# FatMan Analog MIDI Synth

Plan set supplement to Electronic Muscian
March 1994

This material fills in details that were omitted from the Electronic Musician article because of space limitations. It also reflects many changes that have been made because of errors in the EM schematic or tweaks and improvements made while evaluating the prototypes built readying the FatMan for production.

If you're going to be building "from scratch", we're as interested in seeing that you succeed as we are in having kits go together successfully. If it weren't for you, the magazines that support our efforts would have little justification for printing what would be no more than a multi-page advertisement.

FatMan firmware downloaded from Bulletin Boards may not be the most current version. The most current FatMan operating system (FATMOP) is available as a source file compatible with MCS-51 Assembler and Linker and Intel format hex file on 3.5" disk. Included on the same disk are .dxf and .eps files of the circuit board traces, parts legending and drill guide (laser prints of these files will have better resolution than the photo copy to the right). Included with the disk is the 32 page FatMan Assembly and Using Manual, which is about half step-by-step assembly instructions and half Testing, Tuning and Touring with pointers on what to check if things aren't working as planned. The manual has detailed wiring diagrams that will be useful even if you are rolling your own.

FatMan Info Pac (order FatPac) $20.00

2764-45 EPROM with
FatMop OS (order FatPROM) $15.00


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Edmond, OK 73013
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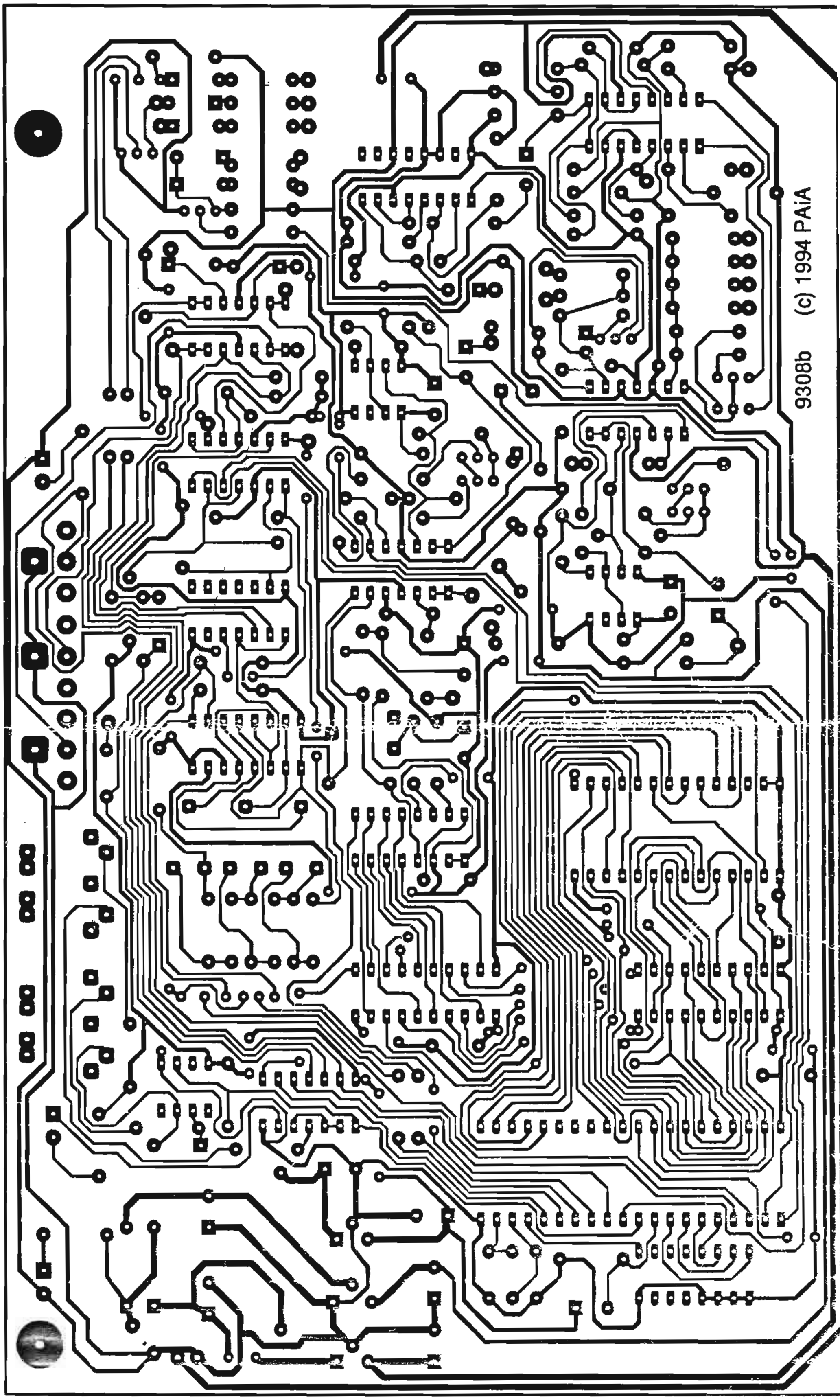
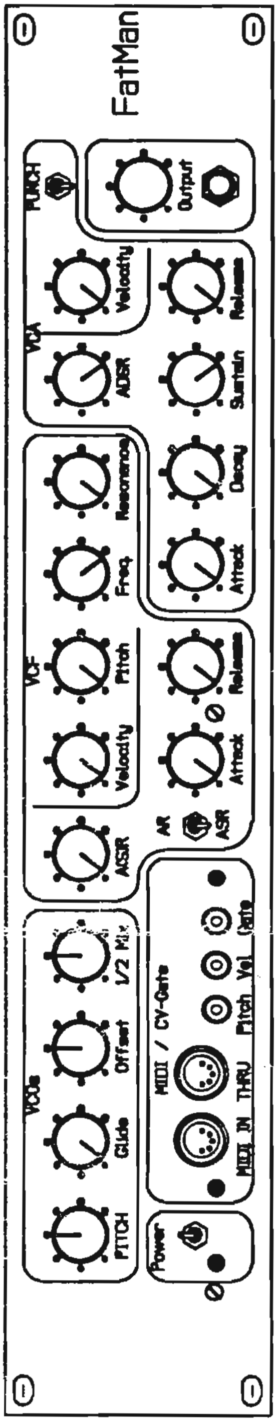
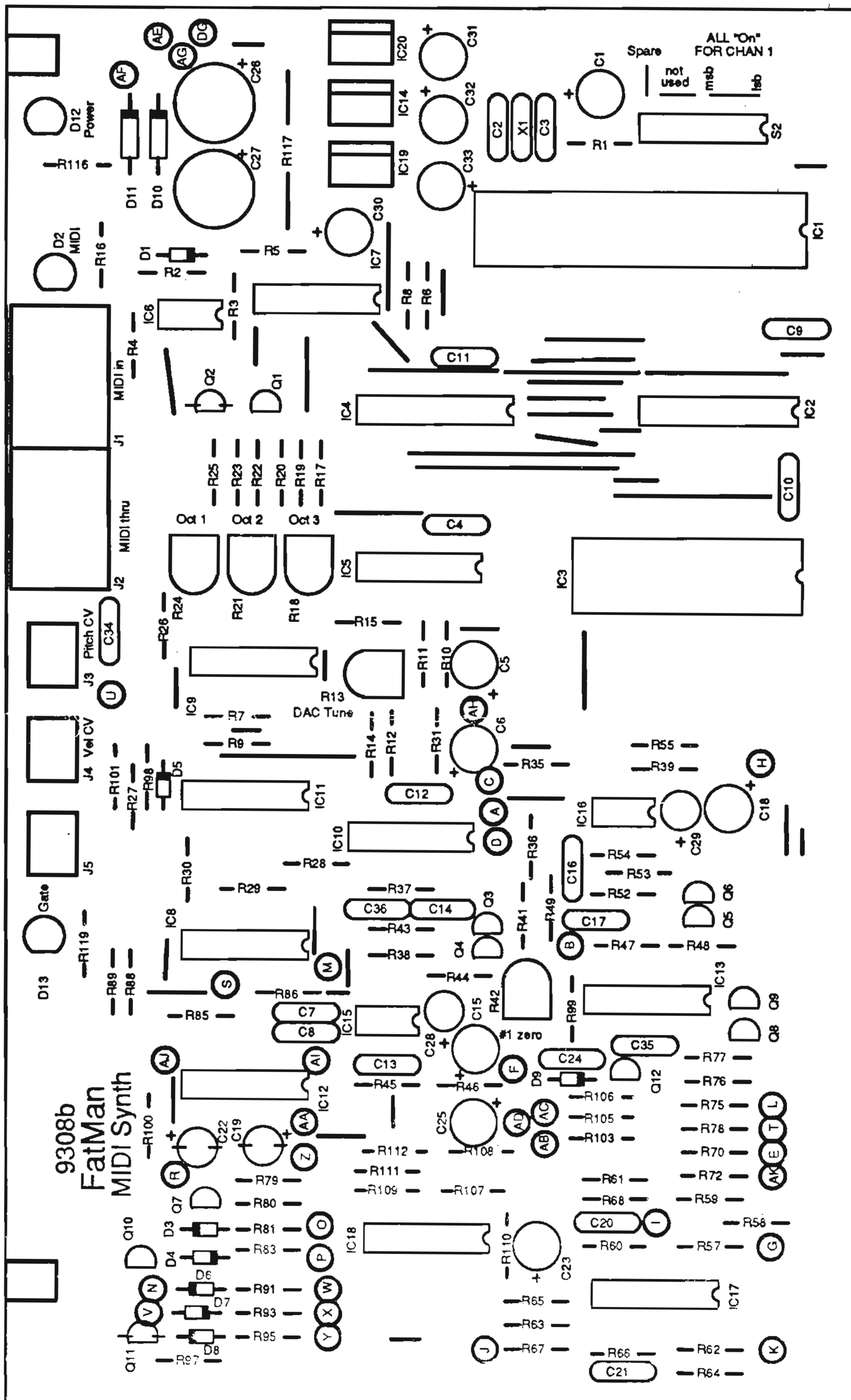



*This FatMan circuit board foil pattern is full size*




Panel layout is shown above. Controls should be set as shown for first test to see that the signal path is intact and control voltages functional.

The Parts Placement legening in the drawing to the right is full size.



