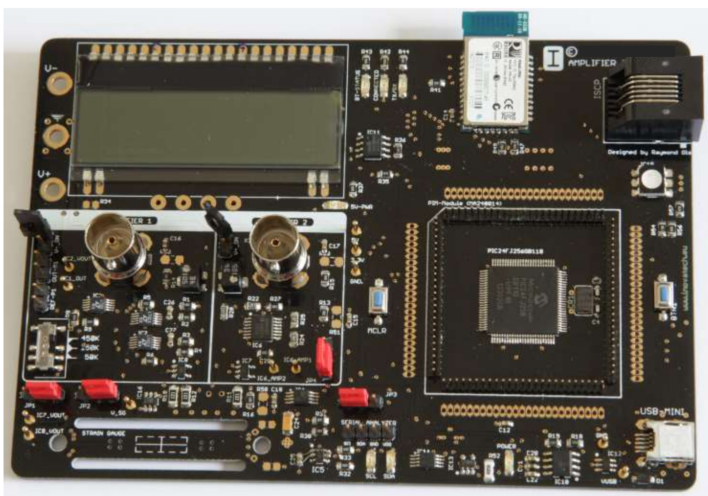
INOVATECH

IAT-BOARD

Instrumentation Amplifier Test Board



ABSTRACT

This document describes the instrumentation amplifier proto board, that was developed to test 2 different amplifier configurations and to write and debug the initial firmware for the Stiffness Measurement Tool (SMT).

In this document the function blocks of the IAT-board are described and the tests that should be executed on the IAT-board in the 3 different build scenarios, knowing

- Pre-assembly
- Intermediate assembly
- Completed assembly

Raymond Olsman

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THE INSTRUMENTATION AMPLIFIER TEST-BOARD

General description

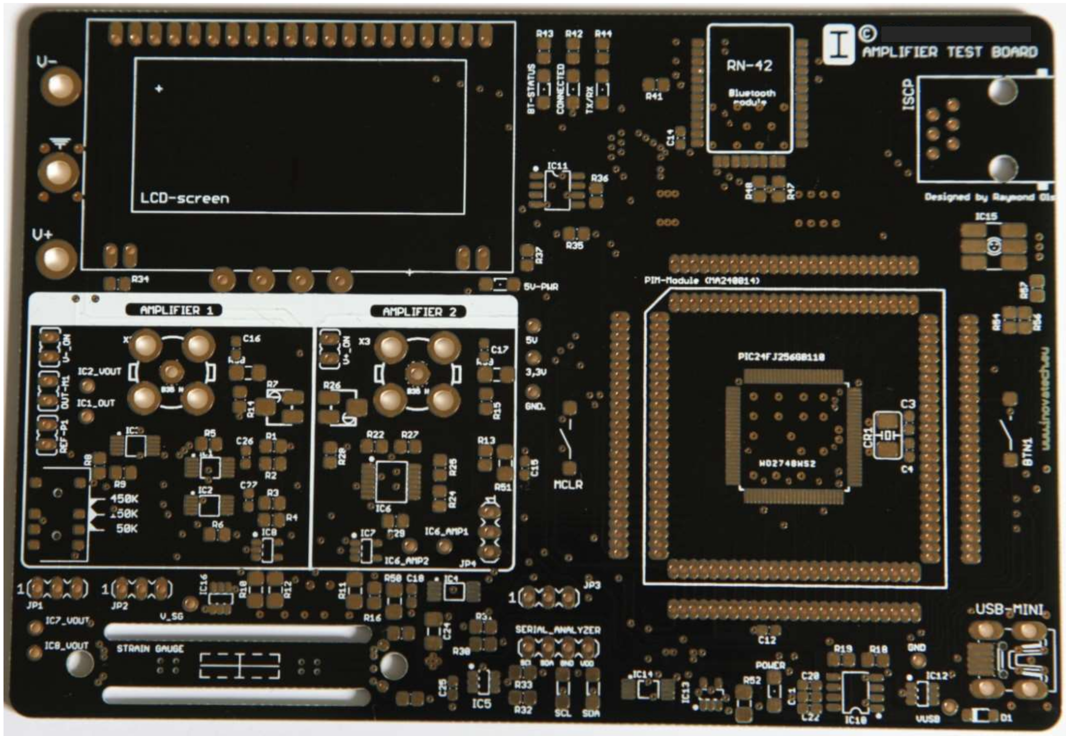
The **I**nstrumentation **A**mplifier **T**est-board (IAT-board) is designed to develop knowledge on the use of strain gauges in combination with amplifiers. The flavours of amplifier IC is tremendous. To get started with amplifiers a selection is made out of the population from linear technology and Analog Devices. The amplifiers are "relatively" arbitrarily chosen, however the choice for the brands is based on internet research. Both brands are generally known and have both good documentation and sample services, and are used by many engineers that publish information either on websites or YouTube.

Function blocks

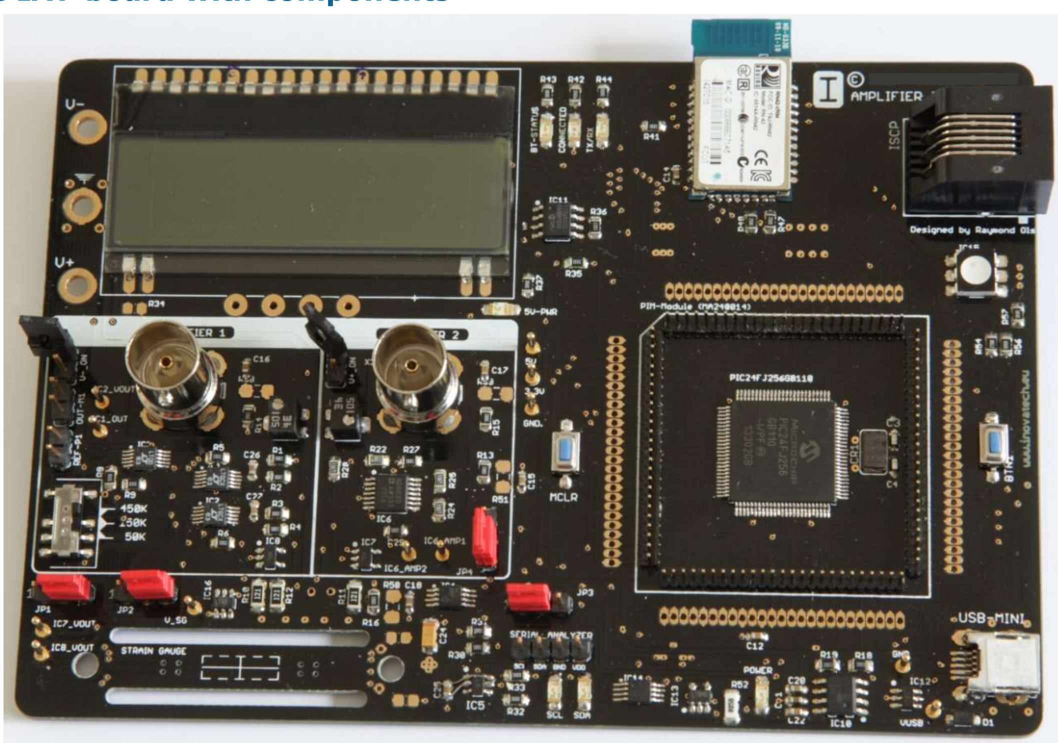
Function block is a part of the test board that fulfils a specific function, each function block will be described further on in this document. The IAT-board has the following functions

