Tortuga Audio

V4 Preamp Controller Manual

Tortuga Audio

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Chapter 1. Introduction

Purpose

This manual is the complete guide to a Tortuga Audio preamp built on the V4 controller platform. It's ordered so day-to-day operation comes first - the Controller menu, item by item - and the underlying LDR technology, legacy remote pairing, and reference material follow afterward, so using the preamp never requires wading through engineering detail you don't need.

1.1. What a preamp does

A preamp sits between your source components and your power amp or powered speakers. Its core job is simple: select which source plays, and control how loud it is. Every preamp needs some way to attenuate that signal. Conventional preamps use a potentiometer or a resistor-ladder network switched manually or by relays - basically a mechanical device is used to throttle the audio signal.

1.2. The V4 system

A Tortuga Audio preamp does its job electronically and optically using Light Dependent Resistors (LDRs) instead of a conventional pot or resistor ladder. An embedded V4 controller is the engine behind all that - it drives and measures the LDRs, keeps channels matched, remembers your settings, and puts all of it behind an on-screen display, a control knob, and an infrared remote.

The essential V4 system consists of the V4 board itself, the OLED display module that includes a rotary encoder and infrared receiver, plus a handheld infrared remote control.

Figure 1. The V4 system | board & OLED display & encoder & remote

The V4 preamp is operated and controlled primarily through a handheld infrared remote and secondarily via a rotary encoder with integral pushbutton.

The ePot.V4 is the 5th generation Tortuga Audio preamp controller since the release of our first version in 2012.

The ePot.V4 system at a glance

Topic	Description
Preamp controller system	The V4 controller platform performs volume control with Light Dependent Resistors (LDRs) in place of a conventional pot or resistor ladder. The V4 controller is the electronics behind all that - it drives and measures the LDRs, keeps channels matched, switches inputs, remembers your settings, and puts all of it behind an on-screen display, a control knob, and an infrared remote.
Passive preamp	Even though the V4 uses power to control the LDRs, the V4 is fundamentally a passive attenuator wherein no power supply is applied to the audio signal producing the purest audio signal possible.
Optical volume control	LDRs are optical devices with no mechanical parts to wear out, scratchy contacts, or channel drift with age
Self-calibrating LDRs	Precision LDR current control with built-in high resolution analog measurement and pulse width modulated command generation that enables in-situ calibration of the LDRs
Subjective performance	If you believe the truth is in the listening, it’s unlikely you’ll be disappointed.

1.3. The V4 board

The V4 is a populated printed circuit board measuring 2.7 inches wide by 5.2 inches long. The heart of the V4 is a software driven 32 bit ARM microcontroller. A microcontroller is basically a computer that runs without a conventional operating system. The code runs on the "bare metal" and the firmware handles everything by itself with no operating system safety net.

The V4 departs slightly from this structure in that it employs a basic Real Time Operating System (RTOS) that divides the firmware into separate tasks to make execution robust and responsive.

The features of the V4 board are discussed in detail in section Section 1.3

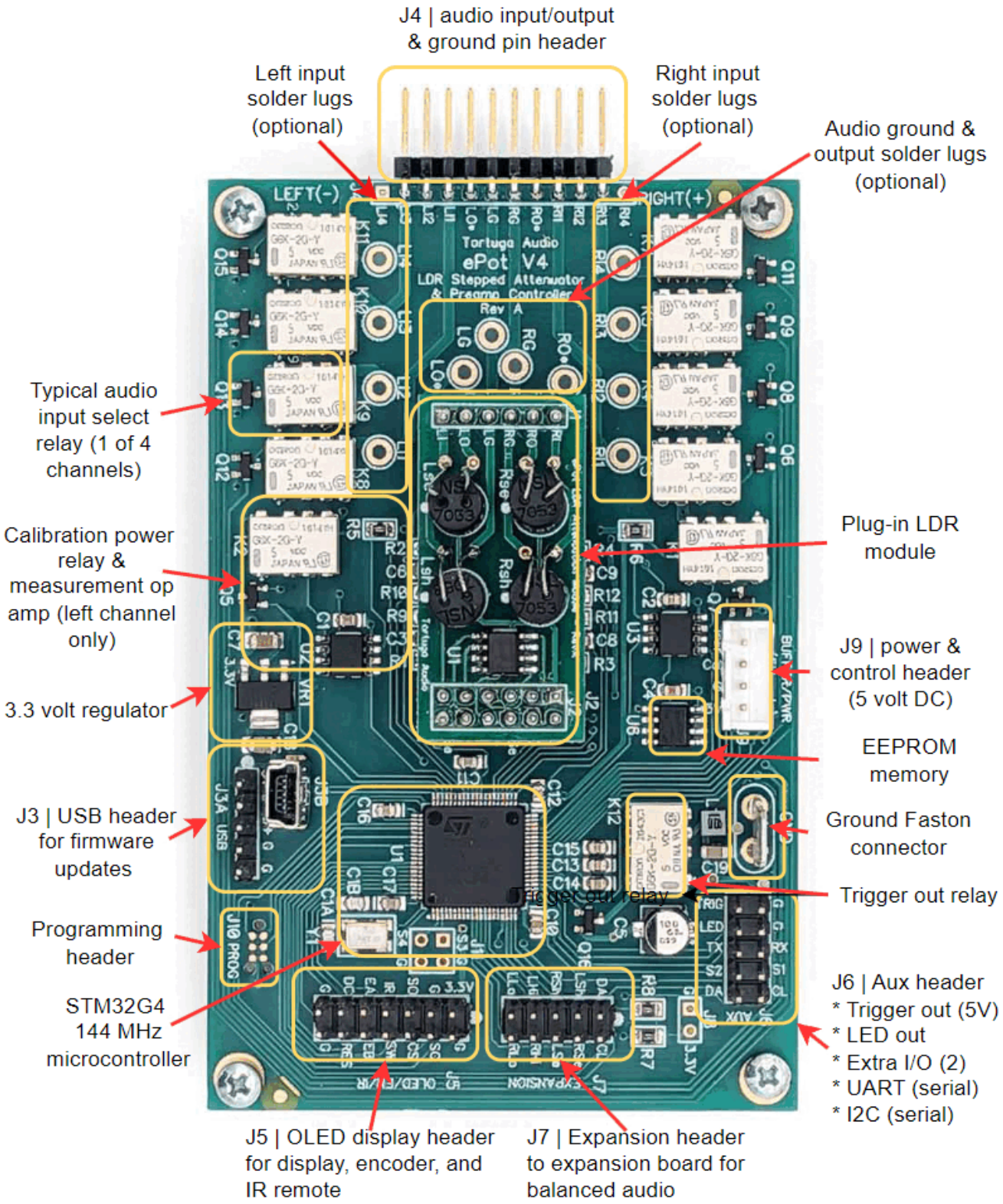


Figure 2. The V4 system | board & OLED display & encoder & remote

1.4. The OLED display

The OLED display is a 3.2 inch, 256×64 bit, high contrast, white-on-black graphical display. It works interactively with the remote to allow the user to navigate a control menu tree to adjust controls or change options. The OLED display is capable of displaying a wide range of text, numbers, lines, and images with each pixel having a 4 bit grayscale brightness level between 0 and 15. The high

contrast display enables the user to easily view, configure and control the V4 based preamp.

Figure 3. Default volume control view

Figure 4. OLED display assembly - front view

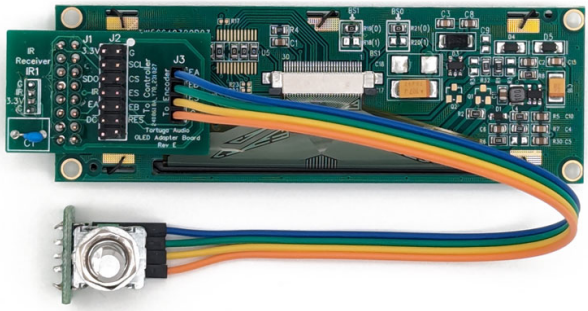


Figure 5. OLED display assembly - rear view

The infrared sensor is located at the right end of OLED assembly shown in Figure 4. The infrared sensor must have a clear line of sight into the room where the user has the remote given that infrared devices have limited ability to transmit around obstacles.

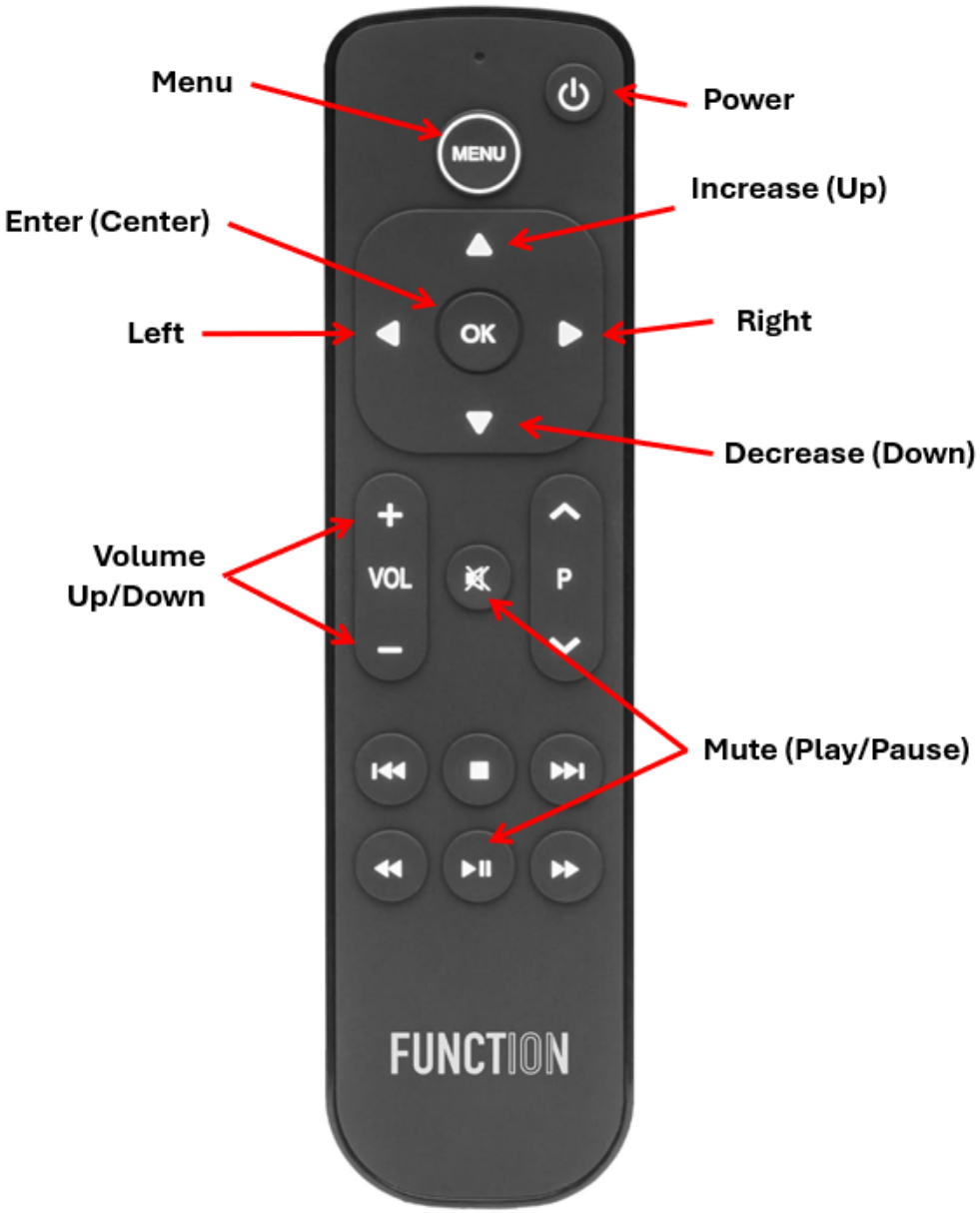
Figure 5 shows the back side of the OLED assembly. The OLED ribbon cable and encoder cable both terminate on the OLED interface board located on the left-rear end of the OLED assembly.

The OLED assembly is powered by the V4 board via the 14 pin ribbon cable.

1.5. The Remote

A remote is the primary way to control the V4. The remote allows you to control volume, mute, select inputs, adjust channel balance, and more, all while navigating the V4 controller manu without leaving your listening chair.

The V4 uses the NEC infrared protocol originally developed by the Nippon Electric Company of Japan (now Renesas). The NEC protocol is widely used in over 50% of infrared remotes today. Current V4 firmware is capable of learning the codes of any NEC compatible infrared remote.



Early versions of V4 firmware were limited to only communicating via the silver Apple remote that now no longer in production.

Tortuga Audio currently supports the Function remote made by function101.com. The Function remote was introduced in response to Apple no longer offering its simple 7-function silver remote and serves as both an Apple replacement as well as general purpose universal remote.

See The menu for how the remote interacts with the controller menu, and see Remote learning for how to get your V4 controller to learn the control codes of your specific remote.

1.6. The Encoder

The rotary encoder with integral pushbutton is the secondary control device for the V4. The encoder can perform most, but not all, the functions of the remote. A few control tasks are limited to the encoder only.

See The menu and related controls for how the encoder is used with the control menu and functions.

1.7. Balance of system

To assemble a V4 system into a fully functioning preamp, you'll need to acquire additional materisl including, but not limited to, an enclosure, input/output jacks, power entry module, panels with custom cutouts, and a source of clean 5 volt power. To be clear, Tortuga Audio does not currently offer these other items for sale.

1.8. Specifications

▼ *Click to expand and view specification details*

Topic	Description
Preamp type	Passive - definition: no active manipulation of the audio signal by a power supply
Application	2-channel single-ended or balanced audio (balanced requires 2nd board)
Signal isolation	Audio signals are optically isolated from control power
Attenuation method	L-pad resistive voltage divider network using light dependent resistors (LDRs)

Topic	Description
Attenuation perception	Smooth, quiet, continuous transitions between each discrete attenuation step
Attenuation range	100 discrete attenuation steps of ~0.6 dB per step over a 0 to 60 dB range.
LDR current control	Precision 16 bit resolution closed loop LDR current control
Attenuation module	Replaceable plug-in LDR attenuation module each with 4 LDRs (2 LDRs per channel).
Muting	Fully muted output at step 0 using dedicated muting relay
Volume ramping	User selectable volume ramping behavior (down and up) during muting/unmuting
LDR calibration	User-initiated in-situ calibration of each LDR against a 100 step resistanc schedule
Gain	Unity (1x) gain passive - no amplification
Input coupling	Direct coupling with no passive coupling capacitors or active buffering
Input switching	Switching between 4 input devices using miniature electro-mechanical relays
Input impedance	50k default input impedance with up to 9 other impedance settings each adjustable between 1k and 99k and the ability switch between impedance levels with live music to optimize input impedance for their system
Channel balance	Adjustable channel balance up to 20 steps (12 dB) left or right while maintaining overall volume level
Signal interconnection	Pin header or individual solder lugs for connecting inputs, outputs and signal ground
Signal ground	Audio signal grounds are isolated from power ground within controller, however, audio signal ground must share common ground with power supply via an external star ground point in order for LDR calibration feature to function properly
Remote control	The V4 can learn and use any remote that uses the NEC infrared protocol.
Encoder control	Partially controlled via inputs from a rotary encoder with integral pushbutton
OLED display	8 bit grayscale high contrast white-on-black 256x64 pixel graphic OLED display with an intuitive, easy to use, menu based control scheme. OLED display assembly integrates the display, an infrared receiver and an encoder into a single assembly with single 14 pin ribbon connection to the V4 board.

Topic	Description
Auxilliary controls	Optional (via customized firmware) monitoring and control interfaces including trigger out, status LED, serial UART, serial I2C, and digital I/O pins.
Total harmonic distortion	Typically less than 0.5% | essentially inaudible
Power requirements	~5 volts regulated DC rated at or above 0.5 amps
Microcontroller	ARM based STM32G4 32 bit microcontroller running at 144 MHz
Firmware	Object oriented C++ firmware running under a lean real time operating system (FreeRTOS). Firmware updating via USB connection using a vendor based updating application that runs on a PC, Mac, or Linux machine
Printed circuit board	2 layer FR4 board with high quality gold plated nickel immersion solder pads
Optional buffer board	Custom designed plug-in daughter buffer board converts the passive V4 into an active preamp with adjustable gain
Optional power supply	Custom linear power supply provides a very low noise source of primary 5 volt power plus split +/- 12 volts for the optional buffer board

Chapter 2. Getting connected

The following information illustrates how to connect the V4 to audio input/output and power supply.

2.1. Star grounding

A star ground is a way of wiring a circuit's ground connections so every part of the circuit connects back to one single common ground reference point, rather than daisy-chaining from one ground point to the next.

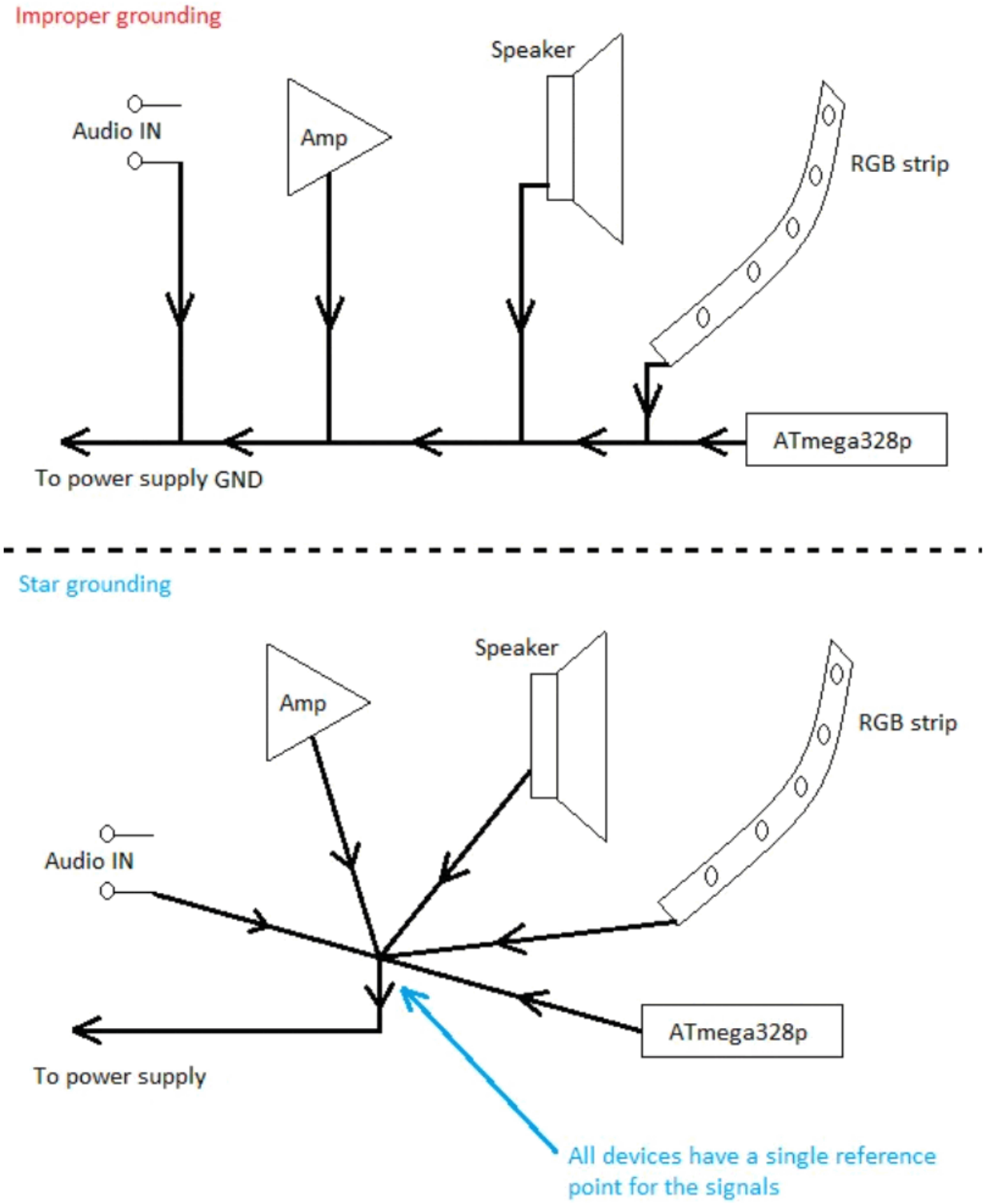


Figure 6. Illustration of proper star grounding

In the illustration above, the "improper grounding" image shows each audio device connecting its ground anywhere it wants along a power supply ground wire that ultimately arrives back at the power supply. The problem with this approach is every ground connection in this schematic is at a different ground voltage potentials (i.e. they are not all equal or all zero)

The reason this matters in a preamp is that ground wires are never perfectly resistance-free. A small amount of current always flows through them, and that current creates a tiny voltage drop along the wire's length. With two or more circuits sharing the same stretch of ground wire on their way back to the power supply, one circuit's current can nudge the voltage on that shared wire, and

the other circuit reads that nudge as if it were part of its own signal.

Bad grounding equals hum, buzz, noise....

...or faint noise riding along with the music, especially picked up from the power supply or from a noisy section of the circuit like a display or a digital chip

With proper star grounding, every audio device gets its own dedicated path back to one common ground point, where none of them can push their noise onto another section's ground path. Each stays electrically isolated from the others except at that single shared point, which is exactly the goal!

Star grounding goal

All devices have a single common ground reference point for their signals

2.2. Single-ended

The diagram below illustrates input/output connections for a single-ended configuration with only a single input device, along with the power connection and star grounding concept.

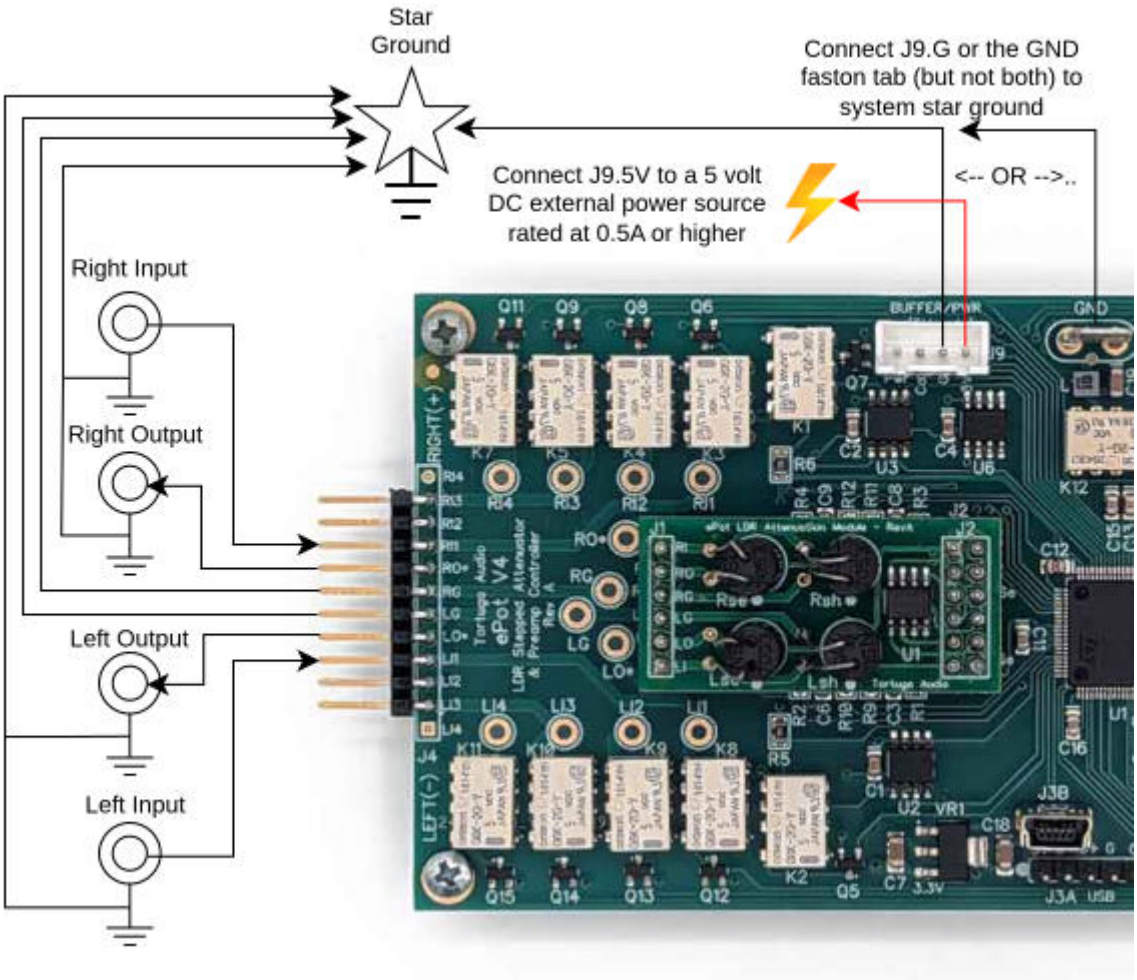


Figure 7. V4 single-ended input/output & power connections

V4 power connection (J9)

As is mentioned elsewhere herein, the earlier Rev A board shown above differs from later Rev B/C boards. For B/C boards the 5 volt power connects to where the GND tab is located on the A boards. That faston ground tab was removed from the B/C boards and replaced with +5/Gnd solder lugs for direct solder connection of 5 volt power to the Rev B/C V4 boards.

