

**SUPSI**

# Study of a system for the absolute position measurement

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STUDENTSUPSI



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# Chapter 1

## Abstract

This document describes the procedures followed during the study of a solution for measuring the absolute position through a magnetic sensor. Initially, the problem was studied in order to find solution that could satisfy all customer requests. Once the most suitable was found, tests were carried out to verify its feasibility. In order to avoid having produced an unusable system, it was decided to support an alternative solution during the testing phase and, besides this, verification systems were added to demonstrate the quality of the results with measured data. Topics such as the analysis of the problem, the measures taken, the design of the system in all its parts and finally the results of tests will be discussed.



## Chapter 2

# Project description and tasks

### 2.1 Description

This project aims to study and develop the electronics and firmware for an absolute position sensor in collaboration with Sensitec GmbH, world leader in the production of magnetic position sensors. The prototype will be used in the context of a project with Sensitec's partner company. They are looking for a replacement to the current absolute positioning method (linear potentiometer). The new system must be absolute, contact less, with ratio-metric output and precise in the order of the  $\mu m$ . These objectives can be achieved thanks to the latest technologies offered by Sensitec. In particular, the Tunnel Magneto Resistive (TMR) technology has been investigated in the context of the diploma work. The advantage of the TMR technology is the absolute measurement on the whole shaft using two sets of magnetic dipoles. The measuring method is also suitable for the Nonius absolute sensors.

#### 2.1.1 About Sensitec GmbH

Sensitec GmbH was founded with the aim to produce sensors and sensor systems based on the Magneto-Resistive effect for industrial and automotive series applications. Today they are one of the world market leaders for high-quality and innovative magnetic sensor solutions.

## 2.2 Tasks

- Understand the measurement system and the specifications required by the client.
- Put into service the Sensitec TMR measurement kit, evaluate performances and limitations.
- Develop the electronics to perform absolute position measurement and transmit the values via communication interface.
- Perform precision and reproducibility tests with an optical reference measurement system. Implement a signal processing algorithm in order to calibrate the sensor.

## 2.3 Objectives

- Understand the operation of new types of position sensors.
- Electronics development for processing TMR sensor's signals.
- Firmware development for microprocessors.
- Implementation of conventional communication methods (SPI, RS232, analog..).

## 2.4 Technologies

- Design of circuits with Altium
- Signal analysis and conditioning
- Algorithms for signal processing
- C language for DSP
- Matlab, Simulink

## 2.5 External contacts

- Marc Kramb, Sensitec GmbH



## Chapter 3

# Project specifications

The project specifications agreed with the customer are:

- Development of a linear measurement system for at least 110mm way.
- Contact-less sensing unit.
- Reach maximal air-gap between sensor and magnetic tape.
- Absolute measure.
- Ratio-metric output.
- As small as possible.
- Technology: TMR (Tunnel Magneto Resistive), Nonius.
- Sensor: TL915.
- Measurement range: 90 mm to 110 mm (320 mm optional).
- Repeatability: 10  $\mu\text{m}$ .
- Supply voltage: +5 V.
- Output: Ratio-metric – 0.25-4.75 V.
- Maximum operating temperature. 125°C (optional).
- Ingress protection: IP67 (optional).
- Dimension: 8mm x Free x 8mm( $W \cdot L \cdot H$ ) .



## Chapter 4

# Nonius-Vernier principle

The Nonius-Vernier principle allows to measure the absolute position by means of two tracks consisting of periodic divisions. The number of periods of the two tracks must differ by one and they must be in phase at both ends. The one with more periods is called master track, while the other one is called Nonius track. An example is shown in figure 4.1.

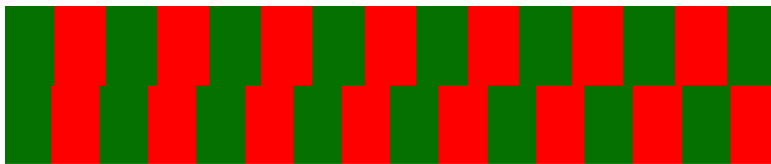


Figure 4.1: Nonius 15/16 scale example

The typical couples of master and Nonius tracks are composed of 16/15, 32/31 or 64/63 periods, but the last combination is considered to be critical because of the small phase deviation.

Through a magnetic or optical sensor, those tracks generate two couples of Sin/Cos signals that have their periods synchronized with the corresponding track, as the example in figure 4.2.

Calculating the *arctan* of the two couples of signals it is possible to obtain the phase shift between the tracks in every point.

The phase shift is calculated as difference between the two *arctan* and it corresponds to the absolute position.

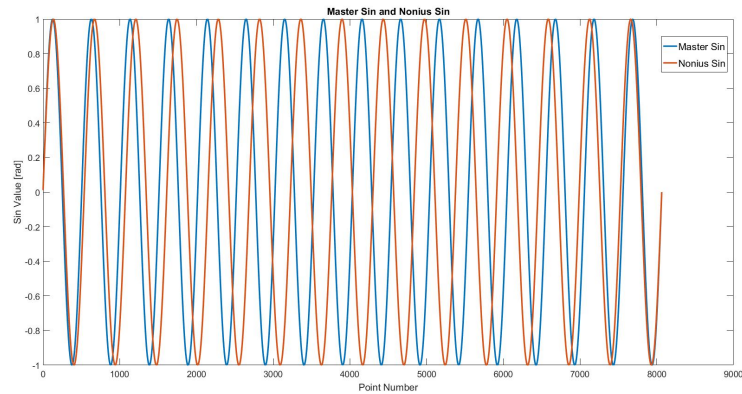


Figure 4.2: Example of master sin and Nonius sin

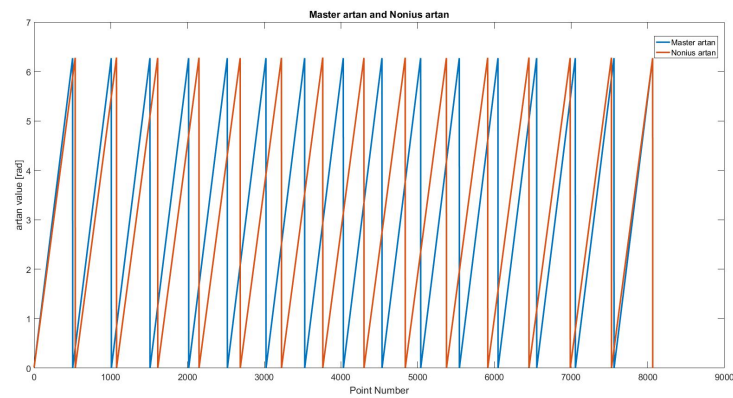


Figure 4.3: Example of master artan and Nonius artan

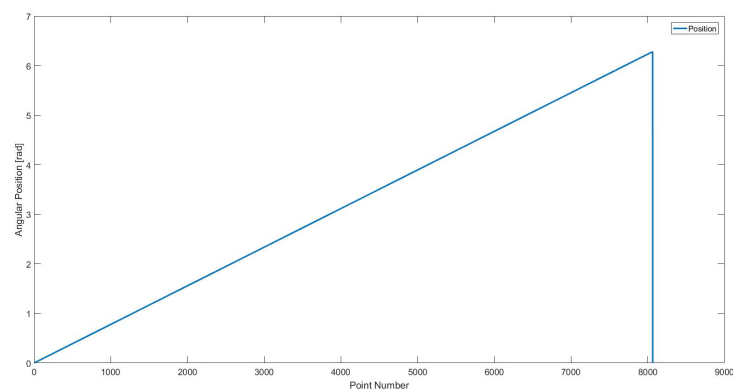


Figure 4.4: Example of position plot

## Chapter 5

# System analysis

In figure 5.1 represent a block diagram of the system required by the customer:

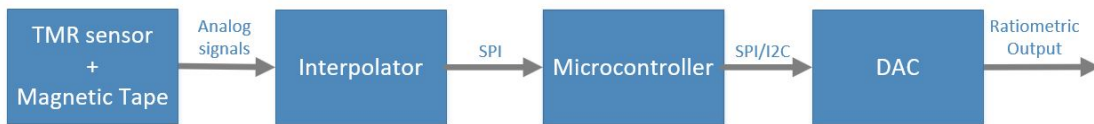


Figure 5.1: System scheme

The main components are:

- TMR sensor (TL915)
- Nonius linear magnetic scale on tape
- Interpolator
- Microcontroller
- DAC

The TMR sensor moving along the magnetic tape, provides a couple of Sin/Cos signals. An interpolator converts those signals into a position information. Then a micro-controller reads the data from the interpolator and elaborates them in order to correct an eventual error. Once the data are ready they are transmitted to a Digital to Analog Converter, to obtain a ratio-metric output. The components of the system will be described in details in the following chapters.

## 5.1 TMR sensor

TMR sensors use the magneto-resistive effect, a quantum mechanical phenomenon that occurs in a magnetic tunnel junction, the same effect that is used in the HDD reading elements. The TMR sensor consists of two ferromagnetic layers, 'free' layer and 'pin' layer, separated by a thin barrier layer, like it is shown in figure 5.2.

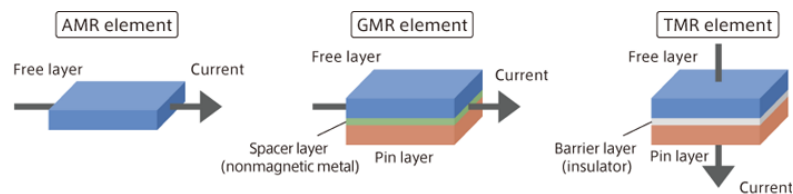


Figure 5.2: Evolution of TMR technology [3]

The resistance through the layers depends on the magnetic field applied on them. If the magnetizations of the 'pin' and the 'free' layers are aligned, that means there's no external magnetic field, the probability that electrons cross the insulating layer is greater. The magnetization direction of the 'pin' layer is fixed and the 'free' layer one's changes according to the external magnetic field direction. This means that the electrical resistance between the two different layers changes with the orientation of the magnetic field that it is applied to them (Fig. 5.3).

