Project Plan

Rotary Wireless Signal Transmission				
Employer	University College of South-East Norway			
Group Members	**Name**		**Initials**	
	Chadi Chehade		CC	
	Carl-Henrik Kristoffersen		CHK	
	Egide Bampo Rubusa		EBR	
	Eton Williams		EW	
Document information	**Revision**	**Date**	**Approved**	**Pages**
	4.0	18.02.2016	CHK	26

Abstract

This document will give the reader an overview of our early-stage plan in the beginning of the project. It will discuss the project model that was chosen, and give an impression of the ambitions of the group.

By reading this document, the reader should get an understanding of what the project is about and how we plan to implement it.

Revision Table

Version	Date	Approval	Description
1.0	05.02.2016	EW	• EW created the document. Text & Structure
1.1	05.02.2016	CC	• CC Document formatting.
1.2	07.02.2016	EW	• Added Risk Analysis, Gantt diagram and Iterative Development Diagram
2.0	08.02.2016	CHK	• Revised and published.
2.1	11.02.2016	EW	• Updated references.
3.0	18.03.2016	CHK	• Revised and published.
4.0	23.05.2016	CHK	• Revised and published.

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1. Introduction

This Project Plan is for the course “Bachelor Thesis with Project Management”, SFHO-3200. The learning objective of the course is to demonstrate knowledge and skills in the planning, execution and documentation of engineering project work. This project period is January 2016 to June 2016, during the final semester of a bachelor degree at the University College of South East Norway (HSN). It awards 20 ECTS credits (European Credit and Accumulation System). [1]

The project group and assignment was officially formed on January 12, 2016. Professor Dag Samuelsen of HSN is the author of the project idea and is our customer. Intended as a multi-disciplinary project, our group consists three electrical engineering (cybernetics) students and one computer (software) engineering student. Each member is expected to contribute an average of 600 working hours for a total of 2400 project working hours. The project operates from the Kongsberg campus of HSN.

Product Objectives
Our project assignment is to create a system that will measure the degree of bending of a model helicopter´s rotor blades during operation. This data is to then be transmitted wirelessly in a way that can be read by an external system. It is the intention that HSN faculty members will use our system for research purposes.

This initial version of our Project Plan, together with Requirements Specification and Test Specification documentation, form part of the documentation requirements for our groups first presentation on February 12, 2016.

2. Project Organization

2.1. Customer

Dag Andreas Hals Samuelsen

University College of South-East Norway
Faculty for Technology and Maritime Sciences
Kongsberg Institute for Engineering Sciences
Campus Kongsberg, D366
Dag.Samuelsen@hbv.no
+47 31 00 89 50

2.2. Project Group

Group 23 – Rotary wireless signal transmission	2016
The group consists of 3 electrical engineering students and 1 software engineering student. We mainly work between 09:00 - 16:00 at HSN campus Kongsberg (Krona). We do not have a personal room yet and usually located in reserved library group rooms.	
	**Eton Williams** Electrical Engineering (Cybernetics) Eton.williams@gmail.com 95 08 50 44 **Primary responsibility:** Project manager & Development
	**Chadi Chehade** Electrical Engineering (Cybernetics) Chadi_1991@hotmail.com 96 88 47 73 **Primary responsibility:** Communication, Documentation & Development
	**Carl-Henrik Kristoffersen** Software Engineering (Virtual systems) Carlhenrik.kristoffersen@gmail.com 41 54 44 77 **Primary responsibility:** Web-design, Documentation & Development
	**Egide Bampo Rubusa** Electrical Engineering (Cybernetics) Egideba22@gmail.com 48 63 52 14 **Primary responsibility:** Development & Testing
Internal censor:	**Karoline Moholth**, 31 00 88 98, Karoline.Moholth@hbv.no
External censor:	**Dag Andreas Hals Samuelsen**, 31 00 89 50, Dag.Samuelsen@hbv.no
Internal supervisor:	**Sigmund Gudvangen**, 31 00 89 05, Sigmund.Gudvangen@hbv.no
External supervisor:	**Dag Andreas Hals Samuelsen**, 31 00 89 50, Dag.Samuelsen@hbv.no

Table 1: Group Overview Table

2.3. Group Values

We have committed to each other to do our best work, to help each other on tasks and to learn as much as possible from this process. We accept that we may make mistakes and are committed to learning from them. In case conflict arises, we will use a solution focused approach. Decisions are made together as a group. If conflicts seem to be unsolvable, we will involve our supervisors.

2.4. Group Work and Communication Plan

As part of our agile project management philosophy, our group has decided to work together around 80% of our project time in order to maximize our group communication and understanding. We use 5-10 minute SCRUM meetings at the beginning of each day to set achievement goals and again at the end of the same day to evaluate progress. Working hours are generally between 9.30-15.30 at campus Kongsberg. During January to March we will work Wednesday, Thursday and Friday. Mondays and Tuesdays are during this time are reserved for a mandatory subject we must all take. During April to May we will be working Monday to Friday.

All project documentation and research is placed in a common shared Dropbox folder. We have also established a private Facebook chat and Facebook group for internal communication.

2.5. External Communication Plan

Our group has designated a Communication Officer Chadi Chehade, for external group communication. We have a weekly meeting on Thursdays with our Internal Supervisor Sigmund Gudvangen. A weekly report sent a day in advance which details individual work and the group work in relation to our project plan. We have meetings with our customer Dag Samuelsen as often as is required. In the inception phase, these meetings have been to map Stakeholder concerns and to agree on Requirement Specification. We have had one meeting with Internal Sensor Karoline Moholth as was recommended to us by our internal supervisor.

We have established a website for communication with the general public, www.RWSTransmission.com. It will have a project description, introduction to our customer and group members. Regular updates and our group presentations will be available as well.

2.6. Document Naming Standards

Documents have the following standard:
Name_Version_Day.Month.Year

e.g. Project Plan_v1.0_31.01.2016

Meeting minutes with our customer, supervisor, advisors or within the group.
23. group_TITLE_Day.Month.Year.

e.g. 23. group_Supervisor Meeting_14.01.2016,
23. group_Day Plan & Minutes_04.02.2016 to 10.02.2016

3. Project Scope

3.1. Project Assignment

Below is the initial text given to us by author Dag Samuelsen, HSN.

Wireless transmission of data between rotating devices [2]

It is desirable to measure the degree of bending of the rotor blades of a model helicopter during operation. This will be done by mounting strain gauges on the blades, and mounting a microcontroller on the rotor top to read data from these gauges, as well as calibration of the measurement data.

The gauges will be connected as a Wheatstone bridge, and these need to be calibrated. How this is done is up to the group to decide. There are two rotor blades, and measurement data of each blade to be transferred

The system in the rotor to be supplied with power by mounting a coil on the rotor shaft, and a permanent magnet on the chassis to the helicopter. A power supply module must therefore be constructed to stabilize the flow of energy from the winding when the rotor speed changes.

Measurement data should be transferred from the rotor top of the helicopter via a rotary transformer coupling (See "Rotary transformer" online).

How the signal should be modulated to obtain a good transfer of measurement data determined by the group. [2]

3.2. Further information on Project

It is our customer's intention that our project will the first in a series of projects. The bending data that this project is intended to retrieve is intended to be used in an autonomous flight control system that could be designed by bachelor groups of a subsequent years. This knowledge significantly affects our understanding of the customers need and the requirements connected to them.

3.3. System Overview

Defining Boundaries.
How do you define what is within a system and what is outside of it? [3]

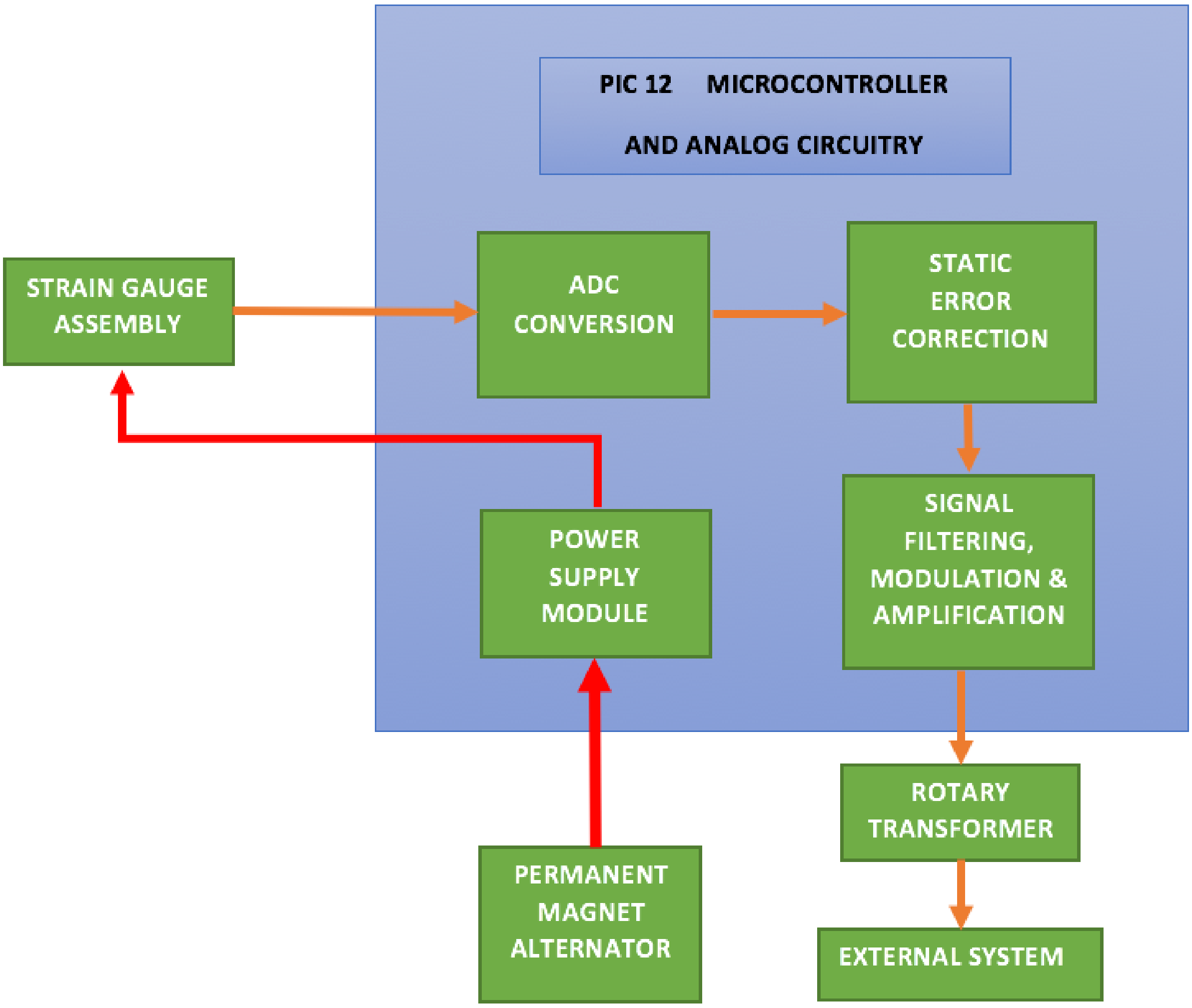


Figure 1: System Overview.