- Power supply from USB interface, including current sensing
- USB to PC connectivity
- MCU family PIC24 from microchip
- Bluetooth serial communication module with Bluetooth stack integrated
- Temperature sensor
- Amplifier 1 with a programmable gain stage (hardware programmable with jumpers and switch)
- Amplifier 2 based on a traditional instrumentation amplifier schematic
- Separate power supply to amplifier IC's on the IAT-board, with ability for multiple different options to facilitate the power (battery, laboratory power supply)
- Sigma Delta ADC interface between amplifier 1, 2 to MCU
- Traditional 16x3 character LCD screen, with on-board dedicated enablable voltage regulator
- Strain gauge in Wheatstone bridge configuration, powered from a reference voltage IC and buffered with amplifiers. These amplifiers are not part of the amplifier circuits 1 and 2 mentioned above
- RGB LED
- Indication LED's
- Reset and general purpose switch
- In system program and debug interface
- Serial communication analyzer interface for I^2C devices (Sigma Delta ADC and temperature sensor)

The IAT-board without components



The IAT-board with components



DEFINITIONS

Pre-assembly tests

These tests must be executed before soldering, recommended is to execute all pre-assembly tests described throughout this document. Since some traces might be connected to parts that are not scope of a particular test description. In most cases the pre-assembly test concerns resistance measurements of the PCB traces.

Intermediate assembly tests

These tests are applicable for a specific IC or function block, it is meant to be executed just after soldering the specific IC or function block to the IAT-board. Be aware that the parts can still be hot due to the soldering. Let the parts cool down first before executing these tests.

Completed assembly tests

After the assembly of the IAT-board is completed and all parts are soldered to the board these tests are to be executed.

IMPORTANT

Before any power is supplied to the IAT-board during the build phase and first test-run after completion. **Always!** make sure that the power supply is set to the minimal voltage, but more important that it is set to a minimum amount of current. Normally 50mA will be sufficient in most cases to get an integrated circuit (IC) into operation. Using low voltage and current safes the IC / PCB from getting permanent damaged, in case of shorts or wrong connections. Good practice is to have the datasheets available and pin check all connections before first tests are done!

Text in these boxes are updates to the IAT-board after the initial tests.

IAT-BOARD FUNCTION BLOCKS

Power supply from USB interface

Main power for the IAT-board will be drawn from the USB interface only the power for the amplifiers comes from a separate supply.

Before the 5V from the USB interface goes into the 3,3V and 5 Volt regulators it will be sensed by a current sensor. Also a Schottky diode is used to prevent damage to the USB-port. Voltage regulator used for the 3,3V is Microchip and the type is MCP1727-3302E, with a very low voltage drop and a low quiescent current. The passive components in the circuit are based on the datasheet of this device.

Interface to MCU

The voltage regulator has interfaces that can be connected to a MCU. The 3,3V regulator is connected to the MCU. Interface to the MCU is the power good interface (PWRGD), this interface is digital, the capacitor on the CDELAY pin sets a delay time after the 92% threshold of the voltage is reached. Delay time is adjustable by the value of the capacitor, delay time (in this case 300ms for a 0,1µF capacitor) prevents unwanted switching. The other interface, not directly related to the voltage regulator, is the connection of the IAT-board to a USB interface.

Typical voltage regulator characteristics

Description		Value	Unit
Fixed output voltage	:	3,3	V
Max output current	:	1,5	A
Low drop voltage	:	330	mV
Low quiescent voltage	:	120	µV
Over temperature protection	:	150	°C

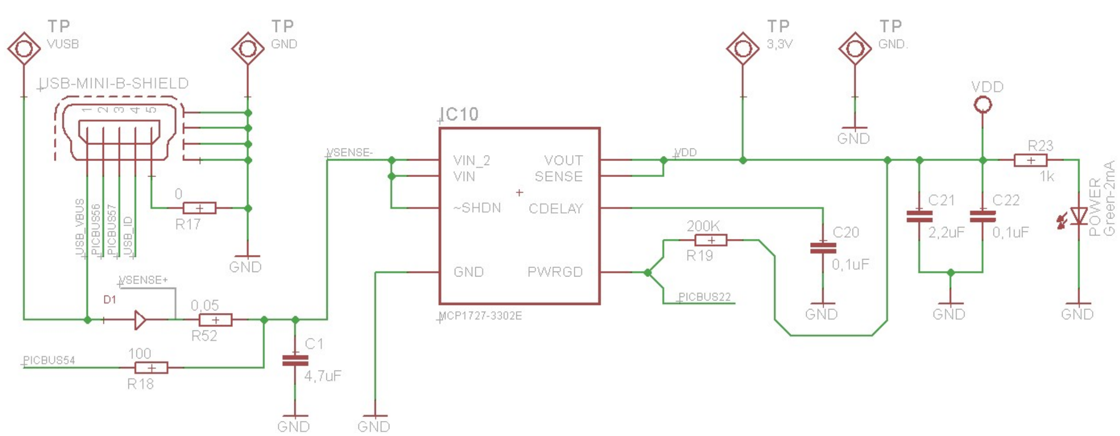


Figure 1: 3,3V power function block

Test

Pre-build IAT-board test

ID	*Description*	*From*	*To*	*Value*	
001.48	VDD pins	IC10	IC9	3,25	V
001.49	VSS pins	IC10	IC9	0	V
001.50	Traces from pins to devices (measures in pin list)	IC..	IC..		Ω
001.51	Input ESD protection on PCB (spark gaps)	No solder mask should be present Is according design, see photo below			

