Just Friends. No code of theirs is used.

`fm1-render --list-mod` prints each module's credits in full.

14.5 Research this project builds on

- **aroum**: the first analysis of the FM-1's updaters, and teardown photos.
- **AL-255**: a disassembly of the FM-1's firmware, its update protocol, and a safety review whose rules this project follows.
- **Echomatter**: showed that the FM-1's own update method accepts a rebuilt firmware package with a new version number, and rolled it back again.

- **kagaimiq**: documentation and tools for JieLi chips, including the recovery mode the dongle uses.
- **czietz** and **masanaohayashi**: reports of reaching that recovery mode on FM-1s with a small USB dongle, and czietz’s tool for it.
- **probonopd**: notes on a sibling keyboard built on the same platform.
- **benny-sparra**: an editor and librarian for the FM-1, and observations of its MIDI.
- **Baud Girl**, whose third-party FM-1 firmware showed how firmware reaches users through the FM-1’s own update method.
- **hugelton** (Felucca), **isod89** (SLOOP), **Keitark** (fm1-nes) and **kurogedelic** (FM-1-transporter): open firmware and tools that run on FM-1s. Their reports of how the board reads its keys and knobs, where its audio goes and how its recovery mode is reached inform this project’s plans.
- **Google’s music-synthesizer-for-android** and the **Dexed** family, whose FM engine M-VAVE’s firmware is built on.

The project’s research notes credit each source in detail.

14.6 The simulator, the art and the manual

- **Audiowide** by Brian J. Bonislowsky (Astigmatic), SIL Open Font License 1.1, for the name, the headings and the cover. The font file is included unmodified, with its licence.
- **IBM Plex Sans** and **IBM Plex Mono**, designed by Mike Abbink with Bold Monday for IBM, SIL Open Font License 1.1, set the printed manual. On the web the manual uses them where they are installed, and your system’s own typeface otherwise.
- **Rosé Pine**, by mvllow and the Rosé Pine contributors, MIT licence: this manual is in the Dawn palette, and the simulator and the art in Moon.
- **Spleen** by Frederic Cambus, BSD 2-Clause licence: the screen’s two smaller typefaces, 8×16 and 6×12. The simulator’s page carries its licence, and so must any firmware built with them.
- The simulator’s main screen font, the panel drawings, the banner and the boot screen are this project’s own. The panel drawings follow M-VAVE’s published dimensions and measurements of a unit.
- The manual is built with **Python-Markdown** and **WeasyPrint**, both under the BSD licence.

14.7 Licences

Lunar Modulator’s own code, and this manual, are under the MIT licence. Code from other projects keeps its own licence, which the repository records beside it with a note of where it came from. Everything listed in this chapter that ships with the simulator or the desktop tools is under the MIT licence, or, for msfa, the Apache License 2.0, or, for the fonts, the SIL Open Font License 1.1, or, for Spleen, the BSD 2-Clause licence. The repository’s tests also use **Felucca’s** `fm6_core.c` by **Leo Kuroshita** (Hügelton Instruments), an Apache-2.0 port of the same FM core, to check FM6 against; it is in no build of the firmware or the simulator.

GPL code, and the GPL switch. Some engines and effects port code that other projects publish under the GNU General Public License: today the sound engines **Acid Bass**, **Comet Kit** and **Crater Kit** (chapter 5) and the MIDI effect **Acid Gen** (chapter 4), all from fm1-x0x, and **Drawbar**, **Trio** and **Phase Bend**, from Felucca. Each sits in a folder of its own in the repository, with its licence and a note of where it came from, and is built in only while the firmware’s GPL switch is on. While we test, the switch is on in every build, the simulator included. - **In the simulator**, the page beside the panel then names each module with GPL code in it, and offers the simulator’s module under the GNU GPL, version 3. It links the licence’s text and the complete source: the repository at the commit the page was built from. When no GPL module is in it, the page says nothing. - **Firmware for the FM-1** built with the switch on is for the person who builds it: it will not be released or passed on. A shared build is made with the switch off and contains no GPL code.

14.8 Trademarks

M-VAVE, Cuvave and FM-1 are the marks of their owners. Lunar Modulator uses “FM-1” only to say which instrument it is written for, and is not made, endorsed or supported by M-VAVE or Cuvave. The names of Mutable Instruments’ modules identify where code came from. Names such as Ableton Move and DX7 describe origins and compatibility only, and Roland, TR-808, TR-909 and TB-303 the machines that inspired Drums, Comet Kit, Crater Kit and Acid Bass. All other trademarks belong to their owners.

CHAPTER 15

The advanced editor

The advanced editor is a second way to play the virtual FM-1. It shows everything the panel hides behind its pages: every parameter of a sound at once, the whole signal flow, the modulation rack and its cables, and what each choice would cost in memory before you make it. It does not replace the panel. It edits the same instrument, so a knob turned on the panel moves its slider in the editor, and a slider moved in the editor opens that page on the panel.

● In the simulator

The editor runs in the browser simulator, beside the panel or in its place. It edits what the simulator plays and nothing else: it never sends anything to a MIDI device, and nothing in it reaches an FM-1.

15.1 Opening the editor

STATUS: ● In the simulator

The switch at the top of the page has three positions. **Panel** is the panel alone.

Workbench puts the panel and the editor together. **Editor** gives the editor the whole page and shows the FM-1's screen in a small card beside it, headed *On the FM-1*, so you can see what the panel shows while you work. Power the simulator on first; until then the editor says so.

