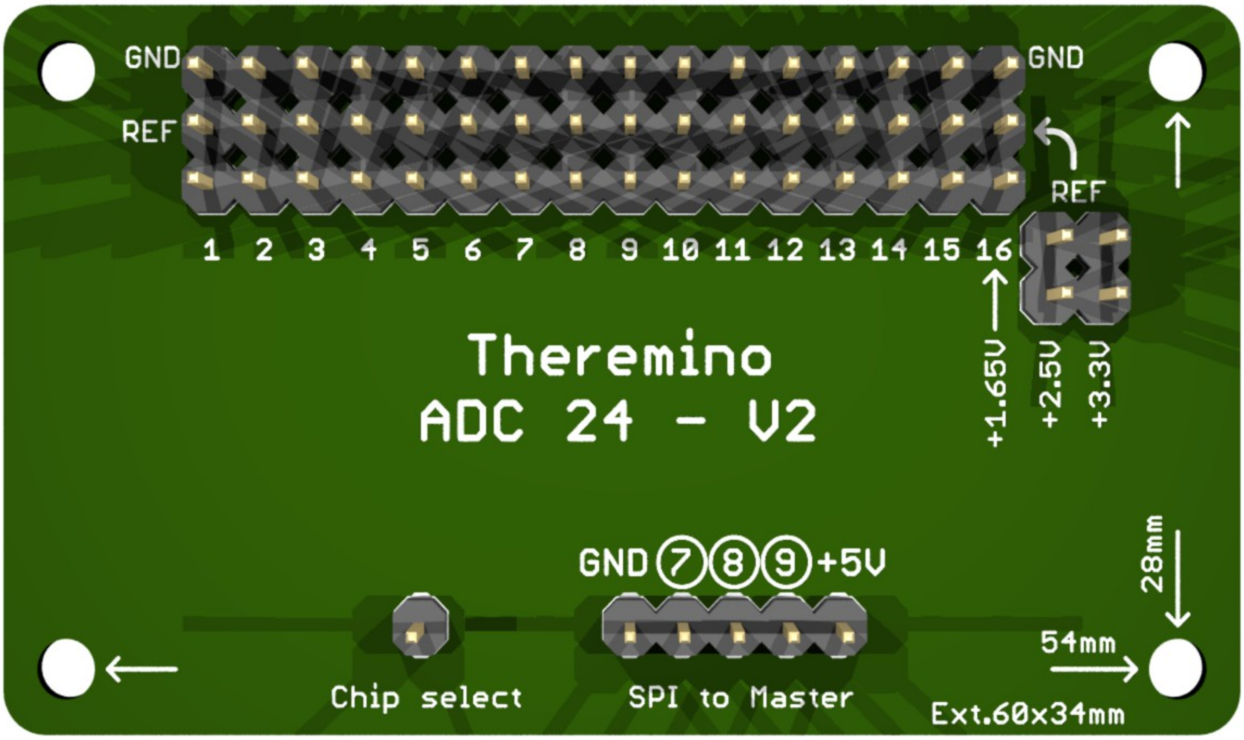
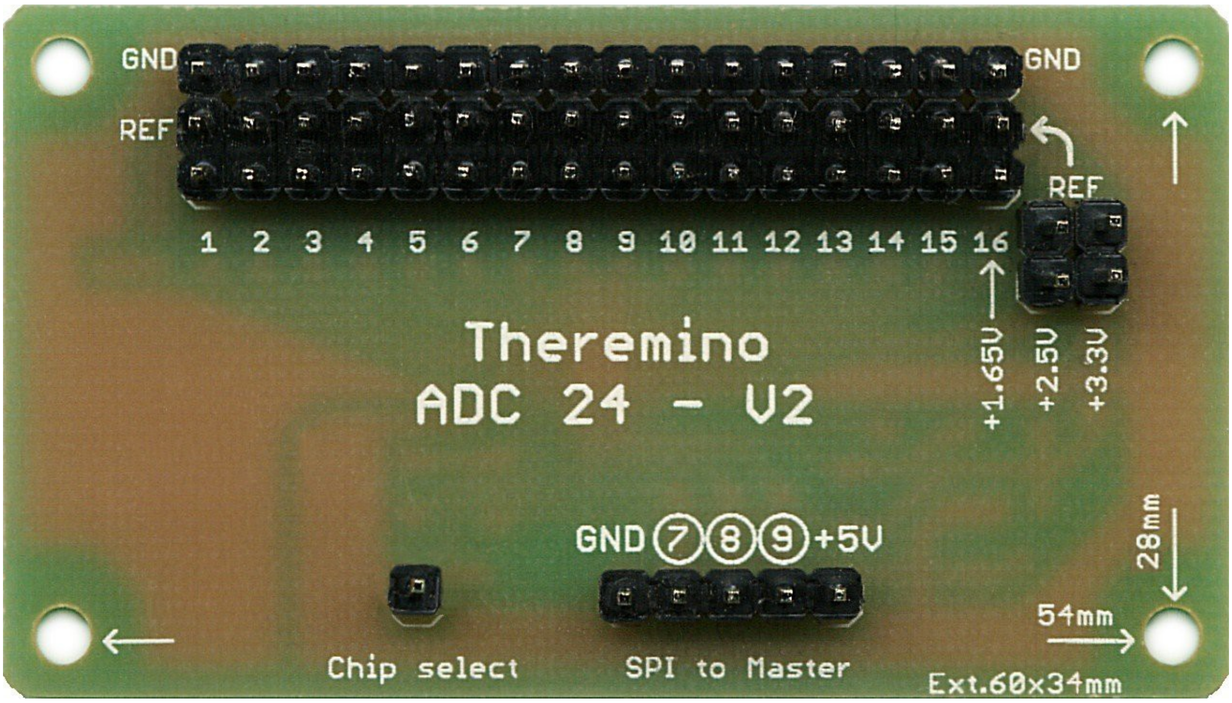
Theremino System



Theremino ADC 24

Main index

The Theremino Adc24 module



The Theremino Adc24 is based on the Analog Devices converter AD7124-8. It is a high performance Sigma Delta converter, designed in 2015, at the culmination of decades of experience in this field. In addition to low noise and high flexibility this ADC consumes very little current, about 900 micro amps.

The sampling rate is selectable in a very wide range (from 10 up to 19200 samples per second) and 8 levels of filtering are available, to choose the best compromise between noise reduction and response speed. The various input configurations, (differential, single-ended or pseudo) allow you to connect all kind of sensors.

Connectivity and modularity - The Adc24 is a module compatible with the Theremino System, which is inherently modular. This allows you to re-evaluate the equipment in time and change them at will, adding new modules and new features. Software, firmware, schematics and projects are completely free and open source.

Applications - The Theremino Adc24 is aimed at the detection and recording of low and medium frequency signals. Its flexibility and its signal/noise ratio are superior to any other similar instrument. For which it is the ideal tool for the recording of micro-tremors (HVSR) and earthquakes, but also of signals from other transducers such as: linear potentiometers for detecting displacements and fractures, load cells, analytical balances, pressure meters, sensors of flexion, photodiodes for low illuminations, magnetometers, micro-barometers, spectrum analyzers slot, thermocouples, pH meters, dataloggers, etc ...

Synchronization - If required, the synchronization with the UTC time is done with GPS receiver, connected via USB. The software that reads the ADC, also reads the GPS and combines the two data.

Hardware and firmware versions

*Warning: There are unapproved copies of our modules. These products differ mechanically and electrically by our projects and have a Copyright, so they are not really open. According to our rules are unreliable and poorly designed products, **see here**. So we will not provide updates and support for them. The only products manufactured according to our directions, can be found at: **store-ino** (Shenzhen, China), **eBay** (Maxtheremino) and, for small-scale construction non-profit, Alessio (**makers@theremino.com**).*

To have the Adc24 operational are required:

- A HAL application with version 6.6 (or following), can be download from ***This Page***.
- A master module with firmware 5.0 (or later), can be download from ***This Page***.

One should not get confused between the version of the Master and the Firmware. Currently (July 2016) the Master have version 4.0, but it is programmed with the firmware at version 5.0.

Even older versions of Master V3.0, and even those who had only 6 Pin and the prototypes of 2012 and 2013, can be programmed with the firmware 5.0 (with PicKit2, as shown in ***This Page***).

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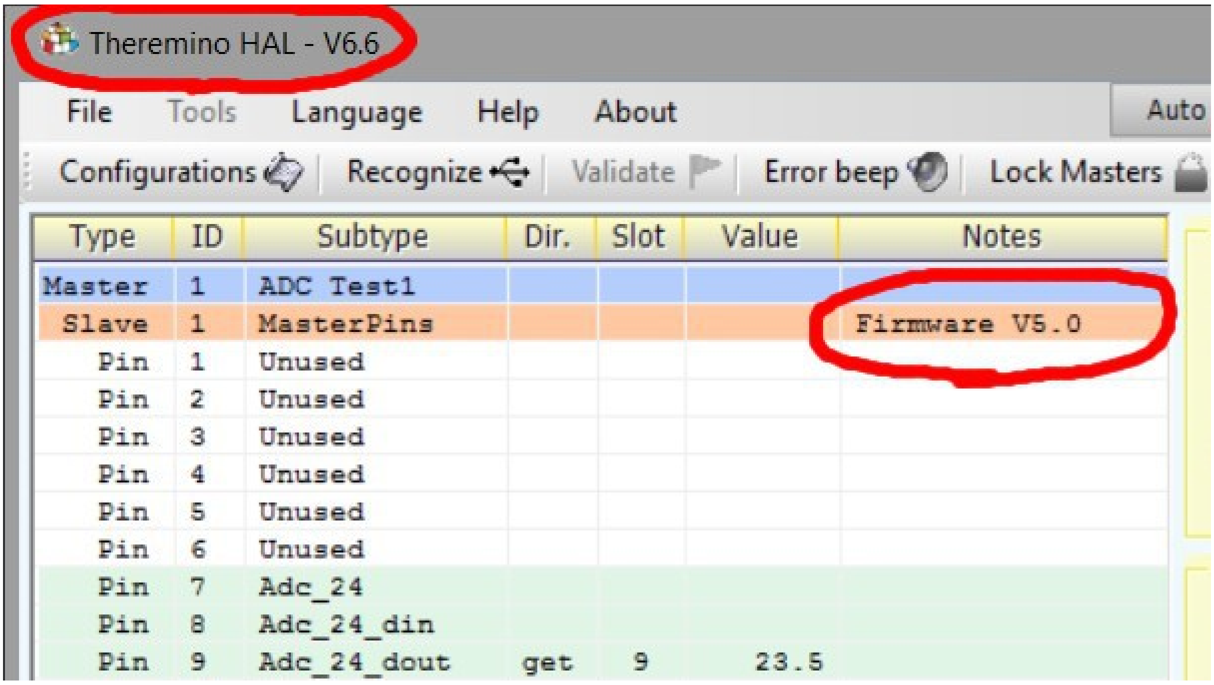
To check the version numbers, just start the HAL application and read its version (in the window title) and the firmware version of the single master (in every Master header row).



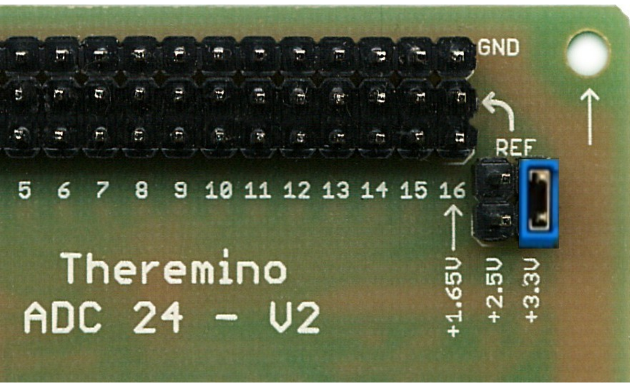
The firmware version appears only on the most recent versions of HAL. If you connect multiple master modules, the list will show the individual versions, the first line of each of them.

The PCB project of the Adc24 schemes, can be download from ***This Page***.

Jumper settings

The jumpers are used to send a supply voltage or bias on the center array of the Pins. The voltage cannot be taken before the jumpers, because otherwise it would not be linked to C8 and R19, which help to reduce noise (see the ***wiring diagram***).

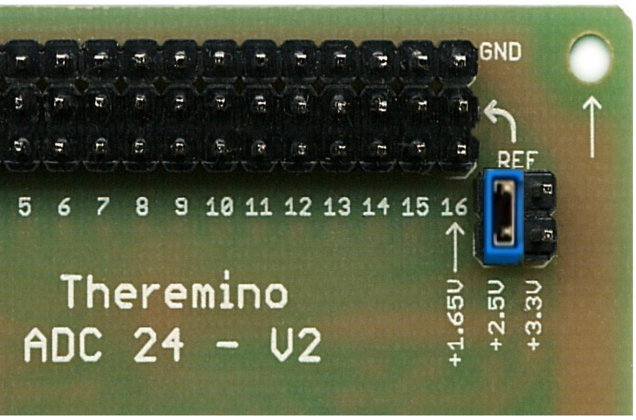
Always take care to insert **only one jumper.** Otherwise they will bring into short bias voltages. No serious problem arise, but is better to avoid.



<--- With this setting, they send 3.3 Volt to the central array of all Pin.

The 3.3 Volt have stabilized since AP2210 regulator that can deliver up to 300 mA with good accuracy (1%) and good stability (48 ppm/°C).

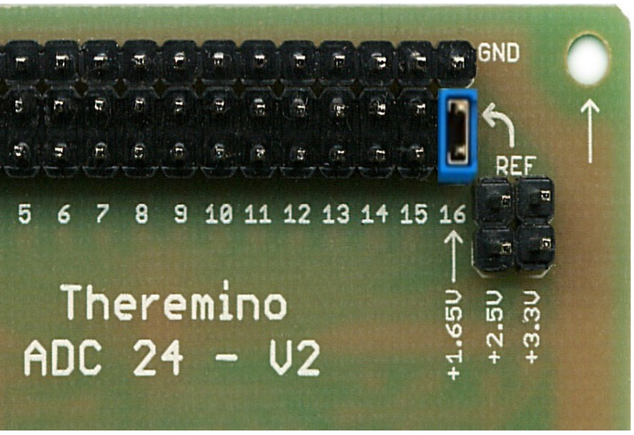
It uses the 3.3 Volt to power the Strain Gauges, stretch sensors used in the balances and load cells to measure the flexion of mechanical components. As well as for other sensors with "bridge" structure of resistors.



<--- With this setting, they send 2.5 Volt to the central array of all Pin.

The 2.5 Volt are stabilized inside the AD7124-8 chip that can deliver up to 10 mA, it has high accuracy (0.2%) and stability (2 ppm/°C - typical).

It uses the 2.5 Volt, as an alternative to 3.3 Volt, to power the Strain Gauges and other sensors. The opportunity to use the 2.5 Volt, instead of the 3.3 Volt, to be assessed case by case (the 2.5 Volt is more stable but the signal produced by the sensors becomes smaller).



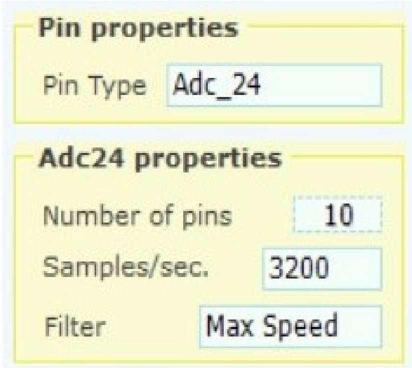
<--- With this setting, it sends the 1.65 Volt, the central array of all Pin.

This voltage is exactly in the middle of the measuring range of the ADC, which ranges from zero to 3.3 Volt.

It uses this voltage as a common reference for the inputs 1 to 15, when it is set as "Pseudo diff."

Important to remember that, it enables the reference voltage as "Pseudo", also by setting only a Pin on Pin 16 (which therefore will no longer be usable as input).

The general parameters (Pin 7)



Pin number

Decreasing the Pin number will reduce the height of the list. If you have many Pins not used you can hide them. However, the commitment of resources does not change, so who prefer can always leave visible all sixteen Pin.

Sampling rate

The sampling rate "Samples / sec.", or shortening "sps", is a very important adjustment. On the one hand one would like to raise it to the maximum, to maximize the bandwidth, the other would be good to reduce it in order to minimize noise. It is therefore to choose the best compromise for your application.

Sps set too high is unnecessary and increases the noise and therefore the instability of the sampled values. A good sampling speed for many applications is from 100 to 500 sps for each Pin (multiply by the number of active Pin). For three Grophones a good sampling rate is 1200 sps.

The "sps" are shared by all active Pin. So if the Pin active are three, for 200 sps for each Pin, you must set a total of 600 sps.

Active Pin are those with type "Adc_24_ch", while those with type "Adc_24_ch_b" are just placeholders and do not count for the sampling rate. And of course do not count even the Pin set as "Unused".

The first 12 master channels have no influence on dell'Adc24 sampling. Only alert is not to use stepper motors on the same Master connected all'Adc24 (HAL application show an error).

Even setting the filters affects the sampling rate. Only with the filters "Fast" and "Max Speed" the sampling rate is unchanged.

Filters

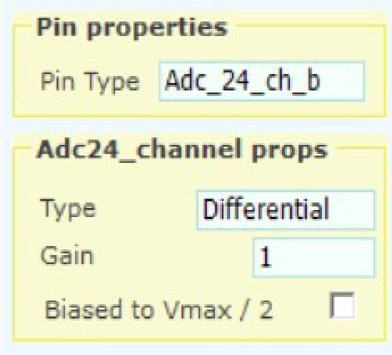
For many applications the best filter is the "Fast", is almost as fast as the "Max speed" but greatly reduces the noise. The slow filters ("Medium", "Slow" and the four filter "Post") make it the most stable measurements, but reduce the sampling rate. They are therefore to be used only for applications that are content with little data per second, for example load cells.

Some of the filters, in conjunction with the right sampling rate, performing a very effective rejection of the mains frequency disturbances (50 or 60 Hz depending on the settings). Another way to think of the filters is also to consider the "downsampler" in practice is sampled many times, with very high sps, it becomes the average of the measures and finally outputting the results with sps lower.

Impossible to expalin all possible combinations of filters, sps and rejection. To explore these topics consult ***data-sheet of the AD7124-8*** (a terrible brick, so good luck to the courageous).

The filters, which we renamed as: Max speed / Fast / Medium / Slow / POST1 / POST2 / Post3 / Post4, match the filters that the product data sheet are called: Sync3 / Sync4 / Sync3 FastSettling / Sync4 FastSettling / Post27 / Post25 / post 20 / Post16.

The parameters of the individual inputs (Pins 1 to 16)



Type

Type "Differential"committed designated Pins for each sensor, but it provides the best performance, highest stability and minimum intermodulation between channels. It is used for the load cells and other high-precision sensors. You can also use it for Geophones if you have enough free Pin.

Type "Pseudo Diff."engages one Pin for each sensor. In this way you can connect up to fifteen sensors because the Pin 16 is reserved as a reference to the mid voltage (1.65 Volt), for all sensors. If you set at least as a Pin "Pseudo", then the Pin 16 have the output as reference voltage and can no longer be used as input.

Type "Single ended"engages one Pin for each sensor. The signal that is sent to Pin refers to GND. Then you can measure voltages from zero to 3.3 Volt if the gain is one, and tensions progressively smaller as you turn up the gain. With the maximum gain (128) the measuring range goes from zero volt to little more than 25 mV positive (with respect to GND).

You can mix types, then you can set up some inputs as "Differential", others as "Pseudo" and others as "Single ended". The only limitation is that the type must be the same for the two Pin of each pair.

