Oakley Sound Systems

5U Oakley Modular Series

midiDAC
Single Channel midiCV Converter

PCB Issue 5

Builder’s Guide

V5.5

Tony Allgood
Oakley Sound Systems
Carlisle
United Kingdom

Introduction

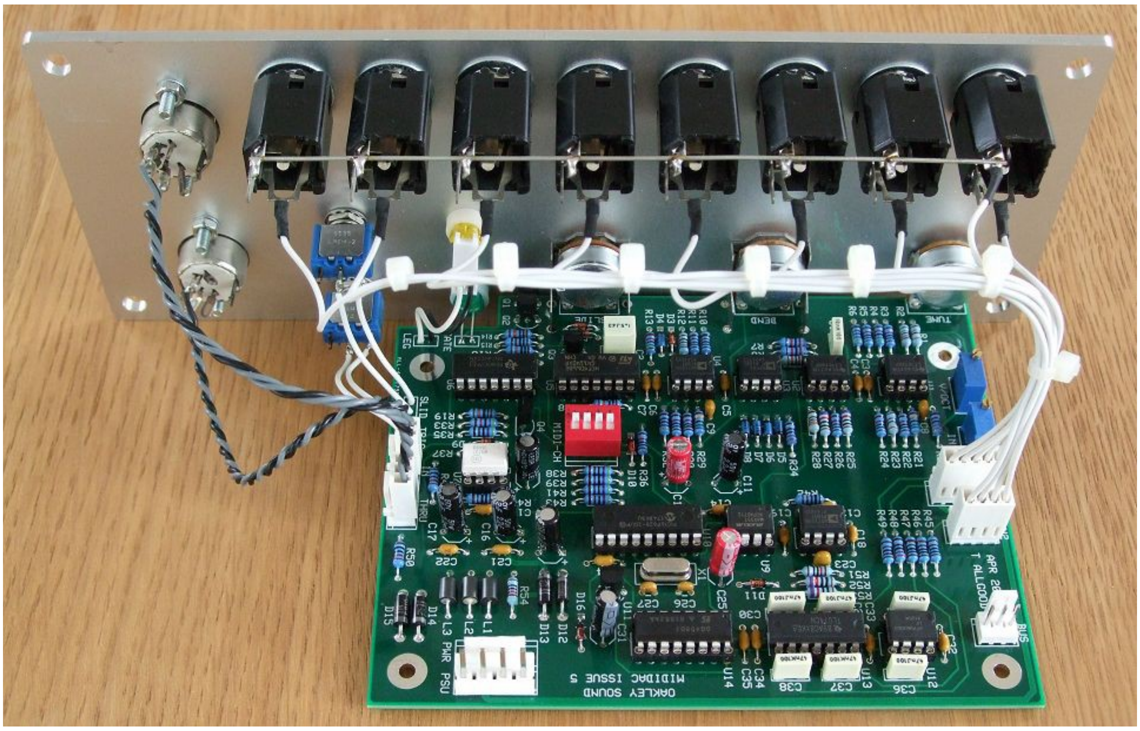
This is the Builder's Guide for the issue 5 midiDAC midi to CV convertor 5U module from Oakley Sound. This document contains a basic introduction to the board, a full parts list for the components needed to populate the boards, a circuit description, and a list of the various interconnections needed to make up the module.

For the User Manual which contains an overview of the operation of the unit, the midiDAC PIC specifications and the calibration procedure, please visit the main project webpage at:

http://www.oakleysound.com/mididac.htm

For general information regarding where to get parts and suggested part numbers please see our useful Parts Guide at the project webpage or http://www.oakleysound.com/parts.pdf.

For general information on how to build our modules, including circuit board population, mounting front panel components and making up board interconnects please see our generic Construction Guide at the project webpage or http://www.oakleysound.com/construct.pdf.



The issue 5 midiDAC fitted to a 2U wide natural finish Schaeffer MOTM format panel. The smaller board mounted connectors are 0.1" Molex KK. The jack sockets are Switchcraft 112APCX.

The Printed Circuit Board

The PCB has been designed to fit within a 2U across MOTM style modular face plate. The size of the board is slightly smaller than older issues at 134 mm high and 107 mm deep. It has three PCB mounted pots to facilitate tune, bend depth and slide rate. The pots are spaced at the standard Oakley and MOTM spacing of 1.625".

The switches and LEDs are typically hand wired directly to the PCB. The various sockets used by the module typically use 0.1" KK Molex or MTA headers, however, they may be also be wired directly into the board if you wish.