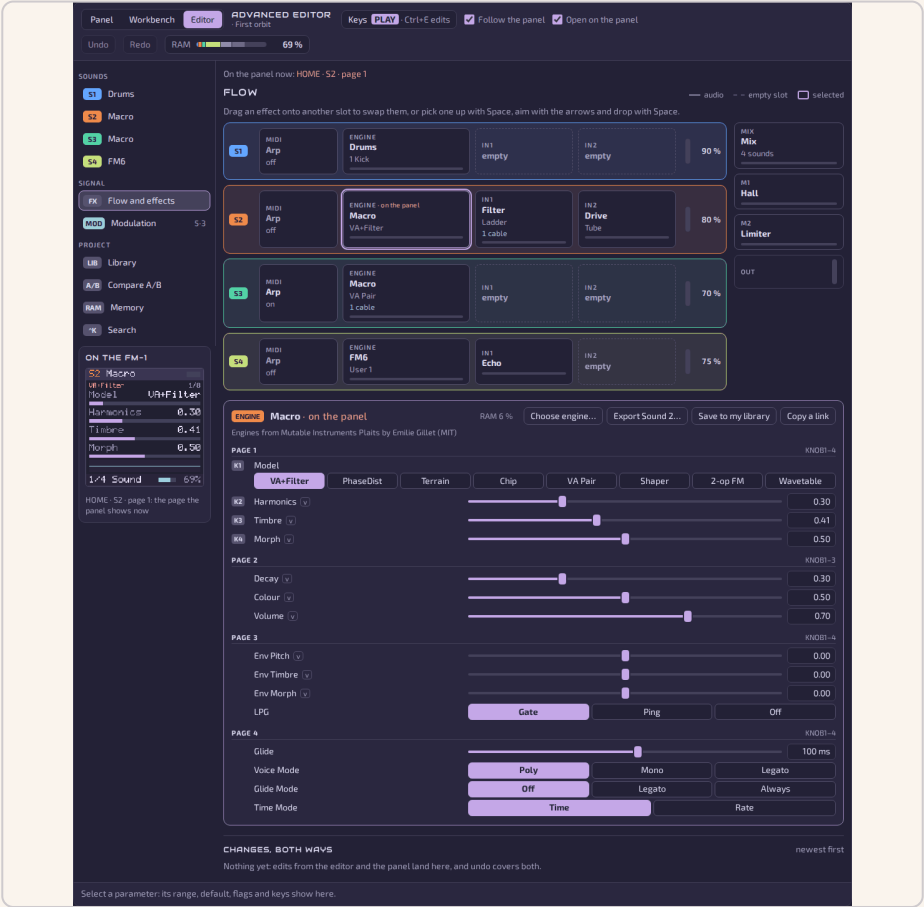


Figure 15.1 The editor on the example project First orbit: the outline on the left, the Flow in the middle with four sounds into the mix and the two master effects, and the FM-1's screen in its card.

Along the top of the editor:

- **Keys PLAY** or **Keys EDIT** says what the computer keyboard does. In **PLAY** the keys play the instrument, as they do on the panel. Click in the editor, or press **Ctrl+E** (**⌘+E** on a Mac), and it reads **EDIT**: the keys edit and play nothing, so a stray letter never changes a view while you mean to play. **Esc** gives the keys back.

- **Follow the panel** moves the editor to whatever the panel shows. **Open on the panel** does the reverse: choosing a block or a parameter in the editor opens its page on the panel.
- **Undo** and **Redo** cover what you do in the editor and what you turn on the panel, alike.
- **RAM** is how much of the FM-1's memory the project uses, as a percentage. Click it for the share of each part. Nothing the editor lets you do can go past 100 %.

15.2 The outline, the Flow and the sounds

STATUS:  In the simulator

The outline on the left lists the four sounds, **Flow and effects**, **Modulation**, and under *Project* the **Library**, **Compare A/B**, **Memory** and **Search**. Click one to open it.

Flow and effects draws the signal path: each sound's engine into its two inserts, the four sounds into the mix, and on into the two master effects. Every block shows its name, a level bar and, when cables end on it, how many (*2 cables*, or *1 cable*, *1 refused* when one of them does not run). Click a block and its values open below it. A long press on a block, a right click or the keyboard's menu key opens a small menu for it: its page, another engine or effect, *Swap with....*, *Export....*, *Save to my library* and *Copy a link*.

A sound opens as a page of sliders grouped by the panel's own pages. A slider moves with the mouse or the arrow keys. **Shift** moves it ten steps, **Alt** a tenth of a step, **Home** and **End** go to the ends, and **Enter** lets you type a value. **D** puts a value back to its default. A small *v* on a parameter means a cable can move it for each note on its own (see [Modulation](#)).

Where a cable moves a value, you see it on the slider as the screen shows it: the parameter's name turns the modulation colour, a chip beside it names the cable's source (click it to open the cable), a bracket shows how far the cables can move the value either side of where you set it, and a white tick shows where it is now. A per-voice cable draws one tick for each sounding note. The slider says the same in words to a screen reader: "Cutoff, 420 hertz, modulated by 1 LFO Out, plus 35 percent". **C** on a parameter that takes a cable makes one into it, from the first module's output, and opens it; on one that does not, the editor says so in the instrument's words.

