Digital isolated 4 channel temperature controller

Version: v4.3D

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Section 1

Overview

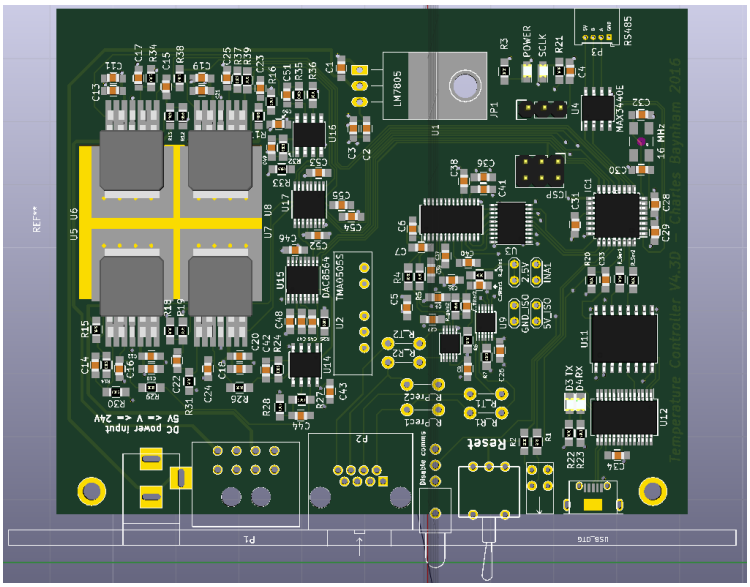

Figure 1.1: Picture / render of the board

This manual describes the operation and design processes behind the Yb^{+} digital temperature controller, version v4.3D. The controller is designed for taking high precision temperature measurements via a thermistor and applying low bandwidth PID feedback in response.

1.1 Microprocessor

The device is controlled by an on-board microprocessor running at 16 MHz. It operates in headless mode and can be configured to automatically recover from power failures. Setup and monitoring is by USB connection, baud rate 57600. This USB connection is electrically isolated from the rest of the board to prevent ground loops or digital noise.

1.2 Output

Output is by either OPA458 high power opamps. Output can be up to 1 A continuous (see Figure 3.1), at voltages up to 24 V depending on the power supply, V_S.

The board contains space for four output channels allowing for voltages between 0 V and V_S. Alternatively the channels can be combined to form two bipolar output channels, permitting outputs up to $\pm V_S$. See Section 2 for details. Note that these are not rail-to-rail opamps: the minimum possible output is around 300 mV, so applications that require lower voltages than these must use the bipolar configuration.

1.3 Input

Error signal acquisition is done by taking a balanced measurement between a thermistor and a set resistor. The board produces an excitation voltage, usually 1.0 V, and measures the difference in current between the thermistor and resistor to produce a temperature measurement. For less demanding applications the set resistor can be on-board. For the highest stability, the precision resistor should be placed next to its paired thermistor.

This measurement is performed by an INA330 chip, of which there are two present on the board. The entire analogue section is electrically isolated from the rest of the board to prevent noise on the electrical ground affecting the measurement.

There are therefore two possible input channels by balanced thermistor measurements. See Section 2 for details.

1.4 Commands

Control of the device is via serial connection over USB. It accepts commands, detailed in Appendix A. A Labview interface is also available which handles this communication.

Section 2

Connector Pins

This section describes the usage and pin-out for all the connectors on the board. See Figure 2.1 for reference as to their locations.

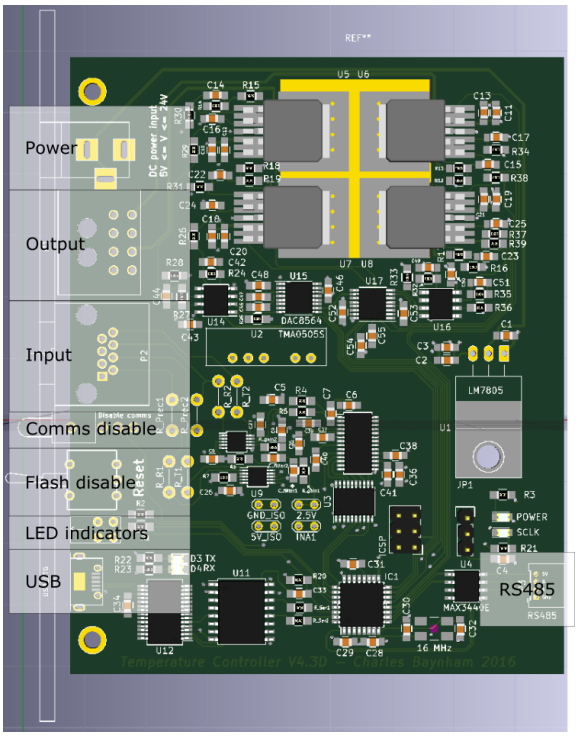

Figure 2.1: Layout of connectors on the board

2.1 Power

Power supply is via a standard 2.1 mm, centre-positive barrel connector. The board expects a DC voltage up to 30 V and of at least 7 V, limited by the LM7805 power regulator that powers most of the electronics. Whatever voltage is supplied here will be the maximum possible output control voltage. When choosing what voltage to supply, the user should take note of considerations in Section 3.1 regarding opamp overheating.

2.2 Output

Pin	Purpose
1	GND
2	GND
3	GND
4	GND
5	Unipolar output 1 or bipolar 1 positive output (`BPA`)
6	Unipolar output 2 or bipolar 1 negative output (`BPA`)
7	Unipolar output 3 or bipolar 2 positive output (`BPB`)
8	Unipolar output 4 or bipolar 2 negative output (`BPB`)

Table 2.1: Pin connections for the output

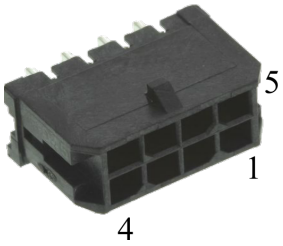

Figure 2.2: Molex MICRO FIT 3.0 series 43045 output connector

The output connector is a Molex MICRO_FIT 3.0 series 43045. It has 8 contacts, 4 of which are the OPA outputs and 4 are GND. In unipolar operation the device to be controlled (hereafter the plant) should be connected to one of the channels and GND. For bipolar operation connect to both the OPA output channels and leave the GND pins unconnected.

2.3 Thermistor input

Pin	Common colour	Purpose
1	Orange and white	GND
2	Orange	Set resistor 1 +
3	Green and white	GND
4	Blue	Thermistor 1 +
5	Blue and white	GND
6	Green	Set resistor 2 +
7	Brown and white	GND
8	Brown	Thermistor 2 +

Table 2.2: Pin connections for the error signal input

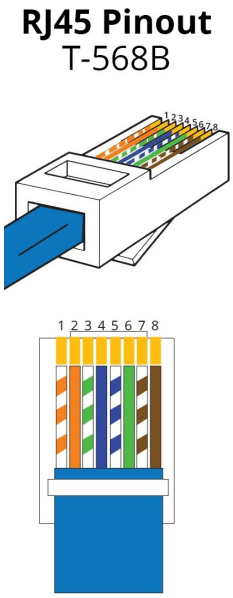

Figure 2.3: Pinout for a RJ45 T568-B connector [2]

The error signal is produced by an INA330 chip that places a 1.0 V excitation voltage (V_{excite}) across both a thermistor (R_{therm}) and a set resistor (R_{set}) and measures the difference in current. The signals in the RJ45 connector should therefore be connected to a thermistor and the set resistor. If an on-board set resistor is in use (see Section 3.4) then the setpoint resistor pin on the input connector should be left floating.

The RJ45 connector accepts standard Ethernet-style cat5 cable. This contains 4 twisted pairs, each of which is assigned to a channel. Table 2.2 assumes the standard T568-B colour scheme for RJ45 mounted CAT5 cable (orange, blue, green, brown: solid and dotted).

[2] Image from `http://blog.showmecables.com/rj45-pinout/`

2.4 Switches

There are two switches present on the board:

The vertical switch, `COMMS_DISABLE` can be used to disable / enable updating of the controller via USE connection. When this is set to disabled, all functions that alter the state of the controller will be prohibited (monitoring commands still work). When set to enabled, the controller functions as normal. This is intended to prevent accidental pertubation of a system under control.

The horizontal, momentary switch `RESET` causes a complete system reset.[3]

2.5 LEDs

The two front-mounted LEDs indicate the status of the lock(s) in progress. The LEDs are unlit if the device is currently outputting a constant voltage. If attempting to perform a lock, the two LEDs display the current distance from the setpoint of the lock controlling their respective control channels. A solid light means that the error signal is less than 0.01 V, a slow flash means between 0.01 V and 0.1 V and a quick flash means greater than 0.1 V. These threshold values are defaults but can be altered over the serial connection (see Appendix A for a full listing of available commands).

Locks are indexed in the order that they are started.

2.6 USB

The USB interface takes a micro-USB cable, allowing for monitoring and control over the system. The interface is isolated from the rest of the board to prevent ground loops.

Communications are handled by a FTDI USB - serial interface IC which presents itself as a virtual COM port. Communication is then done via serial commands at a baud rate of 57600. See Appendix A for more info on commands accepted.

[3]Pressing this switch is actually not strictly equivalent to a power cycle as it does not reset the ADC. However, in the initial setup section of the software the ADS is reset via its SPI interface, so these two methods should give identical results.

Section 3

Options and Hardware Configuration

There are various points at which the board can be customised for a particular use case. Each section indicates default choices that will result in sensible behavior and are pre-installed on the boards.

The file `Pins.h` contains the descriptions of these customizations. If changes are made to the default settings, the user must alter this file and re-flash the device to reflect the changes, as described in Section 3.6.

3.1 OPA Choice

The four channel version of this temperature controller only has the option for output via OPA548. These are compact devices, heatsunk to the ground plane and capable of monitoring for thermal overload and accurately limiting current down to 0 A.

Figure 3.1 shows the output currents that these devices are capable of. The power dissipated by the OPAs depends on the difference between the voltage supply and the operational voltage. For example, if the supply voltage is 15 V and 5 V of output is requested, the OPAs will have to dissipate a 10 V voltage drop across them. Depending on the current supplied, this can result in a considerable power.

The power supply voltage and opamp family should therefore be chosen bearing in mind the intended output voltage and current of the device, with reference to Figure 3.1.

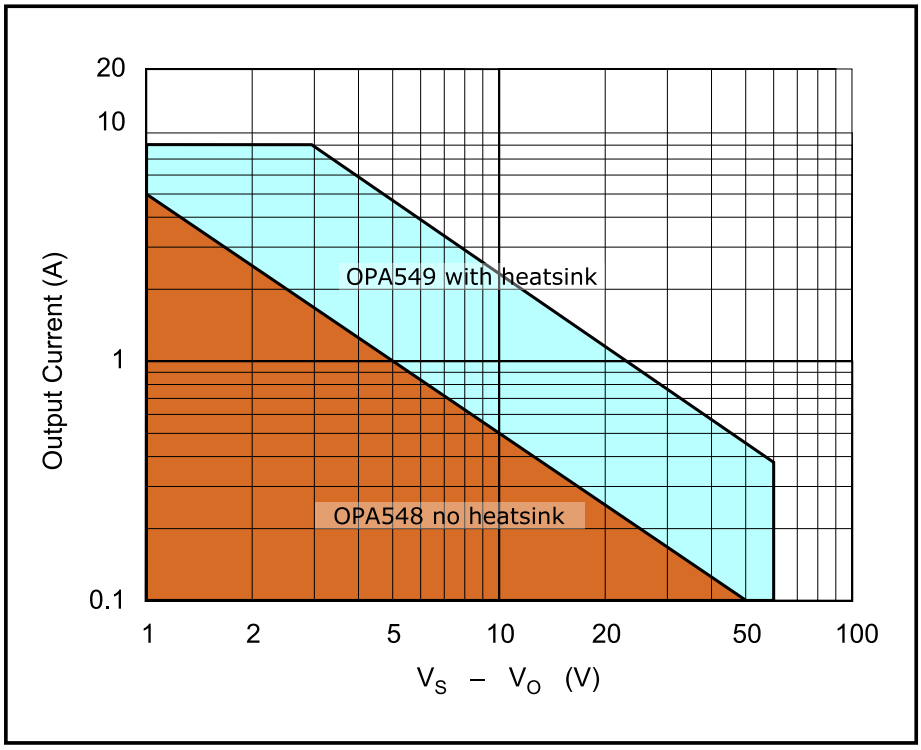

Figure 3.1: Safe Operating Area (SOA) for the OPA devices. V_S and V_O are the supply voltage and output voltage respectively. For the OPA549, this assumes the use of the heat-sink recommended. Diagram adapted from the OPA548 and OPA549 data-sheets. The OPA549 is not available with the 4 channel board option.

3.2 OPA gain

The DAC outputs voltages ranging from 0 V to 2.5 V. These are amplified by the OPA opamps to reach the desired output voltages. The choice of gain resistors R12 to R19 set the gain of this amplification and therefore the maximum possible output voltage using the formula:

$$G = \frac{Rx + Ry}{Rx} \implies V_{max} = \frac{Rx + Ry}{Rx} \times 2.5\,\mathrm{V} \tag{3.1}$$

Default: $100\,\mathrm{k\Omega}$ *and* $500\,\mathrm{k\Omega}$, *gain = 6x,* $V_{max} = 15\,\mathrm{V}$

3.3 Instrumentation gain

The input current sensing chips work by current through a gain resistor to match the current difference between the thermistor and set resistor they are measuring, as described in Section 6.3. The choice of resistors R_{gain1} and R_{gain2} therefore set the range of inputs that are available.

For precise sensing near the setpoint, a large gain should be chosen. However, in order to make possible a wide range of inputs, a smaller gain is appropriate. If you choose to alter the default gains, you must ensure that both R_{gain1} and R_{gain2} are the same and their values are updated in `Pins.h` (see Section 3.6).

Default: 51 kΩ *giving a* 7 °C *to* 36 °C *temperature sensing range*

3.4 Setpoint resistors

For applications that do not require extreme stability, it is possible to place the set resistor on the board in footprints R_{prec1} and R_{prec2}. If this is done, the external precision resistor connections should not be made.

Although it is possible to lock to arbitrary resistance values, various advantages are gained by operating at the point where $R_{thermistor} = R_{set}$. In particular, operating at this point means that noise in the voltage reference or EMF noise from other sources will not affect the setpoint. Also, for small values of V_{out} the device will increase the gain of the input stage of the ADC, allowing greater sensitivity.

Again, for less demanding applications this is unnecessary: on-board precision resistors and digitally defined setpoints will provide sufficient resolution.

Default: 10 kΩ *on-board resistors*

3.5 Sensing series resistors

Unfortunately, the INA330 instrumentation amplifiers struggle to drive even modest capacitive loads, such as that presented by 30 cm of BNC cable. For this reason a 1 kΩ resistor is necessary in series with the thermistor and precision resistor to prevent bias voltage oscillations.

For the most demanding applications this series resistor can be removed and replaced with a piece of wire, reducing sensitivity to board temperature but necessitating short wires to the thermistor / set resistor.

Default: 1 kΩ *precision resistor*

3.6 Pins.h

Once customisation options have been chosen, the user must re-flash the device with a version of the source code reflecting these choices. To do this, the file `Pins.h` should be updated with the changes made and then the software should be compiled and uploaded using e.g. the Arduino IDE. Remember to temporarily re-enable flashing by using the vertical switch on the front panel.

Section 4

Initial setup

The procedure for setting up a board is therefore as follows:

1. *Optional: Choose what configuration you require in accordance with Section 3, or accept the defaults.*
2. *Optional: If you chose to customize your board in the previous step, make these modifications now.*
3. *Optional: Open the* `Pins.h` *file in the MC software folder. Edit it in accordance with your choices or leave it at defaults. (See the Doxygen documentation (Appendix B) for an in-depth description of each option)*
4. Solder the OPA drivers you chose to the board if using the single channel board. The dual channel board comes pre-populated.
5. Using Atmel Studio and an AVRISP mkII programmer, connect to the ISCP header on the board and upload the Optiboot boot-loader file `./CodeforMicrocontroller/optiboot_xplained328p.hex`. This step only has to be performed once per microprocessor.