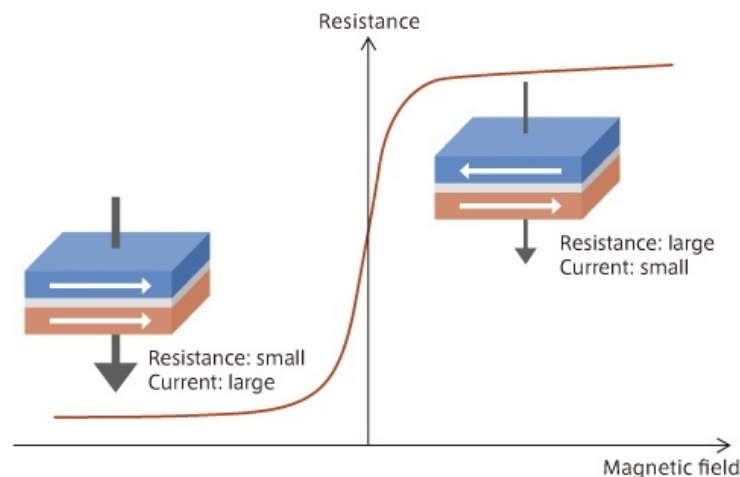


Figure 5.3: TMR effect description [3]

### 5.1.1 Sensitec TL915

The TL915 is a Tunnel Magneto-Resistive (TMR) position sensor produced by Sensitec. It has been designed to be used with a fixed pole length of 2.5mm (magnetic period = 5mm) and, thanks to the MR element disposition, has a built in filter for higher harmonics to

increase signal quality.

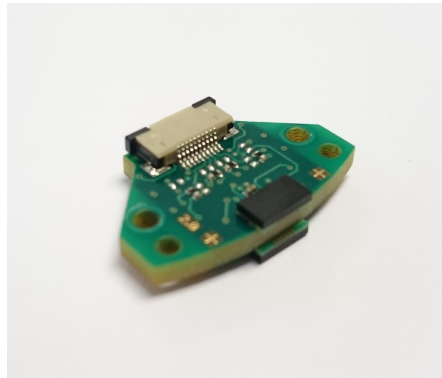


Figure 5.4: TL915 evaluation board

## 5.2 Magnetic Tape

In order to obtain linear measurement, as required from project specification, a Nonius magnetic tape with 63/64 pole couples of  $5\text{mm}$  period, with total length of  $320\text{mm}$ , has been used.



Figure 5.5: Magnetic Tape

## 5.3 Interpolators

The interpolator is the component that calculates, starting from the analog signals, the relative or absolute position. First, it converts to digital values the signals, then it calculates the position or correspondent incremental signals, through a non-linear conversion function (usually  $\arctan$ ).

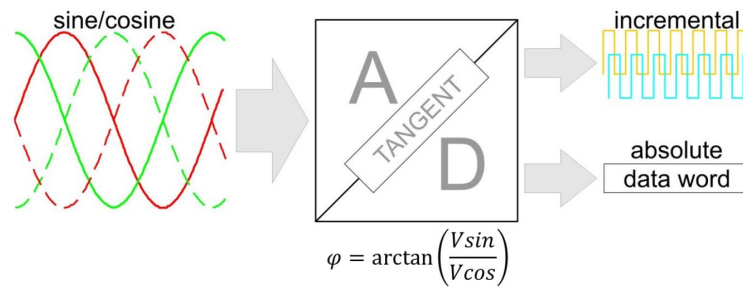


Figure 5.6: General scheme of an interpolator [4]

### 5.3.1 Choice of the interpolator

Among the interpolators available on the market, the customer selected three possible models to choose from:

The candidates were:

- iC-Haus iC-MNF
- iC-Haus iC-MN
- AMAC GC-NIP

In figure 5.7 is reported a summary table with the main features of the selected interpolators. iC-MN interpolator has been discarded because its temperature range is not compliant with the maximum temperature required from specifications. GC-NIP interpolator could not fit the PCB dimensions.

iC-MNF interpolator has thus been chosen, even if its dimension remain critical for the final application, being  $7 \times 7 \text{ mm}$  and having to be placed in a  $8 \text{ mm}$  wide PCB. At the advisor suggestion, also 2 iC-TW28 have been added to be tested as a possible solution, because of their smaller dimension that can be fitted easier in the final PCB. They are not a complete solution as MNF, because they are designed to output a relative position from a single couple of Sin/Cos signals and to obtain an absolute position is necessary to combine the outputs of 2 of them.



		Device name		
		iC-MNF	iC-MN	GC-NIP
Features	Max interpolation rate			8192
	Max. input frequency	200 kHz	200 kHz	130 kHz
	Adjustable low pass filter			10..150 kHz
	Max. propagation delay	2.3 $\mu$ s	5 $\mu$ s (typical- 250..500 ns per bit)	8 $\mu$ s (26 MHz clock)
	Internal gain control	Yes	Yes	Yes
	Output signal	RS422 BiSS, SSI, SPI, Sin/Cos	RS422 BiSS, SSI, Sin/Cos	ABZ, SPI, SSI, BiSS
	Power supply	5 V	5 V	3.3 V (5 V with level-shifter)
	Temperature range	-40° ... +125° C	-40° ... +95° C (110° C on request)	-40° ... +125° C
	Signal offset correction	Yes	Yes	$\pm 10\%$ of standard amp.
	Signal amplitude correction	Yes	Yes	60% ... 120% of standard amp.
	Signal phase correction	$\pm 10.42^\circ$ max	$\pm 10.396^\circ$ max	64 Steps on $\pm 5^\circ$ or $\pm 10^\circ$ range
	Dimension	7 x 7 mm	7 x 7 mm	9 x 9 mm
	Resolution	Max. 26 bit	Max. 25 bit	Max. 22 bit
	Internal ADC	14 bit SAR	13 bit SAR	

Figure 5.7: Summary table of interpolators features

### 5.3.2 iC-MNF

Encoder device iC-MNF is a 3-channel, simultaneous sampling sine-to-digital converter which interpolates Sin/Cos sensor signals using a high precision SAR converter with a selectable resolution of up to 14 bits. Each input has a separate sample-and-hold stage which halts the track signal for the subsequent sequential digitization. Various 2- and 3-track No-nius scale computations and multi-turn gear box synchronization modes can be configured for the calculation of high resolution angle positions; these computations allow for angle resolutions of up to 26 bits [1].

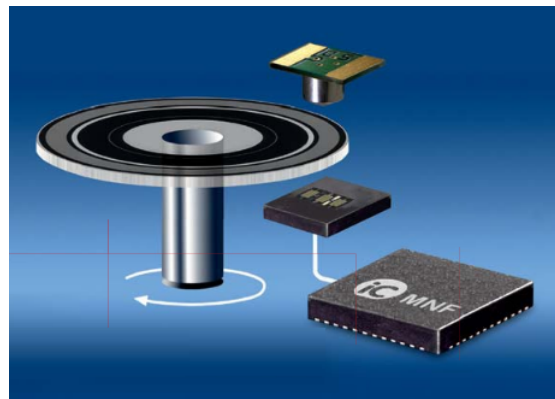


Figure 5.8: iC-MNF

### 5.3.3 iC-TW28

The iC-TW28 is a low-latency (1.5 $\mu$ s) application-specific interpolator for Sin/Cos signals. It provides differential ABZ or UVW outputs via a built-in RS422 line driver or simultaneous single-ended ABZ and UVW outputs in a 5x5 mm QFN32 package. Automatic calibration of the signal path parameters and adaptation during operation provides and maintains min-

imum angular error and jitter. A configurable signal path filter provides dynamic response characteristics, allowing smooth outputs as well as fast response to changing inputs. Suitable for stand-alone or hosted operation, the iC-TW28 is configured by dedicated pins, SPI communication, or Encoder Link. The Encoder Link interface uses the A+ and A- outputs for SPI-like communication for configuration or re-configuration in the field. A build-in LED controller allows controlling the intensity of an optical sensor's LED to maintain optimum input signal amplitudes despite ageing or changes in operational conditions. Complete status monitoring and fault detection capabilities with a dedicated LED driver or interrupt request pin for implementing safety functions are provided. In hosted applications, a 14-bit multi-cycle counter is available which can be extended using a host processor. A capture register allows coded index and touch-probe applications [2].