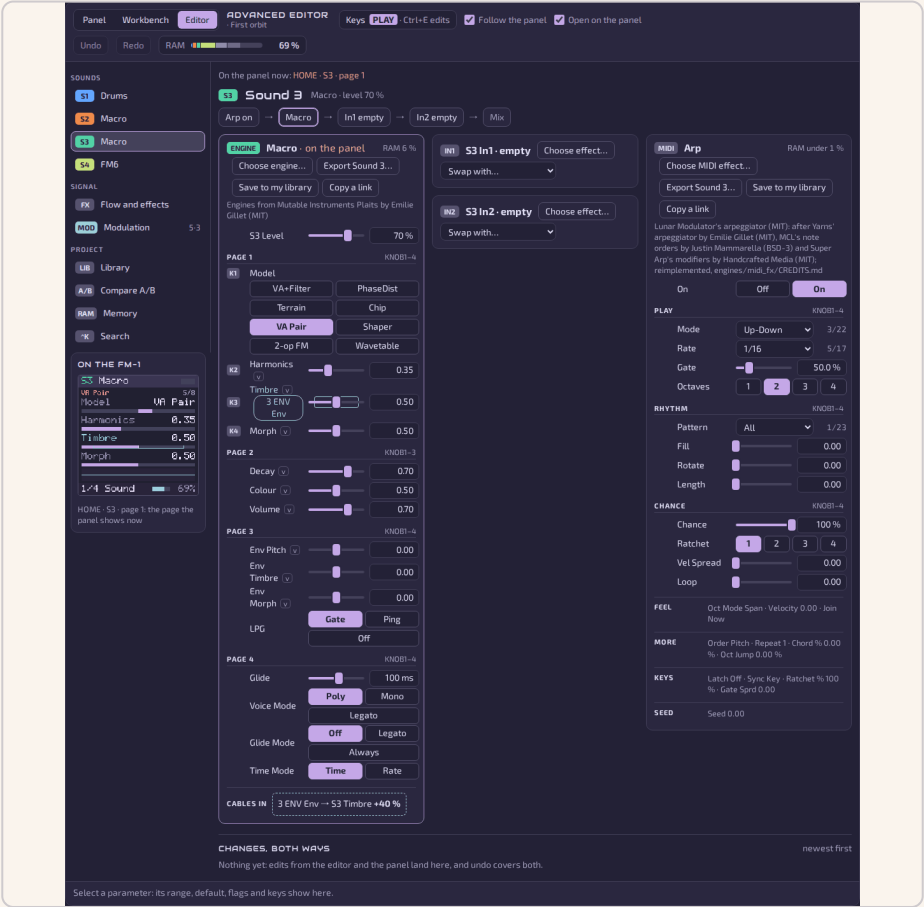


Figure 15.2 Sound 3 in the editor: its engine, two inserts and the cables into it, with a slider for every value.

15.3 Choosing and moving effects

STATUS: • In the simulator

Choose engine..., Choose effect..., Choose MIDI effect... and Choose module... list every choice with the memory the project would use with it, as a percentage. A choice that does not fit says why, in the same words the panel uses, and cannot be picked.

To move an effect, drag it onto another effect slot, of any sound or the master. The two swap places, with their cables. Before you let go, the slot under it says whether the swap fits and what the memory would be. With the keyboard, Space picks the effect up, the arrow keys choose where, Space drops it and Esc cancels; *Swap with...* in an effect's box does the same from a list. Modules in the rack move the same way.

Effects show what goes in and what comes out. Comp, the output limiter and Squash also show how much they are turning the sound down, as a thin bar and *GR 4.8 dB* beside the *Out* meter, while they are doing it.

15.4 Modulation: the table

STATUS: ● In the simulator

Modulation shows the rack and its cables. The default view is the table, the one to use with a keyboard or a screen reader. The rack is eight cards, each with its output drawn live. Under it, the matrix lists every cable: where it comes from, its **VIA**, where it goes, its amount, its live value, and, if it does not run, why.

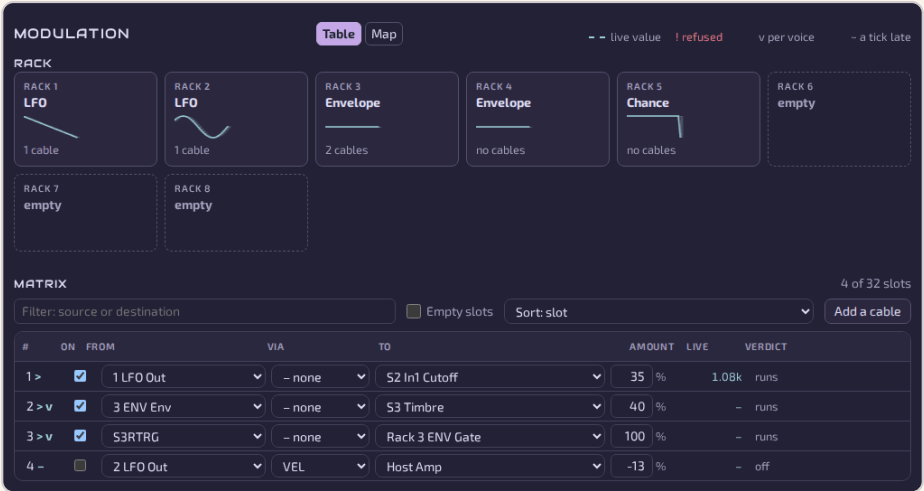


Figure 15.3 The modulation table: the rack as eight cards with live traces, and the matrix of cables below them.

A cable's number opens all of its settings: on or off, source, VIA, destination, amount, offset, polarity, curve and per voice. Remove deletes it. *Add a cable* puts a new one in the first free slot. A mark by the number says more at a glance, in the instrument's own characters: > runs, v is per voice, ~ runs a tick late, ! does not run, and – is switched off. A cable that does not run is kept as you wrote it, with the reason beside it, and runs once the reason is put right; where the reason has a remedy, a button offers it (*Make it global* for a per-voice cable aimed at an effect), and the instrument judges the result. A cable marked ~ closes a loop: the cables run in rack order, so a cable that goes back up the rack reads its source from the tick before. Its settings say which modules the loop passes through. Curves are drawn, each on its button and the chosen one larger, and a per-voice cable shows each sounding note's own value.

The amount is a percentage of the destination's range. Type a number and press Enter, or use ↑ and ↓ (Shift for ten).

15.5 Modulation: the Map

STATUS:  In the simulator

Map, at the top right of Modulation, draws the same cables as a patch bay. It is a second view of the same thirty-two slots: change a cable in the table and the Map follows, and the other way round.



Figure 15.4 The Map with the envelope in rack position 3 in focus: its two cables are bright with their amounts, and the other cables are dimmed.

The Map has three columns. **Sources** on the left are everything a cable can start from: the notes and the clock, the sequencer's lanes, and each sound's own notes. Sources in use are bright; the groups you are not using are folded under a line such as *Sound 1's notes · 5*. The **Rack** in the middle shows its modules with their inputs on the left and their outputs on the right, each output with its live value. **Destinations** on the right are the sounds, their effects, the master and the host, listing the parameters that already have a cable and, behind *13 more*, the rest.

A cable runs from a round or square **jack** on an output to one on an input. Round jacks carry a continuous signal. Square ones carry gates and triggers. Cables are drawn in the lanes between the columns and in a band above the rack; they never cross a module or a label.