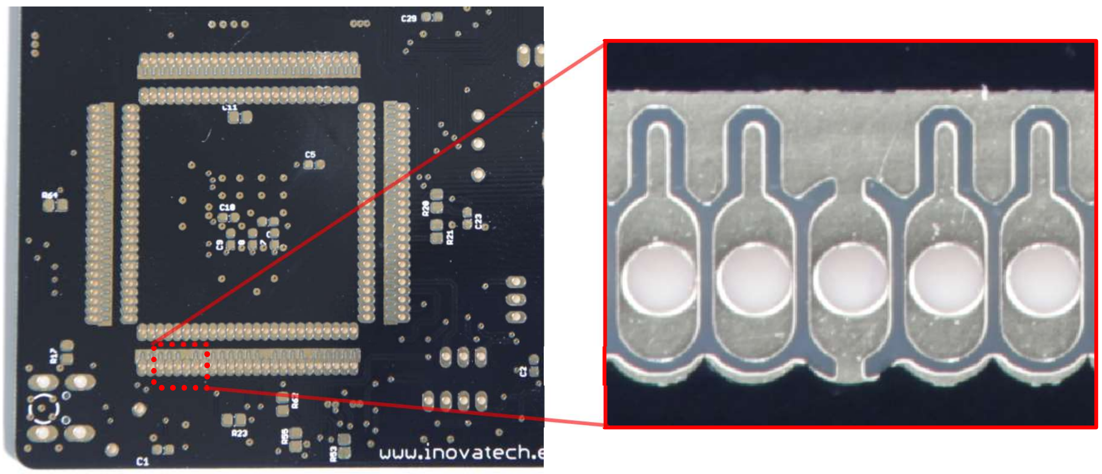


Figure 8: IAT-board spark gaps (simple ESD protection)

Intermediate build IAT-board test

ID	*Description*	*Comp*	*Design*	*Value*
001.52	Short checks	IC12		OK

Completed IAT-board test

ID	*Description*	*Comp*	*Design*	*Value*	
001.53	Current consumption (IDLE) Measure current over contact pads of current Shunt resistor	R52	<500mA	-	mA

I²C indication

The I²C indication is used to have a visual check on the functioning of the data bus. The idle state of the data and clock lines is high, in this case the indication LED's should be off, in order to do this an inverter (IC5) is used, type is 74LVC2G04.

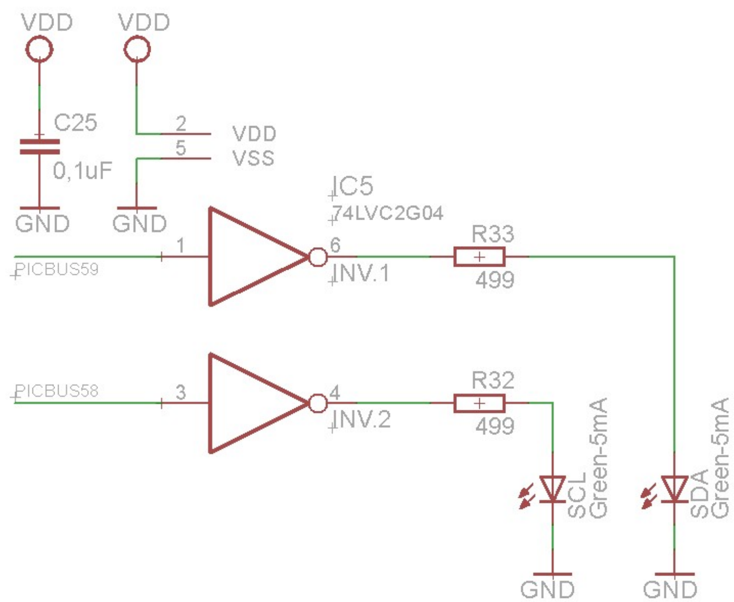


Figure 15: LCD-screen schematic

Interface to MCU

The inverter is connected to the SDA and SCL lines of the MCU, respectively PIN59 and PIN58.

Typical inverter characteristics

Description		Value	Unit
Max voltage	:	5,5	V
Operation current	:	40	µA
Idle current	:	10	µA

Test

Intermediate IAT-board test

ID	*Description*	*Comp*	*Design*	*Value*
001.70	Connection to GND pin 1 should turn on SDA LED	IC5		OK
001.71	Connection to VDD pin 1 should turn off SDA LED	IC5		OK
001.72	Connection to GND pin 3 should turn on SCL LED	IC5		OK
001.73	Connection to VDD pin 3 should turn off SCL LED	IC5		OK

Bluetooth serial communication module with Bluetooth stack integrated

The RN-42 Bluetooth™ module adds the ability to communicate wirelessly to a computer via the serial port (COM). The module is equipped with the Bluetooth software stack, therefor no additional protocols has to be developed for the firmware that goes into the PIC24.

Another additional requirement is that the IAT-board complies as good as possible with CE-regulations. A high frequency module, which a Bluetooth device is, should comply the regulations that are applicable for the country that it is used in, this module complies with most regulations used worldwide. The higher price for such a module pays easily back the effort in development and testing time required, especially in cases of small production numbers.

The purpose of this module is to communicate to specially design computer software, details of this software is out of scope of this document.