3.4. Product Sketch

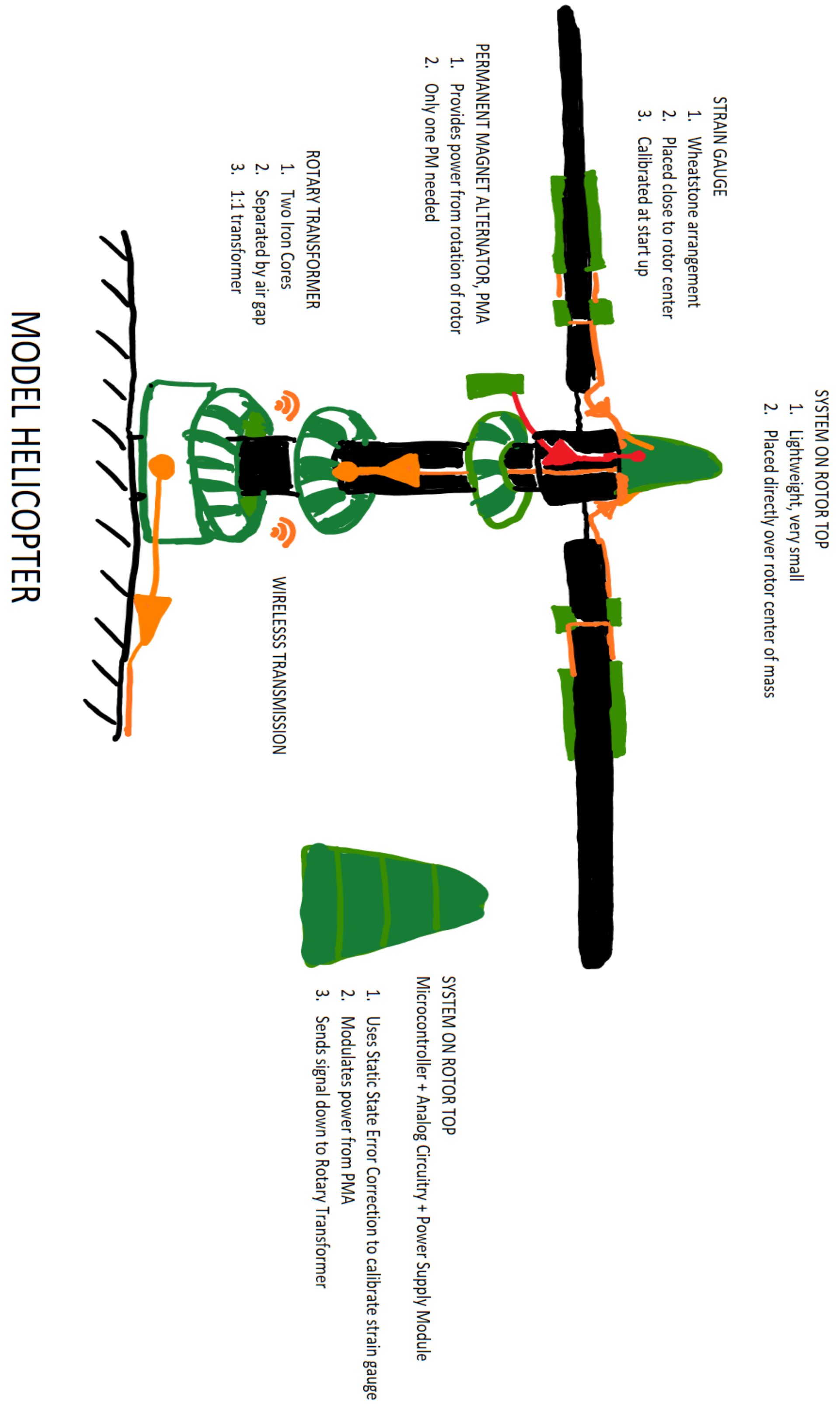


Figure 2: Product Sketch.

3.5. Development Phases

Phase 1:
Unmounted test system. Collect readings from strain gauge with microcontroller and circuitry.

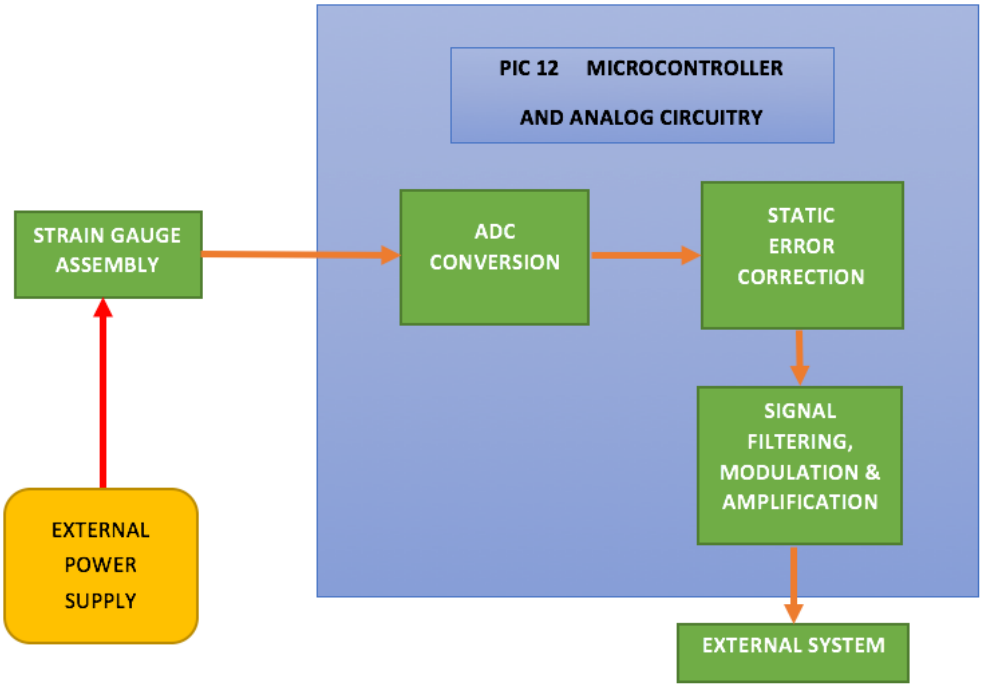


Figure 3: Prototype System Overview

Phase 2:
System mounted on a model helicopter. Prototype has a rotating transformer for signal transmission and permanent magnet alternator and Power Supply Module for power regulation.

3.6. Major Milestones

Milestone	Date
1st Presentation	10th February, 2016
2nd Presentation	Week 11, March, 2016
Hand-In of Project	Week 21, May, 2016
3rd Presentation	Week 23, June, 2016

Table 2: Milestones Table

3.7. Project model

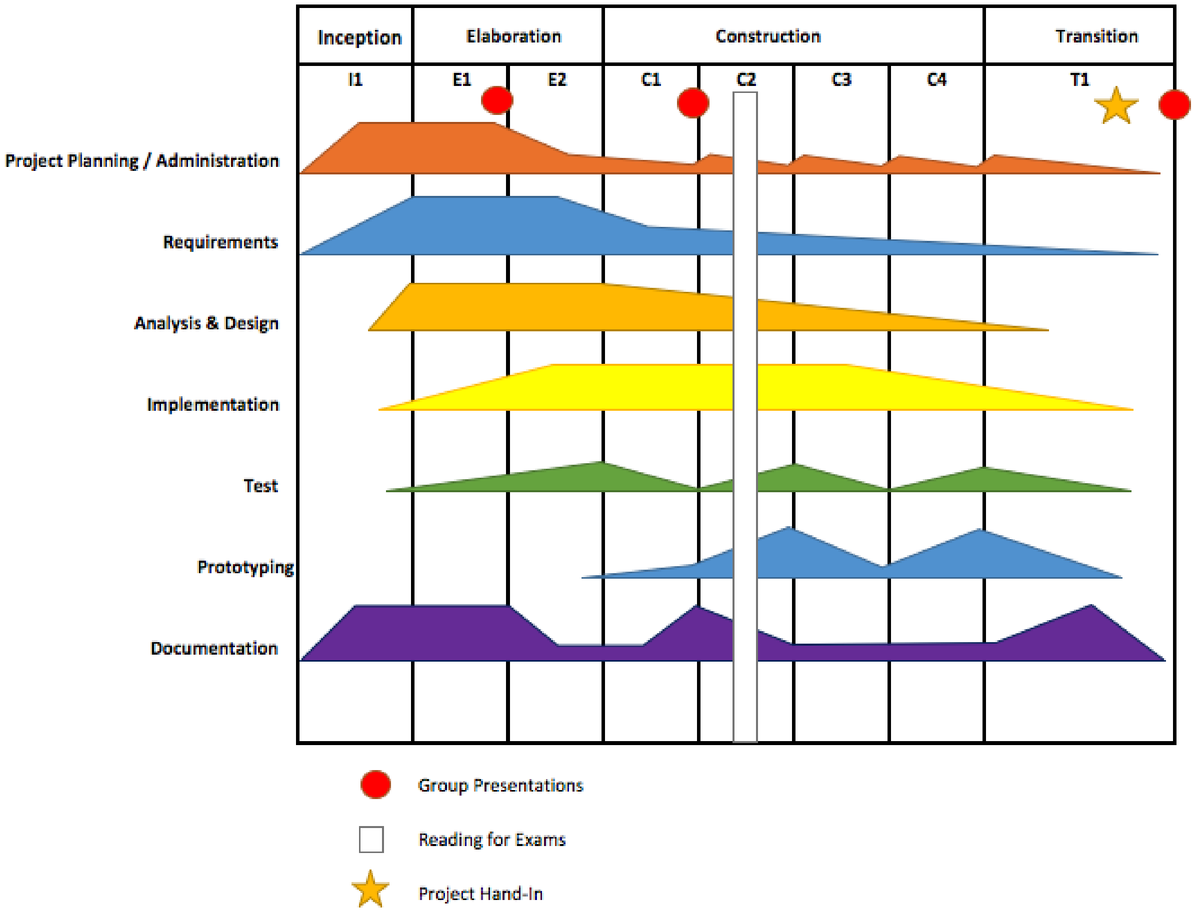


Figure 4: Unified Process Project Model

We have chosen Unified Process as our project model. Typically used for software development, we have adjusted it for our Bachelor Project.

This is an agile project management philosophy that is divided into Inception, Elaboration, Implementation and Transition Phases. Each Phase in the Unified Process Model consists of one or more iterations. These Iterations produce Increments (versions of documents, research information, prototypes). [4] In each iteration, we do work in various disciplines: Requirements, Analysis and Design, Implementation, Testing, etc. [5]

Unified Process encourages regular communication between developers and the customer or user. It places a distinct focus on early verification during iterations, which will allow for important decisions to be made through out the project. [5]

Iteration Plans are used to manage the project. They provide a description of upcoming work: start and stop dates, assignment of responsibilities, activities to be undertaken, risks to be mitigated as well as the measurement criteria or artifacts to be delivered which will determine the success of that iteration. Together with the Project Plan, the Iteration Plan helps the development team to assess project statues so that the project can meet its products requirements on time with the desired quality. [6] In the initial stages of our project, our group daily meeting minutes have been arranged as iteration plans.

We consider the flexibility inherent in this model to be well suited for our Bachelor project.
For example, by the time of the first presentation, we have completed most of the Inception Phase and have already begun the Elaboration Phase. We have begun Analysis and Design early in the project, after the initial High –Level Requirements have been established.

3.8. Project Schedule

The following section describes a coarse schedule through the different phases of the project, in accordance to the project model.

3.8.1. Inception Phase - Project Planning

The focus of this phase is understanding the scope of the project.