The cable	Means
Dashed line	A modulation signal. The jacks at its ends are lit
Dotted line	A gate or trigger
Dashed line over a pale band, a v on its pill	A per-voice cable: each sounding note has its own value
Line in the refusal colour, ending in a cross	A cable that does not run. Its pill has a !
Any line, a ~ on its pill	A cable that runs a tick late. A <i>tick late</i> above the Map brings these forward
Thicker line in the selection colour	The cable chosen in the table below, or the one you clicked

A **pill** beside a cable says its amount, and while the cable has something to say, its live value. To keep the Map readable, pills appear only for the selected cable, for the cables in focus, and for the refused ones.

15.5.1 Focus

Thirty-two cables are too many to read at once. Click a module’s name, a destination’s heading or a source’s name and the Map goes into focus: that block’s cables stay bright and carry their amounts; every other cable dims and loses its label. F does the same for the jack or block that has the keys, and again to leave. Esc, or *All* above the Map, shows everything again. *Refused* brings forward the cables that do not run, and *A tick late* the ones that close a loop.

15.5.2 Making a cable

Drag from an output jack to an input jack. While the cable is in your hand every destination opens, so any parameter can be a target. Over an input, the Map asks the instrument what would happen and says so in the line above the Map: *Runs*, or why not, in the refusal’s own words. Let go to drop the cable. It goes into the first free slot at 25 % and is selected, so its settings are open under the Map; one **Undo** takes it away.

Without a mouse: press `Enter` on an output jack, move between inputs with the arrow keys, and press `Enter` again to drop the cable. `Esc` puts it back. There is one tab stop in each column; the arrow keys walk within it, and every jack has a name. Screen readers should use the table, which lists every cable in words.

15.5.3 Room

The Map needs a window about 620 pixels wide for the editor. Below that, as on a phone, the switch is not shown and Modulation stays a table, with each cable as a small card.

15.6 Files, the library and links

STATUS:  In the simulator

Every block takes files. Drop a `.lunar` sound on a sound, an effects file on a sound's effects or on a master slot, a mod rack on the rack, or a whole project anywhere.

Before anything loads, the editor says what the file would do, what it would replace and what it would bring, and how much memory the project would use, or why it does not fit. **Load** goes ahead; nothing changes until you choose it.

Each box has *Export...*, which saves that block as a file, *Save to my library* and *Copy a link*, a link that opens that block's file in someone else's browser. In Chromium you can also drag a sound's tag in the Flow (S2) to the desktop, and it becomes the sound's file. The **Library** lists what you have saved in this browser, with Recent and the examples; load a project from it, or drag a saved sound or effects onto the block it fits, and the block says whether it fits while you hold it there.

Search (`Ctrl+K`, `⌘+K` on a Mac) finds a sound, an effect, a parameter by name (`s2 cutoff`), a cable or a command. Arrows choose, `Enter` goes there, `Esc` closes it. A few signs narrow it: `>cutoff` is the cables into a Cutoff, `lfo>` the cables out of an LFO, `!` the cables that do not run, `~` the ones a tick late, `v` the per-voice ones, `s2` what belongs to Sound 2, and a unit such as `hz` the parameters in hertz. They combine (`>cutoff!`).

A link can open the editor at a place: add `?view=edit&sel=s1` or `?view=edit&sel=s3.in1:Cutoff` to the simulator's address.

Undo goes back one change at a time. It covers a slider, a choice of engine or effect, a swap, a module moved, a cable made, edited or removed, and a file loaded. A change from the panel's knobs is one step too.

15.8 Keys, the keyboard and screen readers

STATUS:  • In the simulator

Everything in the editor can be done from the keyboard. Tab moves through the controls, each with a name and a two-pixel ring around it. Sliders say their value in words (“Cutoff, 420 hertz”). The editor announces your changes and any refusal, at most once a second, and never a live value.

Colour is never the only signal: the marks $>$, v , $\sim$, $!$ and $-$ come with words, cable styles differ by line as well as colour, and a memory share that does not fit is spelt out as “over”. In forced-colours mode the cables use the system's colours and keep their dashes. With reduced motion set, nothing flashes or moves apart from the meters, which are information.

15.9 Phones and tablets

STATUS:  • In the simulator

On a tablet the outline becomes a narrow rail and the Workbench stacks the panel above the editor. On a phone the switch has two tabs, **Panel** and **Edit**. Edit shows the outline as a row of tabs along the top, a small screen, and the modulation matrix as a list of cables with every setting named. *Add a cable* asks in three steps, with a sheet at the bottom of the screen: where it comes from, where it goes, and how much, with the instrument's verdict before you make it. A long press on a block opens its menu. The Map is for wider windows.

15.10 Browsers

STATUS:  • In the simulator

The editor is tested in Chromium, Firefox and WebKit (the engine of Safari) on a desktop. It needs a browser with audio worklets and workers; the simulator's own requirements are in [chapter 2](#). Its views are checked with axe-core's rules at desktop, tablet and phone widths. It has not been tried on a phone or a tablet itself, only at their window sizes, and not with a screen reader itself, only with the accessibility tree a browser builds for one.

Glossary

Base value

The value a locked parameter returns to on steps that have notes but no lock of their own. Turning a knob with no step held sets it ([chapter 7](#)).

Block

The small piece of sound the firmware computes at a time: 64 samples, 1.45 ms at 44,118 Hz.

BPM

Beats, here quarter notes, per minute: the sequencer's tempo, from 20 to 300.

Cable

A connection in the modulation matrix, from a source such as an LFO to a parameter or a module's input, with an amount ([chapter 8](#)).

Capture

The sequencer's record-after: it keeps the last phrase you played while not recording, so you can turn it into a clip afterwards ([chapter 7](#)).

Choke group

Drum pads that cut each other short: a hit stops every other pad of its group that is still ringing, as a closed hi-hat stops an open one ([chapter 5](#)).

Clip

A loop of notes, locks and conditions on one track, from 1 to 256 steps long. Each track has eight clip slots and plays one clip at a time.

Condition

A rule, written A:B, that plays a step only on the A-th pass of every B passes of its clip.

Count-in

The bar of clicks the sequencer plays before it records, when you start recording with the sequencer stopped.

