2X8D Sequencer Performance Specification

A Eurorack Synthesizer Module

The 2X8D Sequencer is a digital EuroRack version of the MFOS Ten Step Analog Sequencer with more features. There are two 8 step sequencers than can instead be operated as one 16 step sequencer. The below table should give a sense of its features.

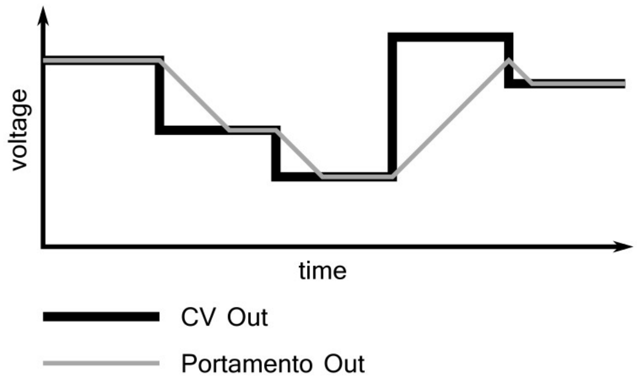
Signal Description

This table describes the signals connected to UI elements on the face plate.

#	Signal Name	UI Element	Voltage Range	Signal Description
Step Specific UI				
1	Step Indicator	LED	-	Turns on when its step is active. If its step select is off, the LED doesn't turn on.
2	Step Select	Toggle Switch	-	Turn on to insert this step into the sequence. If on then CV, gate, and trigger outputs are generated for this step.
3	CV Level	Pot	-	Controls the CV Out voltage value during this step.
Inputs				
4	Sequence Length	SP8T Rotary Switch	-	Selects the last step in the sequence. Can set from 1 to 8. If set to 6, the 6th step is the last one in the sequence. Then the sequence either stops or resets.
5	Running Direction	3 Position Toggle Switch	-	Outputs the sequence going forward, backward, or randomly. One for each channel.
6	Octave	SP10T Rotary Switch	-	The CV Level pots will only sweep through 3 octaves at once. This switch selects the octave that the pot starts at. One for each channel. Really only need 9 positions, but 10 position switches are more common.
7	Clock Rate	Coarse Pot and Fine Pot	-	How fast the sequence changes steps. In other words, the number of seconds each note is played before changing to the next one. Fine pot is 10 times as sensitive as Coarse pot.
8	Clock Multiplier	SP8T Rotary Switch	-	Has settings 1/8, 1/4, 1/2, 1, 2, 4, 8, 16 In series mode: Unsure. Multiplies what was set by Clock Rate. In parallel mode: Affects the B sequencer clock rate based on the A sequencer clock rate, which can be from either an internal or external source.
9	Step	Push Button	-	Moves the sequence to the next step. Useful when paused and programming it. Affected by Running Direction.
10	Pause	Push Button	-	Clicking causes the sequencer to pause. Clicking again causes it to start.