Project Planning:

Group Values and Vision
Project Background: SFHO 3200 at HSN
Project idea
Project model determination
Project scope, constraints and assumptions
Stakeholder Analysis
Initial Budget
Risk Analysis

Iteration Plans: Time scheduling, assignment of work. evaluation criteria
Plan Inception and Elaboration Phase

Analysis and Design

High-Level Requirements Analysis

Purchasing

Identify vendors for Components

Documentation

Documentation Templates established. Daily SCRUM meetings, Weekly reports, Internal Supervisor meetings, Customer meetings, Timesheets, Website

MILESTONE 1st Presentation 12th February, 2016

20-minute group presentation
Project Plan v1.0
Requirements Specification v1.0
Test Specification v1.0
Meeting minutes, Weekly Reports, Timesheets

3.8.2. Elaboration Phase – initial system analysis and design

The focus of this phase is establish and validate the system architecture. A construction plan detailing cost and schedule is created.

Project Planning

Iteration Plans: Time scheduling, assignment of work
Planning Construction Phase

Research

Calibration of Strain Gauge Assembly, Rotary Transformer Design, Permanent Magnet Alternator Design, Power Modulation

Analysis and Design

Further System-Level Requirements
Identify and validate System Architecture

Purchasing

Begin purchasing of Components

Build

Begin Phase 1 prototype

Testing

Unit Testing
High-Level Test Specification and Acceptance Criteria

Documentation

Group SCRUM meetings, Weekly reports, Internal Supervisor meetings, Customer meetings, Timesheets, Iteration reports, update project website, research documentation, Construction Plan, test reports

MILESTONE 2st Presentation 14:00-15:30, MARCH 31, 2016

20-minute group presentation - Technical Solution
Project Plan v3.0
Requirements Specification v3.0
Test Specification v3.0
Technical Documents v2.0
~~Construction Plan v2.0~~
~~Test Reports v2.0~~
Meeting minutes, Weekly Reports, Timesheets

3.8.3. Construction Phase – system implementation and integration.

Construction is the largest phase in the project. In this phase the remainder of the system is built on the foundation laid in Elaboration. System features are implemented in a series of short, time boxed iterations.

Project Planning

Iteration Plans: Time scheduling, assignment of work
Planning Transition Phase

Analysis and Design

Modelling Hardware and software
Interfaces
Evolve Requirements Specification

Purchasing

Complete purchasing of Components

Build

Phase 1 prototype
Phase 2 prototype

Testing

Execute initial testing
Evolve test specification and plans

Documentation

Group SCRUM meetings, Weekly reports, Internal Supervisor meetings, Customer meetings, Timesheets, Iteration reports, update project website**,** test reports

3.8.4. Transition Phase – final validation and testing

Feedback received from the initial release may result in further refinements to be incorporated over the course of several Transition phase iterations.

Project Planning

Iteration Plans: Time scheduling, assignment of work. Short time boxed iterations.

Prototyping

Phase 3 prototype

Testing

High-Level Testing
Validation

Stakeholder Acceptance

Acceptance Testing

Documentation

Group SCRUM meetings, Weekly reports, Internal Supervisor meetings, Customer meetings, Timesheets, Iteration reports, update project website, test reports,
Final Report, After analysis, Final Bachelor

Documentation

Group SCRUM meetings, Weekly reports, Internal Supervisor meetings, Customer meetings, Timesheets, Iteration reports, update website

MILESTONE Hand in Bachelor Project Documentation 17 May, 2016

MILESTONE 3rd Presentation 8 JUNE, 2016

40-minute group presentation: Technical and Sales Pitch
Project Plan v4.0
Requirements Specification v4.0
Test Specification v4.0
Test Reports v3.0
Technical Documents v3.0
After Analysis
Final Prototype delivered
Meeting minutes, Weekly Reports, Timesheets

3.9. Time Estimation and Management

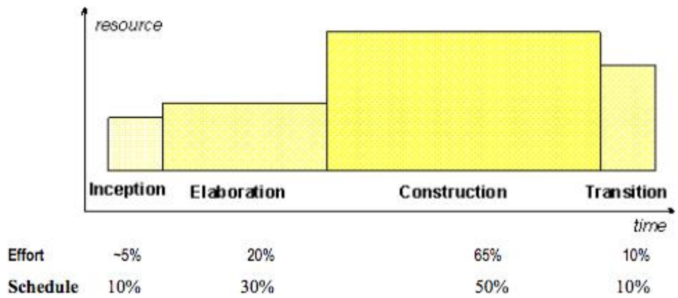


Figure 5: Unified Process Resources VS Time Graph. [6]

We used the above time estimates for typical Unified Process projects for our initial planning of the Project Phases.

Group members will be using PAYMO [7] an online time tracking and project time management tool to track individual hours as well as produce timesheet documentation.

3.10. Timeline

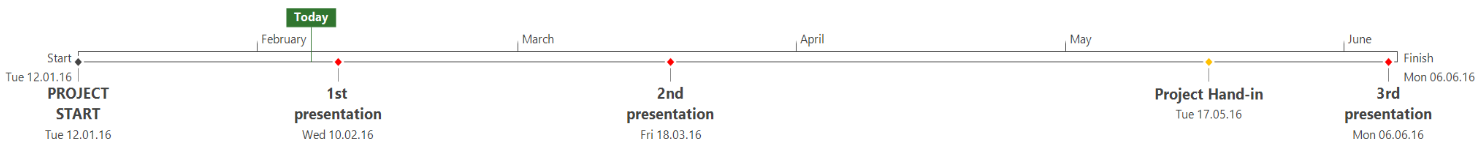
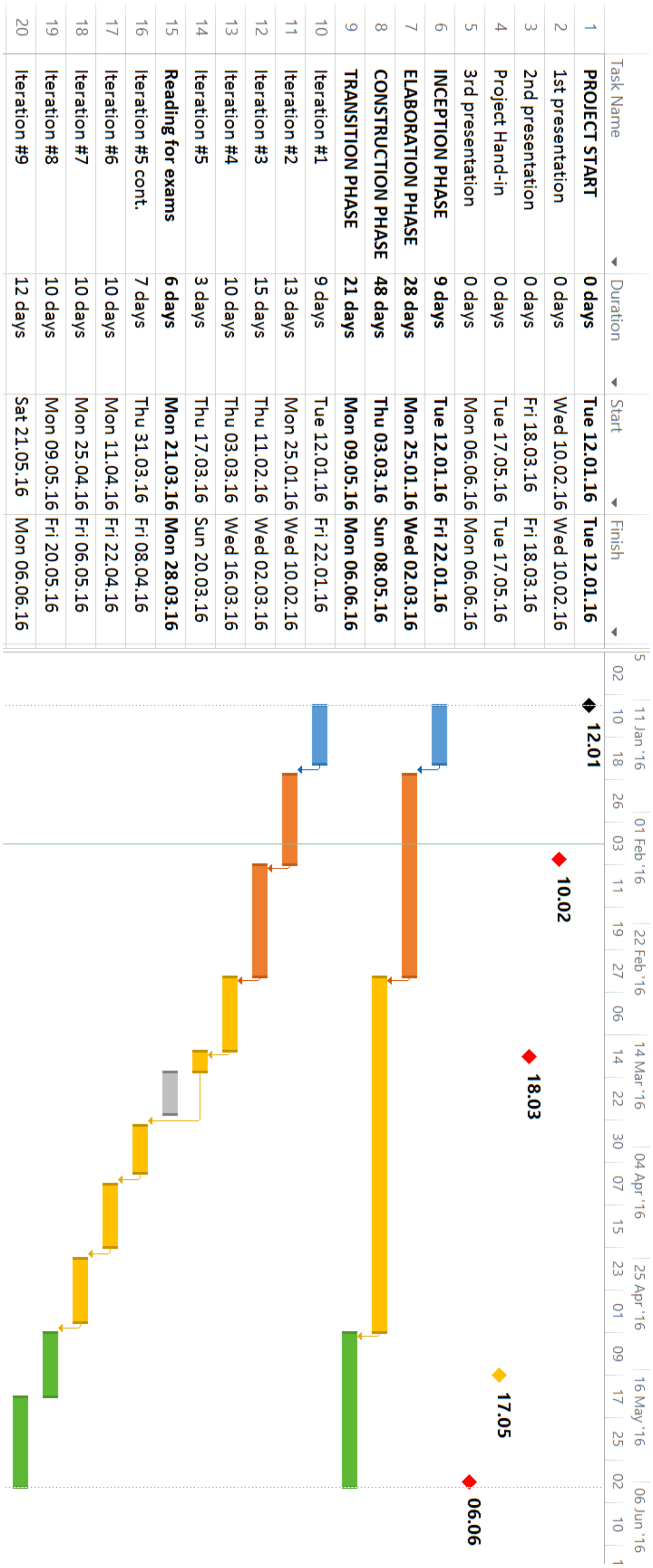


Figure 6: Timeline.

3.11. Gantt Diagram



	Task Name	Duration	Start	Finish
1	**PROJECT START**	**0 days**	**Tue 12.01.16**	**Tue 12.01.16**
2	1st presentation	0 days	Wed 10.02.16	Wed 10.02.16
3	2nd presentation	0 days	Fri 18.03.16	Fri 18.03.16
4	Project Hand-in	0 days	Tue 17.05.16	Tue 17.05.16
5	3rd presentation	0 days	Mon 06.06.16	Mon 06.06.16
6	**INCEPTION PHASE**	**9 days**	**Tue 12.01.16**	**Fri 22.01.16**
7	**ELABORATION PHASE**	**28 days**	**Mon 25.01.16**	**Wed 02.03.16**
8	**CONSTRUCTION PHASE**	**48 days**	**Thu 03.03.16**	**Sun 08.05.16**
9	**TRANSITION PHASE**	**21 days**	**Mon 09.05.16**	**Mon 06.06.16**
10	Iteration #1	9 days	Tue 12.01.16	Fri 22.01.16
11	Iteration #2	13 days	Mon 25.01.16	Wed 10.02.16
12	Iteration #3	15 days	Thu 11.02.16	Wed 02.03.16
13	Iteration #4	10 days	Thu 03.03.16	Wed 16.03.16
14	Iteration #5	3 days	Thu 17.03.16	Sun 20.03.16
15	**Reading for exams**	**6 days**	**Mon 21.03.16**	**Mon 28.03.16**
16	Iteration #5 cont.	7 days	Thu 31.03.16	Fri 08.04.16
17	Iteration #6	10 days	Mon 11.04.16	Fri 22.04.16
18	Iteration #7	10 days	Mon 25.04.16	Fri 06.05.16
19	Iteration #8	10 days	Mon 09.05.16	Fri 20.05.16
20	Iteration #9	12 days	Sat 21.05.16	Mon 06.06.16

Figure 7: Gantt Diagram.

3.12. Stakeholder Analysis

Name	Description	Stakeholder Concerns
Dag Samuelsen (HSN)	Customer / User	The creation of a system to measure the bending of model helicopter rotor blades to be used for research purposes.
Faculty at HSN	User	Use of the system to obtain bending data of model helicopter rotor blades for research purposes.
Rotary Wireless Signal Transmission (RWST).	Project Group Members: Chadi Chehade, Carl-Henrik Kristoffersen, Egide Bampo Rubusa, Eton Williams	A rewarding learning experience. Successful project.
Sigmund Gudvangen	Internal supervisor provided by HSN.	Project planning, execution and documentation
Component Suppliers	Online vendors or physical store vendors.	Provide products and services

Table 3: Stakeholders Table.

3.13. Financial

3.13.1. Product Budget

Detailed product budget can be found in appendix A.

3.13.2. Project Budget

Item	Cost (NOK)
T-shirts with project logo	1200,-
PAYMO Time Management	1036,-
~~Web server and domain~~	

Table 4: Project Budget.

4. Risk Analysis

Identifying and Assessing Risks Identifying and assessing project risks is an essential startup task. Our project has Identified potential risks that would decrease the likelihood that the development team will be able to deliver the project with the right features, the specified level of quality, on time and within budget.

