M109 Sequencer

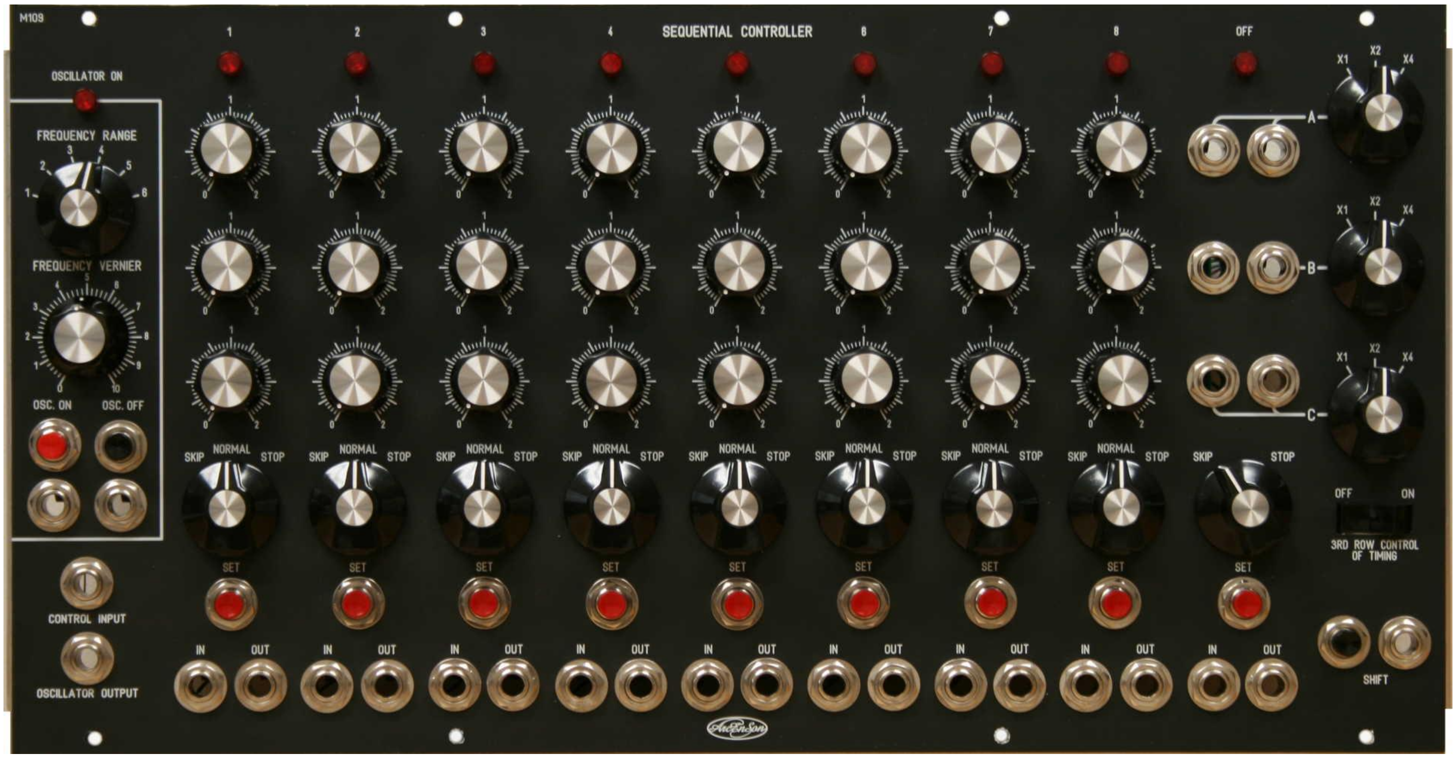


Figure 1

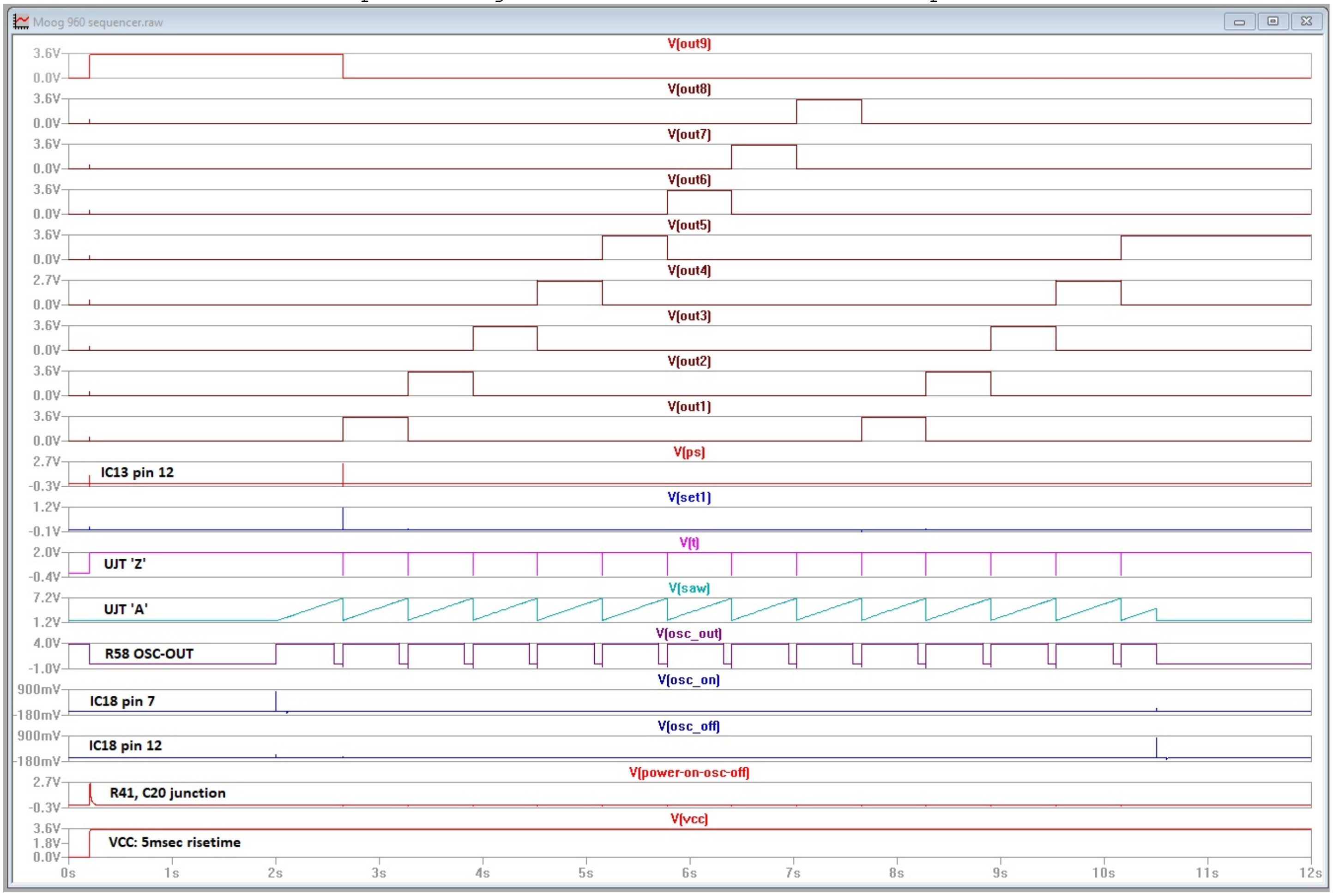
Introduction

The M109 Sequencer is an accurate copy of the renowned Moog 960 Sequential controller module. It has 8 stages of 3 different control voltages. These control voltages are available at the right side of the front panel. The stages are advanced using an internal oscillator adjustable in 6 different ranges. The oscillator speed can at the same time be ‘tweaked’ using the available frequency vernier.