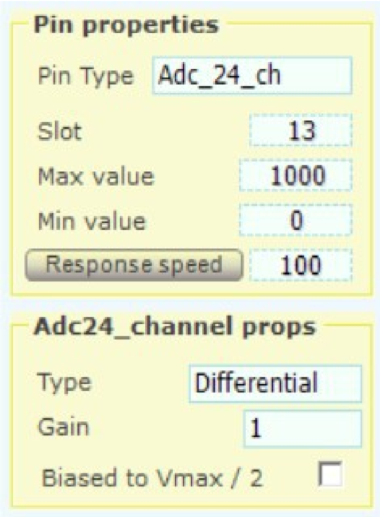
Gain

The gain can be adjusted from 1 to 128. It is used to amplify signals before sending them to the ADC. In this way it minimizes noise and stable measurements are obtained, also with sensors that produce very weak signals. To minimize noise you should turn up the gain as much as possible, but you should be careful not to saturate the inputs, even with the maximum signal. Then for earthquakes you set a gain of 32 (useful also for strong earthquakes) to 128 (for the maximum snsitivity), while for the micro-tremors you set always a gain of 128.

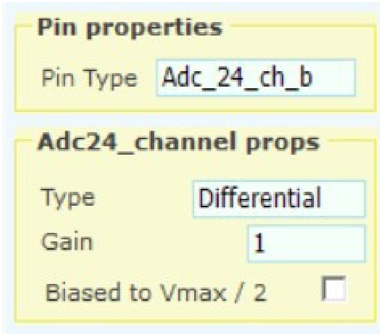
Biased to VMax / 2

Enabling "Biased to Vmax / 2", the Pin emits the reference voltage of 1.65 Volt (half of the 3.3 Volt full scale). The polarization must be enabled on only one of the Pin of the sensor. The is used for some sensors, such as Geophones or accelerometers, but should not be used with sensors with bridge structure, such as the load cells.

The input pairs



In these images we see the settings of a pair of Pin when they are set as "Differential".



The inputs are always in pairs: 1-2, 3-4, 5-6, 7-8, 9-10, 11-12, 13-14 and 15-16.

When you set the inputs in "Differential" Pin the first of the pair it is "Adc_24_ch", while the second Pin of the pair is "Adc_24_ch_b" type. This type "b" only serves as a placeholder, has the same parameters of the first Pin and does not emit data.

In "Differential" behavior in pairs it is natural, because it takes two Pin for each input. But when you set the inputs as "Pseudo Diff" or "Single Ended", we would not expect this combination. It is not a big limitation but you must know, otherwise you will not understand why, by changing the settings of a Pin, also change the settings of the associated.

Limitations caused by the behavior in pairs

In all modes of operation (Differential Pseudo and Single) behavior in pairs implies that:

- The type (Differential, Pseudo or Single) applies to both the inputs of the pair.
- The gain (Gain) applies to both the inputs of the pair.
- The polarization (Biased to Vmax/2) It can be enabled and disabled, independently, for each input.

Security Considerations

There maximum switching voltage the inputs must be from zero Volt to 3.3 Volt positive. And then to measure higher voltages you will have to add some resistors to each input.

If you exceed the minimum or the maximum voltage, they take part the internal protective diodes that limit the negative voltage - 0.6 Volt and the positive at + 3.6 Volt.

The internal protection diodes are very effective and can withstand static electricity discharge by thousands of volts and also a decent current for brief moments. But if you exceed 10 mA (positive or negative), can heat up too much and cause permanent damage, making the input unusable or even causing a total AD7124 malfunction (which is not replaceable).

Many sensors, for example the **Geophones** and **Load cells**, Can be directly connected safely, because their output voltage does not exceed 3 volts and, even in the case exceeded, the current that does not produce even approaching to 10 mA, tolerable by protective diodes.

But if you measure devices that can send strong currents to inputs or if you connect equipment powered from the main network (220 Volt AC), that may send strong extra-voltages to ignition, or even in all cases of doubt, it would be better add a resistor in series to each input. The value of this resistor will depend on extra-tensions that are expected to have to support.

Resistor in series to the input	**Maximum extra-bearable tension**
No resistor (Direct)	From -2.5 volts to +5.5 Volt
Resistor 1 K ohm	From -12 volts to +15 Volt
Resistor 10 K ohm	From -100 Volt to +100 Volt for a short time (Note 1)
Resistor of 100 K and over (for at least 2,000 Volt)	From 1000 Volt negative to 1000 Volt positive

***(Note 1)** If you plan to work for a long time (more than one second) with extra-voltages over 30 Volt, the resistor 10 K should be at least 2 Watts, to prevent too warm, or use resistors by at least 100 K ohm.*

The resistors must be positioned near the entrance to the ADC and must be of lowest possible value (Compatible with the safety requirements), because the high resistance values became worse the precision of the measurements and increase the noise.

These resistors are not included in the design basis, because it would worsen the operation of more delicate sensors and prevent submitting accurate bias voltages to the sensors.

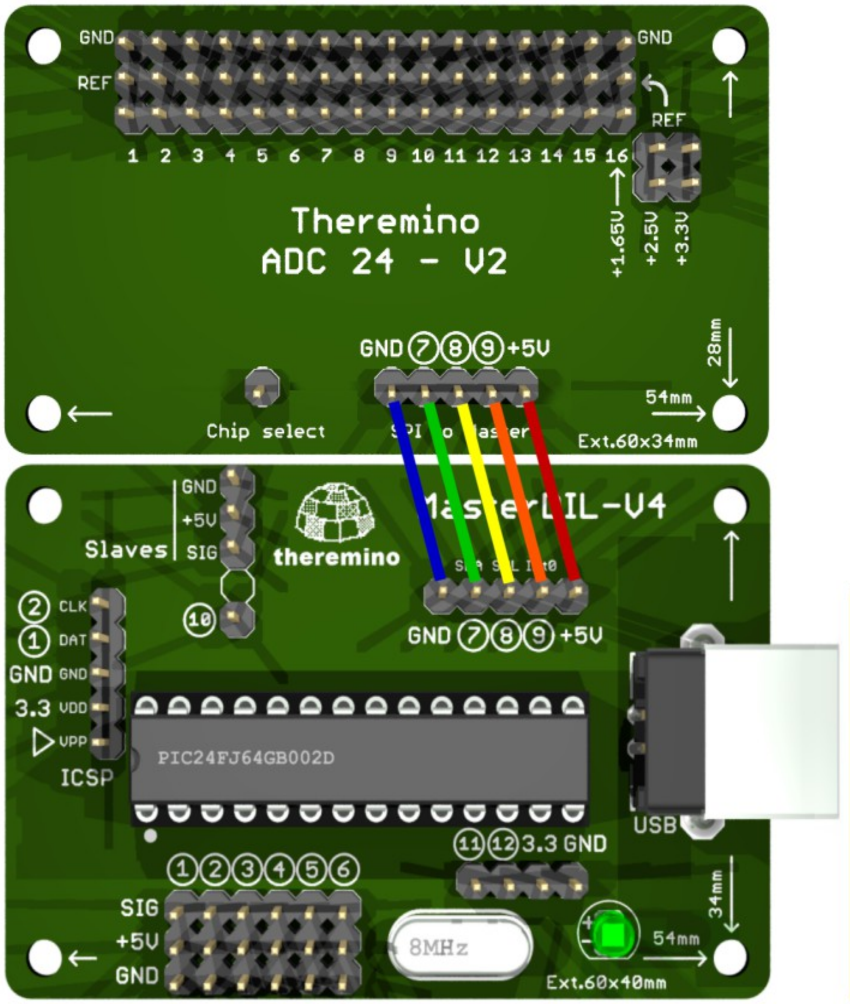
The dangers come only from the wires connected to the inputs, no error in the software settings can damage the Adc24.

Measure negative and positive voltages

The protection resistors shown on this page are only intended to limit the current and to avoid damage to the ADC, but the measurable voltage always remains between zero and 3.3 Volt. To measure negative or positive voltages of tens, hundreds or even thousands of volts, you will have to use two or three resistors for each input, as shown in ***section on datalogger***.

Connections

The connections between the ADC24 module and the Master are made with wires with Dupont female-female, purchased on sites ***store-ino*** and ***thereminoshop***, or on eBay (seller ***maxtheremino***).



Connect the five cables properly. The right order of connection is GND, 7, 8, 9, + 5V, as shown in silk screen print.

The single connector, labeled "Chip select", must not be connected. Leaving it open it is internally biased with a resistor to ground. The "Chip select" could be used in the future to connect more Adc24 modules to a single Master. Currently the HAL application, and firmware, do not have this capability.

If the modules are placed side by side you could use cables of 5 or 10 centimeters (hard to find), otherwise using normal cables from 20 centimeters.

For long connections it would be better to use a shielded cable (good ones for intercoms, with four colored wires inside). The maximum distance depends on many factors, including the capacitance of the cable and samplings per second. With long connections (more than a few meters) it should not exceed 4800 samples per second.

Connect Geophones

Before making connections twist well the wires, in order to reduce noise picked up by capacitive and magnetic on. Twisting them tight, much tighter than what you see in these images (with inversions every few millimeters), you get a good shielding action, as well as a softer wire and a neater cabling.

In the pictures you can not see, but of course you do not have to solder the wires on Pin dell'Adc24. On the site ***store-ino*** are available the soft silicone red-black cables, with two-Pin connector. If those cables are not available it is also possible to use normal little wires and other colors. For microtremors analysis it is better to use shielded cables as explained in the following pages.

For earthquakes it is recommended to set Gain 1, 2 or 4, for micro-tremor to set it to 128.

Connect one to eight Gephones

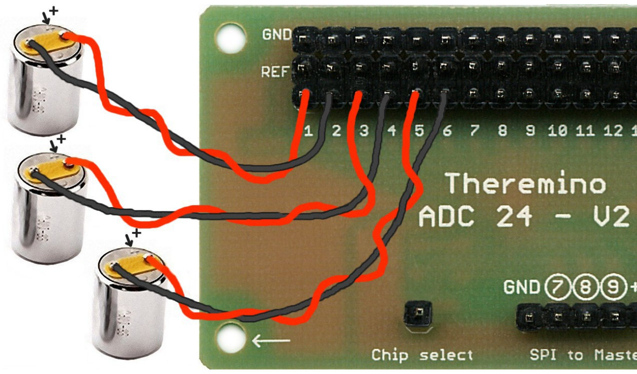
In the HAL application, set the first two Pin of the Adc24 as follows:

- Set the Pin 1 as "Adc_24_ch", "Differential", "Gain 1 to 128" and **nothing "Bias"**.
- Set the Pin 2 as "Adc_24_ch_b" with **"Bias enabled"** (Type and Gain do not matter).

The Geophones have two poles, it is recommended to use black wire to the negative and red for the positive.

- Connect the red wire to the Pin signal 1
- Connect the Black wire to the Pin signal 2

In the same way you can connect up to eight pairs of Geophones to Pin: 1-2, 3-4, 5-6, 7-8, 9-10, 11-12, 13-14 and 15-16.



Connect up to 15 Geophones

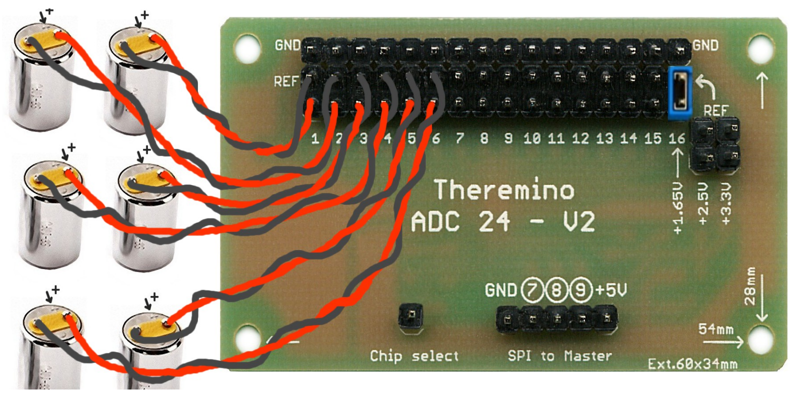
By the way "Pseudo differential" you can connect up to 15 Geophones.

- Set all Pin (1 to 15) which connect the Geophones, as "Adc_24_ch", "Pseudo diff.", "Gain 1 to 128" and **nothing "Bias"** (recheck Pseudo and Bias after setting them all).
- Connect the red wire to the signal (marked 1, 2 ... up to 15) and the black wire to the central pole (REF).

Note that the Pin 16 is used to output the reference voltage (1.65 Volt) for all the Geophones.

If you also set a single Pin as "Pseudo", the Pin 16 it is set as a reference automatically.

The jumper (in the image in blue color) leads the reference voltage on the center line of all Pin.



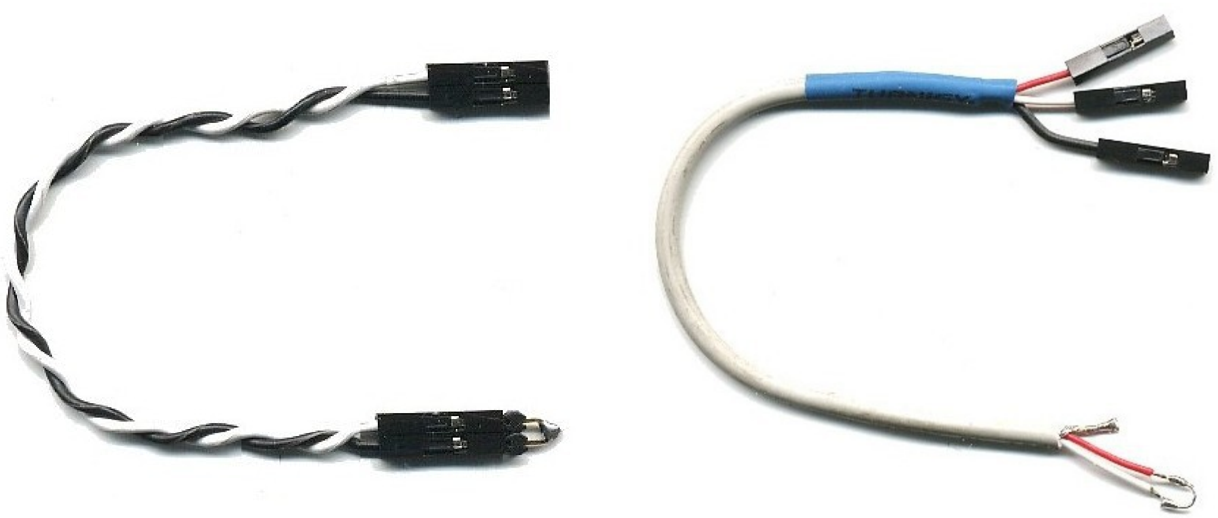
Connect Geophones for microtremors

The analysis of micro-tremors are easily disturbed by periodic noise, even if of very low intensity but prolonged in time. These periodic noises appear as peaks in the spectrum analysis and can be at any frequency from less than 1 Hertz to hundreds of Hertz.

The interference coming from the electrical system are 50, 100 and 150 Hz, but can make beats with the sampling frequency and produce any other frequency. Often these noises are so low as to be masked by the signals of the Geophones but can also distort the analysis because, extending over time, have a strong effect in the calculation algorithms based on the division of the vertical by the horizontal signal (HVSR).

Tests with the new application "Theremino AdcTester" showed that the Adc24 has a very low noise (0.17 uV) (see the ***Noise characteristics*** section), an intermodulation virtually unmeasurable (0.02 uV) and the same gain on all channels (see the AdcTester instructions).

Therefore if there are these noises, they are originate entirely from the connecting cables or by the Geophones. In the pictures you see the two cables used to make measurements with the AdcTester.



Unshielded cable (left) picks many micro volts of noises, ten times greater than the Adc24 background noise (0.17 uV). Near electric equipment or high voltage disturbances cables can also get to hundreds of uV and then even higher than the useful signal (the micro-tremors ranging from 5 to 50 uV).

With shielded cable (right) noises are less than the Adc24 noise and increase it only a little even in the worst situations.

Use shielded cables could improve the cleaning of the signals also for the seismic events, for the analysis of the buildings and also for any other kind of sensor, when the signals to be measured are very low.

Connect Geophones with shielded cable

The new versions of Tromographs will have shielded cables between the Geophones and Adc24, as shown in the following image.

The red wire is the positive and should be connected to the first pin of the pair (Adc24_ch). The white wire is negative and is connected to the second pin (Adc24_ch_b). The black wire is the screen and must be connected to the ground of the Adc24 (GND).

The shielded cable is also soldered on a side of the Geophone to also shield the inner coil. To do this you must know how to weld well, carefully shaping a small section of metal casing, prepare both the Geophone that the cable sheathing, welding carefully and without too much heat. The welding must be done with great skill so as not to stick out from the side and making sure it is not a "cold welding" that may come off.

The shielded cable must be small (2 or 3 mm external) and soft (rubber material) so as not to create efforts that could cause vibrations with the temperature changes. It would not hurt to also add a drop of hot glue to firmly attach the shielded cable to the Geophone.

It is not necessary that the shielded cable has twisted the wires inside. This would be a protection against alternating magnetic fields, but there is still the coil of the Geophone which picks them a much greater extent.

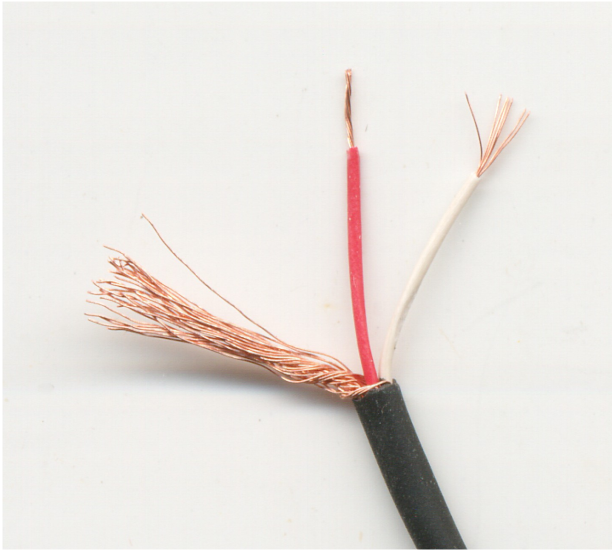
It is helpful to add a capacitor 4.7 uF (the little rectangle between the two Geophone electrodes) which limits the bandwidth to 150 Hz. This prevents the high-frequency disturbances are reported in the useful band of the aliasing phenomenon. A further and important aliasing reduction could be obtained by increasing the sampling frequency to 1200 SPS (400 Hz for each geophone x 3 = 1200).

To solder the capacitor you remove two squares of green paint with a small, sharp screwdriver. In this way one can solder and desolder the capacitors without heating the wire anchoring zone, and thus without risking to move them or to dissolve their insulating sheath. Even if you use larger capacitors should the same solder at this point and not on the wires that are delicate and can easily deteriorate.