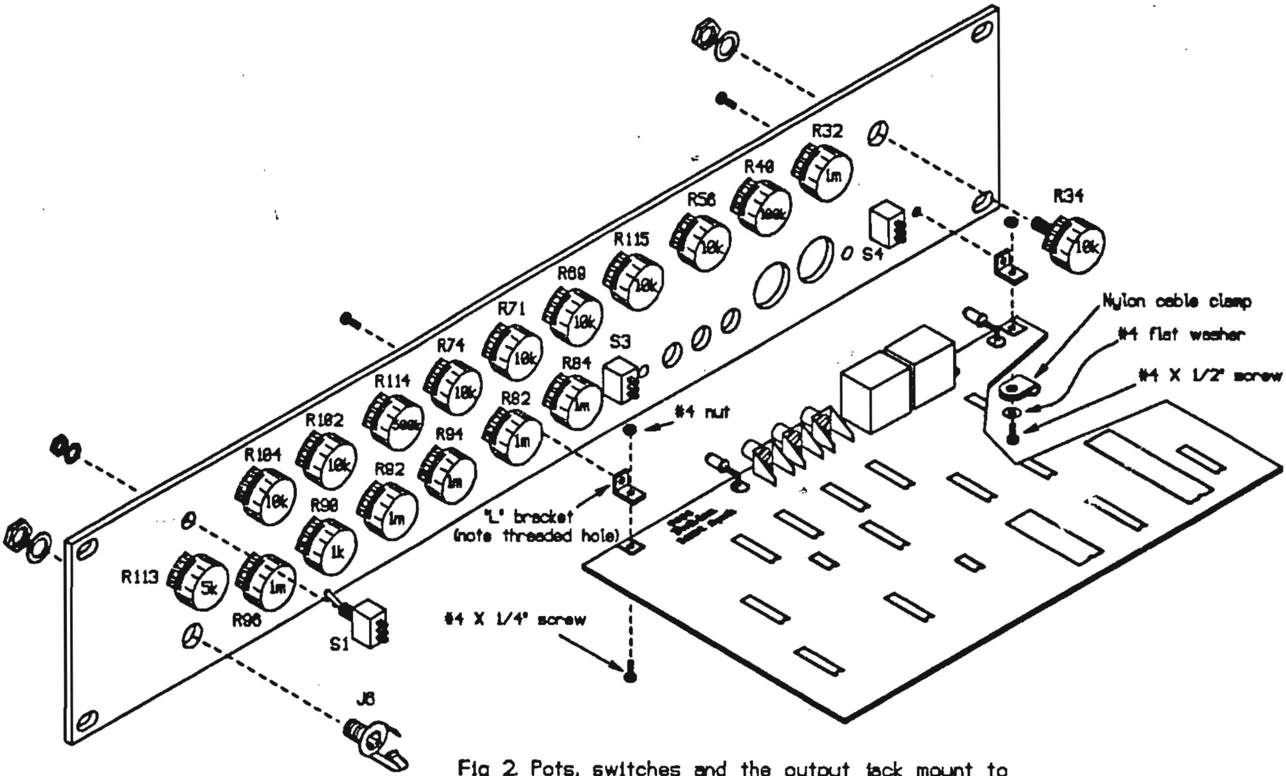



Fig 2. Pots, switches and the output jack mount to the front panel as shown. The circuit board attaches to the panel using "L" brackets and 4-40 hardware. Note the nylon cable clamp. The three LEDs and phono jacks protrude through holes provided for them.

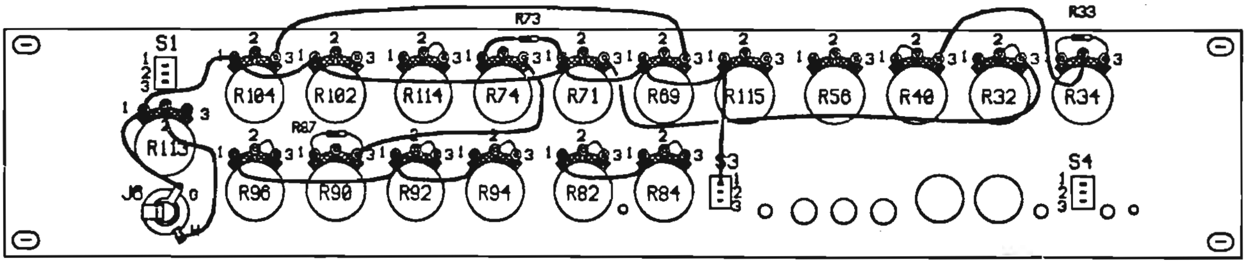



Fig 3. This point-to-point wiring of the front panel mounted parts will be easier if done before the circuit board is mounted. Note fixed resistors R33, R87 and R73 (with sleeving) which mount on pot lugs.

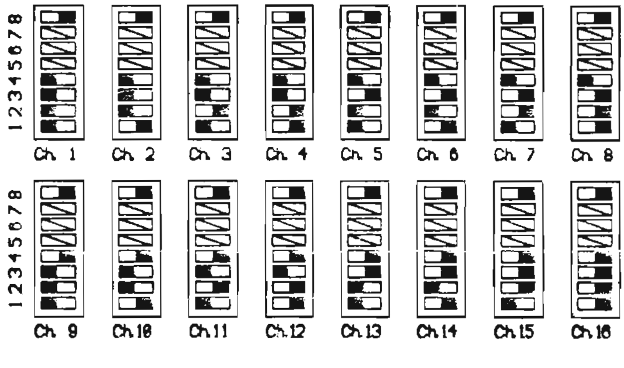



Fig 4. DIP switch sections 1 -4 select MIDI Channel as shown.