Before, some analysis..

A complete ‘in depth’ analysis of the inner original circuits has been done over a period of 3 months. The original logic circuits section was filled with vintage RTL logic IC’s working at 3.6volts. Mostly M7xx and MC7xx series logic IC’s. These IC’s have since then been obsolete so an upgrade was to be considered. So… I first had to ‘see’ ALL the possible behaviours of that beast and build an accurate simulation to get it working well. Some very kind people in web DIY forums assisted me with much specific information about the RTL IC’s behaviours so I had to make a software simulation using LTSpice. But since these IC’s had no Spice models available… I browsed the web for online RTL’s data book and found a Motorola PDF book of M7xx and MC7xx family with ALL their inner transistors and resistors displayed! I then ‘very patiently’ drawn all the inner transistors and resistors that composed each IC’s used in the 960 schematic. This includes MC778P Flip-Flops, MC717C NOR gates, etc..
This gave a complete working schematic of the actual original circuit inside LTSpice. I then started to test many switches positions any many ‘starting states’ of the circuit and wrote some notes of what waveforms this produced.

Here is one of the LTSpice original circuit waveforms snapshot I made:



Now the rest of the work was to:

- Make a software implementation of all the shift registers behaviours using a Microchip PIC micro-controller.
- Create a new 1V/oct SAW tooth based oscillator
- Replace the 3 CV outputs amplifiers with new precise opamps but keeping the 3 original voltage gains.
- Use 74HC IC's for all the gates logic section (mostly NOR & inverters)
- Replace all the original rotary switches with types that will be *the same types in all the circuit*.

Features

The design features a PIC16F877 running at 20Mhz. The use of the onboard IDC connector brought the possibility of in circuit programming and testing within the software development process.

The M109 Sequencer has a wide variation of functions both as an independent module and in combination with the M109B Sequential Switch (Moog 962 clone).

The sequencer module consists of a voltage controlled clock oscillator which drives three rows of eight steps each. Indicator LEDs show sequence and step position status. A separate potentiometer for each step permits up to eight different voltage settings to be selected for each row. The DC voltage output corresponds to the column of pots below the lighted stage. Voltage range switches for each row determine the DC voltage range of each pot with two volts {X1}, four volts {X2}, or eight volts {X4} maximum extent.

Two parallel outputs are provided for each row. Jacks for trigger inputs and outputs appear below each column. Trigger inputs activate that stage independently of the clock oscillator trigger. Trigger outputs are available for any other trigger activated input. Manual trigger buttons as well are included for each of the eight stages {found below the trigger jacks}. Switches found immediately below each step position permit **SKIP**, **NORMAL** and **STOP** functions. ***BUT.. a fourth hidden position gives a RESET to first stage whenever the switch is turned to far right (4th position).***
A ninth position (stage) providing **SKIP** {continuous progression through the eight steps} or **STOP** {one progression to closure} functions is included at the end of the row.

Timing control for the eight steps is accomplished via the **THIRD ROW CONTROL** of timing rocker switch. This rocker switch connects the third row of the sequencer into the control input of the clock speed (1V/oct) for each stage according to the settings on the third row potentiometers.

The **SHIFT** input admits an external clock input to the sequencing circuit. This input may be used in addition to or exclusive of the internal clock oscillator trigger. Manual SHIFT from step to step is accomplished with the button next to the **SHIFT** jack, as well as individual manual trigger buttons for each step found under each step column.

Manual buttons or external trigger sources initiate the clock oscillator start and stop functions. The clock oscillator is capable of producing frequencies from **0.03Hz up to 274Hz.** It has both octave {range} & vernier {fine adjust} controls. One control input jack is available, as well as one rectangular wave output {approximately 90/10% duty cycle}. The clock oscillator is standardized to 1Volt per octave.