Current sound

The one of the four sounds that the keys and MIDI play and the sound's page edits;

SEL with **PRESETS** chooses it ([chapter 5](#)).

Desktop tools

`fm1-render` and `fm1-seq`, programs that run Lunar Modulator's engines, effects and sequencer on a computer and write the result to files.

Drum track

A sequencer track whose clips are not transposed, so each note keeps its drum, and whose single drum notes can be muted or soloed.

Encoder

A knob that turns without end, in steps you can feel. Seven of the FM-1's knobs are encoders; **MASTER** is not.

Engine

The part of the firmware that makes the notes: Macro, Shapes, Six-Op FM and the others in [chapter 5](#).

Envelope

A modulation module that rises and falls with each note: attack, decay, sustain and release ([chapter 8](#)).

Event log

A file in which the desktop tools record everything the sequencer does, one line per note, lock or clock message.

Firmware

The software built into an instrument that makes it work.

First take

A recording into an empty clip. It starts on a bar, and the clip grows a bar at a time while you record.

Flash

The memory that keeps the firmware and saved data when the power is off.

FM synthesis

Making sound by letting oscillators (operators) change each other's frequency, which gives bright, bell-like and metallic tones.

Focused track

The sequencer track you work on: steps, recording, Capture and the keys go to it ([chapter 7](#)).

Glide

A slide in pitch from one note to the next, also called portamento: from the note you hold (Glide Mode Legato) or from the last note you played (Always), over a set time or at a set speed per octave (Time Mode) ([chapter 4](#)).

Identity

The model name and number an FM-1 reports about its firmware, such as `FM-1_015`. More reliable than a file name ([chapter 11](#)).

Insert

An effect slot of one sound's own, before the sounds are mixed. Each sound has two, In1 and In2 ([chapter 6](#)).

Lane

One of the eight places a track keeps the locks of one parameter. A track can lock up to eight parameters at once.

Legato

Playing a note before letting go of the previous one. The Legato voice mode then moves the one voice to the new note without starting its sound again ([chapter 4](#)).

LFO

Low-frequency oscillator: a modulation module that moves a parameter up and down in a repeating shape ([chapter 8](#)).

Limiter

The last stage of the sound path, which keeps the output below full scale.

Lock

See *parameter lock*.

Loop window

The part of a clip that plays, starting at the beginning of a bar. Notes outside it are kept, silent.

Low-pass gate

A combined filter and amplifier that closes as a note dies away, so the sound gets quieter and darker together, as acoustic instruments do.

Master effects

The two effect slots, M1 and M2, that every sound goes through after the mix.

Matrix

The list of the 32 modulation cables, which **EDIT** shows.

Memory meter

The bar and percentage at the right of the screen's bottom bar: how much of the FM-1's free memory the sounds, effects, sequencer and modulation would take ([chapter 6](#)).

Metronome

The sequencer's click on every beat, with an accent on the first beat of each bar.

MIDI

The standard way instruments and computers exchange notes, controller movements and clock.

MIDI clock

Timing pulses, 24 to a quarter note, with Start and Stop messages, that keep instruments playing in time with each other.

Module

One of up to eight units in the modulation rack: an LFO, an envelope, a random source or another kind ([chapter 8](#)).

movy1

The plain text format in which the sequencer saves a set. It comes from Movy, and both read each other's files.

Nudge

Moving a note a little earlier or later than its step, in ticks, up to a step either way.

One rule

Nothing is installed on, or written to, an FM-1 until a complete copy of its memory has been read out and written back, byte for byte, on that unit ([chapter 1](#)).

Operator

In FM synthesis, one oscillator with its own envelope. Six-Op FM and FM6 have six.

Overdub

Recording into a clip that already has notes, adding to them.

Parameter

One adjustable setting of an engine or effect, such as Timbre or Decay.

Parameter lock

A value for one parameter stored on one step of a clip, which the parameter takes when that step plays.

Pass

One time round a clip's loop. Conditions count passes.

Playhead

The step the sequencer is playing on a track.

Potentiometer

A knob with end stops whose position is its value, such as **MASTER**.

Probability

The chance that a step plays each time it comes round: on the step page, from 100 % down to 10 %.

Quantise

Pulling recorded notes towards their steps. Lunar Modulator's is non-destructive: notes keep their played timing.

Rack

The eight positions that hold the modulation modules ([chapter 8](#)).

Recovery dongle

A small device between a computer and the FM-1's USB-C socket that starts the processor's recovery mode ([chapter 11](#)).

Recovery mode

A mode built into the FM-1 processor's read-only memory, in which a computer can read and write the flash whatever it holds.

Role

In this manual, a sequencer function that still has to be given a key, drawn with a dashed outline, such as **LOOP**.

Routing

Where a sequencer track sends its notes: one of the four sounds, or a USB-MIDI channel.

Sample rate

How many samples of sound the firmware computes each second. Lunar Modulator's is 44,118 Hz.

Scene

One clip slot across all tracks, launched together.

SEQ mode

The sequencer's view, which **SEQ** opens: the 16 white keys are the steps of a bar and the black keys are sequencer controls ([chapter 7](#)).

Session view

The planned sequencer screen that shows every track and clip slot at once.

Set

Everything the sequencer holds: tempo, swing, song, tracks and their clips.

SHIFT

The sequencer's second function key: **SEL**, everywhere but in FX mode. Held, it changes what the keys, knobs and buttons do.

Simulator

The browser version of Lunar Modulator: the firmware's engines, effects, sequencer and modulation behind a drawing of the FM-1's panel.

Song

A list of scenes played in order.

Step

One sixteenth note of a bar in the sequencer; 16 steps make a bar.

Step page

The screens that show a held step's own settings: velocity, length, probability, condition and invert.

Swing

Delaying every second sixteenth to give a pattern a shuffle.

System exclusive

MIDI messages that carry data of a manufacturer's or project's own, such as a whole sequencer set.

Tick

The sequencer's smallest step of time: 1/24 of a step, or 96 to a quarter note.

Track

One line of the sequencer, playing one sound: one of the four sounds or a MIDI channel.

Transpose

Moving notes up or down by semitones without changing which keys you play.