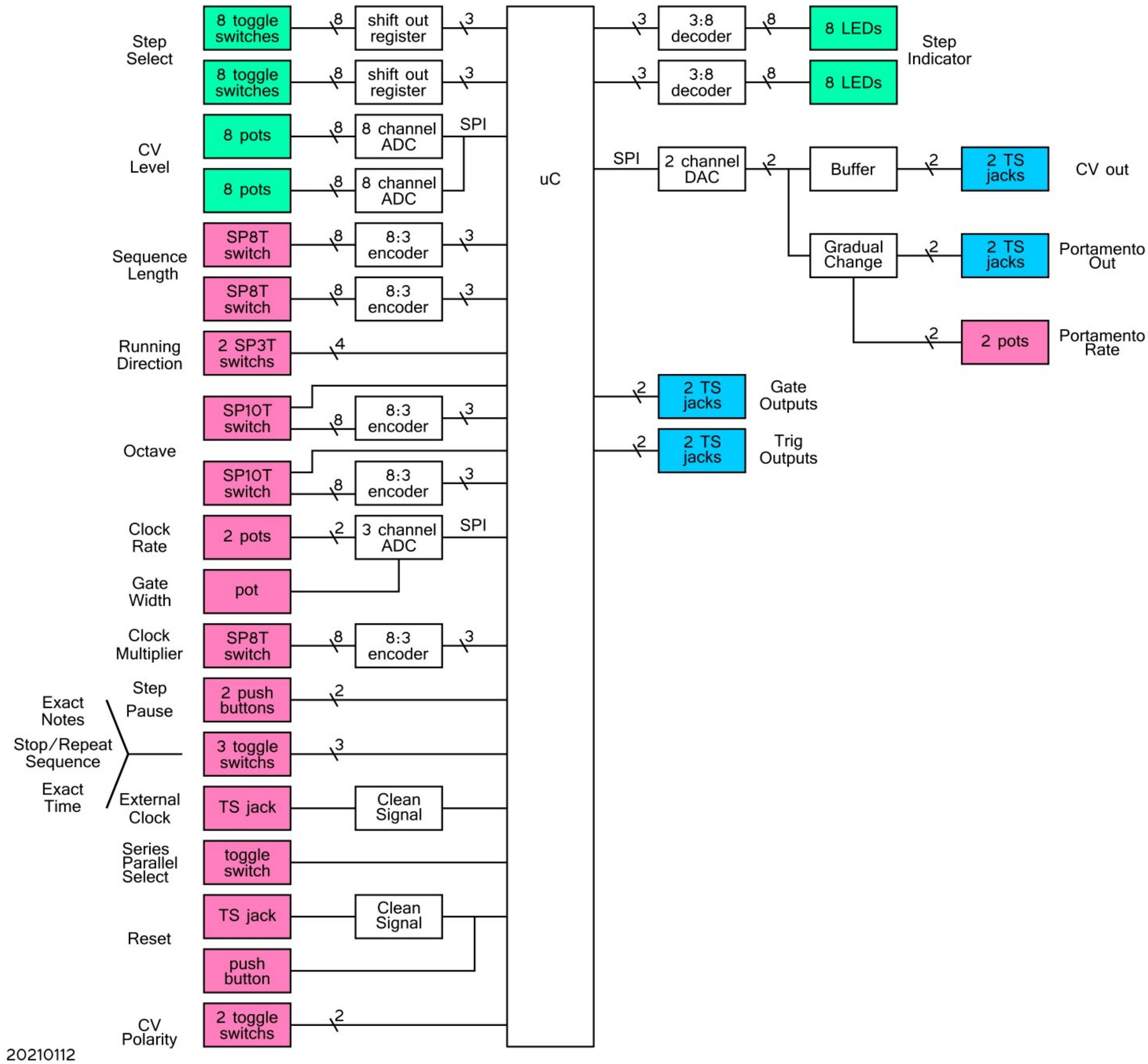
11	Gate Width	Pot	-	Lets the gate signal not last the entire length of the note, which lets an ADSR fed by the Gate signal to drop off before the end of the note.
12	Exact Notes	Toggle Switch	-	When on, CV outputs will round to the nearest proper note based on 1V/octave.
13	Exact Time	Toggle Switch	-	When on, Clock Rate will change by 1/8? second increments. Chose this value when testing.
14	External Clock	Jack	0V - 5V	Synchronizes the output to an external clock. Can probably do this in software with interrupts?
15	Series/ Parallel Select	Toggle Switch	-	Configure the sequencer as either two 8 step sequencers (A and B), or a single 16 step sequencer.
16	Stop/Repeat Sequence	Toggle Switch	-	Stop: When the sequence is at the end, stop it. Needs to assert Reset to play again. Repeat: when the sequence is at the end, start again from the beginning.
17	Reset	Push Button and Jack	0V - 5V	Starts playing the sequence from the first step.
18	CV Polarity	Toggle Switch	-	Switch between outputting ±5 V or 0-10 V CVs. Testing might change the unipolar setting to 0-5 V.
19	Portamento Rate	Pot	-	Controls how fast the voltage from Portamento Out changes. Not connected to the uC. Done in hardware.
Outputs				
20	CV Out	Jack	±5V	Outputs a voltage that changes each step based on CV Level. 1V/octave. If Step Select is off it still outputs the note given by CV Level. One for each 8 step sequence. In series mode they output the same voltage. See the appendix for voltage values.
21	Portamento Out	Jack	±5V	Same as CV Out, but the CV slides between the last output level and the next one. This is done outside the microcontroller.
22	Trig Out	Jack	0 - 5V	Goes high for every active step for a very short time, something like 10 ms. Stays at 0 V if Step Select is off.
23	Gate Out	Jack	0 - 5V	Stays high until a step is not active. The Gate Width control lets it not last the entire note length. Stays at 0 V if Step Select is off.