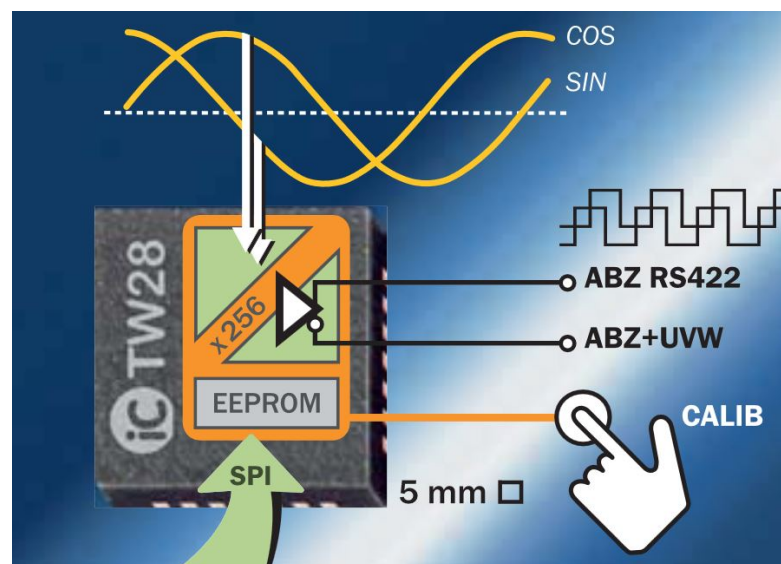


Figure 5.9: iC-TW28

## 5.4 Micro-controller - dsPIC33EP512MC502

For this project has been chosen the Microchip dsPIC33EP512MC502, a 28 pin micro-controller with integrated DSP and enhanced on-chip peripherals.



Figure 5.10: dsPIC33EP512MC502

The main features that has been used are:

- 32-bit Quadrature Encoder Interface (QEI) module
- 2 SPI modules
- UART module

### 5.4.1 Micro-controller evaluation board

The evaluation board Microstick II has been used to program and debug the micro-controller. It is a board specifically designed to be used with 28-DIP ICs and to be plugged into proto-type boards.

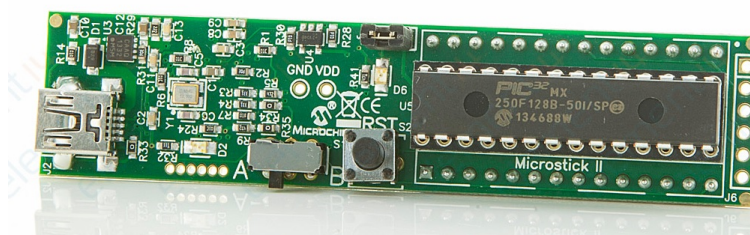


Figure 5.11: Microstick II



## Chapter 6

# Test bench

In order to prove the quality and reliability of the measurements obtained with the system described before designing a final prototype, a test bench has been designed by me and built in the SUPSI department of mechanics. The CAD assembly is represented in figure 6.1.

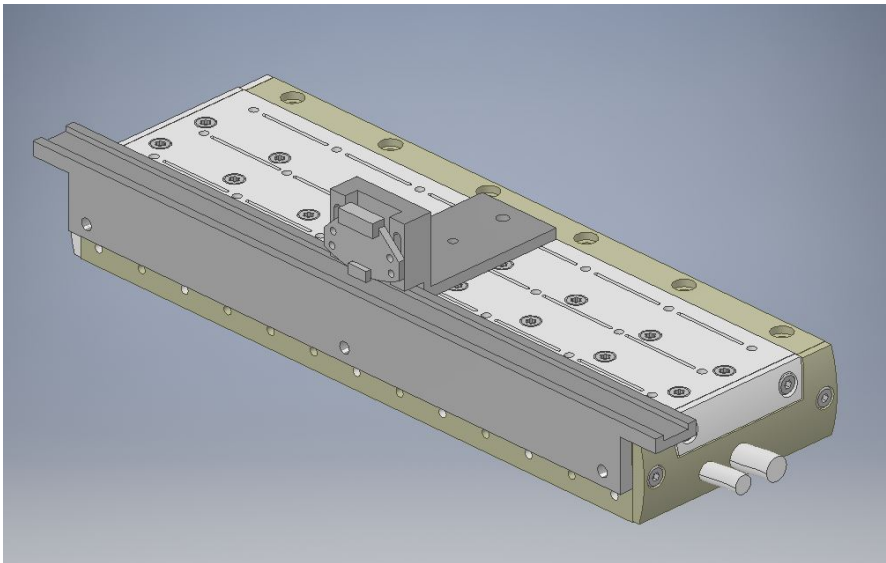


Figure 6.1: CAD rendering of the test bench

The base of this system is a linear motor from JennyScience, the Linax Lxc-135F10. It has a  $100nm$  incremental encoder, that is more than sufficient to test our magnetic solution, and a stroke of  $135mm$ , enough for the test. It has been controlled through a Jenny Science XENAX Xvi 75V8, sending commands via serial interface.

## 6.1 Sensor and Tape supports

Two different supports have been designed to integrate the parts needed with the motor.

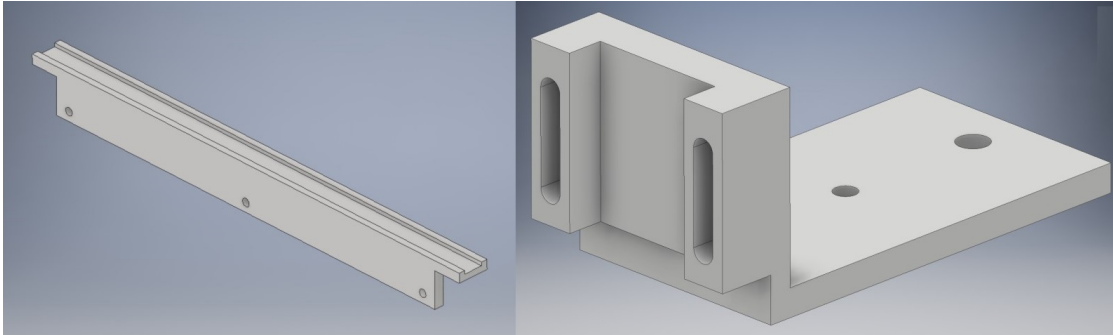


Figure 6.2: Supports

The sensor holder is designed to permit to adjust its distance from the magnetic reference and position it in the exact middle of the magnetic tape.

At first those supports were realized with the 3D printing technique (figure 6.3) and then machined in aluminum.

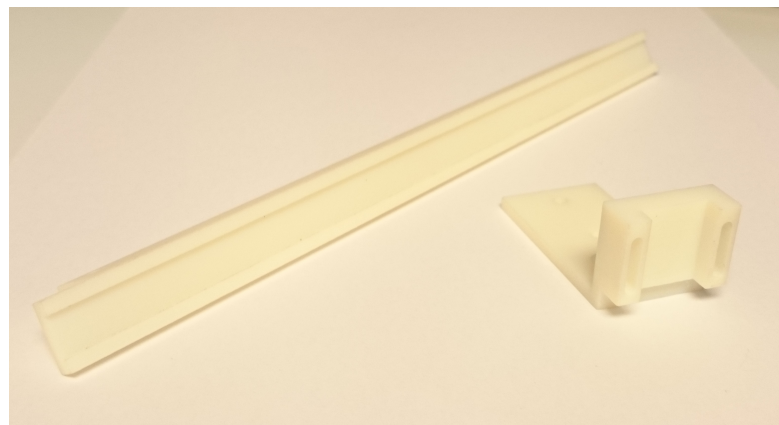


Figure 6.3: 3D printed supports

The final result is visible in figure 6.4. In the final system a 3D printed support has been added for cable managing.

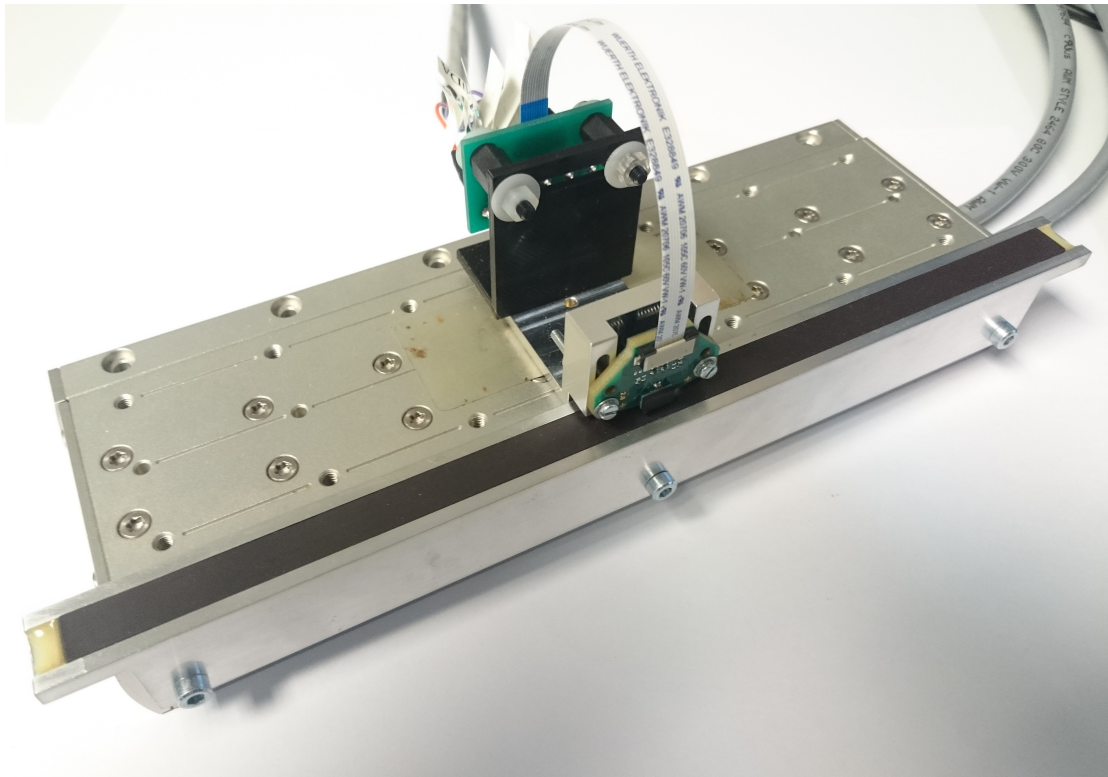


Figure 6.4: Complete test bench assembly





## Chapter 7

# Hardware Design

A PCB has been designed and produced in order to have a complete test system. There was the necessity of a comparative position measurement, so the test system include a connector for the optical quadrature encoder present in the linear motor. Also a 4 differential channel ADC with simultaneous sampling has been added, to have the possibility of acquire the sensor signals value simultaneously at the data acquisition from the other devices. In this way it is possible to have a source of raw data for error correction.