USB-MIDI

MIDI carried over a USB cable, as the FM-1 exchanges it with a computer.

Velocity

How hard a note is played, from 1 to 127.

Voice

One sounding note. An engine's voice count is how many notes it can play at once.

Voice Mode

Whether an engine plays a voice per note (Poly) or one voice for every note (Mono, Legato) ([chapter 4](#)).

Index of controls

Every control on the FM-1, with the sections of this manual that describe it. The index is generated from the text each time the manual is built, so it always matches the edition you are reading.

- **Controls are listed by kind:** the encoders, the potentiometer, the buttons, the labels printed under the black keys, and the connectors. Names are written as the panel prints them.
- **The first entry** under each control, in bold, is its place in the panel tour ([chapter 3](#)), which shows where it sits on the instrument.
- **Sequencer functions without a key yet**, such as `LOOP`, are listed last, with a dashed outline. Which button or combination carries each of them is still to be decided ([chapter 7](#)).
- **Keys** are not listed one by one. [Chapter 3](#) describes the keyboard, and [chapter 7](#) what the keys do in the sequencer.

Encoders

SELECT

3.1 Knobs (page 24); 1.5 About this manual (page 10); 2.1.4 Playing from the computer keyboard (page 14); 2.2 A first session (page 16); 3 Panel tour (page 23); 3.2 Buttons (page 25); 3.4.6 The global page (page 32); 4.8.1 The ARP pages (page 44); 5 Sound engines (page 49); 6.1 The effect chain (page 105); 7.2.3 The step pages (page 158); 7.3.1 To lock a parameter on a step (page 161); 7.6.2 Length and the loop window (page 166); 7.7.4 The song page (page 170); 7.9.3 Choosing a tempo (page 175); 7.12 The Set, Clip and Track pages (page 179); 7.14 Controls at a glance (page 180); 8.3 The rack (page 194); 8.4 The matrix (page 195); 8.6 Chains (page 199); 10.1.1 To open the global page (page 210)

PRESETS

3.1 Knobs (page 24); 2.1.2 Turning it on (page 12); 2.1.4 Playing from the computer keyboard (page 14); 2.1.6 The controls under the panel (page 15); 2.2 A first session (page 16); 3 Panel tour (page 23); 3.1.1 How far one step goes (page 25); 3.2 Buttons (page 25); 3.4.7 Lists (page 32); 5 Sound engines (page 49); 5.1

Choosing an engine (page 51); 5.2 Four sounds at once (page 52); 6.1.2 Memory (page 108); 12.1.2 Playing (page 225); Glossary (page 257)

ALGORITHM

3.1 Knobs (page 24); 2.1.4 Playing from the computer keyboard (page 14); 2.2 A first session (page 16); 3 Panel tour (page 23); 3.1.1 How far one step goes (page 25); 3.2 Buttons (page 25); 3.3 Keys (page 28); 3.4.7 Lists (page 32); 3.4.8 Messages (page 33); 4.4 Octave and transpose (page 40); 4.8.1 The ARP pages (page 44); 4.8.3 Acid Gen (page 47); 5 Sound engines (page 49); 5.2 Four sounds at once (page 52); 5.3 Macro (page 54); 5.5 Six-Op FM (page 63); 5.6 FM6 (page 67); 5.6.1 Loading voices from SysEx (page 68); 5.7 Shapes (page 71); 5.8 Sophie (page 77); 5.9 Drums (page 80); 5.10 Acid Bass (page 83); 5.11 Comet Kit (page 86); 5.12 Crater Kit (page 90); 5.13.1 Drawbar (page 94); 5.13.2 Trio (page 96); 5.13.3 Phase Bend (page 99); 6.1 The effect chain (page 105); 6.1.2 Memory (page 108); 6.5 PSX Verb (page 112); 8.3 The rack (page 194); 8.4 The matrix (page 195); 8.5 Per voice (page 197); 12.1.2 Playing (page 225)

Knob1

3.1 Knobs (page 24); 1.5 About this manual (page 10); 2.1.4 Playing from the computer keyboard (page 14); 2.2 A first session (page 16); 3 Panel tour (page 23); 3.2 Buttons (page 25); 3.4.2 The sound's page (page 29); 3.4.6 The global page (page 32); 4.8.1 The ARP pages (page 44); 4.8.3 Acid Gen (page 47); 5.3 Macro (page 54); 5.8 Sophie (page 77); 5.9 Drums (page 80); 5.11 Comet Kit (page 86); 5.12 Crater Kit (page 90); 6.1 The effect chain (page 105); 6.1.1 The Mix page (page 108); 6.5 PSX Verb (page 112); 7.1.2 What the screen shows (page 156); 7.2.3 The step pages (page 158); 7.7.4 The song page (page 170); 7.9.3 Choosing a tempo (page 175); 7.12 The Set, Clip and Track pages (page 179); 8.2 The gesture: making a cable with a knob (page 194); 8.3 The rack (page 194); 8.4 The matrix (page 195); 8.7 Recipes (page 200); 10.1.2 What it shows (page 210); 10.1.3 The project key (page 211)

Knob2

3.1 Knobs (page 24); 3.4.6 The global page (page 32); 3.4.7 Lists (page 32); 4.8.1 The ARP pages (page 44); 4.8.3 Acid Gen (page 47); 7.2.3 The step pages (page 158); 7.7.4 The song page (page 170); 7.12 The Set, Clip and Track pages (page 179); 8.4 The matrix (page 195); 8.7 Recipes (page 200); 10.1.2 What it shows (page 210); 10.1.3 The project key (page 211)

KNOB3

3.1 Knobs (page 24); 2.2 A first session (page 16); 4.8.1 The ARP pages (page 44); 4.8.3 Acid Gen (page 47); 7.2.3 The step pages (page 158); 7.7.4 The song page (page 170); 7.12 The Set, Clip and Track pages (page 179); 8.4 The matrix (page 195); 8.5 Per voice (page 197); 8.7 Recipes (page 200); 10.1.2 What it shows (page 210)