2.3. Balanced

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Need balanced wiring here.
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Chapter 3. Control & operation

Control & operation of the V4 system is designed around the use of a handheld remote as the primary control device. A rotary encoder with integral pushbutton serves as a secondary control device. A monochromatic white-on-black OLED display provides the visual man-machine interface.

The OLED display utilizes a simple, mostly flat, menu tree structure that allows the user to visually navigate up and down the menu tree using both the infrared remote and the rotary encoder.

Each item in the menu tree represents a control function or feature. Some controls provide direct manipulation of the V4 operation while others adjust settings and options. At least one control is purely informational.

3.1. Rules for navigating the menu

Each menu item and its associated control are covered in their own sections below.

The rules for navigating the menu tree are fairly simple and intuitive. Here they are spelled out.

You select and activate a menu item by clicking on it. The Volume control is the default control function and is where all other controls escape back to by default.

Rules for navigating the ePot.V4 control menu

Topic	Rules
Volume control (the default control)	When the V4 is turned on, the controller reverts to the default volume control. This is where the controller - and the user! - spend most of their time together.
Escape via Menu button	No matter where you are in the menu tree, you can always escape back out to the main menu by pressing the Menu button on the remote. One or more escapes will land you back at the default volume control. Pressing the Menu button when you are already at the default volume control simply escapes you back out to the menu tree once again.
Return via Ok/Enter button	No matter where you are in the menu tree, pressing the Ok/Enter/Center button on the remote usually takes you immediately back to the default volume control view.
Navigating menu tree	Use the Raise and Lower buttons on the remote to navigate down and up the menu tree which is detailed below.

The menu tree is composed of the 14 menu items listed in the table below. Each menu item has an associated control that the use enables by clicking on the menu item. Each of the menu items and their associated control are explained in the listed control sections.

V4 control menu tree at a glance

Menu item	Control	What it does
Power	Section 3.2	Power-on behavior settings

Menu item	Control	What it does
Volume [DEFAULT]	**Section 3.3**	**Adjust playback volume**
Input	Section 3.4	Select the active input and rename its on-screen label
Balance	Section 3.5	Adjust left/right channel balance
Display	Section 3.6	Adjust screen brightness, contrast, and related display settings
Impedance & Calibration	Section 3.7	Set input impedance and run LDR calibration
Number of Inputs	Section 3.8	Choose how many inputs appear when cycling through Input
Volume Ramp	Section 3.9	Choose whether volume ramps smoothly or jumps immediately when muting or switching inputs
Volume Options	Section 3.10	Choose whether the left/right gesture adjusts balance or switches inputs
Volume Units	Section 3.11	Toggle the volume readout between steps and dB
Volume Max	Section 3.11.1	Cap the volume the preamp comes up at on power-on
Warmup	Section 3.12	Set trigger-out delay and tube warmup wait time (Exemplar variant only)
Info	Version / Info	View model, hardware/firmware revision, and serial number
System	Section 3.13	Switch between single-ended and balanced system type
Firmware	Section 3.14	Enter the bootloader to update firmware
Reset	Section 3.15	Erase impedance & calibration data
Remote Learning	Remote learning	Teach the preamp to respond to any infrared remote
About	About (section pending)	Model information screen (Pandora variant only)

3.2. Power

Applying power When power is first applied, the display briefly shows the word "Boot," then the Tortuga turtle logo, which after a very brief pause fades to black, at which point the preamp is now booted and in standby, ready to be turned on.

Turning on sequence Regardless of how turn-on is initiated, the turn-on sequence

	starts with the "Tortuga Audio" display splash followed soon after by the model name. The Tortuga Audio name then fades away, and the controller enters default Section 3.3 control mode. At this point the controller will ramp or jump to the previous volume setting the controller was left at when it was last turned off.
Turning on | remote	Pressing either the Ok/Enter, Menu, or Power buttons will turn the unit on from standby/off. Earlier versions of the V4 firmware may turn on from pressing other buttons on the remote as well.
Turning on | encoder	A brief press/release of the encoder pushbutton will turn the unit on from standby/off.
Turning off sequence	Regardless of how turn-off is initiated, the display briefly indicates an "off" message, followed by the Tortuga Audio turtle splash which then fades to black at which point the controller is indeed turned off.
Turning off | remote	For remotes with a dedicated power on/off toggle button like the Function remote, the simplest way to turn off the V4 is to press the power button. You can also press the Menu button, press the Raise button to go up 1 step to the Power menu, then press the Ok/Enter button to execute the turn off. press Power, in the upper-right corner of the function remote, at any time. Alternatively, mute the volume first, then press Enter - the display shows "Mute," and a second Enter press turns the unit off.
Turning off | via encoder	press and hold the encoder's pushbutton for 2-10 seconds, without turning it, then release.

3.3. Volume

The volume control/view Volume is the default for the V4 controller. It's where the controller starts off after being turned on, and it's where every other control function escapes back to by pressing the Menu button on the remote (see The menu).

The volume control serves a dual purpose. In addition to volume adjustment, the volume control allows the user to optionally switch inputs without jumping out to the menu and selecting the Input control. The other option is to channel balance adjustment. You can chose which secondary control mode is enabled by selecting your preferred mode via Section 3.10.

Figure 8. Volume menu view

Figure 9. Volume control view

Information | volume

The volume control shows the volume as a step between 1 and 100 by default, but can also be displayed as decibels (dB) ranging from -60 to 0 dB (approx 0.6 dB per step). The volume level is also shown a slider bar immediately below the numeric volume level. Switching between step display and dB display of volume level is handled in Section 3.11. When volume is Muted (set to zero volume), the volume control will display "Mute" instead of a numeric value.

Information | input channel

The upper left corner of the display shows text in the form of a dynamic label. The first value is the input # and the remaining text is a user label for the selected input #. The default label is "1Input1" which indicates the controller is set to input #1 which has text label "Input1". The text labels can be edited - see Section 3.4 for editing input labels.

Information | balance

When Section 3.10 is set to balance adjust mode, the left or right balance adjustment is shown numerically by a value to the left or right of the volume level. The example below shows the channel balance shifted 6 steps to the left.

Figure 10. Volume, with the balance secondary control active

Volume adjust | remote

Volume can be changed using the Raise and Lower buttons on the control ring of the remote. A quick press/release will increment volume by /-1 step. By holding down the raise/lower buttons, the volume change will auto-repeat until the button is released. The Function remote also has dedicated Vol and Vol- buttons which increment volume only 1 step by key press and do not auto-repeat. Which buttons you use for volume adjustment is entirely a personal preference - the raise/lower buttons are more responsive, the Vol+/- buttons are more conservative.

Volume adjust | encoder

Volume can also be changed using the encoder. Turning the encoder to the right increases volume, while a turn to the left decreases volume.

Balance adjust | remote

While in the volume control view, and with Section 3.10 set to balance, the Right and Left buttons on the remote will shift channel balance right or left accordingly.

Balance adjust | encoder

While in the volume control view, and with Section 3.10 set to balance, a press/hold of the encoder pushbutton while

	simultaneously turning the encoder will shift the channel balance right (clockwise) or left (counterclockwise) accordingly.
Input switch | remote	While in the volume control view, and with Section 3.10 set to input, the Right and Left buttons on the remote will switch to the next input number.
Input switch | encoder	While in the volume control view, and with Section 3.10 set to input switching, turning the encoder will switch to the next input number.

3.4. Input

Selects which input is active, and lets you rename the on-screen label for the input you're on. You can also switch inputs from the default volume control view if Section 3.10 is set to input switching.

Figure 11. Menu view

Figure 12. Control view

Information | input label	The main text indicates the currently selected input device. The default display labels are typically Input1, Input2, Input3 etc. These labels can be edited.
Information | input# & volume	The upper-left corner shows the active input number and the volume level last associated with that input. Thus "#3|59" indicates input 3 is at volume step 59.
Switch inputs | remote	Input channel can be switched 3 different ways with the Function remote: 1) raise/lower buttons; 2) left/right buttons, or; 3) the Pup/Pdown buttons.
Switch inputs | encoder	Input channel can be switched by turning the encoder knob clockwise or counterclockwise, with clockwise switching to the next highest input number.

About volume ramping during input switching

The V4 has a volume ramping feature that allows the user to elect how volume transitions during muting/unmuting. You can either transition volume immediately to/from mute, ramp volume down only, ramp volume up only, or ramp volume both up & down during transitions. This is explained in detail in section Section 3.9. The relevance of volume ramping to input switching, is that the controller automatically follows volume ramping rules during input switching.

3.4.1. Input Label Editing

The label is each input channel can be edited to have its own custom label. We recommend you limit labels to a max of 6-8 characters.

Figure 13. Input, in label edit mode

Enter editing mode	To edit the label of the current input, click the Mute/Play button to enter label editing mode. Earlier versions of firmware may use the Mute button while more current versions use the Play button.
Navigating between characters	Use the right/left buttons on the remote to navigate between the label characters. The currently selected character will be obviously brighter than the others.
Adding characters to label	Pressing the right button past the last character of the label will add another character to the label. Each new character is initially the small case letter "a".
Erasing characters	Pressing the Play button will erase the currently highlighted character. Left and Right move between characters, the one being edited shown brighter than its neighbors; Raise and Lower cycle the highlighted character through A-Z, a-z, and 0-9; Right past the last character appends a new one; Mute deletes the highlighted character. Edits save as you make them.
Exit back to input control/view	Pressing the Menu button will escape up one level back to the Input control view.
Exit back to volume control/view	Pressing the Ok/Center button will escape back to the default volume control view.

3.5. Balance

Left/right channel volume balance can be adjusted independently of overall volume in two different ways. The first way is through this dedicated Balance menu/control. The second way is through the default volume control view provided that Section 3.10 is set to balance adjust mode.

Figure 14. Balance menu label

Figure 15. Balance control view

Information | bias level The channel bias level is shown by the number of bias steps left or right. If there are no values shows, then the balance is neutral. The example shown below in Balance example indicates a bias that is 3 steps towards the right channel.

Figure 16. Balance, biased 3 steps right

Maintaining volume level during bias adjustment

Unless compensated for, the overall volume level will change if one side is adjusted up (or down) while the other side remains constant. The V4 compensates for this by automatically alternating between increasing one side's bias while reducing the other side's bias in order to maintain overall volume level during bias adjustment.

Balance adjusting | remote The left and right buttons shift the channel balance one step per press toward that side.

Balance adjusting | encoder Turning the encoder clockwise shifts bias right, turning it left shifts bias to the left.

Zero balance acknowledgement Each time the user adjusts channel balance back to zero/neutral position, the display will briefly flash acknowledging reaching neutral again.

3.6. Display

The display control allows the user to adjust the screen brightness level. An optional display timeout feature turns off the display screen after a prescribed period of user inactivity. When the display is asleep, any user control input immediately wakes the display back up but is otherwise ignored.

Display

Figure 17. Menu view

Figure 18. Control view

Default settings	Brightness is typically set to 7 by default. Display timeout is turned Off by default.
Information | brightness level	The brightness level runs between 1-14 with 1 representing dim yet still visible and 14 representing maximum brightness.
Information | timeout setting	The display can be optionally set to turn itself off after a set period of no user interaction with the controller. The display timer can be set to run between 5-99 seconds. Setting the timer below 5 seconds simply disables the display timeout feature and is evidenced by the "Off" message.
Adjust brightness | remote	Use the raise and lower buttons to adjust the display brightness accordingly between 1 (minimum) and 14 (maximum).
Adjust brightness | encoder	Use the encoder to raise (clockwise) and lower (counterclockwise) the display brightness between 1 (minimum) and 14 (maximum).
Set display timeout | remote	Use the right and left buttons to adjust the display timeout setting between 5 seconds (minimum) and 99 seconds (maximum). Setting the level below 5 seconds turns off the display timeout timer.
Set display timeout | encoder	Press/hold in the encoder pushbutton while simultaaneously turning the encoder to adjust the display timeout setting between 5 seconds (minimum) and 99 seconds (maximum).

Display screensaver/timer

The display also has a 15 minute screensaver timer that turns off the display after 15 minutes of user inactivity in order to preserve the life of the OLED display. The screensaver timer is not adjustable by the user and can’t be turned off. The screensaver timer is inactive when the user opts to use the display timeout timer.

3.7. Impedance & Calibration

This control allows the user to both adjust the preamp's input impedance level and to initiate a calibration cycle of the LDRs at the current impedance setting/level. The default impedance setting/level is setting #1 set at 50k ohms. The level at this default setting cannot be changed. However, there are up to 9 additional optional impedance settings between 1k and 100k that can be configured and enabled, allowing the user to explore switching between impedance settings while listening to music.

The topic of impedance and LDR calibration is a core part of Tortuga Audio's technology and is covered in more detail in LDR volume-control technology.

Figure 19. Impedance/Calibration menu

Figure 20. Impedance/Calibration control view

Figure 21. Setting #2 is unconfigured (turned off)

Figure 22. Setting #2 at 10k, but locked pending calibration

Information | impedance setting #

The control view shows the impedance setting number in the upper left hand corner. There are up to 10 different possible settings. Setting #1 is the default setting. Each setting has an associated impedance level between 1k and 99k. Setting #1 is set to 50k ohms by default and can't be edited. If you want to explore an alternative impedance level, you'll have to configure another setting.

Information | impedance level

The control view shows the impedance level on the left side of the display ranging from 1k to 99k. This is the impedance level associated with the currently selected impedance setting #.

Off

Indicates that this impedance setting # is turned off and not active

Information | calibration status

Immediately to the right of the impedance setting #, you'll find the calibration status which will either be: ***CalOK*** or ***LOCKED***.

CalOK

Indicates the board has completed a calibration

cycle at this impedance setting and that this impedance setting # is active.

LOCKED

Means there isn't valid calibration data for the current impedance setting and that a calibration cycle must be completed before the current impedance setting/level will become active and allow the V4 to pass any output.

Blinking Frame

When an impedance setting is LOCKED, you will notice a slowly blinking frame around the display indicating the impedance setting requires calibration before it can become fully operational.

Adjust impedance setting # | remote	Use the raise and lower buttons to navigate between the 10 impedance settings. For settings that have already been calibrated, this will change the impedance of the V4 controller in real-time as music or test tones are played.
Adjust impedance setting # | encoder	Turn the encoder right (clockwise) or left (counterclockwise) to navigate between the 10 impedance settings. For settings that have already been calibrated, this will change the impedance of the V4 controller in real-time as music or test tones are played.
Adjust impedance level | remote	Use the right and left buttons to increase and decrease the impedance level. You disable the impedance setting altogether by adjusting the level down to zero/off. As soon as you change the impedance level of a setting that has previously been calibrated, the existing calibration is no longer valid and the Blinking Frame starts blinking again. If you return to the original level for the current setting, the existing calibration remains valid.
Adjust impedance level | encoder	Press/hold-in the encoder while simultaneously turning the encoder to increase (clockwise) and decrease (counterclockwise) the impedance level.

3.7.1. Calibration

A full calibration cycle runs each of 4 attenuation LDRs through a 100 step LDR calibration process wherein the control signal to each LDR is adjusted until the measured resistance level equals the target value for the current volume step. The resulting control signal values are stored and used

during normal volume control. For 4 LDRs, 400 separate LDR calibration steps are required for a complete calibration cycle which typically takes around 10 minutes.

Calibration start | remote

Start a calibration cycle by pressing the Play button on the remote while in the Imped/Cal control view. Earlier versions of the firmware used the Mute button to start calibration.

Calibration next | remote

You can advance to the next LDR in the sequence by briefly pressing the right button while a calibration cycle is already in progress.

Calibration previous | remote

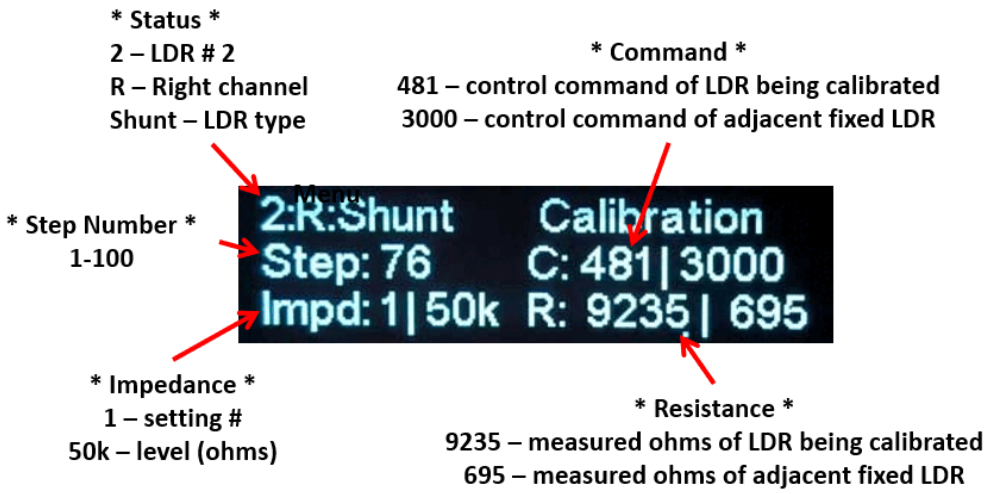
You can backtrack to the previous LDR in the sequence by briefly pressing the left button while a calibration cycle is already in progress.

Calibration stop | remote

Stop calibration and return to the Imped/Cal control view by pressing the Menu button. Stop calibration and return to the default volume control view by pressing the Ok/Center button.

Information

A typical calibration information display is shown above. This information only becomes available once a calibration cycle has been started.



Calibration information at a glance

Info	Description
Status	Shows the current LDR (#1-4), whether it's R=right or L=left channel, and whether the LDR is a Series or Shunt LDR.
Step	Shows the calibration step 1 through 100 of the LDR shown in the Status info
Impedance	Shows the impedance setting # followed by the impedance level in thousands of ohms

Info	Description
Command	Shows the pulse width modulation (PWM) command value with the first value representing the LDR currently being calibrated. The second value represents the adjacent LDR which typically has a fixed command value that doesn't change while calibrating the primary LDR. The command values are a 16 bit value that can range from 0 to a maximum of 65,000.
Resistance	Shows the resistance of the LDRs with the first value being the resistance of the LDR currently being calibrated, and the second value being the resistance of the adjacent LDR being held at a constant value.

3.8. Number of Inputs

Sets how many inputs are actively available. The V4 can switch between a maximum of 4 stereo input sources. This feature allows user to limit the number of active inputs that can be switched.

Figure 23. #inputs menu view

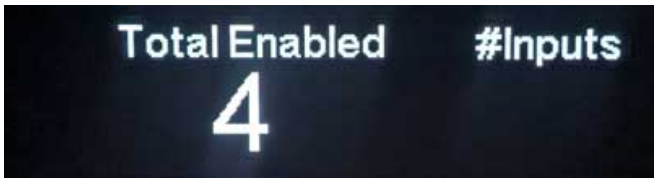


Figure 24. #inputs control view

Information | count — The display shows "Total Enabled" with the current count (1-4) in large text; "#Inputs" in the upper right identifies the menu item.

Adjust #inputs | remote — Use the Raise and Lower on the remote adjust the count between 1 and 4.

Adjust #inputs | encoder — Turn the encoder to increase (clockwise) or decrease (counterclockwise) the #input count between 1 and 4.

3.9. Volume Ramp

The Volume Ramp feature allows the user to adjust how volume changes when muting and unmuting the output. The user can opt between the following 4 volume ramping behaviors:

No ramping — Volume immediately goes to zero during muting, and then abruptly goes back to current setpoint when unmuted.

Ramp up only — Volume immediately goes to zero during muting, but smoothly ramps back up to setpoint when unmuted

Ramp down only — Volume smoothly ramps down during muting, but abruptly resumes current setpoint volume when unmuted.

Ramp up & down — Volume smoothly ramps both down and back up again during muting/unmuting.

Default ramp setting	The default factory setting is "Ramp up only".

Volume Ramp

Figure 25. Menu view

Figure 26. Control view

Information | selected option	The display shows "Options" with the current choice in large text (e.g. "Ramp up & down"); "VolRamp" in the upper right identifies the menu item.
Change ramping | remote	The Raise and Lower buttons on the remote cycle through the four options; press Enter to lock one in and return to volume control mode per Section 3.3
Change ramping | encoder	Turn the encoder to switch between the ramping options.

3.10. Volume Options

The Volume Options control allows the user to select the secondary behavior of the default volume control/view described in Section 3.3. Whereas the primary behavior is volume control, the secondary control behavior can be either channel balance adjustment, or, input switching.

The default secondary control behavior of the volume control/view is input switching.

Figure 27. Vol control menu

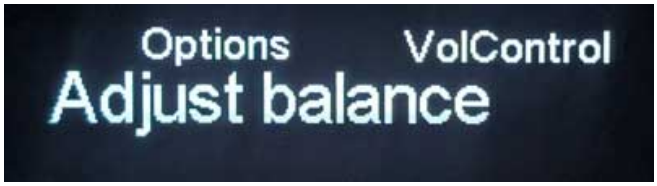


Figure 28. Vol control view

Information | selected option	The display shows "Options" with the current choice in large text (e.g. "Adjust balance" or "Input switch"); "VolControl" in the upper right identifies the menu item.
Change volume control option | remote	Use the Raise and Lower buttons on the remote to switch between balance adjusting and input switching as the secondary control mode of the volume control/view.
Change volume control option | encoder	Turn the encoder to switch between the two secondary control mode of the volume control/view.

3.11. Volume Units

Volume Units is another control option that determines how volume is displayed in the default volume control/view. Volume is displayed by default as steps between 1 and 100, with step 0 being a special Mute step which mutes output completely. The user may opt to view volume in units of decibels (dB) between -60 and 0 dB.

