# aurora: An Open Source Platform for Analog/Digital Control and Interactive Ambient Lighting in a Traditional DJ Form Factor


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**6.29.2008**


**Abstract - The aurora platform is a USB powered dual MCU data acquisition device in a typical DJ form factor. This open source device incorporates many features commonly missing in commercial MIDI controllers. aurora incorporates vertical and horizontal faders as well as backlit knobs and buttons. In addition to providing total control of PC MIDI software, aurora enhances the user's performance using three independent LED drivers control red, green, and blue LEDs mounted to the underside of the PCB for ambient lighting effects. The cost sensitive packaging, and low cost of production make aurora highly competitive with existing commercial models.**


## I. Introduction

Modern audio and visual performance software platforms consistently equal or surpass comparable hardware. The relatively low cost and exceptional creative control of these platforms, combined with the lack of affordable instruments and devices, has prompted many artists to seriously consider the advantages of computer aided performance.

User communities often play a strong role in dictating not only software feature sets, but also the form and function of devices used to control this software. Many of these software packages are MIDI compatible. In most cases, the software can be easily operated with an external MIDI controller or a MIDI compliant device.

As the art of PC based performance evolves, traditional manufacturers such as Pioneer, Vestax, and M-Audio will target users with hardware tailored for specific applications. To date, commercial MIDI devices lack the traditional layout and appeal of analog mixers. Additionally, current designs avoid using power hungry features like backlighting. The aurora mixer addresses these issues.

It provides expanded functionality not found in conventional controllers. aurora fuses the midi controller and audio mixer into one portable, intuitive platform. Unlike similar devices, analog or digital, aurora offers visual feedback that can be tuned to the users needs.

This paper describes the aurora device in detail. The concept and design are discussed. Thorough descriptions of the mixer's hardware and firmware are presented.

## II. The aurora Platform

The initial concept for the aurora 224 was to create a portable, practical, USB midi device within the familiar form factor of a two channel audio (or video) mixer. In addition, there was a desire to create something that is "open source" and designed for manufacture. These requirements, combined with visual feedback - ultimately in the form of bottom mounted LEDs - guided the design of the aurora.

As with many devices, the utility of a mixer can be measured, in large part, by the ease with which it can be used. Additionally, in a portable device, mobility directly competes with ergonomics for spatial resources. aurora, at only 7in x 10in, has all the trappings of a classic mixer – cross fader, EQ levels, channel selector buttons – sharing less area than a sheet of paper with 18 effects knobs and six buttons. The layout and organization of these components is especially important. Not only does this affect the usefulness of aurora, it also directly influences how easily the electronics can be designed and integrated.

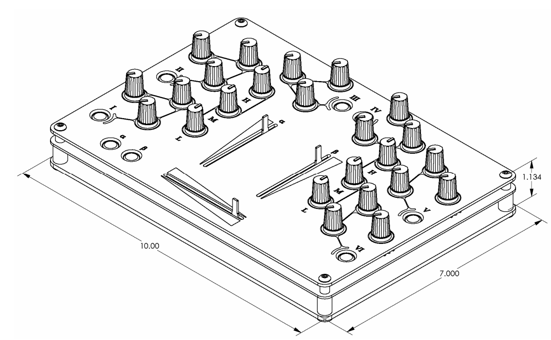



**Figure 1 – aurora mixer**

Balancing this equation started with grouping the effects knobs into triads, each with one button. This grouping scheme is not only visually interesting, but conveys a lot of information to the user. Keeping the locations symmetric also naturally associates half of the triads with each channel, so functions assigned by channel are easy to track.

Also critical is the illumination of the knobs. Mixers are typically used in poor light, and MIDI devices are almost always used near a computer monitor, which will negatively affect low light vision. Any unlit features on aurora are difficult to see in these conditions. The solution was to provide knobs that would easily betray their position in a low light environment. Color coding further improves usability in these conditions; all the effects knobs are white, while the EQ knobs are color coded: red for high, orange for mid range, and green for low. To the eye, the effects knobs naturally form groups because of their arrangement. Each group's accompanying button can indicate the group state (active or inactive) with a red indicator LED. Each button is also set into the panel and highlighted by a chamfer which has been left in natural aluminum. The purpose of this is to reduce the chances of accidental activation while maintaining easy access. The combination of color, symmetry, illumination, and the careful placement and separation of components creates a high level of organization and makes efficient usage of the device's limited power budget and small size.