KNOB4

3.1 Knobs (page 24); 2.1.4 Playing from the computer keyboard (page 14); 3 Panel tour (page 23); 3.2 Buttons (page 25); 3.4.2 The sound's page (page 29); 4.8.1 The ARP pages (page 44); 4.8.3 Acid Gen (page 47); 6.1 The effect chain (page 105); 6.1.1 The Mix page (page 108); 7.1.2 What the screen shows (page 156); 7.2.3 The step pages (page 158); 7.7.4 The song page (page 170); 7.12 The Set, Clip and Track pages (page 179); 8.2 The gesture: making a cable with a knob (page 194); 8.3 The rack (page 194); 8.4 The matrix (page 195); 8.5 Per voice (page 197); 8.7 Recipes (page 200); 10.1.2 What it shows (page 210)

Potentiometer

MASTER

3.1 Knobs (page 24); 1.4 Safety and care (page 9); 2.1.2 Turning it on (page 12); 2.1.4 Playing from the computer keyboard (page 14); 2.1.5 Playing from a MIDI keyboard (page 15); 3 Panel tour (page 23); 3.1.1 How far one step goes (page 25); 3.1.2 Turning knobs in the simulator (page 25); 3.1.3 On the FM-1 (page 25); 3.4.1 The top and bottom bars (page 29); 3.4.8 Messages (page 33); 4.7 Playing from MIDI (page 42); 5.1 Choosing an engine (page 51); 6 Effects (page 103); 6.26 The limiter (page 152); 9.1.2 What the simulator receives (page 205); 12.1.1 Sound and starting up (page 224); 13.1 The instrument (page 231); 13.2 Lunar Modulator (page 232); Glossary (page 257)

Buttons

OCT-

3.2 Buttons (page 25); 2.1.4 Playing from the computer keyboard (page 14); 3 Panel tour (page 23); 3.1 Knobs (page 24); 3.2.1 Button lights (page 27); 3.3 Keys (page 28); 3.4.8 Messages (page 33); 4.4 Octave and transpose (page 40); 7.2.6 To

change velocity or pitch (page 160); 7.14 Controls at a glance (page 180); 12.1.2 Playing (page 225)

OCT+

3.2 Buttons (page 25); 2.1.4 Playing from the computer keyboard (page 14); 3 Panel tour (page 23); 3.1 Knobs (page 24); 3.2.1 Button lights (page 27); 3.3 Keys (page 28); 3.4.8 Messages (page 33); 4.4 Octave and transpose (page 40); 7.2.6 To change velocity or pitch (page 160); 7.14 Controls at a glance (page 180); 12.1.2 Playing (page 225)

FX

3.2 Buttons (page 25); 2.2 A first session (page 16); 3.2.1 Button lights (page 27); 3.4.3 The effects page (page 30); 6.1 The effect chain (page 105); 7.1.1 SEQ mode and the keys (page 155); 8.3 The rack (page 194)

SEL

3.2 Buttons (page 25); 2.1.4 Playing from the computer keyboard (page 14); 2.2 A first session (page 16); 3 Panel tour (page 23); 3.1 Knobs (page 24); 3.2.1 Button lights (page 27); 3.2.2 Functions still to be given a key (page 27); 3.3 Keys (page 28); 3.4.3 The effects page (page 30); 3.4.4 What the colours mean (page 31); 3.4.7 Lists (page 32); 4.2 Glide and voice modes (page 37); 4.8 Arpeggiator (page 43); 5.2 Four sounds at once (page 52); 6.1 The effect chain (page 105); 7 Sequencer (page 153); 7.1.1 SEQ mode and the keys (page 155); 7.2.2 To add a pitch to a step (page 158); 7.2.5 To nudge notes (page 159); 7.2.6 To change velocity or pitch (page 160); 7.2.7 Full velocity (page 160); 7.2.8 To clear steps (page 160); 7.3.6 To clear locks (page 162); 7.5.2 Quantise (page 165); 7.6.1 The Clip page (page 166); 7.6.4 Double Loop (page 167); 7.6.7 Undo (page 168); 7.7.3 Song (page 170); 7.7.4 The song page (page 170); 7.8.5 Metronome (page 173); 7.8.6 Step recording (page 174); 7.9 Capture (page 174); 7.9.2 To capture while stopped (page 175); 7.9.4 To capture while playing (page 176); 7.11.1 Play and stop (page 177); 7.11.2 Tempo (page 178); 7.12 The Set, Clip and Track pages (page 179); 7.14 Controls at a glance (page 180); 8.3 The rack (page 194); 8.6 Chains (page 199); 10.1.4 Settings (page 212); 12.1.2 Playing (page 225); Glossary (page 257)

ENV

3.2 Buttons (page 25); 3.1 Knobs (page 24); 3.2.1 Button lights (page 27); 3.4.5 The sequencer, modulation and arpeggiator pages (page 32); 8.2 The gesture:

making a cable with a knob (page 194); 8.3 The rack (page 194); 8.5 Per voice (page 197)

LFO

3.2 Buttons (page 25); 3.1 Knobs (page 24); 3.2.1 Button lights (page 27); 3.4.5 The sequencer, modulation and arpeggiator pages (page 32); 8.2 The gesture: making a cable with a knob (page 194); 8.3 The rack (page 194)

EDIT

3.2 Buttons (page 25); 3.2.1 Button lights (page 27); 3.4.5 The sequencer, modulation and arpeggiator pages (page 32); 8.4 The matrix (page 195); 8.5 Per voice (page 197); 8.6 Chains (page 199); 12.1.2 Playing (page 225); Glossary (page 257)

GLO

3.2 Buttons (page 25); 3.2.1 Button lights (page 27); 3.3 Keys (page 28); 3.4.6 The global page (page 32); 4.4 Octave and transpose (page 40); 7.1.1 SEQ mode and the keys (page 155); 8.3 The rack (page 194); 10.1.1 To open the global page (page 210)

HOME

3.2 Buttons (page 25); 2.2 A first session (page 16); 3.4.2 The sound's page (page 29); 6.1 The effect chain (page 105); 7.1.1 SEQ mode and the keys (page 155); 8.3 The rack (page 194); 10.1.1 To open the global page (page 210); 12.1.2 Playing (page 225)