## FatMan Design and Tuning Analysis

As shown in fig 5a, the schematic of the digital circuitry, FatMan's brain is an 8031 MicroController (IC1). Firmware for the system is burned into the EPROM (IC3) which is attached to the uP's address and data lines with the Octal Latch IC2. The DIP switch S2 connects to five of the uP's input port lines. Four of the switches in this package are used to select MIDI Channel and the fifth is an unused input to the processor.

The receive (RxD) line of IC1 receives MIDI Data from the mandatory optocoupler IC6 which isolates the ground of the MIDI sending device from FatMan's ground. The output of the optocoupler is also buffered by a pair of inverter stages (IC7:b & a) which drive the MIDI Thru output J2. A third inverter stage, IC7:c, drives the LED D2 to give an indication of MIDI activity on the input J1.

DAC TUNING

FatMan's VCOs are linear in the way their frequencies respond to Control Voltage changes. This means that CVs must change exponentially to produce proper pitches. For example, to produce a pitch an octave above the present pitch the CV must double; for an octave lower the voltage must be halved. Linear Digital to Analog Converters are generally no good at generating these kinds of voltage increments because if the DAC is scaled to produce the largest voltage necessary, a couple of octaves lower you're dealing with semi-tone voltage changes that are much smaller than the resolution of the Least Significant Bit.

FatMan gets around this problem by having the DAC (IC5) be responsible for only a single octave's worth of the CV. In tech-talk, the voltages for 12 equally tempered pitches are sparsely mapped along an exponential curve in the 256space of the 8-bit DAC. Octave changes are handled by the ranging network consisting of a 1/4 Multiplexer (IC9) that selects one of four taps on the voltage divider string R17-R26. These component values produce a voltage at each tap that is 1/2 the voltage of the tap above.

On the digital side of things, the DAC is glued to the uP data lines with the octal latch IC4. The ranging MUX is controlled by the processor's T0 and T1 lines. These signals are level shifted to 8V by discrete transistors Q1 and Q2.

In normal operation, the voltage generated by the DAC can be thought of as going from C down to C#, with octave ranging changes happening between C# and the C immediately below it. So that the maximum output range of the DAC can be used (for maximum error of less than one cent), the DAC is ranged to produce a voltage from a nominal 3V for C (FFh into the DAC) down to a nominal .177v for C# (0Eh into the DAC). The 3V offset introduced by the current flow through R12 and R14 causes the voltage from the DAC's output buffer (pin 7 of IC10) to go from a nominal 6V down to a nominal 3.177V.

Huh?

What's this 3.177V business? Well, that is the voltage corresponding to the octave below 6V (which is 3V) plus the voltage required to produce the next semi-tone up. Since in equal temperament each semi-tone has a frequency 1.059 times the preceding semi-tone, and since our Voltage/Frequency response is linear, the next semitone above 3V is 3*1.059 =3.177V (if you think it's difficult to read, try explaining it some time.)

At the step between C# and the C below it, the DAC buffer output returns to 6V and the octave switching network switches to divide this in half so the CV to the VCOs becomes 3V, which as you now know is the voltage an octave below 6V.

During calibration the output of the DAC as set by R13 is adjusted so that it exactly matches the offset voltage from R12 and R14. When these conditions are met, the output of the buffer will be some voltage *X* in response to the maximum DAC output (FFh as data) and exactly *X*/2 when the DAC is contributing no output at all (00h as data). We've stated the "nominal" value of x as 6V, which may seem sort of sloppy (the actual voltage may be as low as 5V.) until you realize that it's the ratio of 2:1 that matters, and not the exact value of the voltages.

The DAC must be tuned over the octave from C0 to C1 because C0 is the only C that causes 00h to be sent to the DAC. In firmware, this lowest C is an exception to the normal ranging that happens between C# and C.

Once the DAC is tuned, the trimmers that set octave intervals (R18, R21 and R24) are adjusted so that the pitch changes by octaves as you go down the keyboard by octaves. These adjustments do not interact between themselves or with the tuning of the DAC, so you usually only have to go through them once for them to be right, and the circuitry is simple and stable so they tend to stay right for a long time.

In the final calibration step, the two VCOs are made identical by adjusting the zero offset of VCO #1 so that it's the same as VCO #2. A subtlety of the tuning process is that it compensates for any zero offset in VCO #2 (which means that exactly zero voltage may not produce exactly zero frequency, trickier than it sounds). So as long as VCO #1 is the same, everything is wonderful.