   The board must be powered via the barrel-jack connector during this step.
6. Using the Arduino IDE, compile and upload the code to the device. After this is done, remember to re-enable flashing using the `FLASH_DISABLE` jumper.

After this process is complete, the device will appear over USB as a COM port. In order to test that everything went well, send the command `*TST` (at baud rate 57600). If the response "OK" is received, the software is installed correctly and communication between the microprocessor and the ADC is working.

*TST not currently implemented

Section 5

Voltage Conversion Formulae

The readings output by the device will be in volts, whereas usually the user will be interested in determining the resistance of a thermistor. For more details about how this voltage is produced, see Section 6.3. The voltage output V_{out} is the voltage produced by the INA330 instrumentation amplifier according to its gain resistor R_{gain1} or R_{gain2}. To convert this to a resistance, you must know the resistance of the set resistor (default $R_{set} = 10\,\mathrm{k}\Omega$), the excitation voltage ($V_{excite} = 1.0\,\mathrm{V}$), the gain resistance ($R_{gain} = 51\,\mathrm{k}\Omega$) and the series resistance (default $R_{series} = 1\,\mathrm{k}\Omega$). Use the following formulae:

$$R_{therm} = \left[\frac{1}{R_{set} + R_{series}} - \frac{V_{out}}{V_{excite}.R_{gain}}\right]^{-1} - R_{series} \tag{5.1}$$

or

$$V_{out} = V_{excite} R_{gain} \left[\frac{1}{R_{set} + R_{series}} - \frac{1}{R_{therm} + R_{series}}\right] \tag{5.2}$$

Thus, close to the set point, i.e. for small values of V_{out}, V_{out} is linearly related to resistance.

Section 6

Hardware Design

The board is designed to be rack-mounted with dimensions of 100 mm × 80 mm. It is compatible with IEC 60297-3/-4 specs regarding dimensions and can fit front panels such as e.g. RS 258-2920.

6.1 Isolation

Since the error signals read by this board are at DC, much care was taken to avoid ground loops and crosstalk that could introduce bias. The ADC described in Section 6.2 implements various filtering methods, but the board is also designed to prevent extraneous noise.

The USB input interface is opto-isolated from the rest of the board, with power for the FTDI USB chip provided by the computer host. Also the entire analog section; incorporating the ADC, instrumentation amplifiers and input opamps; is isolated from the rest of the board and powered by a DC-DC converter.

Although the output stages are not isolated from the rest of the board due to their high power requirements, care has been taken to manage high frequency digital return current in order to avoid signal crosstalk. The board has internal ground and power planes to reduce EMI and these both contain a bottleneck at the DAC: the point at which digital signals end and analog signals begin. This design is intended to keep digital return currents within the digital section of the board, avoiding pollution of the output stages.

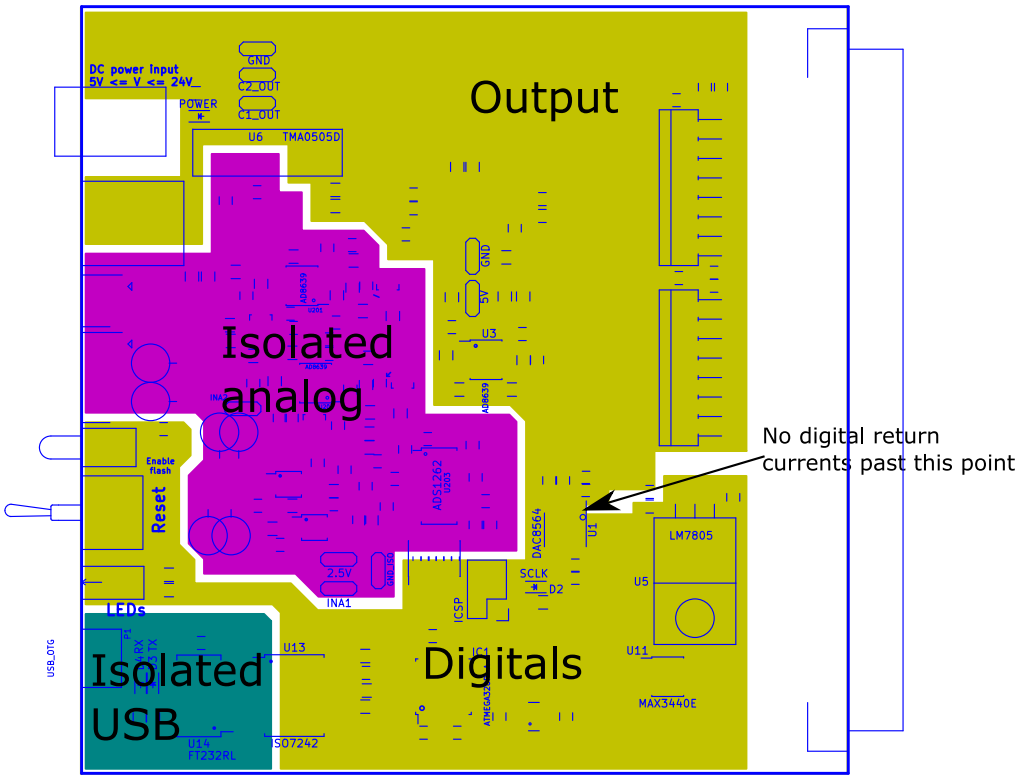

Figure 6.1: Segmentation of the 2 channel board for isolation and ground loop considerations. 4 channel board is similar

6.2 ADS1262 - Analog to Digital Converter

The ADS1262 is a nominal 32-bit ADC produced by Texas Instruments. During a temperature reading it is configured to use a two stage digital filter. The first order provides a fixed 5th order sinc filter. The second stage is a programmable order sinc filter, set to 4th order. These two together result in an 0.58 Hz -3 dB bandwidth, with poles at 50 Hz. On top of this, a simple analog external RC low-pass filter prevents aliasing.

The ADS1262 has inherently low input offset bias however, to combat any residual bias, every measurement is taken twice with the input signal paths swapped over via the internal analog MUX.

The IC also contains an optional Programmable Gain Amplifier (PGA) stage. The micro controller monitors the signals it reads and, if it detects several measurements in a

row that would have benefited from increased gain, it automatically boosts the gain stage to increase sensitivity further. If the signal later becomes too large for the gain selected this is also automatically detected and corrected by the micro controller.

Because of this re-sampling and filtering, a single measurement can take up to 5 s to complete. Programs that interface with the temperature controller should therefore be aware that commands such as `ERRO? 1t` can take up to 5 s and should take appropriate steps to avoid timeout. The Labview interface handles this automatically.

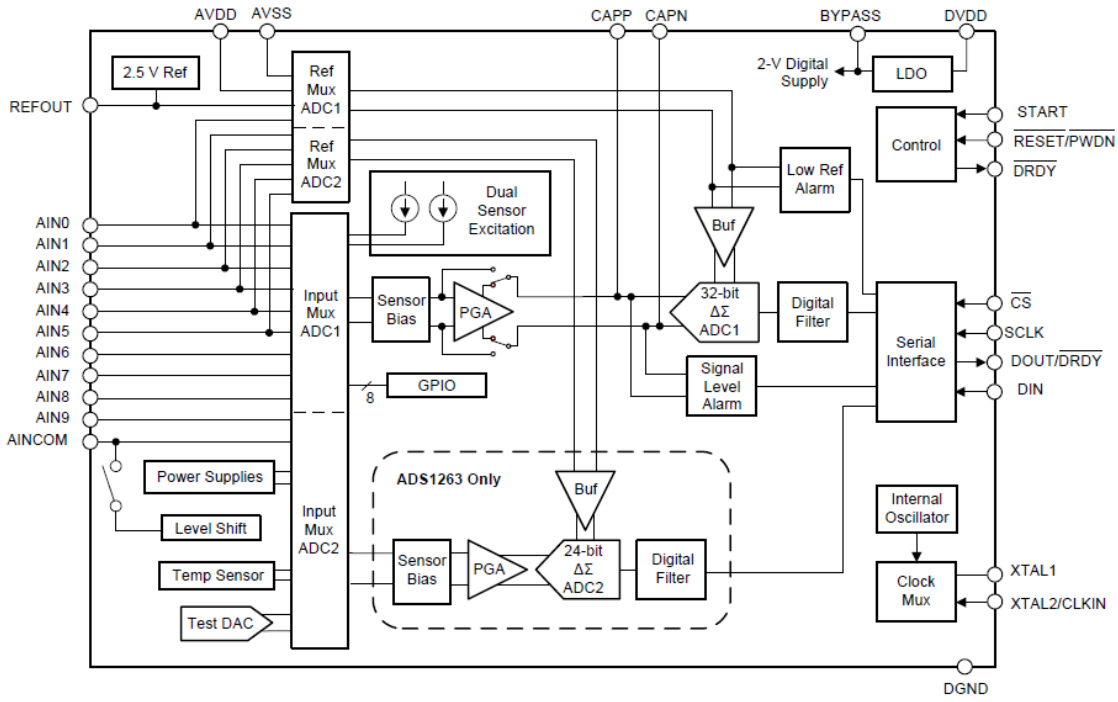

Figure 6.2: Flow diagram of the ADS1262. Reference: ADS1262 datasheet by Texas Instruments

6.3 INA330 - Thermistor Amplifier

The thermistor / setpoint precision resistor comparison is done by an INA330 chip. These chips take a reference voltage, 1.0 V on this board, ratiomatically derived from the stable 2.5 V reference of the ADS1262. This is buffered and used to drive both the thermistor and the resistor. The current difference between these two arms is then forced through a

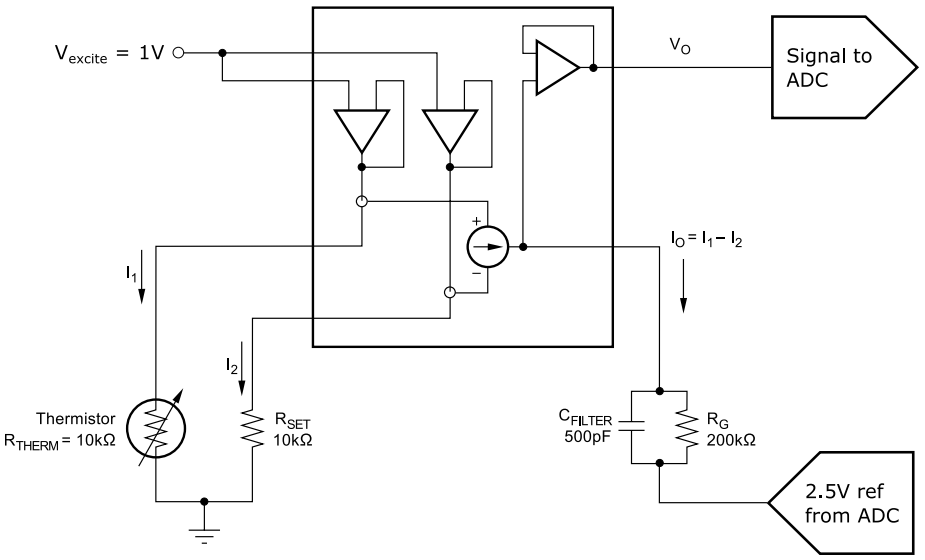

Figure 6.3: Flow diagram of the INA330. The 2.5 V reference comes from the ADC and the output voltage is refereed to this reference. The 1.0 V excitation reference is derived from the 2.5 V reference ratiomatically for maximum common-mode rejection. Diagram adapted from INA330 datasheet by Texas Instruments.

gain resistor, R_{gain1} or R_{gain2} (by default 51 kΩ), amplifying it with respect to the 2.5 V reference. This signal is then read by the ADC and compared to the 2.5 V reference in differential mode.

Figure 6.3 shows a schematic of the INA's operation. For a resistance to voltage conversion formula use Equation 5.1.

6.4 OPA548/9 - Output Amplifiers

The final output to the plant is handled by an OPA548. These amplify the 0 V $\rightarrow$ 2.5 V signal produced by the DAC to the voltage required by the user, set by gain resistors as described in Section 3.2.

6.5 DAC8564 - Digital to Analog Converter

The production of the analog signal is done by the DAC8564: a 16-bit digital to analog converter, referenced to its own internal 2.5 V reference.

Its output ranges from 0 V to 2.5 V. This signal is then either amplified by the OPAs to become the output level, or doubled by a AD8639 auto-zeroing opamp to control the current limiting feature of the OPAs.

6.6 ATMega328p - The micro controller

The brain of the device is an ATMega328p MC. This is the same processor that is found on the Arduino Uno or Nano, and the board is configured (instructions in Section 4) to appear as an Arduino Nano to the computer. However, by breaking the Arduino into pieces several advantages are gained including reduced board space and the option to add on-board isolation to the USB interface.

The ATMega is clocked from a 16 MHz full-swing crystal. When the board is assembled for the first time the ATMega's flash memory will be blank and the device with not be programmable over the usual USB interface. For the first time only, programming must be done by the ISCP header provided, as described in Section 4.

6.7 RS485

The board is equipped with a 4 pin Molex PicoBlade 53048-0410 connector that enables RS485 communications. This is currently unimplemented, but will allow for control of up to 255 RS485 boards from a single USB connection.

Section 7

Software Structure

The code running on the micro-controller is written in C++. The ATMega328 is set up to appear the same as an Arduino Nano: it is therefore possible to compile and upload the code using the usual Arduino IDE. Note that re-flashing like this this requires two things: a) the `FLASH_DISABLE` switch should be set correctly (see Section 2.4) and b) the boot-loader must have been installed using the ISCP header (see Section 4).

The code-base makes considerable use of the object-orientated programming style. While this can appear daunting at first, in the long run it simplifies modifications and results in more compartmentalized code that is easier to understand. This overview and the more in-depth Doxygen documentation both assume some familiarity with concepts such as virtualisation, inheritance, abstraction and polymorphism.

There are very many online and offline resources that can give you an overview of these ranging from 1 page to multiple-volume books. For a quick starting point, try `https://www.cs.bu.edu/teaching/cpp/inheritance/intro/` and `https://www.cs.bu.edu/teaching/cpp/polymorphism/intro/`.

7.1 Doxygen

The code is thoroughly commented throughout to aid comprehension. These comments have been written to comply with the requirements of the documentation program Doxygen `http://www.stack.nl/~dimitri/doxygen/`. It is therefore simple to compile all these comments into a manual by installing the Doxygen program on your computer, launching the wizard, selecting the `Doxyfile` file in the temperature controller's source code and

running the wizard. This will produce a neatly linked set of HTML files that can be opened in any browser. It will also produce LaTeX output, the result of which is appended to this document in Appendix B.

The Doxygen output is detailed and should be considered the authority if modification to the code is required, but this section provides an overview of the code structure.

7.2 Code Overview

As per usual object-orientated design, the jobs performed by the temperature controller are split between objects. Two of the most important are ErrorChannels and CtrlChannels. These classes manage interactions with the world. They are abstract classes, and provide a template of functions which must be fulfilled by their derived classes.

For instance, CtrlChannels have a method setCtrl() which sets the output voltage available at the OPA. This method takes a double as a parameter, the new control level, which adheres to a convention used throughout the code: all error readings or control outputs are given as a number between -1 and +1 where -1 corresponds to the lowest possible level and +1 corresponds to the highest.

A specialisation of CtrlChannel is V4_OPA_OutputChannel. This overrides the "pure virtual" methods in CtrlChannel and writes a voltage to the output channel it manages. On initialisation this object is assigned to one of the OPAs. A value of for output -1 would correspond to 0V, a value of +1 would be `+MAX_VOLTAGE` V.