Volume Units

Figure 29. Volume units menu

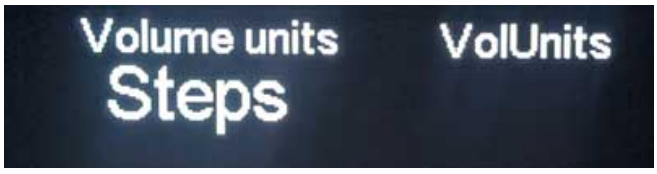


Figure 30. Volume units control view

Information | selected option	The display shows "Volume units" with the current choice in large text (e.g. "Steps" or "dB"); "VolUnits" in the upper right identifies the menu item.
Change option | remote	Use the Raise and Lower buttons on the remote to switch between the two options.
Change option | encoder	Turn the encoder to switch between the two options.

3.11.1. Volume Max

The VolMax control sets the maximum initial allowable volume upon turn-on or when switching from one input to another. VolMax is an equipment protection feature that prevents accidentally starting at too a high volume.

For example, if a volume setpoint was left at a very high level when input was previously selected, VolMax automatically resets that level to the VolMax setting when subsequently switching back to that input.

VolMax is entirely user defined between 1 and 100. Setting it to 100 effectively defeats the feature. VolMax is set at 60 by default.

Volume Max

Figure 31. Menu view

Figure 32. Control view

Information | VolMax value	The display shows "Max initial volume" with the current VolMax value in large text; "VolMax" in the upper right identifies the menu item.
Adjust VolMax | remote	Use the Raise and Lower buttons on the remote to adjust the

	VolMax value up or down between 1 to 100. It defaults to 60; setting it to 100 disables the limit entirely.
Adjust VolMax | encoder	Turn the encoder clockwise to increase the value and counterclockwise to decrease the value.

3.12. Warmup

Content not yet drafted. Sets trigger-out delay and tube warmup wait time.

Model-specific: this Controller menu item only appears on the Exemplar variant.

3.12.1. Version

Version (formerly Info) is a read-only information control that has no other purpose than displaying the model name, hardware revision, firmware version, system type, and serial number.

Info

Figure 33. Menu view

Figure 34. Control view

Model name	The first line is the model (e.g. "ePot V4 Max").
Hardware version	The second line packs hardware revision, firmware version, and system type together. The hardware versioning reads like "HW:Rev-A"
Firmware version	The firmware version comes after the hardware version. The example "FW:100" indicates firmware version 1.0.0. This number will change if newer firmware is ever installed.
System type	The final piece of information on the second line is the system type which will read either SEnd (single ended) or Bal (balanced)
Serial number	The third line holds the final piece of information which is the serial number of the product build. The serial number is permanent.
Controls	There are no controls. This control is read-only information.

3.13. System

Content not yet drafted. Switches between single-ended and balanced system type.

3.14. Firmware

Puts the V4 into firmware update mode: starts the microcontroller's built-in bootloader and waits for a connection from ST's STM32CubeProgrammer utility over USB. Once started, the preamp stops responding to the remote and encoder until it's power-cycled or new firmware is loaded.

Firmware

Figure 35. Menu view

Figure 36. Control view

Remote with Firmware open, press Enter five times in a row - the display counts your presses. On the fifth, the bootloader starts.

Encoder opens this item but doesn't adjust it.

3.15. Reset

Erases impedance and calibration data for all 10 impedance settings. Rarely needed - mainly a way to clear things out and start calibration over from scratch.

Reset

Figure 37. Menu view

Figure 38. Control view

Remote with Reset open, press Right five times in a row to confirm - the display counts your presses. On the fifth, all 10 impedance settings' calibration data is cleared and the preamp returns to Section 3.3.

No calibration means no audio output!!!

After a reset, the default #1 impedance setting has no calibration data, and the preamp produces no audio until it's calibrated again - run Section 3.7 before doing anything else.

3.16. Remote learning

Remote learning refers to the ability of the V4 controller to learn the command codes generated by any infrared remote that uses the NEC protocol. Remote learning replaces the previous method of Remote Pairing where the V4 controller was pre-programmed with command codes that only worked with special specific remotes.

Remote learning was introduced in August 2026 with the release of firmware Rev 220. V4 boards with earlier firmware remain subject to Remote Pairing which is discussed here → Remote pairing (firmware before Rev 220).

13 command functions

You can teach the V4 up to 13 command function codes, each associated with a button on the remote. You cycle from one command function to the next by turning the encoder one click at a time. The 13 command functions are listed in the table below.

The 13 possible learned command functions

Topic	Description
Power (toggle)	• Flips the state of the V4 between on and off. • Not all NEC remotes have a Power toggle button • Pressing the Menu or the Ok/Center button while the V4 is off, will also turn on the V4
Mute (toggle)	• Flips the state of the V4 between muted and unmuted • NEC remotes with no dedicated Mute button should use the Play/Pause button instead
Raise	• Specific functionality depends on active control context • Typically used to increase a value or setting • Auto repeat key - will auto-generate repeat commands if held down
Lower	• Specific functionality depends on active control context • Typically used to decrease a value or setting • Auto repeat key - will auto-generate repeat commands if held down
Menu	• Escape from a control back out to Menu • Escape from Menu back to default volume control/view
Ok/Enter/Center	• The middle button within the raise, right, lower, left control ring • Specific functionality depends on active control • Most common response is return to the default volume control/view
Left	• Specific functionality depends on active control context • Typically used to decrease a value or setting • Auto repeat key - will auto-generate repeat commands if held down
Right	• Specific functionality depends on active control context • Typically used to increase a value or setting • Auto repeat key - will auto-generate repeat commands if held down

Topic	Description
Play/Pause	• Acts as an alternate Mute button for NEC remotes without a dedicated Mute button • Initiates a calibration cycle but only when the Imped/Cal control is active
Vol+	• Increases volume by 1 step (no auto-repeat) • This button and the Vol- counterpart, provide alternate methods to change volume but without the fast auto-repeat response of the Raise/Lower buttons • Vol+ and Vol- are both unique to the Function remote
Vol-	• Decreases volume by 1 step (no auto-repeat)
Pup	• Switches input to next highest input number • Pup and Pdown are both unique to the Function remote
Pdown	• Switch input to the next lowest input number

Entering learning mode

Scroll down the main menu tree until your reach "Learn" and then press the Ok/Center button to select the Learn control. Be aware that once you enter learning mode, the V4 stops responding normally to your remote so you can't escape out of learning mode with just the remote.

Information | function status

The display always shows which function is currently selected and whether than function has learned a valid code yet or not.

Moving between functions | encoder

While in learning mode, turning the encoder 1 click in either direction switches to the next or previous command function in the list. You can readily click back and forth between command functions to check if they already have valid command codes.

Teaching a button | remote

For example, if the display indicates "Raise" is the current command function, point the remote at the preamp and press/release the Raise button 3 times in a row. The V4 waits for the same code to arrive 3 times in a row before accepting the button as valid for that command function and saving it to eeprom memory.

Exit learning mode | encoder

A brief press/release of the encoder pushbutton escapes you out of learning mode and back to the Learn menu, at which point the newly learned remote resumes control of the V4.

Codes are retained

Once a code is confirmed, it's written to non-volatile memory immediately, survives power cycles and firmware updates, and stays in effect until relearned or cleared.

3.17. Remote pairing (firmware before Rev 220)

Prior to the release of Rev 220 firmware, each V4 has to be "paired" with an Apple infrared remote or a compatible alternative brand, and learning a remote's command codes was not possible. V4 units with older firmware must be paired to their remote before the V4 will respond.

The remote pairing process is explained in detail below.

3.18. Remote pairing

Tortuga Audio adopted the simple silver Apple remote as its remote back around 2014 up until such time as Apple stopped making and offering it. Each Apple remote has an ID number between 0 and 255. This ID number allows up to 256 different devices to each be controlled by a unique Apple remote.

Remote pairing is a process that "teaches" your Tortuga preamp the ID number of your Apple (or legacy Tortuga remote) so that the preamp will only communicate with your Apple remote and ignore all others.

Figure 39. LDR300x.V3 with Apple remote

3.18.1. Why is pairing necessary?

Every Apple remote has a randomly assigned ID number between 0 and 255. That ID number can be changed (see below) if necessary. The purpose of the ID number is to allow the use of multiple Apple remotes to control different products without creating command code conflicts. For example, yuou may have an Apple remote for your Apple TV in addition to your Apple remote for your Tortuga preamp. Without ID numbers it would be chaos with both devices reacting to any remote. Pairing is usually only required with a new remote. Pairing may also be required after a major firmware upgrade.

3.18.2. Do I need to pair my remote?

A remote is included with each Tortuga Audio preamp and that remote will already have been paired with your preamp. However, if you lose your remote or otherwise replace it with another, you will most likely need to pair any new replacement remote with your preamp.

The end of pairing

With the release of firmware version 2.2.0 of Tortuga Audio's V4 series, the remote pairing process described herein is no longer relevant and has instead been replaced with remote learning process wherein you can now teach your V4 series preamp the buttons on any remote that follows the NEC protocol which is the majority of infrared remotes. Click on Remote learning for more information on remote learning.

3.18.3. Apple remote out of production

In mid 2023 Apple quietly ended production and sale of it's 7 button silver remote. This sent numerous companies scrambling for a compatible aftermarket alternative. Tortuga Audio has adopted the Function101 remote as its primary remote going forward.

3.18.4. Can I change the default ID of my Apple Remote?

Yes! But the only reason for doing so is if you have two Apple remotes for two different devices and both remotes happen to have the same ID number (one chance in 256). The Apple remote ID can be changed by simultaneously pressing both the Menu and the Enter/Center key on the Apple Remote for 5+ seconds and then releasing. Nothing noticeable will happen - no beeps or flashing lights. This process will change the ID number to some new value. After changing the ID you will then have to pair the Apple remote with your Tortuga preamp.

3.18.5. How do I pair my remote with my preamp?

Pairing your remote with your Tortuga preamp is a fairly straight forward process that can be accomplished in less than a minute.

Below you'll find a step by step guide on pairing your remote.

How to pair my Tortuga Audio remote

Step	Action	Description
step 1	Turn preamp on	Preamp must be plugged into power and turned on. Since the preamp presumably can't respond to the remote yet, turn on the preamp by a brief press/release of the encoder control knob.

Step	Action	Description
step 2	Enable pairing	**All V2 & early vintage V25 preamps with 7-segment displays**:: Press/hold in encoder pushbutton for 20+ seconds and then release. The displays should begin blinking indicating the preamp is now in pairing mode. **Later model V25 preamps with 7-segment displays**:: Press/hold in the encoder pushbutton for 20+ seconds until the displays goes blank (turn off) indicating preamp is now in pairing mode. **V25 & V3 preamps with OLED display**:: **V4 preamps prior to Rev 2.2.0 firmware**:: Press/hold in the encoder pushbutton for 20+ seconds. When display changes and explicitly says that the preamp is now in pairing mode you can release the encoder pushbutton. Congratulations, your preamp controller is now in pairing mode!
step 3	Complete pairing process	Press the center/enter button on the remote to complete the pairing process. The display will stop blinking or otherwise respond confirming that the preamp & remote are now paired.
step 4	Confirm pairing	The preamp controller should now be responding to your remote normally.

3.18.6. Pairing trouble shooting

Preamps with OLED display

"The Pairing Mode" message appeared on the display, I pressed a key on the remote, but the preamp still does not respond to my remote"

Occasionally the pairing process fails even if you did everything right and thus must be repeated. Pressing the Up or Down button to complete the pairing process is usually more reliable than pressing the Center button.

Preamps with 7 segment displays

"I press/hold the Encoder push button for 20 seconds and release and the display blinks for only a second or so and then stops or the display goes blank"

This probably means you didn't hold the Encoder push button in long enough.

It's also important that you don't turn the encoder while holding in the encoder push button. This

will confuse the controller into thinking you want to change the input.

Chapter 4. Light Dependent Resistors

4.1. Volume control with LDRs

This section introduces the Light Dependent Resistor (LDR), provides a brief tutorial on how volume control works generally, and how volume control with LDRs is similar yet uniquely different from conventional volume control technology.

4.1.1. What is an LDR?

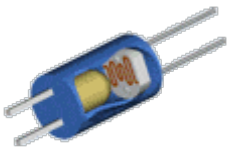


Figure 40. LDR = Light Dependent Resistor

A light dependent resistor (LDR) is the marriage of a photoresistor with a light emitting diode (LED) in a small sealed package approximately the size of an M&M candy. Each LDR has 2 pairs of wires. One pair connects to the LED end while the second pair connect to the photoresistor end.

Inside the LDR, the LED shines light on the phtoresistor. The resistance of an LDR varies inversely in proportion to the brightness of the LED with brightness determined by the control current running through the LED. Increasing LED current increases the LED brightness which in turn reduces the the photoresistor resistance.

Through precise control of its LED current, LDRs can smoothly regulate resistance over a wide enough range to provide effective high performance audio volume control.

LDRs optically isolate the control circuitry from the audio signal passing through the photoresistor. The audio signal only encounters a variable resistance that is regulated by photons (i.e. light) and not electrons.

Tortuga Audio preamps utilize LDRs to control volume (i.e. to attenuate the audio signal).

4.1.2. Why LDRs for volume control?

We use LDRs because their subjective sound quality is amazing. Adjectives like clear, open, unveiled, organic, articulate, and uncolored all apply to the LDR. All while maintaining excellent bass and overall dynamics even in a passive preamp.

plug-in LDR modules

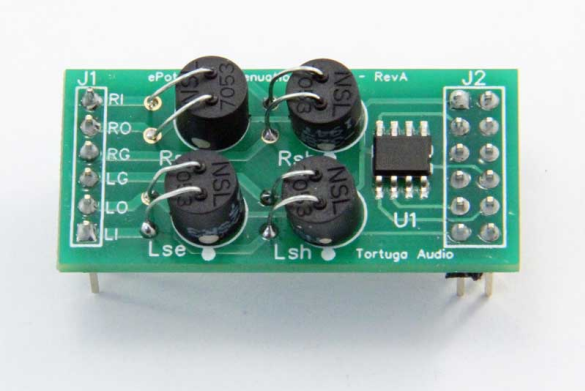


Figure 41. V3/V4 type module

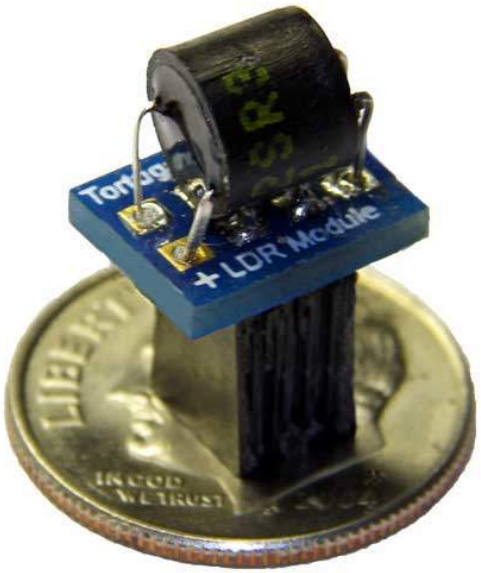


Figure 42. V2/V25 type module

If LDRs are so great why then why don't all preamps use LDRs? A reasonable question with several answers.

First, LDRs are notoriously difficult to use for volume control. They are inherently nonlinear which means they are difficult to control accurately over the wide range of resistance needed for effective volume control.

Secondly, the performance curve of individual LDRs are not consistent even within the same make and model from the same production batch. Moreover, their performance curves may even drift slightly over time.

Last but not least, LDRs have higher distortion characteristics than most other alternatives although not enough that it really matters subjectively (the distortion is well below human detectable levels).

For all the above reasons most audio designers avoid taking on the challenge of using LDRs. That is not an irrational view.

Tortuga Audio took on this challenge over 15 years ago and has not looked back. We overcame these technical challenges. We are now on our 5th generation LDR preamp control technology.

4.1.3. Volume control is attenuation

When engineers talk about volume control they use the term "attenuation". Attenuation is the opposite of amplification. When you amplify an audio signal you are increasing its average voltage level. A higher voltage audio signal will be louder relative to a lower voltage signal. On the other hand, when you attenuate an audio signal you are reducing its average voltage level.

Attenuating an audio signal is typically done using a voltage divider. A potentiometer (a "pot") is the most common type of voltage divider. Almost every time you turn a volume control knob, you are turning a voltage divider pot. But not when you're using a Tortuga Audio preamp!

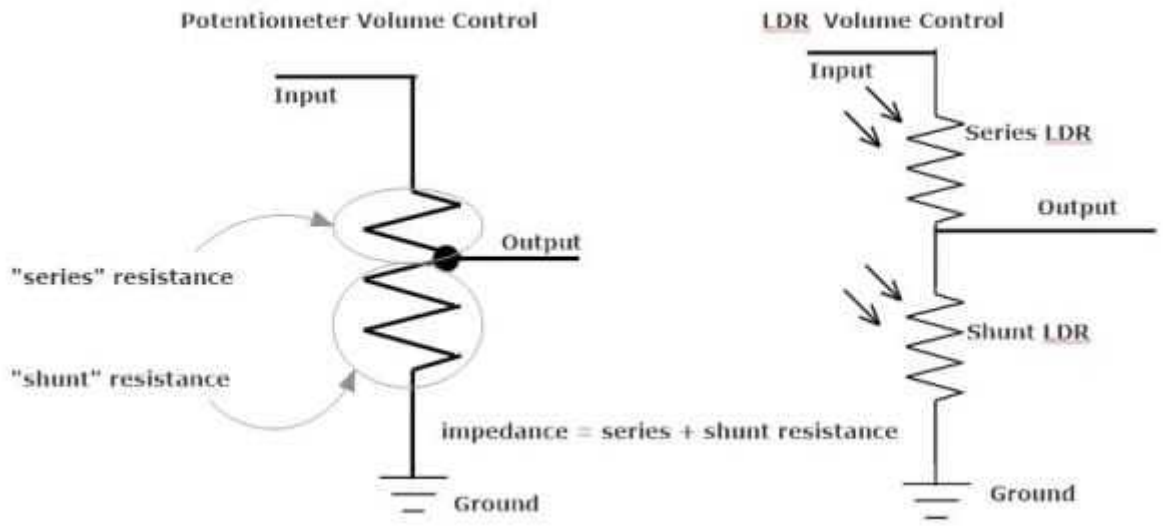


Figure 43. potentiometer & LDR type voltage dividers

4.1.4. How does volume control work

The figure above shows two different voltage dividers. On the left there's a potentiometer and on the right is a pair of LDRs configured as a voltage divider. You'll note there are obvious similarities between the two, at least schematically.

In both examples you have an Input signal feeding into a series resistor, followed by a shunt resitor connected to ground. The Output signal is the offtake point between the series and shunt resistors.

With a conventional potentiometer, the series and shunt resistors are a single continuous resistor material with a "wiper" output defining the split between the upper series resistance and the lower shunt resistance. As the user turns the shaft of the potentiometer, the wiper physically moves across the resistance material.

With an LDR voltage divider, the series and shunt resistors are in fact each a separate discrete LDR. The Output point is always between the two LDRs. Each LDR is controlled to achieve a specific resistance level.

The governing equations of most volume control are shown below

volume control governing equations

1) Ratio = Voutput/Vinput = Rshunt / (Rshunt + Rseries)

2) Attenuation in units of decibels (dB) = 20 x log (Ratio)

3) Impedance = Rseries + Rshunt

Let's say you have an Rseries = 5k ohms and an Rshunt = 45k ohms. That yields an effective impedance of 50k ohms as seen by any device connected to the input of the attenuator. That gives us a ratio = 45 / (1 + 45) = 0.9. Plugging that into our attenuation formula we get dB = 20 x log (0.9) = -2.1 dB which would yield a modest level of attenuation that would be quite loud as a practical matter.

4.1.5. How do LDRs control volume?

Volume control with LDRs works basically the same as a potentiometer except that with LDRs the RSeries and RShunt resistance levels are controlled independent of each other. Once the LDRs are calibrated, a microcontroller controls each LDR to achieve the resistance ratios that correspond to the current target dB attenuation. While a pot does this mechanically, the resistance levels of both the series and shunt LDRs is done electronically with no mechanical wear parts.

Repeatable and reliable electronic control of LDRs is at the core of Tortuga Audio's LDR volume control technology.

4.2. Adjustable impedance with LDRs

Tortuga Audio introduced adjustable impedance to its LDR preamp controller/attenuators in early 2015 as an optional feature. Tortuga Audio makes no claims guaranteeing the outcome of changing the controller's impedance level. This feature is being provided solely as an exploratory option for those curious and wishing to explore possible outcomes.

Adjustable inpt impedance is not a common feature in audio equipment. Most audio equipment has a fixed input impedance that was established by the audio designer. Tortuga Audio's LDR based preamp controller/attenuators are unique in this regard.

Adjustable impedance allows the user to configure up to 10 different input impedance settings each with its own defined impedance level between 1K and 99k. Impedance setting #1 is fixed at 50k and cannot be modified. Settings #2 through #10 are initially disabled and are entirely optional and can be ignored.

Once two or more impedance settings are properly configured, the user may switch instantaneously between different input impedance levels while playing music or running test signals. The user is free to explore and possibly fine tune their preamp's impedance level to find an optimal level for their source(s) and amplifier.

4.2.1. Input & output impedance & why it matter?

Impedance is another word for resistance and is usually expressed in units of "ohms". In audio, impedance often involves complex relationships between simple fixed resistance plus dynamic resistance from capacitors and inductors that vary with the frequency of the audio signal. Impedance is also another way of talking about how hard audio equipment has to work to do its job. And the harder you have to work, the harder it is to be good at your job!

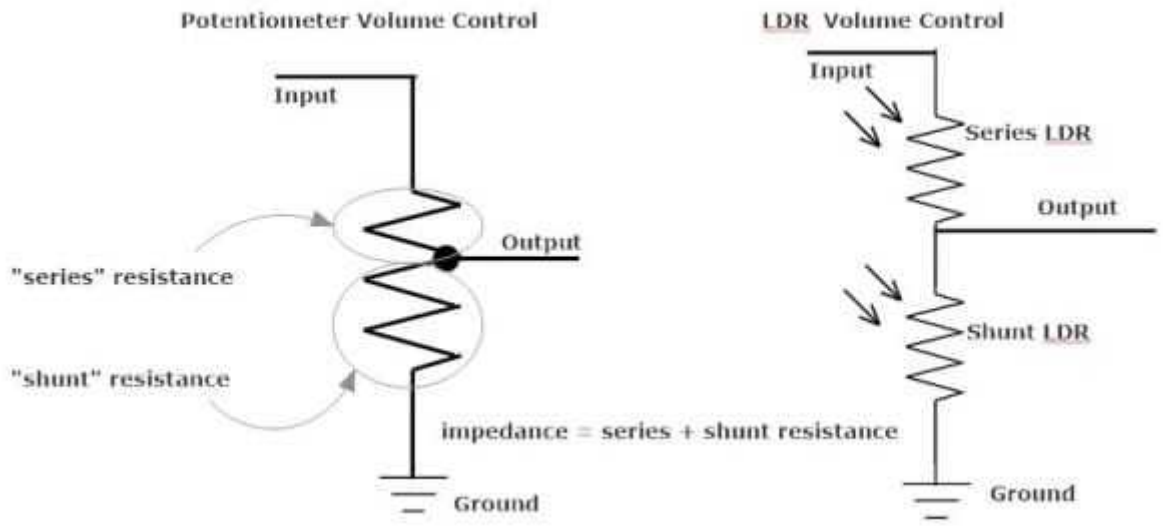


Figure 44. potentiometer & LDR type voltage dividers

Impedance of a typical volume control voltage divider is shown in the figure above as the mathematical sum of the "series" and "shunt" resistance. Most volume controllers are in the range of 10k-100k ohms. Tortuga Audio typically sets the default input impedance of its LDR volume controllers in the 20-50k range.