Midi channel is selected by four lines in 'traditional' binary fashion. Thus midi channel can be switched by either onboard DIP switches or links, or by a 16 position rotary HEX switch mounted on the front panel. I tend not to change midi channel once I have built the unit, so I use DIP switches only. Because of this, there is no midi channel selector on the suggested front panel layout. However, the board is equipped to take a 0.1" header to allow simple connection to a rotary HEX switch if required.

The issue 5 PCB is a four layer design which means it has copper tracks on both the upper and lower surfaces as well as two internal layers. The upper internal layer is designated solely to 0V. All boards sold by Oakley Sound Systems are lead (Pb) free and RoHS compliant but may be soldered with Pb/Sn solder if you wish.

Power is admitted to the board via 0.156" Molex connector for MOTM/Oakley or 0.1" MTA connector for fitting into Synthesizer.com systems.

The PCB has four mounting holes, one in each corner. However, using the midiDAC with the recommended pots and brackets, will give you sufficient support without the need for additional mounting hardware. The pots on the issue 5 midiDAC board are 16mm Alps or Alpha types.

Parts List

For general information regarding where to get parts and suggested part numbers please see our useful Parts Guide at the project webpage or http://www.oakleysound.com/parts.pdf.

The components are grouped into values, the order of the component names is of no particular consequence.

A quick note on European part descriptions. R is shorthand for ohm. K is shorthand for kilo-ohm. R is shorthand for ohm. So 22R is 22 ohm, 1K5 is 1,500 ohms or 1.5 kilohms. For capacitors: 1uF = one microfarad = 1000nF = one thousand nanofarad.

To prevent loss of the small '.' as the decimal point, a convention of inserting the unit in its place is used. eg. 4R7 is a 4.7 ohm, 4K7 is a 4700 ohm resistor, 6n8 is a 6.8 nF capacitor.

Resistors

1% 0.25W metal film types are recommended for all values, except for R25, R27, R52 and R53, which should be precision 0.1% 0.25W types.

75R	R21, R29
120R	R17, R51, R54
220R	R50, R40, R37
680R	R12
1K	R10, R11, R15, R42, R44, R45, R46, R47, R49
2K2	R34, R48
3K3	R28
3K9	R23
4K7	R35, R6, R32, R43, R39, R41, R38
10K	R3, R5, R22, R24, R26, R30, R31, R36
10K, 0.1%	R25, R27, R52, R53
11K	R9
15K	R13
18K	R2*
22K	R7, R8
33K	R20
47K	R4, R33
100K	R18, R14, R16, R19
390K	R1

* R2 sets the range of the pitch CV (KCV) output. See section later in this document.

Capacitors

100nF 50V/63V axial multilayer ceramic	C33, C5, C32, C19, C15, C7, C6, C18, C35, C24, C14, C22, C21, C34, C4, C3

18pF C0G 2.5mm ceramic	C27, C26, C13
33pF C0G 2.5mm ceramic	C23, C8, C9
10nF, 100V polyester	C1
47nF, 100V polyester	C28, C29, C30, C36, C37, C38
1.5uF, 63V polyester	C2
1uF, 63V electrolytic	C12
2u2, 63V electrolytic	C11, C31, C10, C17, C16, C25
47uF, 35V electrolytic	C20

Discrete Semiconductors

1N4148 signal diode	D1, D2, D3, D9, D10, D11
BAT42 Schottky diode	D4, D5, D6, D7, D8
5V6 zener diode	D16
1N4001 rectifier diode	D12
1N5819 Schottky diode	D14, D13, D15
BC549 NPN transistor	Q1, Q2, Q4
BC559 PNP transistor	Q3
5mm green LED	Gate LED
5mm yelllow LED	Legato LED

Integrated Circuits

HCF4066BE analogue switch	U5
16F628 pre-programmed PIC	U10
6N137 opto-coupler	U7
74HC04N hex invertor	U6
78L05 +5V regulator	U11
DG408DJ analogue switch	U14
AD712JN dual op-amp	U4, U8
LF412CN dual op-amp	U12
LT1013DP dual op-amp	U1, U2
TL084CN quad op-amp	U13
MAX551ACPA 12-bit DAC	U9
REF02 +5V reference	U3

Trimmers

2K multiturn (eg. Bourns 3296W)	V/OCT
100K multiturn (eg. Bourns 3296W)	INIT

Pots

All pots PCB mounted 16mm Alps or Alpha types.

