Bauer "Sigma-6" MIDI Synthesizer

Design and Operation

Patch Parameter Matrix

OSC1 FREQ. MULT.	**OSC2** FREQ. MULT.	**OSC3** FREQ. MULT.	**OSC4** FREQ. MULT.	**OSC5** FREQ. MULT.	**OSC6** FREQ. MULT.
MIXER LEVEL	MIXER LEVEL	MIXER LEVEL	MIXER LEVEL	MIXER LEVEL	MIXER LEVEL
DETUNE	DETUNE	DETUNE	DETUNE	DETUNE	DETUNE
MODULATION SOURCE	MODULATION SOURCE	MODULATION SOURCE	MODULATION SOURCE	MODULATION SOURCE	MODULATION SOURCE
CONTOUR START LEVEL	CONTOUR DELAY TIME	CONTOUR RAMP TIME	CONTOUR HOLD LEVEL	CONTOUR RESET TIME	RAMP VELOCITY*
AMPLD ENV ATTACK TIME	AMPLD ENV HOLD TIME	AMPLD ENV DECAY TIME	AMPLD ENV SUSTAIN LVL	AMPLD ENV RELEASE TIME	ATTACK VELOCITY^
LFO FREQUENCY	LFO RAMP TIME	LFO AM DEPTH	LFO FM DEPTH	MIXER O/P GAIN	O/P AMPLD CONTROL #

* Contour ramp time varies inversely with key velocity in proportion to this setting

^ Envelope attack time varies inversely with key velocity in proportion to this setting

Oscillator FREQUENCY MULTIPLIER values*

0	1	2	3	4	5	6	7	8	9	10	11
0.5	1	1.333	1.50	2	3	4	5	6	7	8	9

* The "fundamental" frequency (x1) is determined by the MIDI note number

Oscillator Amplitude Modulation Source

0	1	2	3	4	5	6	7
None	CONTOUR+	CONTOUR−	AMP. ENV	MOD'N*	EXPRN+*	EXPRN−*	LFO

* MOD'N = MIDI CC01 | EXPRN = MIDI CC-2, CC-7, or CC-11 (config. option)

Mixer Output Gain

0	1	2	3	4	5	6	7	8	9
0.5	0.7	1	1.2	1.5	2	2.5	3.3	5	10

Output Amplitude Control Source

0	1	2	3
CONST (1)	CONST (0.5)	ENV * VELO	EXPRN*

* EXPRN = MIDI CC-2, CC-7, or CC-11 (config. option)

Patch parameter can be overridden by a global configuration parameter, to allow selection between amplitude envelope or expression (CC), without the need to adjust the patch parameter in each preset selected.

Overview

The “Sigma-6” is a MIDI-controlled digital monophonic sound synthesizer implemented entirely in software using a 32-bit micro-controller (without hardware floating point math). The synth can be played with any type of MIDI controller, for example a MIDI keyboard, wind controller (EWI) or MIDI sequencer.

Tone Generation

The synth model comprises 6 identical wave-table oscillators feeding into a mixer. Each oscillator generates a pure sinusoidal wave-form. The frequency of each oscillator is determined by the MIDI note number (from Note-On messages) multiplied by an “Oscillator Frequency Multiplier” factor (patch parameter). This parameter is settable to one of 12 fixed values, as shown in the table.

An additive synthesis technique is applied to generate a desired sound timbre. The Sigma-6 synth engine provides 6 “partials” each settable to one of 12 frequencies relative to the fundamental. Moreover, each oscillator may be de-tuned independently. Although similar in concept to the Hammond “draw-bar” organ tone generator, an advantage of the Sigma-6 design is that it allows amplitude modulation of each oscillator independently, by a choice of modulation sources including MIDI modulation or expression CC messages, envelope generators (“contour” or ADSR), or a low-frequency oscillator (LFO).

A problem which has plagued other simple digital synthesizer designs is aliasing of high-order audio frequency partials with the sampling frequency. The Sigma-6 firmware avoids this problem by calculating the frequency of each oscillator whenever a note is initiated and when its frequency is modified. If the frequency of any oscillator is higher than half the sampling rate (*aka* “Nyquist rate”), then that oscillator is muted. This process guarantees that the audio output signal will be devoid of aliasing artefacts.

User Interface

The front-panel user interface comprises a graphic LCD panel, six push-buttons and six potentiometers feeding into ADC inputs on the micro-controller. The synth enclosure may be made more compact by putting the 6 control pots in a separate removable plug-in module. The pot module is needed only for patch programming – the synth can function without it.