Portamento Description



The Portamento Out output follows the CV Out output, but is limited to a certain slew rate. If Portamento Out doesn’t reach the CV Out level before it changes again, Portamento Out starts moving towards the new output level. The slew rate is adjusted by the Portamento Rate knob. The “slew shape” isn’t necessarily linear. It could be exponential or some other shape.

Block Diagram



For the Clock Rate pots, instead of reading each pot individually, I might connect them in series then just read the final output voltage. This would be faster (one ADC read instead of two) and would reduce the requirement from a 3 channel to a 2 channel ADC, but it also might make tuning the clock rate jumpy or less sensitive.

Power

EuroRack provides 5 V and ±12 V rails. The microcontroller might require a 3.3 V rail, which can be provided by a linear regulator from the 5 V rail.

Rough Face Plate Layout

Step Specific UI								Inputs						Outputs	
1	1	1	1	1	1	1	1	4	7	7	11	15	18	20	22
2	2	2	2	2	2	2	2								
3	3	3	3	3	3	3	3	5	6	8	12	16	19	21	23
1	1	1	1	1	1	1	1	4	6	9	13	17	18	20	22
2	2	2	2	2	2	2	2								
3	3	3	3	3	3	3	3	5		10	14	17	19	21	23

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Step Specific UI

Step Ind. A1 LED	Step Ind. A2 LED	Step Ind. A3 LED	Step Ind. A4 LED	Step Ind. A5 LED	Step Ind. A6 LED	Step Ind. A7 LED	Step Ind. A8 LED
Step Select A1 SPDT	Step Select A2 SPDT	Step Select A3 SPDT	Step Select A4 SPDT	Step Select A5 SPDT	Step Select A6 SPDT	Step Select A7 SPDT	Step Select A8 SPDT
CV Level A1 Pot	CV Level A2 Pot	CV Level A3 Pot	CV Level A4 Pot	CV Level A5 Pot	CV Level A6 Pot	CV Level A7 Pot	CV Level A8 Pot
Step Ind. B1 LED	Step Ind. B2 LED	Step Ind. B3 LED	Step Ind. B4 LED	Step Ind. B5 LED	Step Ind. B6 LED	Step Ind. B7 LED	Step Ind. B8 LED
Step Select B1 SPDT	Step Select B2 SPDT	Step Select B3 SPDT	Step Select B4 SPDT	Step Select B5 SPDT	Step Select B6 SPDT	Step Select B7 SPDT	Step Select B8 SPDT
CV Level B1 Pot	CV Level B2 Pot	CV Level B3 Pot	CV Level B4 Pot	CV Level B5 Pot	CV Level B6 Pot	CV Level B7 Pot	CV Level B8 Pot