50K linear	TUNE, BEND
250K log	SLIDE
Alpha pot brackets	2 off

Connectors

MTA156 4 way header	PSU – Oakley/MOTM power supply
MTA100 6-way header	PWR – Synthesizers.com power supply
5-way 0.1” header and socket	CN1
4-way 0.1” header and socket	CN2
3-way 0.1” header and socket	THRU, BUS
2-way 0.1” header and socket	IN

Miscellaneous

4MHz Crystal (parallel resonant)	X1
Axial leaded ferrite beads	L1, L2, L3
LED lens and clips	Two off, colours to suit LEDs
SPDT or SPST toggle switches	Two off, one for Trigger and one for Slide
4-way DIP switch	One off
Knobs	Three off
1/4” sockets	Eight off
5-pin midi sockets	Two off

Suitable lengths of insulated multistrand wire for interconnects.

You may well want to use sockets for the ICs. I would recommend low profile turned pin types as these are the most reliable. You need eight 8-pin DIL, three 14-pin DIL, one 16-pin DIL, and one 18-pin DIL.

Pitch CV Range – the value of R2

When the idea of the midiDAC was first born there were few midi to CV convertors around. Indeed, the midiDAC was the first for the 5U MOTM system. There was also no set standard over what voltage range should the full 127 notes of the midi cover. The only experience I had was with midi to CV convertors that were external units designed to plug into older analogue gear. The lowest note played on the instrument's own keyboard usually generated 0V and thus any external midi to CV convertor should behave the same. This was especially important since many older analogue keyboards would misbehave if you used any negative voltages. Therefore, I created a standard for my own modules which also worked well with older equipment.

This standard was that an input of midi note number 60 would produce 5V which would give a middle C (C4 or 261.6Hz) with the VCO's pitch controls set to their normal lowest positions. Midi note 0 would then produce 0.000V and negative voltages, excepting the use of pitch bend, would not be produced. The highest C, C9, would thus require +10.00V.

However, with the advent of Eurorack systems a different standard was being created. Without the ties to vintage analogue electronics but with the restriction of the lower +/- 12V power rails it became useful to start at voltages below 0V. The most common system uses a 0.000V output to represent midi note number 36 (C2 or 65.4Hz). Therefore middle C (C4) is now 2.000V. This is operating at three octaves lower than the original Oakley system.

All previous issues of the midiDAC had an INIT trimmer by which the output voltage could be set within a certain range. However, it did not have a large enough range to drop it by 3V and bring it into alignment with this new wave of products. The fifth issue of the midiDAC addresses this problem and with the addition of one resistor, R2, we can now have compatibility with these other systems.

If you wish your midiDAC to behave in a similar fashion to more recent midi to CV convertors, such as Mutable Instruments Yarns, then make sure you fit R2 and its value should be 18K. You should do the same if you are building your midiDAC for use with MU (eg. Synthesizers.com) modules.

If, however, you are supplementing an existing Oakley system which already has an older issue midiDAC, and you are happy with its range, then do not fit R2 and leave the space on the board empty.

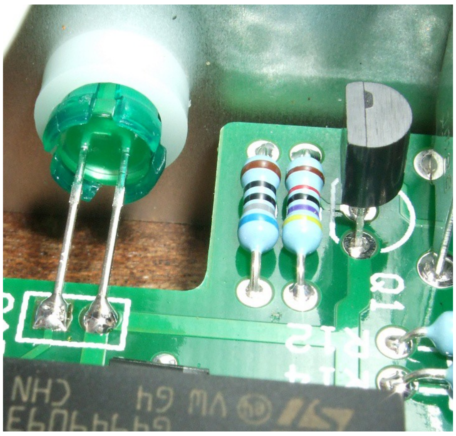
Connecting the LEDs

The two LEDs should be connected first since it can get quite tricky to get to them once the sockets are fitted.

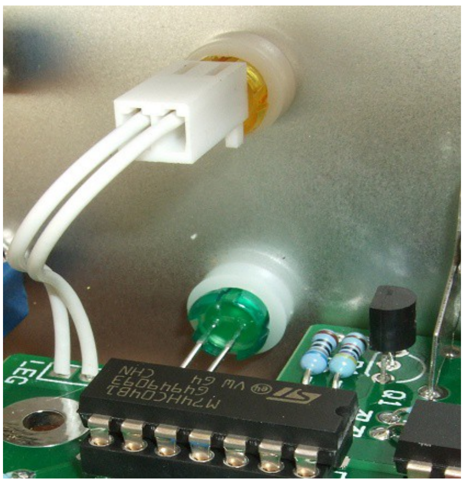
LEDs have two pins and they must be fitted the correct way around otherwise the LED will not light. Pin 1, the square pad, should go to the anode of the LED. And pin 2 to the cathode.