### 7.1 Test system description

Given the availability of only 2 SPI, the iC-MNF and the ADC have been connected to SPI1, everyone with its CS, and the two iC-TW28 are in cascade on SPI2 with a single CS. The quadrature encoder signals have been connected directly to the micro-controller due to the presence of QEI module (Quadrature Encoder Interface) that supports 5V signals. A USB-UART converter has been added to connect the micro-controller to the PC.

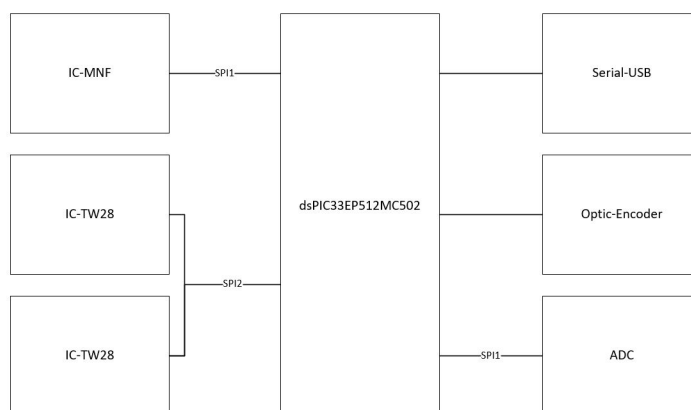


Figure 7.1: PCB block scheme

## 7.2 Connectors

It was decided to connect the micro-controller evaluation board to the PCB (figure 7.2), in order to have the debug interface and simplify the design, avoiding problems that are not relevant to the project.

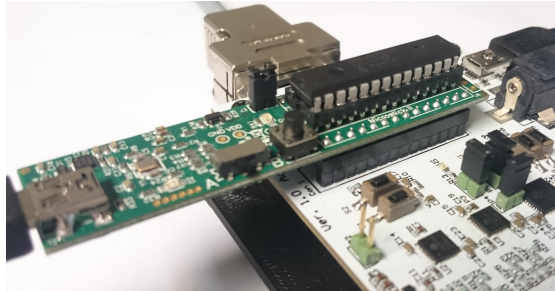


Figure 7.2: Micro-controller connected to the board

The sensor needs to move freely and therefore it was necessary to connect it with a multi-core cable, so in the design was placed a 10 pin connector (figure 7.3).



Figure 7.3: Cable board to sensor

The signals of the optical encoder must be taken from a DB9 female connector, then a male one has been placed positioned on the card (figure 7.4).

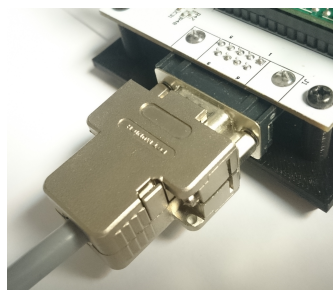


Figure 7.4: Optical encoder connector

In figure 7.5 there is the electrical scheme of all the connectors previously described.

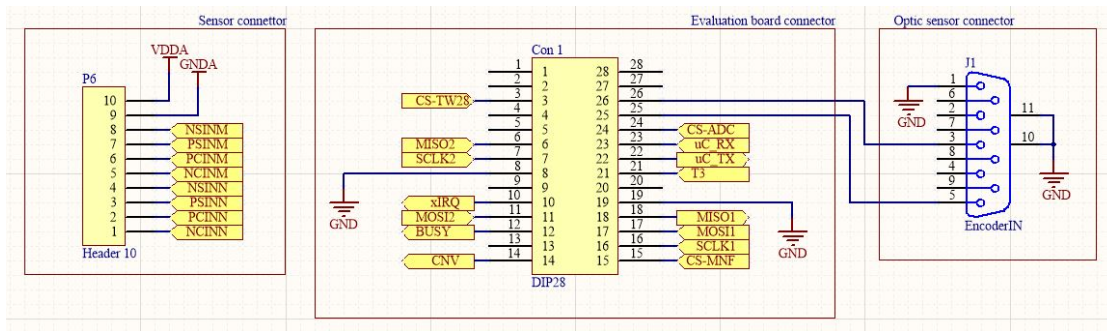


Figure 7.5: Connectors scheme

### 7.3 iC-MNF

The connections for the iC-MNF were made using the data-sheet and the evaluation board scheme as a reference. The *reset* and *preset* buttons have been added to the circuit and also the connection between pin T3 and the micro-controller, to have the possibility to use the functions related to it. Each of the sensor signals pass through a  $0\Omega$  resistor, a precaution if the device needs to be separated from the circuit. Also the power supply has a jumper that can be removed in order to shut down completely the iC-MNF.

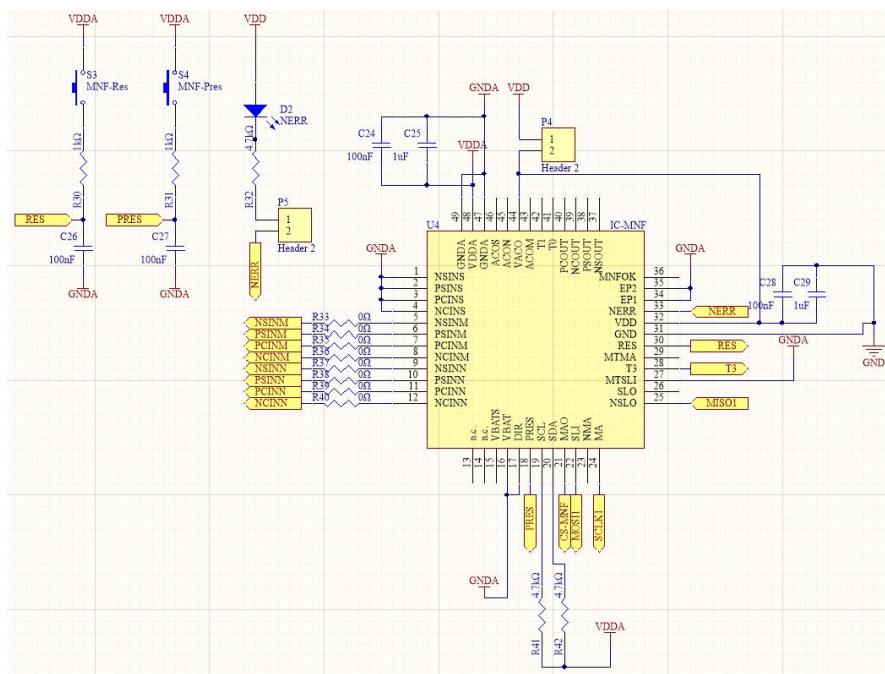


Figure 7.6: iC-MNF schematic

## 7.4 iC-TW28

The wiring for the couple of iC-TW28 has been taken from its data-sheet. Their SPI have been connected in cascade configuration according to the manufacturer's specifications.

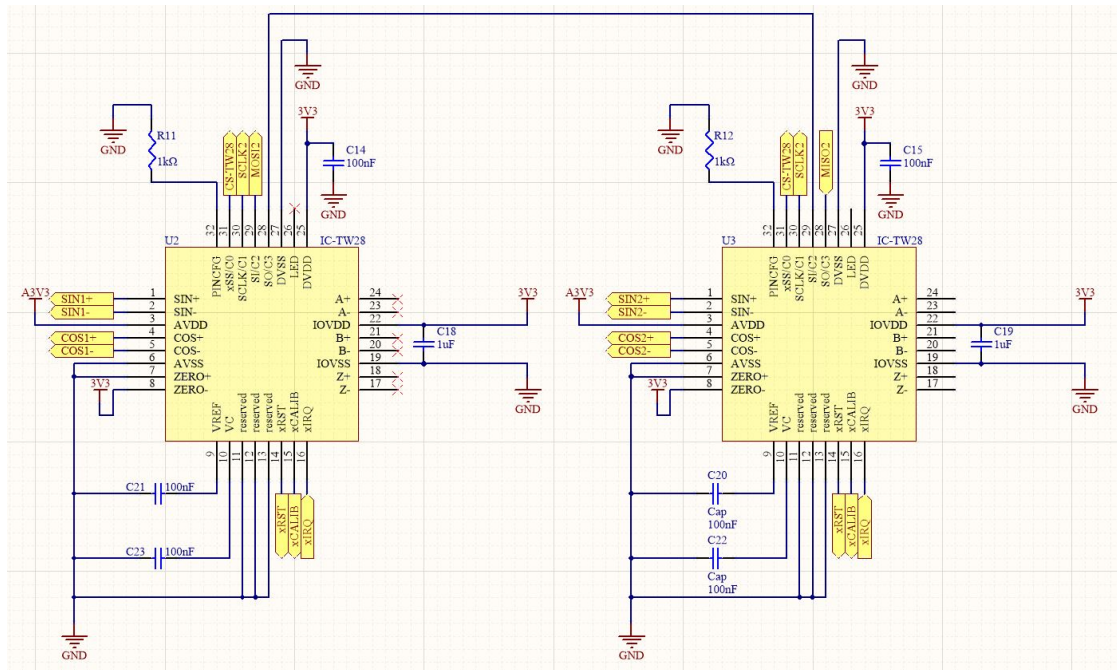


Figure 7.7: iC-TW28 schematic

Because the iC-TW28s can't tolerate the sensor signals levels, each of them pass through a resistive tension divider with scale factor 3 to 1.