A different specialisation of CtrlChannel is V4_OPA_OutputChannelBipolar. This object also performs output, but rather than outputting a voltage on a single OPA, it uses 2 OPAs at the same time in order to output a bipolar differential level.

ErrorChannels have similar functionality but are used for input instead of output. However, since taking a reading can take several seconds (see Section 6.2) there is a bit more structure involved. Readings are initiated with startReading(). Before this happens, the calling code should check that no reading is already in progress by calling globalReadInProgress(). Once a reading has been started, its progress can be checked by calling readingReady() and then its result can be output using getReading().

Other important objects in the code are:

Controllers Contain references to an ErrorChannel, a CtrlChannel and an Algorithm. Every time doLoop() is called, attempt to take a reading from the ErrorChannel, process it with the Algorithm and output it with the CtrlChannel.

Algorithms An abstract class that defines an object responsible for processing an input error signal and returning the new control level. This object should contain information about the set-point and any limits applied. An example implementation is PIDAlgorithm.

CommandHandler An independent object that can be included as an Arduino library in any project. This object manages the input and parsing of serial commands. It uses a hashing algorithm to minimize memory consumption and assigns all memory on the stack to avoid fragmentation. It is responsible for calling the appropriate function when a command is issued. See its own Doxygen documentation for much more detail.

A typical cycle in the code looks like this:

1. Check CommandHandler for new commands and execute them if present.
2. For all Controllers, see if a lock is in progress
3. If so:
   - If an ADC reading is in progress do nothing.
   - If no reading is in progress, start one.
   - If an ADC reading for this channel is complete, get the result and move to step 4.
4. Feed the result of the reading into the contained Algorithm
5. Get the new control level back from the Algorithm and pass this to a CtrlChannel for output.

Appendices

Appendix A

Available Commands

The commands recognised by the controller are defined in the file `./Code_for_microcontroller/YbTempCtrl/CommandDefinitions.h` and the Doxygen documentation (Appendix B) for this file contains a complete list of them.

This documentation is reproduced here for convenience. The following is automatically generated from the code's markup, so please excuse any odd formatting. All parameters should be separated by spaces. All commands must be followed by a newline (ASCII 10) character.

A.0.1 CommandDefinitions.h File Reference

Defines all the commands that the device listens for.

```
#include "CommandHandler\CommandHandler.h"
```

Functions

- template<size_t size>
  CommandHandlerReturn registerCommands (CommandHandler< size > *h)

  Register the commands.

Detailed Description

Defines all the commands that the device listens for.

This file contains definitions of all the commands that can be issued to the device.

Command processing is done via the CommandHandler class which has its own documentation.

All functions to be called by CommandHandler take exactly the same form: they return void and take a const ParameterLookup object as an argument. This object dispenses c strings as the params, e.g. `params[1]` is the first parameter, etc. (`params[0]` is the command itself). See the definition of #commandFunction for the required spec.

All commands are parsed and stored using a hash function for memory efficiency, and are case-insensitive.

The following is a summary of the available commands. If query form of a command with different functionality exists is it listed separately. If it's identical, this is shown as e.g. `*TST(?)`. If no query / non-query form exists, it is not shown in this table; calling it will result in an error.

Command	Description	Params	Output
*TST	Test comms	0	"Loud and clear!"
*TST?	Test comms	0	"Query received"
*IDN(?)	Identify	0	"ARDUINO PID"
*VER(?)	Output version string	0	e.g. "v4.1"
*RST	Reset the device (N.B. does not clear EEPROM)	0	-
STOR	Store a command in EEPROM to be executed on startup	"command to be called on startup"	"Done"
		Multiple commands can be stored by separating them with a ';'	"#StoreCommand error: command too long"
RETR	Retrieve any stored commands from EEPROM	0	Stored command or "None"

Command	Description	Params	Output
WIPE	Erase any stored commands in EEPROM	0	”Done”
ERRO(?)	Query the error signal on given channel.	[channel = 1t,2t,1v,2v] for signals 1 or 2 from thermistor input or voltage input	Error signal float
			If thermistor reading, voltage read from -2.5 -] +2.5
	If this channel is being controlled, return the previously measured value. Else, measure it now and then return.		If voltage reading, return voltage from -5 -] +5 V
			e.g. ”-0.00151”
STAT(?)	Return a string describing the status of the controller	0	t.b.c.
CONT	Set the control signal.	[output channel = 1, 2, 3, 4, BPA, BPB] [voltage = 0 - max for single, -max - +max for BP]	e.g. ”#SetControl BP 2.500”
	N.B. If this is called during a lock this will set the control signal to the given value, but this may subsequently be changed by the locking algorithm		
CONT?	Query the control signal	[output channel = 1, 2, 3, 4, BPA, BPB]	e.g. ”2.500”
THER?	Check the thermal state of the given channel. For the bipolar channel, return ”BAD” if either OPA is overheated	[output channel = 1, 2, 3, 4, BPA, BPB]	e.g. ”GOOD” / ”BAD”

Command	Description	Params	Output
LIMI	Set software limits on the output voltage	[output channel = 1, 2, 3, 4, BPA, BPB]	e.g. "#SetLimits 1 0.000 3.000"
		[min voltage]	
		[max voltage]	
LIMI?	Query limits	[output channel = 1, 2, 3, 4, BPA, BPB]	e.g. "0.000 3.000"
THRE	Set thresholds at which the LEDs will start flashing.	[thresholdHigh] [thresholdLow]	e.g. "#setThresholds 0.1 0.01"
	LEDs will flash fast when the absolute error signal is] thresholdHigh, slow when it's between thresholdHigh and thresholdLow and light solidly when it's [thresholdLow		
THRE?	Query current LED thresholds	0	e.g. "0.1, 0.01"
CLIM	Set hardware limits on the output current	[output channel = 1, 2, 3, 4, BPA, BPB]	e.g. "#SetCurrentLimit 1 1.000"
		[max current in amps]	
CLIM?	Get current hardware on output current	[output channel = 1, 2, 3, 4, BPA, BPB]	e.g. "1.000"
SETP	Set setpoint for lock	[output channel = 1, 2, 3, 4, BPA, BPB]	If no lock running on this channel: "#SetSetpoint error: no lock running on channel xxx"
			Else, e.g. "#SetSetpoint 1 0.000"
SETP?	Query lock setpoint	[output channel = 1, 2, 3, 4, BPA, BPB]	If no lock running on this channel: "#SetSetpoint error: no lock running on channel xxx"
			Else, e.g. "0.000"

Command	Description	Params	Output
LOCK	Start PID lock	[input channel = 1t,2t,1v,2v]	e.g. "#StartLock 1t BP 0.000 1 0.5 0 10"
		[output channel = 1, 2, 3, 4, BPA, BPB]	
		[setpoint]	
		[Kp] [Ki] [Kd] [N=10]	
VOLT	Output a constant voltage	[output channel = 1, 2, 3, 4, BPA, BPB] [voltage = 0 - max for single, -max - +max for BP]	e.g. "#ConstVoltage 1 2.500"
	N.B. Unlike "CONT", this function will output a constant voltage, disabling any PID lock that was previously running on this output channel		

Function Documentation

template<size_t size> CommandHandlerReturn registerCommands (CommandHandler< size > * *h*) Register the commands.

Register the commandFunction functions with the CommandHandler object, defining:

- The command used to call them
- The number of parameters they must be called with

Parameters

h	Pointer to a CommandHandler object

Template Parameters

size	Number of commands this CommandHandler can contain. This will be inferred by the number specified in its definition.

Returns

A CommandHandlerReturn enum detailing any errors that occured during the execution of this method.

Appendix B

Full Doxygen documentation

The following pages are the full documentation of the code, produced automatically by Doxygen. Doxygen is a code commenting system that allows you to write structured comments throughout your code which can later be extracted into a code reference.

To get the latest version of this reference, incorperating any changes, you need to install Doxygen, run the Doxywizard, load the file `./Code_for_microcontroller/YbTempCtrl/Doxyfile` and click "Run doxygen". This will produce HTML and LaTeX output.

It will also generate a file called `make.bat` in `./Code_for_microcontroller/YbTempCtrl/doc/latex/make.bat`. Execute this file to produce the updated LaTeX code reference. To incorperate this into the manual you are currently reading, just recompile the latex from `./Manual/TemperatureControllerManual.tex`.

Yb Temperature Controller

Generated by Doxygen 1.8.11

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1 Yb+ temperature controller

1.1 Introduction

This is the source code for the Yb+ temperature controller, programmed and designed by Charles Baynham.

It is intended for high precision control of cavities, however can be used to control laser diode temperature or other low-bandwidth lock processes that could benefit from digital control. Error signal input can be either by voltage (from -5V to +5V) or through a balanced thermistor reading, mediated by a built-in INA330 IC. For demanding temperature applications, the latter method is recommended.

This code is designed to be uploaded to an ATMega328 microprocessor. It is written in C++ and can be compiled and uploaded via the Arduino IDE. However, if you intend to work on it for any significant length of time, I *highly* recommend that you install a more capable IDE. I wrote this software in Visual Studio Community which is a free download from Microsoft and will make your life so much easier.

1.2 Documentation

If you are reading these comments in a pdf or html format then you are currently looking at the compiled documentation. If, however, you are reading this README.md file in a text editor then your first step before editing the code should be to get hold of the full code documentation.

The code is documented throughout using the Doxygen commenting system. These can be compiled easily into a pdf or a local html website by:

1. Installing Doxygen from `http://www.stack.nl/~dimitri/doxygen/download.html`
2. Using the Doxygen GUI to load the file in this folder, `Doxyfile`
3. Selecting `Run doxygen` on the `Run` tab.

This will produce the html documentation and, if you have pdflatex installed, source files for a pdf.

Alternativly, open the Documentation.pdf file that should be bundled with this repo.

1.3 Version Control

This folder is a GIT repository that maintains a full history of development including every change since this code was started. This history is contained in a hidden folder called `.git` which should not be accessed directly.

The upshot of this is that the code you see may not be the latest, and may instead be a "snapshot" of a previous state. To ensure you are looking at the latest iteration, and to make updates, install a git client of your choosing. `https://windows.github.com/` is very lightweight, `http://www.sourcetreeapp.com/` is more fully featured and `https://desktop.github.com/` strikes a balance between the two.

Once installed, "checkout" the master branch for the latest code version. See `http://rogerdudler.github.io/git-guide/` for a simple guide.

Note that this code makes use of several submodules. If you "clone" the code, you will by default not get these. In order to correctly get the code for these as well, run the command `git submodule update --init --recursive` after cloning the main code. If you use a more advanced GUI such as SourceTree then this should be handled for you automatically.

1.4 Available commands

The device listens for commands on a virtual serial COM port served via USB. The USB connection is electrically isolated to avoid ground pollution.

Baud rate should be set to 57600.

The board also contains footprints to enable RS485 communication via a backplane connection, however this is not yet implemented.

For a detailed description of all the commands available, see the documentation for CommandDefinitions.h.

1.5 Code outline

This code is split into classes according to the object orientated paradigm. A typical lock could be implemented as follows:

1. Define a YbCtrl::ErrorChannel object (or rather, an implementation of YbCtrl::ErrorChannel) to handle input.
2. Define a YbCtrl::CtrlChannel object to handle output
3. Define a YbCtrl::Algorithm object to implement the locking transfer function required.
4. Pass these three objects to a new YbCtrl::Controller object.
5. Loop, calling YbCtrl::Controller::doLoop() on each iteration.

For more detail, every class and method is individually documented. See the Classes section or the Namespaces section to see more.

Todo Implement RS485 Modbus protocol

Copyright

2 arduino-pin-toggler

2.1 Introduction

This Arduino library manages the toggling of arbitary pins at controllable rates. For example, it can be used to flash an LED at different speeds according to the state of your device.

It works using interrupts and is designed to be lightweight when running, so will not interfere with existing code.

This library requires exclusive usage of TIMER1 so is incompatible with libraries that also use this timer.

2.2 Usage

Include the class by adding `#include <pinToggler.h>` to your sketch.

Init the class by passing it an array of pins that will be toggled. E.g.

```
int pins[3] = {13, A4, A5};
pinToggler<3>::init(pins);
```

The template parameter (`<3>` above) defines the total number of pins being controlled.

These pins will start `LOW`, not toggling.

To start the toggling, set their speed to `OFF`, `SLOW`, `MEDIUM`, `FAST` or `MAX`. E.g.

```
pinToggler<3>::setFlashRate(0, SLOW);
```

N.B. The template parameter (here `<3>`) must match the one used in pinToggler::init() or this will throw an error. Also the LED parameter in pinToggler::setFlashRate refers to the pins passed to pinToggler::init(), zero-indexed in the order that they appeared in in the array.

The speeds refer to fractions of the max speed, defined by FLASH_FREQ_HZ.

Warning

Note that all the function calls here are static members of the class. Although a class object is created, this happens internally. For memory management purposes, be aware that this class allocates `3 * numPins` bytes on the heap. Thus, to avoid memory framentation, pinToggler::init() should be called as early in your code as possible.

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3 Todo List

File CommandHandler.h
Write the CommandHandler documentation

File Pins_2chan.h
Add option for user to configure different hardware gains on the two OPAs.

File Pins_4chan.h
Add option for user to configure different hardware gains on the two OPAs.

page Yb+ temperature controller
Implement RS485 Modbus protocol

Member YbCtrl::CtrlChannelReturn
Change to enum class

Class YbCtrl::TemporaryLooper
This class is currently unused: the code in Controller exists but is commented out. It could be used to implement e.g. an autotuning lock or a relocking routine

4 Module Index

4.1 Modules

Here is a list of all modules:

Algorithms 7

Control signal output 8

Error signal input 9

5 Namespace Index

5.1 Namespace List

Here is a list of all documented namespaces with brief descriptions:

YbCtrl
Namespace to hold all the temperature controller classes 10

6 Hierarchical Index

6.1 Class Hierarchy

This inheritance list is sorted roughly, but not completely, alphabetically:

YbCtrl::Algorithm 11
YbCtrl::PIDAlgorithm 27
YbCtrl::Controller 14
YbCtrl::CtrlChannel 18
YbCtrl::V4_OPA_OutputChannel 38
YbCtrl::V4_OPA_OutputChannelBipolar 44
YbCtrl::ErrorChannel 23
YbCtrl::V4_ADC_ChannelPair 34
pinToggler< numPins > 31
YbCtrl::TemporaryLooper 33

7 Class Index

7.1 Class List

Here are the classes, structs, unions and interfaces with brief descriptions:

YbCtrl::Algorithm
Abstract class for algorithms 11
YbCtrl::Controller
Object to manage the locking loop 14
YbCtrl::CtrlChannel
Abstract object to allow outputting a control signal 18
YbCtrl::ErrorChannel
Abstract object to allow measuring an error signal 23
YbCtrl::PIDAlgorithm
Implementation of an Algorithm to perform a PID lock 27
pinToggler< numPins >
Class for toggling pins 31

YbCtrl::TemporaryLooper
Temporarily divert the lock, before returning to normal 33

YbCtrl::V4_ADC_ChannelPair
Implementation of an ErrorChannel for the ADS1262 34

YbCtrl::V4_OPA_OutputChannel
Implementation of a CtrlChannel for a single-ended output 38

YbCtrl::V4_OPA_OutputChannelBipolar
Implementation of a CtrlChannel for a bipolar output 44

8 File Index

8.1 File List

Here is a list of all documented files with brief descriptions:

ADS1262_reg.h ??

Algorithm.h ??

CommandDefinitions.h
Defines all the commands that the device listens for 51

Controller.h ??

CtrlChannel.h ??

ErrorChannel.h ??

MemoryFree.h ??

PIDAlgorithm.h ??