The control pots allow adjustment of six patch parameters at a time. Which group of six parameters out of a total of 42 is determined by the row selected in the “Patch Parameter Matrix”. (See table on previous page.) The “active” group is selected by a push-button scrolling through the available groups. The six parameters in the active group (table row) are displayed on the LCD screen.

Patch parameters retain their stored (preset) values until a control pot associated with a particular parameter is moved. Then, that parameter value would be changed in accordance with the pot setting.

Instrument Presets

The micro-controller provides persistent storage for a collection of “instrument presets”, also known as “patch programs”. Each preset is an array of 42 parameters defining a particular patch. The user interface provides a facility to save the “active” patch in non-volatile memory for later recall. Another function is provided to load one of many predefined presets (stored in flash memory) which then becomes the “active” patch. Each stored preset has an ID number and a short name associated with it.

A stored preset may also be selected by a MIDI “Program Change” message.

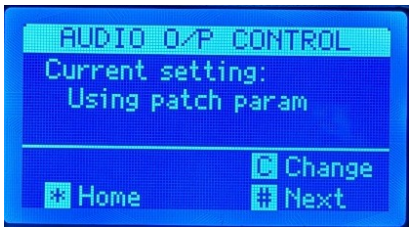
Configuration Options

The synth maintains a bunch of configuration options and control parameters which are independent of the selected preset. Examples: MIDI channel and message types recognised, control change number for “expression”, vibrato control mode (auto, CC-1, CC-85), pitch bend mode, bend range, reverb level, etc.

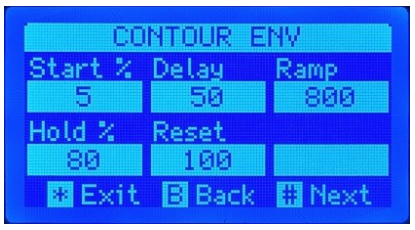
‘Home’ screen

‘Patch’ screens

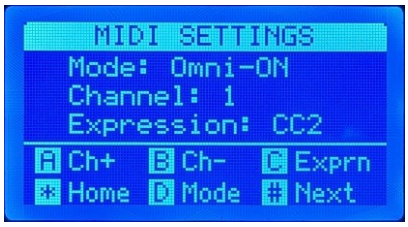
‘Config’ screens



‘Preset’ screens



‘Util’ & ‘Save’ screens



Audio Output Amplitude Control

The Sigma-6 provides a choice of methods to control the overall audio output level (loudness). The choice depends on the type of instrument selected, which usually falls into one of two categories:

1. A percussive type of instrument such as a harp, piano, guitar, vibraphone, etc, where the audio level is best controlled by an envelope shaper, perhaps also responding to MIDI velocity data;

2. A wind instrument such as a flute, clarinet, oboe, etc, or an organ-like instrument, where the audio level may be best controlled by MIDI pressure or expression (control change) messages.

A patch parameter can be set to select either of these options. The setting therefore depends on the preset currently selected. However, the patch setting may be incompatible with the MIDI controller connected. For example, option 1 – envelope shaper and velocity control – is preferable for a MIDI keyboard or sequencer, whereas option 2 – pressure/expression control – is preferable for a MIDI wind controller (EWI).

To avoid needing to adjust the patch parameter for audio level control every time a different preset is selected, there is a "global" configuration parameter which overrides the individual patch settings. This setting can be found in the "Config" menu… (press button [B] in the Home screen).

Presets and User patch

In the Sigma-6 design, a "Preset" is simply a patch definition comprising 42 parameters stored in the MCU flash read-only memory (ROM). When a preset is selected, the patch parameters are copied from flash memory into data memory (RAM) where they can be modified using the Pot Control Panel. The RAM copy is called the "active patch".

Preset zero is an exception… its patch parameters are stored in re-writable non-volatile memory (EEPROM). This is called the "User Patch". The "active patch" (current parameters) may be saved as the User Patch, which may be convenient if you are experimenting with a new instrument sound and wish to save the patch to continue experimenting with it after a power-down/re-start. To re-load the last User Patch saved, simply select preset 0.

Note that whenever the synth configuration (EEPROM data) is defaulted, the User Patch will be overwritten with default parameter values (copied from flash program memory).

How to Add a new Instrument Patch

Since patch definitions (presets) are stored in flash program memory, the only way to add a new preset is to enter the parameter data into the program source code and re-build the firmware. Patch definitions are written in the C source file: "sigma6_synth_data.c".