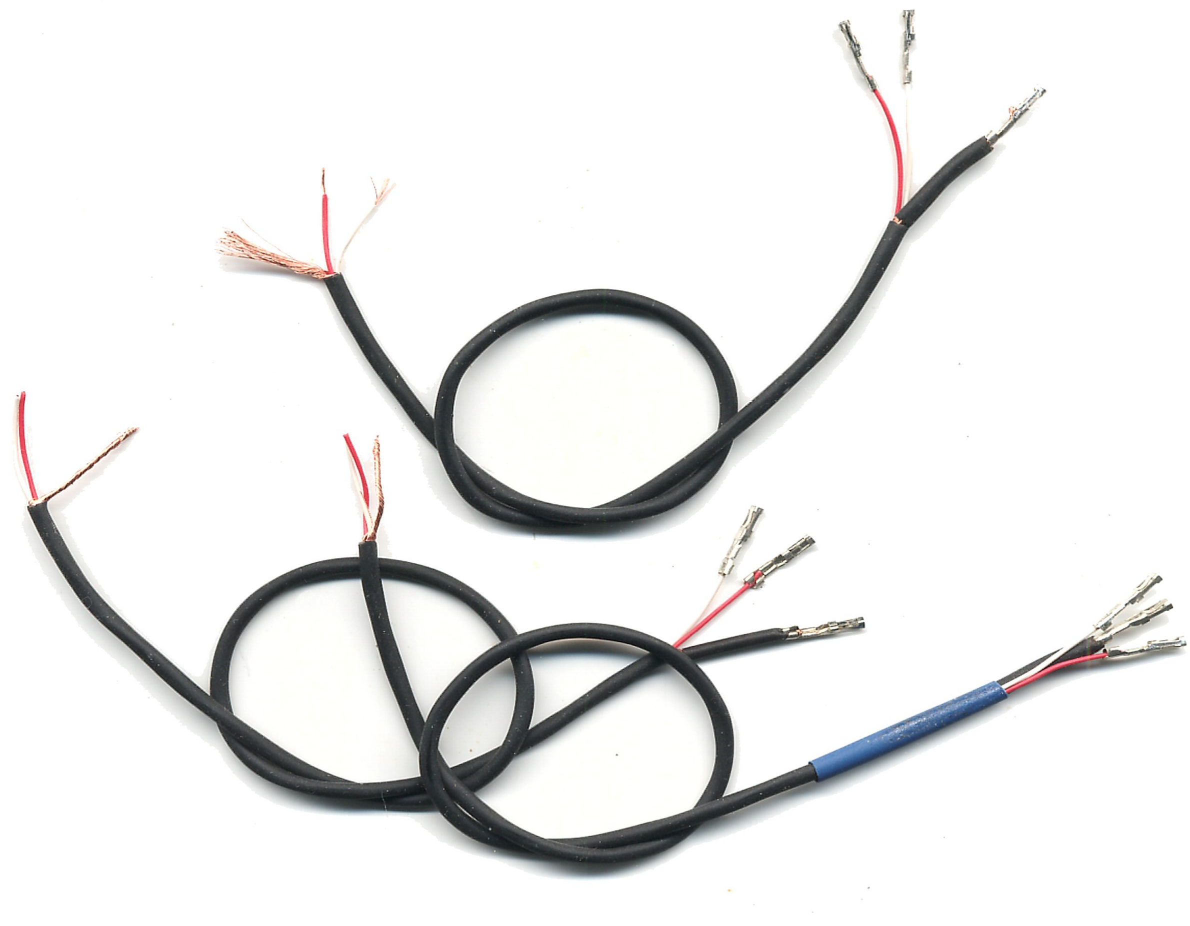
The capacitors must be Ceramic, and better if a Surface Mount (SMD 0805) why they have best Features and cost just a few cents. The electrolytic capacitors or tantalum do not go well because they are biased. The polyester capacitors would be nice but are huge and expensive.

Those who can not do this or can not find a suitable shielded cable will have to wait the Geophones with the cable. We talked to the chinese ***store-ino*** and soon they will make available Geophones with the capacitor, the shielded cable and a drop of hot glue to secure it.

Connect Geophones with shielded cable - Images



Prepare the pitches for the condenser eliminating the green paint with sandpaper. Cut 25 cm long cables. Strip for 2.5 centimeters from the side of the connectors and to 1.5 centimeters from the side that is joined to the geophone. Crimp the Dupont connectors with the specific tongs and a lot of skill. Otherwise you can get the connectors from Dupont cables, open peeling back the plastic foil with a tip, solder the wire to the back and close them with the insulating plastic.



Connect Geophones - Regulations

In the most common case (3 Geophones with 4.7 uF capacitor for microtremors and building analysis) the HAL Pin 7 regulations are:

- Samples/sec. = 1200
- Filter = “Max speed” (or “Fast” when using 4800 and 9600 sps)

More info about Pin7 regulations in ***this page***.

Setting single Adc24 channels is explained in the page ***connect geophones***.

The following table shows the best sampling and filter capacitor combinations

Configuration	Sampling	Aliasing frequency	Noise (gain 128)	Geoph. cap.	Note
3 Geophones SPS **600**	200 sps	100 Hz	0.17 uV	4.7 uF	Minimum noise generated by the ADC but aliasing more pronounced
3 Geophones SPS **1200**	400 sps	200 Hz	0.22 uV	4.7 uF	Good compromise between noise and aliasing
3 Geophones SPS **2400**	800 sps	400 Hz	0.29 uV	1 uF	Passband flatness up to 300 Hz but possible aliasing from 300 to 800Hz
3 Geophones SPS **4800**	1600 sps	800 Hz	0.37 uV	1 uF	Passband flatness up to 300 Hz with reduced aliasing
3 Geo. + 3 Acc. SPS **1200**	200 sps	100 Hz	0.22 uV	4.7 uF	Minimum noise generated by the ADC but aliasing more pronounced
3 Geo. + 3 Acc. SPS **2400**	400 sps	200 Hz	0.29 uV	4.7 uF	Good compromise between noise and aliasing
3 Geo. + 3 Acc. SPS **4800**	800 sps	400 Hz	0.37 uV	1 uF	Passband flatness up to 300 Hz but possible aliasing from 300 to 800Hz
3 Geo. + 3 Acc. SPS **9600**	1600 sps	800 Hz	0.91 uV	1 uF	Passband flatness up to 300 Hz with reduced aliasing but higher noise

The capacitor to be applied on geophones should be at least 1 uF. This value is suitable for applications which require a wide bandwidth, such as the seismic refraction.

With 4.7 uF you get better protection against high-frequency interference, which, for the aliasing, are unfolded in the useful band. The only defect of the 4.7 uF capacitor is to cause a slight attenuation (from 2 to 3 dB) even at medium frequency (10 to 100 Hz).

With the SENSHE 4.5Hz 28.8 Volt/m/s geophones, you get the following end scale and noise values.

	Gain = 1	Gain = 2	Gain = 4	Gain = 8	Gain = 16	Gain = 32	Gain = 64	Gain = 128
Saturation (mm/s)	+/- 57.3	+/- 28.6	+/- 14.3	+/- 7.32	+/- 3.58	+/- 1.79	+/- 0.89	+/- 0.45
Noise (nm/s)	+/- 70	+/- 52	+/- 39	+/- 28	+/-20	+/- 15	+/- 12	+/- 10

Noise calculated for 1200 samples per second. The unit nm/s means nano-meters per second.

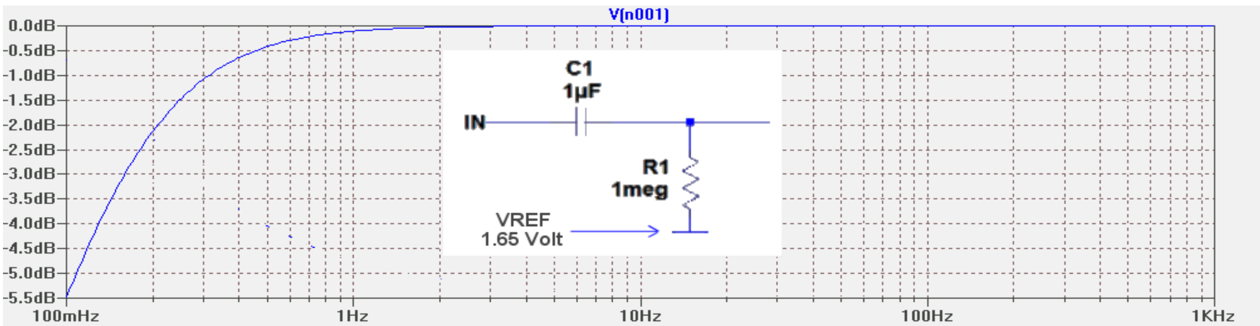
Connect Accelerometers - Part 1

The accelerometers have a bandwidth that extends up to the continuous (0 Hz). For some applications this is an advantage (the smartphones can feel the Earth's gravity and rotate the screen), but to feel the movements of the ground the DC component of the signal is not needed.

In accelerometers gravity causes a strong vertical axis imbalance, which at rest does not measure 500 (central value of our scale of 0 1000), but about 300, or 700. And also the horizontal channels are not centered on 500, but could mark, for example 450, because of the construction inaccuracies, this imprecision is also present in the best accelerometers.

If the input signals are not centered, then by setting gain higher than 1, it would amplify the imbalance, and it would go to work outside the usable area (of lower output values of zero or more than one thousand).

So in order to eliminate the continuous component from the three input signals must interpose three high pass filters, such as that illustrated in this graph.



If the connecting wires are too long then you gather many noises and sampled values are not centered on the value 500.

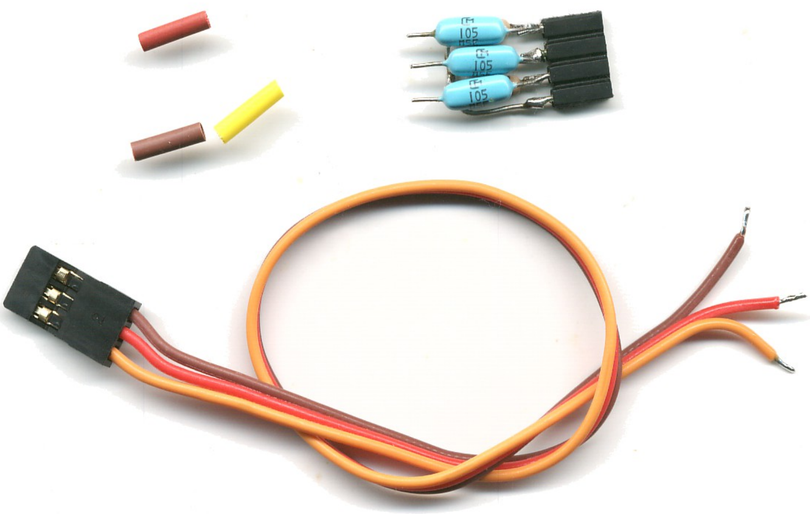
To keep short runs you should use a female connector 2.54 good quality, as ***specified here***.

Solder the components directly to the socket so as to minimize the most sensitive to disturbance (the one that is directly connected to the input Pin).

Accelerometer module must also be connected to ground (GND) and the power supply (5 Volts or 3.3 Volts depending on the one used). They then use two Dupont cables, one connected to the Adc24 GND and the other at 3.3 Volt or 5 Volt on the Master.

Connect Accelerometers - Part 2

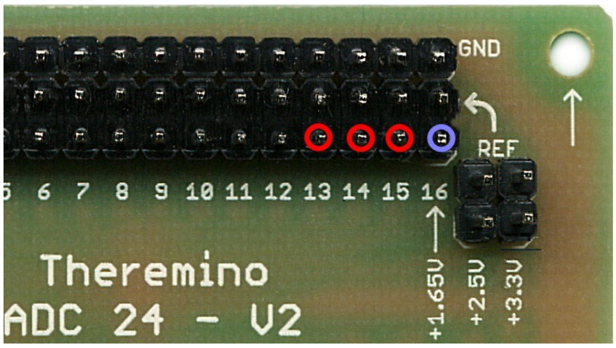
Prepare the adapter as seen in this image.



Welding good is important preparation. Use tin with lead and resin (tin unleaded is good only for the automatic production). Before welding, each component must be shortened and tinned. The wires must be stripped for 2 mm, curled and tinned.

Finally piecing together and are welded with a single cast, no retouch or "brush" with the soldering iron.

See ***This Page***.



To simplify wiring, you should use the Pin 13, 14 and 15 for the accelerometer, and 16 for the common pole of the three resistors.

The three Adc24 inputs must be set as "Pseudo" and **without bias**. By setting the inputs as Pseudo, the 1.65 Volt automatically turns on Pin 16, to bias the three resistors.

The central pins are not connected then it is still possible to insert a jumper on 2.5 Volt or 3.3 Volt, in the case would connect other sensors that require it.

The "Gain" of the three inputs can be adjusted from 1 to 128, depending on the type of analysis to be carried out. The rule is higher for larger amplitude signals, but it has to leave a certain margin of safety, not to saturate the inputs during the higher intensity events.

Connect Accelerometers - Part 3

The signal produced by the accelerometers is the derivative of that produced by the Geophones. Or conversely you could say that the signal of the Geophones is the integral of the acceleration.

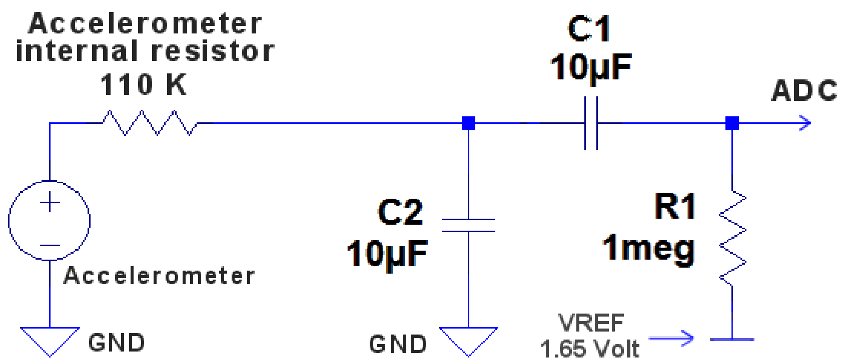
How does an accelerometer to sense the acceleration? It has a reed that bends due to the acceleration and is the position of this reed which is converted to an electrical signal. The reed mass is small so it has a high resonance frequency (1 to 10 KHz depending on the model). Starting from the continuous (zero Hertz) and up to its resonant frequency an Accelerometer a perfectly linear response to the acceleration.

How does a Geophone to integrate the acceleration? It has a mass that is pushed by the acceleration and is the movement of this mass which is converted into an electrical signal. The mass is considerable and therefore has a low resonance frequency (1 to 10 Hz depending on the model). Since the resonance frequency and up to the maximum frequency the Geophone has a response to accelerations which decreases linearly. And a linear decrease, which is halved for every doubling of frequency, it is mathematically an integration.

The two signals are equivalent and may be converted into one another by the software. But the Geophones signal has a more distinct look because it is historically the most widely used in seismic analysis. Moreover, the integration removes much of the high frequency noise and makes the graphics more "clean."

Integrate the accelerometer signals is particularly useful because they are inherently more noisy, but also because having signals of the same type allows you to compare them.

We will then modify the filter to integrate the signal and obtain a signal equal to that of the Geophones.



In the previous pages filter were only C1 and R1, we now add a C2 which, together with the internal resistor accelerometer, form a single-pole low-pass, which is a perfect integrator.

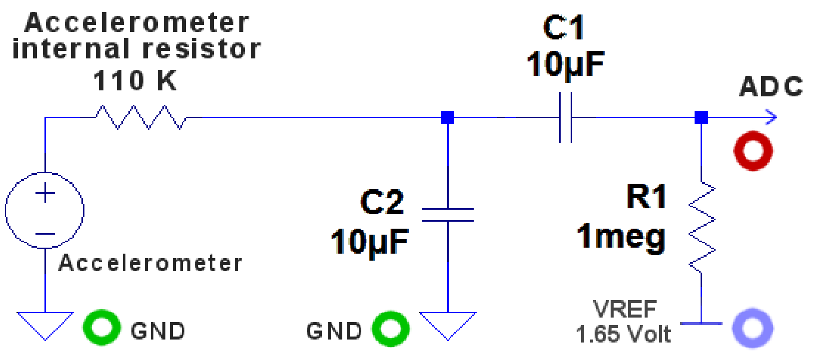
In the filter of the previous pages C1 was 1 uF, now it is 10 uF, but you can also use other values, as explained on the next page.

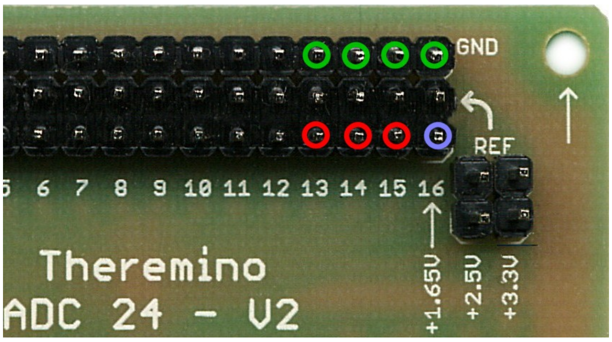
The accelerometer must be a LIS344 otherwise it might have a different internal resistance.

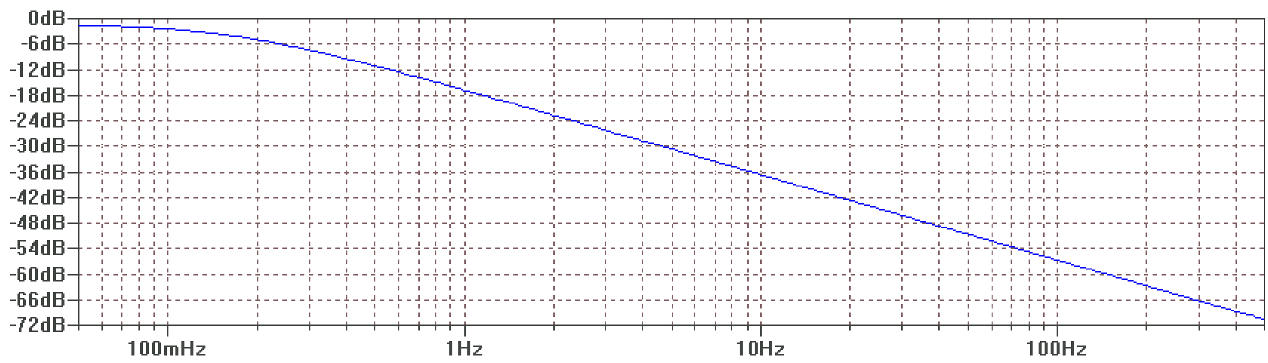
Links to GND is good that they are on the Adc24, then the furthest contact strip. In this way the capacitors C2 will have the short wire and the noise will be minimized.

Connect Accelerometers - Part 4

The connections are the same as the previous scheme but will also use three mass pins (GND) to connect one side of the capacitors C2. The fourth mass pin could be useful to bring the mass to the accelerometer module.







The frequency response of this filter has a slope of 6 dB per octave, so it is a perfect integrator from about 0.1 Hz up to the highest frequencies of our interest.

\- - - - - -

Even with this filtering the signal of the accelerometers is noisier than the Geophones signal, but instead his response extends down to 0.1 Hz, then ten or twenty times better than the more expensive Geophones (1 or 2 Hz) and without the long swinging problem afflicting these Geophones after a strong perturbation.

A response up to 0.1 Hz very lengthens the initial stabilization time. If it is not necessary it could reduce the capacity of the capacitors C1 and C2, as per the following table:

Capacity of C1 and C2	Frequency response from:	Initial stabilization time (approximate)
10 uF	0.1 Hz	50 seconds
4.7 uF	0.2 Hz	25 seconds
2.2 uF	0.5 Hz	10 seconds
1 uF	1 Hz	5 seconds

Connect Load Cells

To get a general idea of how the load cells are made consult ***This Page***, and especially download the "Connecting_LoadCells" file and read it all. In the last part of the file there is a comparison of various types of weighing scales.

We have experienced that by connecting the load cells to Theremino Adc24 improves accuracy and resolution from ten to a hundred times, compared to the characteristics declared by the scale. By setting low sampling rates, which minimizes dell'Adc24 noise and the performance limit is only due to the unstable mechanical and subject to temperature changes.

Connections and settings

First of all you place the jumper on 3.3 Volt, in order to bring the 3.3 Volt to the central of all Pin. You should not use the 3.3 Volt directly, but you must send it to the sixteen inputs. In this way it is also to connect the damping resistor and the capacitor (R19 and C8) and the load cell works better (it eliminates noise pickup by the links and the measurements are more stable).

The load cells tipically have four wires:

- Connect the Red wire to the 3.3 Volt of Pin line 1 (middle row)
- Connect the Black wire to the GND of Pin line 1 (GND is near the edge of the PCB)
- Connect the Green wire to the signal Pin 1
- Connect the White wire to the signal Pin 2

Set the first two Pin dell'Adc24 as follows:

- Set the Pin 1 as "Adc_24_ch", "Differential", "Gain = 128" and no "Bias".
- Leave the Pin 2 "Unused". Or, if you prefer, you may set as "Adc_24_ch_b", "Differential", "Gain = 128" and no "Bias".