Audio equipment typically has both an input and an output impedance.

Input impedance tells us how hard we have to work to get a signal into a device. Devices with high input impedance place minimal current demands on connected upstream components. This is good thing and usually translates into a better sounding system because the equipment pushing the audio signal doesn't have to work as hard.

Output impedance tells us how the output audio signal holds up under load wherein a lower output impedance is almost always better.

A device with low output impedance is like a strong, steady water main that delivers constant full pressure regardless of whatever you connect to it. The signal arrives at the next component at the intended volume and with the intended sound, regardless of what that component is or how long the cable is.

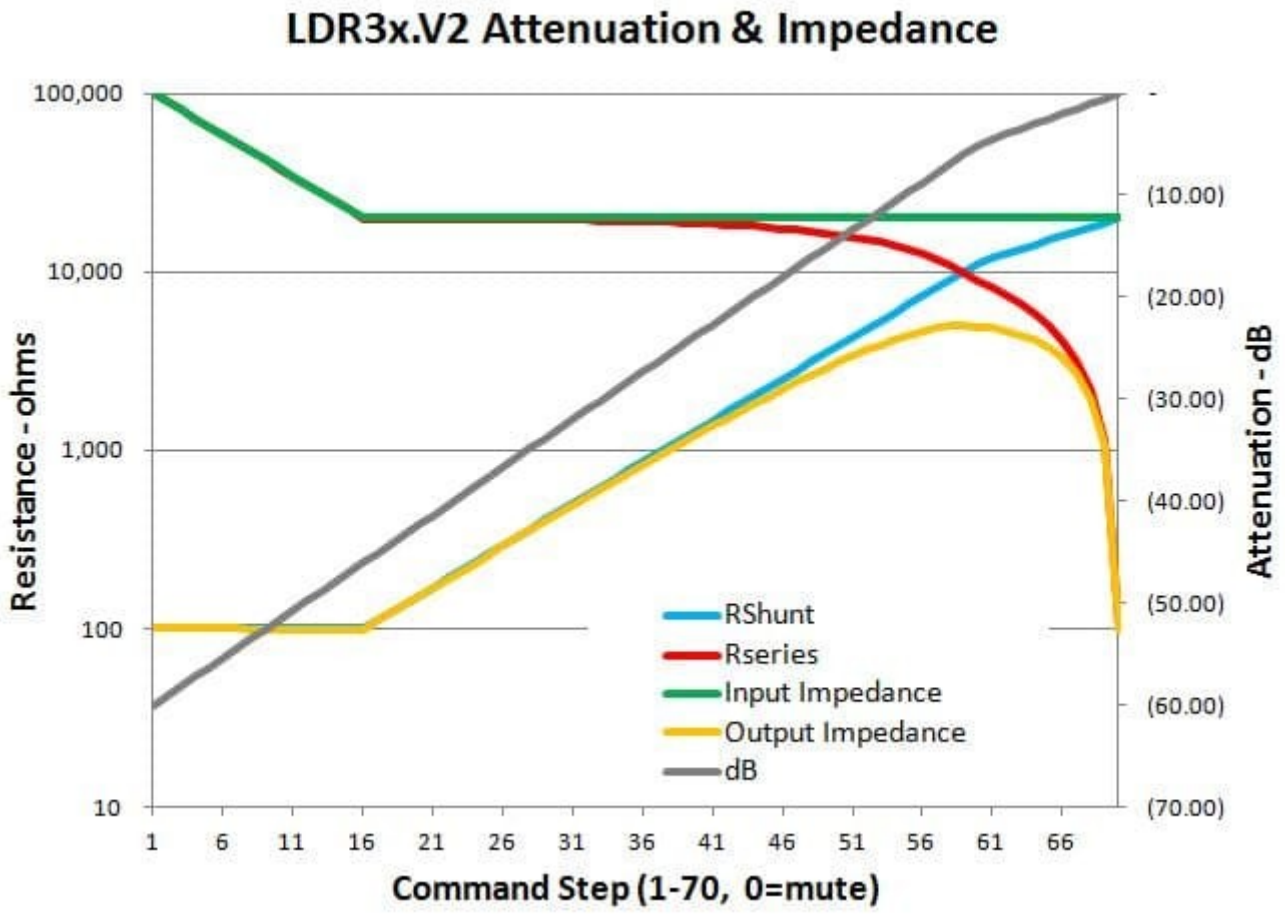
Conversely, a device with high output impedance is more like a garden hose fed by a weak pump. A weak pump struggles to maintain pressure (voltage) as flow (current) increases. Plug it into one amplifier and it sounds fine. Plug it into another and the volume drops, the treble softens, or the bass gets flabby. Long cables make the problem worse, because a weak source cannot push high frequencies through them cleanly. The essential point is this: low output impedance means the device's sound does not change based on what you plug it into.

Input vs. output impedance

The relationship between input and output impedance are inextricably linked by physics. While most volume controllers have a fixed input impedance, output impedance is typically not fixed but is instead dependent on the input impedance and the attenuation level.

Let's unpack this by taking a closer look at the figure below that shows the relationship between

impedance and the attenuation level of one of our earlier LDR3x.V2 LDR attenuators. This attenuator has 70 volume steps over a 60 dB range with a 20k nominal input impedance.



dB schedule (black line)

The dB schedule is the attenuation schedule. This is our defined goal. All the rest falls out from this schedule. This particular example is a linear fixed dB per volume step except for a reduction in the schedule slope to lessen the incremental sound pressure changes as you approach full volume.

Input impedance (green line)

The green line shows the input impedance as volume is adjusted between step 1 (minimum volume) and step 70 (maximum volume). Note the fact that the impedance doesn't actually remain fixed at 20k but ramps up to 100k as the command step falls below 15. This is an artifact of the math of attenuation plus the limitations of LDRs. Simply put, we can't maintain a fixed input impedance of 20k with a 60 dB control range. Doing so would require us to operate outside of the acceptable LDR window of minimum 100 ohms and maximum 100k ohms. To live within these constraints we allow the impedance to increase from 20k to 100k when volume is low. In practice, this has no discernible impact on the sound quality.

RSeries (red line) & RShunt (blue line)

Recall that by definition, the sum of RSeries and RShunt is equal to the input impedance which is to say the green line equals the sum of the red line and the blue line. The LDR resistance schedule for RSeries and RShunt is derived from governing voltage divider equations that are not covered here.

Output impedance (yellow line)

The yellow output impedance curve is by far the more interesting and non-intuitive of the these curves. Starting at minimum volume, note how output impedance is at its lowest and remains unchanged as input impedance falls from 100k to the target 20k. Once the input impedance reaches 20k, the output impedance climbs in sync with the increasing volume. But as the RSeries begins to drop quickly towards full volume, the output impedance hits a peak at -6 dB and then drops very rapidly reaching the same low level at both ends of the volume control range.

Output impedance - a deeper dive

The fact that most volume control devices do not have a fixed output impedance has real-world implications that are worth noting for those interested in understanding this topic more fully. Here are some additional points to consider regarding non-constant output impedance.

Observations

- Typical volume controls do not have a fixed output impedance
- Output impedance changes every time you turn the knob
- At full volume and at full mute, an output signal pushes easily through when impedance is minimal
- Output signal weakens as the volume increases into the middle of its range
- Output is weakest (impedance highest) around 6 dB below full volume, which is a fairly loud setting

Why it matters

- **Sound can change with volume -** Because the control's ability to drive the next component varies with the setting, the tonal balance and the sense of dynamics can subtly shift as you adjust the volume. A system that sounds right at one level may sound a little softer or duller at another.
- **Outcome depends on connected equipment -** A passive volume control relies on current drive of its source, the input impedance of the amplifier, and the length and quality of cables to the amplifier. Any or all of these can show up as lost treble, flabby bass, or reduced volume.
- **Higher impedance volume controllers are more affected.** While increasing input resistance is gentle on the source feeding it, the price for doing so is a proportionally higher worst-case output impedance. Choosing a design impedance value is always a compromise between being easy on the source and being strong enough to drive the attached power amp with authority.

How active beats passive

- **Performance independent of attached equipment -** Conventional active preamp performance is rarely dependent on the impedance of attached upstream or downstream equipment.
- **Performance independent of volume level -** Input and output impedances remain fix and optimal so the system sounds the same no matter where the volume knob sits.

How passive beats active

- A well matched passive attenuator operating between a robust low impedance source and a high impedance power amplifier, will have excellent performance, be dead black quiet between the notes, and lack nothing in tone or dynamics compared to any active preamp regardless of price.

4.2.2. Why change input impedance?

Conventional audio preamps have a fixed input impedance, chosen by the designer as a compromise. One of the benefits of using LDRs in lieu of fixed resistors or potentiometers is the ability to adjust the overall input impedance of the LDR attenuator. This is done entirely within the software and requires no additional hardware.

Adjustable input impedance lets the user resolve that compromise for their own system. The benefits fall into the following categories:

- **Matching the source -** Every source component has its own output impedance and its own preference for how heavily it is loaded. Tube outputs, some DACs, and phono stages have relatively high output impedance and want a light load, meaning a high preamp input impedance, or they lose level and bass. Many solid-state sources are happy driving a heavier load and can sound more dynamic doing so. An adjustable input lets you give each source what it wants instead of hoping the fixed value is close enough.
- **Better current drive to the amplifier -** As we discussed earlier, the input and output impedance are unavoidably linked in a passive volume control. The attenuator's worst-case output impedance is a fixed fraction of its total resistance, so lowering the input impedance also lowers the output impedance. That makes the preamp stronger at pushing the signal through cables into the power amp, which preserves treble and dynamics. Adjustability lets you trade a little source loading for better amplifier drive, or the reverse, depending on which side of the system is more sensitive.
- **Lower noise -** Lower impedance circuits generate less thermal noise and are less prone to picking up hum and radio interference. If the source can tolerate a heavier load, dropping the input impedance quiets the system.
- **Compatibility with multiple sources -** A listener with several sources, or one who changes equipment over time, does not have to accept a setting that suits one component and compromises another. The preamp adapts rather than forcing a new purchase.
- **Tuning by ear -** Because the ideal impedance value depends on the specific combination of source, cables, and amplifier, no designer can know the optimal impedance in advance.

Making input impedance adjustable turns impedance from a hidden fixed spec into a control the listener can use to find the best sound for their system.

4.2.3. Adjusting input impedance

Impedance setting #1 is fixed at a default level in all Tortuga Audio preamps; typically 50k but may also be 75-80k in some units. All Tortuga Audio preamps are shipped with a default input

impedance at setting #1. The default impedance level at setting #1 can not be changed.

The user may configure up to 9 additional impedance settings #2 through #10 each with its own impedance level between 1k and 99k. Older preamps allowed for up to 5 different impedance settings (#1 plus 4 additional). This was later increased to 10 including the default setting #1 plus 9 additional.

Once one or more additional impedance settings have been properly configured and initialized, the user is then able to instantaneously switch back and forth between impedance levels while listening to music. This flexibility allows the user determine which input impedance level is optimal for a given system.

It's important to remember that each new impedance setting/level requires the preamp to be run through at least 1 cycle of calibration in order to establish a new attenuation table at the new impedance level. A second calibration pass is highly recommended for newly established levels. Calibration must be run for each setting/level individually since calibration only operates on the currently selected setting/level.

Please consult the preamp controls section for detailed instructions on setting up impedance settings, adjusting impedance levels, and running calibration to generate a new attenuation table.

4.2.4. Switching between impedance settings

Once 2 or more impedance settings have been set up, you can switch between them in real time while listening to music or pushing through test signals.

Please note that if you switch to an impedance setting that is not defined, the audio output will shut off because there is no defined attenuation table. Switching back to a defined setting/level will switch the music back on.

You may or may not notice a qualitative difference between different impedance levels. Much depends on the specific equipment in your system.

Based on customer feedback and our own experience with adjustable impedance the optimal setting is one that provides sufficient impedance bridging (ratio of amp input impedance to source output impedance) between the source and the amp. Increasing the impedance bridging ratio further usually does not provide additional benefit and may in some cases actually have a negative impact on sound quality.

4.2.5. Please be patient and deliberate

Exploring adjustable impedance is something you should only do deliberately and with a patient attitude. Configuring a new setting for the first time or changing an existing impedance level can be a bit confusing and the process and procedures may not seem intuitively easy. A careful read of this information on adjustable input impedance, together with information on LDR calibration and the related preamp controls is highly recommended.

4.3. LDR calibration

4.3.1. Calibration in brief

Calibration is a self-contained measurement system that measures and records the resistance of each LDR against a 100-step attenuation schedule. The control command needed to achieve each targeted resistance step gets stored in permanent memory and subsequently used to set the resistance level of each LDR during normal operation.

- Built-in software driven process
- Normalizes LDR performance without need for pre-matched LDRs
- Requires no special or external equipment
- Only runs when preamp is otherwise offline and not operating normally
- Once started runs automatically without any user intervention
- Corrects for any drift as LDRs age
- Allows LDRs to be replaced if needed thus extending the life of the pramp indefinitely

4.3.2. Why is LDR calibration a thing?

Using LDRs for audio volume control is technically challenging because the relationship between control current and resistance within each LDRs is highly nonlinear, can vary considerably from one individual LDR to the next, and can also change over time as an LDR ages. This nonlinearity is clearly evident in the resistance versus control current shown in the graph below.

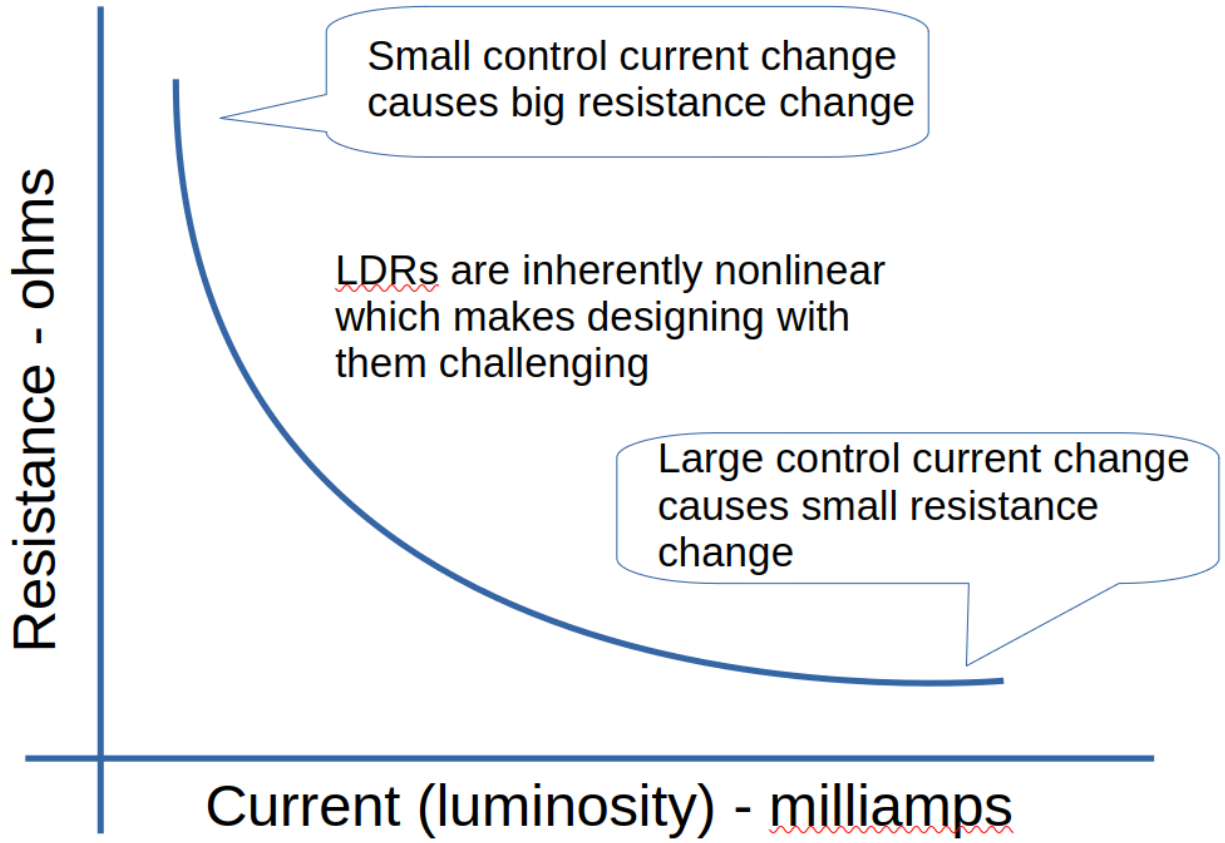


Figure 45. Typical nonlinear LDR behavior

The conventional approach to overcoming these LDR challenges is to measure hundreds of LDRs to find sets of matching pairs. However, even when initially matched, LDR behavior can change as they normally age. This can degrade the stereo imaging and sound stage over time and allow channel balance to drift left or right. Moreover, if one of the matched LDRs fails, the preamp might be rendered unusable.

Tortuga Audio introduced in-situ LDR calibration in May, 2014 with the release of its V2 preamp controller. Built-in "auto" calibration of LDRs eliminated the need for testing and matching LDRs. Moreover, it allowed LDRs to be mounted in plug-in modules that are easily replaced should an LDR ever go bad. In-situe LDR calibration is a unique feature of Tortuga Audio preamps.

4.3.3. What happens during calibration?

During calibration, four LDRs are each run through 100 calibration steps resulting in 400 total steps for a full calibration cycle that typically lasts for 10-15 minutes. If a calibration cycle hasn’t finished after 20 minutes, there’s probably a problem with at least 1 of the 4 LDRs.

During each calibration step, the resistance of the LDR is measured and compared to a target value. The target values are dependent on the specific input impedance value that the preamp is currently set at. If the input impedance is subsequently changed to a new value, calibration must be run again to build a new calibration table.

The control settings for each step of each LDR are stored in the controller’s EEPROM memory. These

stored control settings are subsequently read from memory during normal operation and are used to set the resistance level of the LDRs (2 LDRs per stereo channel) to achieve the desired volume.

4.3.4. How to run calibration

Calibration is initiated by the user through the infrared remote control. Once initiated by the user, the calibration process runs unattended and is typically completed within 10-15 minutes for all 4 LDRs.

Detailed procedures for running calibration in your Tortuga preamp can be found in the online documentation for your particular controller model. The procedure may vary depending on which preamp controller model (V2, V25, V3, V4 etc.), which firmware version and the type of display your preamp has.

4.3.5. When to run calibration

There's no fixed requirement for when you should run calibration. You could literally go months or even years without ever needing to run calibration. However, we recommend running calibration once every few months to ensure optimal performance.

If your preamp's channel balance seems to have drifted either right or left of center, running calibration will most likely recenter the stereo image.

If the calibration process does not complete within a 20 minute period or otherwise stalls or goes into a repeating loop, this is a reliable indication that at least one LDR has gone out of specification and needs to be replaced. The LDRs are easily replaceable plug-in modules.

4.3.6. Calibration best practices

Interconnect status during calibration

During calibration the preamp inputs and outputs are automatically disconnected within the preamp controller. The system is designed so that calbraton can proceed with all interconnect cabling left plugged into the preamp.

However, there may be times when disconnecting the interconnects can be advantageous during calibration. The reason for this is calibration is very sensitive to even modest ground loop currents and the preamp shares a common signal ground with all connected devices. When no sources or amps are connected to the preamp there's only a single ground connection via the preamp's power supply. This arrangement minimizes noise and ensures the best results.

Allow preamp to thermally stabilize

LDR's are sensitive to ambient temperature changes. Therefore, you should avoid running calibration until the preamp has had time to stabilize at room temperature. If you just relocated your LDR preamp from either a hotter or colder location, you should wait at least an hour before starting a calibration cycle.

Avoid interrupting calibration cycle

Interrupting the calibration process won't harm your preamp but it may result in less than ideal calibration results. If calibration gets interrupted, we suggest you rerun the process and allow it

complete normally. Later versions of the firmware will lock-out the preamp from outputting sound until such time as a calibration cycle is successfully completed.

Run calibration twice at each new impedance level

If you establish a new input impedance level in your preamp it's best to run calibration at least 2 times in a row. The first calibration pass at a new impedance level requires estimating certain values which are then more accurately determinable on subsequent passes.

Chapter 5. The V4 board

Whereas other sections in this manual focus mostly on the control and operation of the V4, this section is primarily focused on the hardware itself.

5.1. V4 vs V3 design changes

The V4 is an evolution of our earlier V3 series, so let's start with a quick review of what changed when we made the move to the V4.

The ePot.V4 combines everything we learned to date about previous models, retains all the positives, with the result being that the V4 represents our best LDR attenuator/controller ever. Here are the key design changes.

V4 vs V3 design changes

Design criteria	V3	V4	Comments
Processor	STM32F2 32 bit M3 ARM microcontroller	STM32G4 32 bit M4 ARM microcontroller with integral math processor	• Faster clock • Built-in math processor • 16 bit resolution pulse-width-modulated output • 16 bit analog-to-digital measurement with oversampling • Superior measurement & control
LDR control	• 16 bit DAC chip for LDR current command generation • 12 bit ADC for LDR current measurement	• 16 bit pulse width modulation (PWM) with 1st order filter smoothing • 16 bit effective ADC for LDR current measurement	The V4 has more accurate and effective LDR measurement and control and is less dependent on difficult to source components
Signal switching	Analog IC switching chips that ran on split +/- 5 volt power	Miniature electro-mechanical relays that run on simple +5 volt power	The V3 analog chips worked but were susceptible to noise and power supply quirks that could cause controller to reset. The V4 uses rock solid proven relays.
Inputs	Selects between 6 stereo input devices	Selects between 4 stereo input devices	Could not fit relays for 6 inputs on the V4 board & keep it same size as the V3

Design criteria	V3	V4	Comments
Power supply	• External 12 volt 0.5 amp regulated or unregulated • Internal +/- 5 volt split voltage switching regulator • Internal 3.3 volt linear regulator	• External 5 volt 0.5 amp regulated only • Internal 3.3 volt linear regulator	The V4 eliminated the complexity of a split voltage power supply for the main board. The V4 performance benefits more from cleaner external power
Muting relay	• Quasi-muting achieved via LDRs only • LDRs would "leak" audio slightly during mute	• Dedicated muting relay • Shunts audio output signal to ground totally suppressing output	The V4 offers true "dead silent muting"
Firmware	Legacy code with compounded technical debt	Substantially refactored codebase to improve code quality, reliability and maintainability	The V4 has benefited from extensive rework of the original code to conform with newer design standards and adopt more reliable system architecture and communications protocol
Communications	• Single SPI bus for display & eeprom • UART for board-to-board communications	• Separate dedicated SPI bus for display & eeprom • I2C for board-to-board communications	The V4 uses a more robust and reliable approach to board-to-board communications required for balanced audio configuration

5.2. V4 board versions

The V4 has had one minor version update since its initial release in late 2024. A major update is planned for late 2026.

The V4 board is 2.7 inches wide and 4.25 inches long. The V4 is the same width as the V3 but is 0.15 inches shorter. The overall height including the plug-in LDR module is slightly greater than 1 inch but we recommend allocating 1.5 inches of vertical space above the board; 2 inches if you opt for the solid state buffer board addition. There are no parts mounted on the underside of the board but a minimum clearance of 0.125 inch is recommended underneath the board to avoid making contact with any through-hole soldered parts and to allow for adequate air circulation.