Pins.h
Hardware limits and pins 54

Pins_2chan.h
Hardware limits and pins 54

Pins_4chan.h
Hardware limits and pins 58

TemporaryLooper.h ??

V4_ADC_ChannelPair.h ??

V4_OPA_OutputChannel.h ??

V4_OPA_OutputChannelBipolar.h ??

__vm/.YbTempCtrl.vsarduino.h ??

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Contains all the code for the Arduino CommandHandler library 54

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CommandHandler/Microprocessor_Debugging/debugging_enable.h **??**

CommandHandler/Microprocessor_Debugging/debugging_init.h **??**

Microprocessor_Debugging/debugging_disable.h **??**

Microprocessor_Debugging/debugging_enable.h **??**

Microprocessor_Debugging/debugging_init.h **??**

9 Module Documentation

9.1 Algorithms

Locking algorithms.

Classes

- class YbCtrl::Algorithm

  Abstract class for algorithms.
- class YbCtrl::PIDAlgorithm

  Implementation of an Algorithm to perform a PID lock.

9.1.1 Detailed Description

Locking algorithms.

The classes in this module are responsible for transforming error signals into control signals. They are based on the template base class Algorithm which defines various methods, most important of which is Algorithm::output(double). This method takes an error signal as a parameter (using the -1 -> +1 format that is universal in this codebase) and outputs a desired control signal (also using the same format).

9.2 Control signal output

Manage output of a control signal.

Classes

- class YbCtrl::CtrlChannel

  Abstract object to allow outputting a control signal.
- class YbCtrl::V4_OPA_OutputChannel

  Implementation of a CtrlChannel for a single-ended output.
- class YbCtrl::V4_OPA_OutputChannelBipolar

  Implementation of a CtrlChannel for a bipolar output.

9.2.1 Detailed Description

Manage output of a control signal.

The classes in this group are collectivly responsible for managing the output of control signals to the real world. Their template base class is CtrlChannel.

9.3 Error signal input

Manage input of an error signal.

Classes

- class YbCtrl::ErrorChannel

  Abstract object to allow measuring an error signal.
- class YbCtrl::V4_ADC_ChannelPair

  Implementation of an ErrorChannel for the ADS1262.

9.3.1 Detailed Description

Manage input of an error signal.

The classes in this group are collectivly responsible for managing the input of error signals from the real world. Their template base class is ErrorChannel.

10 Namespace Documentation

10.1 YbCtrl Namespace Reference

Namespace to hold all the temperature controller classes.

Classes

- class Algorithm
  Abstract class for algorithms.
- class Controller
  Object to manage the locking loop.
- class CtrlChannel
  Abstract object to allow outputting a control signal.
- class ErrorChannel
  Abstract object to allow measuring an error signal.
- class PIDAlgorithm
  Implementation of an Algorithm to perform a PID lock.
- class TemporaryLooper
  Temporarily divert the lock, before returning to normal.
- class V4_ADC_ChannelPair
  Implementation of an ErrorChannel for the ADS1262.
- class V4_OPA_OutputChannel
  Implementation of a CtrlChannel for a single-ended output.
- class V4_OPA_OutputChannelBipolar
  Implementation of a CtrlChannel for a bipolar output.

Enumerations

10.1.1 Detailed Description

Namespace to hold all the temperature controller classes.

All the classes contained in the YbCtrl namespace are involved with the input of error signals, output of control signals or calculation of the appropriate ctrl signal from the corresponding error signal.

10.1.2 Enumeration Type Documentation

10.1.2.1 enum YbCtrl::CtrlChannelReturn [strong]

Error codes for CtrlChannel operation.

Todo Change to enum class

Enumerator

NO_ERROR No error

NOT_IMPLEMENTED Feature not implemented by derived class

NO_SUCH_CHANNEL This channel does not exist

CHANNEL_NOT_MANAGED This channel has no managing Controller

INVALID_PARAMETER Parameter passed was invalid

OUT_OF_MEMORY Out of memory

10.1.2.2 enum YbCtrl::ErrorChannelReturn [strong]

Error codes for ErrorChannel operation.

Enumerator

NO_ERROR No error

NOT_IMPLEMENTED Feature not implemented by derived class

WRITING_TO_REG_FAILED ADC comms failed

TIMEOUT Reading timeout

OUT_OF_RANGE Reading out of PGA range

PGA_ERROR Undefined PGA error

NO_SUCH_CHANNEL Channel does not exist

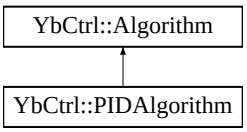
11 Class Documentation

11.1 YbCtrl::Algorithm Class Reference

Abstract class for algorithms.

`#include <Algorithm.h>`

Inheritance diagram for YbCtrl::Algorithm:



Public Member Functions

- virtual double output (double input)=0
  Do the locking calculation.
- virtual char * reportState (char *ptr)=0
  Report state.
- virtual void setOutput (double output)=0
  Sets the output.
- virtual void setSetpoint (double setpoint)=0
  Sets the setpoint.
- virtual double getSetpoint ()=0
  Gets the setpoint.
- virtual void setLimits (double min, double max)=0
  Sets output limits.
- virtual bool lockingAlgo ()
  Does this algorithm lock?
- virtual operator bool ()
  Is this algorithm valid?

11.1.1 Detailed Description

Abstract class for algorithms.

This abstract class defines a template for a lock algorithm. The main method is output() which is responsible for taking an error signal and calculating a subsequent output from it. output() obeys the convention followed everywhere in this code that both input and output signals can range from -1 to +1.

As with all abstract classes, the pure virtual methods in this class MUST be overridden by derived classes. The virtual methods SHOULD be overridden.

For an example implementation, see PIDAlgorithm.

11.1.2 Member Function Documentation

11.1.2.1 virtual double YbCtrl::Algorithm::getSetpoint ( ) [pure virtual]

Gets the setpoint.

Returns

The current setpoint.

Implemented in YbCtrl::PIDAlgorithm.

11.1.2.2 virtual bool YbCtrl::Algorithm::lockingAlgo ( ) [inline], [virtual]

Does this algorithm lock?

Returns a boolean describing whether this Algorithm implementation locks or not. E.g. the PIDAlgorithm, a derived implementation of this class, does lock so it overrides this method with

```
return true;
```

Currently there are no examples of Algorithms that do not lock.

Returns

true / false

Reimplemented in YbCtrl::PIDAlgorithm.

11.1.2.3 virtual YbCtrl::Algorithm::operator bool ( ) [inline], [explicit], [virtual]

Is this algorithm valid?

Return true if this Algorithm is valid for use in calculations. E.g. see PIDAlgorithm for an example of why this may be useful.

Reimplemented in YbCtrl::PIDAlgorithm.

11.1.2.4 virtual double YbCtrl::Algorithm::output (double *input*) [pure virtual]

Do the locking calculation.

Parameters

in	*input*	The error signal, ranging from -1 to +1

Returns

The new ctrl level, ranging from -1 to +1

Implemented in YbCtrl::PIDAlgorithm.

11.1.2.5 virtual char* YbCtrl::Algorithm::reportState (char * *ptr*) [pure virtual]

Report state.

Send a string that identifies the currently running algorithm.

Parameters

out	*ptr*	A buffer to contain the output. Should be at least 128 chars long.

Returns

Returns ptr

Implemented in YbCtrl::PIDAlgorithm.

11.1.2.6 virtual void YbCtrl::Algorithm::setLimits (double *min,* double *max*) [pure virtual]

Sets output limits.

Set limits on the algorithm's output. Values are from -1 to +1.

Parameters

in	*min*	The new minimum
in	*max*	The new maximum

Implemented in YbCtrl::PIDAlgorithm.

11.1.2.7 virtual void YbCtrl::Algorithm::setOutput (double *output*) [pure virtual]

Sets the output.

Set the output to a specified level, smoothly if possible.

Parameters

in	*output*	The new output, from -1 to +1.

Implemented in YbCtrl::PIDAlgorithm.

11.1.2.8 virtual void YbCtrl::Algorithm::setSetpoint (double *setpoint*) [pure virtual]

Sets the setpoint.

Change setpoint, smoothly if possible.

Parameters

in	*setpoint*	The new setpoint, from -1 to +1

Implemented in YbCtrl::PIDAlgorithm.

The documentation for this class was generated from the following file:

- Algorithm.h

11.2 YbCtrl::Controller Class Reference

Object to manage the locking loop.

`#include <Controller.h>`

Public Member Functions

- Controller ()
  Constuct an empty Controller.
- Controller (ErrorChannel *errorInt, CtrlChannel *ctrlInt, Algorithm *algorithm)
  Constuct a Controller.
- operator bool () const
  Is this Controller valid?
- void reset ()
  Wipe this Controller.
- int doLoop ()
  Do a locking cycle.
- CtrlChannel * getCtrlChannel ()
  Gets the control channel.
- ErrorChannel * getErrorInterface ()
  Gets the error interface.
- Algorithm * getAlgorithm ()
  Gets the algorithm.
- int replaceCtrlChannel (bool)
  Remove the current CtrlChannel.
- int replaceCtrlChannel (CtrlChannel *newInterface)
  Replace the current CtrlChannel.
- char * reportState (char *ptr)
  Reports the state.

11.2.1 Detailed Description

Object to manage the locking loop.

This object manages pointers to an ErrorChannel, a CtrlChannel and an Algorithm.

It uses these objects to get the error signal, calculate a new output level and send that output every time doLoop() is called.

This object can be marked as valid or invalid. It is considered invalid if any of its three contained objects are a) not present or b) themselves marked invalid.

11.2.2 Constructor & Destructor Documentation

11.2.2.1 YbCtrl::Controller::Controller ( )

Constuct an empty Controller.

This empty controller is marked invalid.

11.2.2.2 YbCtrl::Controller::Controller (ErrorChannel * *errorInt*, CtrlChannel * *ctrlInt*, Algorithm * *algorithm*)

Constuct a Controller.

Constuct a controller using pointers to its substituents. This is the recommended constructor form.

N.B. a CtrlChannel may only be assigned to a single Controller at a time. To ensure this, a pointer is placed within the CtrlChannel to its controlling Controller, if it exists. This constuctor checks for the presence of this pointer and, if it points to another rival Controller, it refuses to use the passed CtrlChannel and this Controller is marked invalid.

Parameters

in	*errorInt*	The error interface
in	*ctrlInt*	The control interface
in	*algorithm*	The algorithm

11.2.3 Member Function Documentation

11.2.3.1 int YbCtrl::Controller::doLoop ( )

Do a locking cycle.

Does one cycle of the loop. Reads error, performs calculation and outputs result

Returns

Returns 0 (error code not implemented)

11.2.3.2 Algorithm* YbCtrl::Controller::getAlgorithm ( ) [inline]

Gets the algorithm.

Returns

The algorithm.

11.2.3.3 CtrlChannel* YbCtrl::Controller::getCtrlChannel ( ) [inline]

Gets the control channel.

Returns

The control channel.

11.2.3.4 ErrorChannel* YbCtrl::Controller::getErrorInterface ( ) [inline]

Gets the error interface.

Returns

The error interface.

11.2.3.5 YbCtrl::Controller::operator bool ( ) const [explicit]

Is this Controller valid?

Return true if the ErrorInterface, CtrlChannel and Algorithm are all present and valid. Otherwise return false.

11.2.3.6 int YbCtrl::Controller::replaceCtrlChannel (bool) [inline]

Remove the current CtrlChannel.

Calls replaceCtrlChannel() with a null pointer.

Parameters

in	*<unnamed>*	Any bool. Value is ignored

Returns

Error codes

Return values

0	Success

11.2.3.7 int YbCtrl::Controller::replaceCtrlChannel (CtrlChannel * *newInterface*) [inline]

Replace the current CtrlChannel.

Replaces the current CtrlChannel with a new one, releasing control of the current CtrlChannel.

Parameters

in	*newInterface*	The new CtrlChannel

Returns

Error codes

Return values

0	Success
1	Error: new CtrlChannel is already assigned.

11.2.3.8 char* YbCtrl::Controller::reportState (char * *ptr*) [inline]

Reports the state.

Write into ptr a string that identifies the currently running loop. This is delegated to the Algorithm

Parameters

out	*ptr*	Pointer to a buffer. Should hold at least 128 chars.

Returns

Returns ptr

11.2.3.9 void YbCtrl::Controller::reset ( )

Wipe this Controller.

Relinquishes control of the current CtrlChannel and wipes all parameters.

The documentation for this class was generated from the following files:

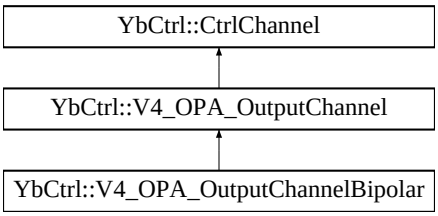
- Controller.h
- Controller.cpp

11.3 YbCtrl::CtrlChannel Class Reference

Abstract object to allow outputting a control signal.

`#include <CtrlChannel.h>`

Inheritance diagram for YbCtrl::CtrlChannel:



Public Member Functions

- virtual double recallCtrl ()=0

  Read out the current output.
- virtual CtrlChannelReturn setLimits (double minimum, double maximum) final

  Set software limits on the max/min ctrl signal.
- virtual operator bool () const =0

  Is this object valid?
- virtual CtrlChannelReturn setCurrentLimit (double val)

  Limits the current.
- virtual double getCurrentLimit ()

  Gets the current limit.
- virtual CtrlChannelReturn isOverheated (bool &state)

  Check for overheated.
- virtual CtrlChannelReturn getLimits (double &min, double &max)=0

  Gets the output limits.
- virtual CtrlChannelReturn getCurrentLimit (double &out)

  Gets the current limit.
- virtual void setCtrl (double val) final

  Sets the control signal.
- void setContainingController (Controller *newController)

  Sets the containing Controller.
- Controller * getContainingController ()

  Gets the containing Controller.
- CtrlChannelReturn getContainingController (Controller *&out)

  Gets the containing controller.
- CtrlChannelReturn addConflictingChannel (CtrlChannel *newConflict)

  Adds a conflicting channel.
- CtrlChannelReturn closeConflictingControllers ()

  Closes conflicting controllers.

11.3.1 Detailed Description

Abstract object to allow outputting a control signal.

This object is a tempate for class that writes an output to the real world. Child classes will implement specifics, e.g. writing a voltage to an OPA.

As with the Algorithm class, this class is abstract and so derived classes must override many of its methods.

For an example, see V4_OPA_OutputChannel.

11.3.2 Member Function Documentation

11.3.2.1 CtrlChannelReturn YbCtrl::CtrlChannel::addConflictingChannel (CtrlChannel * *newConflict*) [inline]

Adds a conflicting channel.

Adds a channel that is considered to be conflicting with this one. I.e. this channel and the conflicting one should not be simultaneously controlled.

This is useful e.g. for bipolar vs. single-sided channels which use the same outputs.

Up to 2 channels can be added using this function. Any Controllers associated with these channels can be closed with closeConflictingControllers

Returns

Error code

11.3.2.2 CtrlChannelReturn YbCtrl::CtrlChannel::closeConflictingControllers ( )

Closes conflicting controllers.

Close any Controllers that are managing either this channel or any conflicting ones. Conflicting channels are identified by adding pointers to them with addConflictingChannel.

Note

Similarily to setCtrl() vs writeCtrl(), this is the public interface which is defined by the base class. The derived classes will overwrite the private pure virtual member writeLimits() which is called by this function and which will actually set the limits.

Returns

Error code

11.3.2.3 Controller* YbCtrl::CtrlChannel::getContainingController ( ) [inline]

Gets the containing Controller.

Returns

The containing controller. NULL if none present.

11.3.2.4 CtrlChannelReturn YbCtrl::CtrlChannel::getContainingController (Controller *& *out*) [inline]

Gets the containing controller.