Notes

The load cells give a small signal that does not deviate much from the mid-scale (value 500) even with the maximum load. So you should always set the gain to the maximum. The only case of having to reduce the gain is of low quality with load cells, which are so unbalanced from going off the scale (zero or one thousand). In these cases it will set a gain of 64 or even less, up to make them work in the valid area. Also check with the maximum load

Be very careful disable the "Bias" on both the Pin. If you fail the cell does the same, but it's a hundred times more unstable (the value dancing in exaggerated manner).

Sometimes the Green wire may be Blue and the White one could be Yellow. If adding the load the signal goes negative, just swap these two wires between them.

To test the load cells serves HAL application, and is also useful the application "Balance," that you download from ***This Page***.

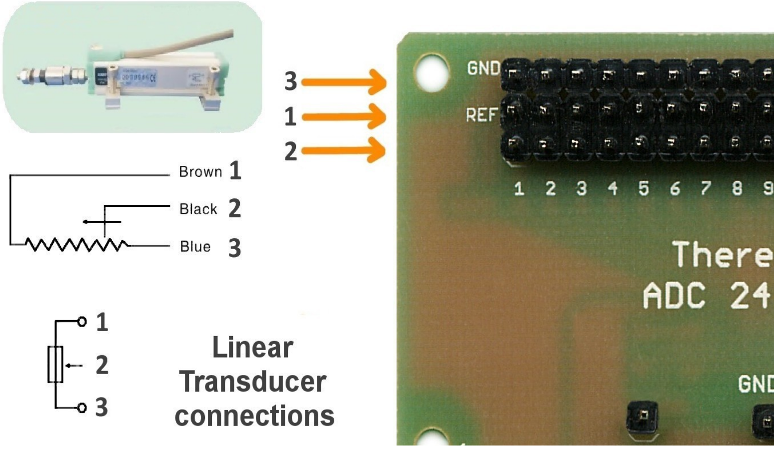
Connect Single Ended sensors

You can connect up to sixteen transmitters with potentiometer structure.

For correct operation you must check the following two points:

1) Place the jumper on 3.3 Volt, as explained in ***This Page***.

2) Configure the inputs as "Single ended", with gain "1" and no "Bias".



The resistive value of the ideal potentiometers ranges from 1k to 10k. Even lower and higher values may work, but in the first case it would consume too much current and in the second it would lower linearity and an increase of noise pickup from the wires.

CAUTION: Ensure the center of the potentiometer (2), is connected to an input terminal. If you connected the center of the potentiometer to "GND" or "REF", the potentiometer could be heated and damaged.

Instead the two extremes of the potentiometer (1) and (3), which carry the power supply (+ 3.3Volt) and (GND), can be exchanged between them without damage. Exchange (1) with (3) can serve, to reverse the measure with respect to the direction of movement.

Connect other types of transducers

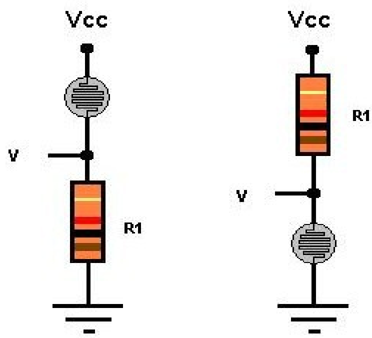
The connections of the image refers to Transducers Linear, but the principle is valid for all sensors that behave as a potentiometer.

There are also transducers away with a wire that is extracted. The applications are many, for example, you can monitor the distance between two walls with incredible precision. Even with walls several meters away from each other you can get to the thousandths of a millimeter and beyond. The limit is only due to the continuous micro-tremors, caused by natural events and human activities.

Connect Variable Resistors

You can transform a variable resistor in a potentiometer, with the addition of a fixed resistor (R1), connected as in this image (the second scheme produces an inverted signal).

Depending on the excursion of the variable resistor, you must use a fixed resistor of suitable value. Try changing the R1 resistance value and check with the viewer of the HAL application, until you get the desired travel.



Building a data logger

With Adc24 Theremino you can build a data logger "do it yourself". To design it can take an example from the commercial Datalogger.

Definition of data logger: *"A measuring instrument that samples one or more analog signals at pre-programmed intervals, converts them into digital data and stores it."*

There are many manufacturers and datalogger models, have largely stratospheric prices and not even appoint them. A good logger, quite cheap and well designed, it is the ***Picotech ADC-24***, for its reading characteristics ***this PDF file***, and for the inputs ***this PDF file***.

Features	Picotech ADC-24	Theremino Adc24 + Theremino Master
Bits	24	24
Sampling frequency	Up to 16 samples / sec.	Up to 19200 samples / sec.
Number of channels	8 or 16 (Diff or Single)	8 or 15 or 16 (Diff, Pseudo or Single)
Accessory outputs	4 digital	9 digital and 6 Adc 10 bit (the Master)
Measurement scales	From +/- 39 mV to +/- 2500 mV	From +/- 25 mV to +/- 3300 mV
Overvoltage protection	+/- 30 volts	+/- 100 Volt with 10k resistors in series with the inputs, such as ***explained here***. (From -2.5 to + 5.5 volts without resistors)
Supply Current	100 mA	Less than 15 mA (including the Master)
Common mode Rejection	from 95 to 125 dB	From 90 to 115 dB (depending on the gain)
Noise rejection (50 and 60Hz)	120 dB typical	From 115 to 130 dB (depending on the filter)
Selectable gains	From 1 to 64	1 to 128
Gain error	0.2% (Annual calibration recommended)	0.05% or better (without any calibration and at temperatures from -40 °C to + 105 °C)
Offset error	400 uV (annual calibration recommended)	+/- 20 uV (without any calibration and at temperatures from -40 °C to + 105 °C)
Offset drift	Not specified	10 nV / °C
Input current	Unspecified (about 3 uA)	3 nA
Input impedance	1 to 2 Mega ohms	Greater than 1 Giga ohms
Noise free bits (16 sps - gain 1)	18	21
Noise free bits (16 sps - gain 64)	15	18
Approximate price	694 Euro (with tax and free shipping.)	27 Euro (plus 10 Euros for the Master, shipping included)

The price difference is due to the fact that the Picotech is a finite set and tested, while the Theremino is a "do it yourself".

In total cost for Theremino Logger should be considered the costs of connectors, electronic hardware and container, as well as the time needed to build it and test it.

Measurement scales

To obtain a datalogger able to measure voltages higher than 3.3 Volt, enough to form a voltage divider with two resistors for each input. The simplest scheme (only for positive voltages), is composed of a resistor 10 Mega ohms in series to the signal (so it has an impedance equal to that of the tester) and a resistor between the input and ground, to be calculated to obtain the full scale required.

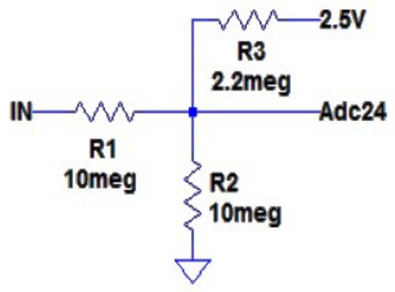
Simply changing the resistor to ground you can get all scales that are desired, for example 10, 20, 50 and 100 volts. For higher flow resistor 10 Mega should bear too high voltages. So it is good to replace it with a chain of resistors 10 to 10 Mega one. This way you could get up to 1000 Volt with confidence.

To measure both positive and negative voltages, you must add a biasing resistor, so it takes three resistors for each input.

They recommend 1/4 or 1/8 Watt resistors with at least 1% accuracy. The maximum would measure many and select the most similar to the design value. And even the most similar to each other, if you use multiple inputs with the same scale.

The following table shows the values for the most common courses and the wiring diagram is on the first course, that is -10 volts to +10 volts.

Range	R1	R2	R3
-10 Volt to +10 Volt	10 Mega	10 Mega	2.2 Mega
-20 Volt to +20 Volt	10 Mega	3 Mega	1.2 Mega
-25 Volt to +25 Volt	10 Mega	2.2 Mega	1 Mega
-50 Volt to +50 Volt	10 Mega	1 Mega	470 K
-100 Volt to +100 Volt	10 Mega	470 K	220 K
from 0.1 Volt to 3.2 Volt	10 K (Note 1)	not present	not present
from 0 Volt to 10 Volt	10 Mega	4.7 Mega	not present
from 0 Volt to 20 Volt	10 Mega	1.8 Mega	not present
from 0 Volt to 50 Volt	10 Mega	680 K	not present
from 0 Volt to 100 Volt	10 Mega	330 K	not present
from 0 Volt to 200 Volt	10*10 Mega in series	1.6 Mega	not present
from 0 Volt to 500 Volt	10*10 Mega in series	650 K	not present
from 0 Volt to 1000 Volt	10 *10 Mega in series	330 K	not present



(Note 1) The range in blue is a basic range of the ADC, without the divider input and with only one protection resistor.
The protective resistor 10 K protects the entrance to extra-voltages (momentary) of +/- 100 volts.

The dividers of this table guarantee a very high input impedance, those with at least 10 Mega ohm green background and those with yellow background at least 100 Mega ohm. If you do not require a high impedance so, you can reduce all values of ten or a hundred times and ranges will remain exactly the same.

Reducing the value of the resistors are reduced the errors due to the input current, as well as the noise produced by the resistors, the picked up noise from the environment for capacitive way and the inter-modulation between the channels. The tables ***these pages*** deepen the calculations and provide other examples of dividers, with ten and one hundred times lower input resistance.

Errors due to the input current

Luckily our Adc24 has a low input current (about 3 nA), and we can then use resistor values quite high. Counterpart If we are working with Picotech the input current would be a thousand times greater (than 2.5 uA) and we would be forced to use lower resistance values, influencing more the circuits under test and endure significantly more errors.

The voltage errors of which we speak, are caused by the current of the ADC inputs loss and are "related to entry". That is, the actual error on the input voltage, considering the effects of the resistive divider, and after all the relationships of scale in the acquisition software.

Even with complex divider the voltage errors, reported at the entrance, depend only from R1 and are calculable by the formula: error (Volt) = R1 * input current (about 3 nA).

The following table shows the voltage error and the maximum extra voltage, for different values of R1.

Value of the R1 resistor	Error reported at the datalogger input (With 3 current inputs of the ADC nA)	Maximum extra voltage
100 Mega (10 * 10 Mega series)	300 mV	+/- 1000 Volt
10 Mega	30 mV	+/- 100 Volt
1 Mega	3 mV	+/- 100 Volt
100K	300 uV	+/- 100 Volt
10 K	30 uV	+/- 30 volts and up to +/- 100 volts for a few seconds (to not heat R1 too much)

Fortunately these voltage errors do not affect the accuracy of the measurements, But only on the zero. So long as the capture software has a zero calibration function, to ground the inputs and press "Reset."

If you measure the differential then the errors should be eliminated automatically. But in practice it is very difficult to have two sets of identical resistors, whereby also in this case you will have to calibrate zero.

Choose the best compromise

You might think you can reduce at will the mistakes, a lot of decreasing resistor values. For example, lowering them to a few tens of ohms. But doing so would load the circuit under test, producing unknown errors, dependent on the circuit under test and can not be corrected with the calibration.

So it is necessary to determine, case by case, the best compromise between high input impedance (not to affect the circuit under measurement), and low input impedance (to minimize the errors due to the input current to the ADC and noise pickup from the environment).

Maximum extra voltage

All dividers of these pages have an input resistance (R1) of at least 100 K ohm. Then all, even those of the lowest ranges, can withstand extra-voltages up to 100 Volt.

The protection diodes of the Adc24 would drain 10 mA of current, and then voltages even ten times greater, but can not exceed 100-150 volts, because of limitations of voltage and dissipation of the input resistor R1. For effective protection at higher voltages, R1 should not be a single resistor, but is They must use more resistors in series.

Resistors wiring

Absolutely **not** recommended to add a switch to change the flow rates; noise and inter-modulation introduced by long wires would degrade the measures.

To get maximum performance and minimal noise you must solder the resistors directly onto a three-Pin female connector, minimizing the conductive part directly connected to the input.

The wiring will be similar to the images that are seen in ***This Page***.

even the ***Picotech ADC-24***, Despite being very expensive, it has only the basic flow of the ADC (from 39 mV to 2.5 V) and does not include switches. To achieve the desired ranges must weld the appropriate resistors on its ***Terminal board***.

Why not to build a Terminal Board

As already seen in the previous pages, the Picotech has an input current a thousand times greater than our Adc24. Therefore its input to dividers are of very low impedance strength (maximum 10 K ohm instead of our 10M ohm). With so input low impedances, long connections of their Terminal Board do not create too much noise.

But if you want to use impedances similar to digital testers (ie 10 M ohm) it is good to do NOT make a Terminal Board of any kind, but solder directly resistors to a female connector, taking very short wires of the resistors.

Finally, to go to the input connectors, they will use small shielded cables by 2 or 3 mm in diameter (see for example ***this page***). It is a job that requires a lot of skill and precision welding. For advice on small welds ***This Page***.

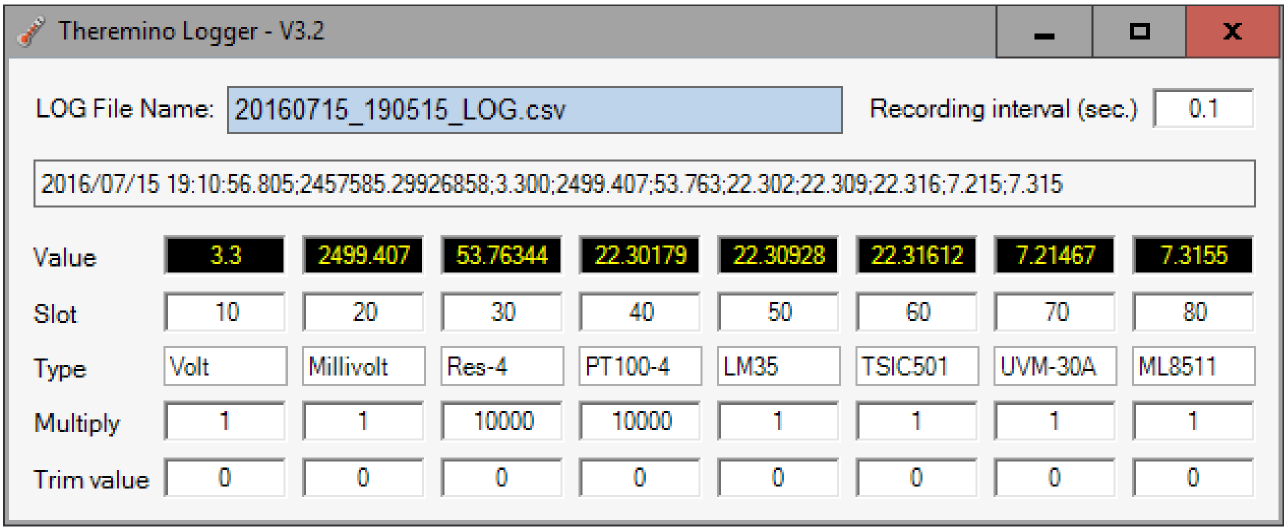
Calculate the voltage according to the used input circuit

In addition to the resistor values of the input circuit, the formulas for calculating the voltage must take into account many factors, the full scale of 3.3 Volt ADC, normalization from 0 to 1000 carried out by the HAL and the input type used (Differential , Pseudo or single ended).

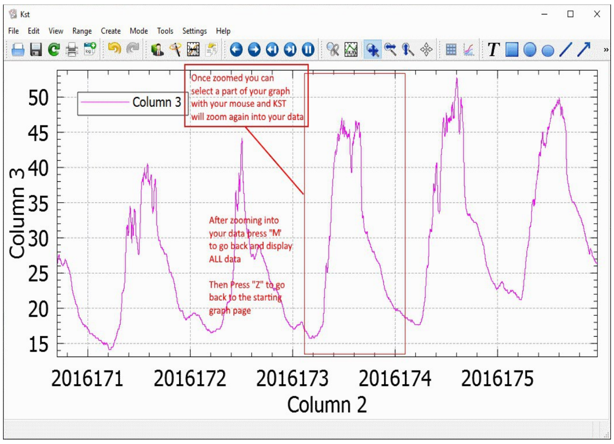
By measuring the voltage drop on a low value resistor it is also possible to calculate the current that flows there.

There are several possible methods of calculation, as explained in ***This Page***.

The Theremino_Logger application



This simple application is the natural complement of the Adc24, essential to build a datalogger. Downloading the Theremino Logger and instructions for use are in ***This Page***.



Display LOG

The Log files are viewable with KST which is a free application and open source.

KST is perfect solution for all science-logging needs.

A radio controlled datalogger

With Theremino Logger on a ***Tablet TCU*** you get a ***system similar to these*** without spending thousands of Euros. The result is a complete datalogger controllable via radio, which can store data for years, consuming only 2 watts (less than 500 mA at 5 volts).

The complete system It can be enclosed in a sealed container, without the need to open it. It controls via radio via TeamViewer and data are accessible in local network, via the Windows folders.

Geo-Electrical Measurements

With the Adc24 geo-electrical measurements are greatly simplified. The resolution is such that it is enough to prepare only one scale for the voltage and a unique scale for the current. So all necessary components are a dozen of resistors, as from the next page scheme.

Measure the voltage

It predisposes the voltage scale from minus 25 Volt to plus 25 Volt, with two resistors 10 Mega ohm, followed by two resistors from 2.2 Mega ohm grounded and two 1 Mega towards 2.5 Volt.

The resolution of the voltage measurement is about 3 micro volts. It is a superabundant resolution but it is a good thing to have a good margin for measurement errors, noise and disturbances.

Measure the current

It predisposes the scale of the current to be less than 3 amperes to more than 3 amps, with a 10 ohm resistor 10 Watt (and a 0.5 ampere fuse to be safe in the event of short).

The following components are the same that are used to measure the voltage, that is, two resistors 10 Mega ohm, followed by two resistors from 2.2 Mega ohm grounded and two 1 Mega ohm towards 2.5 Volt.

The current measurement resolution is about 400 nano amperes. It is a superabundant resolution but it is a good thing to have a good margin for measurement errors, noise and disturbances.

Maximum common mode voltage

The measurements are performed in the differential, but the door excitation voltage some of the inputs to voltages greater than the supply of the Adc24 or even minor zero. With the components proposed the maximum common-mode voltage goes from negative 25 Volt to 25 Volt positive. Thus in addition to the normal 12 Volt excitation voltage, you can also use a voltage of 24 Volt.

Extra-voltage resistance

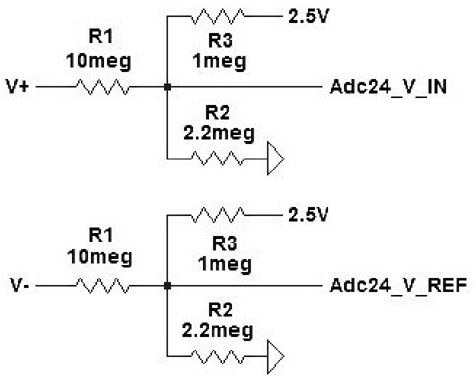
Both for the measurement of the voltage for which the current, the ADC is completely isolated by the resistors 10 Mega ohm, which guarantee the resistance to extra-voltages up to thousands of Volt positive and negative. The safety limit is given only by the maximum voltage bearable by the resistors, which normally for 1/4 Watt resistors is at least 250 Volt and with resistance to short pulses up to over 1000 Volt.
Even if the current measurement resistor should endure very strong currents, caused by wiring errors and even if, in the absence of fuse, were to take fire and stop, all other resistors would remain cold and the ADC would not risk anything.