Musical Application

Like other controllers, this sequencer outputs both variable control voltages and trigger signals when activated. Rather than a manual keyboard or other instrument, this module is driven by an internal clock oscillator which sequences up to eight different tuneable “keys” or steps. Each step can be set for a different voltage. As three parallel rows are activated with each step, a total of 24 different voltages are available with eight on each row. A Sequential Switch can alternate between each row, thus providing a sequence of 24, rather than 8 steps of three voltages each. The control voltages, like those of a keyboard, need not be relegated to frequency control. Varying timbre and volume changes are possible, as well as many other modulations. Separate rows may be used to control frequency timbre and loudness simultaneously. Varying rhythms can be obtained using the **THIRD ROW CONTROL** of timing rocker switch and the separate potentiometers of the third row or by controlling the clock oscillator with an external source. Triggers for each step can fire envelopes for separate articulation, rests or filter sweeps on specific notes. Overall tempos are easily changed with control voltages from a keyboard or other controller.

In addition to its common uses, the sequencer may be driven at audio speeds to form a “graphic waveform generator”. Great variations of timbre can be obtained by varying the voltage of each step in the sequence.

Separate triggers for each stage can trigger the alternation of totally different sounds. In combination with the Moog 961 Interface, highly flexible rhythm tracks can be created with different instrumental sounds alternating on different beats. For interesting longer sequences, several steps can be triggered at once. The control voltages of all lighted steps will add together to form a single output for a row. Very long sequences of ascending 'ostinati' are difficult to tune, but provide an alternative to the often overused sequence of eight steps.

Random selection of the sequencer steps is possible in combination with white noise and a sequential switch (Moog 962) {one of many "random access" patches}. Each control voltage step can be tuned to conform to a particular tonality or key – thus creating melody "trains" which are all in tune with a particular central element.

Power requirements

The M109 Sequencer requires a split supply of +/-15vdc @ +62mA/-39mA for analog section and a separate +5vdc @ 17mA for digital. Both digital & analog grounds are tied together on the PCB.

The printed circuit board & circuits

The PCB has been designed to fit behind a 8U Moog style front panel. It is a double side board 11.475" x 4.5" and is mounted using six 4-40 1.5" high hexagonal standoffs to keep accessible all the front panel underneath wirings. All the wirings are hidden behind the PCB connecting all the needed controls mounted on front panel. All the parts are through hole types. Power is connected by use of a 6 pins 0.156" Molex type connector. The PCB has 6 mounting holes.

All the PCB to front panel wirings are made using 8 pins headers.

The micro-processor job..

Nine SET inputs are connected to the micro-processor PORTD and PORTE bit0. Each input passes through a high pass 'pi' network and goes to the micro's associated port.
Each stage outputs go from micro's PORTC & PORTB bit5, and pass through one stage of a 74HC14 schmitt inverter IC then through a 1k resistor to the associated output jack. Each of the nine outputs are +5v rising edge pulse. Each stage outputs (1 to 8) drive 2 transistors. One NPN that drives the stage's LED and drives a PNP which is connected in common emitter to the stage's 3 potentiometers vertical array feeding them with 12vdc. This 12vdc is further reduced in the CV output amplifier sections to 3 possible CV ranges: 0-2v, 0-4v, 0-8v. Each of the 3 rows has its own CV BUSS. These three BUSS sum each column potentiometer's cursor's resistor which are 100k 1%. One column at the time. These 3 BUSS currents are sent to 3 separate precision CV opamps.
Each SET input jacks accept the same type of signal. Each SET input jack has a protection diode to keep from loading LOW the PIC input if the external trigger signal goes and stays low.