If you create any appealing new instrument sounds, whether or not you incorporate these sounds into the program code, be sure to email your creations (as patch parameter values) to me so that I can include them in future firmware updates (assuming I like the sounds you created).

To facilitate the task to generate the data for a new patch definition, the synth provides a utility function to output the "active patch" parameter values in a format suitable for copying into the C source file. The data is transmitted via the "console" serial port. You will need to connect a PC running a serial Terminal application, for example "PuTTY" for Windows (free to download). Set the terminal baud rate to 57600.

From the Home screen, press button [**#**] to show the "Misc. Utility" menu. Then press button [**A**] to start the serial output function. Your terminal screen should show a listing like this:

```
{ 1, 4, 5, 8, 9, 10 },          // Osc Freq Mult. ID (0..11)
{ 0, 2, 1, 2, 7, 1 },           // Osc Ampld Modn src (0..7)
{ 0, -21, 19, -27, -31, 0 },    // Osc Detune, cents (-600..+600)
{ 12, 12, 12, 11, 12, 12 },     // Mixer Input levels (0..16)
5, 20, 2000, 0, 2000, 0,        // Ampld Envelope (A-H-D-S-R-V)
5, 50, 800, 80, 100, 0,         // Contour Envelope (S-D-R-H-R-V)
100, 500, 0, 55,                // LFO Hz x10, Ramp ms, Osc FM%, AM%
50, 2                           // Mixer Gain (x10), Amp Ctrl (0..3)
```

If you intend to re-build the program code, copy and paste the text from the terminal screen into the source file, then add a line above with the new preset name, as in the existing patch definitions.

If you want to send me a new patch to incorporate in the firmware, simply copy and paste the listing into an email message and send it. Optionally, suggest a name for your instrument sound.

Otherwise, if it is inconvenient for you to use the serial output utility, you could just write the 42 parameter values into a text file or directly into an email message to send. Another option is to take photos of the 7 control screens showing the parameter values.

How to Emulate Hammond Organ Sounds (approximately)

The Sigma-6 sound engine has similarities to the Hammond organ tone-wheel system. Whereas a typical draw-bar organ provides up to 9 harmonic frequencies added together in variable proportion, the Sigma-6 provides a maximum of 6 oscillator frequencies added together. Both systems are capable of generating a diverse range of sound timbres. However, the Sigma-6 software tone-generator differs from the Hammond electro-mechanical tone-wheel system in several ways, as follows:

- The mixer input level of each oscillator is adjustable in 16 steps (logarithmic scale, 3 dB apart), compared to 8 steps (approx. 4 dB apart) in the Hammond draw-bar system.
- Each of the 6 oscillators can be set to one of 12 frequencies relative to the “fundamental”, including sub-harmonics at 1/2, 4/3 and 3/2 of the fundamental, plus harmonics at the 7thand 9thorder. (The Hammond system generates harmonics up to the 8th-order, but omits the 7th order.)
- Each of the 6 oscillators can be de-tuned independently up to +/- 600 cents (half an octave). (The relative tuning of the 9 partial frequencies in the Hammond system is not adjustable, although the tone-wheels are not precisely synchronized, which contributes to the Hammond’s unique and appealing sound.)
- The amplitudes of the each of the 6 oscillators can be modulated independently by a choice of modulation signal sources, including MIDI modulation or expression CC messages, 2 envelope generators (“contour” or ADSR), or a low-frequency oscillator (LFO). This feature allows the timbre (harmonic composition) of the sound to vary as the note progresses in time.

Note that emulation of the Hammond tone-wheel system was **not** a design objective for the Sigma-6 synth. Nevertheless, the Sigma-6 is capable of generating sounds reminiscent of some Hammond-like sounds, plus a whole raft of sounds that the Hammond system is not capable of, due to its design limitations.

Draw-bar organs use a numeric “short-hand” notation to represent draw-bar settings, also known as the “registration”. This is written as a set of 9 digits, each in the range 0 ~ 8. For example, 00-8050-200 sets the fundamental to level 8 (maximum = 0dB), the 3rd harmonic to level 5 (approx. −12dB) and the 5th harmonic to level 2 (approx. −24dB). All other harmonics have zero amplitude. This is a rough approximation of a descant recorder spectrum.

To translate a draw-bar registration to the Sigma-6 patch scheme, first choose up to 6 harmonics with the highest amplitude settings. Many Hammond registrations use 6 or less of the 9 available “harmonics”. These translate easily to the Sigma-6 scheme. From the table below, note the relative frequencies of the harmonics required. Set each of the oscillators in the Sigma-6 to one of these frequencies, then set the corresponding mixer input amplitude to match the respective draw-bar setting.