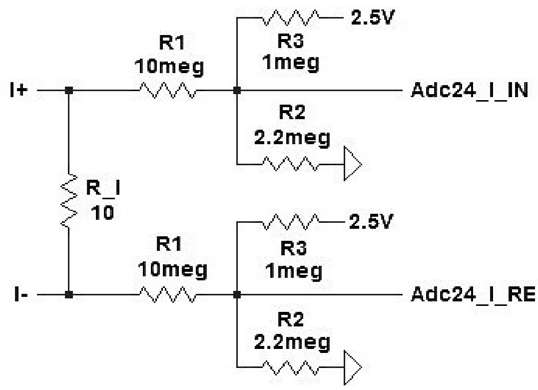
Geo-electrical measurements - Input Circuits

These circuits are chosen to have a good voltage margin before saturate, so as to also work in difficult conditions, even with strong disturbances caused for example by electrical lines, and also with the excitation voltages up to 24 Volt.

Common mode range	Differential voltage range	R1	R2	R3	min Value *(Note 1)*	max Value *(Note 1)*
-25 Volt to +25 Volt	-50 Volt to +50 Volt	10 Mega ohm	2.2 Mega ohm	1 Mega ohm	-51.300	51.300

*(Note 1)With these values gives an output directly to the Volt. More information **This Page**.*





Wiring resistors

Are not they beautiful to look at, do not seem professional and to get them you have to know how to solder well. However, this solution provides the best performance. Reducing the sensitive area will minimize the sensitivity to electrical noise and inter-modulation between channels.

Where to begin the red and blacks wires, there are no more problems disorders and even the danger of damaging the ADC with extra tensions and errors.

You must build four of these adapters, connectors must be of good quality, ***as explained here***. The wires of the first two go directly to the pickets that measure the voltage and the wires of the other two go to the 10 ohm resistor, which will have in the series fuse and battery.

The current measurement resistor

In the diagram it is shown as R_I ten ohms. Normally this resistor works with currents of a few milli-amperes, and never higher than 100 mA. So its dissipation not exceeding one-tenth of watts and you could use any tiny 1/4 or 1/8 Watt.

But if they are wrong commutations and connects directly to the excitation voltage bursts instantly (would be 14 Watts with twelve volt and even 58 Watts with twenty-four volts). So it is advisable to use a 10 Watt resistor with a series 500 mA fuse.

Geo-electrical measurements - Settings and calculations

On this page we assume that you have connected the inputs **V_IN, V_REF, I_in and I_REF,** the schemes of the previous page, the first four ADC Pin.

Configure the inputs

The configurations, to be set on Pin 1, 2, 3 and 4 of the HAL application are these:

- **V_IN --- Pin 1** (= -51.3 Min / Max = 51.3 / Differential / Gain = 1 / Without Bias)
- **V_REF --- Pin 2** (Unused or Adc24_ch_b)
- **I_in --- Pin 3** (= -51.3 Min / Max = 51.3 / Differential / Gain = 1 / Without Bias)
- **I_REF --- Pin 4** (Unused or Adc24_ch_b)

On **Pin 1** we will read the value for the voltage and the **Pin 3** that of the current, for which we call these values **Vv** and **Vi**.

These two values are sent on two slots. Then check that they are the same that are set Theremino Logger (or other application that needs to read them). Take care also that no other input (HAL), and no other applications, write in the same slot.

Calculate current and voltage

The effect of the voltage dividers has been calibrated in the HAL application, with -51.3 and +51.3 values that produce output values directly in Volt. So the Voltage and current values are calculated with these simple formulas:

- `Voltage(Volt) = Vv`
- `Current(amperes) = Vi * 0.1 (0.1 compensates for the 10 ohm resistor)`

Adjust the sampling rate and filter

To make these adjustments must be selected **Pin 7.** More information on the Pin 7 adjustments on ***This Page***.

If you only use Pin 1, 2, 3 and 4 then as "Pin number" you can set "4".

The Pin 2 and 4 are not active so the actual channels are only two. So, assuming you want one hundred samples per second, you set "samples / sec" with "200" value.

For the geoelectric we recommend the "Fast" filter that does not cause a slowdown of sampling and reduces noise enough.

Temperature measurements with RTDs

The RTD sensors (Resistance Temperature Detector) include: the NTC (Negative Temperature Coefficient), PTC (Positive Temperature Coefficient) and in particular the PTC to platinum, which normally are the PT100, PT500 and PT1000.

The resistors Platinum change in very repeatable value. IEC 751 prescribes for PT100, 500 and 1000 a TCR of 0.00385Ω/Ω/ °C. The temperature of zero degrees PT100 have a hundred ohms resistance, the PT500 and PT1000 five hundred ohms thousand ohms; for precise values consult ***this file***.

Measure other RTD

Not just resistors to platinum, but all RTD (PTC and NTC) can be measured by the circuits of the next pages, with exactly the same components that are used for PT1000.

The patterns of these pages are generic resistance gauges, so they can measure any type of RTD. Then the software will calculate the temperature from the resistance, with appropriate tables, or with formulas, or with calibration points, depending on the sensor used and its linearity.

With the PTC and NTC the accuracy is lower than that of the resistors and the platinum in many cases one could use a simple two-wire connection.

Why not use thermocouples

For thermocouples it takes a special metal adapter for the reference junction:
http://www.phidgets.com/products.php?product_id=3106

And the final result are measurement errors of +/- 2 °C, such as from features here:
http://www.phidgets.com/products.php?product_id=1051

The PT100 resistors are over ten times more precise, they do not need special adapters, or the cold junction compensation and ***some models up to 1000 °C***.

The thermocouples are only preferable for temperatures from 800 to 1600 degrees, but one must also consider that thermocouples for high temperatures are inaccurate at low mean temperatures, and that under fifty degrees do not measure precisely (are constructed with materials that at low temperatures give a practically constant potential difference).

In the rare cases where the thermocouples were really necessary, given the need to compensate for the cold junction and the complications that would arise, we recommend not to use this Adc24, but incorporate specially-designed thermocouples. For example, the great ***Phidgets adapter***.

RTD - Constant current or constant voltage?

The measuring classic schemes of RTD suggest to use a constant current, usually of about 500 uA or 1 mA. With the constant current you should get the "advantage" of having a linear voltage variation with temperature. This was an advantage when the calculations were made in mind or tables, but today there is always a processor that makes the accounts, and the processor has no problem simultaneously measure both voltage and current, and unite the whole world into one .

Even the circuits with current generator, always expect to measure the current with a resistor and to compensate its variations, given that the current generators are never accurate.

Another supposed advantage of the current generator was fixed to keep the dissipation in the sensor. This was true when they used strong currents, but today with Adc24 using such low currents, to eliminate the problem of the sensor heating (something uW, ie millionths of a Watt). And in any case it works almost constant current, the current change is minimal.

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Since the AD7124 could generate a constant current, just to measure the RTD, we have long studied the subject before deciding.

So we did a lot of calculations and many simulations and found that using a constant voltage, instead of the constant current, you only have advantages:

- You should not use an extra Pin to output the current, then you can measure up to five Four-wire RTD, with a single Adc24. And even eight or sixteen RTD connection with a three-wire and two-wire.
- You do not have to carefully calibrate the current and resistors, depending of the RTD values, to avoid going off the scale.
- You can use the same resistive values for a wide spectrum of RTD, with typical resistance from 100 ohm up to 10 K ohm and beyond.
- You get a more precise measurement of the constant-current circuits, because with our patterns are never in danger of going off the charts and you can work with higher voltage changes. For example with a PT1000 variations from -70 to +300 degrees they are of about half a Volt, instead of 100 mV which would be obtained with a PT100 and the constant current circuit, proposed in the Application Notes of the AD7124.

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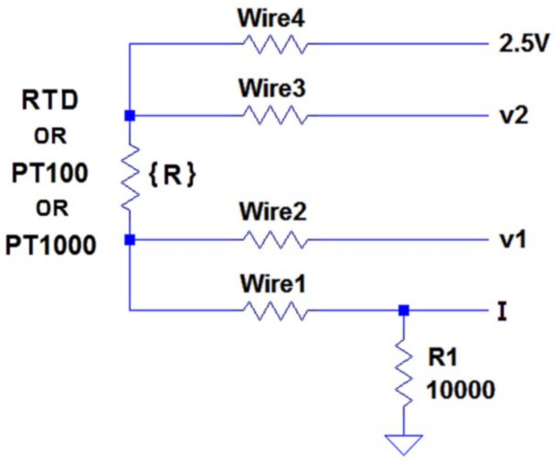
Anyone wishing to check our calculations, can begin reading the Application Notes of the AD7124, so that they get an idea of the argument and then, if necessary, ask the LTSpiceIV simulation files, writing to us at ***engineering@theremino.com***

RTD - Input Circuits

With the following schemes can be measured resistors PT100, 500 and 1000, as well as fixed resistors and also any type of RTD (PTC and NTC), with values at zero degrees to less than 100 ohm to over 10K ohm.

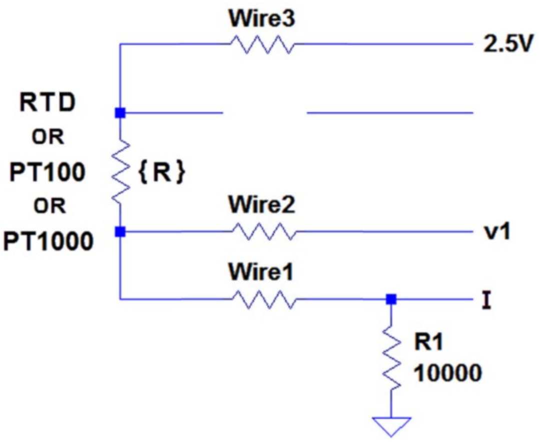


<--- Connection four-wire, with which you can connect up to five RTD on a single Adc24.

With four wires eliminates the measurement errors caused by the resistance of the connecting wires, even if the wires are different from each other and do not have the same resistance.

Typical example of unequal resistances would be a shielded cable with three inner wires. With a shielded three-wire cable is well connected to her stocking "wire3". But if you use a shielded cable with four wires, then the shield must be connected to "GND".

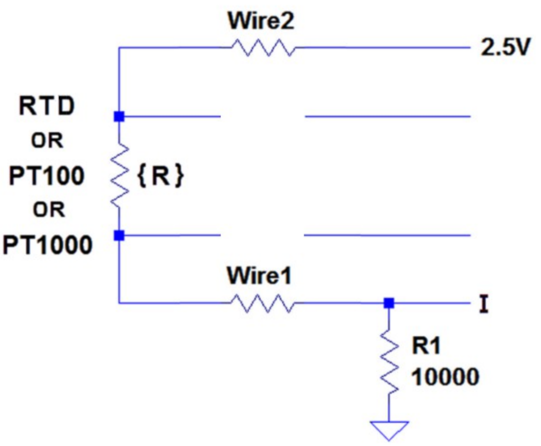
The resistance is calculated as follows: **R = 10000 * (v2 - v1) / V (I)**



<--- Three-wire connection, with which you can connect up to eight RTD on a single Adc24.

With three wires they eliminate the measurement errors caused by the resistance of the connecting wires, but only if the wires are perfectly equal to each other (exactly the same length, the same diameter and same material). If you use a shielded cable must have three inner wires and the shield to ground (GND).

The resistance is calculated with a more complex formula:
R = 10000 * (2.5 - 2 * v1 + V (I)) / V (I)



<--- Two-wire connection, with which you can connect up to sixteen RTD on a single Adc24.

This scheme does not compensate for the resistance of the wires, so it is usable only with short connections, in applications that do not require great precision.

But adjusting for comparing the slope and zero of the curve (Multiply and Trim), and not changing over the wires and the probe, you can achieve the same accuracy of the previous schemes.

The resistance is calculated as follows: **R = 10000 * (2.5 - V (I)) / V (I)**

If R1 is different from 10K ohm then in formulas it must replace 10000 with its value.
If you use the Theremino Logger application then the value of R1 is set in the "Multiply" box.

RTD - Setting Inputs

Connecting Four-wire RTD - Maximum 5 RTD **(Note 1)**

Suppose you've configured the inputs to the first three Pin:

- **V2** **Pin 1** (= -3.3 Min / Max = 3.3 / Differential / Gain = 1 / Without Bias)
- **V1** **Pin 2** (Unused or Adc24_ch_b)
- **I** **Pin 3** (Min = 0 / Max = 3.3 / Single Ended / Gain = 1 / Without Bias)
- **Not used** **Pin 4** (Unused)

On Pin 1 we will read its value to the voltage on Pin 3 and that of the current, so in the formulas above these values are called **(v2 - v1)** and **(I)**.

(Note 1) If we are content to read up to four RTDs, you can waste a Pin every four. But per able to make it stand only five out of a Adc24, and given that the inputs are only settable in pairs, one should arrange them as in this example:

- The Pins 1 to 10 set as "Differential" to measure the five voltages (v2 - v1).
- The Pin 11 to 15 set as "Single", to measure the five current (I) referred to GND.
- Pin 16 remains free (Unused)

Connecting three-wire RTD - Maximum 8 RTD

The measuring inputs, both the current and that of the voltage, to be read with reference to "GND", then you must set them both so:

- Min = 0 / Max = 3.3 / Type = Single Ended / Gain = 1 / and of course nothing Bias

Connecting two-wire RTD - Maximum 16 RTDs

The single measuring input must be read with reference to "GND", then you must set so:

- Min = 0 / Max = 3.3 / Type = Single Ended / Gain = 1 / and of course No Bias

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The values sampled by Pin will be sent on one or two slots. Check that they are the same that are set Theremino Logger (Or other application that needs to read them). Take care also that no other input (HAL), and no other applications, write in the same slot.

Adjust the sampling rate and filter

To make these adjustments must be selected **Pin 7.** More information on the Pin 7 adjustments ***This Page***.

The temperature measurements are always very slow, then to reduce noise normally using the minimum speed, ie 10 sps. Depending on the amount and the type of noise, some filters may be more appropriate, then it is good to try them all and choose case by case.

RTD - Miscellaneous notes

The resistor R1

The resistor R1 must be precise and stable, a good solution would be to use a stable resistor in temperature, but not accurate, measure it and enter its resistance value in the software. Or you could adjust its value, always in the software, so that the measured temperature corresponds to that of a reference thermometer.

To maximize the voltage swing, R1 should be more or less the same average value of the sensor. So with PT1000 you should use a R1 of about 1000 ohms, which would cause a dissipation of about 1 mW on the sensor (a bit high but still tolerable). But for the PT100 it should use an R1 of about 100 ohm, with a power dissipation of about 15mW on the sensor. Which in many cases it could significantly alter the measured temperature.

To be safe you use the 10 K ohm value that limits the dissipation in the sensor to a few tens of micro watts, which heat the sensor to a negligible amount. Unfortunately with 10 K ohm it has a very small voltage variation and errors increase in proportion.

Increase the useful signal

With the PT1000 you have a large enough signal, but with the PT100 the useful signal is very small. It could increase a bit reducing R1 to 4700 ohm.

For further improvement, but only if you use the four-wire connection, you may amplify the differential voltage signal (v2 - v1) by increasing the gain to 2, 4, 8 or 16. But beware that if you amplify it too could limit the measuring range.

To compensate for the gain you must set a value of R1 divided by the value of Gain in the calculation formulas.

So if for example you have R1 = 10000 and set a gain of 4, then you must set the value 2500 in the formula (or "Multiply" box of Theremino Logger).

Reduce noise

First defense against interference is to use a shielded cable. Note that when the four-wire connection you should not use the shield to one of the wires, but you must use a shielded cable with four internal wires.

As a supplement could be added capacitors 10 uF or even from 100 uF, low series resistance (ESR) or ceramic, between each of the ADC input and GND.

With regard to noise reduction also read ***This Page***.

RTD - Formulas to calculate the temperature

The temperature calculation is carried out in two steps: first we calculate the resistance, as explained in the previous page; then using tables, or better a formula, to transform the resistance in temperature

For there is a platinum RTD ***polynomial formula*** extremely precise. In ***this site*** you can find more detailed information and a chart that compares the polynomial formula, with other less precise formulas.

With the same formula could also linearize the non-platinum RTD (NTC and PTC), it would be enough to find the eight coefficients for each sensor model. But, given the lower precision of these sensors, usually using a simple formula or table.

Formula valid for all platinum RTD

We implemented the polynomial formula in the application "Theremino Datalogger", in a function that calculates the temperature with mean absolute error of 0.015% throughout the temperature range from -200 °C to + 850 °C.

The following function computes the temperature in degrees centigrade. The parameters are: "R" which is the measured resistance; and "Rzero" which is the resistance at zero degrees. The same function is valid for all the platinum RTD (PT100, PT500, PT1000 and any other value).

```
const c0 As Single = -245.19
const c1 As Single = 2.5293
const c2 As Single = -0.066046
const c3 As Single = 0.0040422
const c4 As Single = -0.0000020697
const c5 As Single = -0.025422
const c6 As Single = 0.0016883
const c7 As Single = -0.0000013601

Function TempFromPtRes (ByVal R As Single, ByVal Rzero As Single) As Single
    R = R * 100 / Rzero
    Return c0 + R * (c1 + R * (c2 + R * (c3 + c4 * R))) / _
                     (1 + R * (c5 + R * (c6 + c7 * R)))
end Function
```

Accuracy and tolerances of platinum RTD

The previous function should give errors around 0.01 °C from -100 °C to +100 °C and errors of less than 0.1 °C up to 850 °C. But the really achievable accuracy with the commercial RTD sensors is less.

RTDs are commonly available in two accuracy classes:
Class A devices have a tolerance of ± 0.2 °C, compared with DIN, up to 500 °C.
Class B devices have a tolerance of ± 0.35 °C, compliance with DIN, until 400 °C.

With a simple calibration by comparison you can calibrate RTD that you buy within 0.1 °C and even better for the low average temperatures. The calibration should be done for every single device and calibrated devices must not be exchanged or replaced.

The Theremino Adc24 features

Power supply:	5 Vdc
Energy consumption:	< 5 thousandths of a Watt (900 uA at 5 Volt)
Sampling rate:	From 10 to 19200 samples per second
Types of inputs:	Configurable as "differential", "Pseudo" or "Single Ended"
Number of inputs:	From 1 to 16, 24-bit (Σ-Δ) inputs (8 differential, pseudo 15 or 16 single ended)
Dynamic range:	127 dB @ 100 SPS (with three concurrent channels and gain 1)
Full-scale:	+/- 3.3 Vpp (differential) or from 0 to 3.3 Volt (Pseudo and Single)
Adc step (x 1):	0.4 uV (Differential) - 0.2 uV (Pseudo and Single)
Adc step (x 128):	3.2 nV (Differential) - 1.6 nV (Pseudo and Single)
Input impedance:	Greater than 1 Giga ohms
Input Current:	Less than +/- 4 nA
Input Current:	Variation with temperature +/- 25 pA / °C
Maximum voltage:	From -0.3 Volt to +3.6 Volt (maximum voltage applicable to the inputs)
Maximum current:	+/- 10 mA (maximum current applicable to inputs)
HBM ESD Rating:	Human Body Model = 4 kV
ESD Rating FICDM:	Field-Induced Charged Device Model = 1250 V
MM ESD Rating:	Machine Model = 400 V
Output 3.3 Volt:	Up to 300 mA, accuracy (1%), stability (48 ppm / °C).
Output 2.5 Volt:	Up to 10 mA, accuracy (0.2%), stability (2 ppm / °C).
1.65 Volt output:	Only for biasing the sensors (accuracy and stability equal to 3.3 Volt / 2).
Data interface:	Three-wire SPI, QSPI ™, MICROWIRE ™ and DSP
Data format:	Protocol of Analog Devices (see ***data-sheet of the AD7124-8***)
Speed serial line:	From 30 baud to 5 mega baud
Time accuracy:	About 500 uS or less (***Note 1)***)
Temperature:	From -40 °C to +105 °C (functional)
Temperature:	From -65 °C to +150 °C (in stock)
Dimensions:	60 x 34 x 12 mm
CE conformity:	Not applicable. It is a component, so do not certifiable (***Note 2)***)

(Note 1) The imprecision of 500 uS also includes the sampling delay, and communication with the acquisition software. They are worse values of the GPS precision and commercial devices with integrated GPS, but entirely irrelevant on the analysis, since it is about one-twentieth of a cycle of the highest seismic frequencies.