The stages rotary switches are made from SP4T Alpha Taiwan adjustable rotary switches.
NOTE: The same switches are used for the oscillator's ranges 6 positions SP6T and the CV outputs gain 3 positions SP3T selection.
Each 4 positions MODE switches are selected using a 3 to 8 line decoder (U2 74HC138). U2's 8 outputs select the first 8 appropriate stage's switch to be read. When stages 1 to 8 are read, U2's pin 6 (9^{TH}_STAGE signal) is set HIGH. To read stage9's rotary switch, PORTE bit1 is put LOW to deactivate U2 (tristated outputs) and to select D9 LOW to read the 9^{th} rotary switch.

The possible switch values are:
Stages 1 to 8:
SKIP:6 NORMAL:5 STOP:3 **(and a hidden 4th right position RESET:7)**
Stage 9:
SKIP:6 STOP:3
The value is read through PORTA bits 0,1,2.

The oscillator's running status (ON=0 OFF=1) signal is read on PORTA bit3. This digital state plays a big role on how the PIC's software implemented registers react. It also starts or stops the PIC's registers shifting.
The oscillator's SAW resetting pulses are also wired to the PIC's PORTB bit0 where each pulses trigger an interrupt that does all the registers jobs.

The 1V/oct oscillator..

The oscillator is 1V/oct SAW waveform type. The VCO core is mostly from Elby-designs ASM-1. It has been modified to be in the Moog 960 circuit specs.
In fact 2 waveforms are important in this final VCO:

- the SAW waveform that is used to produce the rectangular 90% duty cycle output
- the saw resetting pulses that are read and used to trigger the PIC interrupts

The 0 to +5v SAW waveform is driven to U8A comparator input to form a positive pulses train. It is compared to VR3 voltage (+4.5v) to generate rising pulses at U8A output. This rectified by D14, lowered to +5vpp then buffered by U18B,C.
Q7 is used to enable or not the OSC output to the final jack.

The positive going resetting SAW pulses at U6 output are transformed to 0 to 5v pulses through U7 then buffered through U18D. These are 8 usec positive pulses that are sent to the micro-processor's interrupt pin. These pulses make the 'shifting' of the stages outputs.

The VCO's 6 frequency ranges are selected from a series of five 1K0 0.1% precision resistors wired directly on the frequency range rotary switch.
These produce 0,1,2,3,4,5vdc to the 1V/2oct R46 49.9k 1% suming resistor.
When the Frequency Vernier potentiometer is at center position, These 6 positions give: 0.09, 0.40, 1.56, 6.25, 35.0, 100Hz.
The **FREQUENCY VERNIER** potentiometer can fine tune the selected range +/- 1.5oct.

The logic gates IC's..

A flip-flop is used to enable or disable the internal oscillator. It is made from triple inputs NOR 74HC27 U11A,B. The oscillator's enabling flip-flop ON/OFF inputs accept a +5v button pressed or an external +5v rising edge pulse. At start the flip-flop is shut OFF through a long going high state from C8 10uf slowly discharging. It also shuts OFF every time the 9th stage goes ON. A positive pulse goes through C7 .001uf resetting the flip-flop state.
The SHIFT circuit is made out of ICs U17E,F, U11C, U12, U18A.
These ICs form two one-shot circuits. One for the external rising edge SHIFT signal ORed with the VCO's SAW resetting pulses and the other for the SHIFT push button. All these gates finally generate 10usec. rising edge pulses that will be used for the micro-controller interrupt pin.

The three CV amplifiers..

The 3 final CV BUSS are fed to 3 separate precision CV opamps (U13, U14, U15) in a non-inverting way. For example; LF412 U13A first sums and inverts the incoming BUSS#1. It then inverts again (U13B) with a gain of one to get a non-inverting summed result at the output jack. The first inverting opamp has its gain adjustable through the selection of 8.66k R67, 25.5k R69 and 59k R71 from the S8 three positions rotary gain selector (X1, X2, X4). Each column potentiometer gives a variable 0..12vdc value through its cursor. The gain resistors are calculated for 100k summing resistors on each buss and for these 3 voltages ranges:
X1, X2, X4 feedback resistors give final values of:

- X1: 0..2vdc
- X2: 0..4vdc
- X4: 0..8vdc

Adjustments and trimmings:

All the trimming procedures are done in the oscillator section.