Accordingly, the top panel is sparse. Each triad is simply identified by a simple curve which visually connects the three knobs, selector button and a roman numeral. The EQ knobs are labeled with a single letter each, and the channels are indicated simply as *a* and *b*. The black anodized surface serves to set off the labeling and illumination. This is just enough information to get organized and communicate with others, without anything distracting or superficial. This is depicted in Figure 2.

**Figure 2 – a completed aurora mixer**

aurora's height is one area where optimization did not affect ergonomics. However, balancing a thin, sleek design with the height needed to produce effective back lighting was tricky. Labertian LED's and a simple, clear bottom solve much of this. Stack up is another concern. The desire was to produce a device that, if motivated, anyone could produce without special tools and within a reasonable budget. This means no wire harnesses or other complicated interconnects that would increase cost or deter a hobbyist from building their own. Careful selection of components and assembly methods allows the aurora mixer to maintain a finished appearance in a simple, elegant design, and a deceptively naked style.

This open frame look is the natural result of a design that was meant to be at once striking and simple. In fact, to build a functional aurora unit, the only custom piece of hardware required is the PCB. Even in a fully assembled unit, only the top and bottom panels and PCB are required to be specially ordered. Every other component is a readily available, off-the-shelf part. Using these "found objects" as components in the design naturally produces an industrial look. This is balanced by the highly finished top and bottom panels and over-molded knobs.

Despite its small size, aurora does not feel cramped or crowded, and there is a comfortable amount of room between the knobs, buttons, and slides. Combining lots of functionality in a small package, aurora is light enough and small enough to go anywhere the user wants, and will fit in even the most cramped setup. Combining these features with user controllable visual feedback, aurora adds a new dimension to midi and human interface devices.

**Figure 3 – an illuminated device**

## III. Hardware Technical Description

The aurora hardware platform is a USB powered dual MCU data acquisition device. The device features twenty four backlit analog potentiometers and three linear slide potentiometers. Eight user toggle buttons with LED feedback are also available. Three independent LED drivers control red, green, and blue LEDs mounted to the underside of the PCB for ambient lighting effects. Two ICP headers allow for in circuit programming. The Aurora circuitry can be defined by four separate circuits. They are: 1) power management, 2) the digital circuitry, 3) the analog and measurement circuitry, and 4) the PWM controlled LED drivers. These blocks are depicted in Figure 4.

aurora's power is derived from a 5V USB supply. A UB232R module was selected to accomplish USB/UART connectivity. U8, a slew rate limited pMOS switch, regulates device in rush current and prevents operation while the device is being enumerated. U9 and U10 are both linear regulators and comprise the digital and analog power supplies respectively. The measurement reference voltage is 3.3V and at seven bits of resolution, one LSB is 26mV. A single ended measurement scheme was employed for simplicity. The digital and analog regulators are both linear and isolated.

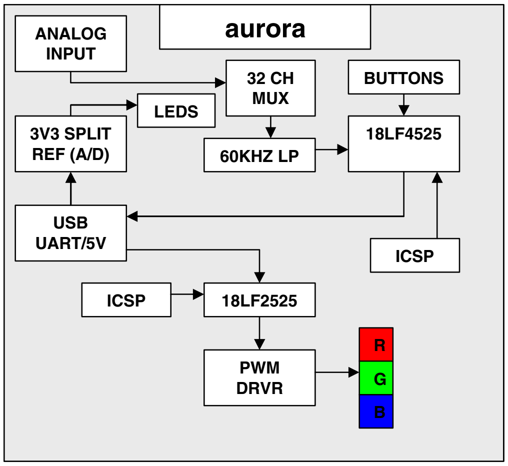



**Figure 4 – aurora Hardware Diagram**

The digital portion of the hardware is comprised of two 8-bit MCUs operating at 20MHz. Device U1 is a PIC18LF4525 that performs the ADC measurements, detects user button presses, and transmits data back to the PC. Device U3 is a PIC18LF2525 and functions as a 3 channel 8 bit PWM controller. It receives data from the PC. Diode D1 isolates the ICP programming voltage from the rest of the device circuitry. In normal operation, the forward voltage of the diode reduces the PIC operating voltage and limits the clocking frequency. PIC18LF parts are rated to operate under these types of conditions. IC U2 is an open drain power on reset chip and the MCUs share the MCLR signal. The digital decoupling strategy uses several capacitors in parallel, placed close to device ground to minimize ripple caused by switching. By choosing multiple values, low impedance frequencies across a large range are decoupled from DC. Optimal decoupling is achieved at roughly the third harmonic of 20MHz. The capacitance can be increased if desired; be aware that around the kHz and lower MHz band, the on-chip PLL is very sensitive to variations in VDD. This will cause of the MCU to reset. CTERM and RTERM are used to reduce the negative effects of discharging the ADC's sample and hold capacitor. If the Sallen-Key is omitted, RTERM and CTERM form an LP filter.

