

# Features

- Interfaces [ESP32-S3-DevKitC-1](#)
- 24 bit ADC
- RTD temperature sensing
  - Also used for compensation
- pH interface
- EC interface
- Backup connectors
  - i2c screen
- 3 external DS18B20 sensors
- PCB mounted temperature sensor
- 2 RJ45 connections to control 2x4 pumps
- Legacy connections to connect old hardware in case of partial success

## Circuit Description

### General Points

- A lot of 0 ohm resistors have been used to cut off the circuit at different points
  - Some of these may not make much sense as I have kept a lot of the 0 ohm resistors from the designs I referenced
  - I also have a lot to be able to write and test the firmware progressively (ie: one part of the circuit a time)
- Lots of random test points -> For debugging but also for observation
  - Some are hook like for use with the scope

### ICs Overview

| Part No.                   | Descriptive Name      | Rough Unit Price | Usage                                      | I2C Addr  | Sheet                |
|----------------------------|-----------------------|------------------|--------------------------------------------|-----------|----------------------|
| <a href="#">PCA9555PWJ</a> | 16 bit IO expander    | 1.64\$           | Chip select management, pump on/off signal | 0x40/0x41 | Controller Interface |
| <a href="#">TMP1075DR</a>  | Board mounted digital | 0.7\$            | Housing temp, placed close to              | 0x16      | Misc IO              |

| Part No.                            | Descriptive Name                               | Rough Unit Price | Usage                                                                                 | I2C Addr | Sheet                  |
|-------------------------------------|------------------------------------------------|------------------|---------------------------------------------------------------------------------------|----------|------------------------|
|                                     | thermometer                                    |                  | raspberry pi (worst heat spot in the case normally)                                   |          |                        |
| <a href="#">AD7124 - 24 bit ADC</a> | 24 bit ADC                                     | 15\$             | ADC                                                                                   | SPI      | Analog Interfacing     |
| <a href="#">ESP32-S3-WROOM-1</a>    | ESP32-S3 MCU with Bluetooth and Wifi           | 4\$              | Micro controller. v0.1 of the mainboard will use a <a href="#">ESP32-S3-DevKitC-1</a> |          | Controller Interfacing |
| <a href="#">ADG1608BRUZ</a>         | 8 Channel multiplexor                          | 12\$             | Used for gain resistance switching                                                    |          | EC Interfacing         |
| <a href="#">AD5683RBMZ</a>          | 16 bit DAC                                     | 9.6\$            | EC conductivity cell excitation current                                               |          | EC Interfacing         |
| <a href="#">AD8220BRMZ</a>          | JFET Input instrumentation amplifier           | 10.8\$           | EC Signal amplification                                                               |          | EC Interfacing         |
| <a href="#">ADG884BRMZ</a>          | 0.5Ω dual SPDT audio switch                    | 2.9\$            | Conductivity cell switching for bipolar excitation current                            |          | EC Interfacing         |
| <a href="#">SHT30-DIS-B2.5KS</a>    | Board mounted digital humidity and temperature | 2.53\$           | Humidity and temperature sensing                                                      | 0x44     | Misc IO                |

## Sheet by Sheet Notes

### Controller Interfacing

- Interfaces [ESP32-S3-DevKitC-1](#)
  - Powered through 5V on the 5V pin
- I2C 16 channel IO Expander -> [PCA9555PWJ](#)
  - Dispensing pump on/off signal -> **Disp1 and Disp2 bus**
  - SPI chip selects
  - 4 button state reading

- I2C 4.7K pullup to 3.3V
- [Hook test points](#) for I2C, SPI, 5V, GND -> for use with scope
- **J1** socket to hook up perf board pcb that contains the buttons for the devices interface
  - Signal pull downs included on mainboard
- Connections to *Legacy Backup Connections* sheet
  - SPI
    - Has one spi "expansion port" in case we need to easily connect an additional SPI device
  - I2C
  - **VCC\_EC** is connected to the IO expander
    - We turn it on only when needed in order to avoid interference issues with the pH probe

## Legacy Backup Connections

These connections are to allow us to connect the old sensor interfaces we used up to this point in case any part of the circuit does not work.

## Analog Interfacing

This sheet contains the power supply and ADC used to interface :

- An RTD temperature sensor
  - pH sensor
  - EC sensor
- The ec interface is based on the [CN0411 evaluation board by Analog Devices](#), the pH interface is based on the [Analog Devices CN0326 evaluation board](#).