Figure 16: RN-42 Bluetooth module

Interfaces from the RN-42

The RN-42 has several interfaces towards the MCU, table below describes these interfaces

RN-42 pin	*Function*	*State*	*To*
GPIO2	Connection status	High = Connected	PIC_P74+LED
GPIO3	Auto-discovery mode	High = Enabled	PIC_P73
GPIO4	Set factory defaults	High = Reset	PIC_P71
GPIO5	Status, toggles based on state	Low = Connected	PIC_P72+LED
GPIO6	Set Bluetooth master.	If GPIO6 = high, module connects to the stored address. If GPIO3 = high, module enters new Discovery/Pairing mode	PIC_P79
GPIO7	Set baud rate	High = force 9,600 Low = 115K or firmware setting	PIC_P80
GPIO8	UART TX/RX data activity		LED
RESET	Reset the RN-42 module	Low = Reset	PIC_P6
UART_RX	UART receive input		PIC_P70
UART_TX	UART transmit output		PIC_P78
UART_RTS		High = Disable host transmitter	PIC_P77
UART_CTS		High = Disable transmitter	PIC_P76

Traditional 16x3 character LCD screen

To display data directly from the MCU, without using a computer, a LCD screen has been added to the IAT-board. The LCD is from *Electronic Assembly* and the type is DOG-series, this particular LCD screen has a very small footprint and height and is especially chosen because of these features.

When it is not required to use the LCD it can be switched off by switching off the voltage regulator IC11

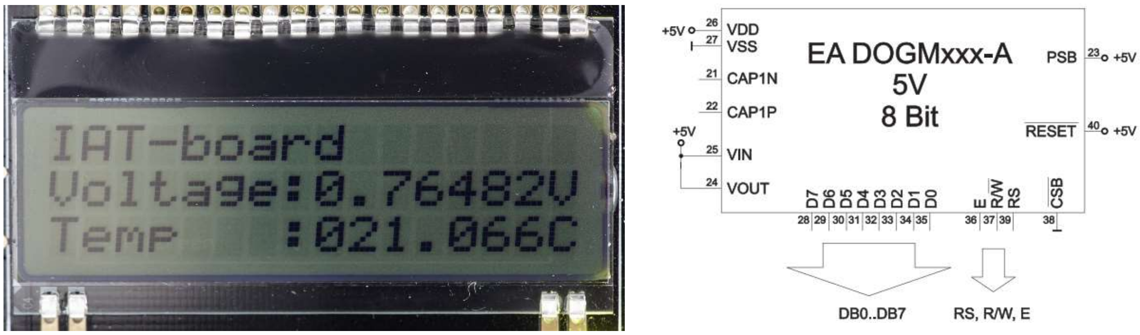


Figure 19: LCD screen, 16x3 characters

Interfaces from LCD-screen

The LCD interface is traditional in terms of the data interface, it's possible to communicate with the LCD via a 4- or 8-wire data interface. Full interface description is given in the datasheet

Typical LCD characteristics

Description		Value	Unit
Characters per row	:	16	°C
Accuracy		+/-2	
Number of rows	:	3	°C
User-selectable accuracy		0,5 – 0,0625	
Operating voltage	:	3.3 / 5	V
		2.7 – 5.5	
Operating current (typical)	:	200	µA
Operating current (shut down)	:	2	µA
Communication interface	:	4 or 8 or SPI	Bits
		I^2C	

Note that the (short) summary in this table is just a tiny grasp out of some characteristics of this sensor, refer to the datasheet in case more information is required.

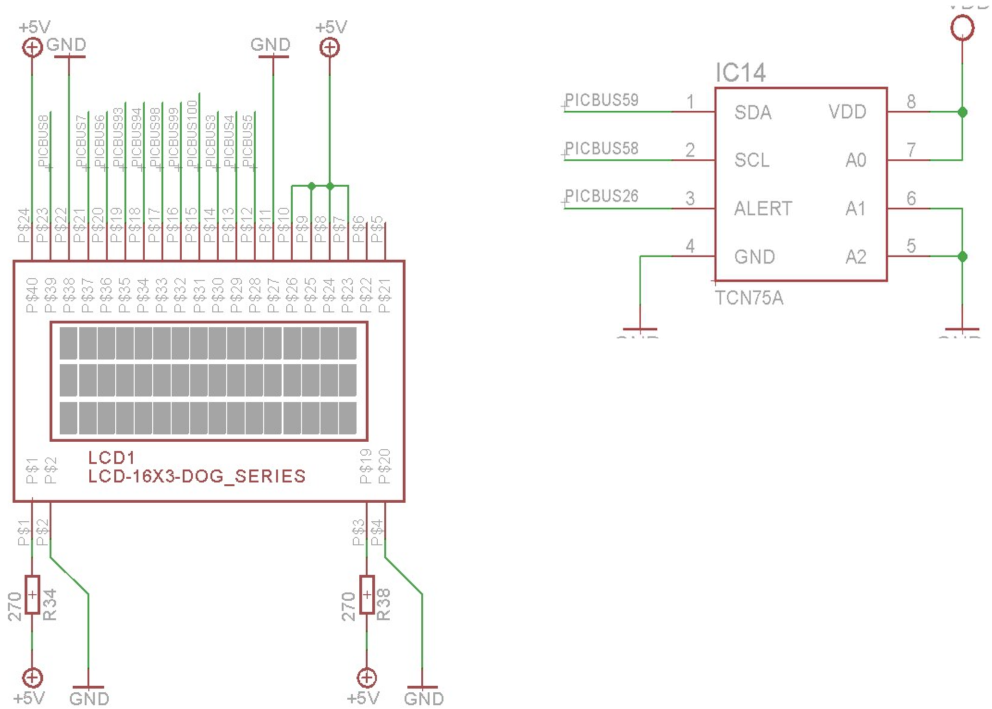


Figure 20: LCD-screen schematic

Test

Pre-build IAT-board test

ID	Description	From	To	Value	
001.110	VDD pin	IC11	LCD	4,8	V
001.111	VSS pin	IC11	LCD	0,15	Ω
001.112	Data PCB traces to MCU (minimal value)	LCD	IC9	-	Ω
001.113	Data PCB traces to MCU (maximal value)	LCD	IC9	-	Ω

Resistance reference = 13Ω

Intermediate build IAT-board test

ID	Description	Comp	Design	Value
001.114	Short checks	IC1		OK

Completed IAT-board test

ID	Description	Comp	Design	Value	
001.115	Voltage on VDD pins	LCD	5V	4,8	V
001.116	Initialize LCD-screen from MCU	LCD		OK	
001.117	Print "Hello World" on all 3 LCD rows	LCD		OK	

Amplifier 2 build from a traditional instrumentation schematic

This part of the board contain one instrumentation amplifier, the AD8630 from Analog Devices, the gain of this amplifier circuit is set to 200, which requires the potentiometer to be set to 255.375Ω .