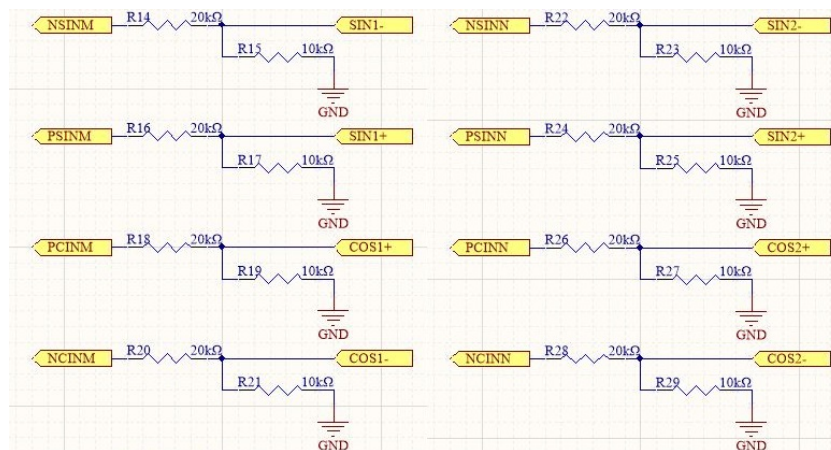


Figure 7.8: Tension dividers schematic

To generate 3.3V necessary for the iC-TW28s a linear regulator has been integrated with the circuit. It can be disabled removing an apposite jumper, consequently turning off the iC-TW28s too.

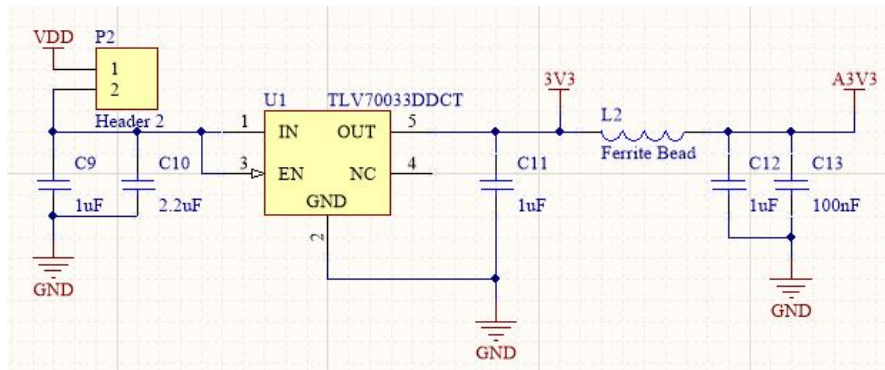


Figure 7.9: 3.3V LDO schematic



The schematic of LTC-2357-16 has been taken from its evaluation board schematic. A DC-jack connector has been added to connect an external power supply (7V) necessary for the correct data conversion. Each of the sensor signals pass through a  $0\Omega$  resistor, a precaution if the device needs to be separated from the circuit. Also the power supply has a jumper that can be removed in order to shut down completely the ADC.

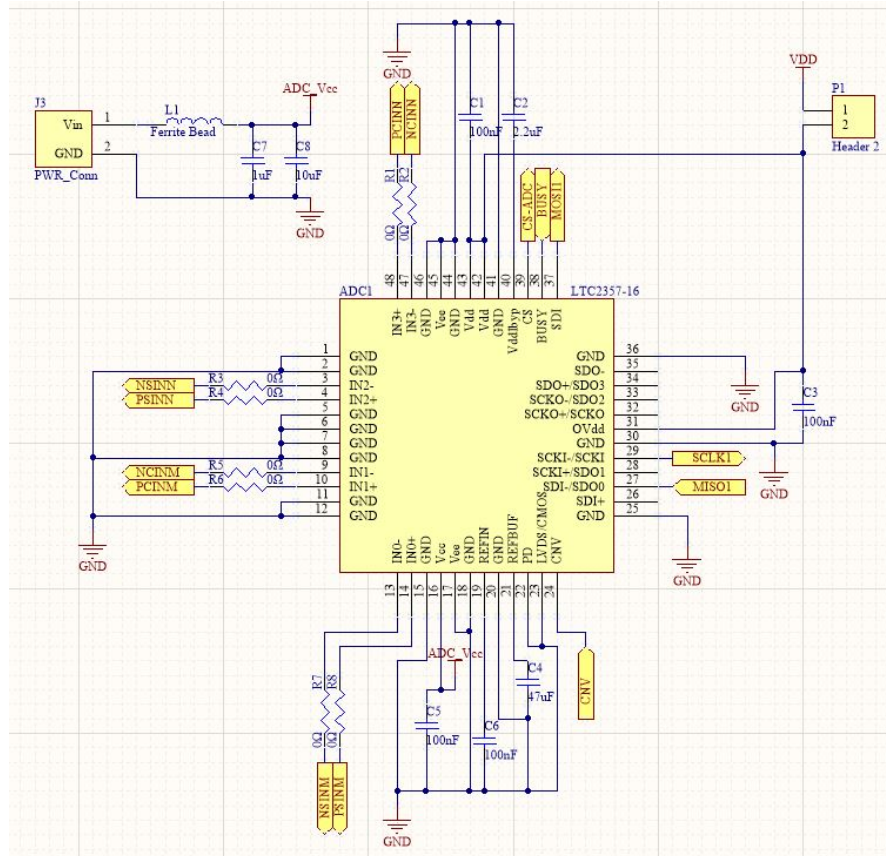


Figure 7.10: ADC schematic

## 7.6 FT230X

The schematic was taken from the data-sheet. The Vbus of the USB cable has been used to give the power supply at the whole board.

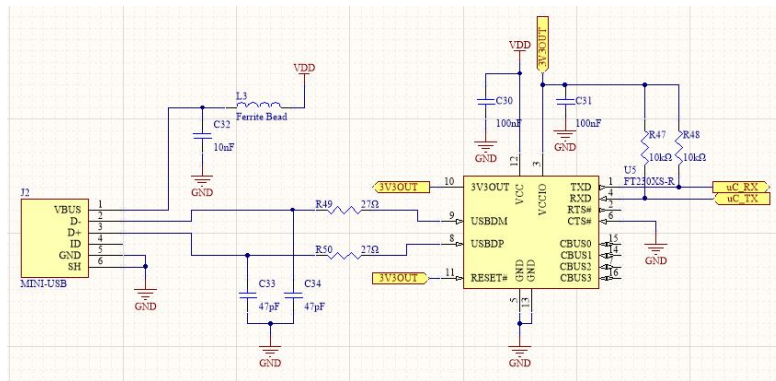


Figure 7.11: FT230X schematic

## 7.7 PCB Layout

### Top Layer

In the top layer particular attention has been paid to the analog signals track. A separate analog ground plane has been created around the iC-MNF.

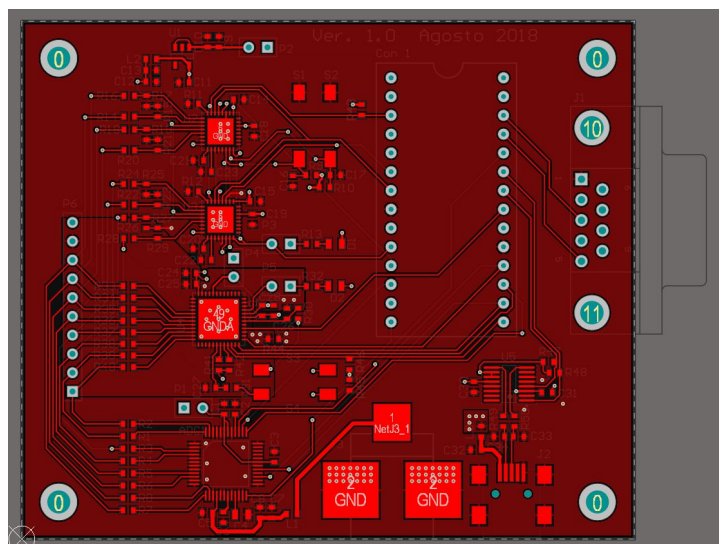


Figure 7.12: Top layer

## Bottom Layer

The bottom layer has no components and the same division between analog and digital ground planes as the top layer.

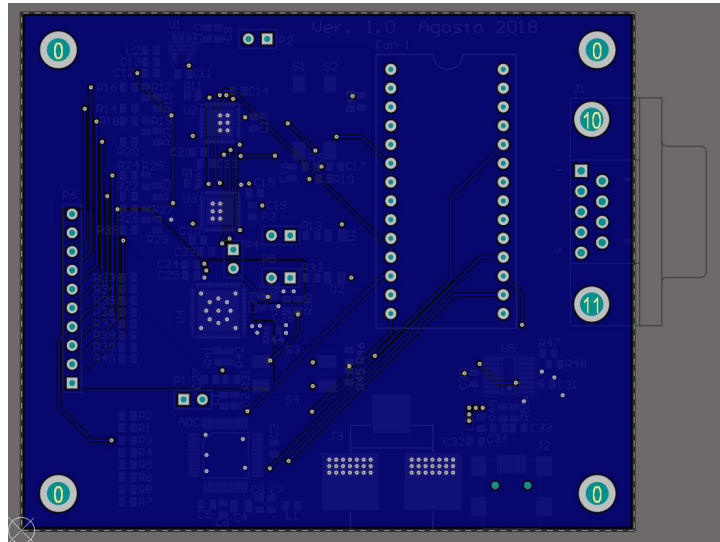


Figure 7.13: Bottom layer

## Power Plane

Three separate power plane for 3.3V, analog power supply and 5V have been created on the power plane.