The single output of the DAC and Octave Range Switcher is split into Pitch and Velocity CVs with the sample and hold circuits built using OpAmps IC12:a&b, CMOS switches IC11:a&b and capacitors C7 and C8. System firmware outputs values to the DAC and Range Switcher corresponding to the Pitch CV then turns on IC11:a to sample the voltage by charging capacitor C7. IC11:a is then turned off to isolate the voltage on C7. The processor then repeats these actions for the Velocity CV, turning on the second CMOS switch (IC11:b) to charge C8. The voltages on the capacitors are read out by their corresponding OpAmp buffers IC12:a & :b. Comparators IC8:a&b provide level translation from 5V to the higher voltage needed for the CMOS switches by tying their open collector outputs to the 8V rail through R29 and R30.

Leaving the bits and bytes behind, we turn our attention to the analog sound generating and processing part of FatMan shown in fig 5b.

What would an analog synth be without a GLIDE control you can grab and twist for really expressive

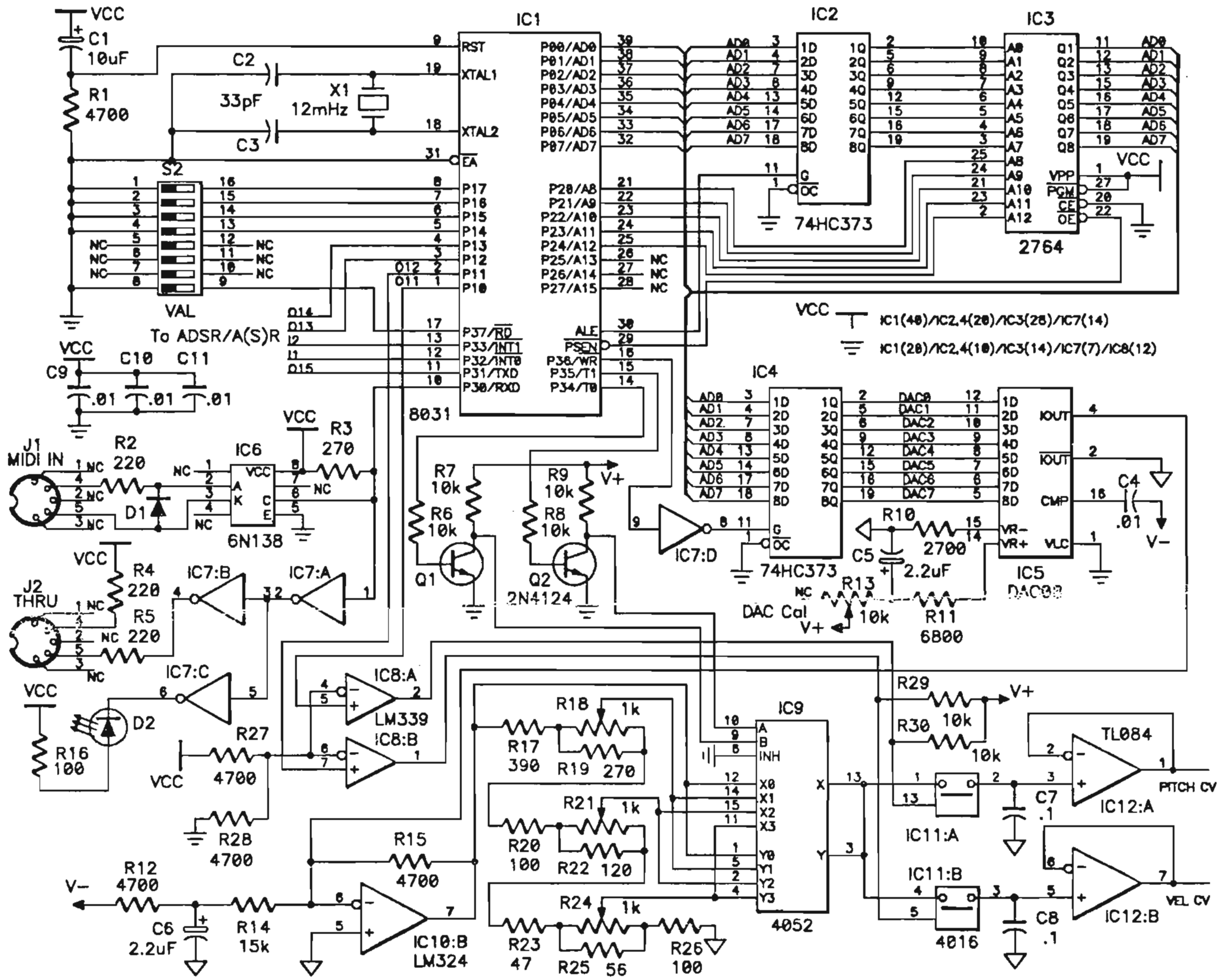



*Fig 5a. An 8031 uProcessor provides the computing horsepower needed to decode MIDI and keep Control Voltages straight. Equally tempered Control Voltages are provided by the combination of the DAC and Octave Range switching.*

portamento. FatMan uses the common approach of charging a capacitor (C12) through a variable resistor (R32). IC10:a buffers the voltage on the capacitor and drives the Master Pitch control R34 which is used to transpose both oscillators over slightly more than an octave range.

The two VCOs are identical except for the Offset control (R40) which allows the pitch of VCO #1 to be raised and lowered an octave relative to VCO #2. VCO #1 also has a trimmer that allows it's zero intercept to be adjusted to match that of VCO #2.