The way I wired my LEDs is to have the gate LED directly attached the PCB with its own leads, and the slide LED using flying wires attached to a 0.1” Molex KK connector which simply slips over the leads of the LED.

Attach the board to the panel and secure with the pot nuts. Then fit the gate LED into its clip and trim off the leads so that they are just long enough to lie across the GATE solder pads. Then ensuring that the leads are making contact with the pads solder them in place.



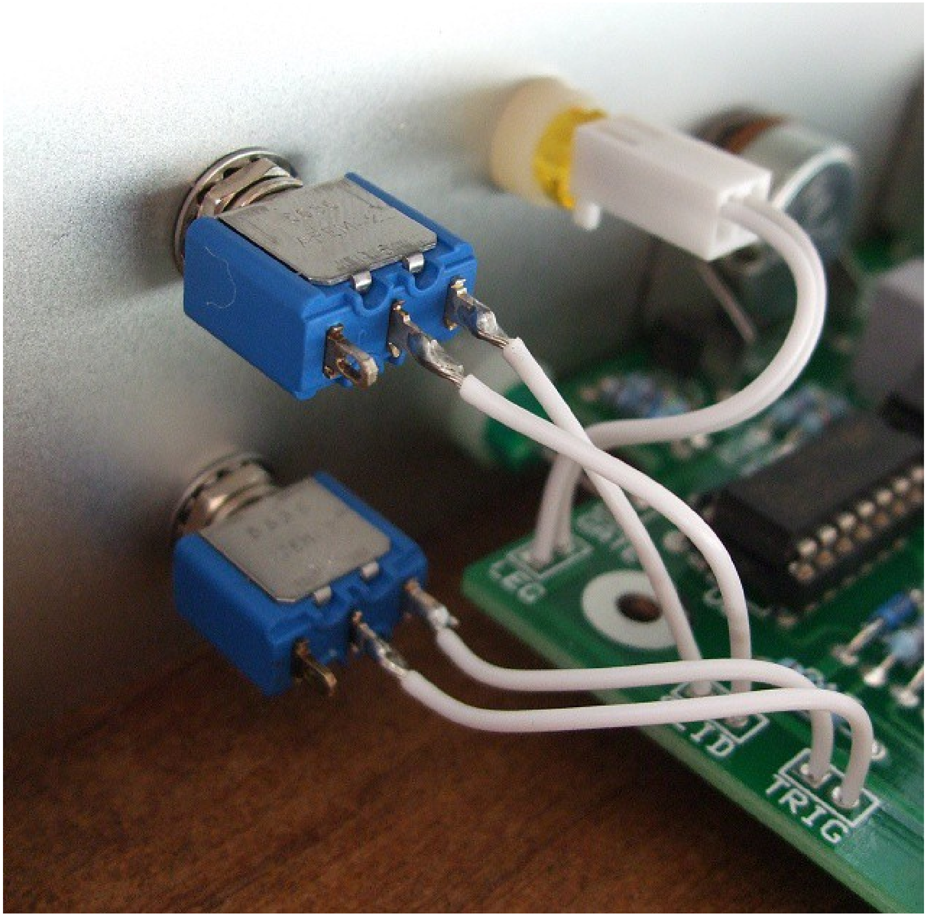
The slide LED can be wired in the usual fashion of using fly wires. I tend to use Molex KK housings and crimps simply because it keeps things tidy and means you don't have to solder or insulate the LED's leads.