(Note 2) CE certification applies only to finished products, to the ultimate consumer. The ADC24 module is an electronic component, intended for those who build equipment. So it is the same manufacturer, having to build law and certify the finished device. For more information on this topic, read ***This Page***.

For more complete information consult ***the AD7124-8 data-sheet***.

The PCB design and schematics of Theremino Adc24, they download from ***This Page***.

Noise characteristics

In this new version (November 2016) we have improved this page. In previous publications of this document the noise values were obtained starting from the noise steps, manually estimated from the HAL scope and then recalculated using formulas to find the RMS value. This manual and cumbersome process had produced systematic errors and even some gross miscalculations.

Now the noise values are measured with the AdcTester, so they are more accurate and deviate very little from the data sheet values. We have also eliminated some insignificant columns and added data for different gain values. All values are "Input Referred" that is, with the noise reported at the low noise pre-amplifier input that, in these tests, was set with gain from 1 to 128.

Filter = “Max Speed”

SPS	Gain = 1 (uV eff.)	Gain = 4 (uV eff.)	Gain = 16 (uV eff.)	Gain = 64 (uV eff.)	Gain = 128 (uV eff.)
10	0.15	0.10	0.05	0.03	0.02
200	1.0	0.45	0.22	0.12	0.10
600	1.5	0.68	0.34	0.20	0.17
1200	1.9	0.85	0.45	0.26	0.22
4800	6.9	2.05	0.87	0.41	0.37
9600	73	18	4.8	1.42	0.91
19200	590	147	37	9.25	4.95

Filter = “Fast”

SPS	Gain = 1 (uV eff.)	Gain = 4 (uV eff.)	Gain = 16 (uV eff.)	Gain = 64 (uV eff.)	Gain = 128 (uV eff.)
10	0.15	0.10	0.05	0.03	0.02
200	0.95	0.43	0.21	0.12	0.09
600	1.43	0.64	0.32	0.19	0.16
1200	1.86	0.83	0.42	0.25	0.21
4800	2.85	1.36	0.72	0.39	0.35
9600	4.9	2.6	1.3	0.69	0.59
19200	46	12.6	4.1	1.73	1.43

The "Fast" filter reduces the noise of ten times at high SPS, and gradually less, reducing the sampling frequency. From 600 sps downside the influence of the "Fast" filter is minimal.

The "Medium", "Slow" and "Post" filters further reduce the noise, but slowing down sampling a lot, are therefore usable only for slow applications, such as scales, thermometers, PH meter, etc.

Comparation with GeoPreamp

In commercial equipment for noise measurements it is usually carried out with inputs connected to resistors 4000 ohms. This value simulates the impedance of 4000 ohms output, some of Geophones 4.5Hz, and is similar to the output impedance of other sensors from 3000 to 5000 ohms.

Products without pre-programmable amplifier, prefer Geophones from 4000 ohms to increase the signal to noise ratio. The 4000 ohms Geophones are expensive but provide more signal (80 V/m/s), with respect to economic SENSHE by 4.5 Hz (375 ohms and 26 V/m/s).

However is interesting to note that, regardless of the absolute gain, the SENSHE are more efficient, provide a signal only three times less, with a ten times lower resistance. So with an amplification of four times, the SENSHE provide 104 V/m/s, and have a lower noise of from 4000 ohms Geophones, because of their resistance ten times lower.

With SENSHE 375 ohms and a "Gain = 4", the signal is 30% greater, 50% less noise and saving money is remarkable. But of course this is only possible if you have an ADC with programmable pre-amplifier, low noise, like the Theremino Adc24.

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So we did that measures both at 4000 to 375 ohms. For these measures the sampling rate is typically set to 200 Hz and it is not necessary to divide the frequencies with the analysis of the spectrum, since in the delta sigma ADC the noise is evenly distributed, over the entire band for which they are designed (from 0.1 Hz and above).

In our measurements the Theremino Adc24 (600 sps, equal to 200 per channel), noise has just over 16 counts pp, equivalent to almost 120 dB dynamic range, compared with its 6.6 volt maximum pp. While similar commercial equipment, with 200 sps, have noise equal to 21 counts pp, equivalent to 118 dB dynamic range, compared to 4 volts maximum pp.

The characteristics of some commercial appliances declare 21 counts pp RMS, And this is incomprehensible (the measures are effective or value, that is, RMS, or are peak to peak), so it is likely that there are errors, perhaps for translations. It is reasonable to conclude that, for all practical purposes, there are no substantial differences in the noise between the Theremino Adc24 (used without preamp) and commercial tromograph.

Summarizing in a table:

Device	Gain	dynamic range	Noise	Sampling frequency
GeoPreamp	1500	60 dB	0.10 uV rms.	Not applicable (analog)
Theremino Adc24	128	86 dB	0.17 uV rms.	600 sps (3 x 200 sps)
Theremino Adc24	1	120 dB	1.45 uV rms.	600 sps (3 x 200 sps)
Similar commercial tromgraph	1	118 dB	1.50 uV rms.	200 sps

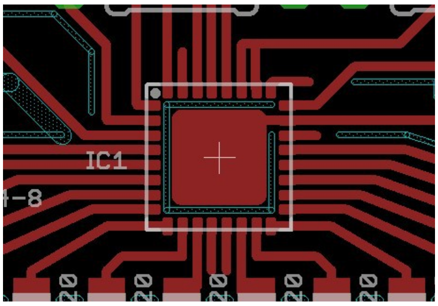
Conclusion

For earthquakes and events "Strong Motion" the Theremino Adc24 does not differ substantially from similar commercial appliances. As for the vibration analysis and microtremor, the presence of the preamplifier makes it considerably higher.

Comparation with commercial appliances

The Theremino ADC24 differs from commercial tromografs, for the presence of a differential input pre-amplifier, low noise, programmable.

Basically it is like having a Theremino GeoPreamp, followed by a 24-bit ADC, for each input.



The preamplifier is programmable to gain from 1 to 128 times, and it is also possible to have some channels with different gain by others.

In addition the sampling rate setting range of (sampling rate) is very broad, from 10 to 19200 samples per second. So some applications can set low samplings rate, to decrease the noise, while other applications will set them to high sampling rate, to have a more rapid response.

These features allow you to adapt precisely Theremino ADC24 to different types of analysis and obtain the maximum dynamic and the least possible noise.

For example, the analysis of micro-tremors, where signals are weak and there is no risk of saturating, he turns up the gain at 128 and minimizes noise. You then obtain a noise significantly lower than that of commercial appliances not equipped with programmable preamplifier and just slightly greater than that obtainable with the Theremino GeoPreamp.

The low background noise allows to make more precise HVSR analysis, as well as to amplify the band of 1 to 4 Hz, where the Geophones signal is low. You can then use 4.5 Hz Geophones in place of the very expensive 2 Hz Geophones. And the Geophones from 4.5 Hz are the best, not only for the least cost, but also because they have a shorter recovery time.

Finally, but not least, unlike the commercial tromografs, all features are specified. For example know input current and know that it is very low (in the order of nano amperes), it allows to design specific Datalogger, for each type of analysis.

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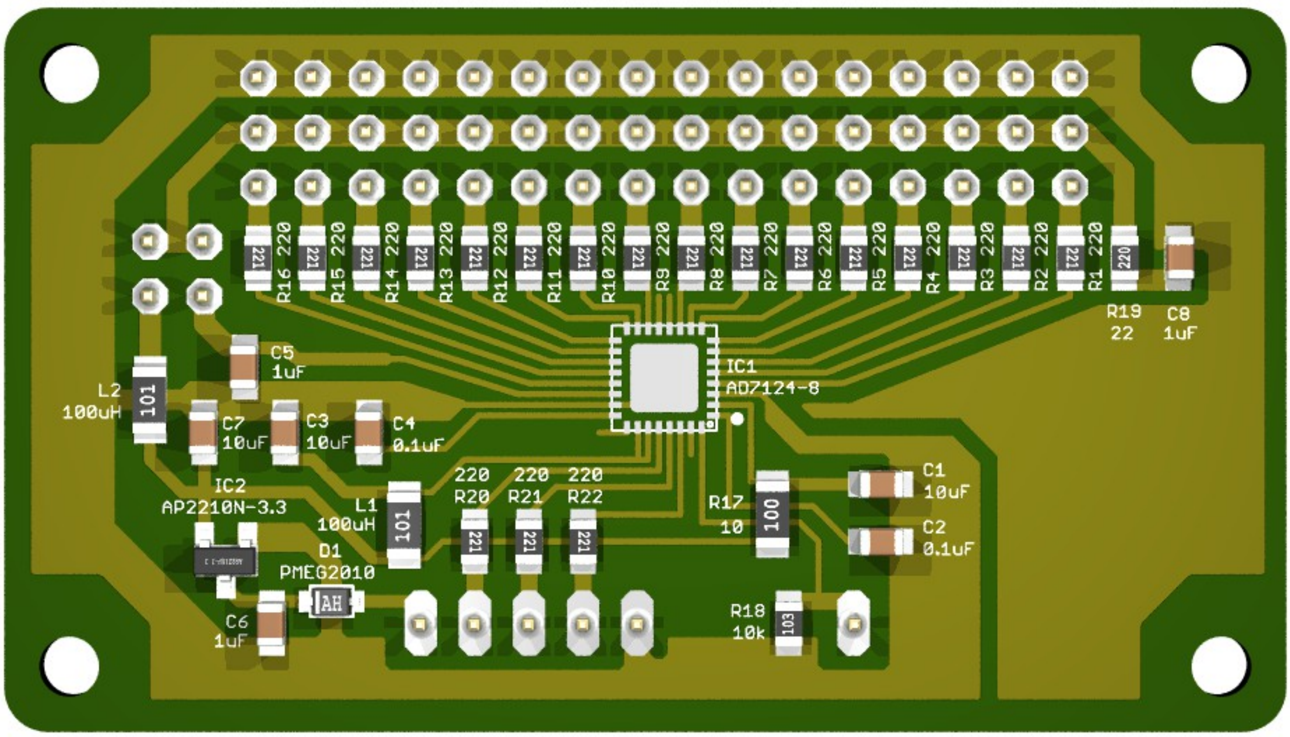
As this document has been compiled with the greatest care, something can always escape. If you find errors please write to engineering@theremino.com

Assembly plans and schemes

The PCB design and schematics of Theremino Adc24, they download from ***[This Page](#)***.

This can be useful in case of problems, to make a visual inspection of the components.



Almost 100% of operating defects is caused by visibly broken components, poorly welded or badly positioned during construction, or from tin balls which short-circuit the two tracks, or by connecting slopes interrupted. With a good lens and a lot of light, you can control all components in minutes.

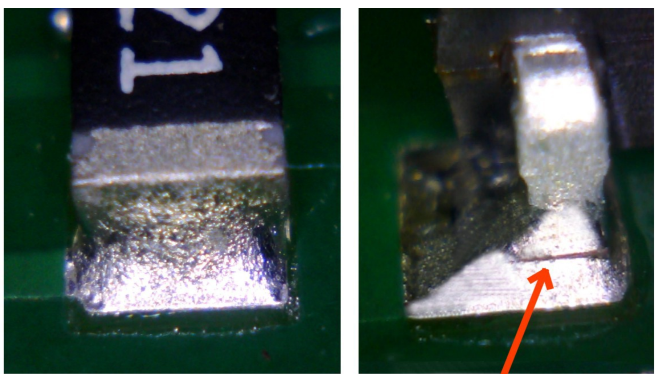
Instructions for visual inspection

The components are made of ceramic and knocking on hard material edges can crack. With plenty of light and a good lens, monitor that no cracks or broken edges.

The components may be welded in the wrong or badly positioned, check all the welds of each component, on the one hand and on the other hand.

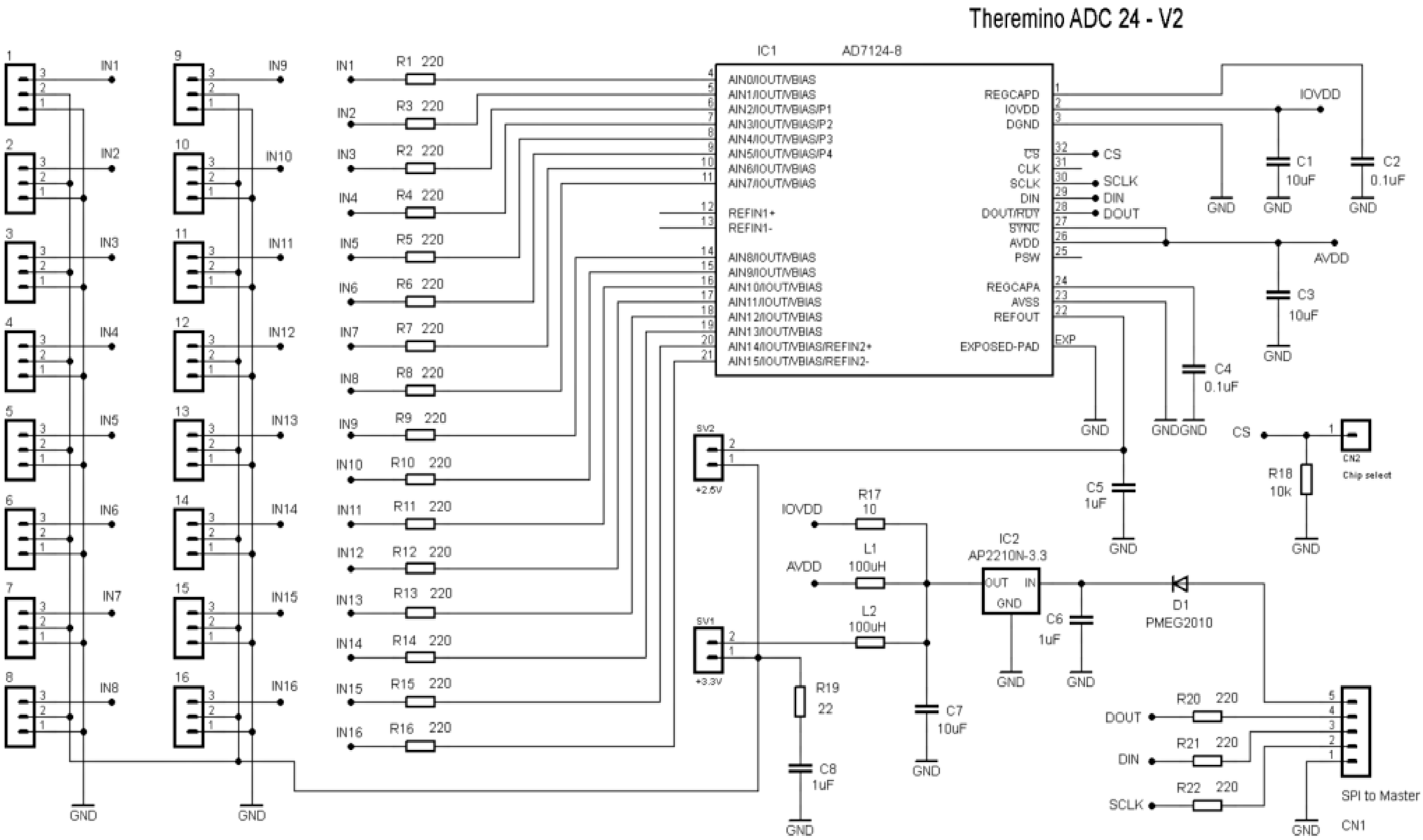
Check that there are no balls or tin bridges that may cause short circuits between the tracks.

Finally, check that there are no tracks interrupted by scratches or lines.



OK Defective

Wiring diagram



For easier reading the values you could print the high-resolution image you download ***clicking here***.

The resistors R1 to R16 help the internal protective diodes to withstand ESD events and cause a mild low pass (with the input capacitance), to attenuate the radio frequency disturbances. The capacitors C1 to C8 filter the supply voltages, to minimize the interference during the samplings.

The diode D1 protects the ADC module, in the case would connect the power supply wires to the contrary. After the diode the supply voltage continues and is stabilized at 3.3 Volt by IC2, which is a low noise regulator (less than 300 nV/sqrtHz), with 75 dB of attenuation of disturbances of the power supply and with high precision and stability (better of 50 ppm / °C). Finally, the 3.3 Volt powers the digital part of the ADC (IOVDD) through R17 that prevents the return of disturbances to the analog part.

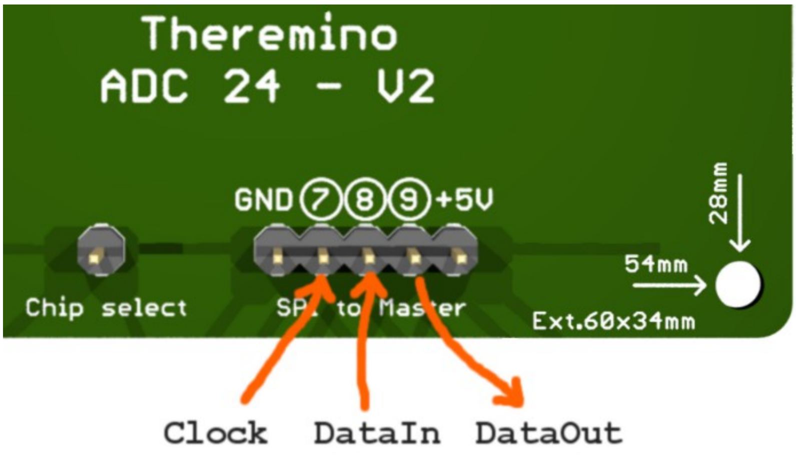
The 3.3 Volt, further filtered L1 and L2, feeds the ADC and the reference voltage to 3.3 Volt towards the Pin. The resistor R19 and capacitor C8 dampen the over-oscillations in the case would connect sensors with too long cable.

The resistors R20, R21 and R22 prevent over-oscillations of the digital signals (DOUT, DIN, and SCK) and the resistor R18 keeps connected to ground, and then activated, the enable input (chipselect).

Send to Pin the reference voltage of 3.3 Volt, puts the jumper on SV1.
Send to Pin to 2.5 Volt super precise from the chip, puts the jumper on SV2.
Send Pin to the reference voltage of 1.65 Volt, puts the jumper on Pin 2 and 3 Pin 16.

Be careful to place **only one of the three jumper**, Otherwise they will bring into short supply voltages, one with the other. nothing should happen but it is better not to try.

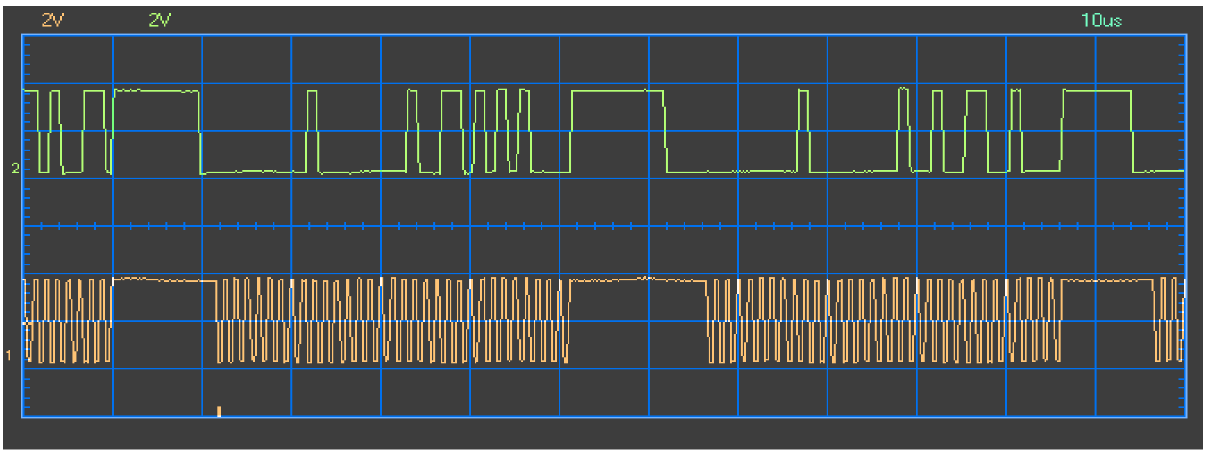
Interface to the micro



The Theremino Adc24, connected to a “Theremino Master” module and controlled by the application Theremino HAL is immediate and easy to use. But who would want to spend a few months to plan, it could start from scratch and groped to interface with other board (eg Arduino).