Taking VCO #1 as being otherwise typical, the Pitch CV drives a voltage to current converter (V/I) consisting of IC10:c, transistors Q3 and Q4 and the associated resistors. The current output of this circuit, from the collectors of the transistors, charges capacitor C14 and produces a linear voltage ramp which is read out by the buffer amp IC10:d. IC16 is a 555 type timer that senses when the voltage ramp at the output of the buffer exceeds a threshold at which point an internal transistor is turned on to short out the capacitor and quickly discharge it. When the capacitor discharges to a lower threshold the transistor is turned off and the capacitor can once again charge and repeat the cycle.

The result of this relatively slow charging and quick discharging is a ramp (sawtooth) waveform and in the interest of simplicity this is the only oscillator waveform available. A ramp is the most harmonically rich of the common waveforms, having both the even harmonics of a triangle and the odd harmonics of a pulse. The filter can be used to track the pitch of the oscillators and reject all harmonics in the ramp leaving only the fundamental sine wave.

Potentiometer R56, the Osc1/Osc2 Mix control, allows the VCF to be driven by either VCO1 or VCO2 or a mix of the two. The VCF design is a State Variable Filter which has been configured to give a low-pass response with resonance, adjustable with R114, at the corner frequency. The filter is built around IC17, an LM13600 type Dual Operational Transconductance Amplifiers (OTA) with C20 and C21 as the tuning capacitors. Two control currents for setting the gain of the two OTAs in IC17 are produced by the V/I consisting of IC13:d, Q8, Q9 and associated resistors. Four separate voltages are summed to set the corner frequency of the filter; a static voltage that sets the initial frequency is adjustable with R74, Velocity CV adjustable by R69, Pitch CV adjustable by R71, and finally the output of the filter's dedicated transient generator adjustable with R115.

The filter's AR transient generator works by charging C22 through R83 and R84 for the Attack portion of the cycle and discharging it through R81 and R82 for the Release section. Charging and discharging currents are steered by D3 and D4 as Q7 is switched on and off by the TxD line of the uP. Voltage on the capacitor is buffered by IC12:c and the comparator IC8:c monitors the buffer's voltage and switches the processor's INT1 input when the peak voltage is reached. The firmware's response to this is to switch from Attack to Release. Closing the Sustain switch S3 prevents this "peak reached" signal from getting back to the uP so that the Release portion of the cycle won't happen until the key that initiated the response is released. The result is to switch the transient from a non-sustaining AR to an Attack / Sustain / Release (ASR) response.

FatMan's Voltage Controlled Amplifier uses one OTA from IC18. The main components of the V/I that control this element are IC13:c and Q12. This voltage to current converter is unlike the others in that it must be stable for zero control voltage (so the VCA can turn off completely). Adding D9 to the circuit clamps the output of IC13:c and keeps it from going negative and C24 provides frequency compensation for the high loop-gain state that exists at near-zero control voltages

The Attack/Decay/Sustain/Release (ADSR) transient generator dedicated to the VCA is similar to the filter's A(S)R. Under control of a pair of the uP's output lines (P12 & P13), capacitor C19 charges and discharges though steering diodes D6-D8 at rates set by R92, R94 and R96. The Sustain control R90 sets the voltage level to which the Decay portion of the cycle falls. IC12:d buffers the voltage on the capacitor and comparator IC8:d signals the processor when the peak of the Attack is reached.

When the Punch switch S1 is closed the combination of C34 and R98 add a slight delay (about 20 ms.) between the time that the ADSR reaches its Attack peak and the time that this information reaches the uP. The result is a short Sustain interval that adds punch to sounds with fast Attack and Decay dynamics. When S1 is open, the ADSR behaves in the normal, technically correct way.

FIRMWARE

The FatMan firmware is responsible for recognizing MIDI Note On and Off messages and breaking them down into Note number and Velocity values. Note number is checked for being in the range of 36-84 and then converted into octave ranges by division and the data required to drive the DAC by look-up table.

The Velocity data from Note On and Off messages are handled in much the same way, except that the 0 to 127 step range of this data is first scaled to range from 36-84.

Pitch Wheel messages are also supported. In the FatMan, Wheel data modulates the Pitch data before it gets to the DAC. This is possible because only 12 of the 256 possible values of the DAC are used for pitch and the space between these values is available for modulation. Musical range of FatMan's Pitch Wheel is +/- a semi-tone. Since there are no pitches available above the highest C or below the lowest, wheel data is ignored on these bends.

The firmware is also responsible for turning on and off the proper sample and hold at the proper time to produce Pitch and Velocity CVs. It manages the A(S)R and ADSR transient generators, turning on their Attack cycle when a note is played and managing Decay, Sustain and Release as appropriate for the status of the transient and any Note Off messages which may be received.