Parameters

out	*out*	The containing Controller

Returns

Error code

11.3.2.5 virtual double YbCtrl::CtrlChannel::getCurrentLimit ( ) [inline], [virtual]

Gets the current limit.

Gets the current limit. Value in amps

Returns

The current limit in amps. -999 if not implemented

Reimplemented in YbCtrl::V4_OPA_OutputChannel.

11.3.2.6 virtual CtrlChannelReturn YbCtrl::CtrlChannel::getCurrentLimit (double & *out*) [inline], [virtual]

Gets the current limit.

Gets the current limit and stores it in out. Value in amps

Parameters

out	*out*	The current limit in amps

Returns

Error code

Reimplemented in YbCtrl::V4_OPA_OutputChannel.

11.3.2.7 virtual CtrlChannelReturn YbCtrl::CtrlChannel::getLimits (double & *min,* double & *max*) [pure virtual]

Gets the output limits.

Store the output limits in the passed references.

Parameters

out	*min*	The minimum
out	*max*	The maximum

Returns

Error code

Implemented in YbCtrl::V4_OPA_OutputChannel.

11.3.2.8 virtual CtrlChannelReturn YbCtrl::CtrlChannel::isOverheated (bool & *state*) [inline], [virtual]

Check for overheated.

Check if this channel is overheated

Parameters

out	*state*	True if overheated, false otherwise

Returns

Error return

Reimplemented in YbCtrl::V4_OPA_OutputChannel, and YbCtrl::V4_OPA_OutputChannelBipolar.

11.3.2.9 virtual YbCtrl::CtrlChannel::operator bool ( ) const [explicit], [pure virtual]

Is this object valid?

Return true if this object has been constucted with valid parameters

Implemented in YbCtrl::V4_OPA_OutputChannel.

11.3.2.10 virtual double YbCtrl::CtrlChannel::recallCtrl ( ) [pure virtual]

Read out the current output.

Read out the current output. Values from -1 to 1.

Returns

Current ctrl level

Implemented in YbCtrl::V4_OPA_OutputChannel.

11.3.2.11 void YbCtrl::CtrlChannel::setContainingController (Controller * *newController*) [inline]

Sets the containing Controller.

Set this object's managing Controller to the given target

Parameters

newController	The new managing Controller

11.3.2.12 void YbCtrl::CtrlChannel::setCtrl (double *val*) [final], [virtual]

Sets the control signal.

Set the control signal to the given value. Also, if this channel is managed by a Controller, inform that Controller's Algorithm of the updated output level

Note

This method is declared in an external object file. This is necessary because, at the point of including this header file, the Controller object has not yet been fully defined. Since setCtrl() uses methods in Controller, it cannot be compiled until Controller is fully defined. Therefore the code must be in a .cpp file, to be compiled later after all the headers are resolved.

See the documentation for setLimits for an explaination as to why this structure is needed

Parameters

val	The value, from -1 to +1

11.3.2.13 virtual CtrlChannelReturn YbCtrl::CtrlChannel::setCurrentLimit (double *val*) [inline], [virtual]

Limits the current.

If implemented, limit the current to the given value.

N.B. this method DOES NOT use -1 -> +1 notation; the input is in amps.

Parameters

in	*val*	The current limit in Amps

Returns

Error code

Reimplemented in YbCtrl::V4_OPA_OutputChannel, and YbCtrl::V4_OPA_OutputChannelBipolar.

11.3.2.14 CtrlChannelReturn YbCtrl::CtrlChannel::setLimits (double *minimum*, double *maximum*) [final], [virtual]

Set software limits on the max/min ctrl signal.

Also, if this channel is managed by a Controller, inform that Controller's Algorithm of the new limits

Note

This method is defined in an external object file. This is necessary because, at the point of including this header file, the Controller object has not yet been fully defined. Since setCtrl() uses methods in Controller, it cannot be compiled until Controller is fully defined. Therefore the code must be in a .cpp file, to be compiled later after all the headers are resolved.
Similarily to setCtrl() vs writeCtrl(), this is the public interface which is defined by the base class. The derived classes will overwrite the private pure virtual member writeLimits() which is called by this function and which will actually set the limits.

Parameters

in	*minimum*	The new minimum
in	*maximum*	The new maximum

Returns

Error status

The documentation for this class was generated from the following files:

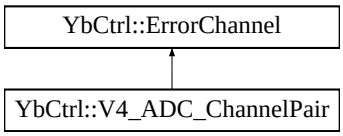
- CtrlChannel.h
- CtrlChannel.cpp

11.4 YbCtrl::ErrorChannel Class Reference

Abstract object to allow measuring an error signal.

`#include <ErrorChannel.h>`

Inheritance diagram for YbCtrl::ErrorChannel:



Public Member Functions

- virtual double recallError ()=0
  Recall error signal.
- virtual ErrorChannelReturn recallError (double &output)=0
  Recall error signal.
- virtual bool readInProgress ()
  Check if there's a read in progress by this channel.
- virtual bool globalReadInProgress ()
  Check if there's a read in progress globally.
- virtual bool readingReady ()
  Check if the current reading is ready.
- virtual bool readingTimeout ()
  Check if the current reading is has timed out.
- virtual void abortReading ()
  Aborts a reading currently in progress.
- virtual ErrorChannelReturn startReading ()
  Start reading.
- virtual ErrorChannelReturn getReading (double &readingOutput)=0
  Get the latest reading.
- virtual operator bool () const =0
  Is this object valid?

11.4.1 Detailed Description

Abstract object to allow measuring an error signal.

This object is a tempate for class that reads an input from the real world. Child classes will implement specifics, e.g. reading a voltage from an ADC.

As with the Algorithm class, this class is abstract and so derived classes must override many of its methods.

For an example, see V4_ADC_ChannelPair.

11.4.2 Member Function Documentation

11.4.2.1 virtual void YbCtrl::ErrorChannel::abortReading ( ) [inline], [virtual]

Aborts a reading currently in progress.

If a reading is in progress, abort it, If not, do nothing

Child objects should either override all of readInProgress, readingReady, readingTimeout and startReading or none of them.

Reimplemented in YbCtrl::V4_ADC_ChannelPair.

11.4.2.2 virtual ErrorChannelReturn YbCtrl::ErrorChannel::getReading (double & *readingOutput*) [pure virtual]

Get the latest reading.

Gets the completed reading and stores it in readingOutput. The reading uses the format -1 -> +1, where -1 corresponds to the minimum value the ErrorChannel can read and vice versa.

If no conversion is in progress / the conversion failed, return an error message.

Otherwise return ErrorChannelReturn::NO_ERROR.

This method must be overridden by child objects.

Parameters

out	*readingOutput*	Output variable for the reading.

Returns

ErrorChannelReturn error code.

Implemented in YbCtrl::V4_ADC_ChannelPair.

11.4.2.3 virtual bool YbCtrl::ErrorChannel::globalReadInProgress ( ) [inline], [virtual]

Check if there's a read in progress globally.

Returns true if a reading has been started with startReading, has not been aborted with abortReading and has not been returned by getReading BY ANY ErrorChannel.

Otherwise returns false

Before it is overridden, this function always returns true. This is so that simple ErrorChannels that do not require this start / check / read method can instead just return a value from getReading each time.

Child objects should either override all of readInProgress, readingReady, readingTimeout and startReading or none of them.

Returns

true / false

Reimplemented in YbCtrl::V4_ADC_ChannelPair.

11.4.2.4 virtual YbCtrl::ErrorChannel::operator bool ( ) const [explicit], [pure virtual]

Is this object valid?

Return true if this object has been constucted with valid parameters

Implemented in YbCtrl::V4_ADC_ChannelPair.

11.4.2.5 virtual bool YbCtrl::ErrorChannel::readingReady ( ) [inline], [virtual]

Check if the current reading is ready.

Returns true if a reading has been started with startReading, has not been aborted with abortReading, has not been returned by getReading and has successfully completed

Otherwise returns false

Before it is overridden, this function always returns true. This is so that simple ErrorChannels that do not require this start / check / read method can instead just return a value from getReading each time.

Child objects should either override all of readInProgress, readingReady, readingTimeout and startReading or none of them.

Returns

true / false

Reimplemented in YbCtrl::V4_ADC_ChannelPair.

11.4.2.6 virtual bool YbCtrl::ErrorChannel::readingTimeout ( ) [inline], [virtual]

Check if the current reading is has timed out.

Returns true if a reading has been started with startReading, has not been aborted with abortReading, has not been returned by getReading, has not successfully completed and has exceeded a maximum timeout.

Otherwise returns false

Before it is overridden, this function always returns false. This is so that simple ErrorChannels that do not require this start / check / read method can instead just return a value from getReading each time.

Child objects should either override all of readInProgress, readingReady, readingTimeout and startReading or none of them.

Returns

true / false

Reimplemented in YbCtrl::V4_ADC_ChannelPair.

11.4.2.7 virtual bool YbCtrl::ErrorChannel::readInProgress ( ) [inline], [virtual]

Check if there's a read in progress by this channel.

Returns true if a reading has been started with startReading, has not been aborted with abortReading and has not been returned by getReading BY THIS ErrorChannel

Otherwise returns false

Before it is overridden, this function always returns true. This is so that simple ErrorChannels that do not require this start / check / read method can instead just return a value from getReading each time.

Child objects should either override all of readInProgress, readingReady, readingTimeout and startReading or none of them.

Returns

true / false

Reimplemented in YbCtrl::V4_ADC_ChannelPair.

11.4.2.8 virtual double YbCtrl::ErrorChannel::recallError ( ) [pure virtual]

Recall error signal.

Read out the last measured error. Values from -1 to 1.

Returns

Last measured error signal from -1 to +1

Implemented in YbCtrl::V4_ADC_ChannelPair.

11.4.2.9 virtual ErrorChannelReturn YbCtrl::ErrorChannel::recallError (double & *output*) [pure virtual]

Recall error signal.

Read out the last measured error into output. Values from -1 to 1.

Parameters

out	*output*	Target for the error signal

Returns

Error code

Implemented in YbCtrl::V4_ADC_ChannelPair.

11.4.2.10 virtual ErrorChannelReturn YbCtrl::ErrorChannel::startReading ( ) [inline], [virtual]

Start reading.

Start a new reading if none in progress (by this channel or globally).

If a reading is already in progress, abort it and start another one.

Child objects should either override all of readInProgress, readingReady, readingTimeout and startReading or none of them.

Returns

ErrorChannelReturn error code.

Reimplemented in YbCtrl::V4_ADC_ChannelPair.

The documentation for this class was generated from the following file:

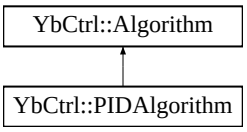
- ErrorChannel.h

11.5 YbCtrl::PIDAlgorithm Class Reference

Implementation of an Algorithm to perform a PID lock.

`#include <PIDAlgorithm.h>`

Inheritance diagram for YbCtrl::PIDAlgorithm:



Public Member Functions

- PIDAlgorithm (double K, double Ti, double Td, double initialOutput, double target=0, double N=10, bool disableProportional=false)

  Constuctor.
- PIDAlgorithm ()

  Alternative constuctor.
- bool lockingAlgo () override

  Does this algorithm lock?
- operator bool () override

  Returns true if this object has been initialised with valid parameters.
- double output (double input) override

  Do the PID calculation.
- void setOutput (double output) override

  Sets the output.
- void setSetpoint (double setpoint) override

  Sets the setpoint.
- void setLimits (double min, double max) override

  Sets output limits.
- double getSetpoint () override

  Gets the setpoint.

Protected Member Functions

- char * reportState (char *ptr) override

  Report state.

11.5.1 Detailed Description

Implementation of an Algorithm to perform a PID lock.

An implementation of Algorithm that performs a PID lock based on the parameters passed during its constuction.

The lock performed by this object implements the following transfer function:

$$G(s) = -K\left(1 + \frac{1}{sT_I} + \frac{sT_D}{1 + \frac{sT_D}{N}}\right)$$

When created without parameters passed to the consructor, this object will be marked invalid. This allows the user to reserve space on the stack, while still recording which PIDAlgorithms are properly setup.

As usual, all inputs / outputs are to be given in -1 to +1 format.

11.5.2 Constructor & Destructor Documentation

11.5.2.1 YbCtrl::PIDAlgorithm::PIDAlgorithm (double *K*, double *Ti*, double *Td*, double *initialOutput*, double *target* = `0`, double *N* = `10`, bool *disableProportional* = `false`)

Constuctor.

Parameters

`in`	*K*	Proportional gain
`in`	*Ti*	Integral time constant
`in`	*Td*	Differential time constant
`in`	*initialOutput*	The initial output
`in`	*target*	The target error signal
`in`	*N*	High frequency damping coefficient. ~10 is a good value.
`in`	*disableProportional*	Disable proportional gain
`in`	*timingCycles*	To speed up execution, the PID parameters are recalulated according to the measured loop speed every timingCycles loops.
`in`	*debug*	Enable debug output

11.5.2.2 YbCtrl::PIDAlgorithm::PIDAlgorithm ( ) `[inline]`

Alternative constuctor.

A PIDAlgorithm constructed without parameters is marked invalid. This can be useful for reserving stack space for these objects, allowing them to be declared in advance.

E.g.

```
PIDAlgorithm algos[3];

bool valid = algos[1]; // returns false

algos[1] = PIDALgorithm(1,1,0,0,0);

bool valid = algos[1]; // returns true
```

11.5.3 Member Function Documentation

11.5.3.1 double YbCtrl::PIDAlgorithm::getSetpoint ( ) [inline], [override], [virtual]

Gets the setpoint.

Returns

The current setpoint.

Implements YbCtrl::Algorithm.

11.5.3.2 bool YbCtrl::PIDAlgorithm::lockingAlgo ( ) [inline], [override], [virtual]

Does this algorithm lock?

Returns a boolean describing whether this Algorithm implementation locks or not. E.g. the PIDAlgorithm, a derived implementation of this class, does lock so it overrides this method with

```
return true;
```

Currently there are no examples of Algorithms that do not lock.

Returns

true / false

Reimplemented from YbCtrl::Algorithm.

11.5.3.3 double YbCtrl::PIDAlgorithm::output (double *input*) [override], [virtual]

Do the PID calculation.

See p242 of http://www.cds.caltech.edu/~murray/courses/cds101/fa02/caltech/astrom-ch6.pdf for an in depth explaination of how this works

Parameters

in	*input*	The current error signal input. Values from -1 to +1

Returns

The calculated new ctrl signal. Values from -1 to +1

Implements YbCtrl::Algorithm.

11.5.3.4 char* YbCtrl::PIDAlgorithm::reportState (char * *ptr*) [inline], [override], [protected], [virtual]

Report state.

Send a string that identifies the currently running algorithm.

Parameters

out	*ptr*	A buffer to contain the output. Should be at least 128 chars long.

Returns

Returns ptr

Implements YbCtrl::Algorithm.

11.5.3.5 void YbCtrl::PIDAlgorithm::setLimits (double *min,* double *max*) [override], [virtual]

Sets output limits.

Set limits on the algorithm's output. Values are from -1 to +1.

Parameters

in	*min*	The new minimum
in	*max*	The new maximum

Implements YbCtrl::Algorithm.

11.5.3.6 void YbCtrl::PIDAlgorithm::setOutput (double *output*) [override], [virtual]

Sets the output.

Set the output to a specified level, smoothly if possible.

Parameters

in	*output*	The new output, from -1 to +1.

Implements YbCtrl::Algorithm.

11.5.3.7 void YbCtrl::PIDAlgorithm::setSetpoint (double *setpoint*) [override], [virtual]

Sets the setpoint.

Change setpoint, smoothly if possible.

Parameters

in	*setpoint*	The new setpoint, from -1 to +1

Implements YbCtrl::Algorithm.

The documentation for this class was generated from the following files:

- PIDAlgorithm.h
- PIDAlgorithm.cpp

11.6 pinToggler< numPins > Class Template Reference

Class for toggling pins.