Draw-bar number	1	2	3	4	5	6	7	8	9
Harmonic order	0.5	1.5	1	2	3	4	5	6	8
Sigma-6 Freq. Mult.	0.5	1.5	1.0	2.0	3.0	4.0	5.0	6.0	8.0

The following table gives approximate equivalent Sigma-6 mixer levels corresponding to the 8 draw-bar settings used in Hammond organ registrations.

Draw-bar setting	0	1	2	3	4	5	6	7	8
Attenuation (dB)	X	−28	−24	−20	−16	−12	−8	−4	0
Attenuation (Av)	0	0.04	0.06	0.10	0.16	0.25	0.40	0.63	1.0
Sigma-6 mixer setting	0	7	8	9	11	12	14	15	16

Example: Translate the draw-bar registration **80-7654-030** to Sigma-6 patch parameter settings.

Solution:

Draw-bar number	1	2	3	4	5	6	7	8	9
Harmonic order	0.5	1.5	1	2	3	4	5	6	8
Sigma-6 Oscillator #	1	x	2	3	4	5	x	6	x
Sigma-6 Freq. Mult.	0.5	x	1.0	2.0	3.0	4.0	x	6.0	x
Draw-bar setting:	8	0	7	6	5	4	0	3	0
Sigma-6 mixer setting	16	x	15	14	12	11	x	9	x

Selection of popular Hammond organ registrations with equivalent Sigma-6 parameter settings

Instrument Name	Draw-bar Registration	OSC1 Freq. Mult Mix Level	OSC2 Freq. Mult Mix Level	OSC3 Freq. Mult Mix Level	OSC4 Freq. Mult Mix Level	OSC5 Freq. Mult Mix Level	OSC6 Freq. Mult Mix Level
Bright Accomp.	87-8000-456	0.5 16	1.5 15	1.0 16	5.0 11	6.0 12	8.0 14
Dulciana	00-4432-000	1.0 11	2.0 11	3.0 9	4.0 8	X 0	X 0
Full Swell Organ	30-7645-2xx	0.5 9	1.0 15	2.0 14	3.0 12	4.0 11	5.0 8
Melody Organ	80-0808-000	0.5 16	2.0 16	4.0 16	X 0	X 0	X 0
Electric Oboe	00-4675-300	1.0 11	2.0 14	3.0 15	4.0 12	5.0 9	X 0
Rock Organ #1	08-0800-000	1.5 16	2.0 16	X 0	X 0	X 0	X 0
Rock Organ #2	80-8000-000	0.5 16	1.0 16	X 0	X 0	X 0	X 0
Rock Organ #3	88-8800-000	0.5 16	1.5 16	1.0 16	2.0 16	X 0	X 0
Jazz Organ #1	30-5060-040	0.5 9	1.0 12	3.0 14	6.0 11	X 0	X 0
Jazz Organ #2	40-6160-040	0.5 11	1.0 14	2.0 7	3.0 14	6.0 11	X 0
Meditation	00-7800-453	1.0 15	2.0 16	5.0 11	6.0 12	8.0 9	X 0
Mellow Reed	00-8042-660	1.0 16	3.0 11	4.0 8	5.0 14	6.0 14	X 0
Pink Floyd	74-0004-000	0.5 14	1.5 11	4.0 11	0.5 # 14	1.5 # 11	4.0 # 11
Recorder, Alto	00-8271-200	1.0 16	2.0 8	3.0 15	4.0 7	5.0 8	X 0
Salicional	00-4544-22x	1.0 11	2.0 12	3.0 11	4.0 11	5.0 8	6.0 8
Sumkinda Pipe	00-8360-400	1.0 16	2.0 9	3.0 14	5.0 11	X 0	X 0
Stopped Flute	00-7540-000	1.0 15	2.0 12	3.0 11	X 0	X 0	X 0
Swell Diapason	00-7866-540	1.0 15	2.0 16	3.0 14	4.0 14	5.0 12	6.0 11
Theatre Organ	87-8656-xxx	0.5 16	1.5 15	1.0 16	2.0 14	3.0 12	4.0 14
Electronic Organ	00-8008-432	1.0 16	4.0 16	4.0 12	5.0 9	6.0 8	8.0 7

[X = Don’t care, Osc. not used | # = Osc. De-tuned]