Useful information for the brave:

- The interface to the micro is very flexible (Three-wire SPI, QSPI ™, MICROWIRE ™ and DSP).
- The supply voltage is 5 Volt (minimum 3.5, maximum 12) with a current of about 900 uA.
- The Clock, DataIn and DataOut signals are from zero to 3.3 Volt.
- The maximum clock frequency is 5 MHz (but you can hardly reach it with an Arduino or similar).
- To be able to sample at 19200 SPS firmware needs to be optimized.
- At some points you have to give the ADC to digest the controls time (see Wait in our firmware).
- To sample fast you have to use a structure with two interrupt to Ping-Pong like ours.
- We suggest you copy the basic structure of the Master firmware you download from ***This Page***.



Reading of 19200 samples per second clocked at 800 KHz (lower track = Clock, upper = DataOut)

For complete information on the communication protocol, internal registers and timings, see the ***data-sheet of the AD7124-8***.

Test the Adc24 modules

The Analog Devices AD7124-8 converter was developed for aerospace and military applications, which contains within it a number of self-testing procedures and can control himself in every aspect, even the most improbable.

In the firmware of the Master they are not implemented all tests available, but only those needed for rapid testing. With the app you can Theremino HAL testing the Adc24 quickly, even with open inputs, without having to connect sensors or test equipment.

Basic tests

This test verifies that the communication between the master and the Adc24 being flawless and within seconds you can test the form with near 100% reliability.

Not the input circuits are tested, but it is only a few components and the probability of defects is minimal. For complete safety it is good to also do a visual inspection of the underside components.

Test of the differential inputs

This test verifies that the inputs are actually working. You do not need to do this test. If the basic test was successful, this test will definitely be positive. But it is a still a good experiment, to become familiar with ADC parameters.

Testing Pseudo inputs and Single Ended

This test verifies that the inputs also work in the way "Pseudo-differential" and "Single Ended". You do not need to do this test. If the basic test was successful, this test will definitely be positive. But it is a still a good experiment, to become familiar with ADC parameters.

Test the input components

With this test, rather long and laborious, the components that go to the inputs connectors are also checked. You do not need to do this test. If the basic test was successful, this test will almost definitely positive. Between the connectors and the ADC there are only a resistor and a cross-linking and the likelihood that they have defects are minimal.

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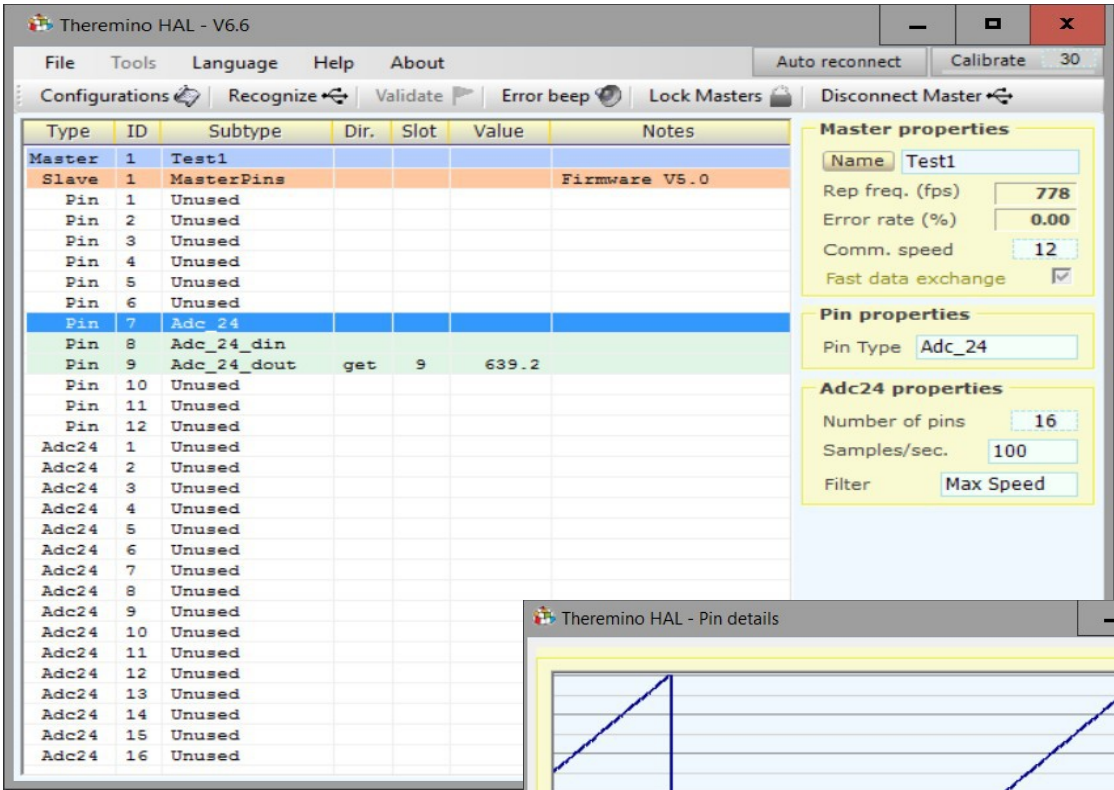
The tests are also useful for practicing with dell'Adc24 settings, so you may want to set them manually using the instructions.

Experts can speed setting parameters, downloading ***This ZIP file***. To enter the test in the database, you delete or rename the previous "Theremino_HAL_ConfigDatabase.txt" and is used in its place the file that you extracted from the ZIP. Or you can open two files with notepad, and add the four tests to its database. With the ZIP file also download the Wave Generator, which takes to the last of the four tests.

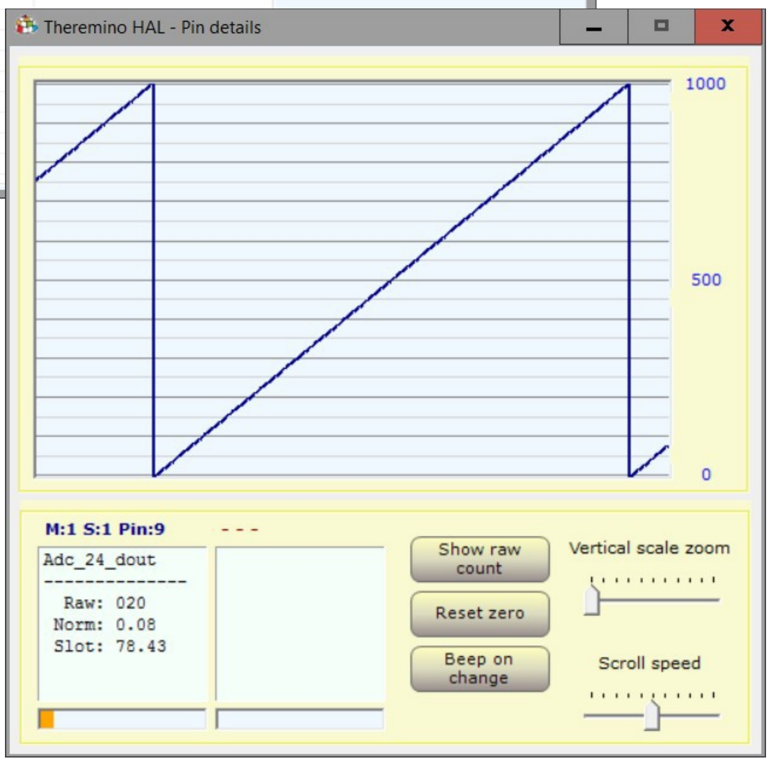
Testing - Basic Test

- Adc24 connect the module to a Theremino Master with five female-female leads, as shown in ***This Page***.
- Start the application "Theremino HAL" (from version 6.6 or greather), or press "ACK" if it was already open.
- Select the Pin 7 line and set the "Pin" Property as "Adc24"
- If the Pin 7 was already "Adc24", bring it first to "Unused" and then again to "Adc24", to ensure that all ADC parameters are set with the start values.
- Check that appear 16 Pin dell'Adc24, as in the following image:



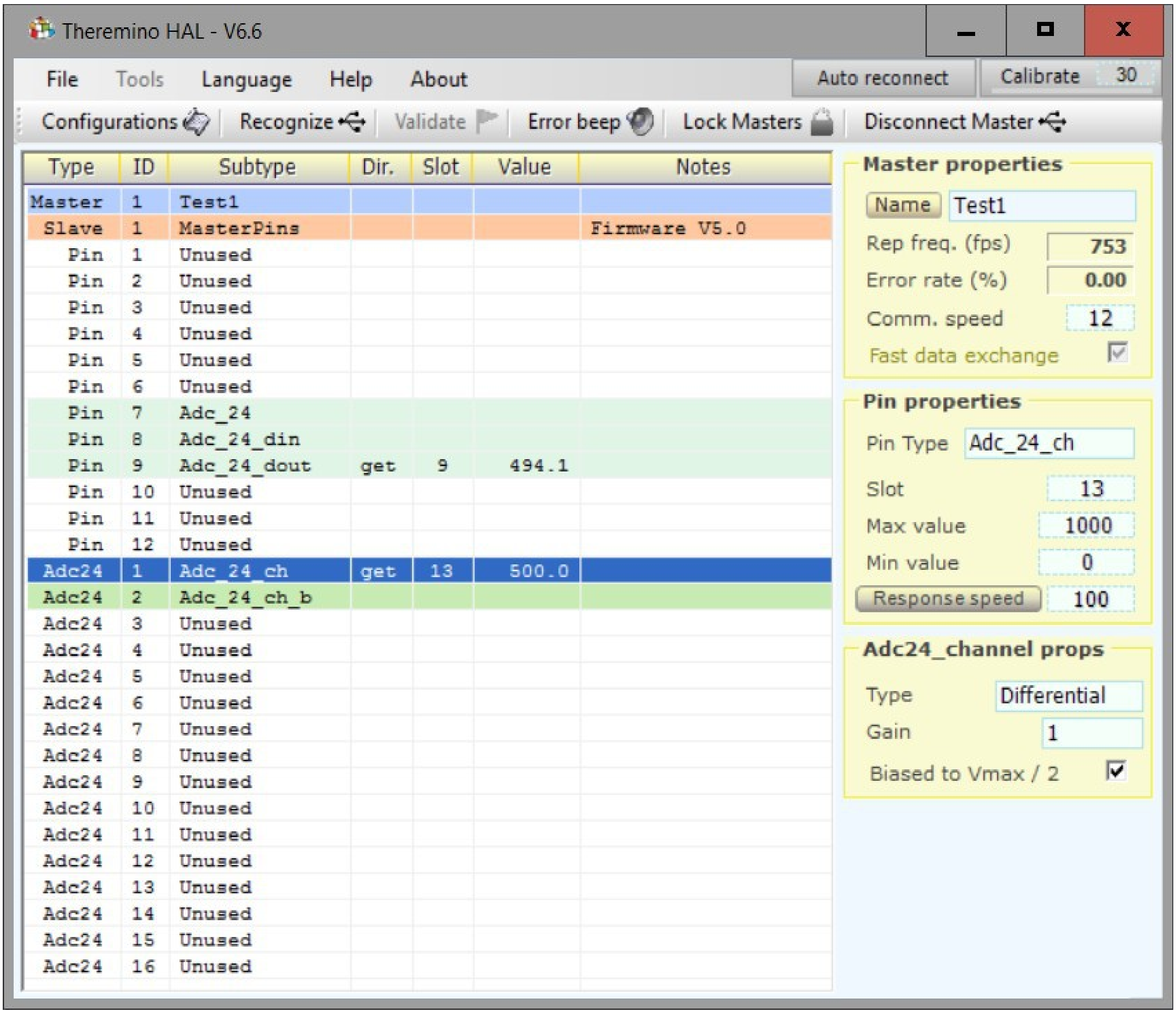
Control, in line Pin 9, the "Value" column number grows by about one hundred units per second.

Double clicking on the line of the Pin 9, opens the oscilloscope and you should see the growth of the "Value", as in this image.



Testing - Test of the differential inputs

Adc24 connect the module to a Theremino Master, start the "Theremino HAL" application and set the Pin 7 as "Adc24", following the basic testing list.



- Select the first dell'Adc24 line (Pin ID = 1) and set its "Pin Type" as "Adc_24_ch"
- Select the second dell'Adc24 line (Pin ID = 2) and set its "Pin Type" as "Adc_24_ch_b"
- In the panel "Adc24_channel props" activate the "Biased to Vmax / 2". Do this activation on both lines, selecting them one at a time.
- Make sure the "Value" on the first of two Pin (Adc_24_ch) is 500.0

If desired, you can extend this test to all eight differential inputs, then also on Pin 3-4, 5-6, 7-8, 9-10, 11-12, 13-14 and 15-16.

Testing - Testing Pseudo inputs and Single Ended

Inputs "Pseudo Diff"

Adc24 connect the module to a Theremino Master, start the "Theremino HAL" application and set the Pin 7 as "Adc24", following the basic testing list.

- Select the Pin 1 dell'Adc24 and set its "Pin Type" as "Adc_24_ch".
- Select the Pin 2 dell'Adc24 and set its "Pin Type" as "Adc_24_ch_b".
- Set the Pin 1 dell'Adc24 as "Pseudo Diff", with "Gain" = 1
- Pin 2 is automatically set to "Pseudo" (they are always in pairs).
- Activate the "Biased to Vmax / 2" is on Pin 1 and on Pin 2.
- Make sure the "Value" on the Pin 1 is 500.0
- Make sure the "Value" on the Pin 2 is 500.0

If desired, you can extend this test to all fifteen Pseudo inputs, then also on Pin 3, 4, 5, 6, 7, 8, 9, 10, 11, 12, 13, 14 and 15 (in "Pseudo" the input 16 is not usable because it is used as a reference for the other fifteen)

Inputs in "Single Ended"

Connect the Adc24 module to a Theremino Master, start the "Theremino HAL" application and set the Pin 7 as "Adc24", following the basic testing list.

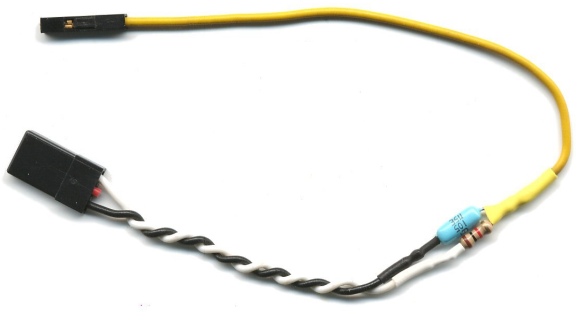
- Select the Pin 1 dell'Adc24 and set its "Pin Type" as "Adc_24_ch".
- Select the Pin 2 dell'Adc24 and set its "Pin Type" as "Adc_24_ch_b".
- Set the Pin 1 dell'Adc24 as "Single ended" with "Gain" = 1
- Pin 2 is automatically set to "Single ended" (they are always in pairs).
- Activate the "Biased to Vmax / 2" is on Pin 1 to Pin 2 on
- Make sure the "Value" on the Pin 1 is nearly 500 (usually 496.4).
- Make sure the "Value" on the Pin 2 is nearly 500 (usually 496.4).

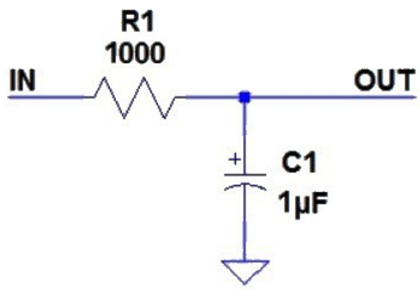
If desired, you can extend this test to all sixteen inputs, then also on Pin 3, 4, 5, 6, 7, 8, 9, 10, 11, 12, 13, 14, 15 and 16.

Testing - Test the input components

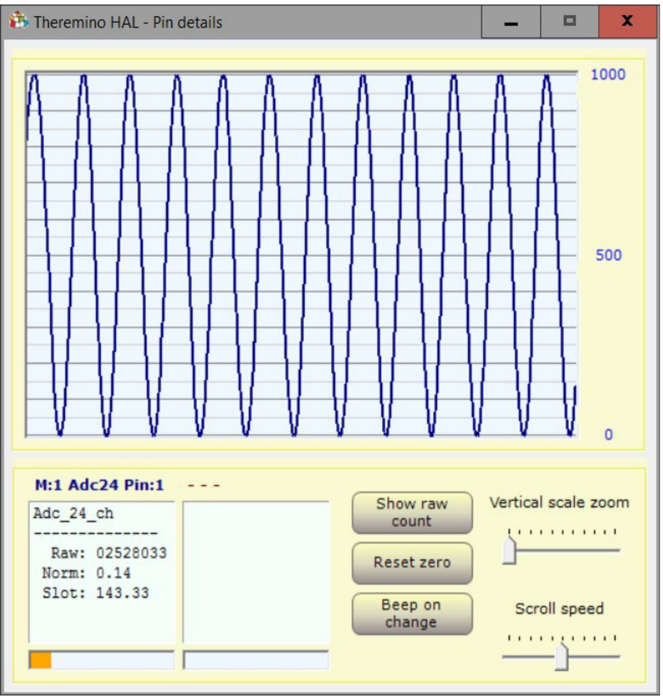
Connect the Adc24module to a Theremino Master, start the "Theremino HAL" application and set the Pin 7 as "Adc24", following the basic test instructions.

Building this simple adapter





- Connect the black connector three-wire to Pin 1 of the Master (black wire to GND and white wire SIGNAL).
- Plug the single-pole (yellow wire) to Pin 1 dell'Adc24.
- Download and launch the ***Theremino WaveGenerator***, Set it to "Sinusoidal" with "Speed" = 1 and "Output slot" = 1.
- On the HAL set the Pin 1 (not the one on the Adc24 but the first on top on the list) as PwmFast, set it on Slot 1, with frequency 15 KHz (15,000) and enable "duty-cycle from Slot."
- Set the Pin 1 dell'Adc24_ch.
- Set the Pin 1 dell'Adc24 as "Single ended" with "Gain" = 1
- Check in Pin 1 dell'Adc24, that the "Biased to Vmax / 2" is deactivated.
- Double-click on the line of the Pin 1 of the Adc24 to open the oscilloscope.



Oscilloscope must appear the sinusoid, as in this image.

You can experiment, increase "Scroll speed" at best, compare the waveform before and after sampling (by a single click on the Pin 1 of the Master and then on Pin 1 of the Adc24). Select the Pin 7 and try different sampling rate. Try also the effect of the filters on the effective sampling rate.

Finally you can select the Pin 1 of the Adc24, set it as "Pseudo" (the amplitude is halved) and try what happens with Gain other than 1. Try also differential with Gain = 1 (Half amplitude from 0 to 500). Finally enable "Biased to Vmax / 2", this is an error, but there are dangers. (no error in the settings can damage the Adc24).

If you want you can extend this test to all sixteen inputs, moving the yellow wire on all Pin and programming them all equal (Single ended, with gain = 1, and without enabling "Biased to Vmax / 2").