`#include <pinToggler.h>`

Inherits pinTogglerBase.

Static Public Member Functions

- static int init (const uint8_t *LED_Pins)

  Initiate the pins and TIMER1.
- static int setFlashRate (const size_t LED, const FLASHRATE rate)

  Change the flash rate of an LED managed by this routine.
- static int getPin (const size_t LED)

  Return the pin corresponding to a given LED.

11.6.1 Detailed Description

template<int numPins>
class pinToggler< numPins >

Class for toggling pins.

This class maintains a list of pins that it controls as outputs. It initiates TIMER1 and uses this to trigger an interrupt routine, allowing arbitary numbers of pins to be toggled at selectable rates.

This class implements a singleton and all access to it is via static methods. The first usage of init() will define the value of numPins. Attempts to use init() with another value of numPins after this will fail with an error code.

For example usage see the Arduino sketches located in the `examples` directory.

Template Parameters

numPins	The number of pins that this object will handle.

11.6.2 Member Function Documentation

11.6.2.1 template<int numPins> static int pinToggler< numPins >::getPin (const size_t *LED*) [inline], [static]

Return the pin corresponding to a given LED.

Parameters

LED	The zero reference LED to get the pin of. The LED number should correspond to the index of this pin in the array passed to init().

Returns

Pin number. N.B. If an error occurs the return value will be negative, according to the error codes in setFlashRate.

11.6.2.2 template<int numPins> static int pinToggler< numPins >::init (const uint8_t * *LED_Pins*) [inline], [static]

Initiate the pins and TIMER1.

Setup and start the ISR triggered by TIMER1, and set TIMER1 running. Also, set all input pins as outputs and set their output to LOW.

Parameters

in	*LED_Pins*	Pointer to a <numPins> dimention array of pins to be controlled. The values in this array will be copied so it can be deleted from memory after this function call is complete.

Return values

0	No error
-1	init() has been called already
-2	Stack assignment failed: out of memory

Returns

Error code

11.6.2.3 template<int numPins> static int pinToggler< numPins >::setFlashRate (const size_t *LED*, const FLASHRATE *rate*) [inline], [static]

Change the flash rate of an LED managed by this routine.

This method sets the flash rate of one of the pins controlled by the pinToggler class. Pins are placed under control by passing them to init(), after which they are refered to by their zero-indexed position in the array passed to init().

Parameters

LED	The zero reference LED to set the flash rate of. The LED number should correspond to the index of this pin in the array passed to init().
rate	The rate at which to flash this LED. Options are enumerated in FLASHRATE.

Return values

0	No error
-1	init() has not been called.
-2	init() was called with a different value of numPins
-3	The given pin does not exist

Returns

Error code

The documentation for this class was generated from the following file:

- arduino-pin-toggler/pinToggler.h

11.7 YbCtrl::TemporaryLooper Class Reference

Temporarily divert the lock, before returning to normal.

```
#include <TemporaryLooper.h>
```

11.7.1 Detailed Description

Temporarily divert the lock, before returning to normal.

Class for defining actions that need to take place instead of the loop, for a short time, after which the controller reverts to locking as normal.

Todo This class is currently unused: the code in Controller exists but is commented out. It could be used to implement e.g. an autotuning lock or a relocking routine

The documentation for this class was generated from the following file:

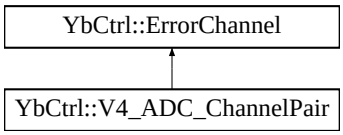
- TemporaryLooper.h

11.8 YbCtrl::V4_ADC_ChannelPair Class Reference

Implementation of an ErrorChannel for the ADS1262.

`#include <V4_ADC_ChannelPair.h>`

Inheritance diagram for YbCtrl::V4_ADC_ChannelPair:



Public Member Functions

- virtual double recallError () override
  Recall error signal.
- virtual ErrorChannelReturn recallError (double &output)
  Recall error signal.
- virtual operator bool () const override
  Is this object valid?
- bool readInProgress () override
  Check if there's a read in progress by this channel.
- virtual bool globalReadInProgress () override
  Check if there's a read in progress globally.
- bool readingReady () override
  Check if the current reading is ready.
- bool readingTimeout () override
  Check if the current reading is has timed out.
- void abortReading () override
  Aborts a reading currently in progress.
- ErrorChannelReturn startReading () override
  Start reading.
- ErrorChannelReturn getReading (double &readingOutput) override
  Get the latest reading.
- V4_ADC_ChannelPair ()
  Default constuctor.
- V4_ADC_ChannelPair (uint8_t channel1, uint8_t channel2, bool highRes=true)
  Constuctor.

Static Protected Attributes

- static constexpr uint8_t __maxLowReadings = 3
- static constexpr double __lowGainThreshold = 0.4

11.8.1 Detailed Description

Implementation of an ErrorChannel for the ADS1262.

Reads two channels from the ADS1261 and return the difference. The ADS1262 can read a differential of at most 2.5V in either direction, so the -1 -> +1 scale used in this code corresponds to a -2.5 -> +2.5V scale at the ADC

11.8.2 Constructor & Destructor Documentation

11.8.2.1 YbCtrl::V4_ADC_ChannelPair::V4_ADC_ChannelPair ( ) [inline]

Default constuctor.

The object created thus will be marked as invalid

11.8.2.2 YbCtrl::V4_ADC_ChannelPair::V4_ADC_ChannelPair (uint8_t *channel1*, uint8_t *channel2*, bool *highRes* = true) [inline]

Constuctor.

The error signal measured by readError(double&) will be channel 1 - channel 2

Parameters

in	*channel1*	ADC channel 1
in	*channel2*	ADC channel 2
in	*highRes*	Should this channel be measured quickly or carefully?

11.8.3 Member Function Documentation

11.8.3.1 void YbCtrl::V4_ADC_ChannelPair::abortReading ( ) [override], [virtual]

Aborts a reading currently in progress.

If a reading is in progress, abort it, If not, do nothing

Child objects should either override all of readInProgress, readingReady, readingTimeout and startReading or none of them.

Reimplemented from YbCtrl::ErrorChannel.

11.8.3.2 ErrorChannelReturn YbCtrl::V4_ADC_ChannelPair::getReading (double & *readingOutput*) [override], [virtual]

Get the latest reading.

Gets the completed reading and stores it in readingOutput. The reading uses the format -1 -> +1, where -1 corresponds to the minimum value the ErrorChannel can read and vice versa.

If no conversion is in progress / the conversion failed, return an error message.

Otherwise return ErrorChannelReturn::NO_ERROR.

This method must be overridden by child objects.

Parameters

out	*readingOutput*	Output variable for the reading.

Returns

ErrorChannelReturn error code.

Implements YbCtrl::ErrorChannel.

11.8.3.3 virtual bool YbCtrl::V4_ADC_ChannelPair::globalReadInProgress ( ) [inline], [override], [virtual]

Check if there's a read in progress globally.

Returns true if a reading has been started with startReading, has not been aborted with abortReading and has not been returned by getReading BY ANY ErrorChannel.

Otherwise returns false

Before it is overridden, this function always returns true. This is so that simple ErrorChannels that do not require this start / check / read method can instead just return a value from getReading each time.

Child objects should either override all of readInProgress, readingReady, readingTimeout and startReading or none of them.

Returns

true / false

Reimplemented from YbCtrl::ErrorChannel.

11.8.3.4 virtual YbCtrl::V4_ADC_ChannelPair::operator bool ( ) const [inline], [explicit], [override], [virtual]

Is this object valid?

Return true if this object has been constucted with valid parameters

Implements YbCtrl::ErrorChannel.

11.8.3.5 bool YbCtrl::V4_ADC_ChannelPair::readingReady ( ) [override], [virtual]

Check if the current reading is ready.

Returns true if a reading has been started with startReading, has not been aborted with abortReading, has not been returned by getReading and has successfully completed

Otherwise returns false

Before it is overridden, this function always returns true. This is so that simple ErrorChannels that do not require this start / check / read method can instead just return a value from getReading each time.

Child objects should either override all of readInProgress, readingReady, readingTimeout and startReading or none of them.

Returns

true / false

Reimplemented from YbCtrl::ErrorChannel.

11.8.3.6 bool YbCtrl::V4_ADC_ChannelPair::readingTimeout ( ) [override], [virtual]

Check if the current reading is has timed out.

Returns true if a reading has been started with startReading, has not been aborted with abortReading, has not been returned by getReading, has not successfully completed and has exceeded a maximum timeout.

Otherwise returns false

Before it is overridden, this function always returns false. This is so that simple ErrorChannels that do not require this start / check / read method can instead just return a value from getReading each time.

Child objects should either override all of readInProgress, readingReady, readingTimeout and startReading or none of them.

Returns

true / false

Reimplemented from YbCtrl::ErrorChannel.

11.8.3.7 bool YbCtrl::V4_ADC_ChannelPair::readInProgress ( ) [inline], [override], [virtual]

Check if there's a read in progress by this channel.

Returns true if a reading has been started with startReading, has not been aborted with abortReading and has not been returned by getReading BY THIS ErrorChannel

Otherwise returns false

Before it is overridden, this function always returns true. This is so that simple ErrorChannels that do not require this start / check / read method can instead just return a value from getReading each time.

Child objects should either override all of readInProgress, readingReady, readingTimeout and startReading or none of them.

Returns

true / false

Reimplemented from YbCtrl::ErrorChannel.

11.8.3.8 virtual double YbCtrl::V4_ADC_ChannelPair::recallError ( ) [inline], [override], [virtual]

Recall error signal.

Read out the last measured error. Values from -1 to 1.

Returns

Last measured error signal from -1 to +1

Implements YbCtrl::ErrorChannel.

11.8.3.9 virtual ErrorChannelReturn YbCtrl::V4_ADC_ChannelPair::recallError (double & *output*) [inline], [virtual]

Recall error signal.

Read out the last measured error into output. Values from -1 to 1.

Parameters

out	*output*	Target for the error signal

Returns

Error code

Implements YbCtrl::ErrorChannel.

11.8.3.10 ErrorChannelReturn YbCtrl::V4_ADC_ChannelPair::startReading ( ) [override], [virtual]

Start reading.

Start a new reading if none in progress (by this channel or globally).

If a reading is already in progress, abort it and start another one.

Child objects should either override all of readInProgress, readingReady, readingTimeout and startReading or none of them.

Returns

ErrorChannelReturn error code.

Reimplemented from YbCtrl::ErrorChannel.

11.8.4 Member Data Documentation

11.8.4.1 constexpr double YbCtrl::V4_ADC_ChannelPair::__lowGainThreshold = 0.4 [static], [protected]

The threshold below which a reading is considered to have required a higher gain

11.8.4.2 constexpr uint8_t YbCtrl::V4_ADC_ChannelPair::__maxLowReadings = 3 [static], [protected]

The max number of readings to take getting less than __lowGainThreshold before boosting the gain

The documentation for this class was generated from the following files:

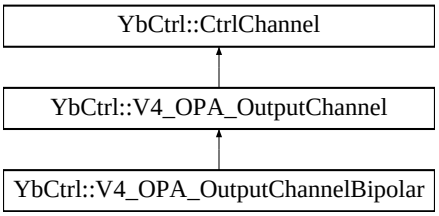
- V4_ADC_ChannelPair.h
- V4_ADC_ChannelPair.cpp

11.9 YbCtrl::V4_OPA_OutputChannel Class Reference

Implementation of a CtrlChannel for a single-ended output.

`#include <V4_OPA_OutputChannel.h>`

Inheritance diagram for YbCtrl::V4_OPA_OutputChannel:



Public Member Functions

- virtual operator bool () const override

  Is this object valid?
- virtual CtrlChannelReturn setCurrentLimit (double val) override

  Limits the current.
- virtual double getCurrentLimit () override

  Gets the current limit.
- virtual CtrlChannelReturn getCurrentLimit (double &out) override

  Gets the current limit.
- virtual CtrlChannelReturn isOverheated (bool &state)

  Check for overheated.
- virtual void enableOutput ()

  Enable OPA output.
- virtual void disableOutput ()

  Disable OPA output.
- virtual double recallCtrl () override

  Read out the current output.
- V4_OPA_OutputChannel (uint8_t channelVPlus, uint8_t channelVLim, uint8_t OPA_ES, bool smallerOPA, uint8_t DAC_CS_pin)

  Constructor.
- CtrlChannelReturn getLimits (double &min, double &max) override

  Gets the output limits.
- virtual CtrlChannelReturn setLimits (double minimum, double maximum) final

  Set software limits on the max/min ctrl signal.
- virtual void setCtrl (double val) final

  Sets the control signal.
- void setContainingController (Controller *newController)

  Sets the containing Controller.
- Controller * getContainingController ()

  Gets the containing Controller.
- CtrlChannelReturn getContainingController (Controller *&out)

  Gets the containing controller.
- CtrlChannelReturn addConflictingChannel (CtrlChannel *newConflict)

  Adds a conflicting channel.
- CtrlChannelReturn closeConflictingControllers ()

  Closes conflicting controllers.

11.9.1 Detailed Description

Implementation of a CtrlChannel for a single-ended output.

This object manages output via a single OPA548 / OPA549. It allows for control of the output voltage between 0 and MAX_VOLTAGE.

Its most important method is setCtrl(double)

11.9.2 Constructor & Destructor Documentation

11.9.2.1 YbCtrl::V4_OPA_OutputChannel::V4_OPA_OutputChannel (uint8_t *channelVPlus*, uint8_t *channelVLim*, uint8_t *OPA_ES*, bool *smallerOPA*, uint8_t *DAC_CS_pin*) [inline]

Constructor.

Parameters

in	*channelVPlus*	DAC channel corresponding to V+
in	*channelVLim*	DAC channel corresponsing to Vlim
in	*OPA_ES*	ATMega pin corresponding to the OPA's E/S pin
in	*smallerOPA*	Is this OPA an OPA548? If so, true. Else if it's an OPA549, false

11.9.3 Member Function Documentation

11.9.3.1 CtrlChannelReturn YbCtrl::CtrlChannel::addConflictingChannel (CtrlChannel * *newConflict*) [inline], [inherited]

Adds a conflicting channel.

Adds a channel that is considered to be conflicting with this one. I.e. this channel and the conflicting one should not be simultaneously controlled.

This is useful e.g. for bipolar vs. single-sided channels which use the same outputs.

Up to 2 channels can be added using this function. Any Controllers associated with these channels can be closed with closeConflictingControllers

Returns

Error code

11.9.3.2 CtrlChannelReturn YbCtrl::CtrlChannel::closeConflictingControllers ( ) [inherited]

Closes conflicting controllers.

Close any Controllers that are managing either this channel or any conflicting ones. Conflicting channels are identified by adding pointers to them with addConflictingChannel.

Note

Similarily to setCtrl() vs writeCtrl(), this is the public interface which is defined by the base class. The derived classes will overwrite the private pure virtual member writeLimits() which is called by this function and which will actually set the limits.

Returns

Error code

11.9.3.3 Controller* YbCtrl::CtrlChannel::getContainingController ( ) [inline], [inherited]

Gets the containing Controller.

Returns

The containing controller. NULL if none present.

11.9.3.4 CtrlChannelReturn YbCtrl::CtrlChannel::getContainingController (Controller *& *out*) [inline], [inherited]

Gets the containing controller.

Parameters

out	*out*	The containing Controller

Returns

Error code

11.9.3.5 virtual double YbCtrl::V4_OPA_OutputChannel::getCurrentLimit ( ) [inline], [override], [virtual]

Gets the current limit.

Gets the current limit. Value in amps

Returns

The current limit in amps. -999 if not implemented

Reimplemented from YbCtrl::CtrlChannel.

11.9.3.6 virtual CtrlChannelReturn YbCtrl::V4_OPA_OutputChannel::getCurrentLimit (double & *out*) [inline], [override], [virtual]

Gets the current limit.