## AD7124 ADC

- SPI controlled
- Way **overkill** most likely, I'm interested in seeing if we can get as good readings as the ones advertised in the circuit notes.
- Replaces ADC used in **CN0346 pH evaluation board**
- Decoupled according to datasheet
  - REGCAPA, REGCAPD
  - AVDD, IOVDD
- **Uses external reference turned on by default**
  - **External reference 1** (REFIN1- and REFIN1+) -> RTD temperature sensing
  - **External reference 2** set to **AD5683 reference output**

- Gpio pins 1 to 3 used to drive **gain resistor multiplexer** (*EC Interfacing*)
- RTD Sensing
  - Pin 9 used for the excitation current
  - **Uses external reference 1**
- EC Sensing
  - R20S and R200S are connected to perform a calibration measurement to compensate for the multiplexers on resistance
    - We most likely aren't interested in this low range but are keeping it for testing / practice purposes
  - VRD is the output of the DAC's reference 2.5V voltage
- Not much to say about the pH interfacing at the ADC level
- Excitation current fed through precision 5K resistor R9 and in an analog input
  - To perform calibration of internal excitation current generator
  - This comes from the pH interface development board, not sure how needed it actually is, we'll find out
  - Using Ohm's law

## ADP7102 LDO

- **3.3V variant**
- 350mA self resetable fuse overcurrent protection
- Zener diode for ESD protection **I think ?**
- EMI filtering on LDO input
- Decoupled output according to datasheet
- 66 $\Omega$  resistor for power on LED -> LED rated at 30mA at 2V
- Digital and Analog power isolated by ferrite bead
  - Frankly I'm just trusting the design for this part and have yet to go down that rabbit hole

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## EC Interfacing

- **AD5683 DAC**
  - The DAC is the voltage source for the conductivity cell, by default at startup at **400mV**.
  - Decoupled according to datasheet
- VDAC fed through **gain resistor** using **ADG1608BRUZ** multiplexer
  - results in VPROBE

- VPROBE is switched into a bipolar excitation current using **ADG884BRMZ** switch and **PWM1**
- Voltage drop accross the sample and hold circuit supposedly **23nV**
  - I haven't put much effort into understanding the math here and mostly trust the design / have kept it unchanged
- Conductivity cell connections
  - Jumpers to make signal go through precision resistors for error calibration in the **200Ω** and **20Ω** range
  - BNC Connector (will be the main connection used)
  - Screw terminal backup
- **J7** provides the ability for a system wide 0 scale calibration
- **AD8220** instrument amplifier -> **amplifies by 10**
- Sample and hold circuit
  - This is needed to my understanding for the following :
    - To get a stable peak voltage we can measure with the ADC
    - To avoid loading the conductivity cell
      - Unsure about this one

## Calculating the conductivity

- Theoretically 23nV Vdrop accross sample and hold circuit
- Assumes negligeable electrolysis -> **Obeys ohm's law**
  - $R = \frac{V}{I}$
- The conductance is the reciprocal of the resistance which gives us :
  - $G = \frac{1}{R} = \frac{I}{V}$
  - Peak to peak voltage can be obtained with
 
$$V_{cond, pp} = 0.1 \cdot V_{out1} + 0.1 \cdot V_{out2}$$
    - The 0.1 cancels out the amplification provided by the **AD8220 instrument amplifier**
- The current  $I$  accross the conductivity cell can be derived from **ohm's law** (I'm unsure about myself here):
  - $I_{cond} = \frac{2 \cdot V_{dac} - V_{cond}}{R_{gain}}$
  - This seems to be an application of ohm's law but I am unsure
  - Why is Vcond substracted to 2Vdac ? This would give us the **voltage drop** not the actual voltage
    - If I'm not mistaken, this is to get the voltage accross the conductivity cell in order to apply ohm's law to that part of the circuit