Consequences	Description	Scale
Insignificant Consequences	The project is barely affected	1
Minor Consequences	The project experiences problems without stopping	2
Medium Consequences	The project is very affected and measures should be evaluated	3
Major Consequences	The project stops and measures must be evaluated	4
Disaster	The project is cancelled	5

Table 5: Risk Consequences.

Probability	Description	Scale
Unlikely	Less than 1 occurrence every 1000 hours	1
Less Likely	Average of 1 occurrence every 1000 hours	2
Likely	Average of 1 occurrence every 1000 hours	3
More Likely	Average of 1 occurrence every 1000 hours	4
Very Likely	More than 1 occurrence every 1000 hours	5

Table 6: Risk Probablility Table.

4.1. Risk Matrix

		Probability				
		1.Unlikely	2.less Likely	3.Likely	4.More likely	5.Very like
Consequences	**5.Disaster**	5	10	15	20	25
	4. Major Consequence	4	8	12	16	20
	3.Medium Consequence	3	6	9	12	15
	2. Minor Consequence	2	4	6	8	10
	1.Insignificant Consequence	1	2	3	4	5

Table 7: Risk Matrix.

Low	Favorable risk, no measure must be taken
Medium	Favorable risk, measures must be considered
High	Unfavorable risk measures must be initiated

Table 8: Color Explanation Table.

4.2. Risk Assessment

Event	P	C	R	Mitigate
Financial crisis at HSN	1	4	4	Purchase components ourselves
Delivery delay of prototype components	1	4	4	Order all components as soon as they are identified
Prototype damaged beyond repair	1	4	4	Maintain up-to-date documentation
High Cost Components damaged beyond repair	3	4	12	Exercise extreme caution
Low Cost Components damaged beyond repair	3	3	9	Order enough spare components
Loss of group member	1	4	4	Maintain up-to-date documentation
Conflict between team members	4	2	8	Engage in team building exercises / hanging out. Solution focused approaches in handling disagreements. If conflict persists, involve project supervisors.
Illness among project supervisor or advisor	3	3	9	Ask them to identify "fall back advisors" among themselves. i.e: Sigmund-> Karoline, Dag->Sigmund
Misunderstanding between the project group members about requirements	2	3	6	Have frequent group meetings to review discuss about requirements
Low team motivation	3	3	9	Small iterations with relatively achievable goals.
Defective components from supplier	2	4	8	Order from reliable suppliers. Order spare components when affordable.
The customer rejects the product	1	5	5	Frequently verify and validate the product to make sure that it complies with the user's requirements. Review the requirement specification occasionally to make sure that the product under development will cover customers need as expected.
Loss of project files	1	5	5	All documentation saved to common Dropbox. Dropbox has version history (30 days) in case of accidental deletion.
Unable to complete development	3	5	15	Perform high level planning. An iterative approach is deemed to secure completion of all the fundamental requirements. Additionally the competence of each group member should be put into consideration.

Table 9: Risk Assessment Table.

5. References

[1] O. H. Graven, "SFHO-3200 Hovedoppgave med prosjektstyring," HiBu - Faculty of Technology, 2011-2012.

[2] D. Samuelsen, "Bachelor Project Oppgave to Group 23," Kongsberg, 2016.

[3] K. Shipp and M. Ramage, Systems Thinkers, Springer London, 2009.

[4] G. Pollice, "Using the IBM Rational Unified Process for Small Projects," [Online]. Available: http://www.uml.org.cn/softwareprocess/pdf/tp183.pdf. [Accessed 2 February 2016].

[5] S. Daley, "Microsoft Project 2013 and the Project Management Domain," [Online]. Available: http://www.quepublishing.com/articles/article.aspx?p=2130297&seqNum=4. [Accessed 2 February 2016].

[6] D. West, "Planning a Project with the Rational Unified Process," Rational Software, 2002. [Online]. Available: http://www.nyu.edu/classes/jcf/CSCI-GA.2440-001/handouts/PlanningProjWithRUP.pdf. [Accessed 5 February 2016].

[7] "Paymo," [Online]. Available: https://app.paymoapp.com. [Accessed 12 January 2016].

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[9] O. Aasheim, S. Asjad, H. Dinh, D. Hasan, E. Gudbrandsen and J. Schäffer, KPEC – FPGA based ECU, University College of Buskerud and Vestfold, 2015.

[10] O. B., J. Berntsen, H. E., T. C., E. Nistad and Ø. Årsnes, Video coacher: An automated video training system, Kongsberg: University College of Buskerud and Vestfold, 2014.

[11] A. Barstad, C. Olsen, E. Haavaldsen, H. Blikra, J. Qureshi and M. Moeschinger, Mosquito Defence Systems, Kongsberg: University College of Buskerud and Vestfold, 2015.

Requirement Specification

Rotary Wireless Signal Transmission				
Employer	University College of South-East Norway			
Group Members	**Name**		**Initials**	
	Chadi Chehade		CC	
	Carl-Henrik Kristoffersen		CHK	
	Egide Bampo Rubusa		EBR	
	Eton Williams		EW	
Document information	**Revision**	**Date**	**Approved**	**Pages**
	4.0	20.05.2016	CC	18

Abstract

The requirements specification document defines the boundaries and constraints for our system. The purpose of this document is to describe the need and wants which the stakeholders require from the system, and what limitations occur as a result.

After reading this document, one should be able to understand which requirements have to be fulfilled in order to verify that the system is built correctly.

Revision Table

Version	Date	Approval	Description
1.0	15.01.2016	CC	• Created the document.
1.1	04.02.2016	CHK	• Document formatting, added requirement titles.
1.2	05.02.2016	CC	• Added paragraphs.
2.0	08.02.2016	CHK	• Revised and published.
2.1	11.02.2016	EW	• Updated references.
2.2	29.02.2016	CC	• Added requirements
3.0	17.03.2016	CHK	• Added, changed and removed requirements. Revised and published.
3.1	06.05.2016	CHK	• Added and changed requirements.
3.2	12.05.2016	CC & CHK	• Updated requirements.
3.3	13.05.2016	CHK	• Improved flow of writing.
4.0	20.05.2016	CHK	• Revised and published.

Contents

List of Requirement Tables

List of tables

1. Introduction

The requirements specification document describes what requirements have to be met to be able to produce a fulfilling system in accordance to the test specification document. The requirements in this document are set by our employer. The group itself has included additional requirements that has proved necessary as the project has been in development. These are mostly requirements derived from existing requirements, adding more detail to the overall boundaries of the system.

The following sections of the document will list all the requirements in tables, where each table has:

- An ID
- A priority
- A date
- A status
- A user story
- An acceptance criterion
- Comments

The complete list of requirement changes can be found in the changelog in the end of the document.

2. Description of Requirements

The description of requirements section describes how requirements are defined so that the reader can easily understand every element of each requirement.

We have chosen to divide our requirements in to two sub classes, which are *Main Requirement Specifications* and *System Requirement Specifications.*

Main requirement specifications are directly specified by the employer. System requirements are derived from the m*ain requirements* and must be met in order for the system to work. They are usually more detailed and fulfills aspects of the main requirements.

2.1. ID

The requirement ID serves as a reference to the requirement, every requirement has its unique ID. It will only be stated the ID of the requirement in different documents, you will need to find the ID in the requirements specification document to see the actual requirement.

The ID is built from a specific format consisting of two parts:

[Requirement type]-[Requirement Number].

E.g.

- MRS-01, where "MRS" is an abbreviation of Main requirement specification, and "01" is its unique number.

- SRS-01, where "SRS" is an abbreviation of System requirement specification, and "01" is its unique number.

2.2. Priority

In order to define the importance/priority of each requirement, they are graded on a scale from A to C. On this scale, A is the most important and C the least important. The definition of importance/priority in this document is in regards to whether or not it is critical for a successful system that the requirement is fulfilled. Failing to meet a requirement issued priority A, will make for an incomplete, and possibly failing system.

Priority Grade	Definition	Comments
A	Necessary in order to achieve a successful final system.	Needs of stakeholders.
B	The system will lack important features for a final system.	
C	Desired requirements that will not affect the functionality of the final system.	Wants of stakeholders.

Table 1: Priority Grade Table

2.3. Date

The date is simply just the date the requirement was first created. Any changes will be documented in the requirements changelog.

2.4. Status

In order to know if the requirement has been fulfilled or not, there will be 4 different status varieties.

Status	Definition
Changed	Requirement was changed and the change will be visible in the changelog.
Pending	Requirement is not yet finished, but intended for final build.
Completed	Requirement has successfully been implemented in the final build.
Abandoned	Requirement was abandoned and will not be included in final build.

Table 2: Requirement Status Table

2.5. User Story

Our user story is built on the template of the five W's [1]. We found that only three of the W's would suffice to define the requirements in our case. Therefore our user story consist of three W's, which are: *Who, Wants and Why* [2]. These are important parameters for defining our requirements.

A user story is necessary to justify the need for the requirement. Here are some examples:

WHO: Høgskolen i Sørøst-Norge (HSN).

WANTS: Transfer stable and reliable signal readings wirelessly through rotary transformer.

WHY: Only way to transfer signal while rotors rotate.

WHO: Group 23 (G23).

WANTS: System to withstand different weather conditions.

WHY: For the system to be functional even if bad weather conditions.

2.5.1. Who

Who is the person of interest that states the requirement. This is usually one of the stakeholders.

2.5.2. Wants

Wants describes what the *Who* wants from the product. This does not necessarily give what actually must be implemented in order to meet the requirement.

2.5.3. Why

Why describes the reason for *why* the requirement is set in the first place. All features and requirements must have a reason. The *why* is very important in the process of justifying the requirements and features of the project.

2.6. Acceptance Criterion

The acceptance criterion specifies what requirement must be met, before the status can be set to complete. This is the most important parameter of each requirement.

The acceptance criteria should be a short description covering everything necessary to fulfill the requirement.

Let us look at the examples from the user story paragraph:

WHO: HSN.

WANTS: Transfer stable and reliable signal readings wirelessly through rotary transformer.

WHY: Only way to transfer signal while rotors rotate.

Acceptance criteria: Read a data signal from rotary transformer that corresponds to the data sent to the transformer.

WHO: G23.

WANTS: System to withstand different weather conditions.

WHY: For the system to be functional even if bad weather conditions.

Acceptance criteria: Water proof housing for rotor top system required.

2.7. Comments

The comment field provides, if necessary, additional information to better understand the requirement or its relationship to other requirements.

3. Handling changes made by stakeholders

If a significant change occurs to the overall system or a majority of the requirements are dropped/changed during the project, the group together with supervisor will discuss and evaluate if the change is feasible. The process consists of evaluating if the new criteria can be met within our time frame without hurting the overall quality of the product.

Our Unified Process project model has a high tolerance for these kind of changes, as it lets us reiterate repeatedly and take changes into consideration on several occasions. It is unlikely that the project will suffer from this.

4. Abbreviations

Throughout this document, you will come across some abbreviations, which are explained here.

Abbreviation	Full name
HSN	University college of Southeast Norway, Department of engineering in Kongsberg. (Høgskolen i Sørøst-Norge.)
G23	Group 23.
MRS	Main requirement specification.
SRS	System requirement specification.

Table 3: Abbreviations Table

5. Requirements

MRS-01	**Priority:** *A*	**Measure bending**	**12.01.2016**
Status	Changed, pending.		
WHO	HSN		
WANTS	Measure bending of both rotor blades.		
WHY	Test-bench purposes/further development.		
Acceptance Criteria	Collect 2 separate signals that changes accordingly to the bending medium. For our proof-of-concept prototype, we want a signal varying between 0 V to 4 V, based on a reference voltage of 2.048 V. The strain sensors should respond to stimuli by hand, so a gain resistor must be chosen accordingly.		
Comments			

MRS-02	**Priority:** *A*	**Strain gauge data availability**	**12.01.2016**
Status	Changed, pending.		
WHO	HSN		
WANTS	Strain gauge data available for external system.		
WHY	Test-bench purposes.		
Acceptance Criteria	Read digital FSK-modulated data on an external system. Verify that 0-bits are represented by lower modulated frequency and 1-bits are represented by higher modulated frequency.		
Comments	Fulfilled through MRS-03. Rotary transformer, signal conditioning and external receiver system must be fulfilled first.		