V4 board versions

Version	Descrip
Rev A	• Released December 2024
Rev B (current)	Rev B represents a minor tweak to the original ReV A to improve ease of connections • Released October 2025 • Changed 5 volt power entry from J9 JST header, to a new adjacent Power connection composed of solder lugs only. • Moved the USB connector to avoid interference with optional solid state buffer board
Rev C (future)	Rev C represents the first major update to the V4 since its original release in 2025. These changes are entirely peripheral and preserve the core design concept of the V4 series, and share a common firmware codebase with earlier board versions. • Released planned for Q4 2026 • 4 layer versus 2 layer board (improved internal PCB construction) • Eliminated need for external clock/crystal • Moved all power regulation to common power island • Relocated OLED display header • Added dual daisy-chained I2C communication headers for balanced operation • Added buffer servo header

5.2.1. The LDR current control loop

In order to be useful, an LDR needs to predictably achieve a range of resistance levels in response to a command schedule. Since LDR resistance is largely determined by the LDR control current, a precision current controller is critical to achieving repeatable performance.

The LDR current controller shown below employs a precision op amp together with a transistor and current sense resistor to create a precision high speed closed loop controller that accurately achieves a target current level in response to a command voltage from a microcontroller.

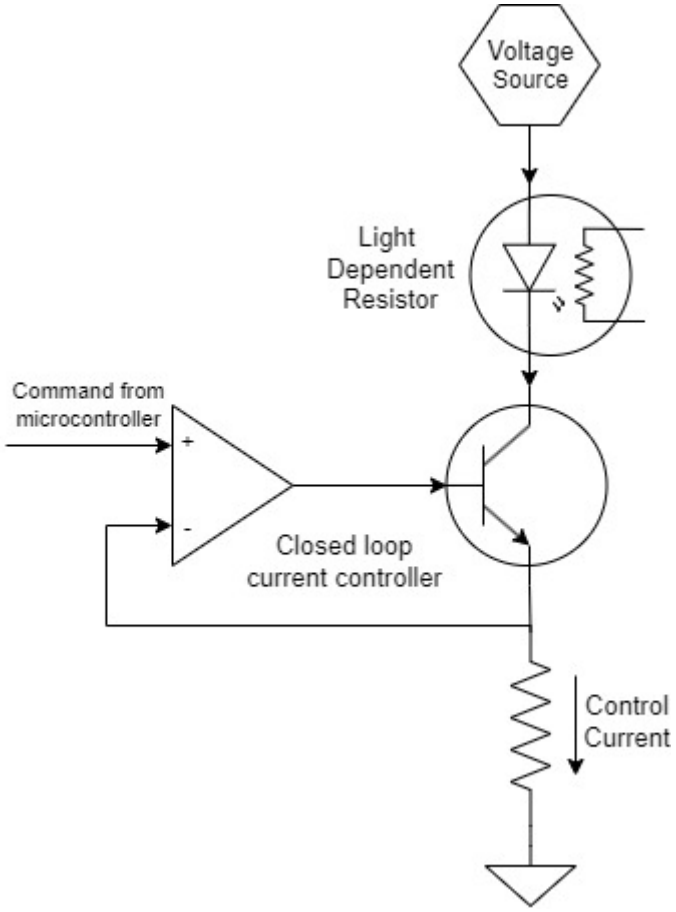


Figure 46. LDR current control loop

Use of a precision op amp is key to this design. Precision op amps are optimized for applications where high accuracy, low noise, thermal stability, and minimal offset are essential to achieve precise signal processing.

The governing equation for the current controller effectively turns the inherently nonlinear LDR into a predictable linear device.

Current control loop governing equation

Control current = Voltage command / Resistance

How it works

The op amp receives a voltage command from the V4 microcontroller that it compares to the voltage across the current sense resistor. The op amp modulates the current flow by driving a transistor that acts as a current flow valve.

Calibration definition

Calibration is a measurement process where the resistance of each LDR is measured against a target schedule, resulting in a stored table of resistance versus voltage command to be used in driving the LDR control loop shown in Figure 46 and reaching the resistance levesl need for each attenuation step.

Why calibration is needed

The relationship between command voltage and the resulting LDR resistance must be determined empirically through a calibration process, because the behavior of

individual LDRs is not sufficiently uniform, nor fixed over time, to use them for precise volume control.

5.2.2. The microcontroller (U1) & PWM

The V4 employs a proven 80 pin STM32G4 embedded 32 bit ARM Cortex microcontroller (U1) to handle all V4 control function including the generation of command signals to the LDR control loop discussed earlier as well as LDR calibration process needed to normalize the behavior of a set of 4 LDRs.

Figure 47. stm32g4 32 bit ARM microcontroller

The microcontroller is programmed using a combination of the C++ and C languages. The "bare metal" application runs under a thin FreeRTOS real time operating system.

The V4 microcontroller runs at a frequency of 140 MHz and employs 16 bit timers to generate pulse width modulated (PWM) square waves with output running between 0 and 3.3 volts. The microcontroller PWM timers divide 3.3 volts into 65,535 discrete steps of 50.35 microvolts per step. This gives the V4 very fine control over volume level allowing for volume control increments of ~0.6 dB which is very smooth indeed, is far superior to any stepped attenuators using discrete resistor pairs, and is indistinguishable (to the human ear) from continuous analog control.

We turn that useless square wave into a smoothly averaged voltage value using a simple yet highly effective first order passive filter. The microcontroller modulates the resulting averaged voltage output by changing the duty cycle (the "ON" time) of the square wave pulse. The final smoothed PWM output becomes the command input to the LDR current control loop discussed earlier.

LDRs behave as first order filters with their own time constant. Translated into plain english, this means they don’t react instantly to control input changes. This filtering effect works in our favor because it further filters out any noise in the PWM command signal, yet they react fast enough to be highly responsive to level changes in listening volume.

The topic of LDR calibration is covered in Section 4.3 as part a section dedicated entirely to discussing how LDRs work and their use in the V4.

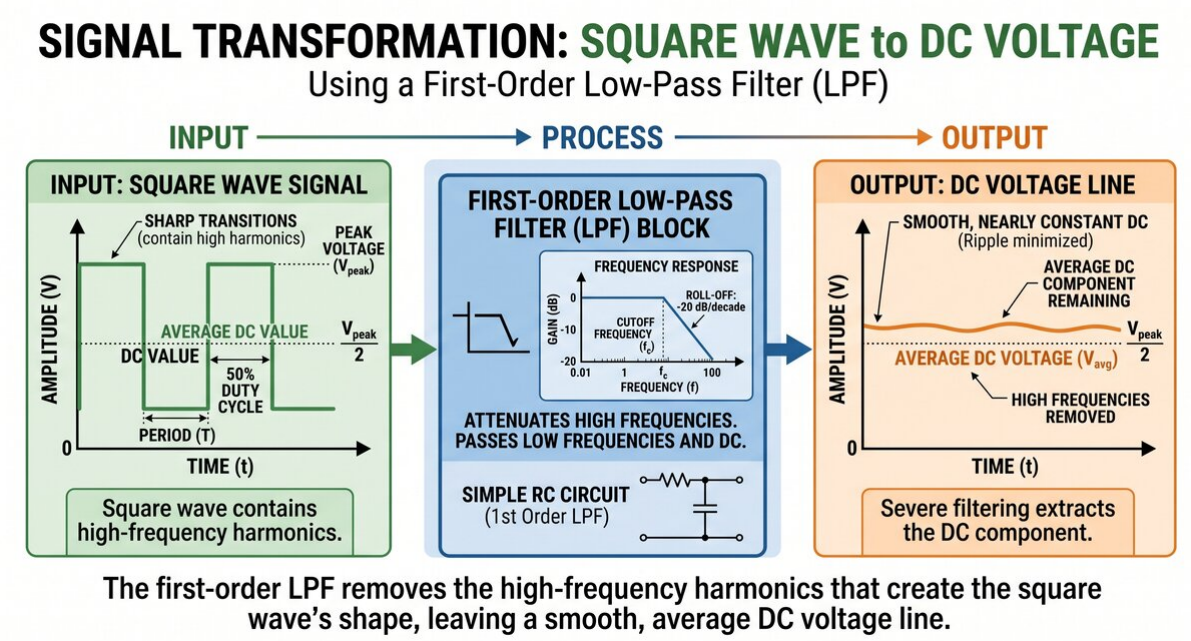


Figure 48. Filtered pulse width modulated signal

5.2.3. Stepped attenuation & 100 volume steps

The V4 can be considered a type of stepped attenuator insofar that it breaks volume into 100 discrete steps of ~0.6 decibels per step over a 60 decibel control range. Unlike a conventional mechanically switched stepped attenuator or rotary potentiometer, LDRs are 100% opto-electronic with zero moving parts.

A granularity level of 100 steps means that the volume change between each step is smooth and continuous with no audible artifacts. There's always a perfect volume level.

Each step change in volume can be made using either a handheld remote control or by using a rotary encoder (control knob) attached to the V4.

5.2.4. LDR module | J1 & J2

The LDRs reside in small plug-in daughter board that plugs into the main V4 board via the J1 and J2 headers. The LDR module is easily removed and replaced. There are 4 LDRs in each module with 2 LDRs per stereo channel. Early copies of the LDR module also had a memory chip present but is absent in later builds as this memory is no longer required.

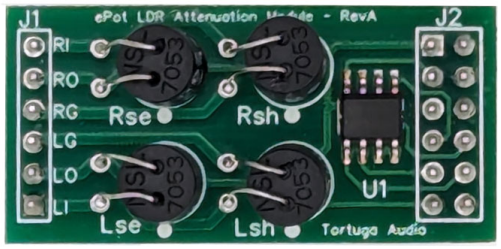


Figure 49. LDR module top view

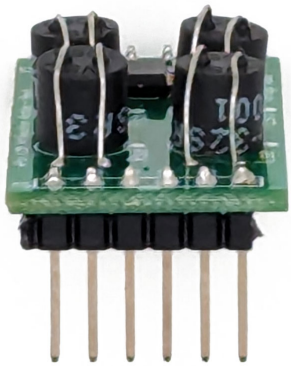


Figure 50. LDR module end view

Each ePot LDR module has 4 LDRs configured as two pairs. The topmost LDR pairs (RSeries and RShunt) are the right channel LDRs and the two bottom LDR pairs (LSeries and LShunt) are the left channel LDRs. If an LDR ever fails or goes out of specification, it's a straightforward matter to replace the plug-in LDR module.

J1 header pinout

The 6-pin J1 header carries the audio input and output signals plus signal ground for both the left and right channels. Each channels is fully independent of the other including audio signal ground. The J1 pinouts are as follows:

J1 header pinout

Pin	Description
#1 - RI	Right input
#2 - RO	Right output
#3 - G	Right ground
#4 - LG	Left ground
#5 - LO	Left output
#6 - LI	Left input

J2 header pinout

The 12-pin dual row J2 header carries the power, control, and communications. Earlier versions of the LDR module produced for the previous V3 series boards held an eeprom memory chip. The memory chip was dropped on later builds of the LDR module and is not required for the V4. The J2 header pinouts are listed below.

J2 header pinout

Pin	V3 (with memory chip)	V4 (no memory chip)
#1	+5V power	(same)
#2	-5V power	N/C
#3	ground	N/C

Pin	V3 (with memory chip)	V4 (no memory chip)
#4	N/C	N/C
#5	right shunt LDR current	(same)
#6	right serial LDR current	(same)
#7	SPI chip select	N/C
#8	SPI MISO (serial data out)	N/C
#9	SPI clock	N/C
#10	SPI MOSI (serial data in)	N/C
#11	left shunt LDR current	(same)
#12	left series LDR current	(same)

How to insert the LDR module

To insert the LDR module into the V4 sockets, first align the pins on the 12-pin J2 header into the J2 socket with the LDR module held at approximately a 45 angle (J1 end up, J2 end down). Then lower the J1 header pins into the J1 socket making sure the pins align. Once you feel that the pins on both the J1 and J2 headers have found their respective sockets, gently press the module down into both sockets.

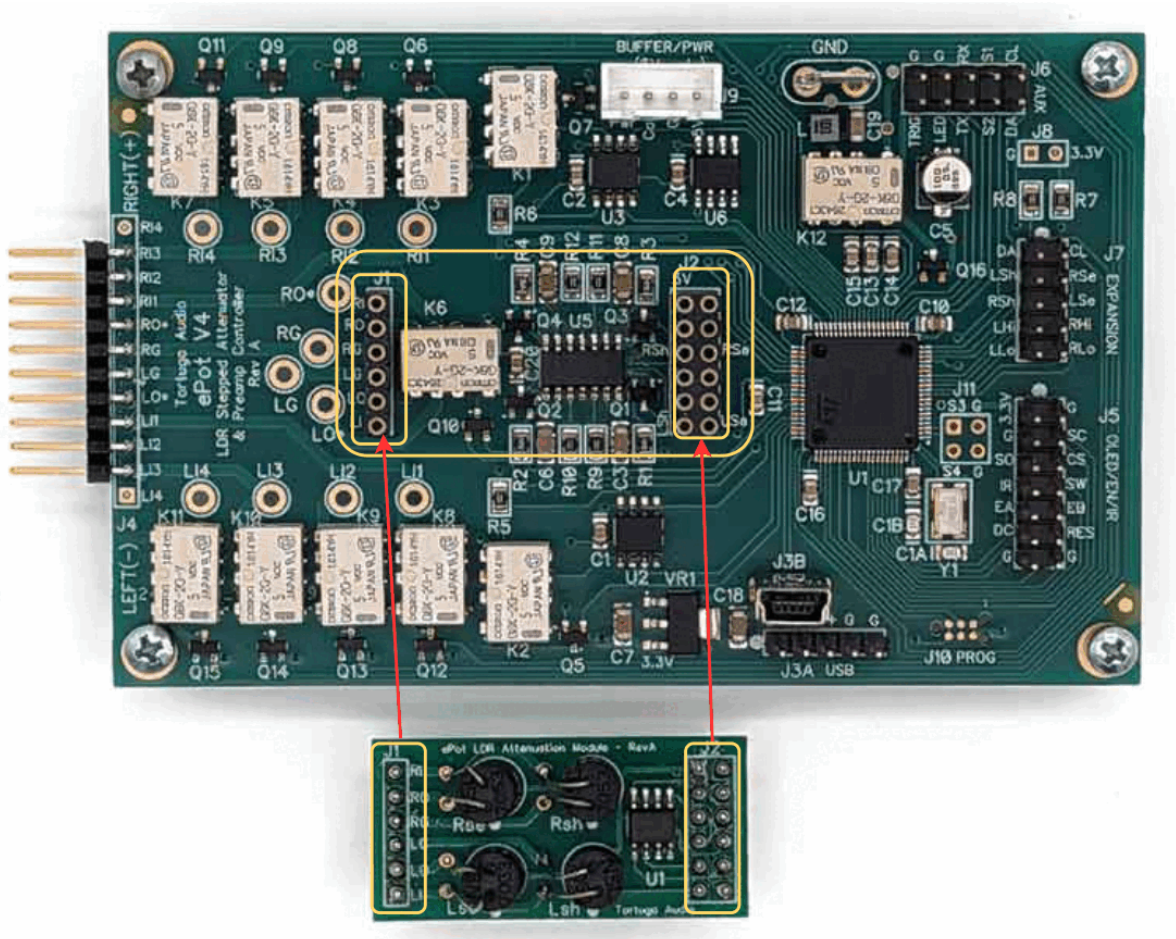


Figure 51. LDR module inserts in the J1/J2 header

DO NOT FORCE THE LDR MODULE!

If the pins are not perfectly aligned into their socket holes, do not expect the module to go in. Re-align the pins on both ends first before attempting to press the module into the sockets. If the module won't align and go in, visually inspect the pins on the LDR module to see if any pins are slightly bent or out of alignment. The pins can usually be easily manually manipulated back into alignment.

5.2.5. Power supply | J9 header

The V4 requires a source of clean 5 volt regulated DC power with a nominal capacity of 0.5 amps although actual current demand is typically no more than 0.3 amps. The V4 uses this 5 volt power directly and also has an on board linear regulator that produces 3.3 volts locally.

With & without a solid state buffer board

Power entry to the V4 board varies depending on the board revision and whether or not the V4 is equipped with the optional solid state buffer board. V4's without a buffer board are powered directly. V4's with a buffer board receive their power from their buffer board and have no direct power connections. This can be somewhat confusing so approach this deliberately.

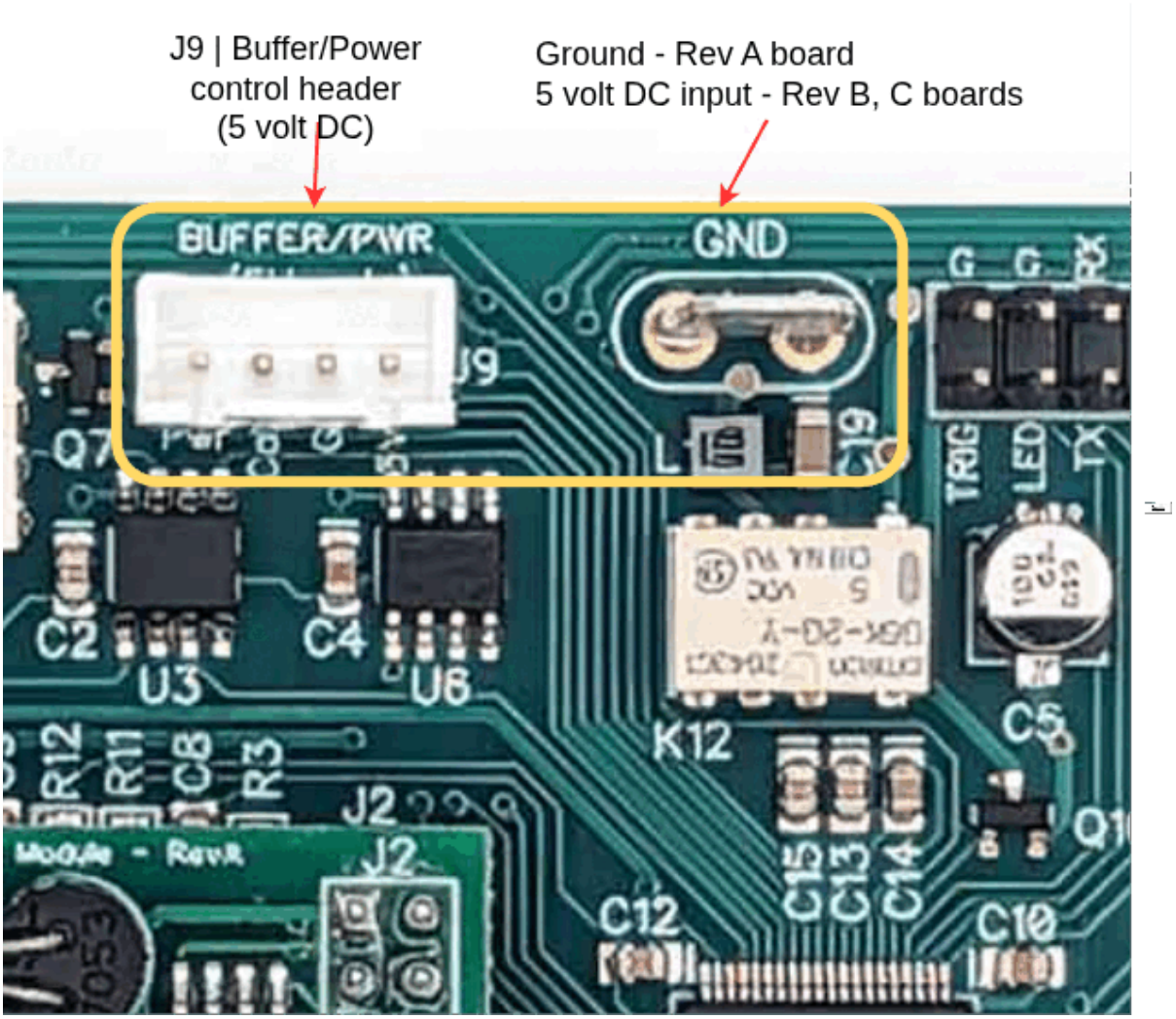


Figure 52. V4 board power entry - Rev A board

Rev A power entry

- power enters the V4 via the J9 header
- adjacent GND lug is an optional ground connection point

Rev B/C power entry

- DO NOT connect power to the V4 via the J9
- The J9 header is solely for connecting the V4 board to the optional solid state buffer board
- Power enters the V4 via the adjacent lug with left lug tab being +5V and the right lug tab being ground.

J9/Power headers pinout

Pin/Item	V4 - Rev A board	V4 - Rev B & C boards
J9 header type	JST male shrouded header	Regular square pin header
J9.5V	+5V power to V4	+5V power from Buffer (when present)
J9.G	power ground to V4	power ground from Buffer (when present)
J9.Cal	calibration start/stop - to buffer board	calibration start/stop - to buffer board
J9.Pwr	power on/off command to buffer	power on/off command to buffer
GND lug connector type	Faston tab - soldered	Direct wire-to-board - soldered
GND lug (left tab)	power ground	+5 volt power (solder lug)
GND lug (right tab)	power ground	power ground (solder lug)

The Rev A J9 header uses a 4 position “JST" type connector made by the Japan Solderless Terminal company, or by other manufacturers using the same connector design. Subsequent board revisions use a naked 0.1 inch square pin male header.

5.2.6. Audio signal inputs & outputs | J4

The V4 switches between 4 stereo input sources using miniature electromechanical relays. These relays are shown in the image below. Audio inputs, output, and signal grounds connect to the V4 via the 12-pin J4 pin header, or alternatively through individual solder lugs for soldering wires directly to the board.