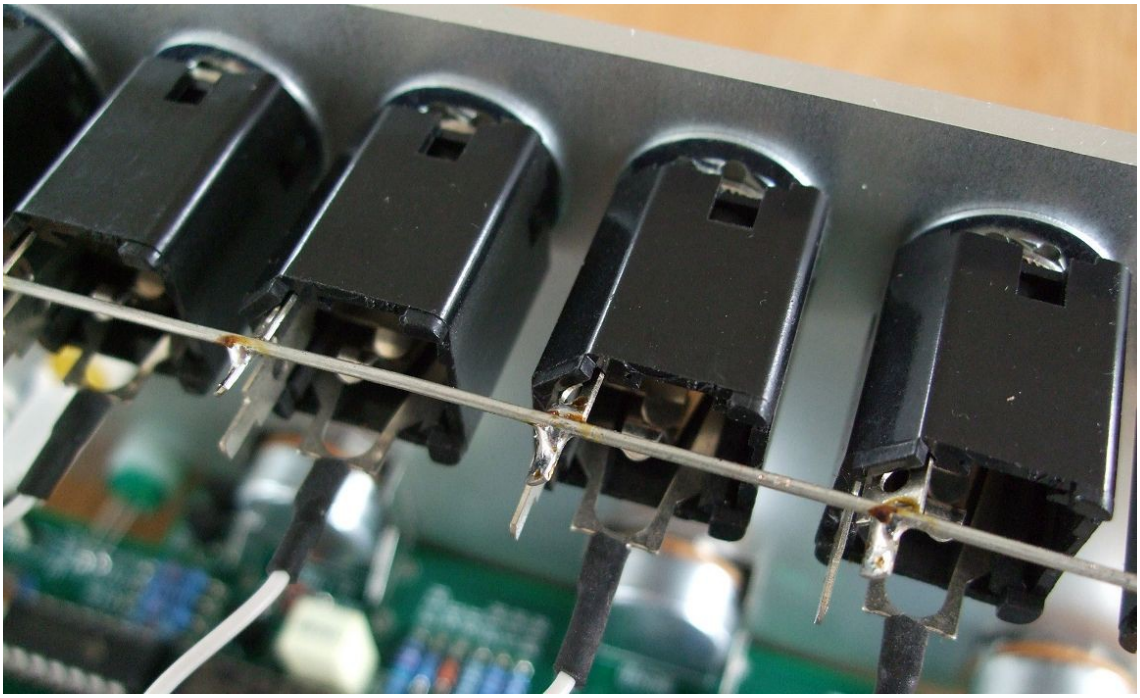
Connecting the Switches

The two switches can now be wired to the panel. These require short lengths of wire to connect them to the board. A standard SPDT switch has three solder tags. You will need to connect the two pads on the board to the top two tags on the relevant switch. The lower tag on each switch is left unconnected.

It doesn't matter which wire goes to which tag, the main thing is that each switch gets the correct pair of wires.



Connecting the Sockets



These are Switchcraft 112APCX types normally used for soldering direct into PCBs but here used with wires and heatshrink. Note the earth lugs of each socket have been connected together with 0.9mm solid core wire and then connected back to the board, pin 5 of CN1, with one wire from the top socket.

The suggested layout uses eight 1/4” jack sockets and two 5-pin DIN sockets. Wiring them up is straightforward enough. Use multistrand hook up wire to connect each socket’s signal lug to the relevant pad on the PCB. Keep your wires short but not too short. There is no need to use screened cable for such short runs.

If you have used Switchcraft 112APCX sockets you will see that they have three connections called lugs or tags. One is the earth or ground tag next to the diagonal part of the casing. The second is the signal tag which will be connected to the tip of the jack plug when it is inserted. The third tag is the normalised tag, or NC (normally closed) lug. The NC lug is internally connected to the signal tag when a jack is not connected. This connection is automatically broken when you insert a jack. The midiDAC uses only the signal and ground lugs on each socket. The other two lugs are not used at all in the suggested layout.

The PCB has been laid out to accommodate 0.1” headers for all interconnects. This is very useful for taking the board in and out for servicing.

The earth lugs of each socket are connected to ground via the standard Oakley ground connection, ie. Pin 3 on the PSU power supply header. This special ground, sometimes called 'panel ground' is available at pin 5 on CN1.

The sockets' ground lugs can be connected together with one piece of solid core wire. I prefer to use 0.9mm diameter wire because of its stiffness and low resistance.

The signal lugs of each 1/4” socket is connected up as follows:

Socket name	Header	Pin
Pitch	CN1	1
Velocity	CN1	2
Bender	CN2	4
Modulation	CN2	2
Aftertouch	CN2	1
CC	CN2	3
Gate	CN1	3
Slide	CN1	4

The MIDI sockets require careful attention. If you get the connection around the wrong way, a lot of confusion will result.

For the MIDI IN connector: pin 1 on the PCB goes to pin 5 on the 5-pin DIN. Note that pin 5 is marked on the socket and is NOT the fifth pin on the socket. Pin 2 on the PCB goes to pin 4 on the DIN plug.

For the MIDI OUT connector: pin 1 on the PCB goes to pin 5 on the DIN plug, pin 2 on the PCB goes to pin 2 of the DIN plug, pin 3 on the PCB goes to pin 4 on the DIN plug. On the PCB pin 1 is always depicted by a square pad.