MRS-03	**Priority:** *A*	**Wireless signal transmission**	**12.01.2016**
Status	Changed, pending.		
WHO	HSN		
WANTS	Transfer data readings wirelessly.		
WHY	So that data can be transferred out of the rotating system. Wiring is not possible as it gets tangled and twisted.		
Acceptance Criteria	Read FSK-modulated signal through a rotary transformer, where bits 1 and 0 are represented by high and low frequency modulation. The data must be obtainable while the system is in rotation at 2000 – 2500 RPMs.		
Comments	Derived from MRS-02.		

MRS-04	**Priority:** *B*	**Microcontroller mount**	**12.01.2016**
Status	Pending.		
WHO	HSN		
WANTS	Microcontroller chip mounted in the rotating system on top or inside of rotor head.		
WHY	Reading and calibrating strain gauge signals.		
Acceptance Criteria	Successfully mounting a circuit board w/microcontroller within the given space. Actual dimensions are not yet known, but assuming a diameter of 3.0 cm gives a circular area of 7.07 cm^2.		
Comments			

MRS-05	**Priority:** *C*	**Sensor readings during flight**	**27.01.2016**
Status	Abandoned.		
WHO	G23		
WANTS	System to provide sensor readings when model helicopter is in normal flight.		
WHY	Extend the usefulness of the test readings.		
Acceptance Criteria	Successfully transfer data to an external system mounted on the chopper during flight.		
Comments			

SRS-01	**Priority:** *A*	**Wheatstone bridge**	**12.01.2016**
Status	Pending.		
WHO	HSN		
WANTS	Strain gauges arranged in Wheatstone bridge.		
WHY	Offset temperature variation and get accurate measurements.		
Acceptance Criteria	Temperature drift is insignificant or absent.		
Comments			

SRS-02	**Priority:** *A*	**Placement of strain gauges**	**12.01.2016**
Status	Changed, pending.		
WHO	HSN		
WANTS	Strain gauge placed close to center of rotor.		
WHY	Minimize centrifugal force caused by high RPM.		
Acceptance Criteria	Centrifugal/centripetal forces do not significantly affect rotor or strain gauge sensors. No significant vibrations should be detectable.		
Comments			

SRS-03	**Priority:** *A*	**Signal calibration**	**12.01.2016**
Status	Changed, pending.		
WHO	HSN		
WANTS	To calibrate signals from strain gauge sensors in microcontroller.		
WHY	For improved accuracy of the collected data.		
Acceptance Criteria	Zero reading after calibration at zero force on rotor blades.		
Comments			

SRS-05	**Priority:** *A*	**Permanent Magnet Alternator**	**12.01.2016**
Status	Changed, pending.		
WHO	HSN		
WANTS	Permanent magnet alternator mounted on rotor shaft.		
WHY	To make system self-sustained with power.		
Acceptance Criteria	Produce at least 7 V_{AC}.		
Comments	The 7805 voltage regulator requires more than 5 volts to operate correctly. Required value is 7 – 25 V as specified in the LM7805 datasheet.		

SRS-06	**Priority:** *A*	**Power Supply Module**	**12.01.2016**
Status	Changed, pending.		
WHO	HSN		
WANTS	Power supply module.		
WHY	Provide stable voltage to the system regardless of power produced from the alternator generator.		
Acceptance Criteria	Power supplied from the power supply module cannot exceed 5 ± 0.5 V_{DC}. Line regulation not greater than 160 mV_{DC}.		
Comments			

SRS-07	**Priority:** *A*	**Signal modulation**	**12.01.2016**
Status	Changed, pending.		
WHO	HSN		
WANTS	System modulates and sends an appropriate signal to rotary transformer.		
WHY	To avoid saturation of iron core, and disturbance from environments (i.e. generator).		
Acceptance Criteria	Same data can be read before and after the rotary transformer.		
Comments	For details about the data before rotary transformer, see test procedure description for T-SRS-07.		

SRS-08	**Priority:** *A*	**Rotary Transformer Dimensions**	**12.01.2016**
Status	Complete.		
WHO	G23		
WANTS	Rotary transformer to be small.		
WHY	So the transformer can be mounted on the rotor shaft.		
Acceptance Criteria	Successfully mounting a rotary transformer on the shaft within the given space. The total diameter must not exceed 6,0 cm. Height should be less than 2,0 cm.		
Comments			

SRS-09	**Priority:** *A*	**System placement and centering**	**13.01.2016**
Status	Changed, pending.		
WHO	HSN		
WANTS	Center of mass of rotor top system directly over center of mass of rotor shaft.		
WHY	Maintain stability during high RPM.		
Acceptance Criteria	System must be balanced/centered with adequate equipment, and not vibrating at 2000 RPM and above.		
Comments	May be outsourced and done by Rotor Top Housing Designer.		

SRS-11	**Priority:** *A*	**Proof of signal output**	**27.01.2016**
Status	Changed, pending.		
WHO	HSN		
WANTS	Temporary External System reads signals from Rotary Transformer.		
WHY	To be able to read data from system.		
Acceptance Criteria	Show that externally read signal changes accordingly to force on rotor blades. The 2 ± 2 V analog signal will be translated into a digital representation of 8-bits, meaning a varying value between 0 and 255 is to be expected.		
Comments			

SRS-13	**Priority:** *C*	**System durability**	**27.01.2016**
Status	Abandoned.		
WHO	G23		
WANTS	System to withstand various environmental conditions.		
WHY	For the system to be functional outside normal research conditions, i.e. the outdoors.		
Acceptance Criteria	Protective housing encapsulating the microcontroller chip. Prevent long-term effects, i.e. corrosion.		
Comments	Difficult to measure long-term effects within the given time frame.		

SRS-14	**Priority:** *B*	**Bending data sample rate.**	**29.02.2016**
Status	Pending.		
WHO	HSN		
WANTS	10 readings of data on both rotor blades each revolution.		
WHY	To have high accuracy data output.		
Acceptance Criteria	At 2000-2500 RPM equals 33-41 revolutions/second. This means the system must be able to collect 330-410 data readings/second for each blade, resulting in a total of 660-820 data readings/second.		
Comments			

SRS-15	**Priority:** *B*	**Amount of data**	**29.02.2016**
Status	Changed, pending.		
WHO	HSN		
WANTS	Separate data readings from each rotor blade.		
WHY	To measure each blade individually.		
Acceptance Criteria	Data output must be separable into two individual data streams. This means when using the FSK-modulation, each reading must have bit flags indicating which blade the data belongs to.		
Comments	For proof-of-concept, this requirement will not be met as we are demonstrating only one strain gauge bridge configuration.		

SRS-16	**Priority:** *A*	**Permanent Magnet Alternator Dimensions**	**12.01.2016**
Status	Completed.		
WHO	G23		
WANTS	Permanent magnet alternator to be small.		
WHY	To be lightweight and able to fit on the rotor shaft.		
Acceptance Criteria	Total diameter must not exceed 4.0 cm. Center hole diameter must be 1.2 cm. Height should not exceed 1.0 cm.		
Comments			

SRS-17	**Priority:** *A*	**Correction of null-offset and drift**	**06.05.2016**
Status	Pending.		
WHO	HSN		
WANTS	Analog circuitry to compensate for null-offset and drift.		
WHY	To maintain correct and stable data readings over longer periods of time.		
Acceptance Criteria	When no stress is inflicted on the strain gauges, a zero-point value equal to the reference voltage should be read by the system. This must also apply for longer periods of time, meaning drift (due to changes in material etc.) must be accounted for.		
Comments			

6. Changelog

Requirement ID	Action	Date	Responsible
SRS-14	Added new requirement.	29.02.2016	CC
SRS-15	Added new requirement.	29.02.2016	CC
SRS-06	Changed: Added measurable values.	11.03.2016	CHK
SRS-03	Changed: Reformulated.	14.03.2016	CHK
MRS-06	Removed: Describes the same as MRS-02.	16.03.2016	CHK
MRS-05	Changed: Reformulated.	17.03.2016	CHK
SRS-02	Changed: Reformulated.	17.03.2016	CHK
SRS-04	Removed: Describes the same as MRS-03.	17.03.2016	CHK
SRS-05	Changed: Added measurable values.	17.03.2016	CHK
SRS-07	Changed: Reformulated.	17.03.2016	CHK
SRS-08	Changed: Reformulated in regards to size.	17.03.2016	CHK
SRS-09	Changed: Added measurable values.	17.03.2016	CHK
SRS-11	Changed: Reformulated acceptance criteria.	17.03.2016	CHK
SRS-12	Removed: HSE-issue. Irrelevant to the system.	17.03.2016	CHK
SRS-13	Changed: Reformulated.	17.03.2016	CHK
SRS-16	Added new requirement.	17.03.2016	CHK
MRS-01	Changed: Added measurable values.	06.05.2016	CHK
SRS-05	Changed: Reformulated acceptance criteria.	06.05.2016	CHK
SRS-15	Changed: Reformulated, added comment.	06.05.2016	CHK
SRS-17	Added new requirement.	06.05.2016	CHK
MRS-02	Reformulated.	12.05.2016	CC & CHK
SRS-06	Reformulated. Added measurable values.	12.05.2016	EW, CC & CHK
SRS-05	Reformulated. Added measurable values.	12.05.2016	EW
MRS-05	Abandoned.	12.05.2016	CC & CHK
SRS-07	Added comment.	12.05.2016	CC & CHK
SRS-08	Reformulated. Increased size.	12.05.2016	CC & CHK
SRS-09	Reformulated.	12.05.2016	CC & CHK
SRS-10	Removed: Redundant.	12.05.2016	CC & CHK
SRS-11	Reformulated. Added measurable values.	12.05.2016	CC & CHK
SRS-13	Abandoned.	12.05.2016	CC & CHK
SRS-16	Completed.	12.05.2016	CC & CHK
MRS-03	Reformulated.	12.05.2016	CHK
SRS-01	Reformulated.	20.05.2016	CHK
SRS-05	Reformulated.	20.05.2016	CHK
SRS-08	Completed.	18.05.2016	CC

Table 4: Changelog Table

7. References

[1] Wikipedia, "Five Ws," [Online]. Available: https://en.wikipedia.org/wiki/Five_Ws. [Accessed 2 February 2016].

[2] J. Boronyak, "The Three C's of User Stories," 11 February 2014. [Online]. Available: http://enfocussolutions.com/the-three-c-s-of-user-stories/. [Accessed 2 February 2016].

Test Specification

Rotary Wireless Signal Transmission				
Employer	University College of South-East Norway			
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Document information	**Revision**	**Date**	**Approved**	**Pages**
	4.0	23.05.2016	CHK	20

Abstract

The principal objective of this document is to demonstrate system, software and hardware test specification. The main objective of the document is to describe the needs of how to test the requirements. The document contains a description of all the tests to be performed, in order to guarantee quality, competitiveness, reduce costs and verify and validate that the requirement is tested. Furthermore, the document shows a plan of how testing should be done and prepares a test strategy.