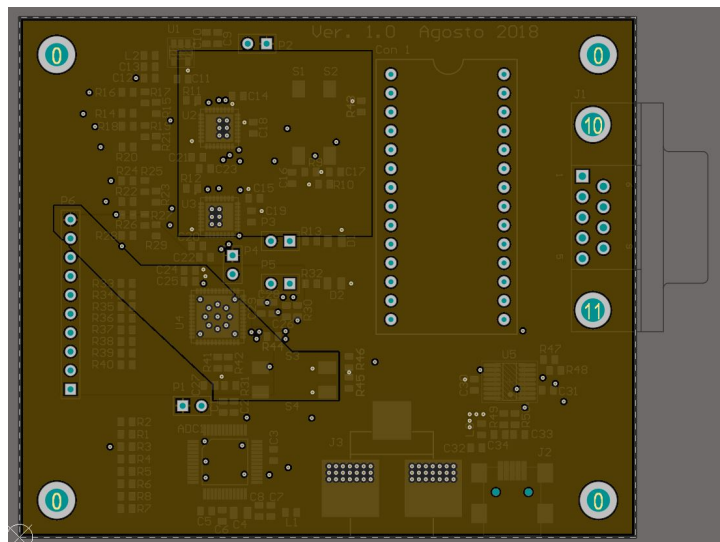


Figure 7.14: Power plane



## Ground Plane

The ground layer has the same division between analog and digital ground planes as the top layer.

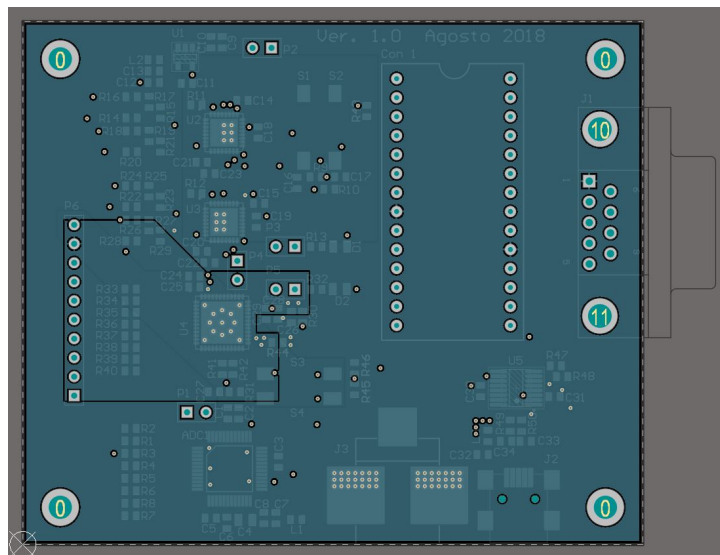


Figure 7.15: Ground plane



## Chapter 8

# Firmware

A apposite firmware has been developed during the project using the software tool MPLAB X IDE. It contains all the functions needed to configure correctly the iC-MNF through the SPI communication, read the optical encoder quadrature signals and communicate with the PC by UART. In this chapter the main functions will be explained, without going into the details of the written code. All the code attached to the project is commented and is therefore easy to understand.

### 8.1 Work-flow

The work flow can be seen in figure 8.1. After the system power on, all the necessary peripherals (QEI, SPI, UART) are initialized. Then all the configuration parameters are loaded into the iC-MNF through the SPI, with error check on every single register set up. Once this operation is completed with no error, the micro-controller enters idle mode, waiting for an UART RX interrupts. This event start and stop the cyclical data acquisition from the iC-MNF and the quadrature encoder and its transmission through the UART, timed by a timer interrupt.

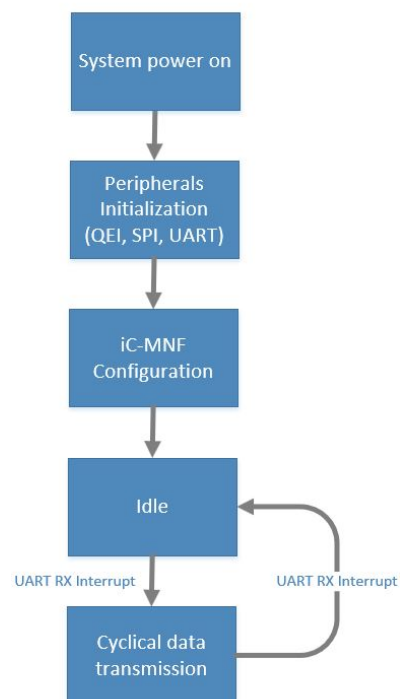


Figure 9.1: Firmware flow chart

## 8.2 iC-MNF dedicated functions and libraries

The iC-MNF has its specific commands to be sent over SPI, so a dedicated functions library has been created. The functions contained in it and their task are:

- readReg - single register read
- writeReg - single register write
- readData - read data position
- writeCmd - send a default command
- SDADstatus - check the data status

All of them contain a error check based on the iC-MNF answer, as it send back on *MISO* all the commands sent to him with data if expected. The files that define those functions are "MNFunc.c" and its header file "MNFunc.h".

A file called "MNFSettings.h" contains all the settings that are used to configure the iC-MNF when the system is powered on. In another file, "RegisterDef.h", there are all the definition of the commands that can be sent to the device, and the addresses of the status registers.

## 8.3 QEI module initialization

A function called "opEncoder\_init()" has been created to initialize the QEI module and contains all the settings necessary to set and enable the module. The files that define this function are "OpEncoder.c" and its header file "OpEncoder.h".

## Chapter 9

# Tests performed

### 9.1 Test with Evaluation Board

Before making a dedicated PCB, tests were carried out with an evaluation board of the IC-MNF (figure 9.1). In the next sections the procedure followed will be explained.

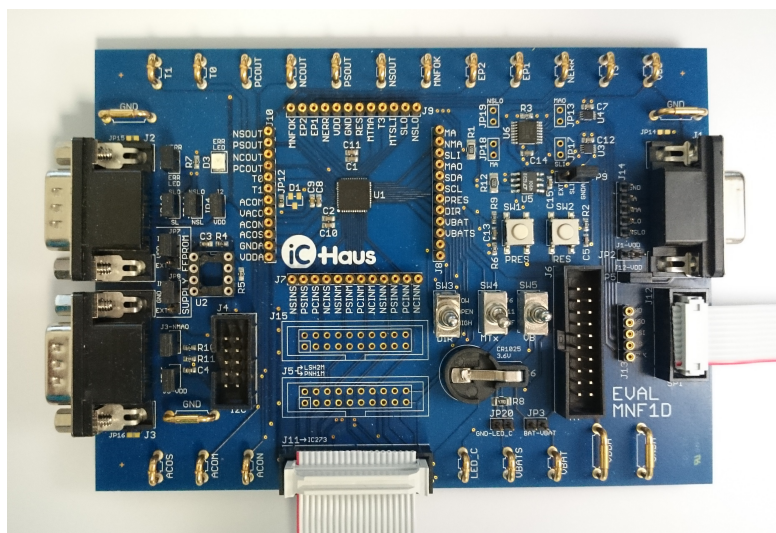


Figure 9.1: iC-MNF Evaluation Board

### 9.1.1 Hardware setup

At first, all connection to the sensor and the micro-controller were made. On the sensor side were needed:

- Power supply
- GND
- Wiring the 2 couples of differential Sin/Cos signals.

For this purpose the 2x10 flat cable connector present on the evaluation board was used. The signals had to be connected carefully because depending on how the sensor is oriented with respect to the magnetic stripe the master and the Nonius signals change output pins, so it is necessary to measure and establish which of the 2 couples of signals was the master and the Nonius.



Figure 9.2: Cable Ev. board to Sensor

On the micro-controller side were needed:

- SCLK
- MISO
- MOSI
- CS
- SPI-Enable
- GND

Also in this case a flat cable connector was used. It was a 5x2 (figure 9.3)

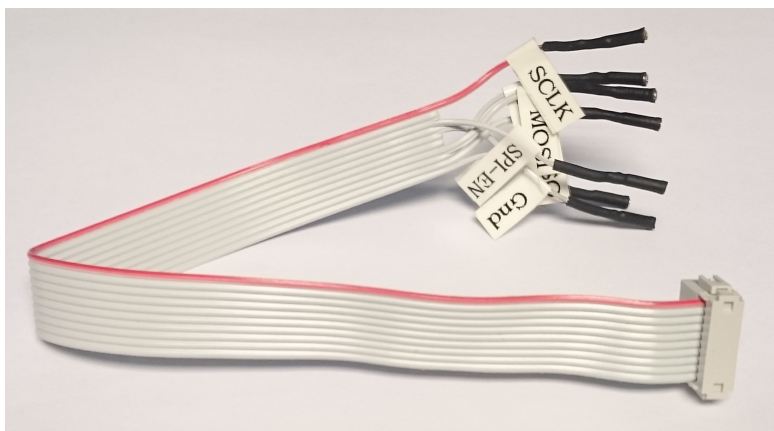


Figure 9.3: Cable Ev. Board to Micro-controller

To speed up the commissioning process of the evaluation board, a IC-Haus proprietary adapter has been used, being compatible with the graphical interface supplied by them. This adapter uses the same connector used to connect to micro-controller.