If you have a problem with the midiDAC it is most likely that you have wired up the midi in socket incorrectly.

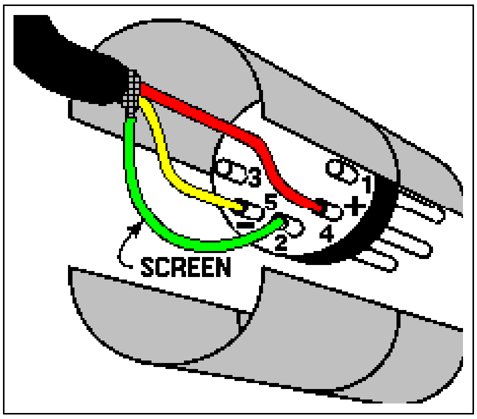


Figure 1. An internal view of the standard MIDI plug.

Power supply connections

MOTM and Oakley

The PSU power socket is 0.156” Molex/MTA 4-way header. Friction lock types are recommended. This system is compatible with MOTM systems.

Power	***Pin number***
+15V	1
Module ground (0V)	2
Socket ground	3
-15V	4

Pin 2 on the MAIN-2 header is connected to pin 3 of the PSU header and has been provided to allow the ground tags of the jack sockets to be connected to the power supply ground without using the module’s 0V supply. Earth loops cannot occur through patch leads this way, although screening is maintained.

MU and Synthesizers.com

The PWR power socket is to be fitted if you are using the module with a Synthesizers.com system. In this case you should not fit the PSU header. The PWR header is a six way 0.1” MTA, but the pin in location 2 is removed. In this way location 3 is actually pin 2 on my schematic, location 4 is actually pin 5 and so on.

Power	***Location number***	***Schematic Pin number***
+15V	1	1
Missing Pin	2	
+5V	3	2
Module ground (0V)	4	3
-15V	5	4
Socket Ground	6	5

+5V is not used on this module, so location 3 (pin 2) is not actually connected to anything on the PCB.

If fitting the PWR header and using it with a standard MU power distribution system, you will also need to connect together the middle two pads of the PSU header on the main board. This link connects the socket and panel ground with the module ground. Simply solder a solid wire hoop made from a resistor lead clipping, or bit of solid core wire, to join to the two middle pads of PSU.

If you are using an Oakley MU Dizzy distribution board with a five way power cable, the link on the PSU header is not required. This will allow the socket ground to be kept separate from module ground to prevent ground loops.

Circuit Description

The midi data is electrically isolated by U7, a high speed logic output opto-coupler. The output of U7 is pulled up via R44 and drives two circuits. One is the PIC, the processing engine of the midi interface. The other is the midi thru circuit. The latter is a circuit that simply copies the data seen on the MIDI input port and presents it to the midi thru output socket if one is fitted. U6 is a simple logic inverter (NOT) gate, and two of these inverting gates in series produce a buffered version of the opto's output signal. Although U6 hardly affects the signal at all, it does give it a current boost allowing it to drive the midi lines via the standard 220R resistors.

Note the midi out connector requires the middle pin to be grounded for shielding purposes. The midi specification states that the midi input should not, however, be grounded, and midi plug pin 2 is left unconnected.

The heart of the midiDAC is a preprogrammed PIC16F628. This is where Trevor Page's firmware is located. X1, a 4 MHz crystal provides the necessary timing for the PIC's internal oscillator. For more details on the operating system of the PIC see the 'Firmware Data' section in the User Manual.

Three of the PIC's output lines directly control a 12-bit multiplying DAC, U9. Although, the DAC is a 12 bit device we actually only use 7 bits. The other 5 bits of data are held low at the appropriate time in serial data stream.

Why use only the top seven bits? Firstly, midi data is arranged, in the main, in blocks of seven bits. For example there are only 128 notes that a normal midi keyboard can send out. Secondly, the PIC does not perform any CV scaling or tuning. This is sometimes used on other midi-CV converters to generate ADSR and pitch bend information that is then merged in the digital domain to the pitch data. 14 or 16 bit DACs are required for this. In the midiDAC all of our CV processing is done in analogue hardware.