Inputs						Outputs	
Sequence Length A SP8T	Clock Rate Coarse Pot	Clock Rate Fine Pot	Gate Width Pot	Series/Para. SPDT	CV Polarity A SPDT	CV Out A Jack	Trig Out A Jack
Running Direction A SP3T	Octave A SP10T	Clock Mult. SP8T	Exact Notes SPDT	Stop/Repeat SPDT	Portamento Rate A Pot	Portamento Out A Jack	Gate Out A Jack
Sequence Length B SP8T	Octave B SP10T	Step Push Button	Exact Time SPDT	Reset Push Button	CV Polarity B SPDT	CV Out B Jack	Trig Out B Jack
Running Direction B SP3T		Pause Push Button	Ext. Clock Jack	Reset Jack	Portamento Rate B Pot	Portamento Out B Jack	Gate Out B Jack

UI component position may change based on component size, logical grouping, or needing to put components of similar height together in order to be soldered to the same PCB. They also don't need to be in a grid pattern.

Microcontroller Behaviour

A lot of the controls can be read when the microcontroller needs them. However, some controls require the microcontroller to react to the immediately (bold entries in the following table).

Also, some behaviour could be different depending on if the sequence is paused (and the user is presumably tuning a step) or if it's running. If you're tuning the CV, the ADC should read just the current CV Level pot continuously.

The following table should be used to make block diagrams that define what the microcontroller does during each step.

#	Signal Name	UI Element	How Microcontroller Interfaces
Step Specific UI			
1	Step Indicator	LED	uC turns on the LEDs when needed.
2	Step Select	TS	During each step, uC reads the Step Select switch for the next step. If off, read the next step after that. Continue until you find a step that's on. Although given that all the switch data is shifted into the uC at once, individual reading for each switch aren't needed.
3	CV Level	Pot	The next step's value is read during the previous step so it's ready to go when needed.
Inputs			
4	Sequence Length	SP8T	Read every step.
5	Running Direction	3 Position TS	Read at the start of either sequence.
6	Octave	SP10T	Read every step.
7	Clock Rate	2x Pot	Read every step. There needs to be a "lock in" feature, so each time the ADC is read, a slightly different value isn't used. This would cause the timing to drift over time. Maybe values within 2% of the previous value are ignored? That might cause fine tuning to be annoying, but that might be fixed by the Fine pot? Solve this problem during testing and see what feels good.
8	Clock Multiplier	SP8T	Read every step.
9	**Step**	**PB**	**uC reacts immediately when asserted.**
10	**Pause**	**PB**	**uC reacts immediately when asserted.**
11	Gate Width	Pot	Read every step.
12	Exact Notes	TS	Read every step.
13	Exact Time	TS	Read every step.
14	**Ext. Clock**	**Jack**	**uC reacts immediately when asserted.**

15	Series/Parallel	TS	Read every step.
16	Stop/Repeat	TS	Read at the end of either sequence.
17	**Reset**	**PB + Jack**	**uC reacts immediately when asserted.**
18	CV Polarity	TS	**uC reacts immediately when switched.** It might be possible to not involve the microcontroller in this function.
19	Port. Rate	Pot	Not connected to microcontroller.
Outputs			
20	CV Out	Jack	Microcontroller programs the DAC at the start of every step.
21	Port. Out	Jack	Not connected to microcontroller.
22	Trig Out	Jack	Microcontroller changes the GPIO as needed during each step.
23	Gate Out	Jack	Microcontroller changes the GPIO as needed during each step.

Notes

Input Voltage Tolerance

All inputs must tolerate -12 to +12 V input signals without distorting the signal. i.e. if you plug a 12V trigger signal into the Reset input, the trigger signal must still go up to 12V, not saturate at 5V.

Practically, there’s only two voltage inputs, both digital: Reset and External Clock. They could be fed through an input buffer schmitt trigger connected to the ±12 V rails, then voltage dividing the output down to a voltage the microcontroller can handle.

Input and Output Impedance

From https://learningmodular.com/glossary/impedance/

Eurorack modules tend to have an input impedance of 100 kΩ; output impedances can vary from near zero to 1k.