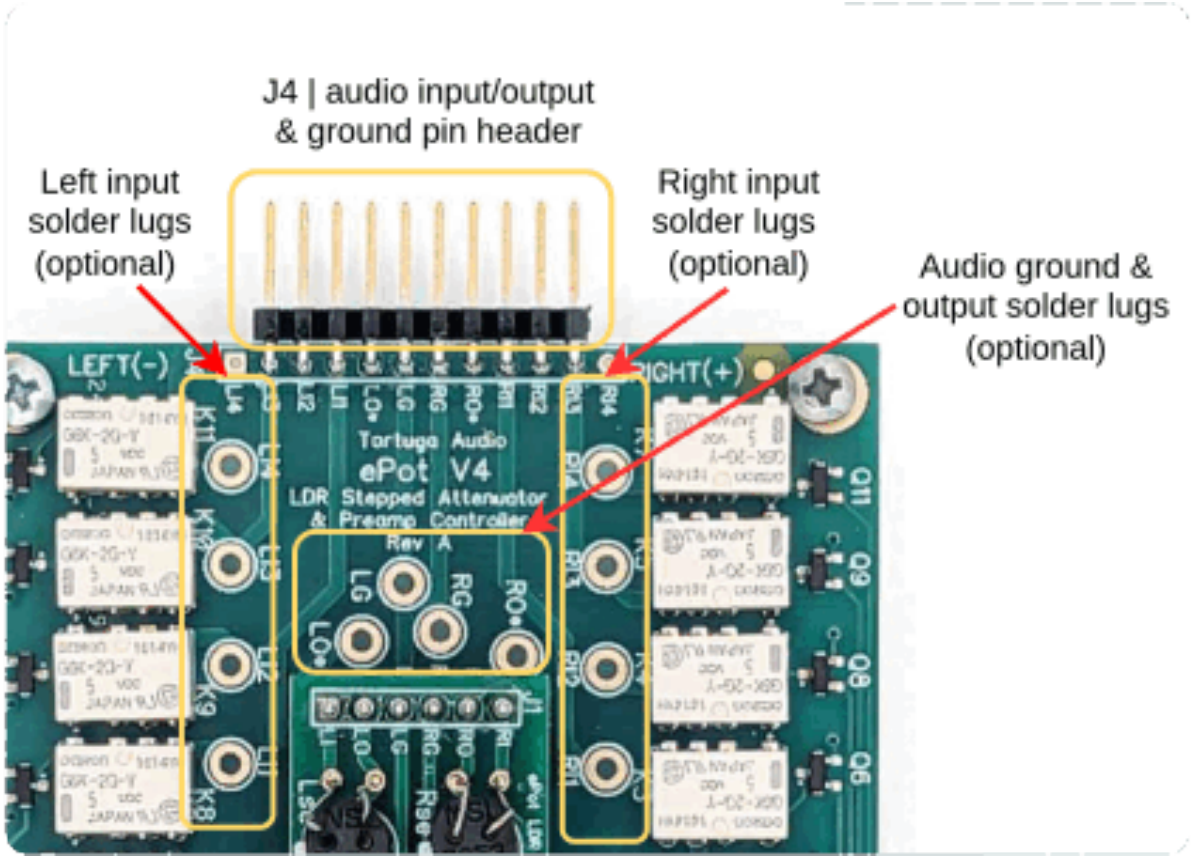


Figure 53. V4 board inputs & outputs - header J4

Audio input/output header pinout

Pin/Item	Function
J4.RI3	right input #3
J4.RI2	right input #2
J4.RI1	right input #1
J4.RO	right output
J4.RG	right signal ground
J4.LG	left signal ground
J4.LO	left output
J4.LI1	left input #1
J4.LI2	left input #2
J4.LI3	left input #3
J4.LI4	left input #4

About V4 audio signal grounds

- The left and right channel grounds (LG & RG) are fully independent grounds that DO NOT connect together anywhere within the V4 board
- The audio signal grounds DO NOT connect within the V4 board to the V4 power supply ground
- In order for LDR calibration to work, the audio signal grounds MUST

CONNECT AT A STAR GROUND POINT somewhere external to the V4 board.

5.2.7. Muting relay

The K6 muting relay sits on the V4 board immediately underneath the LDR module. When the V4 is muted, the audio outputs (RO & LO) are switched to audio signal grounds (RG & LG), effectively killing the output.

5.2.8. OLED display header | J5

The J2 header on the OLED display assembly connects to the J5 header on the V4 board via a 14 ribbon cable. The OLED cable carries the power and control signals for the OLED display module, the IR receiver module, and the rotary encoder. The IR receiver and the encoder are both part of the OLED display assembly.

The encoder module connects to the J2 header on the OLED display via a 4-wire square pin data cable. The encoder module DOES NOT connect directly to the V4 board.

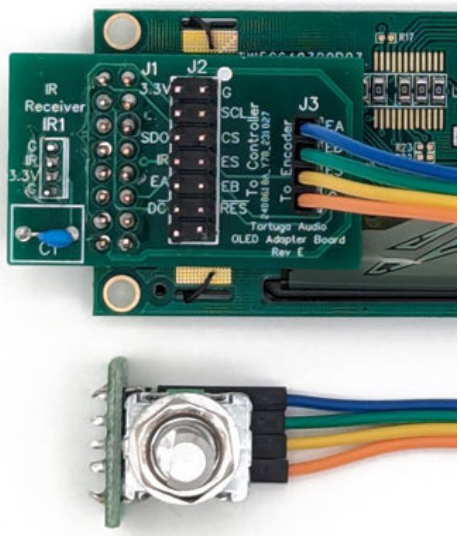


Figure 54. OLED adpater header - J2

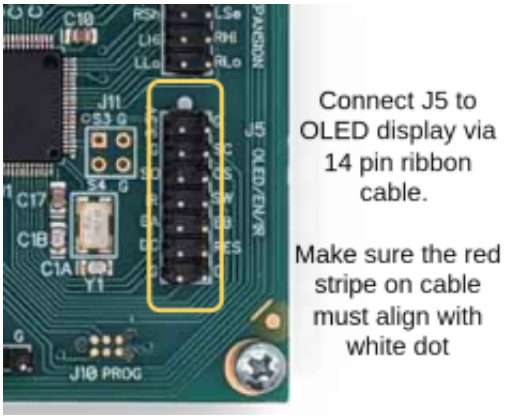


Figure 55. V4 OLED header - J5

The OLED display operates on 3.3 volt and is powered directly from the V4 board via the ribbon cable. The V4 communicates with the OLED display over a dedicated SPI serial data link.

The J5 header pins are labeled as follows in the clockwise direction:

OLED display header pinout

Pin/Item	Function
J5.3V3	3.3 V DC power
J5.G	ground
J5.SC	SPI serial data clock
J5.CS	SPI OLED chip select
J5.SW	encoder switch

Pin/Item	Function
J5.EB	encoder leg B
J5.RES	OLED reset
J5.G	ground
J5.G	ground
J5.DC	OLED data/command select
J5.EA	encoder leg A
J5.IR	IR receiver signal
J5.SO	SPI serial data
J5.NC	no connection

5.2.9. Balanced audio | J7

Whereas single-ended stereo requires only a single 2-channel V4 board, a second V4 board is required for balanced audio applications. A designated primary board connects to an identical secondary board via a 4 wire cable.

The primary board is always assigned to handle the right channel and the secondary board handles the left channel. Within each of these 2 boards, the +phase of the balanced signal connects to the right channel, and the -phase signal connects to the left channel.

No balanced firmware for V4 Rev A or B boards

Firmware for the J7 expansion board header was never released for the Rev A & B versions of the V4 board because we decided to pursue a different approach that required a different interface. The planned Rev C board, has a different header configuration for handling connection between two V4 board for balanced audio.

Planned Rev C board to support balanced audio

A Rev C version of the V4 board is under development with release planned before the end of 2026 that will accommodate balanced audio applications.

```
Missing Rev C board pinout info goes here when it's available
```

5.2.10. Auxiliary status & communication header | J6

J6 is an 10-pin dual row (2x5) male pin header that provides several logic level status output signals, a 5 volt trigger out signal, plus both UART and I2C serial communications ports for communication with 3rd party external devices.

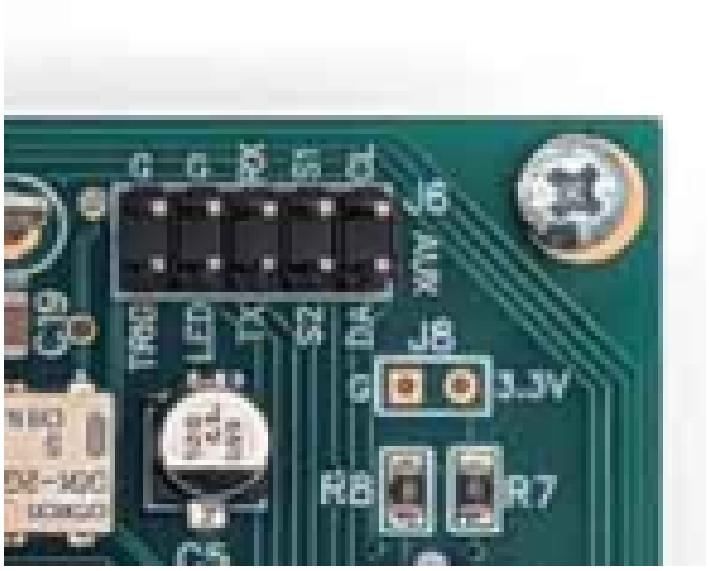


Figure 56. V4 auxilliary header - J6

J6 status outputs are logic level (3.3V) signals only and should NOT be relied on to source or sink more than a few milliamps of current. The J6.LED signal can directly drive a typical LED equipped with an appropriate current limiting resistor. The J6.TRIG signal is a robust 5 volt but requires an external 5 to 12 volt boost to achieve a true 12 volt trigger output.

The J6 pinouts are labeled clockwise from upper left as follows:

Auxiliary status & communication header pinout

Pin/Item	Function	Signal type
J6.G	ground	ground
J6.G	ground	ground
J6.RX	UART serial communication receive	serial data
J6.S1	unassigned spare output S1	3.3V TTL logic
J6.CL	I2C serial communication clock	serial clock
J6.DA	I2C serial communication data	serial data
J6.S2	unassigned spare output S2	3.3V TTL logic
J6.TX	UART serial communication transmit	serial data
J6.LED	unit on/off status signal for panel LED	3.3V TTL logic
J6.Trig	5 volt trigger output	relay switched 5 volt signal

5.2.11. Solid state buffer board (optional)

The V4 Max can accommodate an optional solid state buffer board (sold separately) that mounts directly on to the V4 board using the same sockets as the LDR Module. The LDR Module is then plugged into the solid state buffer board.

The buffer board turns the V4 Max into an active solid state preamp with adjustable gain.

The manual for the solid state buffer board can be found in a separate section [**TBD**].

5.2.12. Firmware updating

The firmware updating procedure for both the Max and Mini can be found in a separate section [**TBD**].

5.2.13. Ambient requirements

The V4 is designed to operate within nominal room temperature conditions that are typical for home stereo equipment. LDRs are known to be temperature sensitive. Therefore large departures from nominal home room temperature conditions may cause the LDR attenuation module to operate poorly. Operating an LDR attenuator module inside of equipment that gets very warm may still work but you may have to run calibration after board has warmed up and stabilized. We have not found this to be a problem within our own preamp products but the caution is valid.

Chapter 6. OLED display assembly

6.1. Overview

The OLED (Organic Light Emitting Diode) display assembly combines a 3.2 inch, 256 x 64 pixel OLED graphic screen with a custom adapter board, a rotary encoder, and an infrared receiver module to create an integrated OLED display assembly for Tortuga Audio's LDR stepped attenuator and preamp controllers. It's a bright, high contrast, white-on-black display with no backlighting. Overall brightness is user adjustable over a 14 step range.

The OLED display assembly is a key part of the menu driven man-machine visual control interface used by all Tortuga Audio preamp controllers and products including the V3 and V4 series. The OLED display replaced Tortuga Audio's earlier 7-segment displays.

The OLED display assembly was originally released in June 2018 for use with Tortuga Audio's V25 preamp controller board. There have been 5 revisions to the OLED display assembly designated as A through E with E being the current version. These revision are discussed in more detail below.

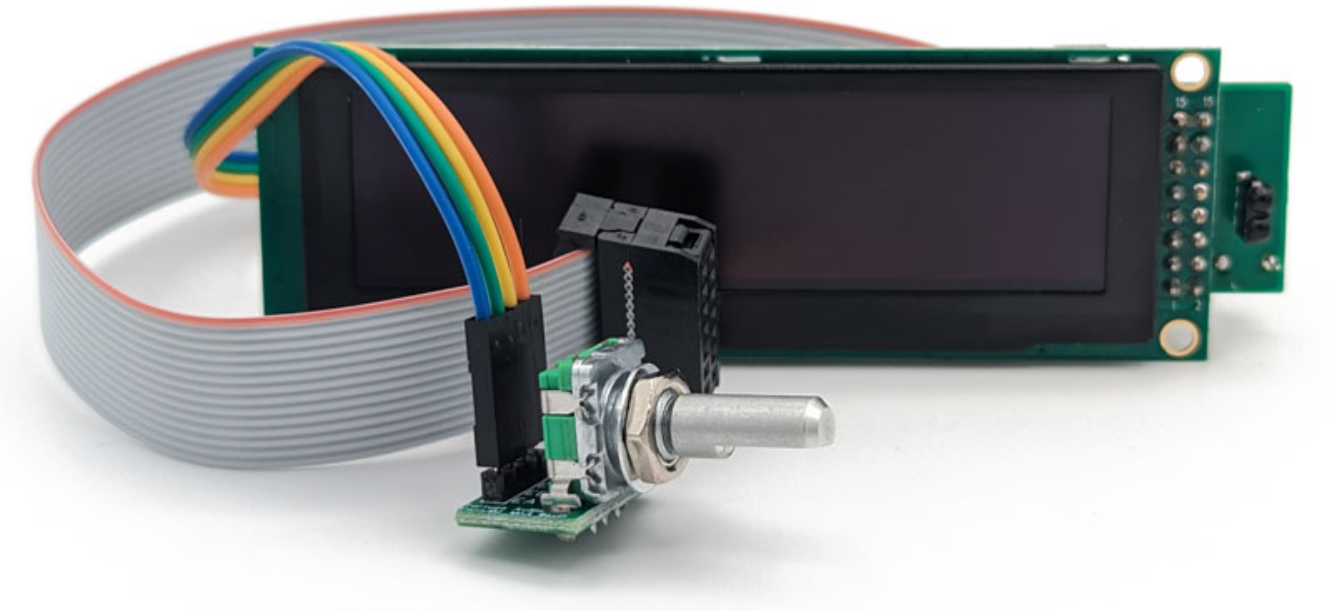
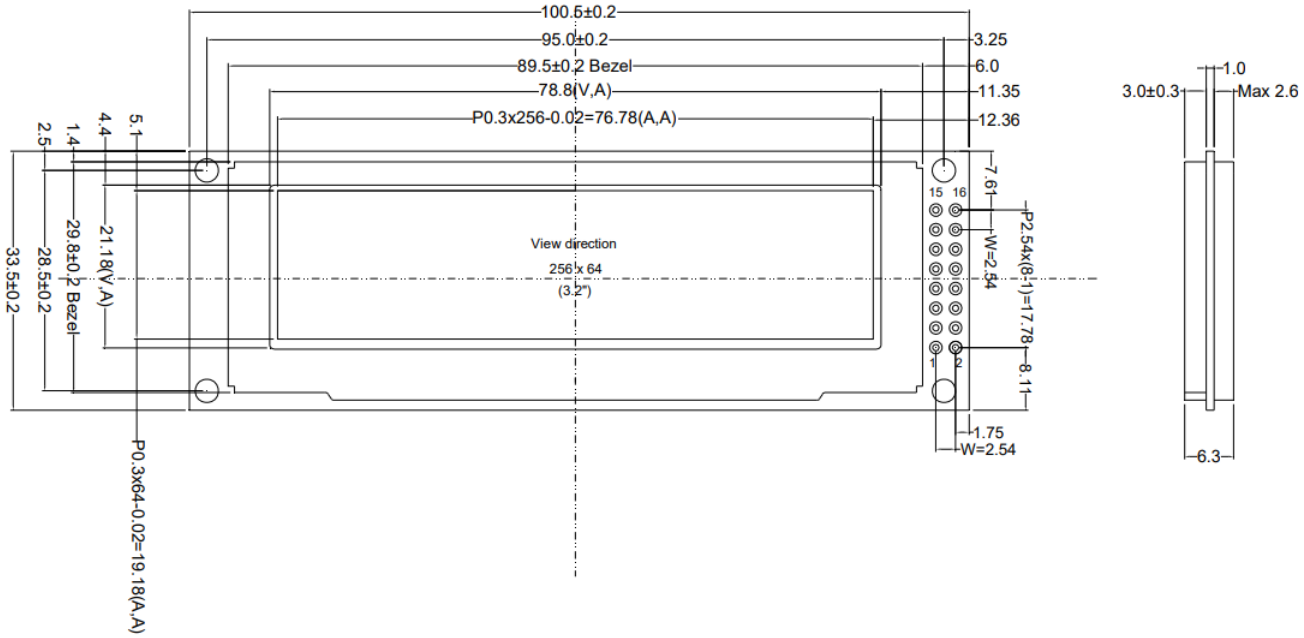


Figure 57. OLED display assembly | Rev E | front view | with cabling, encoder & IR module

6.2. Display board

The display assembly uses a 3.12 inch (diagonal) OLED screen screen manufactured by EastRising designed around the Solomon Systech SSD1322 OLED driver/controller. The 256×64 pixel graphical screen renders 16 shades of white on to a black background.



The display board is equipped with a single 16-pin dual row control/power header. Connection to the display board is handled by Tortuga Audio's custom adapter board described below.

6.3. Adapter board

Tortuga Audio's custom adapter board is soldered directly to the OLED screen board via J1. The adapter board includes a 14-pin J2 interface header for connecting the display assembly to a Tortuga Audio preamp controller board via a ribbon cable. The adapter board also includes a 4-pin J3 header for connecting to a rotary encoder (manual volume/control knob) via a simple 4-wire cable. The adapter board also has a solder pad for attaching an infrared remote receiver module.

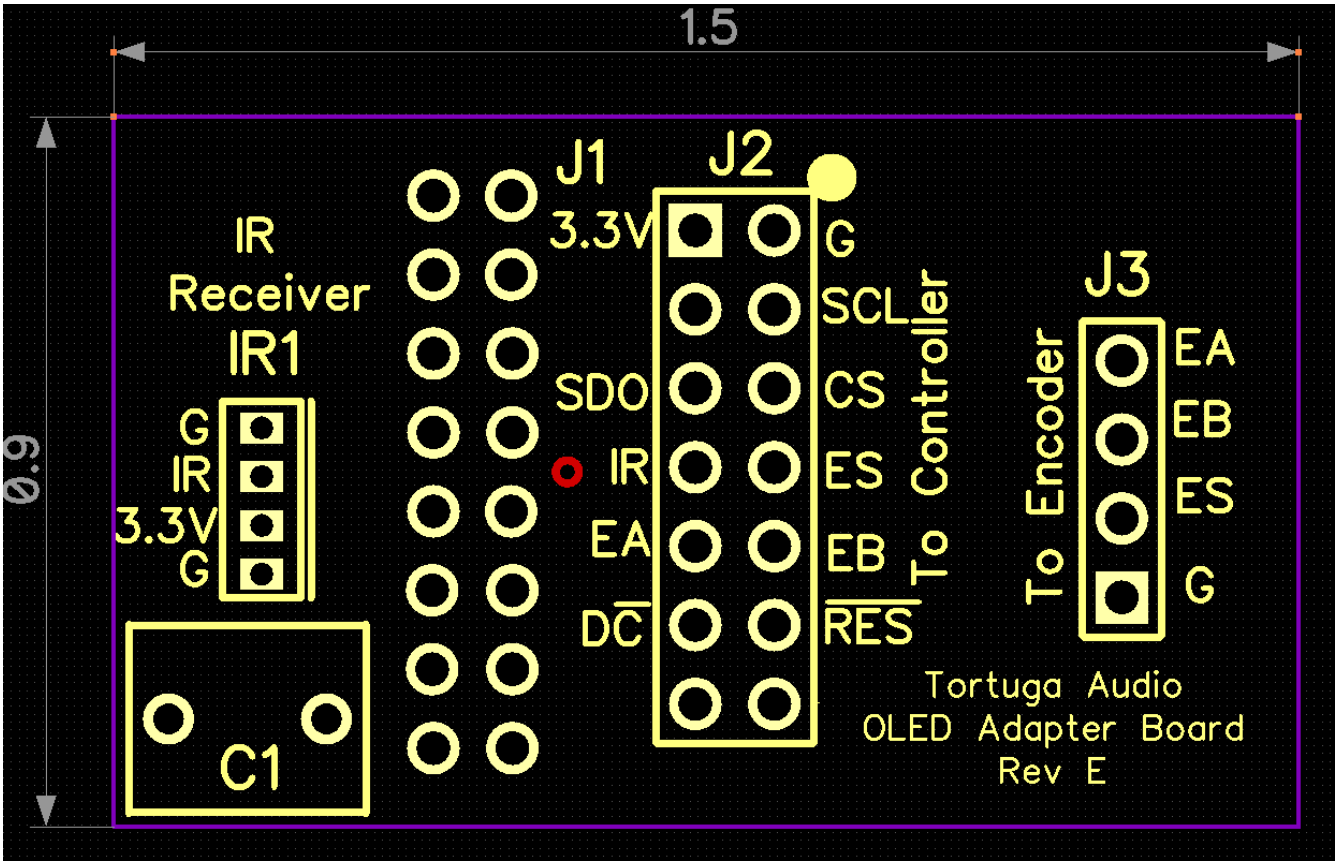


Figure 58. OLED assembly adapter board pin out

6.4. J2 | control header

All power and control signals for the OLED screen, the encoder, and the infrared receiver are routed through a single 14-pin ribbon cable that connects to the J2 pin header on the OLED adapter board. The other end of the control cable connects to a corresponding OLED pin header on the a Tortuga Audio V25, V3 or V4 preamp controller board.

- 3V3 – power (clockwise)
- G – ground
- SCL – SPI clock
- CS – SPI display chip select
- ES – encoder switch
- EB – encoder leg B
- RES – OLED display reset
- **no connection**
- **no connection**
- DC – OLED display data/command
- EA – encoder leg A
- IR – infrared receiver signal
- SDO – SPI data

- **no connection**

Please note that the ribbon cable connector ends are NOT keyed and thus can be connected in reverse. While this is unlikely to damage equipment, please be careful to make sure the red stripe on the ribbon cable is on the same side of each header that has a white dot the circuit board (i.e. align the red stripe with the white dot).

6.5. J3 | encoder header

The rotary encoder provides a means of manually controlling a Tortuga Audio preamp controller. However, the sole means of connecting the encoder to a preamp controller is through the OLED display assembly. The encoder connects to the OLED display assembly via the 4-pin J3 header on the adapter board. The J3 connection notwithstanding, the encoder has no direct connections to the OLED display itself.

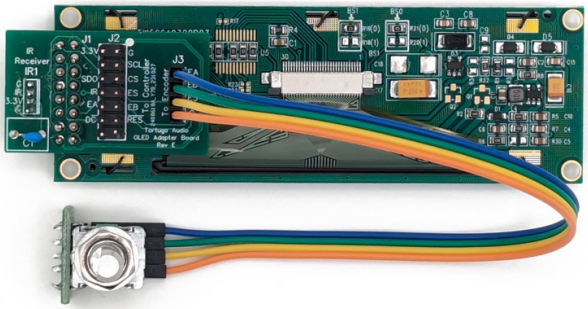


Figure 59. OLED display assembly | Rev E | rear view | with encoder attached

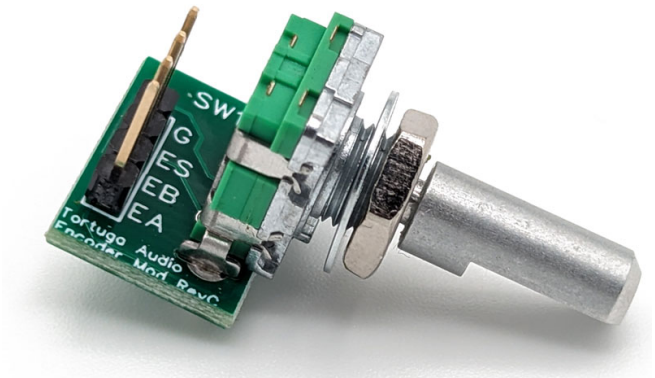


Figure 60. 4-wire encoder with integral push button

The J3 encoder header pin out is listed below.

- EA – encoder leg A
- EB – encoder leg B
- ES – encoder push button switch
- G – ground

Please note that if turning the encoder clockwise lowers rather than increases the volume, that you can simply swap the position of the EA (leg A) and EB (leg B) connections to correct this.

Also, note that the encoder module itself can be purchased separately here.

6.6. IR1 | infrared receiver module

The 4-wire infrared (“IR”) receiver module is soldered into the end of OLED adapter board where the adapter board extends slightly beyond the edge of the OLED display screen. This allows the IR receiver to “see” out into the listening room assuming the OLED display assembly is mounted into the front panel of a preamp and thus is itself facing out into the listening room.