Tables and calculation formulas

Not to complicate this we moved the tables and formulas in these pages of the appendix.

Here the tables deepen some aspects, with additional columns and formulas contain all the intermediate steps necessary to achieve the simplified formulas.

As this document has been compiled with the greatest care, something can always escape. If you find errors please write to engineering@theremino.com

Measure differential

There is a small difference between the measures and the Pseudo Differential or Single. When measuring differential in the range of measured voltages it is possible to double (from 3.3 Volt negative to 3.3 Volt positive, then 6.6 Volt in total).

It must take this into account in the calculations. When measuring in the differential will have a formula of two additional multiplication factor, than when it is measured in Pseudo or Single.

Range of common-mode and differential range

Even when it is measured in "Differential" and then measure the voltage difference between two inputs. The inputs, taken one by one, are to be considered as the "Single ended", that is referenced to ground. And these inputs have a voltage range allowed. If you leave this interval saturate the inputs and measuring a wrong value.

The permitted range of the ADC inputs is, in theory, from zero to 3.3 Volt (but actually the linear zone is slightly lower, that is, from 0.1 V to 3.2 Volt).

For this reason it reduces the input voltage with resistive dividers and centers the permitted range in a symmetrical manner, above and below zero volts, by adding a resistor to the 2.5 Volt.

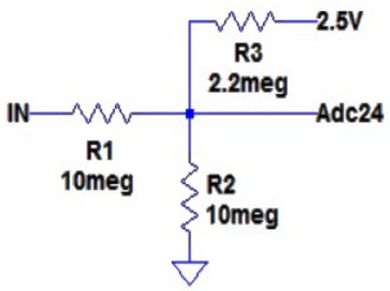
High impedance resistive dividers

These tables have the same ranges of the base table, but with some more columns.

The "R" input column shows the resistance values seen from the outside (the datalogger inputs).
The "R Adc to" column indicates the values of resistance to ADC inputs.
The "Err column. (Adc) "indicates the voltage errors produced by the current of 3 nA to 3 on ADC inputs.
The "Err column. (In) "indicates the rapportati voltage errors to external inputs of the datalogger.

High impedance scales (Common mode range)	R1	R2	R3	R input	R to ADC	Err. (Adc)	Err. (in)
-10 Volt to +10 Volt	10 Mega	10 Mega	2.2 Mega	11.8 Mega	1500 K	4.5 mV	30 mV
-20 Volt to +20 Volt	10 Mega	3 Mega	1.2 Mega	10.9 Mega	790 K	2.4 mV	30 mV
-25 Volt to +25 Volt	10 Mega	2.2 Mega	1 Mega	10.7 Mega	637 K	1.9 mV	30 mV
-50 Volt to +50 Volt	10 Mega	1 Mega	470 K	10.3 Mega	310 K	930 uV	30 mV
-100 Volt to +100 Volt	10 Mega	470 K	220 K	10.1 Mega	148 K	444 uV	30 mV
from 0.1 Volt to 3.2 Volt	10 K (Note 1)	not present	not present	10 K	10 K	30 uV	30 uV
from 0 Volt to 10 Volt	10 Mega	4.7 Mega	not present	14.7 Mega	3200 K	9.6 mV	30 mV
from 0 Volt to 20 Volt	10 Mega	1.8 Mega	not present	11.8 Mega	1500 K	4.5 mV	30 mV
from 0 Volt to 50 Volt	10 Mega	680 K	not present	10.7 Mega	637 K	1.9 mV	30 mV
from 0 Volt to 100 Volt	10 Mega	330 K	not present	10.3 Mega	320K	960 uV	30 mV
from 0 Volt to 200 Volt	10 * 10 Mega in series	1.6 Mega	not present	101.6 Mega	1570 K	4.7 mV	300 mV
from 0 Volt to 500 Volt	10 * 10 Mega in series	650 K	not present	100.6 Mega	646 K	1.9 mV	300 mV
from 0 Volt to 1000 Volt	10 * 10 Mega in series	330 K	not present	100.3 Mega	329 K	987 uV	300 mV

(Note 1) The range in blue is a basic range of the ADC, without the divider input and with only one protection resistor.
The protective resistor 10 K protects the entrance to extra-voltages (momentary) of +/- 100 volts.



<--- Here you see the resistor wiring diagram for the first range (-10 Volt to +10 Volt).

When the input is at zero Volt, the resistor R3, connected to the 2.5 Volt, together with R2 and R1 to ground, creates a bias of 1.65 Volt. To have the 2.5 Volt you must move the ***jumper to 2.5V***.

Medium and low impedance resistive dividers

The same flow of the base table, but with ten times lower resistance values.

Medium impedance scales (Common mode range)	R1	R2	R3	R input	R to ADC	Err. (Adc)	Err. (in)
-10 Volt to +10 Volt	1 Mega	1 Mega	220 K	1.2 Mega	K 150	450 uV	3 mV
-20 Volt to +20 Volt	1 Mega	300K	120 K	1.1 Mega	79 K	237 uV	3 mV
-25 Volt to +25 Volt	1 Mega	220 K	100K	1.1 Mega	64 K	190 uV	3 mV
-50 Volt to +50 Volt	1 Mega	100K	47 K	1.0 Mega	31 K	93 uV	3 mV
-100 Volt to +100 Volt	1 Mega	47 K	22 K	1.0 Mega	15 K	44 uV	3 mV
from 0.1 Volt to 3.2 Volt	10 K (Note 1)	not present	not present	10K	10 K	30 uV	30 uV
from 0 Volt to 10 Volt	1 Mega	470 K	not present	1.5 Mega	320 K	960 uV	3 mV
from 0 Volt to 20 Volt	1 Mega	180 K	not present	1.2 Mega	150 K	450 uV	3 mV
from 0 Volt to 50 Volt	1 Mega	68K	not present	1.1 Mega	64 K	190 uV	3 mV
from 0 Volt to 100 Volt	1 Mega	33 K	not present	1.0 Mega	32 K	96 uV	3 mV
from 0 Volt to 200 Volt	10 * 1 Mega in series	160 K	not present	10.2 Mega	157 K	471 uV	30 mV
from 0 Volt to 500 Volt	10 * 1 Mega in series	65 K	not present	10.1 Mega	65 K	195 uV	30 mV
from 0 Volt to 1000 Volt	10 * 1 Mega in series	33 K	not present	10.0 Mega	33 K	99 uV	30 mV

(Note 1) The range in blue is a basic range of the ADC, without the divider input and with only one protection resistor.
The protective resistor 10 K protects the entrance to extra-voltages (momentary) of +/- 100 volts.

The same flow of the base table, but with resistance values one hundred times smaller.

Low impedance scales (Common mode range)	R1	R2	R3	R input	R to ADC	Err. (Adc)	Err. (in)
-10 Volt to +10 Volt	100K	100K	22 K	120 K	15 K	45 uV	300 uV
-20 Volt to +20 Volt	100K	30 K	12 K	110 K	7.9 K	24 uV	300 uV
-25 Volt to +25 Volt	100K	22 K	10 K	107 K	6.4 K	19 uV	300 uV
-50 Volt to +50 Volt	100K	10 K	4.7 K	100K	3.1 K	9.3 uV	300 uV
-100 Volt to +100 Volt	100K	4.7 K	2.2 K (Note 2)	100K	1.5 K	4.4 uV	300 uV
from 0.1 Volt to 3.2 Volt	10 K (Note 1)	not present	not present	10K	10 K	30 uV	30 uV
from 0 Volt to 10 Volt	100K	47 K	not present	K 150	32 K	96 uV	300 uV
from 0 Volt to 20 Volt	100K	18 K	not present	120 K	15 K	45 uV	300 uV
from 0 Volt to 50 Volt	100K	6.8 K	not present	110 K	6.4 K	19 uV	300 uV
from 0 Volt to 100 Volt	100K	3.3 K	not present	100K	3.2 K	9.6 uV	300 uV
from 0 Volt to 200 Volt	10 * 100 K in series	16 K	not present	1 Mega	16 K	47 uV	3 mV
from 0 Volt to 500 Volt	10 * 100 K in series	6.5 K	not present	1 Mega	6.5 K	19 uV	3 mV
from 0 Volt to 1000 Volt	10 * 100 K in series	3.3 K	not present	1 Mega	3.3 K	9.9 uV	3 mV

(Note 1) The range in blue is a basic range of the ADC, without the divider input and with only one protection resistor.
The protective resistor 10 K protects the entrance to extra-voltages (momentary) of +/- 100 volts.

(Note 2) Careful not calculate with dividers R3 too low, otherwise it will exceed 10 mA maximum of 2.5 volt reference voltage.
With 4.7 K can still use all 16 inputs, but with 2.2 K no more than eight.

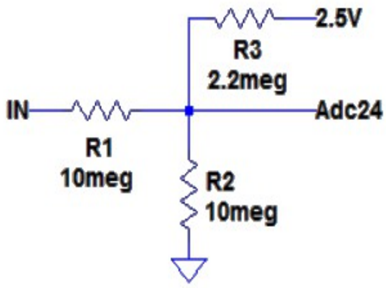
Calibrate in the measurement software

To obtain the value of the voltage that is being measured must be:

- Read the value from 1 to 1000 that the HAL application sends to Slot
- Consider that the ADC full scale is 3.3 Volt, then the value 1000 is 3.3 Volt.
- Calculate the effect of the divider formed by resistors R1, R2 and R3.

Then:

- We call "Vslot" the value from 0 to 1000 which is read from the slot.
- We call "Vin" the voltage from 0 to 3.3 volts at the entrance of the ADC.
- We call "R23" of the parallel resistors R2 and R3.
- And we call "Volts" the tension that we want to achieve.



And here are the formulas for calculation:

- Vin = (Vslot - 500) * 3.3 / 1000
- R23 = R2 * R3 / (R2 + R3)
- Volt = Vin * (R1 + R23) / R23

We can introduce these formulas in three rows of software.

Or we could compute a coefficient "K" which includes all the constants, leave MinValue and MaxValue with basic values (0 and 1000 HAL) and simply do:

- Vin = (Vslot - 500) * K

Coefficients "K" for all dividers proposed in this document.

Common mode range	Differential voltage range	R1	R2	R3	K (Note 2)
-10 Volt to +10 Volt	-20 Volt to +20 Volt	10 Mega	10 Mega	2.2 Mega	0.0216
-20 Volt to +20 Volt	-40 Volt to +40 Volt	10 Mega	3 Mega	1.2 Mega	0.0418
-25 Volt to +25 Volt	-50 Volt to +50 Volt	10 Mega	2.2 Mega	1 Mega	0.0513
-50 Volt to +50 Volt	-100 V to +100 Volt	10 Mega	1 Mega	470 K	0.1065128
-100 Volt to +100 Volt	from -200 Volt to +200 Volt	10 Mega	470 K	220 K	0.2235
from 0.1 Volt to 3.2 Volt	from -3.2 volts to 3.2 Volt	10 K (Note 1)	not present	not present	0.0033
from 0 Volt to 10 Volt	from 0 Volt to 20 Volt	10 Mega	4.7 Mega	not present	0.0103213
from 0 Volt to 20 Volt	from 0 Volt to 40 Volt	10 Mega	1.8 Mega	not present	0.0216333
from 0 Volt to 50 Volt	from 0 Volt to 100 Volt	10 Mega	680 K	not present	0.0518294
from 0 Volt to 100 Volt	from 0 Volt to 200 Volt	10 Mega	330 K	not present	0.1033
from 0 Volt to 200 Volt	from 0 Volt to 400 Volt	10 * 10 Mega in series	1.6 Mega	not present	0.20955
from 0 Volt to 500 Volt	from 0 Volt to 1000 Volt	10 * 10 Mega in series	650 K	not present	0.5109923
from 0 Volt to 1000 Volt	from 0 Volt to 2000 Volt	10 * 10 Mega in series	330 K	not present	1.0330

(Note 1) The blue range is the basic range of the ADC, without the divider input and with only one protection resistor. The protective resistor 10 K protects the input to extra-voltages (momentary) of +/- 100 volts.

(Note 2) The coefficient "K" remains valid even if they all reduced the resistance values of 10 or 100 times.

Calibrate in the HAL application

Instead of entering formulas or constants in the software you can adjust the scale and zero, simply by adjusting the boxes "Min value" and "Maximum value" in the HAL application. With this method, the HAL will send the slot values already converted to Volts or milli-Volts.

Values "Min value" and "Maximum value", to obtain the voltage in volts, with gain = 1

Common mode range	Differential voltage range	R1	R2	R3	min Value (Note 2)	max Value (Note 2)
-10 Volt to +10 Volt	-20 Volt to +20 Volt	10 Mega	10 Mega	2.2 Mega	-21.600	21.600
-20 Volt to +20 Volt	-40 Volt to +40 Volt	10 Mega	3 Mega	1.2 Mega	-41.800	41.800
-25 Volt to +25 Volt	-50 Volt to +50 Volt	10 Mega	2.2 Mega	1 Mega	-51.300	51.300
-50 Volt to +50 Volt	-100 Volt to +100 Volt	10 Mega	1 Mega	470 K	-106.513	106.513
-100 Volt to +100 Volt	from -200 Volt to +200 Volt	10 Mega	470 K	220 K	-223.500	223.500
from 0.1 Volt to 3.2 Volt	from -3.2 to +3.2 Volt	10 K (Note 1)	not present	not present	-3.300	3.300
from 0 Volt to 10 Volt	-10 Volt to 10 Volt	10 Mega	4.7 Mega	not present	-10.321	10.321
from 0 Volt to 20 Volt	-20 Volt to 20 Volt	10 Mega	1.8 Mega	not present	-21.633	21.633
from 0 Volt to 50 Volt	-50 Volt to 50 Volt	10 Mega	680 K	not present	-51.829	51.829
from 0 Volt to 100 Volt	-100 Volt to 100 Volt	10 Mega	330 K	not present	-103.300	103.300
from 0 Volt to 200 Volt	-200 Volt to 200 Volt	10 - 10 Mega in series	1.6 Mega	not present	-209.550	209.550
from 0 Volt to 500 Volt	-500 Volt to 500 Volt	10 - 10 Mega in series	650 K	not present	-510.992	510.992
from 0 to 1000 Volt	-1000 Volt to 1000 Volt	10 - 10 Mega in series	330 K	not present	-1033.000	1033.000

(Note 1) **The range in blue is a basic range of the ADC, without the divider input and with only one protection resistor.**
The protective resistor 10 K protects the entrance to extra-voltages (momentary) of +/- 100 volts.

(Note 2) **"Min value" and "Maximum value" remain valid even if they all reduced the resistance values of 10 or 100 times.**

Miscellaneous Notes

You can enter three digits after the decimal point only by the HAL version 6.7 onwards.

To get the tensions in milli-volts simply multiply by 1000 “Min value" and "Max value." So for the first range values would be: "Min value = -21600" and "Max value = 21600".

If you set the inputs as Pseudo, the "Min value" and "Maximum value" values must be divided by two.

For Single inputs, the values of "Max value" remain valid, but must be set to zero "Low value."

Precision of the ranges

The calibration values of these pages are theoretical values, which will not give precise measurements and even a perfect zero, unless you use very high precision resistors, unavailable and expensive. With normal resistors and no calibration errors will be lower than one percent, then about 10 mV with a full scale of 10 Volt and more on higher scales.

But manually adjusting the values is possible to calibrate each input, up to an accuracy of about one part in one hundred thousand (about +/- 1 mV with 100 volt full scale).

Calibration stability

If you change the resistors to an input, or change the type (Differential, Pseudo or single), or changing the "Gain", then the calibration of that input is no longer valid and you have to retouch it.

But even without anything to change the calibrations change with the passage of time. Calibration scale (the one that makes measuring a 12 Volt as 12.1 or 11.9) does not change much. Instead the zero calibration moves more easily.

The Adc24 module is responsible for only a small part of these changes. The large part is due to variation of the resistors of the input circuit (R1, R2 and R3). And also in good part to the effects of loss of surface currents, caused by air humidity.

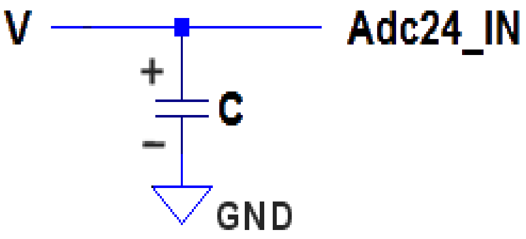
Due to the slow degradation of the calibration data logger, such as Picotech, they should be re-calibrated by the manufacturer every year, with a considerable expense. But just take out an accurate reference voltage or a precise meter and can be recalibrated periodically inputs without spending anything.

Of course, frequent calibration is a bore and a waste of time, for which we listed some methods to increase the stability of calibrations.

- Reduce the impedance of the input circuits. As previously written, this is a good method to reduce errors due to ADC leakage current. But this current is rather constant in time, whereby with this method are reduced mainly the effects due to moisture. You can not use this method if you want to have a high input impedance (usually ten Mega ohms as all good tester).
- Use the lowest possible range, consistent with the common mode voltage and with the necessary scale.
- Enclose Master, Adc24 and input circuit in a sealed container. The only holes will be the input connectors (probably of BNC) and the USB connector. Ensure that all connectors are tight and if necessary seal with glue. Before closing position inside a bag of balls of silica gel to absorb moisture.
- Reduce noise picked up capacitively on electrical surrounding. Hold short connections, use shielded cables (see ***this page***), use a metal container connected to an earth point (GND) dell'Adc24.
- Use higher quality resistors. This is the least of the problems. The resistors even if not very precise (for example 5%), do not change much in value over time or with temperature. So it is advisable to keep this to last, and only after all of the above options.

Input filtering

If the connecting wires are long and there are not shielded, that is a good chance to collect disturbances due to capacitive and inductive, mainly from the wires of the electrical installation, but also from electrical equipment, such as motors and transformers. In many cases, the ADC filters 50 and 60 Hz can eliminate many of the problems, but if they exceed a certain level the measurements become inaccurate.



To reduce noise capacitors can be connected between each input and GND.

The capacitors must be close to to the Adc24 inputs and must have short wires, as well as explained for the input resistors of the previous pages.

Of course this filter complicates the wiring and decreases the reliability, so it must only be added if necessary.

Calculate the value of the capacitors

To establish the capacitors value is not easy. On the one hand you do not want to go down too with the reactivity and on the other it would alleviate a lot of the noise from 50 Hz up.

It must also take into account that some of the input circuits have a very high impedance (several mega ohms) while others, such as the PT100, the have very low, less than one hundred ohms.

For slow measures, for example the temperature, and with low input impedance, for example 100 ohm of PT100, one could use the capacitors up to 100 uF and beyond. But sure they are discharged before connecting.

With the input circuits to average and high impedance, the response time could be longer too. In these cases you should decrease the value of the capacitors 10 uF, or 1 uF 100 nF. And if you want even a bandwidth up to hundreds of Hertz, then you should use capacitors from 10 nF and 1 nF. But in these cases the filtering effect would be minimal and might as well not put them.

If you can not eliminate the interference with the capacitors then you have to use other methods, shielded cables (see ***this page***) and twisted pair wiring with masses and a good star.

Passband as a function of input impedance and capacity

Input impedance	1 nF	10 nF	100 nF	1 uF	10 uF	100 uF
100 ohms	-	-	-	-	300 Hz	30 Hz
1,000 ohms	-	-	-	300 Hz	30 Hz	3 Hz
10 Kilo ohms	-	-	300 Hz	30 Hz	3 Hz	0.3 Hz
100 Kilo ohms	-	300 Hz	30 Hz	3 Hz	0.3 Hz	-
1 Mega Ohm	300 Hz	30 Hz	3 Hz	0.3 Hz	-	-
10 Mega ohms	30 Hz	3 Hz	0.3 Hz	-	-	-

Empty boxes indicate unnecessary or nonsensical combinations.