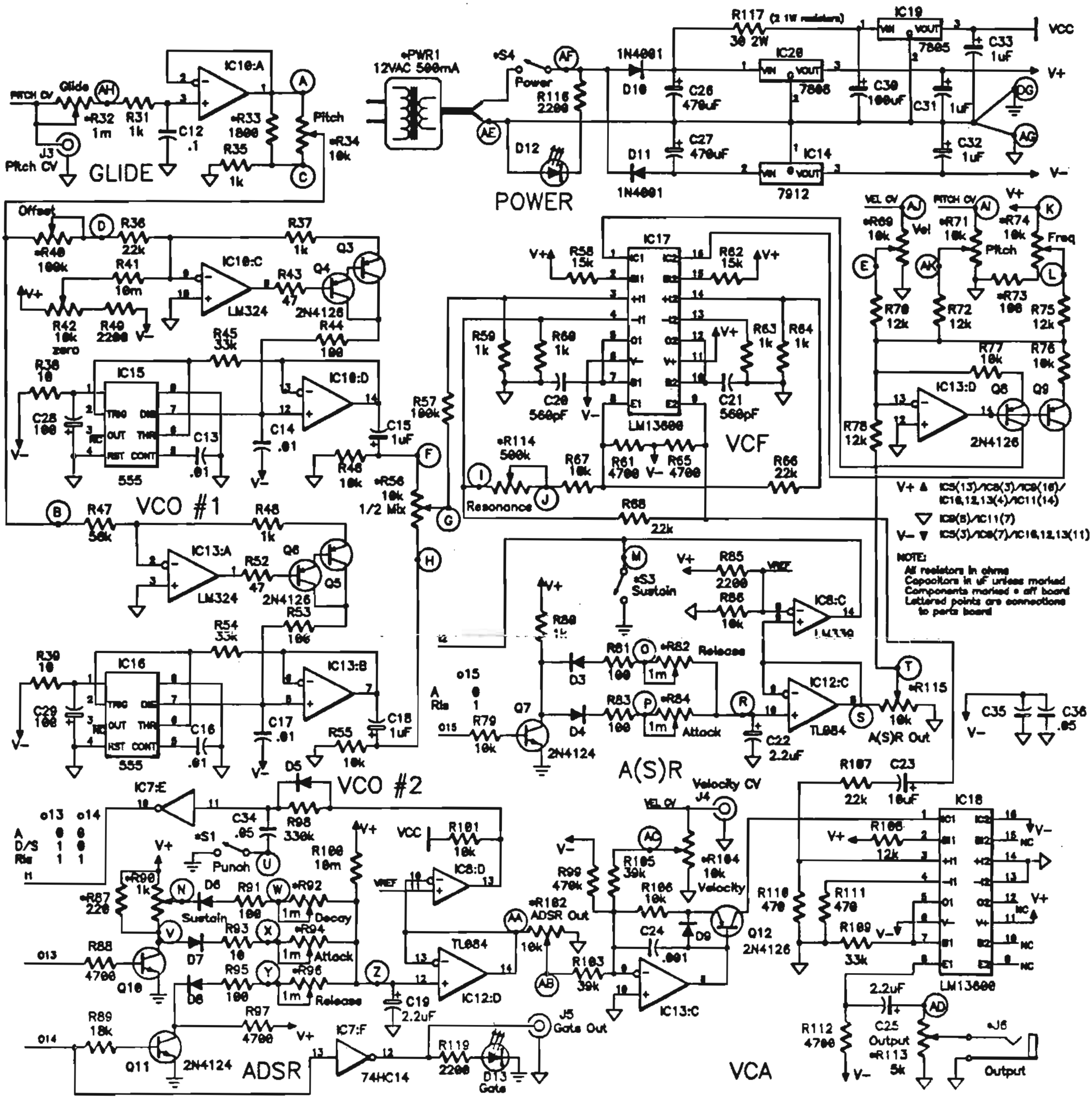



*Fig 5b. The FatMan analog circuitry comporises two VCOs, low-pass VCF with AR Transient Generator, and VCA with ADSR Transient Generator*

FatMan
Packing List
(94.6.14)