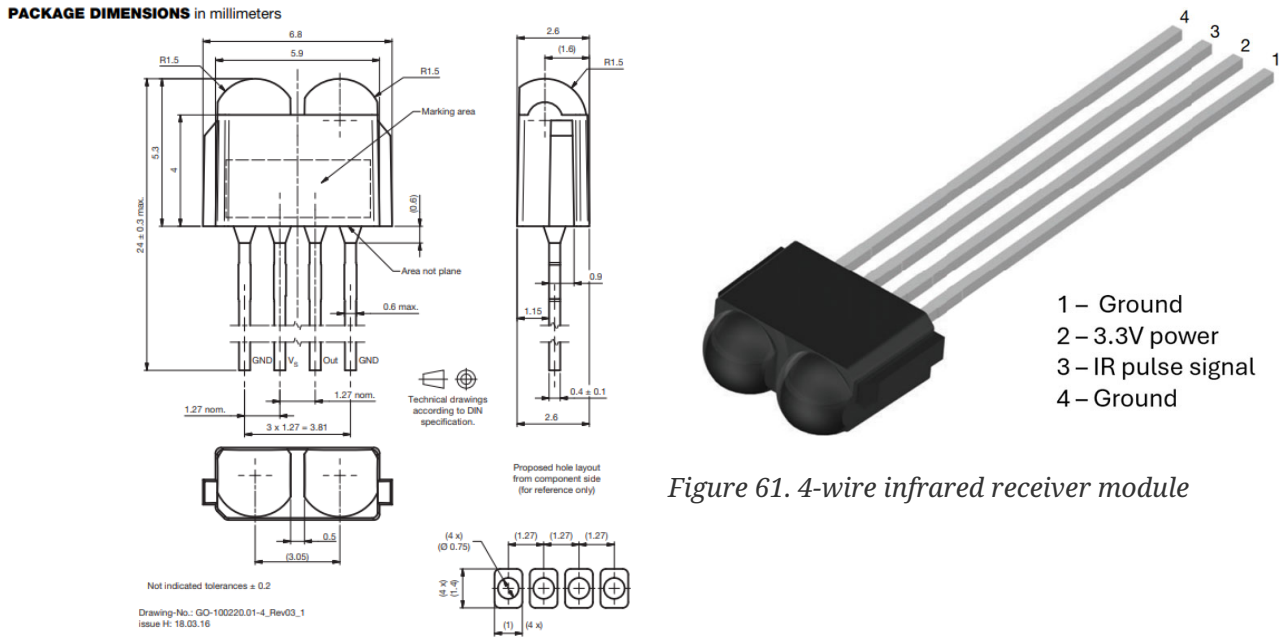


Figure 61. 4-wire infrared receiver module

As with the encoder, the IR receiver has no connections into the OLED display screen itself. It sends its signal to an attached Tortuga Audio preamp controller board via the same 14-pin ribbon cable used by the encoder and the OLED display.

The IR receiver pin out is as follows:

- G – ground
- IR – received signal pulse
- 3.3V – power
- G – ground

6.7. Hardware versions

The have been 5 versions of the OLED display assembly designated A through E. Versions A, B & C use a NewHaven OEM display while version D & E use an EastRising OEM display. Both OEM versions utilize the same underlying OLED display SSD1322 driver and perform identically.

The table below summarizes the differences between each version and their compatibility with Tortuga Audio controller boards.

Criteria	Version A	Version B	Version C	Version D	Version E
Adapter board interface to OEM board	1x22 pin horizontal header (top)	1x20 pin horizontal header (top)	1x20 pin horizontal header (top)	2x8 pin vertical header (right side)	same as D
Display module OEM	NewHaven	NewHaven	NewHaven	EastRising	same as D
Connections to Tortuga Audio controller board	* 14 pin parallel - display signals only * 10 pin - for IR receiver and encoder signals only	* 14 pin serial SPI - display signals only * 10 pin - for IR receiver and encoder signals only	14 pin serial SPI - for display signals, IR receiver and encoder	14 pin serial SPI - for display signals, IR receiver and encoder	same as D but with a smaller more compact adapter board.
V25 - Rev A	Compatible	Not compatible	Not compatible	Not compatible	Not compatible
V25 - Rev B	Not compatible	Compatible	Compatible - requires IR receiver and encoder to be connected individually to V25.J3 header and not through the OLED display interface board	Not compatible	Not compatible
V25 - Rev C	No compatible	Not compatible	Compatible	Compatible	Compatible
V3 & V4	Not compatible	Not compatible	Compatible	Compatible	Compatible

6.8. Legacy hardware info

6.8.1. NewHaven display screen

A NewHaven OEM display screen was used in version A through C and had either a 22 or 20 pin horizontal control pin header along the top. The Tortuga Audio adapter board (not shown here) was soldered to the NewHaven OEM display via the horizonal pin header.

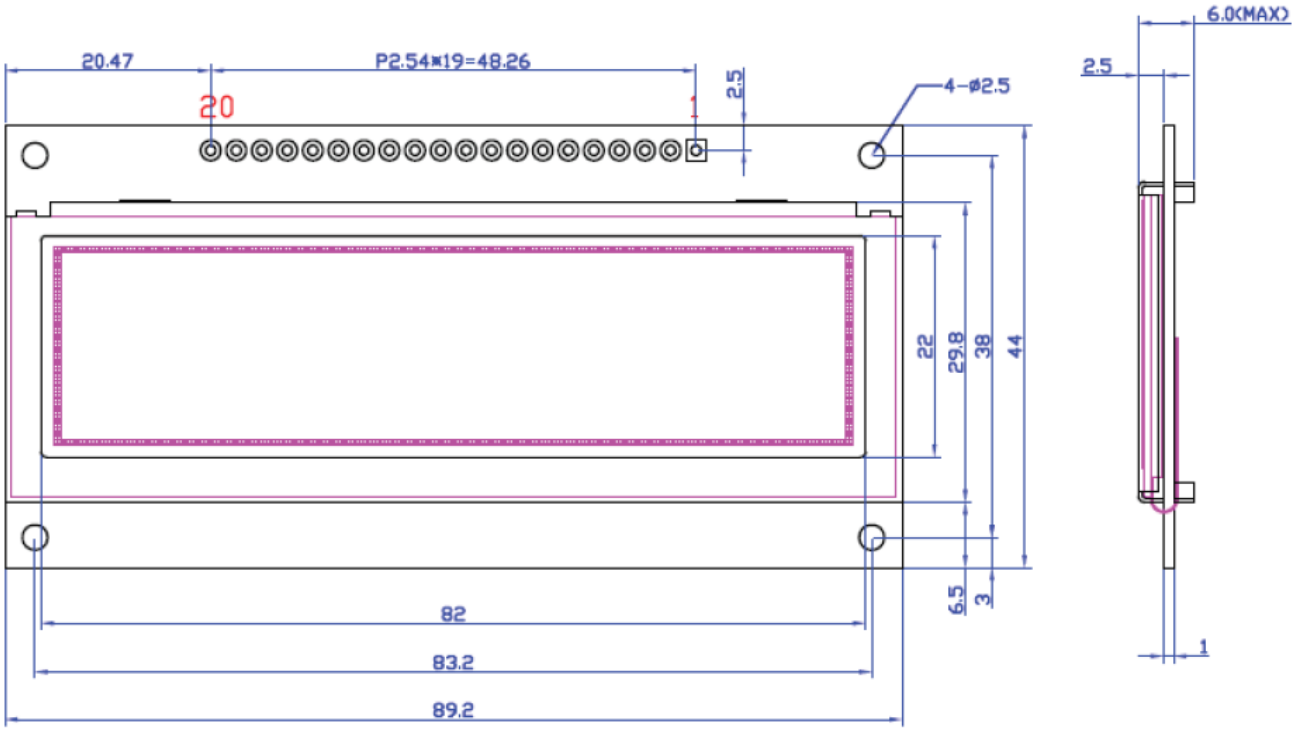
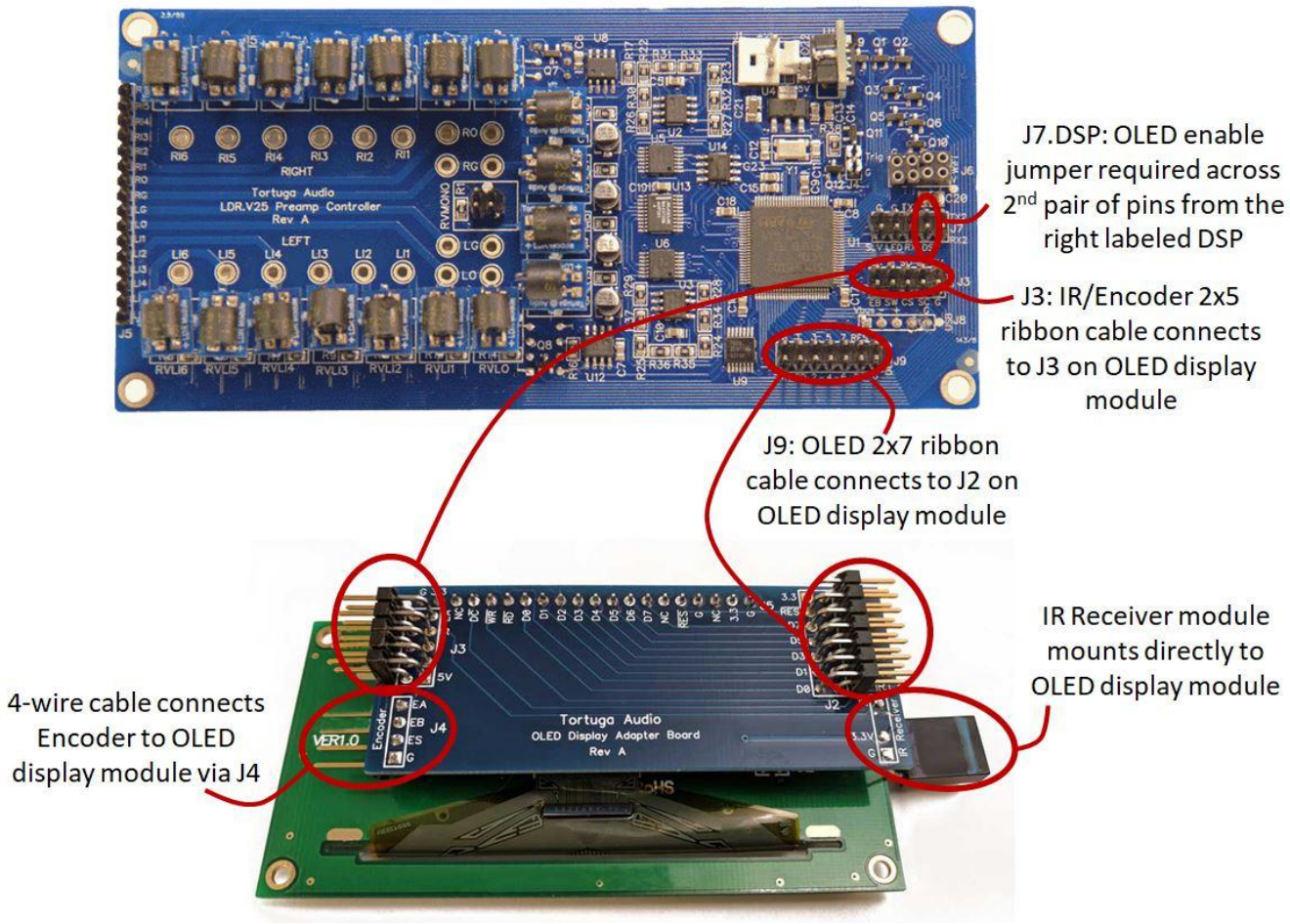


Figure 62. Rev A, B & C OLED display dimensions (excluding adapter board hidden behind the display board)

6.8.2. Secondary ribbon cable

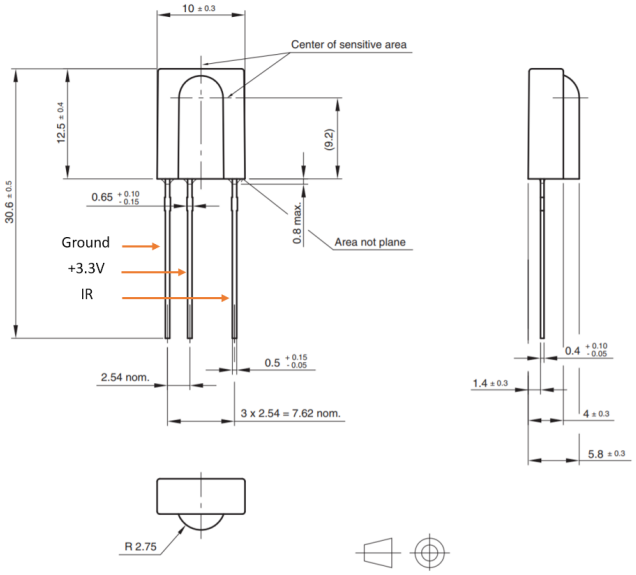
Version A display assembly used a second 2×5 IDC ribbon cable to carry encoder and IR receiver signals. This cable ran between the 10 pin V25.J3 header and the its corresponding 10 pin OLED.J3 header on the adapter board of the Rev A version of the OLED display module.

OLED display assembly versions B onwards do not use the second ribbon cable.



6.8.3. IR receiver module

OLED display assemblies prior to June 2021 used a different 3-wire IR receiver module.



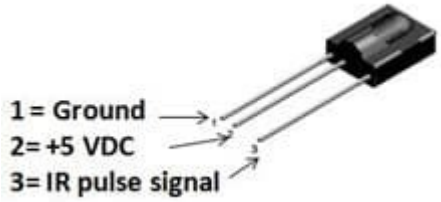


Figure 63. 3-wire infrared receiver module

Chapter 7. Encoder & infrared receiver

7.1. Overview

Since inception, all Tortuga Audio preamp controllers and other preamp products have utilized a rotary encoder with integral push button as a means for manually controlling the preamp device. While limited in control functionality as compared to using an infrared remote control, the encoder has typically provided a means to control volume, power on/off, mute/unmute, channel balance, and even select between audio input sources.

Similarly, all Tortuga Audio preamp products have utilized infrared remote control requiring the presence of an infrared ("IR") receiver module.

It has become our standard practice to make the encoder and the IR receiver an integral part of the OLED display assembly as shown below. While the OLED display assembly is mentioned herein, more information on the OLED display assembly can be found here.

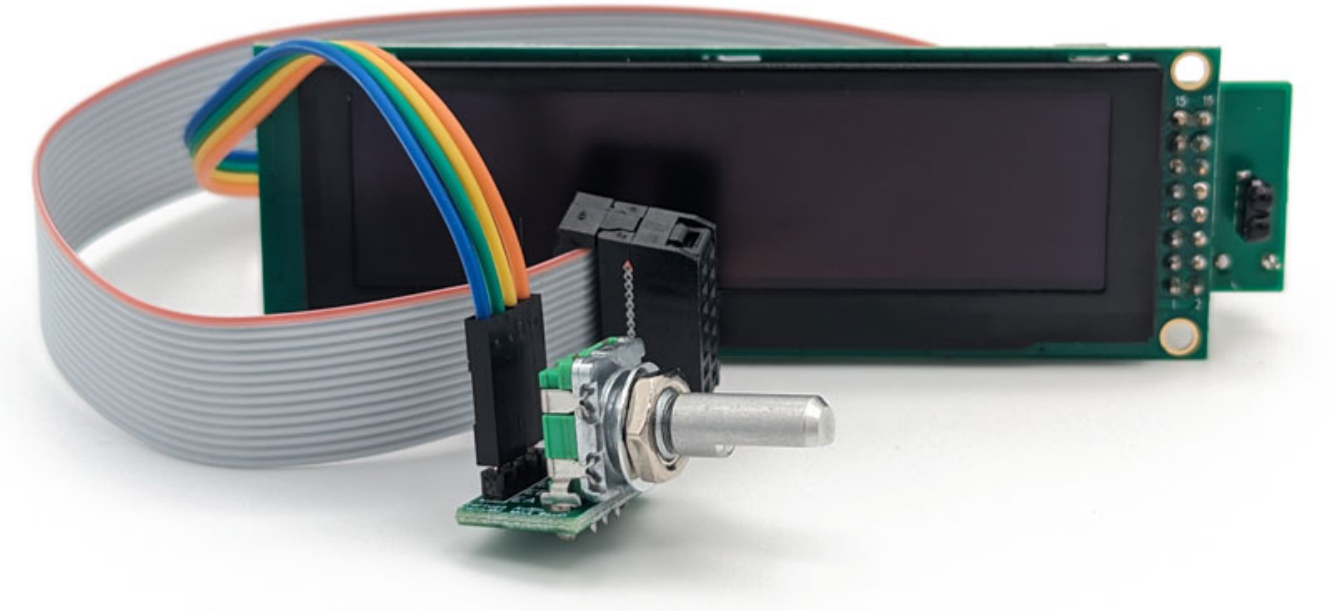
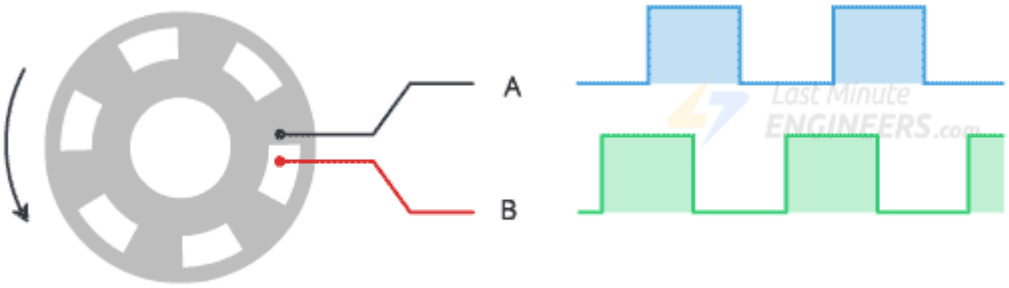


Figure 64. OLED display assembly | Rev E | front view | with cabling, encoder & IR module

7.2. Encoder module

An encoder is a type of rotary switch that generates a series of square wave pulses from two switches that are 90 degrees out of phase with respect to ground. This is referred to as quadrature encoding. The timing and sequence of these pulses vary depending on whether the encoder is being turned clockwise or counter-clockwise. The encoder Tortuga Audio uses also has a secondary push button function. Both the rotary pulses and the push button are monitored by a Tortuga Audio preamp controller which translates these signals into specific command sequences.



Counter Clockwise Rotation

Unlike a typical volume control potentiometer, an encoder has no stops and thus can be turned any number of times. There are approximately 20 pulses generated per full rotation by the specific encoder used by Tortuga Audio.

For convenience, the encoder is mounted on small encoder adapter board equipped with a 4-pin male header. The encoder connects to the OLED display assembly via a 4-wire square pin connector cable to the OLED display adapter board as shown below in images below.

Figure 65. encoder with 4-wire connector cable

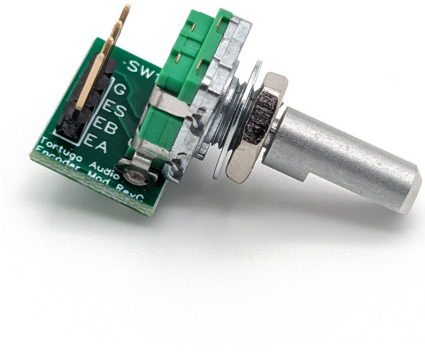


Figure 66. 4-wire encoder with integral push button

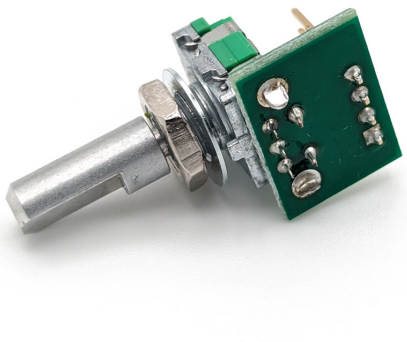


Figure 67. encoder module board | bottom view

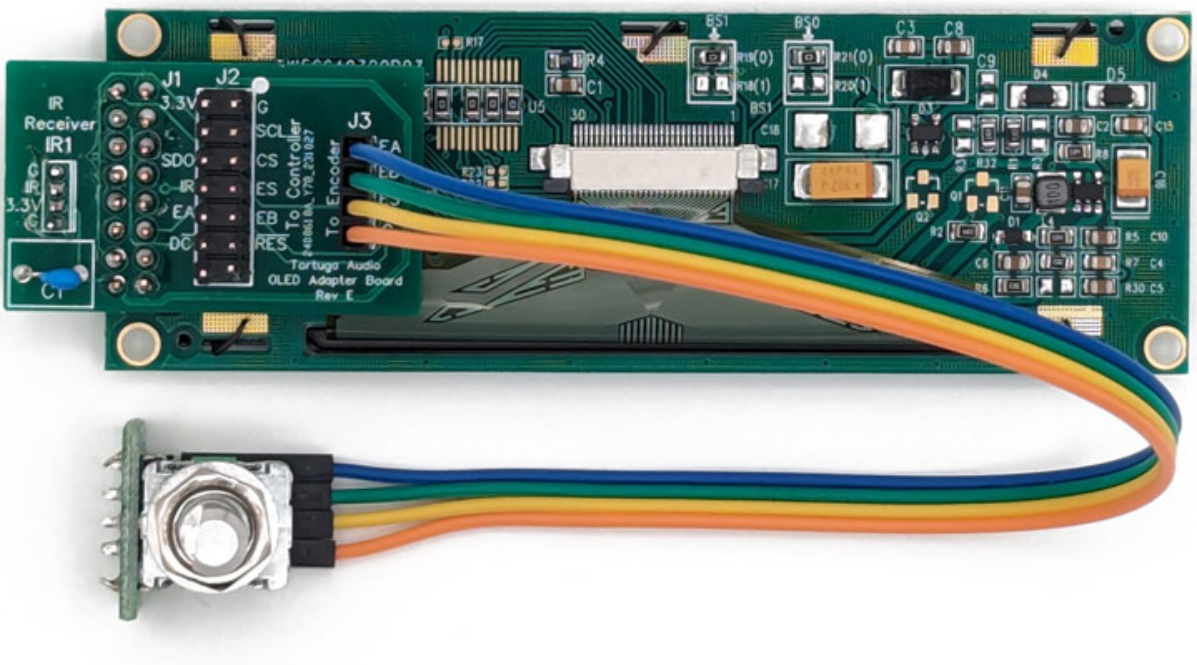


Figure 68. OLED display module showing encoder connected via Rev E adapter board

The J3 encoder header pin out is listed below.

- EA – encoder leg A
- EB – encoder leg B
- ES – encoder push button switch
- G – ground

Please note that if turning the encoder clockwise lowers rather than increases the volume, that you can simply swap the position of the EA (leg A) and EB (leg B) connections to correct this.

7.3. Infrared receiver module

The 4-wire infrared (“IR”) receiver module used in the current version of the OLED display assembly is soldered into the end of OLED adapter board where the adapter board extends slightly beyond the edge of the OLED display screen. This allows the IR receiver to “see” out into the listening room assuming the OLED display assembly is mounted into the front panel of a preamp and thus is itself facing out into the listening room.