Revision Table

Version	Date	Approval	Description
1.0	15.01.2016	CC	• Created the document
1.1	05.02.2016	EBR	• Text and structure.
1.2	05.02.2016	CC	• Document formatting.
2.0	08.02.2016	CHK	• Revised and published.
2.1	11.02.2016	EW	• Updated references.
2.2	18.03.2016	CHK	• Updated test specifications according to requirements specification.
3.0	18.03.2016	CHK	• Revised and published.
3.1	22.05.2016	CC	• Updated test specifications.
4.0	23.05.2016	CHK	• Revised and published.

Contents

List of Test Specification Tables

List of Tables

1. Introduction

The following test specification describe the requirement testing to be performed. The document includes a description of how all the requirements will be tested. Different test methods will be performed to the requirements to ensure that the product is developed and performs according to the requirements set by the customer.

The purpose of testing processes is to determine whether the product under development conform to the requirements given by the customer and to verify that the system being developed satisfies user's needs. This section provides an overview and a description of the entire test specification. The document lists all the requirements in tables.

All the tests are assigned a specific ID, which is unique. A test ID in the test specification corresponds with a similar ID in the requirement specification. Assigning an ID to every test makes it easier to find a specific test from test specification.

All tests are issued an ID consisting of T followed by requirement identification. The T signifies the test of the requirement identified. The method makes it easier to trace different requirements and their corresponding tests.

2. Importance of Testing

To guarantee quality of the product, all the building units of the product under development, have to be tested. Testing is performed to determine the acceptability, safety and verify that all the building units of a system meet the requirement specification. The system under development (rotary transmission system), will involve interfacing different individual units, which are developed separately. The product will be gradually tested throughout the life cycle to verify and validate that the product complies with the requirement specification.

Verification involves frequently confirming that the product being developed complies with requirement specification. The system should conform to its specification. Through this process, we verify and make sure that the product under development behaves the way we want it to do.

Validation involves frequently confirming that we are developing the right product. Through this process, we frequently check to validate that the product under development is what the customer required. Mistakes, which may have been made during the previous phase, are easily detected and corrected after validating the product under development.

Validation always involves comparison against requirements. The system should do what the user really requires. **Verification** and **Validation** must be applied at each stage in the system design.

3. Methods of Testing

There is wide range alternative of testing techniques and methods that vary in formality, rigidity and flexibility. Test methods suitable for a specific project depend on the nature of the project. The test specification document below discusses some of the testing methods we have decided to use to test different requirements and components throughout our project's development.

3.1. White box Testing

White box testing involves the testing by looking at the internal structure of the code. When you are completely aware of the internal structure of the code then you can run your test cases and check whether the system meet requirements mentioned in the specification document.

This is done by giving the input to the system and comparing for expected outputs with actual output. In our case the white box testing method will be used to test the hardware in order to determine if the circuitry behaves as required. [1]

3.2. Black box Testing

Black box testing is a testing method which involves testing the functionality of a product. The method tests a product externally. This method is mainly performed during software testing life circle. The method is often used when performing specific tests such as unit, integration, system and acceptance testing. We intend to use this testing methods by testing all the units separately to determine if they perform accordingly.

3.3. Unit Test

Unit testing involves testing the smallest building unit of a system. At this stage, we test the smallest individual hardware or software units. The white box testing techniques is the mainly used at this stage, to implement codes and verify that the codes behaves the way we want it to do. The smallest building units will mainly consist of integrated circuits(IC) such as operational amplifiers, strain gauges and microcontroller. We intend to test all the smallest building units individually using the black box technique to make sure that they do what their intended to do at lower structural level

3.4. Integration Test

Integration testing involves verifying that newly integrated units interact with each other correctly. At this stage, we also verify and validate the product to make sure that interfacing and pathways between the newly interfaced units are correctly done and behave the way they are intended to behave.

This type of test is done iteratively to verify that every newly added unit interact correctly with existing parts and the system functions as intended. The test at this stage will be performed using the black box testing techniques.

3.5. Functional Testing

Functional testing involves making sure that the functionality of the system complies with the requirement specification. This is where we test the functions of components or systems. Functional testing involves testing the performance of a system to verify that it can do specific actions as specified in user requirement specification.

Additionally the developers verify that particular functions work as the customer required. We intend to perform the function testing to all the components and the systems of our prototype using black box testing technique.

3.6. System Testing

System testing involves making sure that the newly developed product functions as required by the customer in different environments. This type of testing is conducted on a complete, integrated system to verify, validate and evaluate the system conformity with the requirement specification.

3.7. Acceptance Testing

Acceptance testing is conducted after functional and system testing before the product is delivered to the customer. This is where the developer or the customer conduct a test to determine whether or not the system satisfies all the criteria it must satisfy to be accepted by the customer. Acceptance tests are often specified by the customer and given to the developers to perform before they deliver the product.

We intend to perform a customer acceptance test ourselves before delivering the product to the customer to increase our confidence that they will work as required by the customer at his location. The system will be tested as a whole to verify that all components work properly to achieve good performance in customer's environment. The project group aims to discus with the customer acceptance testing to ensure the product satisfies his requirements.

3.8. Static Testing

The objective of this testing method is to improve the quality of software products by finding and correcting errors. The techniques provide a way to improve the productivity of software development. We intend to apply static testing techniques to our product by manually checking the requirements specification documents, design documents, test plans documents and he codes to detect and fix errors.

3.9. Dynamic Testing

This where we execute the used codes to check the functionality and behaviour of the system. The overall objective of this method of testing is to validate that the software product confines with the customer requirements.

The technique is applied by executing the software and validating the output with the expected outcome. We intend to perform dynamic testing method to our product at all levels of testing by using either black or white box testing techniques.

4. Test Specification Tables

The following test specification document shows all the tests listed in tables. Each test includes verification method, acceptance criteria and status. The status describes the situation of a requirement at the present date. The situation of requirement at particular time during the developing process will be given one of two status namely: *Tested* or *pending*, where tested means that a requirement has been tested and pending means that a requirement has not yet been tested. Testing results are discussed in the comments line after testing.

5. Abbreviations

Abbreviation	**Full name**
T	Test
MRS	Main Requirement Specification
SRS	System Requirement Specification
T-MRS	Test - Main Requirement Specification
T-SRS	Test – System Requirement Specification

Table 1: Abbreviation Table.

6. Test Specifications

T-MRS-01	Related to MRS-01	25.01.2016
Status	Pending	
Requirement Description	Measure bending of both rotor blades	
Procedure	1. Configure strain gauges in two wheatstone-bridges mounted on a flexible medium representing a rotor blade. 2. Measure the signal voltage output of the bridge.	
Acceptance Criteria	Collect 2 separate signals that changes accordingly to the bending medium.	
Responsible	All the group members	
Comments	Dag will provide us with a specific set of strain gauges/configuration substitute for a rotor blade.	

T-MRS-02	Related to MRS-02	25.01.2016
Status	Pending	
Requirement Description	Strain gauge data available for external system.	
Procedure	1. A functional wheatstone-bridge configuration is required. 2. Output signal must be processed by microcontroller. 3. Read signal output from microcontroller on an external system.	
Acceptance Criteria	Read data on an external system.	
Responsible	All the group members	
Comments	Fulfilled through MRS-03 / T-MRS-03.	

T-MRS-03	Related to MRS-03	25.01.2016
Status	Pending	
Requirement Description	Transfer stable and reliable signal readings wirelessly through rotary transformer	
Procedure	1. Rotary transformer must be setup. 2. Test that stator coil voltage responds to changes in the rotor coil voltage. 3. Repeat step 2, with rotation at 2000-2500 rpm. 4. Compare signal before and after rotary transformer.	
Acceptance Criteria	Get the same data readings on both sides of the data transfer protocol while system operates with 2000-2500 RPM.	
Responsible	All the group members	
Comments		

T-MRS-04	Related to MRS-04	25.01.2016
Status	Pending	
Requirement Description	Microcontroller chip mounted in the rotating system on top or inside of rotor head.	
Procedure	1. A PCB-design that does not exceed the given constraints is required. 2. Mount the microcontroller chip on an area representing the rotor top. 3. Verify that the circuit board works as expected.	
Acceptance Criteria	Successfully mounting a circuit board w/microcontroller within the given space. Actual dimensions are not yet known, but assuming a diameter of 3.0 cm, giving a circular area of 7.07 cm^2.	
Responsible	All the group members	
Comments		

T-MRS-05	Related to MRS-06	25.01.2016
Status	Pending	
Requirement Description	System to provide sensor readings when model helicopter is normal flight	
Procedure	1. Methods for transferring data out of the rotating system must be implemented. 2. Data stream must be read and stored during flight by an external system mounted on the chopper. 3. Verify that the stored data is valid.	
Acceptance Criteria	Successfully transfer data to an external system mounted on the chopper during flight.	
Responsible	All the group members	
Comments		

T-SRS-01	Related to SRS-01	25.01.2016
Status	Pending	
Requirement Description	Strain gauges arranged in Wheatstone bridge.	
Procedure	1. Configure strain gauges in a Wheatstone-bridge. 2. Expose the system to temperature changed, i.e. direct sunlight. 3. With an oscilloscope, verify that temperature drift is insignificant.	
Acceptance Criteria	Temperature noise is insignificant or absent.	
Responsible	All the group members	
Comments		

T-SRS-02	Related to SRS-02	25.01.2016
Status	Pending	
Requirement Description	Strain gauge placed close to center of rotor.	
Procedure	1. Mount strain gauges as close to the center as possible. 2. Let the system rotate at 2000 – 2500 RPM. 3. Verify that system does not vibrate. *For verifying that strain gauges are unaffected:* 1. Methods for reading data externally must be implemented. 2. Let the system rotate at 2000 – 2500 RPM. 3. Check for signal noise in data read externally.	
Acceptance Criteria	Place it on the inner end of the rotor blade	
Responsible	Centrifugal/centripetal forces do not significantly affect rotor or strain gauge sensors.	
Comments		

T-SRS-03	Related to SRS-03	25.01.2016
Status	Pending	
Requirement Description	To calibrate signals from strain gauge sensors in microcontroller.	
Procedure	1. Signal noise must be identified. 2. Depending on the noise, appropriate countermeasures must be implemented to offset or reduce noise. 3. Verify that data output from microcontroller is consistent with what is expected.	
Acceptance Criteria	Zero reading after calibration at zero force on rotor blades	
Responsible	All the group members	
Comments		

T-SRS-05	Related to SRS-05	25.01.2016
Status	Complete.	
Requirement Description	Permanent magnet alternator mounted on rotor shaft.	
Procedure	1. Assemble generator 2. While assembly check that there is connection between coils in rotor disk, with Ohm-meter(BipBip) 3. Connect diode to rotor of generator 4. Mount rotor disk 1mm from magnet disk 5. Program motor to 2500 RPM 6. Validate that diode is lit	
Acceptance Criteria	Get stable voltage, at least 7Vac to be supplied to PSM(Power supply module)	
Responsible	All the group members	
Comments		

T-SRS-06	Related to SRS-06	25.01.2016
Status	Complete.	
Requirement Description	Power Supply Module provides stable DC energy flow with rotor speed over 2000 rpm.	
Procedure	1. Assemble generator 2. Connect generator to PSM 3. Measure output voltage of PSM	
Acceptance Criteria	Power supplied from the power supply module cannot exceed 5 ± 0.5 V_{DC}. Line regulation not greater than 160 mV_{DC}.	
Responsible	All the group members	
Comments		

T-SRS-07	Related to SRS-07	25.01.2016
Status	Pending	
Requirement Description	System modulates and sends an appropriate signal to Rotary Transformer	
Procedure	1. Assemble rotary transformer 2. Connect programmed microcontroller 3. Connect FFT-scope on both primary & secondary side of transformer. This to check that signal emitted is appropriate compared to signal received.	
Acceptance Criteria	Same data can be read before and after the rotary transformer.	
Responsible	All the group members	
Comments		