A 32 channel analog multiplex is the core of the measurement circuitry. The pin count on device U1 limited the amount of pins available for analog measurement. The ADG732 is controlled by a series of parallel data and strobe lines and is clocked at roughly 44kHz. IC U12 is a single supply rail to rail opamp rated at a Vin noise of 6.5nV/rHz at 10MHz of bandwidth. RMS noise of U12 is roughly 20µV and about 100µVpp over 10MHz. The opamp forms the two pole Sallen Key filter designed to have the primary 3dB point at 60kHz. NP0 capacitors are used to ensure low distortion. Polystyrene capacitors also work but will add cost. Adding a non inverting follower between U12 and the MCU would reduce the impedance at the input of the MCU as well as the charge time of the ADC circuitry. Proper decoupling at these devices minimizes ripple when all analog potentiometers are in a worst case position (the output of U12 looks like a square wave).

The three high brightness LEDs are controlled by three low side nMOS switches. The LEDs are powered by the 3.3V digital rail. The green and blue LEDs have typical forward voltages that are larger than the supply, so maximum brightness is limited. Q1, Q2, and Q3 can be modulated in phase. As a result, the USB power supply must handle large transitions of current (~200mA) on the order of nanoseconds. The drivers are slew rate limited and this reduces the instantaneous load seen at the PC power supply. This is at the cost of power dissipated by the transistor itself because of the internal Rds. An improvement uses an nMOS switch whose drain is connected to the gate of a high side pMOS switch. The pMOS transistor is then slew rate limited and the effects of Rds are reduced.

## IV. Firmware Technical Description

The aurora platform is controlled by two independent PIC18 microcontrollers. A PIC 18LF4525 communicates changes in the status of all knobs, sliders, and buttons by sending packets to an external computer. A PIC 18LF2525 receives packets from the external computer and bit-bangs three channels of PWM to control the red, green, and blue ambient lighting LEDs. An overview of the protocol is given, followed by a breakdown of the code running on the 18LF4525 and 18LF2525.

Due to a lack of time and experience with development of Windows MIDI device drivers, aurora uses a serial interface program such as MAX/MSP or Pure Data to interface with the two microcontrollers. For this reason, there was some freedom in development of a serial protocol. A simple protocol was chosen for ease of use in MAX/MSP and Pure Data. Originally, a dynamically scalable protocol was developed to maximize the effective bandwidth usage, but this effort was ultimately abandoned due to the complexity necessary to decode the packet in MAX/MSP and Pure Data.

The protocol for the PIC 18LF4525 uses a simple synchronization header followed by the MIDI Control Change (cc) identifier and the corresponding data. Two consecutive hexadecimal 0x55's are used for the sync signal. The data byte holds the 7-bit value, similar to the MIDI standard. Eight bit values can be used instead of 7-bit values by recompiling using a preprocessor directive. Each packet from the PIC 18LF4525 is 4 bytes long.

The protocol for the PIC 18LF2525 uses the same sync header followed by the red, green, and blue 8-bit intensity values. Each packet received by the PIC 18LF2525 is 5 bytes long.

Slider and knob positions are encoded as analog voltages. The PIC 18LF4525 uses a single 10-bit ADC to measure the positions of all sliders and knobs. For each position measurement, the analog multiplexer is set to feed the appropriate signal into the PIC and the internal ADC performs the conversion. Due to relatively high amounts of noise in the two least significant bits, only the most significant 8 bits of the reading are kept, which also saves RAM usage. Readings for each knob and slider are fed through a rolling average algorithm for further filtering of noise. The rolling average offers a temporally versatile and computationally efficient way to filter out relatively low frequency noise that was not filtered by the low-pass circuitry.

Changes in the buttons are read into the PIC as digital inputs. Simple software debouncing ensures the integrity of detecting a change in value. A software latching system was employed for each button to ensure that only falling edges change the state of the button. Button indicator LEDs are set according to the current state of the latching system.