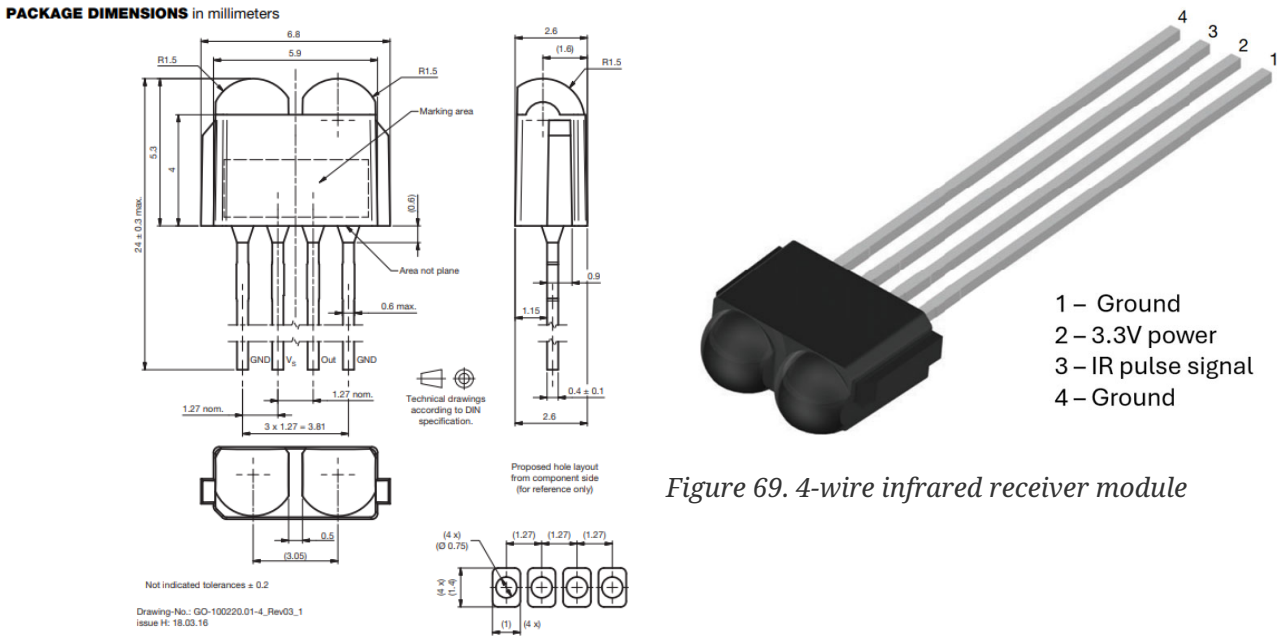


Figure 69. 4-wire infrared receiver module

As with the encoder, the IR receiver has no connections into the OLED display screen itself. It sends its signal to an attached Tortuga Audio preamp controller board via the same 14-pin ribbon cable used by the encoder and the OLED display.

The IR receiver pin out is as follows:

- G – ground
- IR – received signal pulse
- 3.3V – power
- G – ground

OLED display assemblies prior to June 2021 used a different 3-wire IR receiver module as shown below.

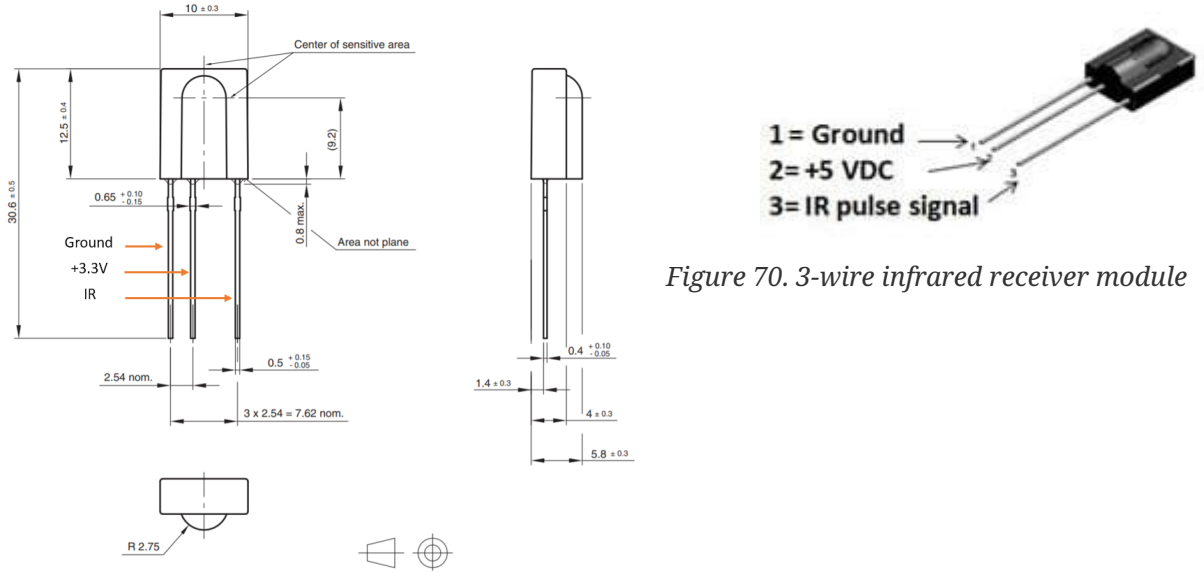


Figure 70. 3-wire infrared receiver module

Chapter 8. Appendix

8.1. LDR diagnosis & replacement

8.1.1. When LDRs Go Bad

Our experience with LDRs is that very few go bad but those that do tend to go bad very early on in their life often within a few days or weeks of initial operation. If they get through this initial period they tend to last for several years if not indefinitely.

When listening to music, the key symptom indicating that an LDR has gone bad is a permanent shift in channel balance favoring either the left or right side. In some cases a channel's volume may become fixed while the other channel operates normally. It's extremely rare for an LDR to fail in such a way that it stops conducting the audio signal completely.

During a calibration cycle, a bad LDR will likely cause the calibration sequence to slow down or stop altogether while trying to calibrate a specific LDR. This is the most reliable way to identify which LDR needs replacing. It's quite rare for more than a one LDR to go bad at the same time.

8.1.2. LDRx/LDRxB models

Remove Top Panel Screws - Remove the 6 socket head screws/washers from the top panel. Some units may not have these screws. Do NOT try to remove the top panel yet. The top panel is mounted into groves in the side panel and therefore must be slid out towards the rear once the rear panel has been detached.

Remove Rear Panel Screws - Remove the 4 socket head screws located in the 4 corners of the rear panel. Gently drop the rear panel assembly down slightly making room for the top panel to clear the top of the rear panel.

Remove/Slide-out Top Panel - At this point you should be able to slide the top panel towards the rear of the unit. Some panels may be difficult to slide out. Be very patient. Try to gently pull the panel. If the panel is resisting using a small flat screw driver to pry the front edge of the top panel away from the rear face of the front panel. Be careful not to gouge either the top panel or rear panel. Continue to nudge and pull the top panel out the rear of the unit until it's fully removed.

Reassembly When Done - When you're done with LDR replacement/maintenance simply reverse the above process. Please use a light touch when sliding the top panel back in place. Don't force it if it sticks or gets skewed - carefully realign before continuing. Also please use a light touch when reinstalling all the screws since the screws may only be going into relatively soft bamboo material. If a screw gets stripped, remove the screw and panel, and put a few drops of superglue into the hole and give the glue time to fully harden. Then try again.

8.1.3. V2/V25 Models

Remove Front/Rear Panel Screws - Remove the 4 socket head screws/washers from both the front and the rear panels.

Slide-out Assembly - The preamp assembly is attached to a slide-out mounting board that is located in the lower most set of slide rails. Gently withdraw the assembly by pulling the rear panel outwards. While doing so gently reorient and feed the front panel into the enclosure box. Stop withdrawing the assembly once you've exposed all the LDRs and can access them with your hand.

Reassembly When Done - When you're done with LDR replacement/maintenance simply reverse the above process. Please use a light touch when sliding the mounting board/assembly back in place. Don't force it if it sticks or gets skewed - carefully realign before continuing.

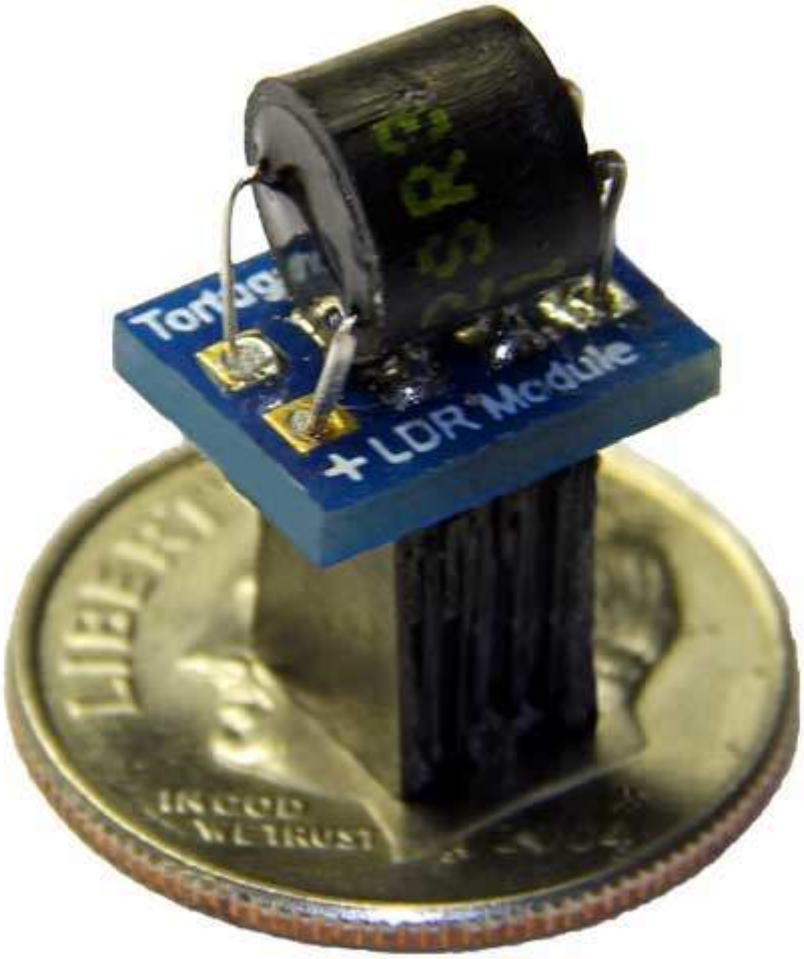
8.1.4. 300x.V3 Model

Remove Front/Rear Panel Screws - Remove only the 2 top socket head screws/washers from both the front and the rear panels. Leave the bottom 2 screws in place.

Lift off top enclosure - The enclosure is made up of a symmetrical top and bottom half-shell with a longitudinal split along both sides. Once the 2 top screws on the front and rear panels are removed there's nothing holding the top shell in place except for friction. Gently lift the top shell up. Do not force it. Wiggle and pry gently. It will come up and off. Please note the front-to-back orientation of the top shell as you remove it. It must go back on the same way or else the 2 shells will not mate properly.

Reassembly When Done - When you're done with LDR replacement/maintenance simply reverse the above process. Put the top shell back in place and replace the 2 socket head screws in the top corners of both the front and rear panels. DO NOT over tighten theses screws - you might shear them off and/or crack the acrylic front panel. Barely snug is sufficient.

8.1.5. LDR modules



Each LDR Module is a female socketed 4-pin module that is easily removed from the controller board and replaced with a new module. Each LDR Module fits onto a 2x2 male pin header on the controller board.

The LDR Modules are not keyed so there's four possible ways to plug in a LDR Module but only one correct way. Each LDR Module has a white dot on its small circuit board.

IMPORTANT! - The white dot on the LDR Module must be aligned with the matching white dot located adjacent to each 2x2 male pin header on the controller board.

8.1.6. LDR Identification

The first step in diagnosing and replacing a bad LDR is to familiarize yourself with the identity and location of each of the four attenuation LDRs on the particular model of preamp controller board present in your preamp. There are currently 2 different models of preamp controller board that uses replaceable plug-in LDR modules; the V2 and the V25. These are both discussed below.

The following table is helpful in identifying the 4 LDRs used in volume control that are subject to the calibration process. The calibration sequence is always #1 through #4. The V2 and V25 boards differ slightly in the physical locations of each of these LDRs.

LDR Function	Calibration Sequence	V2 ONLY Circuit Board Label	V25 ONLY Circuit Board Label
Right Series	#1	RV3	RVRSE
Right Shunt	#2	RV4	RVRSH
Left Series	#3	RV1	RVLSE
Left Shunt	#4	RV2	RVLSH

The V2 and V25 preamp controller boards are shown below with each of the 4 LDRs identified. The above table cross-references the various ways of identifying each LDR.

It is most useful to identify the LDRs in terms of their calibration sequence (#1 through #4) since this sequence is shown on the preamp display during the calibration process.

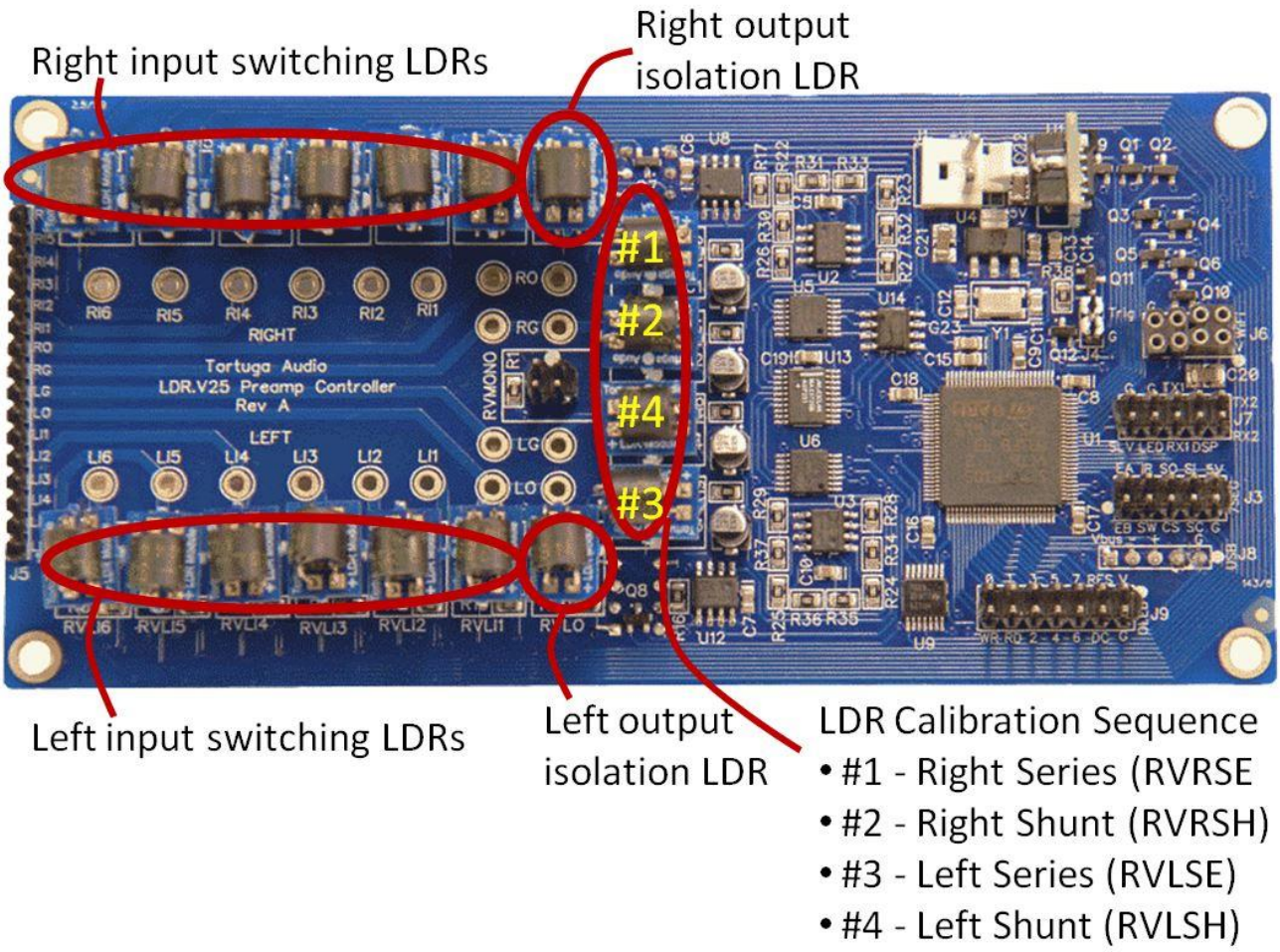
V25 preamp controller

During calibration, a V25 preamp controller with dual 7-segment displays will show the LDR # in the left display and the calibration step # in the right display. A V25 goes through steps 1-99 for each LDR.

A V25 preamp controller with and OLED display offers considerably more status information during the calibration process. Each of the 4 LDRs goes through a 3 phase calibration process referred to as VLo, VRef, and Cal. Each of the 4 LDRs first goes through the brief VLo phase. Then, starting again with LDR #1, each LDR goes through a brief VRef phase immediately followed by the main Cal phase. The Cal phase will take several minutes going 100 individual calibration steps for each LDR.

When a specific LDR (1, 2, 3 or 4) goes sufficiently out of spec, the calibration process in the V25 is most likely to fail to progress through either the VLo or VRef phase. Less common is for the V25 calibration cycle to stall out somewhere in between step 1 and step 99.

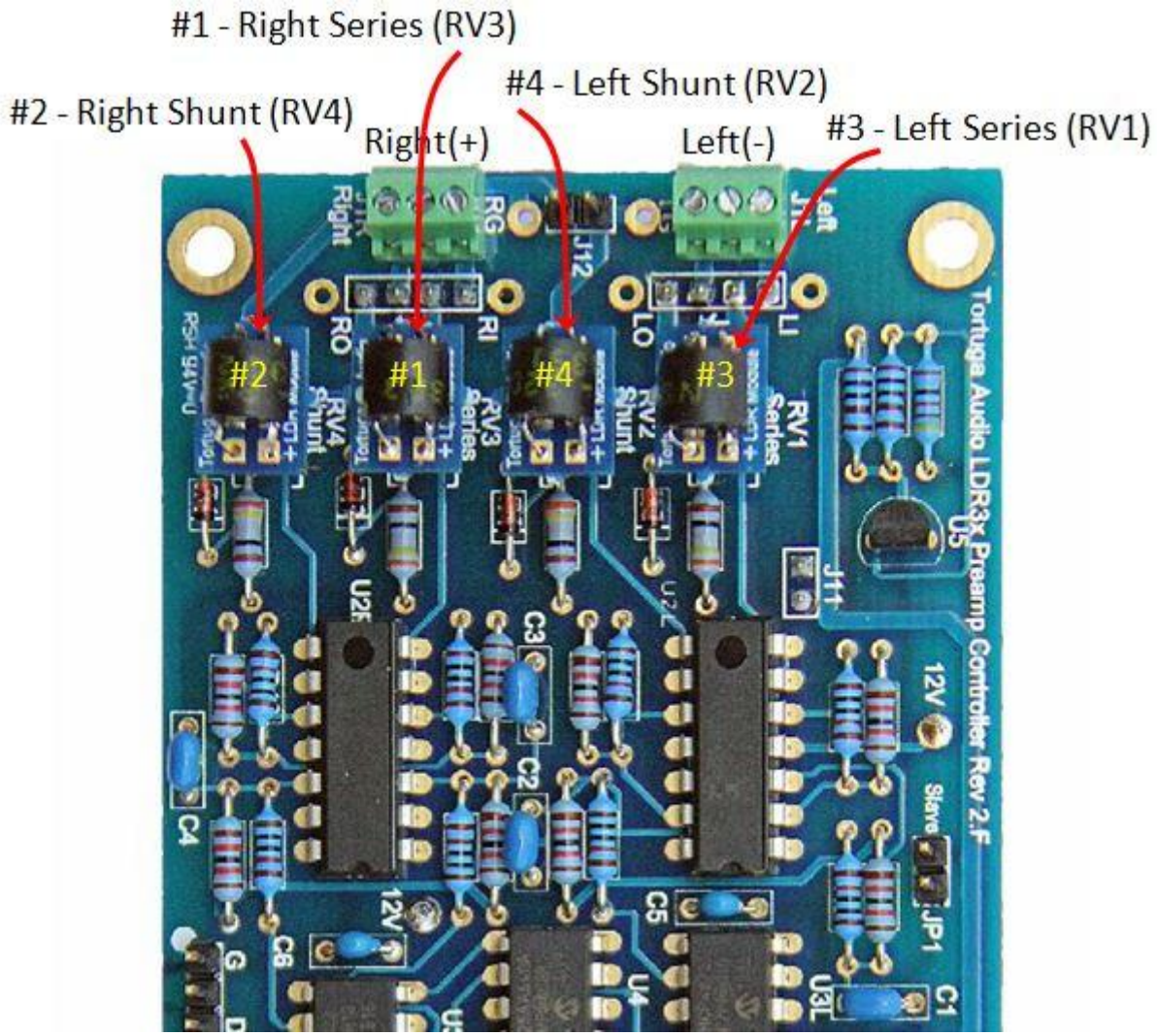
Note that the V25 also uses LDRs for input channel switching and also for isolating the output signal during calibration. Those LDRs are identified below but are on/off only and are not involved in the calibration process.



V2 preamp controller

During calibration, a V2 preamp controller with dual displays will show the LDR # in the left display and the calibration step # in the right display. A V2 goes through steps 1-70 for each LDR.

When a specific LDR (1, 2, 3 or 4) goes sufficiently out of spec, the V2 will have a difficult time starting or completing the 70 step calibration sequence for that LDR. The calibration process may stall out at step 1, step 70, or at some intermediate step between 1 and 70. When this happens, note the LDR # in the left display. This usually indicates the LDR needs to be replaced.



8.1.7. Replacing A Bad LDR

To replace an LDR first remove power from the preamp. Then simply remove (unplug) the suspected bad LDR (the one at which calibration stopped progressing) and replace it with a new LDR Module.

IMPORTANT! - When installing a new LDR module make sure that the white dot on the LDR module circuit board is on the same side as the white dot on the controller circuit board. The LDR modules are NOT keyed so it's possible to plug the module in 4 different ways but only 1 is the correct way.

After a new LDR module is installed, you should immediately run the unit through a cycle of calibration. This will rebuild the attenuation table for your current impedance setting/level and in doing so will measure and incorporate the unique performance curve of the new LDR module.

LDRs operate as pairs of Series & Shunt resistors with one pair for the Right channel and the other pair for the Left channel. If, after replacing a faulty LDR, the calibration process still slows down or halts at the same LDR as before, it's likely that it's companion LDR is the cause of the problem. In this case, remove the new LDR and put the old LDR back. If calibration stopped at LDR #1, replace LDR #2 instead. If calibration stopped at LDR #2, replace LDR #1 instead. If calibration stopped at LDR #3, replace LDR #4 instead. If calibration stopped at LDR #4, replace LDR #3 instead. Then run calibration again. Chances are good that calibration will now run to completion normally. In rare

cases you may find you have to replace both the Series and Shunt LDR Module for a given channel in order for calibration to work properly.

8.1.8. Special Considerations For Balanced Preamps

Balanced preamps utilize 2 preamp controller boards. When facing the front of the preamp looking towards the rear of the preamp, the rightmost controller board is designated as the primary (master) and the left board is designated as the secondary (slave). All user control inputs are handled by the primary board which in turns controls the secondary board.

For purposes of diagnosing LDR replacement in balanced preamps, it's best to view the left/right channel labels on each controller boards as NOT necessarily being synonymous with the Left and Right stereo channels and simply think of them as LDRs #1 through #4 in terms of their calibration sequence.