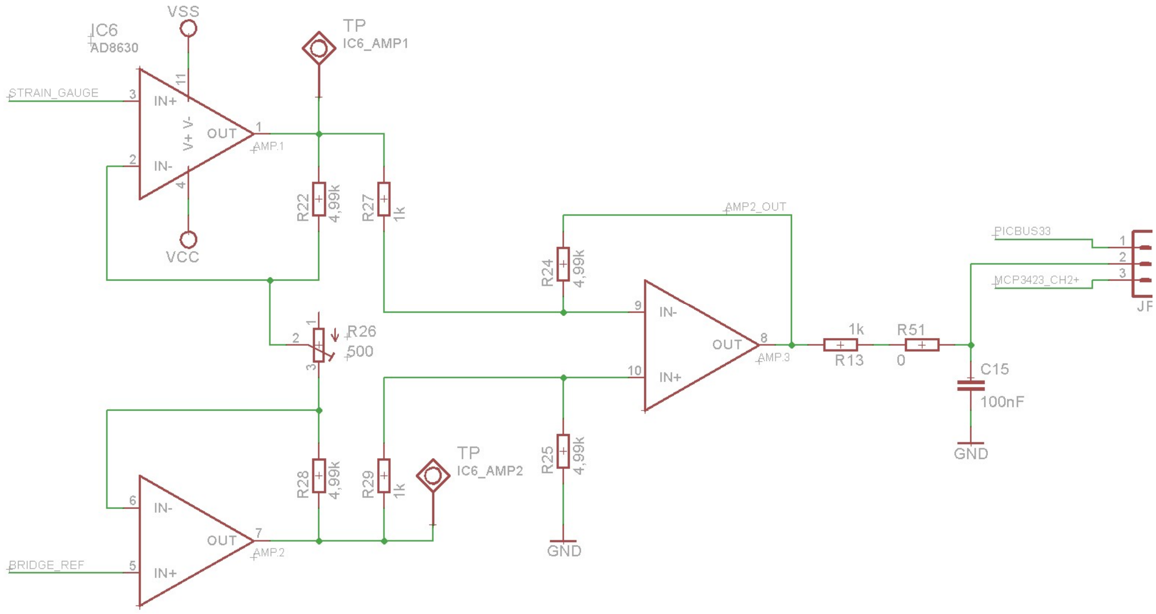


Figure 25: LCD-screen schematic

Amplifier analysis

This amplifier is a so called instrumentation amplifier, which has beneficial characteristics

- High input impedance
- Low input impedance to second stage, the differential amplifier stage
- Selectable gain control via potentiometer
- Common mode rejection, first stage is symmetric. When both input signals are equal the output voltage is 0

The relation between the input voltages and the output voltage is as follows

$$Vout = (V_2 - V_1) \cdot \frac{R_f}{R_2} \cdot \left(\frac{2 \cdot R_1}{R_{gain}} + 1\right)$$

In the appendix the solution to this equation is given.

Interface to MCU

The output of this amplifier can be fed to the Sigma Delta converter (channel 2) or directly to the MCU (analog channel 9, pin 33). Which option to select is done by a 3 terminal header (JP4) with a jumper.

Test

Pre-build IAT-board test

ID	Description	From	To	Value
001.138	Measure trace resistance from buffer amplifier output to next amplifier input	IC7	IC6-AMP1	Ω
001.139		IC8	IC6-AMP2	Ω
001.140		IC7	IC1	Ω
001.141		IC8	IC2	Ω
001.142		IC7	IC3-IN+	Ω
001.143		IC8	IC3-IN-	Ω

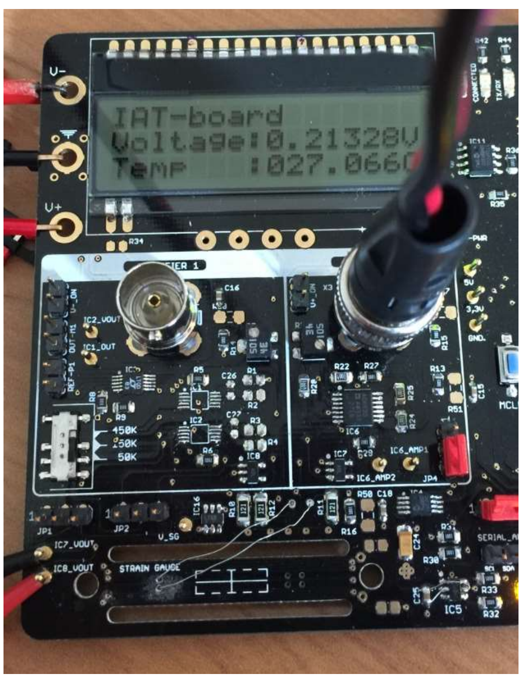
Intermediate build IAT-board test

ID	Description	Comp	Design	Value
001.144	Short checks	IC7		OK
001.145	Short checks	IC8		OK

Completed IAT-board test

ID	Description	Comp	Design	Value	
001.146	Voltage on VDD pins	IC6	5V		V
001.147	Vin (Bridge_ref – Strain_gauge) to Vout	IC6	1,146mV	210,60	mV

Test 001.167 is the reading of the Wheatstone bridge with the strain gauge installed and the board in rest (no force applied to the board). Pictures below show the readings of the LCD which is reading the Sigma Delta ADC and the Fluke multimeters, Fluke 187 is reading the Vin and the Fluke 289 is reading the Vout.



$$Gain = \frac{V_{out}}{V_{in}} = \frac{210{,}60}{1{,}146} = 183{,}77$$

Figure 26: Voltage readings Amplifier 2

Strain gauge in Wheatstone configuration

The amplifiers on the IAT-board are by default connected to a strain gauge in a Wheatstone configuration. This configuration is typical for strain gauges, the purpose of the IAT-board is to find out with what precision the strain gauge change in resistance can be measure by the instrumentation amplifiers in the configuration as design on the IAT-board. The resistance of this strain gauge is 120Ω, the Wheatstone bridge uses for the other resistances the same resistor value. In case another strain gauge resistance is used, change the Wheatstone bridge resistors accordingly.