Oscillator duty cycle adjustment:

1. Disconnect all the possible jack connections on the sequencer.
2. Push the oscillator's ON button to activate the oscillation.
3. Connect an oscilloscope on the **OSC OUTPUT** jack.
4. Put the oscillator **FREQUENCY RANGE** rotary switch to position 6.
5. Adjust the oscilloscope reading to get a clear 5vpp rectangular wave.
6. Adjust VR3 (duty cycle adj) to get around 90% duty cycle within 5% prec.
7. Done

Oscillator 1V/octave adjustment:

1. Disconnect all the possible jack connections on the sequencer.
2. Push the oscillator's ON button to activate the oscillation.
3. Connect an oscilloscope on the **OSC OUTPUT** jack.
4. Connect a variable DC voltage supply on the oscillator **CONTROL INPUT** jack. and adjust it to around +5vdc.
5. Put the oscillator **FREQUENCY RANGE** rotary switch to position 1.
6. Adjust oscillator **FREQUENCY VERNIER** potentiometer and external **CONTROL INPUT** voltage source to get 4Hz at the **OSC OUTPUT** jack.
7. Put the oscillator **FREQUENCY RANGE** rotary switch to position 6.
8. Adjust VR1 (1V/oct) trimmer pot to get 4096Hz within 2% precision.
9. Go back to line 5 and repeat until both frequencies are achieved.
10. Disconnect external variable DV voltage source from **CONTROL INPUT** jack
11. Done

Oscillator VERNIER potentiometer center adjustment:

1. Disconnect all the possible jack connections on the sequencer.
2. Push the oscillator's ON button to activate the oscillation.
3. Connect an oscilloscope on the **OSC OUTPUT** jack.
4. Put the oscillator **FREQUENCY RANGE** rotary switch to position 6.
5. Adjust the oscilloscope reading to get a clear 5vpp rectangular wave.
6. Put oscillator **FREQUENCY VERNIER** potentiometer at center position.
7. Adjust VR2 (osc BIAS adj) to get 100Hz within 5% prec.
8. Done

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ELECTRONIC SPECIFICATIONS

POWER CONNECTOR
PIN ASSIGNMENTS

1	-15V
2	A GND
3	A GND
4	+15V
5	D GND
6	+5V

Panel Size: 8 units width 17”w x 8.75”h.
Frequency Ranges:
Range#1: 0.03Hz to 0.25Hz (center=0.09Hz)
Range#2: 0.13Hz to 1.00Hz (center=0.40Hz)
Range#3: 0.51Hz to 4.16Hz (center=1.56Hz)
Range#4: 2.08Hz to 16.8Hz (center=6.25Hz)
Range#5: 8.40Hz to 68.0Hz (center=25.0Hz)
Range#6: 34.0Hz to 274Hz (center=100Hz)
Oscillator Frequency Vernier: +/- 1.5 oct
Oscillator CV input signal: 1v/oct
Oscillator CV input impedance: 100k
Oscillator output signal: 5volts peak
Rectangular wave 90% duty cycle
Oscillator output impedance: 1k
Oscillator ON/OFF inputs: 100k 3v min trigger

External SHIFT input: 100k 3v min trigger
Stages SET inputs: 100k 3v min trigger
Stages outputs signal: +5volts peak rising pulse
Stages output impedance: 1k

3 x Control Voltage output sections:
Output impedance: 1k
Range Rotary Switches:
X1: 0-2 volts max (each stage pot variations)
X2: 0-4 volts max (each stage pot variations)
X4: 0-8 volts max (each stage pot variations)

Power:
+15V @ 62mA,
-15V @ 39mA,
+5V @ 17mA.