Figure 9.4: IC-Haus SPI adapter

The connection between the micro-controller and PC was made using a USB-UART converter board, equipped with a FT232HQ

### 9.1.2 Procedure followed

The ev. board come with a EEPROM, that contain a configuration for the iC-MNF. The configured communication interface was the BISS, a proprietary standard, and for this project it was preferred to use the SPI, but after loading the correct setting the device reboot with the previous one. To change this setting was necessary to unmount the EEPROM (8 DIP with socket) and modify it is content through a Arduino, that was the fastest and easiest way. Then it was possible to modify all the parameter through SPI, using the GUI or the specific function that is part of the firmware created, that will be described in the firmware dedicated chapter.

Once the SPI was working, the next step was to configure the signal conditioning parameter. The graphical interface has come to help, as it includes self-calibration tools.

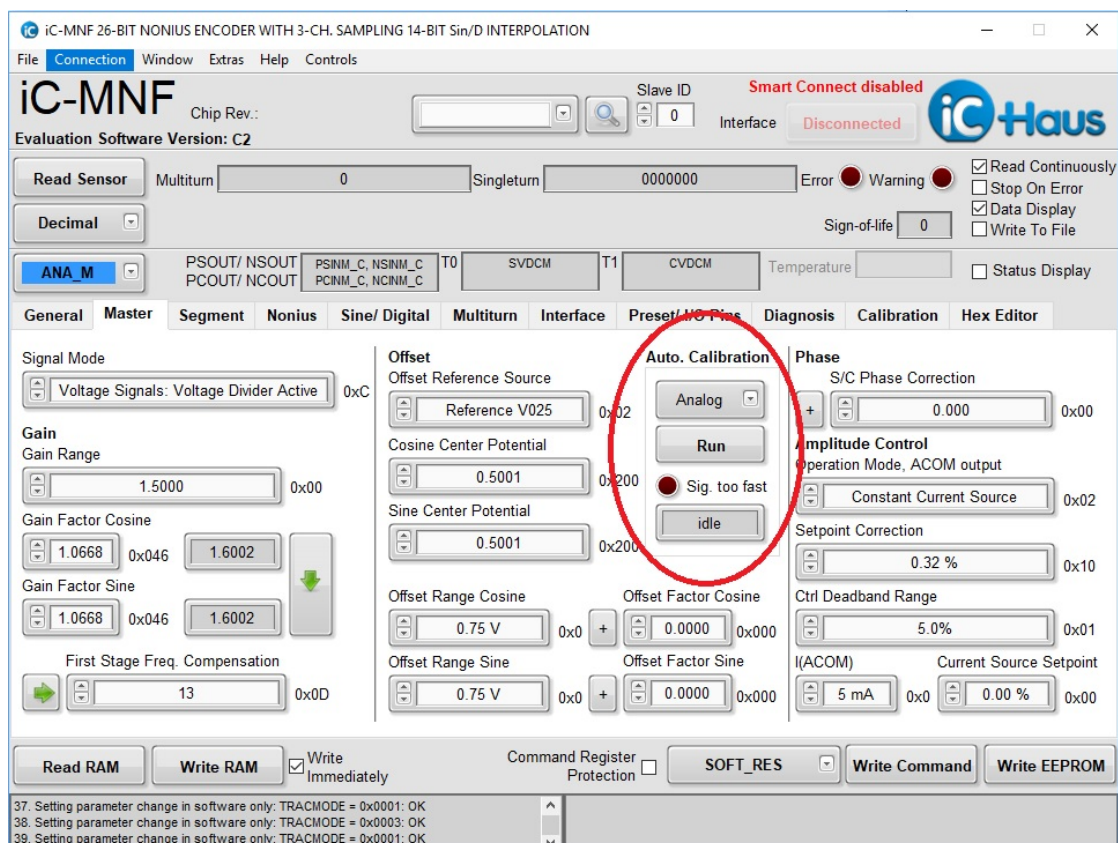


Figure 9.5: Calibration tool

Once the device is connected, with the button shown in figure 9.5, the internal gain and the other analog parameters are calculated while moving the sensor on the magnetic tape.

The parameters obtained can be saved in the EEPROM if present or it is possible to read the single parameter positioning the mouse pointer on the value needed.



### 9.1.3 First results

In this phase was crucial to configure the main parameters and verify the proper operation of the device. A first check on the system status came from the data and position window, where it is possible to check if the system is working.

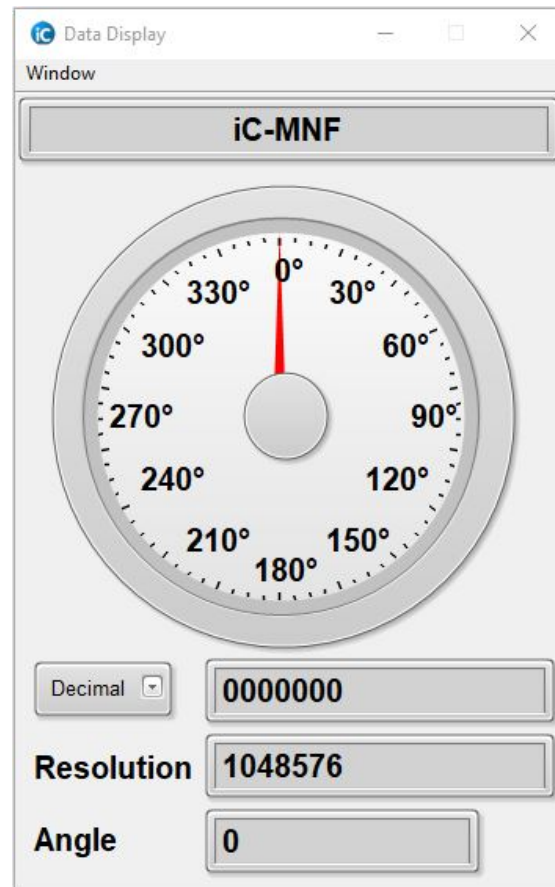


Figure 9.6: Position and data window

To better evaluate the position data, a acquisition system has been set up to transmit them through the micro-controller to a PC. Then with Matlab those data has been elaborated and plotted.

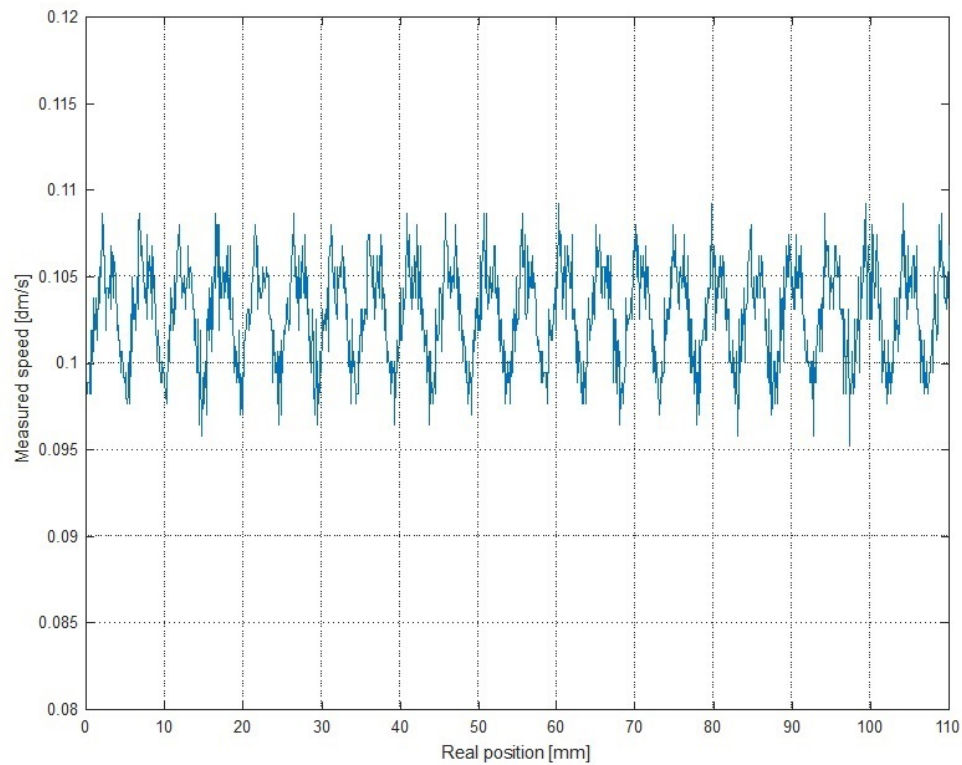


Figure 9.7: Plot Speed/Position

The test was made at a constant speed of  $10\text{mm/s}$  and as can be seen in figure 9.7 there is a periodic error, but the measurement was still acceptable.

After some try and manual adjustment the configuration obtained was good enough to allow to move on to the next phases of the project, during which more detailed tests will be performed.

## 9.2 Final system tests

After the PCB was completed, new test were made. The purpose of these tests was to check the repeatability of the measurements and the error that occurs in them. The final test system is visible in figure 9.8.