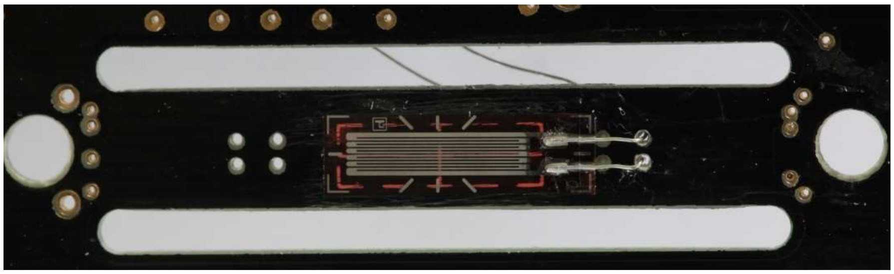


Figure 28: Strain gauge

According the data sheet of this strain gauge it has an own gain of 2 (stain gauge factor) with respect to the strain change. Which means that when the strain of the material changes by 0,1% the resistance of this strain gauge changes by 0,2%, which is from 120Ω to 120,24. This change of 0,1% stain in the material might not sound like a lot, however this is already quite a change. The best way to describe this in an example, is by the use of a standard formula that give a stress in the material at a given strain. This formula is

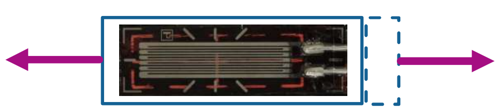
$$\sigma_{material} = \varepsilon \cdot E_{material}$$

In this equation the parameters are identified as follows

$\sigma_{material}$	:	This is the stress in the material at the given strain
ε	:	This is the strain
$E_{material}$	:	This is a material property which is, for metals, a constant. The property is called modules of elasticity

For the example in this document we assume that the strain gauge is attached to a steel object and that the interface between the strain gauge and the steel object is ridged. When we apply a strain of 0,1% (note that strain is a dimensionless parameter) the $E_{material}$ is 210000 N/mm^2, this results in a stress in the material $\sigma_{material}$ of 0,1%*210000 N/mm^2 = 210N/mm^2. This stress is already close to the maximum allowable yield stress of the material, which is normally based on elastic[2] material behaviour.

When we proceed with is example, and assume that the object is a steel rod with a diameter of Ø2mm and that this rod has an force acting on the end of the rod we can calculate the force required to get a strain of 0,1%.