| | | | |
|---|---|---|---|
| 1 | 8031 | 8 Bit MicroController | IC1 |
| 2 | 74HC373 | 8 Bit Latch | IC2,IC4 |
| 1 | 2764 | 8k EPROM | IC3 |
| 1 | DAC08 | 8 Bit DAC (may be 1408) | IC5 |
| 1 | 6N138 | Opto Isolator | IC6 |
| 1 | 74HC14 | Hex Inv. Schmitt Trig. | IC7 |
| 1 | LM339 | Quad Comparator | IC8 |
| 1 | 4052 | Dual 1/4 CMOS MUX | IC9 |
| 2 | LM324 | Quad OpAmp (CA324) | IC10,IC13 |
| 1 | 4016 | Quad Analog Switch | IC11 |
| 1 | TL084 | Quad Bi-fet Amp (CA084) | IC12 |
| 2 | LM13600 | Dual OTA | IC17,IC18 |
| 2 | 555 | Timer | IC15,IC16 |
| 1 | 7805 | +5V Voltage Reg. | IC19 |
| 1 | 7808 | +8V " " | IC20 |
| 1 | 7912 | -12V " " | IC14 |
| 3 | 100uF/16V Electrolytic Capacitor | | C28,C29,C30 |
| 2 | 10uF/16V " " | | C1,C23 |
| 5 | 1uF/16V " " | | C15,C18,C31, C32,C33 |
| 5 | 2.2uF/16V " " | | C5,C6,C19,C22, C25 |
| 2 | 470uF/25V " " | | C26,C27 |
| 3 | .1uF Mylar Capacitor | | C7,C8,C12 |
| 2 | .01uF " " | | C14,C17 |
| 2 | 33pF Ceramic Disk Capacitor | | C2,C3 |
| 6 | .01uF " " " | | C4,C9,C10,C11, C13,C16 |
| 1 | .001uF " " " | | C24 |
| 3 | .05uF " " " | | C34,C35,C36 |
| 2 | 560pF Polystyrene Capacitor | | C20,C21 |
| 2 | 1N4001 | Power Diodes | D10,D11 |
| 8 | 1N4148 | Signal Diodes | D1,D3,D4,D5, D6,D7,D8,D9 |
| 3 | Red LED | | D2,D12,D13 |
| 5 | 2N4124 NPN Silicon Transistors | | Q1,Q2,Q7, Q10,Q11 |
| 7 | 2N4126 PNP Silicon Transistors | | Q3,Q4,Q5,Q6, Q8,Q9,Q12 |
| 1 | 1/4" Phone Jack | | *J6 |
| 2 | PC Mount 5 Pin DIN Sockets | | J1,J2 |
| 3 | PC Mount Phono Jack | | J3,J4,J5 |
| 2 | 10k ohm | PC Mount Trimmer | R13,R42 |
| 3 | 1k ohm | PC Mount Trimmer | R18,R21,R24 |
| 8 | 10k ohm | Panel Mount Pot | *R34,*R56, *R69,*R71, *R74,*R102, *R104,*R115 |
| 6 | 1megohm | " " " | *R32,*R82, *R84,*R92, *R94,*R96 |
| 1 | 1k ohm | " " " | *R90 |
| 1 | 100k ohm | " " " | *R40 |
| 1 | 500k ohm | " " " | *R114 |
| 1 | 5k ohm | " " " | *R113 |

1/4W 5% resistors

| | | | |
|---|---|---|---|
| 3 | 10 ohm | (brown-black-black) | R38,R39,R93 |
| 10 | 100 ohm | (brown-black-brown) | *R73,R16,R20,R26,R44, R53,R81,R83,R91,R95 |
| 15 | 10k | (brown-black-orange) | R6,R7,R8,R9,R29,R30, R46,R55,R67,R76,R77, R79,R86,R101,R106 |
| 1 | 100k | (brown-black-yellow) | R57 |
| 2 | 10 megohm | (brown-black-blue) | R41,R100 |
| 1 | 120 ohm | (brown-red-brown) | R22 |
| 5 | 12k | (brown-red-orange) | R70,R72,R75, R78,R108 |
| 3 | 15k | (brown-green-orange) | R14,R58,R62 |
| 1 | 18k | (brown-grey-orange) | R89 |
| 1 | 1800 ohm | (brown-grey-red) | *R33 |
| 9 | 1000 ohm | (brown-black-red) | R31,R35,R37, R48,R59,R60, R63,R64,R80 |
| 4 | 220 ohm | (red-red-brown) | *R87,R2,R4,R5 |
| 4 | 2200 ohm | (red-red-red) | R49,R85,R116,R119 |
| 4 | 22k | (red-red-orange) | R36,R66,R68,R107 |
| 2 | 270 ohm | (red-violet-brown) | R3,R19 |
| 1 | 2700 ohm | (red-violet-red) | R10 |
| 1 | 330k | (orange-orange-yellow) | R98 |
| 3 | 33k | (orange-orange-orange) | R45,R54,R109 |
| 1 | 390 ohm | (orange-white-brown) | R17 |
| 2 | 39k | (orange-white-orange) | R103,R105 |
| 3 | 47 ohm | (yellow-violet-black) | R23,R43,R52 |
| 2 | 470 ohm | (yellow-violet-brown) | R110,R111 |
| 10 | 4700 ohm | (yellow-violet-red) | R1,R12,R15,R27,R28, R61,R65,R88,R97,R112 |
| 1 | 470k | (yellow-violet-yellow) | R99 |
| 1 | 56 ohm | (green-blue-black) | R25 |
| 1 | 56k | (green-blue-orange) | R47 |
| 1 | 6800 ohm | (blue-grey-red) | R11 |
| 2 | 15 ohm | 1W. Power Resistor | R117 (see pg 6) |

| | | |
|---|---|---|
| 3 | SPST Panel Mount Toggle Switches | *S1,*S3,*S4 |
| 1 | 8 Position DIP Switch | S2 |
| 1 | 12 - 14VAC, 500mA (or greater) Wall Mount Transf. | PWR1 |
| 1 | 12mHz Crystal | X1 |

| | |
|---|---|
| 18 | Set Screw Knobs |
| 1 | 28 Pin IC Socket |
| 1 | 40 Pin IC Socket |
| 2 | "L" Brackets |
| 4 | #4 Nuts |
| 5 | 4-40 X 1/4" Machine Screws |
| 1 | 4-40 X 1/2" Machine Screw |
| 1 | #4 Flat Washer |
| 1 | Nylon Cable Clamp |
| 42" | Bare Wire |
| 8" | Small Insulated Sleeving |
| 38' | #22 insulated, stranded wire (4 ea. 9.5' lengths) |
| 2 | Voltage Regulator Cooling Fins |
| 1 | 9308 FatMan Printed Circuit Board |

*parts marked * mount on the front panel*

*Designations* R50 and R51 *are not used.*