Here I think I’ll follow the MFOS sequencer and use a 220 Ω resistor in series with each output. At 12V this gives a current of 55 mA when the output is shorted to ground. (Make sure outputs are rated to at least 55 mA or increase output resistance). When fed into an input impedance of 100 kΩ, 99.8% of the voltage will be across the input impedance.

https://www.muffwiggler.com/forum/viewtopic.php?t=12112

This forum thread claims output impedances are usually 1 kΩ, which gives 12 mA at 12 V shorted to ground.

CV Level Sweep Range

The sweep range is the range of notes your can tune to by turning a CV Level pot over its full rotation range.

The MIDI range is 128 notes. The CV Level pots have a rotation range of 300°. Making the CV Level pot sweep range all 128 notes would give 2.34°/note, which is quite small:

To tune multiple steps to the same note, multiple pots would have to be turned to somewhere in that angle, which seems difficult. Most songs have a range under 3 octaves, or 36 “notes” (including sharps/ flats). For 300° of pot rotation, that gives 8.33°/note, which seems more manageable:

CV Level ADC Bit Depth
From above, each CV Level pot will sweep over 36 notes. An ADC that takes samples of 6 bits can read 64 different states. However it’s probably useful to be able to play frequencies between the notes. 12 bit ADCs are very common and I’ve found a few cheap ones recommended on synth forums. 12 bits gives 4096 states. For 36 notes, that’s 4096/36 = 113 states/note, which is better than 1% increments of each note. That’s probably good enough.

Total Octave Range
The MIDI range covers octaves -1 to 9, or 11 octaves. The CV Level pots will be able to access 3 of them at once. The Octave switch will be able to select the lowest octave available, letting the CV Level pots tune to that octave and the next two highest.

Given that, the Octave switch needs to have 9 positions. When in the first position the CV Level pots will sweep through octaves -1 to 1. When in the ninth position the CV Level pots will sweep through octaves 7 – 9.

It’s easy to get 10 or 12 position switches like this one from Tayda Electronics for $0.89:

With that particular switch, a larger knob is needed to hide the anti-rotation stub that goes through the face plate. I ordered a sample and its “switch feel” is pretty good.

Interfacing the Octave Switch to the Microcontroller
<u>Option 1: 8:3 Encoder</u>
I’m using 8:3 encoders in a few other places and could use one to connect the switch to the microcontroller. This would entail losing one of the switch positions and only covering 10 of the MIDI octaves. Looking at the MIDI chart in the Appendix, I’d rather have a range of (16.35 Hz – 12.5 kHz) than (8.18 Hz – 7.9 kHz). So I’d cover octaves 0 – 9.

<u>Option 1: 8:3 Encoder + 1 GPIO</u>
As above, but I could connect the ninth switch position to another GPIO.

Switch Position	GPIO 4	GPIO from Encoder		
		GPIO 3	GPIO 2	GPIO 1
1	0	0	0	0
2	0	0	0	1
3	0	0	1	0
4	0	0	1	1
5	0	1	0	0
6	0	1	0	1
7	0	1	1	0
8	0	1	1	1
9	1	don't care		

<u>Option 2: 16:4 Encoder</u>
This one also uses 4 GPIO, but needs an IC that's probably more expensive.

Construction

The mechanical stack up is face plate, then UI components, then UI component PCBs, then electronics PCBs. Stack up is similar to many modules on the market, including this Befaco Rampage:

Design should enable replacing electronics very easily. In general, don't put electrical components (ICs, caps, transistors, ect.) on UI component PCBs. Those PCBs are there to reduce soldering time. If the electronics on the UI component PCBs break then you'll either have to unsolder all the UI hardware (time consuming) or buy new UI hardware (expensive).

On the face plate, put the individual step control stuff, then inputs, then outputs. Signal flow should go from left to right. This module will be in the top left of the rack, so this lets all the jacks be to the right to reduce cable length.

Maybe I can get pots with illuminated stems. Would have to use them with clear knobs, because turning just the pot stem doesn't give fine enough control.