T-SRS-08	Related to SRS-08	25.01.2016
Status	Complete.	
Requirement Description	Rotary transformer to be small.	
Procedure	1. Assemble Rotary transformer 2. Mount on shaft 3. Measure	
Acceptance Criteria	Successfully mounting a rotary transformer on the shaft within the given space. The total diameter must not exceed 6,0 cm. Height should be less than 2,0 cm.	
Responsible	All the group members	
Comments		

T-SRS-09	Related to SRS-09	25.01.2016
Status	Pending.	
Requirement Description	Centre of mass of Rotor Top System directly over centre of mass of rotor shaft	
Procedure	1. Assemble system 2. Start helicopter shaft simulator 3. Validate minimal vibration on system	
Acceptance Criteria	System must be balanced/centered with adequate equipment, and not vibrating at 2000 RPM and above.	
Responsible	All the group members	
Comments		

T-SRS-11	Related to SRS-11	25.01.2016
Status	Pending	
Requirement Description	Temporary External System reads signals from Rotary Transformer	
Procedure	1. Assemble rotary transformer and connect microcontroller 2. Connect external system to rotary transformer 3. Validate signal changes accordingly to force on rotor blades	
Acceptance Criteria	Show that externally read signal changes accordingly to force on rotor blades. The 2 ± 2 V analog signal will be translated into a digital representation of 8-bits, meaning a varying value between 0 and 255 is to be expected.	
Responsible	All the group members	
Comments		

T-SRS-13	Related to SRS-013	25.01.2016
Status	Abandoned.	
Requirement Description	System to withstand various environmental conditions.	
Procedure	1. Assemble housing 2. Validate that its sealed and dry after use.	
Acceptance Criteria	Protective housing encapsulating the microcontroller chip. Prevent long-term effects, i.e. corrosion.	
Responsible	All the group members	
Comments		

T-SRS-14	Related to SRS-14	18.03.2016
Status	Pending	
Requirement Description	10 readings of data on both rotor blades each revolution.	
Procedure		
Acceptance Criteria	At 2000-2500 RPM equals 33-41 revolutions/second. This means the system must be able to collect 330-410 data readings/second for each blade, resulting in a total of 660-820 data readings/second.	
Responsible	All the group members	
Comments		

T-SRS-15	Related to SRS-15	18.03.2016
Status	Pending	
Requirement Description	Separate data readings from each rotor blade.	
Procedure	Assemble entire system with 2 strain gauge configurations. Implement coding in software that flags each dataset separately. Verify that data is intact and kept separated.	
Acceptance Criteria	Data output must be separable into two individual data streams. This means when using the FSK-modulation, each reading must have bit flags indicating which blade the data belongs to.	
Responsible	All the group members	
Comments	For proof-of-concept, this requirement will not be met as we are demonstrating only one strain gauge bridge configuration.	

T-SRS-16	Related to SRS-16	18.03.2016
Status	Complete.	
Requirement Description	Permanent magnet alternator to be small.	
Procedure	1. Assemble Permanent magnet alternator 2. Mount on shaft 3. Measure	
Acceptance Criteria	Total diameter must not exceed 4.0 cm. Center hole diameter must be 1.2 cm. Height should not exceed 1.0 cm.	
Responsible	All the group members	
Comments		

T-SRS-17	Related to SRS-17	07.05.2016
Status	Pending	
Requirement Description	Analog circuitry to compensate for null-offset and drift.	
Procedure	1. Connect strain gauges 2. Start system 3. Measure zero-point value	
Acceptance Criteria	When no stress is inflicted on the strain gauges, a zero-point value equal to the reference voltage should be read by the system. This must also apply for longer periods of time, meaning drift (due to changes in material etc.) must be accounted for.	
Responsible	All the group members	
Comments		

6. Test Changelog

Requirement ID	Action	Date	Responsible
T-MRS-01	Changed: Reformulated.	18.03.2016	CHK
T-MRS-02	Changed: Reformulated.	18.03.2016	CHK
T-MRS-03	Changed: Reformulated acceptance criteria.	18.03.2016	CHK
T-MRS-04	Changed: Reformulated acceptance criteria.	18.03.2016	CHK
T-MRS-05	Changed: Reformulated.	18.03.2016	CHK
T-MRS-06	Removed: See requirements changelog.	18.03.2016	CHK
T-SRS-01	Changed: Reformulated.	18.03.2016	CHK
T-SRS-02	Changed: Reformulated.	18.03.2016	CHK
T-SRS-03	Changed: Added test procedure.	18.03.2016	CHK
T-SRS-12	Removed: See requirements changelog.	18.03.2016	CHK
T-SRS-14	Added new test specification	18.03.2016	CC
T-SRS-15	Added new test specification	18.03.2016	CC
T-SRS-16	Added new test specification.	18.03.2016	CC
T-SRS-17	Added new test specification	07.05.2016	CC
T-SRS-05	Changed: Added test procedure.	18.05.2016	CC
T-SRS-06	Changed: Added test procedure & reformulated	18.05.2016	CC
T-SRS-07	Changed: Added test procedure & reformulated	18.05.2016	CC
T-SRS-08	Changed: Added test procedure & reformulated	18.05.2016	CC
T-SRS-09	Changed: Added test procedure	18.05.2016	CC
T-SRS-11	Changed: Added test procedure & reformulated	18.05.2016	CC
T-SRS-13	Changed: Reformulated, Abandoned.	18.05.2016	CC
T-SRS-04	Removed: Describes the same as MRS-03.	18.05.2016	CC
T-SRS-10	Removed: Redundant	18.05.2016	CC

Table 2: Test Changelog Table.

7. References

[1] Cross Check Networks, "SOA Testing Techniques," [Online]. Available: http://www.crosschecknet.com/soa_testing_black_white_gray_box.php. [Accessed 5 February 2016].

Test Report

Rotary Wireless Signal Transmission				
Employer	University College of South-East Norway			
Group Members	**Name**		**Initials**	
	Chadi Chehade		CC	
	Carl-Henrik Kristoffersen		CHK	
	Egide Bampo Rubusa		EBR	
	Eton Williams		EW	
Document information	**Revision**	**Date**	**Approved**	**Pages**
	1.0	23.05.2016	CC	15

Abstract

This document will describe the test procedures that where done throughout the project.

Revision Table

Version	Date	Responsible	Description
1.0	15.04.2016	CHK	• Created the document.
1.1	20.05.2016	CC	• Added test reports.

Contents

List of Tables

1. Introduction

The purpose of this document is to enlighten the reader, on what did and did not work. It will also be suggested solutions to unsuccessful tests, and suggestions for improvement for further development.

1. Test summary

Include basic information about what was tested and what happened.

Project Name: [Project name]

System Name: [System name]

Version Number: [Version number]

Additional Comments: [Enter any additional comments]

1.1. TEST TYPE (FUNCTION, UNIT, SYSTEM, ETC.)

[Include basic information about what was tested and what happened.]

Test Owner: [John Doe]

Test Date: [mm/dd/yyyy]

Test Results: [Enter a summary of the test conducted and results]

Additional Comments: [Enter any summary comments]

2. Test assessment

Enter your interpretation of how adequate the test was in light of how thorough the test plan said it should be? What wasn't tested well enough?

3. Test results

Summarize the test results. Include a detailed description of any deviations from the original test plan, design, test case, or expected results. Include any issues or bugs discovered during the test.

3.1. UNIT/MODULE/SYSTEM TESTING

Unit, module, and system integration testing activities were performed during the development of the system build or release.

4.2 System Testing

The table below summarizes the results of system testing:

Test Case ID	Date Tested	Tester	Pass/Fail	Severity of Defect	Comments
T-SRS-06	11.05.2016	CC & CHK	Pass	None	Meets requirement.
T-MRS-03	20.05.2016	CC & CHK	Fail	Medium	Parts of test was successful, but test itself failed.
T-SRS-05	20.05.2016	CC & CHK	Fail	Medium	Need stronger magnets. Assembly ok.
T-SRS-08	21.05.2016	CC	Pass	None	Meets requirement.
T-SRS-05	21.05.2016	CC & CHK	Fail	Low	New magnets! Could produce $1V_{AC}$, not in line with requirement SRS-05
T-SRS-16	21.05.2016	CC	Pass	None	Meets requirement.

Table 1: System Testing Summary

4. Variances

Describe any variances between the testing that was planned and the testing that actually occurred. Also, provide an assessment of the manner in which the test environment may be different from the operational environment and the effect of this difference on the test results.

5. Test instances

Provide a brief description of the unexpected results, problems, or defects that occurred during the testing.

6.1 Resolved test incidents

Identify all resolved test incidents and summarize their resolutions. Reference may be made to Test Incident Reports that describe in detail the unexpected results, problems, or defects reported during testing, along with their documented resolutions, which may be included as an appendix to this document.

6.2 Unresolved test incidents

Identify all unresolved test incidents and provide a plan of action for their resolution. Reference may be made to Test Incident Reports that describe in detail the unexpected results, problems, or defects reported during testing, which may be included as an appendix to this document.

6. Test reports

Test ID: T-SRS-06	**Project name:** RWST	**Date:** 11.05.2016
Test type:	Module	**Attendees:** CC & CHK
Test description:	PSM tested. Power Supply Module provides stable DC energy flow with rotor speed over 2000 rpm. Power supplied from the power supply module cannot exceed 5 ± 0.5 V_{DC}. Line regulation not greater than 160 mV_{DC}.	
Equipment:	Oscilloscope Bread board Wiring 4 x Rectifier diodes 1 x L7805 regulator 1 x 10µF Capacitator 1 x 0,1µF Capacitator	
Test results:	Test was successful, acquired a stable voltage of 5 V_{DC} to supply the system.	
Test assessment:	Everything was tested in accordance with the test specification, except could not apply rotational speed to the system. Used an AC signal generator with 6V_{AC} instead of alternator generator, for test purposes.	
Resolved test incidents	Did not work to start with, rewired the PSM circuit and achieved functionality. Might have been wired wrong the first try.	
Unresolved test incidents	Did not apply rotation to the system, because 1st prototype was not finalized.	
Variances:	None	
Test instances:	None	
Suggestions to improvement:	None	
Additional comments:	The test proves that our concept is sustainable.	

Table 2: T-SRS-06 Report

Test ID: T-SRS-05	**Project name:** RWST	**Date:** 20.05.2016
Test type:	Unit	**Attendees:** CC & CHK
Test description:	Permanent magnet alternator mounted on rotor shaft. Generator was tested. Test if generator is able to supply sufficient power to the system, by getting a diode to glow.	
Equipment:	Voltmeter Casted rotor disk (rotor) Magnet disk (stator) Model helicopter shaft simulator Computer w/ software Rapcon programming circuit board Wiring 4 x Magnets 1 x Diode	
Test results:	Test was not successful, could not get the diode lit.	
Test assessment:	Everything worked correspondingly with the test specification except getting the diode lit.	
Resolved test incidents	Successfully soldered coils together to achieve good connectivity. Successfully assembling generator on model helicopter shaft substitute.	
Unresolved test incidents	Could not get diode to glow.	
Variances:	None	
Test instances:	None	
Suggestions to improvement:	Replace the magnets with stronger/bigger ones to get a wider magnetic field.	
Additional comments:	New magnets are bought.	