Gets the current limit and stores it in out. Value in amps

Parameters

out	*out*	The current limit in amps

Returns

Error code

Reimplemented from YbCtrl::CtrlChannel.

11.9.3.7 CtrlChannelReturn YbCtrl::V4_OPA_OutputChannel::getLimits (double & *min,* double & *max*) [inline], [override], [virtual]

Gets the output limits.

Store the output limits in the passed references.

Parameters

out	*min*	The minimum
out	*max*	The maximum

Returns

Error code

Implements YbCtrl::CtrlChannel.

11.9.3.8 CtrlChannelReturn YbCtrl::V4_OPA_OutputChannel::isOverheated (bool & *state*) [virtual]

Check for overheated.

Check if this channel is overheated

Parameters

out	*state*	True if overheated, false otherwise

Returns

Error return

Reimplemented from YbCtrl::CtrlChannel.

Reimplemented in YbCtrl::V4_OPA_OutputChannelBipolar.

11.9.3.9 virtual YbCtrl::V4_OPA_OutputChannel::operator bool ( ) const [inline], [explicit], [override], [virtual]

Is this object valid?

Return true if this object has been constucted with valid parameters

Implements YbCtrl::CtrlChannel.

11.9.3.10 virtual double YbCtrl::V4_OPA_OutputChannel::recallCtrl ( ) [inline], [override], [virtual]

Read out the current output.

Read out the current output. Values from -1 to 1.

Returns

Current ctrl level

Implements YbCtrl::CtrlChannel.

11.9.3.11 void YbCtrl::CtrlChannel::setContainingController (Controller * *newController*) [inline], [inherited]

Sets the containing Controller.

Set this object's managing Controller to the given target

Parameters

newController	The new managing Controller

11.9.3.12 void YbCtrl::CtrlChannel::setCtrl (double *val*) [final], [virtual], [inherited]

Sets the control signal.

Set the control signal to the given value. Also, if this channel is managed by a Controller, inform that Controller's Algorithm of the updated output level

Note

This method is declared in an external object file. This is necessary because, at the point of including this header file, the Controller object has not yet been fully defined. Since setCtrl() uses methods in Controller, it cannot be compiled until Controller is fully defined. Therefore the code must be in a .cpp file, to be compiled later after all the headers are resolved.

See the documentation for setLimits for an explaination as to why this structure is needed

Parameters

val	The value, from -1 to +1

11.9.3.13 virtual CtrlChannelReturn YbCtrl::V4_OPA_OutputChannel::setCurrentLimit (double *val*) [inline], [override], [virtual]

Limits the current.

If implemented, limit the current to the given value.

N.B. this method DOES NOT use -1 -> +1 notation; the input is in amps.

Parameters

in	*val*	The current limit in Amps

Returns

Error code

Reimplemented from YbCtrl::CtrlChannel.

Reimplemented in YbCtrl::V4_OPA_OutputChannelBipolar.

11.9.3.14 CtrlChannelReturn YbCtrl::CtrlChannel::setLimits (double *minimum,* double *maximum*) [final], [virtual], [inherited]

Set software limits on the max/min ctrl signal.

Also, if this channel is managed by a Controller, inform that Controller's Algorithm of the new limits

Note

This method is defined in an external object file. This is necessary because, at the point of including this header file, the Controller object has not yet been fully defined. Since setCtrl() uses methods in Controller, it cannot be compiled until Controller is fully defined. Therefore the code must be in a .cpp file, to be compiled later after all the headers are resolved.
Similarily to setCtrl() vs writeCtrl(), this is the public interface which is defined by the base class. The derived classes will overwrite the private pure virtual member writeLimits() which is called by this function and which will actually set the limits.

Parameters

in	*minimum*	The new minimum
in	*maximum*	The new maximum

Returns

Error status

The documentation for this class was generated from the following files:

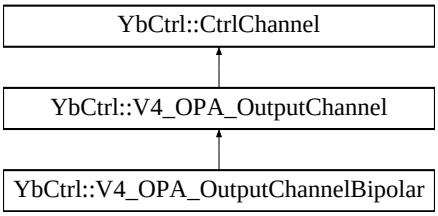
- V4_OPA_OutputChannel.h
- V4_OPA_OutputChannel.cpp

11.10 YbCtrl::V4_OPA_OutputChannelBipolar Class Reference

Implementation of a CtrlChannel for a bipolar output.

`#include <V4_OPA_OutputChannelBipolar.h>`

Inheritance diagram for YbCtrl::V4_OPA_OutputChannelBipolar:



Public Member Functions

- virtual CtrlChannelReturn setCurrentLimit (double val) override

  Limits the current.
- virtual void enableOutput () override

  Enable OPA output.
- virtual void disableOutput () override

  Disable OPA output.
- virtual CtrlChannelReturn isOverheated (bool &state) override

  Check for overheated.

- virtual operator bool () const override

  Is this object valid?
- virtual double getCurrentLimit () override

  Gets the current limit.
- virtual CtrlChannelReturn getCurrentLimit (double &out) override

  Gets the current limit.
- virtual double recallCtrl () override

  Read out the current output.
- CtrlChannelReturn getLimits (double &min, double &max) override

  Gets the output limits.
- virtual CtrlChannelReturn setLimits (double minimum, double maximum) final

  Set software limits on the max/min ctrl signal.
- virtual void setCtrl (double val) final

  Sets the control signal.
- void setContainingController (Controller *newController)

  Sets the containing Controller.
- Controller * getContainingController ()

  Gets the containing Controller.
- CtrlChannelReturn getContainingController (Controller *&out)

  Gets the containing controller.
- CtrlChannelReturn addConflictingChannel (CtrlChannel *newConflict)

  Adds a conflicting channel.
- CtrlChannelReturn closeConflictingControllers ()

  Closes conflicting controllers.

11.10.1 Detailed Description

Implementation of a CtrlChannel for a bipolar output.

Using both output channels simultaneously, allow for positive / negative voltages from -MAX_VOLTAGE to +MAX_VOLTAGE

This object manages output via both OPA548 / OPA549 s. Its most important method is setCtrl(double)

11.10.2 Member Function Documentation

11.10.2.1 CtrlChannelReturn YbCtrl::CtrlChannel::addConflictingChannel (CtrlChannel * *newConflict*) [inline], [inherited]

Adds a conflicting channel.

Adds a channel that is considered to be conflicting with this one. I.e. this channel and the conflicting one should not be simultaneously controlled.

This is useful e.g. for bipolar vs. single-sided channels which use the same outputs.

Up to 2 channels can be added using this function. Any Controllers associated with these channels can be closed with closeConflictingControllers

Returns

Error code

11.10.2.2 CtrlChannelReturn YbCtrl::CtrlChannel::closeConflictingControllers ( ) [inherited]

Closes conflicting controllers.

Close any Controllers that are managing either this channel or any conflicting ones. Conflicting channels are identified by adding pointers to them with addConflictingChannel.

Note

Similarily to setCtrl() vs writeCtrl(), this is the public interface which is defined by the base class. The derived classes will overwrite the private pure virtual member writeLimits() which is called by this function and which will actually set the limits.

Returns

Error code

11.10.2.3 Controller* YbCtrl::CtrlChannel::getContainingController ( ) [inline], [inherited]

Gets the containing Controller.

Returns

The containing controller. NULL if none present.

11.10.2.4 CtrlChannelReturn YbCtrl::CtrlChannel::getContainingController (Controller *& *out*) [inline], [inherited]

Gets the containing controller.

Parameters

out	*out*	The containing Controller

Returns

Error code

11.10.2.5 virtual double YbCtrl::V4_OPA_OutputChannel::getCurrentLimit ( ) [inline], [override], [virtual], [inherited]

Gets the current limit.

Gets the current limit. Value in amps

Returns

The current limit in amps. -999 if not implemented

Reimplemented from YbCtrl::CtrlChannel.

11.10.2.6 virtual CtrlChannelReturn YbCtrl::V4_OPA_OutputChannel::getCurrentLimit (double & *out*) [inline], [override], [virtual], [inherited]

Gets the current limit.

Gets the current limit and stores it in out. Value in amps

Parameters

out	*out*	The current limit in amps

Returns

Error code

Reimplemented from YbCtrl::CtrlChannel.

11.10.2.7 CtrlChannelReturn YbCtrl::V4_OPA_OutputChannel::getLimits (double & *min,* double & *max*) [inline], [override], [virtual], [inherited]

Gets the output limits.

Store the output limits in the passed references.

Parameters

out	*min*	The minimum
out	*max*	The maximum

Returns

Error code

Implements YbCtrl::CtrlChannel.

11.10.2.8 CtrlChannelReturn YbCtrl::V4_OPA_OutputChannelBipolar::isOverheated (bool & *state*) [override], [virtual]

Check for overheated.

Check if this channel is overheated

Parameters

out	*state*	True if overheated, false otherwise

Returns

Error return

Reimplemented from YbCtrl::V4_OPA_OutputChannel.

11.10.2.9 virtual YbCtrl::V4_OPA_OutputChannel::operator bool ( ) const [inline], [explicit], [override], [virtual], [inherited]

Is this object valid?

Return true if this object has been constucted with valid parameters

Implements YbCtrl::CtrlChannel.

11.10.2.10 virtual double YbCtrl::V4_OPA_OutputChannel::recallCtrl ( ) [inline], [override], [virtual], [inherited]

Read out the current output.

Read out the current output. Values from -1 to 1.

Returns

Current ctrl level

Implements YbCtrl::CtrlChannel.

11.10.2.11 void YbCtrl::CtrlChannel::setContainingController (Controller * *newController*) [inline], [inherited]

Sets the containing Controller.

Set this object's managing Controller to the given target

Parameters

newController	The new managing Controller

11.10.2.12 void YbCtrl::CtrlChannel::setCtrl (double *val*) [final], [virtual], [inherited]

Sets the control signal.

Set the control signal to the given value. Also, if this channel is managed by a Controller, inform that Controller's Algorithm of the updated output level

Note

This method is declared in an external object file. This is necessary because, at the point of including this header file, the Controller object has not yet been fully defined. Since setCtrl() uses methods in Controller, it cannot be compiled until Controller is fully defined. Therefore the code must be in a .cpp file, to be compiled later after all the headers are resolved.

See the documentation for setLimits for an explaination as to why this structure is needed

Parameters

val	The value, from -1 to +1

11.10.2.13 CtrlChannelReturn YbCtrl::V4_OPA_OutputChannelBipolar::setCurrentLimit (double *val*) [override], [virtual]

Limits the current.

If implemented, limit the current to the given value.

N.B. this method DOES NOT use -1 -> +1 notation; the input is in amps.

Parameters

in	*val*	The current limit in Amps

Returns

Error code

Reimplemented from YbCtrl::V4_OPA_OutputChannel.

11.10.2.14 CtrlChannelReturn YbCtrl::CtrlChannel::setLimits (double *minimum,* double *maximum*) [final], [virtual], [inherited]

Set software limits on the max/min ctrl signal.

Also, if this channel is managed by a Controller, inform that Controller's Algorithm of the new limits

Note

This method is defined in an external object file. This is necessary because, at the point of including this header file, the Controller object has not yet been fully defined. Since setCtrl() uses methods in Controller, it cannot be compiled until Controller is fully defined. Therefore the code must be in a .cpp file, to be compiled later after all the headers are resolved.
Similarily to setCtrl() vs writeCtrl(), this is the public interface which is defined by the base class. The derived classes will overwrite the private pure virtual member writeLimits() which is called by this function and which will actually set the limits.

Parameters

in	*minimum*	The new minimum
in	*maximum*	The new maximum

Returns

Error status

The documentation for this class was generated from the following files:

- V4_OPA_OutputChannelBipolar.h
- V4_OPA_OutputChannelBipolar.cpp

12 File Documentation

12.1 arduino-pin-toggler/pinToggler.h File Reference

Contains all the code for the arduino-pin-toggler library.

Classes

- class pinToggler< numPins >

  Class for toggling pins.

Macros

- #define PRESCALER 1024

  The prescaler for TIMER1.
- #define FLASH_FREQ_HZ 8

  How often the ISR will trigger.

Enumerations

12.1.1 Detailed Description

Contains all the code for the arduino-pin-toggler library.

12.1.2 Macro Definition Documentation

12.1.2.1 #define FLASH_FREQ_HZ 8

How often the ISR will trigger.

This defines the max toggle rate. In combination with the FLASHRATE chosen with pinToggler::setFlashRate, this determines the rate at which the pins will toggle.

12.1.2.2 #define PRESCALER 1024

The prescaler for TIMER1.

This value is used to calculate the correct value to start TIMER1 on, given this prescaler factor.

This does not need to be changed unless you need particularly fast flash rates.

Specifically, if your application requires `16000000 / PRESCALER / FLASH_FREQ_HZ >= 65536` you will need to alter the prescaler value both here and where it is set in the private setupSingleton() method.

12.1.3 Enumeration Type Documentation

12.1.3.1 enum FLASHRATE

Flash rate options.

These rates are used as parameters to the setFlashRate method.

In combination with FLASH_FREQ_HZ, these set the flash rate of an LED.

OFF and ON allow you to disable flashing, leaving the LED either on or off.

Enumerator

ON Always on

OFF Always off

SLOW Flash at FLASH_FREQ_HZ / 8

MEDIUM Flash at FLASH_FREQ_HZ / 2

FAST Flash at FLASH_FREQ_HZ / 4

MAX Flash at FLASH_FREQ_HZ

12.2 CommandDefinitions.h File Reference

Defines all the commands that the device listens for.

```
#include "CommandHandler\CommandHandler.h"
```

Functions

- template<size_t size>
  CommandHandlerReturn registerCommands (CommandHandler< size > *h)

  Register the commands.

12.2.1 Detailed Description

Defines all the commands that the device listens for.

This file contains definitions of all the commands that can be issued to the device.

Command processing is done via the CommandHandler class which has its own documentation.

All functions to be called by CommandHandler take exactly the same form: they return void and take a const ParameterLookup object as an argument. This object dispenses c strings as the params, e.g. `params[1]` is the first parameter, etc. (`params[0]` is the command itself). See the definition of #commandFunction for the required spec.

All commands are parsed and stored using a hash function for memory efficiency, and are case-insensitive.

The following is a summary of the available commands. If query form of a command with different functionality exists is it listed separately. If it's identical, this is shown as e.g. `*TST(?)`. If no query / non-query form exists, it is not shown in this table; calling it will result in an error.