So why not use an eight bit DAC? With an 8-bit device, although it gives us 256 steps to play with, the absolute accuracy of those steps is typically plus and minus 1/512 of the highest output voltage of the DAC. That is an error of around +/- 0.2%. This may not sound much but it does matter. In musical terms this means that the pitch difference between one pair of adjacent notes will be different to the pitch difference between another pair. In other words, when using a typical eight bit DAC which is specified to 0.5LSB accuracy, the notes played on your keyboard will be noticeably out of tune. Tim Orr, of EMS fame, reckoned that at least 10-bit accuracy was required for users not to **hear** any difference in the steps. In the midiDAC I have chosen to use 12-bits, because 12 bit DACs are affordable and easily available. The errors in a good 12-bit DAC, at around +/- 0.01%, will probably be negligible compared to VCO tracking errors.

The MAX551 is a current output multiplying DAC. This means two other things are needed to get it to convert digital data to an analogue voltage. Firstly, you need a very accurate reference voltage. This will set the maximum output voltage that the DAC circuit will supply. For the midiDAC the reference comes from a reference voltage chip, U3. This generates a stable 5.00V at its output.

A multiplying DAC will invert the reference signal applied at pin 19. So to get a positive output from our DAC, we have invert the 5V reference with U2 (pins 1, 2, 3). This is a precision op-amp, configured as an inverting amplifier to produce the required -5V.

The second item the DAC needs to create a voltage output, is a current to voltage convertor. This is strapped onto the output of the DAC, and in practice it simply consists of a single op-amp. This is U8. It needs to be accurate, have low drift over time and be fast settling. I have chosen an AD712 by Analog Devices. C19 provides stability.

With a -5V reference the output of the current to voltage convertor is a maximum of +5V. We need a higher level of signal than this, so we amplify the signal by exactly two. This is done with the other half of U8, which is configured as a non inverting amplifier of gain two. Notice the 0.1% tolerance resistors to set the gain. This is because we need to have accuracy here so that our pitch bend circuit works correctly.

The alert reader may well point out that we could have obtained a full scale output of 10V by providing the DAC with a -10V reference. This is true, but the datasheet for the MAX551 hints that best performance is obtained with a -5V reference.

C23 and R51 allows the op-amp to drive the high capacitance load of the sample and hold circuits without DC error or instability. D11 is there to protect the demultiplexer chip, U14, from any spurious negative voltages that may occur on power up.

The DAC's output is constantly varying. All six CV outputs, which are controlled by a stream of 12-bit data from the PIC, are represented by this fluctuating output. Each output has its own time slot and this gives rise to a waveform that has six distinct sections that continuously repeat, once every 4000th every second.

The demultiplexer based around U14 will direct each of these six outputs to its own output section. U14 is like an electrically controlled rotary switch. The PIC controls this switch directly via the MUX-A, MUX-B and MUX-B outputs. The switching is tied directly to match the output of the DAC so that the correct order of the time slotted output goes to the correct destination. The PIC also only enables U14 in such a way, via the MUX-INH line, so as to allow the output of U8 to settle accurately before allowing it through to the next stage.

Each output section is called a 'sample and hold', although to be strict the demultiplexer also forms part of the sample and hold. The capacitor in each S/H holds or stores the voltage that is briefly connected to it. The op-amp that is connected to it, allows this voltage to be 'sniffed' without effecting the actual value. The op-amps are connected as voltage followers or buffers. They have gain of 1. Thus, the sampled voltage on the hold capacitors can be found at the output of each op-amp. Note, that pitch CV and pitch bend use low offset FET op-amps, U12, for accurate pitch control.

Note that not all of the eight outputs from the demultiplexer are connected to S/H circuits. The PIC only processes six midi controllers so the other two outputs are unused.

The pitch and pitch bend CV are processed further by the midiDAC. This circuitry is seen on page two of the schematics.

The pitch CV is sent to the slide circuit. This circuit is based on the slide circuit from the Oakley 3031 synthesiser which in turn was based in part on the TB-303. When the slide is not enabled, the first portion of the analogue switch, U5, is off. The pitch CV is then passed through the slide pot straight to the op-amp buffer, U4 (pins 1, 2, 3). The resistance of the slide pot has no effect on the CV because the input impedance of the buffer is very high. The second portion of U5 is on, and the capacitor, C2 is charged up to the CV voltage. Slide is activated, either by the PIC via the SLD logic line, or manually via the 'SLID' header being shorted by the panel mounted SLIDE switch. This then causes the two sections of U5 swap states. The pitch CV now has to charge C2, via the slide pot, every time the CV changes. The higher the resistance of the slide pot, the longer it takes to charge up or down.