- ie:  $V_{dac}$  is the input, the sum of all the individual voltages accross a series circuit is = to the input voltage to that circuit. So the voltage accross the cell is  $V_{dac} - V_{cond}$  (which is actually the measured voltage then ?)
  - The conductivity can then be obtained my multiplying with the **cell constant K**
    - $Y = K \cdot G$
  - If I understand correctly, the conductance could **also be calculated by deriving it from the voltage divider formula.**
    - $V_{out} = V_{in} \cdot \frac{R2}{R1+R2}$
    - rearranges to  $R2 = \frac{R1 \cdot V_{out}}{V_{in} - V_{out}}$
    - $R2$  being the conductivity cells resistance, that would give us  $G = \frac{1}{R2}$
  - $R1$  serves as gain resistor to improve accuracy at various conductivity range
    - This is completely overkill for a hydroponics application I think
    - I want to try out the other conductivity ranges out of curiosity
      - Will require different probes
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## pH Interface

- Functioning of pH probe
  - **Two electrodes**, one **glass measuring electrode** and **one reference electrode**
  - The measuring electrode generates a voltage based on the solutions hydrogen activity
    - Then compared to
  - If solution **more acidic** -> potential increases
  - If solution **more basic** -> potential decreases
  - Bias voltage is only to avoid having a negative potential which the ADC can't read
- Typical pH probe voltage variation range -> +/- 414 mV to +/- 490 mV
- pH probe output is bipolar
  - Biased by 1.25V using the excitation current source of the **AD7124 ADC** set to 250uA and two 5K precision resistors for a voltage divider
- Excitation current calibration can be done using R8 precision resistor on the ADC sheet
- Passive low pass filters on both sides
  - Unclear why these are needed, hence the test points before and after
- Unsure why **R2** is there due to the already very high impedance of the op amp
  - I think for overcurrent protection maybe ?
- The read voltage (- the bias voltage) then just needs to be mapped to a calibrated curve in order to get the pH reading

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## Misc IO

- 3 DS18B20 temperature sensor ports -> interfaced using 3.5mm jack
  - Sounded convenient
  - Wired in **normal mode** (not parasitic power mode)
- **SHT30-DIS-B2.5KS** board mounted digital humidity and temperature sensor
  - Address 0x44
- Dispensing board RJ45s
  - These account for **two** dispensing boards
  - Each board has four active high connections + power and gnd
- USB C power
  - CC lines tied to gnd using 5.1k resistors for 5V up to 3A
  - Did not find any basic enough IC to check plugged power supply has required power capabilities

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## Points of uncertainty

### Schematic Uncertainties

- In general I am **unsure** about my **resistors choices** and the extent of their effect on the circuit. In the supplied BOM they use many different kinds
- Unsure about the **C2 filter** (replacement as the one used by analog devices was unavailable or discontinued)
- Is the TMP1075DR **properly decoupled** ? (tried following datasheet suggestions in section 11)
- Maybe there are ICs / components that can be **optimized between the EC and pH interface** ?
- LDO input voltage filter replacement am uncertain it's suitable
- **ESD protection needed ??**
- Can UART or USB be plugged in while the esp32 is powered by the 5V/GND pins ?
  - The concern being that the documentation says that the powering options are mutually exclusive and maybe UART would provide power
- Does the esp32 provide the 3V3 based off the 5V supply ?
- Will the pull up resistors on the i2c bus not be an issue if our other i2c devices also have their own onboard pullups ?

### ADC and LDO Uncertainties

- Should **REFIN1(+)** and **REFIN1(-)** be decoupled ? Mentioned on page 73 *Grounding and Decoupling*
- Is the default reference set to **REFIN2** or is that potentially an issue for us ?
  - *I don't think so*
- Is 350mA for the fuse too low ?
- LDO power on LED resistor correct value ?

## EC Interfacing Uncertainties

- Why is  $V_{cond,pp}$  subtracted to  $V_{dac}$  for the calculation of the current accross the conductivity cell ?
  - *Seems to be answered in EC Calculations section -> Needs to be checked*
  - **Does it make sense then that  $V_{cond}$  should maybe be called measured voltage as it is different from the actual applied voltage across the cell ?**
- **Can the EC also be calculated using the voltage divider formula ?** *More in the ec section of the sheet by sheet notes*
- **Are the pwm signals bad for noise ?**

## PCB Uncertainties

- Should I be concerned about the different physical sizes of capacitor I use ?

## Other questions

- Will we be able to have adequate calibration for the PT100 style thermistor of the ec interfacing section ?
- Ground loops ? The fuck is that
- I haven't taken the time to understand too much what was happening at the RTD interfacing level

## Other Uncertainties

- Seems the RTD temperature sensor will require calibrating **with specialized equipment we cannot reasonably get access to**