Command	Description	Params	Output
∗TST	Test comms	0	"Loud and clear!"
∗TST?	Test comms	0	"Query received"
∗IDN(?)	Identify	0	"ARDUINO PID"
∗VER(?)	Output version string	0	e.g. "v4.1"
∗RST	Reset the device (N.B. does not clear EEPROM)	0	-
STOR	Store a command in EEPROM to be executed on startup	"command to be called on startup"	"Done"
		Multiple commands can be stored by separating them with a ';'	"#StoreCommand error: command too long"
RETR	Retrieve any stored commands from EEPROM	0	Stored command or "None"
WIPE	Erase any stored commands in EEPROM	0	"Done"
ERRO(?)	Query the error signal on given channel.	[channel = 1t,2t,1v,2v] for signals 1 or 2 from thermistor input or voltage input	Error signal float
			· If thermistor reading, voltage read from -2.5 -] +2.5
	If this channel is being controlled, return the previously measured value. Else, measure it now and then return.		· If voltage reading, return voltage from -5 -] +5 V
			e.g. "-0.00151"
STAT(?)	Return a string describing the status of the controller	0	t.b.c.
CONT	Set the control signal.	[output channel = 1, 2, 3, 4, BPA, BPB] [voltage = 0 - max for single, -max - +max for BP]	e.g. "#SetControl BP 2.500"
	N.B. If this is called during a lock this will set the control signal to the given value, but this may subsequently be changed by the locking algorithm		
CONT?	Query the control signal	[output channel = 1, 2, 3, 4, BPA, BPB]	e.g. "2.500"
THER?	Check the thermal state of the given channel. For the bipolar channel, return "BAD" if either OPA is overheated	[output channel = 1, 2, 3, 4, BPA, BPB]	e.g. "GOOD" / "BAD"
LIMI	Set software limits on the output voltage	[output channel = 1, 2, 3, 4, BPA, BPB]	e.g. "#SetLimits 1 0.000 3.↩ 000"
		[min voltage]	
		[max voltage]	
LIMI?	Query limits	[output channel = 1, 2, 3, 4, BPA, BPB]	e.g. "0.000 3.000"
THRE	Set thresholds at which the LEDs will start flashing.	[thresholdHigh] [threshold↩ Low]	e.g. "#setThresholds 0.1 0.01"

Command	Description	Params	Output
	LEDs will flash fast when the absolute error signal is] thresholdHigh, slow when it's between thresholdHigh and thresholdLow and light solidly when it's [thresholdLow		
THRE?	Query current LED thresholds	0	e.g. "0.1, 0.01"
CLIM	Set hardware limits on the output current	[output channel = 1, 2, 3, 4, BPA, BPB]	e.g. "#SetCurrentLimit 1 1.↩ 000"
		[max current in amps]	
CLIM?	Get current hardware on output current	[output channel = 1, 2, 3, 4, BPA, BPB]	e.g. "1.000"
SETP	Set setpoint for lock	[output channel = 1, 2, 3, 4, BPA, BPB]	· If no lock running on this channel: "#SetSetpoint error: no lock running on channel xxx"
			· Else, e.g. "#SetSetpoint 1 0.000"
SETP?	Query lock setpoint	[output channel = 1, 2, 3, 4, BPA, BPB]	· If no lock running on this channel: "#SetSetpoint error: no lock running on channel xxx"
			· Else, e.g. "0.000"
LOCK	Start PID lock	[input channel = 1t,2t,1v,2v]	e.g. "#StartLock 1t BP 0.000 1 0.5 0 10"
		[output channel = 1, 2, 3, 4, BPA, BPB]	
		[setpoint]	
		[Kp] [Ki] [Kd] [N=10]	
VOLT	Output a constant voltage	[output channel = 1, 2, 3, 4, BPA, BPB] [voltage = 0 - max for single, -max - +max for BP]	e.g. "#ConstVoltage 1 2.500"
	N.B. Unlike "CONT", this function will output a constant voltage, disabling any PID lock that was previously running on this output channel		

12.2.2 Function Documentation

12.2.2.1 template<size_t size> CommandHandlerReturn registerCommands (CommandHandler< size > * *h*)

Register the commands.

Register the commandFunction functions with the CommandHandler object, defining:

- The command used to call them
- The number of parameters they must be called with

Parameters

h	Pointer to a CommandHandler object

Template Parameters

size	Number of commands this CommandHandler can contain. This will be inferred by the number specified in its definition.

Returns

A CommandHandlerReturn enum detailing any errors that occured during the execution of this method.

12.3 CommandHandler/CommandHandler.h File Reference

Contains all the code for the Arduino CommandHandler library.

```
#include <Arduino.h>
#include "Microprocessor_Debugging\debugging_disable.h"
#include <EEPROM.h>
```

12.3.1 Detailed Description

Contains all the code for the Arduino CommandHandler library.

Todo Write the CommandHandler documentation

12.4 Pins.h File Reference

Hardware limits and pins.

```
#include "Pins_4chan.h"
```

12.4.1 Detailed Description

Hardware limits and pins.

This file allows the user to select between pin setups for the 2 channel or 4 channel board.

12.5 Pins_2chan.h File Reference

Hardware limits and pins.

```
#include <Arduino.h>
```

Variables

- const uint8_t ADC_CS = A3
- const uint8_t ADC_START = 2
- const uint8_t ADC_DRDY = A2
- const uint8_t ADC_THERM1 = 9
- const bool ADC_THERM1_HIGHRES = false
- const uint8_t ADC_THERM2 = 8
- const bool ADC_THERM2_HIGHRES = false
- const uint8_t ADC_REF = 10
- const uint8_t ADC_VOLT1_P = 6
- const uint8_t ADC_VOLT1_N = 7
- const bool ADC_VOLT1_HIGHRES = false
- const uint8_t ADC_VOLT2_P = 4
- const uint8_t ADC_VOLT2_N = 5
- const bool ADC_VOLT2_HIGHRES = false
- const uint8_t ADC_TMP = 11
- const uint8_t ADC_POW = 12
- const uint8_t DAC_CS = 9
- const uint8_t OPA_ES1 = A0
- const uint8_t OPA_ES2 = A1
- const bool OPA_1_IS_548 = true
- const bool OPA_2_IS_548 = true
- const uint8_t VPLUS_CHAN_1 = 1
- const uint8_t VPLUS_CHAN_2 = 0
- const uint8_t VLIM_CHAN_1 = 2
- const uint8_t VLIM_CHAN_2 = 3
- double MAX_VOLTAGE
- const double MAX_INITIAL_CURRENT = 2.0
- const double OPA_R1 = 50
- const double OPA_R2 = 200
- const double OPA_GAIN
- const uint8_t LED_1 = A5
- const uint8_t LED_2 = A4

12.5.1 Detailed Description

Hardware limits and pins.

This file contains pin numbers and hard-coded limits specific to the 2 channel board

OPA_GAIN is the gain of the OPA compared to the DAC's output voltage of 2.5V. This is set by resistors on the board, calculated according to the values of OPA_R1 and OPA_R2. It is currently assumed that both OPAs have the same gain.

Todo Add option for user to configure different hardware gains on the two OPAs.

12.5.2 Variable Documentation

12.5.2.1 const uint8_t ADC_CS = A3

Chip select pin of the ADC on the ATMega

12.5.2.2 const uint8_t ADC_DRDY = A2

DRDY pin of the ADC on the ATMega

12.5.2.3 const uint8_t ADC_POW = 12

ADC channel for chip power level measurement

12.5.2.4 const uint8_t ADC_REF = 10

ADC channel for common thermistor reference input

12.5.2.5 const uint8_t ADC_START = 2

∼START pin of the ADC on the ATMega

12.5.2.6 const uint8_t ADC_THERM1 = 9

ADC channel for thermistor 1 input

12.5.2.7 const bool ADC_THERM1_HIGHRES = false

Should thermistor 1 be a high-res measurement?

12.5.2.8 const uint8_t ADC_THERM2 = 8

ADC channel for thermistor 2 input

12.5.2.9 const bool ADC_THERM2_HIGHRES = false

Should thermistor 2 be a high-res measurement?

12.5.2.10 const uint8_t ADC_TMP = 11

ADC channel for chip temperature measurement

12.5.2.11 const bool ADC_VOLT1_HIGHRES = false

Should voltage 1 be a high-res measurement?

12.5.2.12 const uint8_t ADC_VOLT1_N = 7

ADC channel for arbitary voltage negative input 1

12.5.2.13 const uint8_t ADC_VOLT1_P = 6

ADC channel for arbitary voltage positive input 1

12.5.2.14 const bool ADC_VOLT2_HIGHRES = false

Should voltage 2 be a high-res measurement?

12.5.2.15 const uint8_t ADC_VOLT2_N = 5

ADC channel for arbitary voltage negative input 2

12.5.2.16 const uint8_t ADC_VOLT2_P = 4

ADC channel for arbitary voltage positive input 2

12.5.2.17 const uint8_t DAC_CS = 9

Chip select pin of the DAC on the ATMega

12.5.2.18 const uint8_t LED_1 = A5

ATMega pin for LED 1, Arduino labelling

12.5.2.19 const uint8_t LED_2 = A4

ATMega pin for LED 2, Arduino labelling

12.5.2.20 const double MAX_INITIAL_CURRENT = 2.0

Maximum current that the OPAs will be limited to on startup

12.5.2.21 double MAX_VOLTAGE

Maximum voltage for the OPAs to output. Calculated in setup()

12.5.2.22 const bool OPA_1_IS_548 = true

Is OPA 1 an OPA548 (instead of an OPA549)?

12.5.2.23 const bool OPA_2_IS_548 = true

Is OPA 2 an OPA548 (instead of an OPA549)?

12.5.2.24 const uint8_t OPA_ES1 = A0

E/S pin for first OPA

12.5.2.25 const uint8_t OPA_ES2 = A1

E/S pin for second OPA

12.5.2.26 const double OPA_GAIN

Initial value:

```
=
            (OPA_R1 + OPA_R2) / OPA_R1
```

DAC -> OPA gain, set by on-board resistors.

12.5.2.27 const double OPA_R1 = 50

OPA gain resistor 1

12.5.2.28 const double OPA_R2 = 200

OPA gain resistor 2

12.5.2.29 const uint8_t VLIM_CHAN_1 = 2

DAC channel for first OPA's Vlim input

12.5.2.30 const uint8_t VLIM_CHAN_2 = 3

DAC channel for second OPA's Vlim input

12.5.2.31 const uint8_t VPLUS_CHAN_1 = 1

DAC channel for first OPA's V+ input

12.5.2.32 const uint8_t VPLUS_CHAN_2 = 0

DAC channel for second OPA's V+ input

12.6 Pins_4chan.h File Reference

Hardware limits and pins.

```
#include <Arduino.h>
```

Variables

- const uint8_t ADC_CS = A3
- const uint8_t ADC_START = 2
- const uint8_t ADC_DRDY = A2
- const uint8_t ADC_THERM1 = 9
- const bool ADC_THERM1_HIGHRES = false
- const uint8_t ADC_THERM2 = 8
- const bool ADC_THERM2_HIGHRES = false
- const uint8_t ADC_REF = 10
- const uint8_t ADC_TMP = 11
- const uint8_t ADC_POW = 12
- const uint8_t DAC_CS = 10
- const uint8_t OPA_ES1 = A0
- const uint8_t OPA_ES2 = A1
- const bool OPA_1_IS_548 = true
- const bool OPA_2_IS_548 = true
- const uint8_t DAC_CS_Alt = 9
- const uint8_t OPA_ES3 = 7
- const uint8_t OPA_ES4 = 8
- const bool OPA_3_IS_548 = true
- const bool OPA_4_IS_548 = true
- const uint8_t VPLUS_CHAN_1 = 0
- const uint8_t VPLUS_CHAN_2 = 1
- const uint8_t VLIM_CHAN_1 = 3
- const uint8_t VLIM_CHAN_2 = 2
- const uint8_t VPLUS_CHAN_3 = 0
- const uint8_t VPLUS_CHAN_4 = 1
- const uint8_t VLIM_CHAN_3 = 2
- const uint8_t VLIM_CHAN_4 = 3
- double MAX_VOLTAGE
- const double MAX_INITIAL_CURRENT = 2.0
- const double OPA_R1 = 50
- const double OPA_R2 = 200
- const double OPA_GAIN
- const uint8_t LED_1 = A5
- const uint8_t LED_2 = A4
- const uint8_t DISABLE_SERIAL_CTRL = A6
- const uint8_t DIVIDED_SUPPLY_VOLTAGE = A7
- const double DIVIDED_SUPPLY_FACTOR = 11.0

12.6.1 Detailed Description

Hardware limits and pins.

This file contains pin numbers and hard-coded limits specific to the 4 channel board

OPA_GAIN is the gain of the OPA compared to the DAC's output voltage of 2.5V. This is set by resistors on the board, calculated according to the values of OPA_R1 and OPA_R2. It is currently assumed that both OPAs have the same gain.

Todo Add option for user to configure different hardware gains on the two OPAs.

12.6.2 Variable Documentation

12.6.2.1 const uint8_t ADC_CS = A3

Chip select pin of the ADC on the ATMega

12.6.2.2 const uint8_t ADC_DRDY = A2

DRDY pin of the ADC on the ATMega

12.6.2.3 const uint8_t ADC_POW = 12

ADC channel for chip power level measurement

12.6.2.4 const uint8_t ADC_REF = 10

ADC channel for common thermistor reference input

12.6.2.5 const uint8_t ADC_START = 2

∼START pin of the ADC on the ATMega

12.6.2.6 const uint8_t ADC_THERM1 = 9

ADC channel for thermistor 1 input

12.6.2.7 const bool ADC_THERM1_HIGHRES = false

Should thermistor 1 be a high-res measurement?

12.6.2.8 const uint8_t ADC_THERM2 = 8

ADC channel for thermistor 2 input

12.6.2.9 const bool ADC_THERM2_HIGHRES = false

Should thermistor 2 be a high-res measurement?

12.6.2.10 const uint8_t ADC_TMP = 11

ADC channel for chip temperature measurement

12.6.2.11 const uint8_t DAC_CS = 10

Chip select pin of the DAC on the ATMega

12.6.2.12 const uint8_t DAC_CS_Alt = 9

Chip select pin of the DAC on the ATMega

12.6.2.13 const uint8_t DISABLE_SERIAL_CTRL = A6

ATMega pin for disabling serial control: 0 or 5V

12.6.2.14 const double DIVIDED_SUPPLY_FACTOR = 11.0

Factor by which the supply voltage has been divided

12.6.2.15 const uint8_t DIVIDED_SUPPLY_VOLTAGE = A7

ATMega pin for reading supply voltage: analog voltage

12.6.2.16 const uint8_t LED_1 = A5

ATMega pin for LED 1, Arduino labelling

12.6.2.17 const uint8_t LED_2 = A4

ATMega pin for LED 2, Arduino labelling

12.6.2.18 const double MAX_INITIAL_CURRENT = 2.0

Maximum current that the OPAs will be limited to on startup

12.6.2.19 double MAX_VOLTAGE

Maximum voltage for the OPAs to output. Calculated in setup()

12.6.2.20 const bool OPA_1_IS_548 = true

Is OPA 1 an OPA548 (instead of an OPA549)?

12.6.2.21 const bool OPA_2_IS_548 = true

Is OPA 2 an OPA548 (instead of an OPA549)?

12.6.2.22 const bool OPA_3_IS_548 = true

Is OPA 1 an OPA548 (instead of an OPA549)?

12.6.2.23 const bool OPA_4_IS_548 = true

Is OPA 2 an OPA548 (instead of an OPA549)?

12.6.2.24 const uint8_t OPA_ES1 = A0

E/S pin for first OPA

12.6.2.25 const uint8_t OPA_ES2 = A1

E/S pin for second OPA

12.6.2.26 const uint8_t OPA_ES3 = 7

E/S pin for first OPA

12.6.2.27 const uint8_t OPA_ES4 = 8

E/S pin for second OPA

12.6.2.28 const double OPA_GAIN

Initial value:

```
=
            (OPA_R1 + OPA_R2) / OPA_R1
```

DAC -> OPA gain, set by on-board resistors.

12.6.2.29 const double OPA_R1 = 50

OPA gain resistor 1

12.6.2.30 const double OPA_R2 = 200

OPA gain resistor 2

12.6.2.31 const uint8_t VLIM_CHAN_1 = 3

DAC channel for second OPA's Vlim input

12.6.2.32 const uint8_t VLIM_CHAN_2 = 2

DAC channel for first OPA's Vlim input

12.6.2.33 const uint8_t VLIM_CHAN_3 = 2

DAC channel for second OPA's Vlim input

12.6.2.34 const uint8_t VLIM_CHAN_4 = 3

DAC channel for first OPA's Vlim input

12.6.2.35 const uint8_t VPLUS_CHAN_1 = 0

DAC channel for second OPA's V+ input

12.6.2.36 const uint8_t VPLUS_CHAN_2 = 1

DAC channel for first OPA's V+ input

12.6.2.37 const uint8_t VPLUS_CHAN_3 = 0

DAC channel for second OPA's V+ input

12.6.2.38 const uint8_t VPLUS_CHAN_4 = 1

DAC channel for first OPA's V+ input

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