Very Rough Cost Estimate

Item	**Cost**
ICs	$35
UI Hardware	$30
PCBs – JLC PCB	$10
Import Fees – JLC PCB	$10
Per Unit Cost	**$85**

Appendix: Note Table

Partly derived from these sources:
https://pages.mtu.edu/~suits/notefreqs.html
https://www.inspiredacoustics.com/en/MIDI_note_numbers_and_center_frequencies

The notes corresponding to these voltage are what the design of the sequencer intends. However it's very common to sum multiple voltages that are fed into an oscillator's CV input, so programming a step to be a certain note will only play that note if the oscillator is configured correctly. This table's primary use is to show the sequencer output range, and that it follows the 1V/octave standard. Grey values might be removed.

Note	MIDI Note #	Freq. [Hz]	Voltage [V]	
			Bipolar	Unipolar
C-1	0	8.18	-5.000	0.000
D-1	2	9.18	-4.833	0.167
E-1	4	10.30	-4.667	0.333
F-1	5	10.91	-4.583	0.417
G-1	7	12.25	-4.417	0.583
A-1	9	13.75	-4.250	0.750
B-1	11	15.43	-4.083	0.917
C0	12	16.35	-4.000	1.000
D0	14	18.35	-3.833	1.167
E0	16	20.60	-3.667	1.333
F0	17	21.83	-3.583	1.417
G0	19	24.50	-3.417	1.583
A0	21	27.50	-3.250	1.750
B0	23	30.87	-3.083	1.917
C1	24	32.70	-3.000	2.000
D1	26	36.71	-2.833	2.167
E1	28	41.20	-2.667	2.333
F1	29	43.65	-2.583	2.417
G1	31	49.00	-2.417	2.583
A1	33	55.00	-2.250	2.750
B1	35	61.74	-2.083	2.917
C2	36	65.41	-2.000	3.000
D2	38	73.42	-1.833	3.167
E2	40	82.41	-1.667	3.333

F2	41	87.31	-1.583	3.417
G2	43	98.00	-1.417	3.583
A2	45	110.00	-1.250	3.750
B2	47	123.47	-1.083	3.917
C3	48	130.81	-1.000	4.000
D3	50	146.83	-0.833	4.167
E3	52	164.81	-0.667	4.333
F3	53	174.61	-0.583	4.417
G3	55	196.00	-0.417	4.583
A3	57	220.00	-0.250	4.750
B3	59	246.94	-0.083	4.917
C4	60	261.63	0.000	5.000
D4	62	293.66	0.167	5.167
E4	64	329.63	0.333	5.333
F4	65	349.23	0.417	5.417
G4	67	392.00	0.583	5.583
A4	69	440.00	0.750	5.750
B4	71	493.88	0.917	5.917
C5	72	523.25	1.000	6.000
D5	74	587.33	1.167	6.167
E5	76	659.25	1.333	6.333
F5	77	698.46	1.417	6.417
G5	79	783.99	1.583	6.583
A5	81	880.00	1.750	6.750
B5	83	987.77	1.917	6.917
C6	84	1046.50	2.000	7.000
D6	86	1174.66	2.167	7.167
E6	88	1318.51	2.333	7.333
F6	89	1396.91	2.417	7.417
G6	91	1567.98	2.583	7.583
A6	93	1760.00	2.750	7.750
B6	95	1975.53	2.917	7.917
C7	96	2093.00	3.000	8.000
D7	98	2349.32	3.167	8.167

E7	100	2637.02	3.333	8.333
F7	101	2793.83	3.417	8.417
G7	103	3135.96	3.583	8.583
A7	105	3520.00	3.750	8.750
B7	107	3951.07	3.917	8.917
C8	108	4186.01	4.000	9.000
D8	110	4698.63	4.167	9.167
E8	112	5274.04	4.333	9.333
F8	113	5587.65	4.417	9.417
G8	115	6271.93	4.583	9.583
A8	117	7040.00	4.750	9.750
B8	119	7902.13	4.917	9.917
C9	120	8372.02	5.000	10.000
D9	122	9397.27		
E9	124	10548.08		
F9	125	11175.30		
G9	127	12543.85		