The main loop of the 18LF4525 code coordinates measurements, detects changes in values, and prepares data to be sent over the UART. The ISR is responsible for sending packets when triggered by the main code. The ISR is designed to find the most current data to be transmitted, load the appropriate byte into the UART shift register, then return to the main code to continue detecting changes before sending the next byte of a packet. This method allows the most up-to-date data values to be sent and reduces effective latency in relaying information to the computer.

The PIC 18LF2525 receives packets from the external computer that hold 8-bit intensity information for the red, green, and blue channels of aurora's ambient lighting system. The main function essentially does nothing other than reset the watchdog timer. All of the code's functionality resides in the ISR.

The ISR handles each byte of a received packet using a simple but robust communication scheme. The communications system ensures that the two first bytes of the received packet match the synchronization signal (two consecutive hexadecimal 0x55's). If that is true, the following three bytes are assumed to be the red, green, and blue settings. Otherwise, the communication system ignores received bytes until the sync signal is received. This allows the system to resynchronize itself if bit errors occur without excessive overhead.

The 8-bit PWM is designed to run at a frequency of approximately 76.3Hz. This is above the critical flicker fusion (CFF) frequency of a standard observer, and is therefore perceived as a constant light source by observers that are not in motion. The bit-banged PWM is generated on three separate digital output pins of the PIC. The duty cycle for each PWM channel is controlled by three independent internal timers.

In timing sensitive applications, such as bit-banging PWM, knowing the number of instruction cycles between events can become important. The smallest amount of time expected between interrupts is found when the duty cycle of a channel is set to 0.39% ($1/2^8$). This time corresponds to 51.2 µs or 256 instruction cycles at a clock speed of 20MHz. In the worst case, there will be a sufficient number of instruction cycles between interrupts to service consecutive timer interrupts and activity on the UART. Running the PWM much faster can begin to create timing concerns in certain cases.

## IV. Applications and Performance

To lessen the burden of software development and to simplify the aurora/PC interface, the control software was designed in Pure Data and Max\MSP. These two platforms were chosen because they can easily create MIDI packets. Additionally, artists and performers are familiar with these software packages and can easily develop new software interfaces specifically tailored to their application. The simplicity of these programs belies their capability, especially when creating patches that control aurora's onboard ambient lighting.

One application that has been thoroughly tested is using aurora as a DJ controller for Ableton Live. The layout of the faders, knobs, and buttons compliments the Ableton Live software interface. This increased utility allows the performer to spend less time looking at the computer screen and more time interacting with the music and the audience.

As an open source design, users can reprogram the firmware and tailor the platform to their specific tastes. The versatility of the device extends beyond the limits of a MIDI controller. Users can write their own pieces of software, or revise hardware and firmware.

## V. Conclusions

aurora is a mixed signal analog and digital acquisition device packaged cost effectively. It features controllable ambient lighting and easily integrates with typical MIDI software to function like a typical DJ mixer. As an open source project, the mechanical, electrical, and firmware portions are all available for the community to use and learn from.

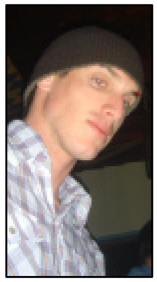
The early DIY synthesizer era, in which commercial designs were prohibitively expensive or simply lacked certain features, forced users to design their own systems. We have created aurora in this same spirit of ingenuity and creativity.

We hope that our project serves as a resource and inspiration for those who wish to build their own custom devices and electronics.

**Please visit www.auroramixer.com for documentation, files and media related to this project.**

## About

**Matt Aldrich** received his B.S. in Electrical Engineering from Yale University in 2004. He is currently a research assistant in the Responsive Environment Group at MIT's Media Lab.



**Mike Garbus** currently works as an Embedded Systems Engineer at a solid state lighting company. He received his B.S. in Electrical Engineering from Virginia Tech in 2003. He started his professional career working at a particle physics laboratory, and has since worked in the private, military, and intelligence industries primarily focusing on signal processing and algorithm design.

**Maro Sciacchitano** designed the form factor and is responsible for the look of aurora. He currently works in solid state lighting and control systems. His past work included marine equipment, instrumentation, vacuum systems and solar powered vehicles. Maro received his B.S. in Mechanical Engineering from Yale University in 2003.