$$F = \frac{A \cdot E_{material} \cdot \varepsilon}{1 - \varepsilon}$$

$$A = \frac{\pi}{4} \cdot d^2$$

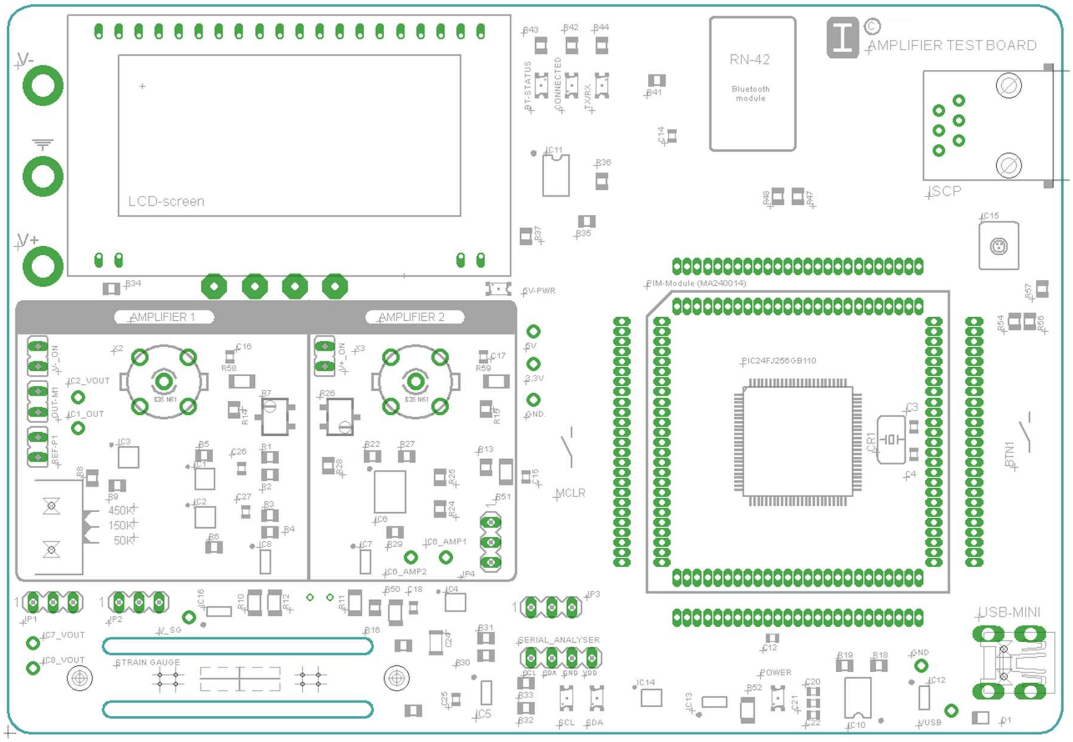
Force required for 0,1% strain is,

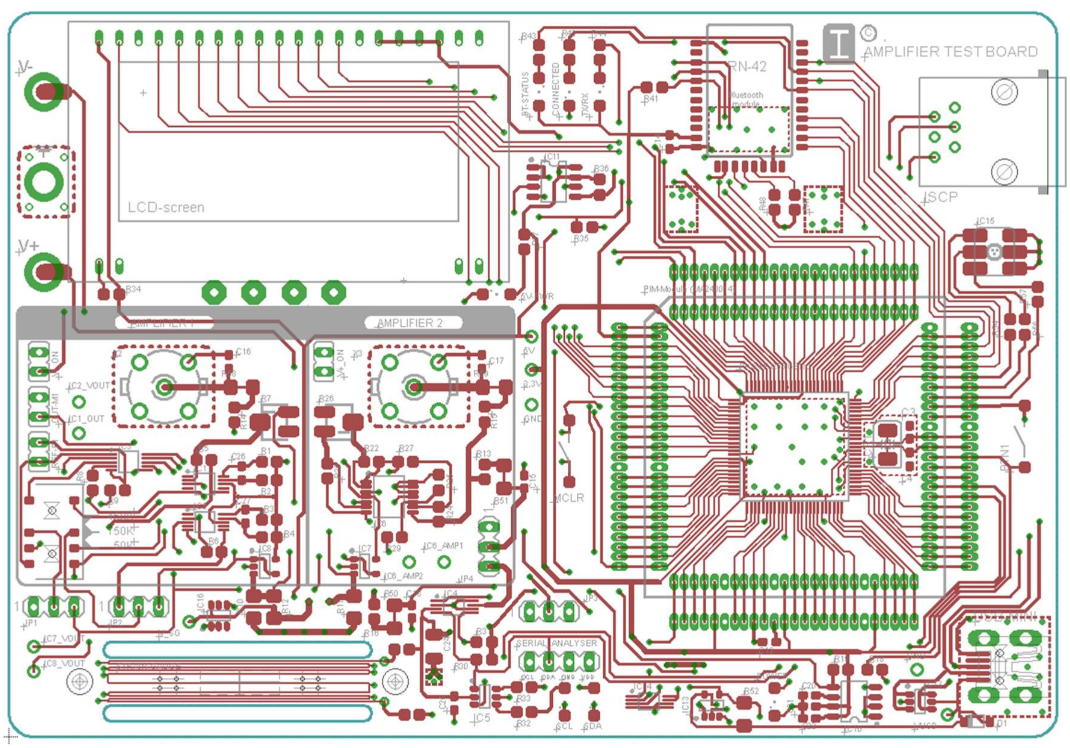
$$F = \frac{\frac{\pi}{4} \cdot (2mm)^2 \cdot 210000\, ^{N}/_{mm^2} \cdot 0{,}1\%}{1 - 0{,}1\%} = 660N$$

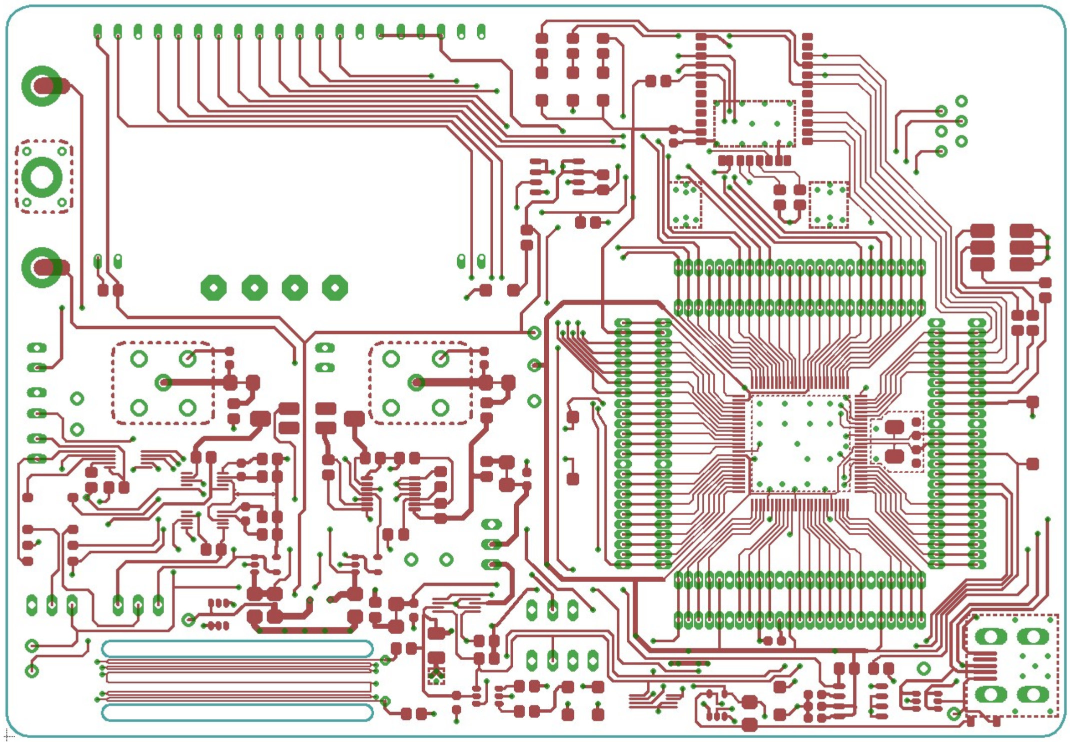
Figure 29: Example steel rod, with axial force applied

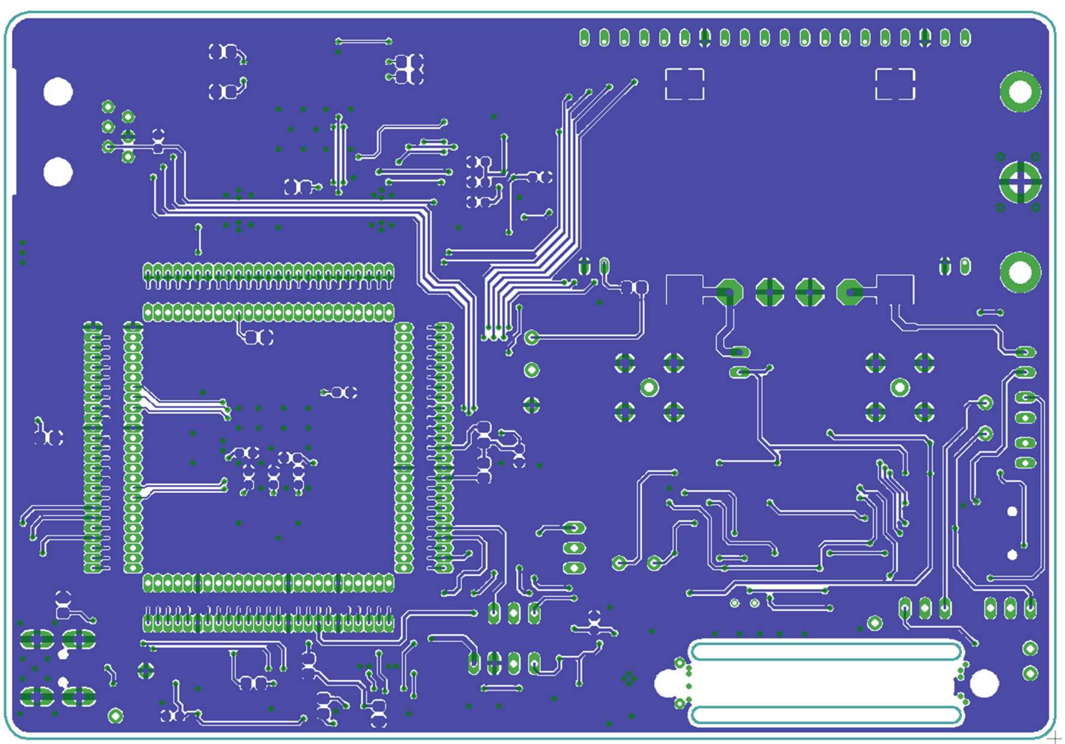
[2] Elastic material behaviour means that when the force is removed from the construction the material goes back to its original shape. When the construction does not go back to its original shape, the construction has undergone a plastic deformation. Plastic deformation is, in most cases, not allowed.