SAVE

3.2 Buttons (page 25); 1.2 Features at a glance (page 8); 3 Panel tour (page 23); 3.4.8 Messages (page 33); 10.2.4 SAVE (page 214)

ARP

3.2 Buttons (page 25); 3.2.1 Button lights (page 27); 3.4.5 The sequencer, modulation and arpeggiator pages (page 32); 4.8 Arpeggiator (page 43); 4.8.2 With the sequencer (page 46); 4.8.3 Acid Gen (page 47)

SEQ

3.2 Buttons (page 25); 2.2 A first session (page 16); 3.2.1 Button lights (page 27); 3.3 Keys (page 28); 3.4.5 The sequencer, modulation and arpeggiator pages (page 32); 7.1.1 SEQ mode and the keys (page 155); 7.1.3 The key lights (page 157); 7.7.1 The session view (page 169); 7.7.4 The song page (page 170); 7.8.6 Step

recording (page 174); 7.10.1 To focus a track (page 176); 7.12 The Set, Clip and Track pages (page 179); 7.14 Controls at a glance (page 180); Glossary (page 257)

PLAY/STOP

3.2 Buttons (page 25); 1.5 About this manual (page 10); 2.1.2 Turning it on (page 12); 2.1.4 Playing from the computer keyboard (page 14); 3.2.1 Button lights (page 27); 4.8.2 With the sequencer (page 46); 7.1 How a pattern is organised (page 154); 7.1.1 SEQ mode and the keys (page 155); 7.7.3 Song (page 170); 7.7.4 The song page (page 170); 7.8 Recording (page 171); 7.8.1 To record (page 172); 7.11.1 Play and stop (page 177); 7.14 Controls at a glance (page 180)

REC

3.2 Buttons (page 25); 3.2.1 Button lights (page 27); 7.8 Recording (page 171); 7.8.1 To record (page 172); 7.8.2 First take and overdub (page 173); 7.8.6 Step recording (page 174); 7.9 Capture (page 174); 7.9.2 To capture while stopped (page 175); 7.9.4 To capture while playing (page 176); 7.10 Tracks and routing (page 176); 7.14 Controls at a glance (page 180); 12.1.2 Playing (page 225)

Labels under the black keys

OP1

3.3 Keys (page 28); 7 Sequencer (page 153); 7.1.1 SEQ mode and the keys (page 155); 7.1.3 The key lights (page 157); 7.2.1 To put notes on a step (page 158); 7.2.5 To nudge notes (page 159); 7.7.4 The song page (page 170); 7.8.6 Step recording (page 174); 7.14 Controls at a glance (page 180)

OP2

3.3 Keys (page 28); 7.1.1 SEQ mode and the keys (page 155); 7.7.2 To launch a scene (page 169); 7.7.4 The song page (page 170)

OP3

3.3 Keys (page 28); 7.1.1 SEQ mode and the keys (page 155); 7.1.3 The key lights (page 157); 7.2.1 To put notes on a step (page 158); 7.2.5 To nudge notes (page 159); 7.7.4 The song page (page 170); 7.8.6 Step recording (page 174); 7.14 Controls at a glance (page 180)

OP4

3.3 Keys (page 28); 7.1.1 SEQ mode and the keys (page 155); 7.6.5 To copy steps and clips (page 168); 7.7.1 The session view (page 169)

OP5

3.3 Keys (page 28); 7 Sequencer (page 153); 7.1.1 SEQ mode and the keys (page 155); 7.1.3 The key lights (page 157); 7.2.8 To clear steps (page 160); 7.3.6 To clear locks (page 162); 7.6.6 To delete a clip (page 168); 7.7.1 The session view (page 169); 7.7.4 The song page (page 170); 7.14 Controls at a glance (page 180)

OP6

3.3 Keys (page 28); 7.1.1 SEQ mode and the keys (page 155); 7.1.3 The key lights (page 157); 7.7.1 The session view (page 169); 7.10.2 To mute a track (page 176); 7.14 Controls at a glance (page 180)

PIT

3.3 Keys (page 28); 7.1.1 SEQ mode and the keys (page 155)

MONO

3.3 Keys (page 28); 4.2 Glide and voice modes (page 37); 7.1.1 SEQ mode and the keys (page 155); 7.1.3 The key lights (page 157); 7.10.1 To focus a track (page 176); 7.14 Controls at a glance (page 180)

POLY

3.3 Keys (page 28); 4.2 Glide and voice modes (page 37); 7.1.1 SEQ mode and the keys (page 155); 7.1.3 The key lights (page 157); 7.10.1 To focus a track (page 176); 7.14 Controls at a glance (page 180)

Connectors

POWER

3.5 Connections (page 34); 2.1.2 Turning it on (page 12); 10.2.4 SAVE (page 214); 11.3.1 How it connects (page 220)

USB

3.5 Connections (page 34)

MIDI IN

3.5 Connections (page 34); 4.7 Playing from MIDI (page 42); 5.2 Four sounds at once (page 52); 7.2.1 To put notes on a step (page 158); 7.2.2 To add a pitch to a step (page 158); 7.8.1 To record (page 172); 7.8.6 Step recording (page 174); 7.9.1 What Capture keeps (page 175); 9.4 On the FM-1 (page 209); 13.5 Still to be measured on the device (page 236)

OUT

3.5 Connections (page 34)

Sequencer functions without a button yet

These functions are planned for the sequencer, and which button or combination carries each one is still to be decided.

COPY

3.2.2 Functions still to be given a key (page 27); 7 Sequencer (page 153); 7.14 Controls at a glance (page 180)

LOOP

1.5 About this manual (page 10); 3.2.2 Functions still to be given a key (page 27); 7 Sequencer (page 153); 7.6.2 Length and the loop window (page 166); 7.14 Controls at a glance (page 180)

SESSION

3.2.2 Functions still to be given a key (page 27); 7.14 Controls at a glance (page 180)

UNDO

3.2.2 Functions still to be given a key (page 27); 7.1.1 SEQ mode and the keys (page 155); 7.6.7 Undo (page 168); 7.14 Controls at a glance (page 180)