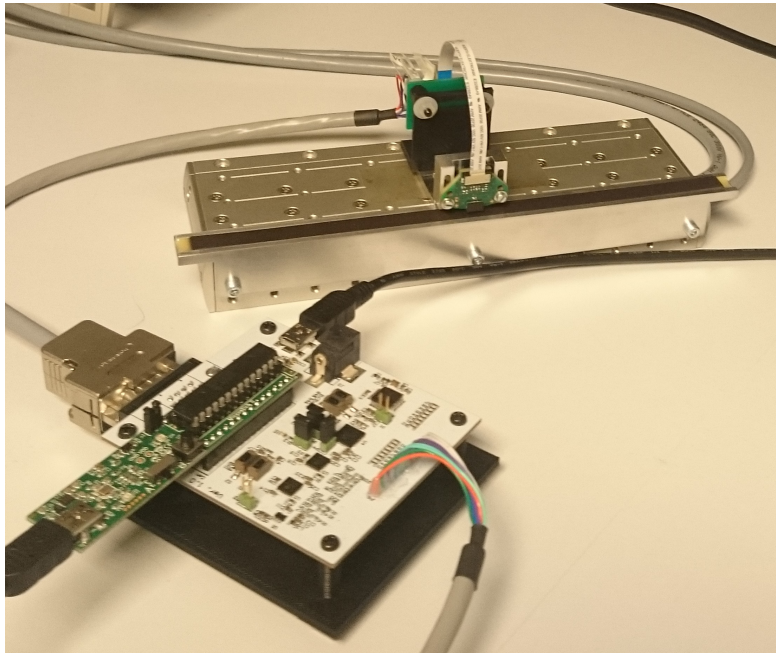


Figure 9.8: Final test system

### 9.2.1 Hardware setup

The PCB has to be connected to the PC with two USB-Mini cables, one for the micro-controller debug interface and one for the data acquisition. The optical encoder is connected through his DB9 connector and the sensor with a 10-cores cable, tin soldered on the board and connected with 10 single pin on the sensor side.

### 9.2.2 Firmware setup

The firmware was set to send the data once every  $1ms$ , with timer interrupt timing, trying to capture simultaneously both magnetic and optic position data.

### 9.2.3 Software setup

On the PC the data and all the commands for both the linear motor and the micro-controller are managed through Matlab. In the code attached to the project there are the functions that handle the serial communications and process the data for efficient graphs.

### 9.2.4 Results

The graph that follows (figure 9.9) shows that there is a coarse periodic error on the measurements. It was obtained acquiring the data running the linear motor from one end of the line to the other for 50 times at a speed of  $5mm/s$  and comparing the magnetic position with the optic one. This error can be corrected and reduced to the repeatability error.

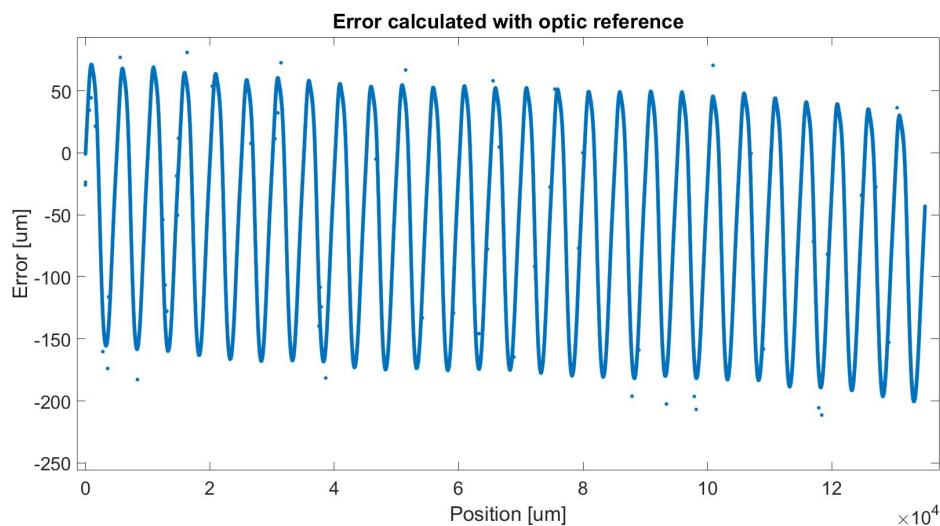


Figure 9.9: Periodic error on position measurements

This effect may be generated by the signals Sin/Cos that are not perfect. In figure 9.10 we can see that the master signals, measured in XY mode, have a good circular shape, but it's not a perfect circumference, as it should be.

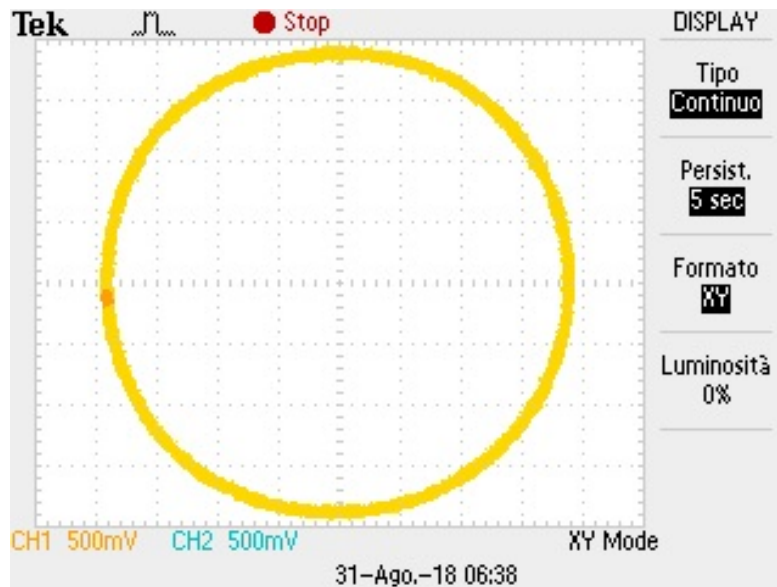


Figure 9.10: Master Sin/Cos signals measured in XY mode

In the graph 9.11 there is the same plot of figure 9.9, but zoomed in. It is possible to see a gap between curves that are generated by the two directions of movement. This gap is probably caused by the delay between the acquisition of optical and magnetic data. Not wanting to exclude it being an error, we can still state that the repeatability error always remains below  $3\mu m$

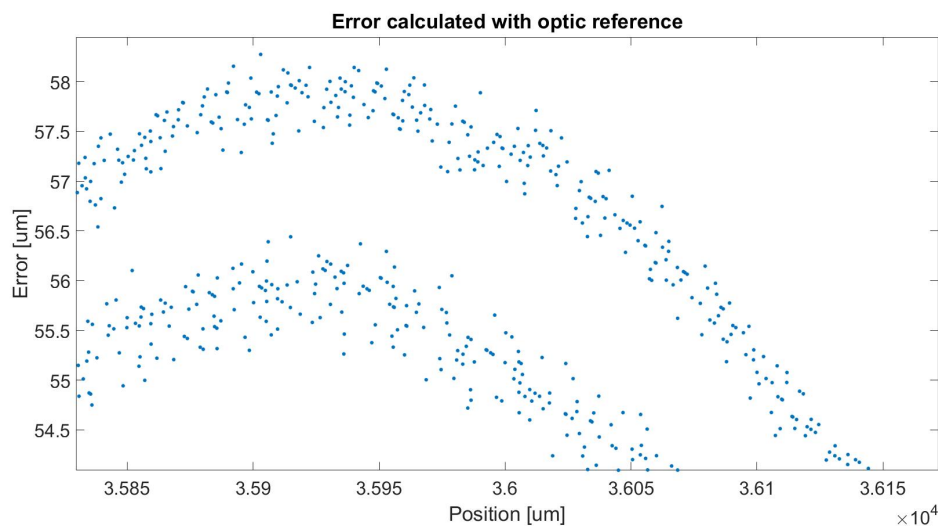


Figure 9.11



## Chapter 10

# Budget and costs

Three orders have been made during the project. The table below summarizes all the costs.

Evaluation Board + uControllers	77.54 CHF
PCB 4 Layer + Stencil	113,37 CHF
PCB components	114,65 CHF
Total	305.56 CHF

Table 10.1: Summary of expenses

The planned budget of 200CHF has been surpassed, but the expenses have been kept as low as possible. Thanks to the customer Sensitec, to whom we owe a big thank you, most of the devices used were supplied to us at no cost.





## Chapter 11

# Future development

There are many aspects of the project that could be investigated in the future. Some of them are briefly described in the following paragraphs.

### Correction of error

The first thing to do is correct the coarse error. It is periodic and related at the magnetization period of  $5mm$ , so it can be reduced or eliminated.

### Commissioning TW28 and ADC

Due to time problems, the iC-TW28 and ADC could not be put into service. It would be useful, also for research scope, to write their firmware and test them.

### Test different distances sensor-magnetic tape

The sensor had to be tested at different distances from the magnetic tape, but it was not possible because of the mole of work for every distance change, which causes a alteration in the levels of the signals and therefore the need to reconfigure the iC-MNF.

### Built the final PCB, respecting the constraints

The final PCB contemplate the dimension constrains that during the test phase have been ignored. Once the development phase is over, it will be necessary to design the PCB that respects these parameters.



## Chapter 12

# Conclusion

The project has lead to a working system that permit to measure and evaluate the precision of a TMR sensor. Many difficulties have been found due to the main component that has been on the market for a few months. Overall results obtained are included in the parameters defined by the project specifications and lay the foundations for the development of a system to be used by the final customer.



## Chapter 13

# Acknowledgements

I would like to mention all those who helped me in writing the thesis with suggestions, criticisms and observations. I thank first of all the white advisor, Mikael Bianchi, and correlator, Giorgio Rigamonti for their support during the project. A big thank you goes to Marc Kramb and Sensitec for the material provided. A special thanks goes to my girlfriend Deborah, who encouraged me or spent part of their time to read and discuss work drafts with me.



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[3] TDK tech note -[Link](#)

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