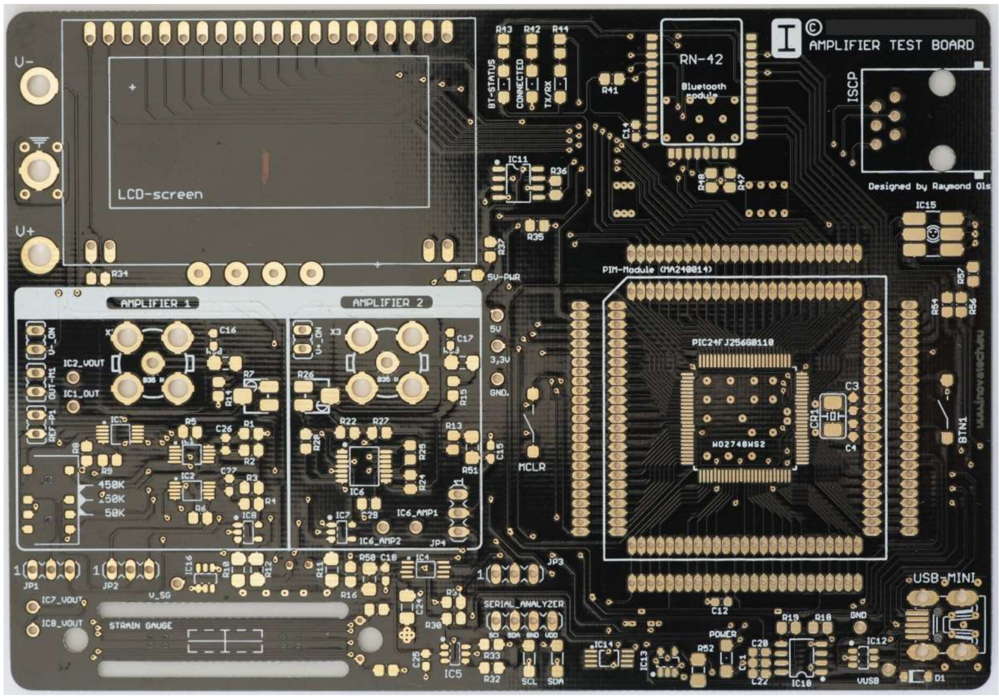
IAT-board PCB details

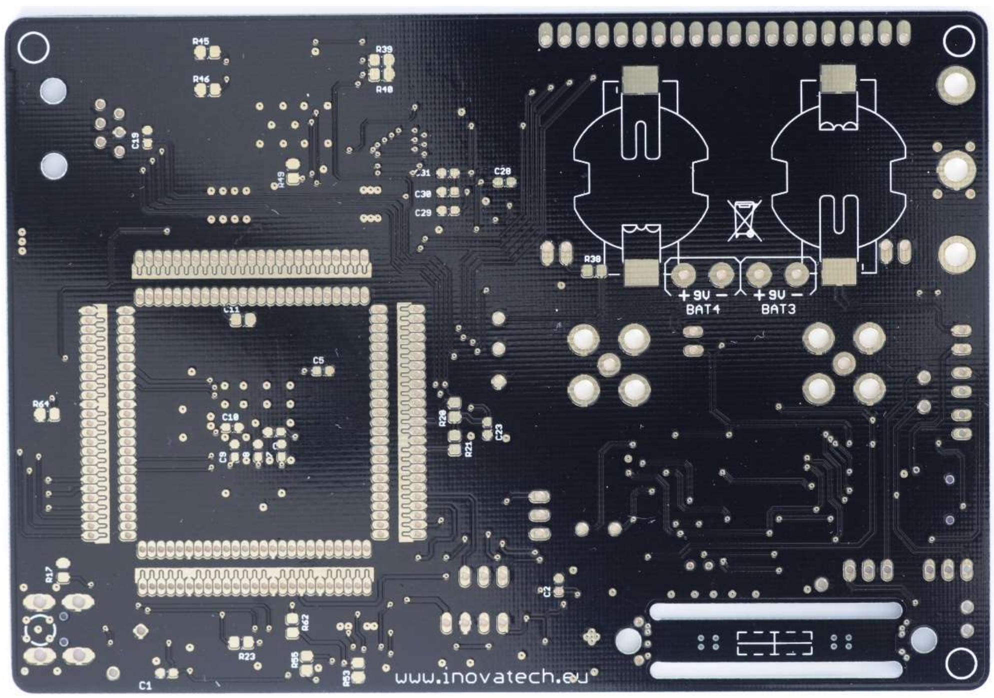









AMPLIFIER TEST BOARD
RN-42
Bluetooth module
ISCP
LCD-screen
AMPLIFIER 1
AMPLIFIER 2
PIM-Module (MA240014)
PIC24FJ256GB110
MCLR
USB-MINI
SERIAL_ANALYZER
STRAIN GAUGE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