The slide signal from the PIC also controls the 'legato' LED via Q2. Q2 is turned on and off by the SLD. When Q2 is on, it shorts out the LED and turns it off. When Q2 is off, current from the constant current source based around Q3, will travel through the LED and it will light up. Both the gate and legato LEDs are connected in series and are driven from the same current source. The current source always takes the same current from the power supply, about 5mA, whether the LEDs are on or off. This means that there are no changes in supply current when the LEDs change state. This prevents LED switching noise from affecting the sensitive CV outputs.

The raw pitch bend CV output from pin 7 of U12 varies from 0 to 10V depending on the status of the pitch bend controller. For normal use, we require the pitch bend to go from -5V to +5V, with 0V representing the pitch bend wheel centralised. To do this we must subtract exactly 5V from our pitch bend CV signal.

This is done with a simple summing amplifier based around U2 (pins 5, 6, 7). This adds the -5V reference voltage to the pitch CV. Since the pitch CV is centralised at +5V, when we add these two voltages together, they cancel. However, a positive (upwards) bend produces a negative voltage so we must invert the summed output with another op-amp circuit. This is based around U4 (pins 5, 6, 7) and features capacitive loading protection via R29 and C9. The output of this circuit goes to the Pitch bend output socket and the Pitch Bend depth pot.

The Pitch bend depth pot allows a fraction of the pitch bend CV to be added to the pitch CV. Thus wiggling the pitch bender will automatically control the pitch of any connected VCOs. The circuitry based around both halves of U1 add the pitch bend CV to the pitch CV and to allow fine tuning of the VCO pitch.

Note the use of 0.1% resistors in the pitch bend summing circuit. If ordinary 5% resistors were used here, it is likely that the -5V and the +5V signals would not be exactly cancelled. This would result in a small error voltage, ie. non zero, at the pitch bend output even when the pitch bend lever is central.

Two forms of setting the initial pitch CV are provided. One is the TUNE pot mounted on the front of the panel. The other is INIT, which is a multiturn trimmer that will allow precise setting of the initial pitch CV, and thus aid centralising the TUNE pot's range. In this version of the midiDAC, the pot and trimmer take their end voltages from the +5V and -5V reference voltages. This should lead to a stable Key CV output even if the power supplies change slightly.

There are 12 notes in one octave, and a jump of 1V must represent one octave when applied to a VCO. Thus, 1/12 = 0.083333V or 83.33mV per semitone step with a perfect DAC. There are 128 notes in the midi scale but if the lowest note is considered at starting at zero volts the highest voltage must be 127 x 83.3mV = 10.58V.

With a -5V reference the smallest step our DAC will increment is only 78.7mV, so we need to amplify up the pitch CV by around 1.06 to get the desired 83.3mV stepping. This is done in the first summing circuit. The V/OCT trimmer allows to fine tune this gain to match your midiDAC to your VCO's sensitivity.

The PIC generates an inverted gate signal from one of its outputs. This is then inverted by a NOT logic gate, U6 (pins 1 & 2) and sent to the CN1 output header on pin 3. R34, D5 and D6 provide some protection to U6 should the gate output be shorted or used as an input. The gate LED is controlled by Q1 which, when the inverted gate goes high, shorts out the LED to turn it off.

U11 provides the regulated +5V supply for the PIC and DAC. R54 and C20 provide power supply decoupling from the higher +15V rail. The three ferrites on the board, L1 to L3, act as high frequency suppression to remove any digital noise from the power supply.

Final Comments

If you have any problems with building the module, an excellent source of support is the Oakley Sound Forum at Muffwiggler.com. I am on this group, as well as many other users and builders of Oakley modules.

If you can't get your project to work and you are in the EU, then Oakley Sound Systems are able to offer a 'get you working' service. If you wish to take up this service please e-mail me, Tony Allgood, at my contact e-mail address found on the website. I can service either fully populated PCBs or whole modules. You will be charged for all postage costs, any parts used and my time at 25GBP per hour. Most faults can be found and fixed within one hour, and I normally return modules within a week. The minimum charge is 25GBP plus return postage costs.

If you have a comment about this builder's guide, or have a found a mistake in it, then please do let me know. But please do not contact me directly with questions about sourcing components or general fault finding. Honestly, I would love to help but I do not have the time to help everyone individually by e-mail.

Last but not least, can I say a big thank you to all of you who helped and inspired me. Thanks especially to all the great people on the Synth-diy and Analogue Heaven mailing lists and those at Muffwiggler.com.

Tony Allgood at Oakley Sound

Cumbria, UK