Table 3:T-SRS-05 Report

Test ID: T-MRS-03	**Project name:** RWST	**Date:** 20.05.2016
Test type:	Unit	**Attendees:** CC & CHK
Test description:	Signal transmission through rotary transformer was tested. Transfer stable and reliable signal readings wirelessly through rotary transformer.	
Equipment:	Rotary transformer (Primary- and secondary-side) Signal generator FFT-scope Wiring	
Test results:	Test was not successful, could transmit signal that was stable and reliable.	
Test assessment:	Test that stator coil voltage responds to changes in the rotor coil voltage was successful. Test that signal is transmitted in rotation, was successful. Comparing the signal before and after was unsuccessful.	
Resolved test incidents		
Unresolved test incidents	Could not get a stable and reliable signal after rotary transformer. Data signal modulator of microcontroller can only produce square signal, and is not suited for use with a transformer.	
Variances:	None	
Test instances:	None	
Suggestions to improvement:	Provide another source for FSK-modulation. A solution could be to synthesize a sine wave using the integrated DAC.	
Additional comments:		

Table 4: T-MRS-03 Report

Test ID: T-SRS-05	**Project name:** RWST	**Date:** 21.05.2016
Test type:	Unit	**Attendees:** CC & CHK
Test description:	Permanent magnet alternator mounted on rotor shaft. Generator was tested. Test if generator is able to supply sufficient power to the system, by getting readings of voltage on the oscilloscope.	
Equipment:	Oscilloscope Casted rotor disk (Stator) Magnet disk (Rotor) Model helicopter shaft simulator Computer w/ software Rapcon programing board. Wiring 4 x 0,9 Kg force magnets	
Test results:	Test was unsuccessful, could only produce approximately 1 V_{AC}.	
Test assessment:	Everything worked correspondingly with the test specification, unable to produce more than 1 $V_{AC.}$	
Resolved test incidents	Successfully inverted the system, using the magnet disc as rotor and coil disc as stator. This way accurate measurements with oscilloscope was possible.	
Unresolved test incidents	Unable to produce more than approximately 1 V_{AC}.	
Variances:	None	
Test instances:	None	
Suggestions to improvement:	Increase magnet size/strength. Increase number coil windings. Use ferrite cores in each coil to concentrate magnetic flux and reduce leakage.	
Additional comments:	The test proves that our concept is sustainable, but its current configuration is not efficient enough. 2nd test.	

Table 5:T-SRS-05 2nd Report

Test ID: T-SRS-16	**Project name:** RWST	**Date:** 21.05.2016
Test type:	Unit	**Attendees:** CC
Test description:	Permanent magnet alternator to be small. Measure that total diameter must not exceed 4.0 cm. Center hole diameter must be 1.2 cm (Press–fit). Height should not exceed 1.0 cm.	
Equipment:	Casted rotor disk (Stator) Magnet disk (Rotor) Model helicopter shaft simulator	
Test results:	Test was successful; the alternator generator met all the requirements.	
Test assessment:	Everything was tested in accordance to test specification.	
Resolved test incidents	Was hard to get the rotor disk mounted on the shaft, resolved it with mounting it as level as possible on the shaft, and used brute force. Possible to use a press machine.	
Unresolved test incidents	None	
Variances:	None	
Test instances:	None	
Suggestions to improvement:	None	
Additional comments:	The test proves that our concept meets the requirement **SRS-16**.	

Table 6: T-SRS-16 Report

Test ID: T-SRS-08	**Project name:** RWST	**Date:** 21.05.2016
Test type:	Unit	**Attendees:** CC
Test description:	Rotary transformer to be small. Measure that the total diameter must not exceed 6,0 cm. Height should be less than 2,0 cm.	
Equipment:	Rotary transformer Model helicopter shaft simulator Caliper	
Test results:	Test was successful, rotary transformer did not exceed 6,0cm diameter, and 2,0cm height	
Test assessment:	Everything was tested in accordance to test specification. Use caliper for accurate measures, possible to use a regular ruler to.	
Resolved test incidents	None	
Unresolved test incidents	None	
Variances:	None	
Test instances:	None	
Suggestions to improvement:	None	
Additional comments:	The test proves that our concept meets the requirement **SRS-08**.	

Table 7: T-SRS-08 Report

APPENDIX A: Test Report Approval

The undersigned acknowledge they have reviewed the **RWST Test Report** and agree with the approach it presents. Changes to this **Test Report** will be coordinated with and approved by the undersigned or their designated representatives.

Signature:	______________________	Date:	____________
Print Name:	______________________		
Title:	______________________		
Role:	Project Manager		

Høgskolen i Sørøst-Norge

Technical Document

Rotary Wireless Signal Transmission				
Employer	University College of South-East Norway			
Group Members	**Name**		**Initials**	
	Chadi Chehade		CC	
	Carl-Henrik Kristoffersen		CHK	
	Egide Bampo Rubusa		EBR	
	Eton Williams		EW	
Document information	**Revision**	**Date**	**Approved**	**Pages**
	2.0	23.05.2016	CHK	82

Abstract

This document describes the technical aspects of our system, and elaborates our concept ideas and implemented designs. After reading this document, the reader should get an in-depth understanding of our system and our design ideas.

Revision Table

Version	Date	Responsible	Description
1.0	21.05.2016	CHK	Created the document.
1.1	22.05.2016	CC, CHK, EBR	Merged technical documents.
1.2	23.05.2016	CC, CHK, EBR	Revised and published.

Contents

Table of Figures

Table of Tables

1. Introduction

The goal of our system is to measure bending data from a unit rotating at high speeds, and provide this data to an external system on a non-rotating body. At first, this might seem like an easy task, but it raises a series of challenges. Firstly, the rotating system must be self-sustained with power. Secondly, noise might be introduced by a vast number of sources. This means that the signal acquired needs to be conditioned properly before transferred. Thirdly, the way of transmitting the signal out must be a wireless and effective method.

In this document, we will elaborate a design that we hope can solve all of these issues.

Alternator Generator

This section provides the necessary information for further development and production regarding the alternator generator. The reader will be presented with the reasons for the design decisions, and the technical details concerning rotor disk, stator disks, coils, windings, phase selection, magnets and implementation of rotary transformer in the generator, with corresponding concerns and how they will be solved to achieve a satisfactory result.

The alternator generator is a vital part of our system. Without a power source, the system will fail as it will not have any functionality without a stable source of power. We will achieve this by using the rotational motion (mechanical energy) of the helicopter rotor to create enough electricity to feed the system. This way we can supply power without having the system to rely on batteries. As long as the helicopter is in operation, the system will produce its own power.

This document will elaborate the different design ideas and approaches to an adequate solution, as well as the physics behind.

2. Theory

In this chapter, we will go through how an alternator generator works. You will learn about the various concepts we made for the miniature generator we have constructed.

2.1 Magnetic Field

A magnet has what we call a north pole and a south pole, resembling a positive-negative relationship. When we consider the magnetic field that surrounds the magnet, we think of field lines that go through the body of the magnet from the south pole to the north pole. From here, the field lines go out from the north pole and bends around the magnet, back into the south pole. The concentration, or group of these field lines, is what we refer to as *magnetic flux*.

Magnetic flux, symbolized by ϕ and measured in weber, W_b describes the strength of the magnetic field. The field lines tend to be more concentrated at the poles. [1]

Magnetic flux density describes the amount of flux per unit area perpendicular to the magnetic field. Flux density is symbolized by B and measured in tesla, T. The flux density is expressed as

$$B = \frac{\phi}{A}, \tag{1}$$

where A is the cross-sectional area in square meters (m^2) of the magnetic field. A higher magnetic flux density allows for higher induced voltage.

2.2 Electromagnetic Properties

What follows are some important properties related to electromagnetic fields.

Permeability describes how easily a magnetic field can be established in a given material. Higher permeability means a magnetic field is established more effectively. The symbol of permeability is μ, and its value depends on type of material. The reference value, permeability of vacuum μ_0, is $4\pi * 10^{-7}\ Wb/At * m$ (Weber/Ampere-turn meter). Ferromagnetic materials typically have permeability hundreds of times larger than this. The relative permeability is expressed as

$$\mu_r = \frac{\mu}{\mu_0}. \tag{2}$$

Reluctance, $\mathcal{R}$, describes the opposition to the establishment of a magnetic field in a material. This value is proportional to the length of the magnetic path and inversely proportional to the permeability and cross-sectional area of the material. Reluctance is expressed by the following equation:

$$\mathcal{R} = \frac{l}{\mu A}. \tag{3}$$

The unit for reluctance is At/Wb (ampere-turns/weber).

2.3 Inductance

If a conductor and a magnetic field is moved relative to each other, a certain voltage is induced in the conductor. The value of this voltage depends on the magnetic field and the conductor, but the fundamental formula is

$$v_{ind} = B_{\perp} l v, \tag{4}$$

where B is flux density, l is the length of the conductor and v is relative velocity in m/s.

If we consider the conductor wound up as a coil, which is a very common setup, Faraday's law states the following:

$$v_{ind} = N\left(\frac{d\phi}{dt}\right), \tag{5}$$

where N is number of turns in the coil, and $d\phi/dt$ is the rate of change in magnetic flux through the coil.

2.4 Alternator Generators

An alternator generator is an electrical generator that converts mechanical energy to electrical energy in the form of alternating current. The power is induced from coils in the rotor, which rotates in parallel with a stationary stator that has current applied to it. This will generate a magnetic field which the coils in the rotor will convert to a current. Permanent magnets can be used to replace the stator, this will make the generator a “magneto generator”.

2.4.1 3-phase & Single phase Generator

In a 3-phase generator, there is three separate sets of coils in the rotor, these are in a star configuration. This to be able to induce power at a more efficient rate, than with a single-phase generator. We can also use this configuration to distribute the total load over three phases/waves so there is less draw on one single wave.

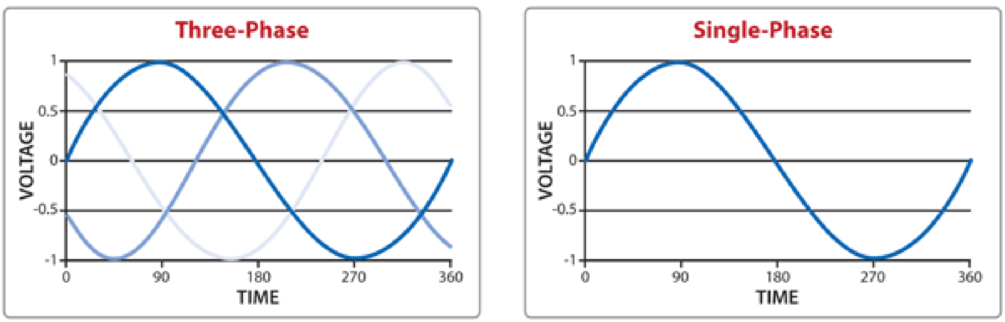

Figure 1: Three-Phase Vs. Single-Phase Wave.

As shown in figure above, in a three-phase system the 3 waves are in sequence but all act the same as the single wave. But because they arrive after each other in a sequence their total power overlaps, is more providing than the single-phase. In the three phase the power is always above zero. With a single-phase it delivers one single wave of power, but the power level varies with the electrical current coming in. That means that power levels can and do drop to zero during the sine cycle.

To illustrate the difference between single-phase and 3-phase, imagine a lone paddler in a canoe. He can only move himself forward while his paddle moves through the water. When he lifts the paddle out of the water to prepare for the next stroke, the power supplied to the canoe is zero.

Now picture the same canoe with three paddlers. If their strokes are synchronized so each is separated by 1/3 of a stroke cycle, the canoe receives constant and consistent propulsion across the water. More power is supplied and the canoe moves across the water more smoothly and efficiently. [2]

Three-phase machines and controls can be smaller, lighter in weight, and more efficient than comparable single-phase equipment. More power is supplied to them in the same period than can be supplied by a single-phase power circuit.
However, the trade-off for this advantage is that three-phase machines and controls are more complex and expensive. [3]

When connecting the rotor disk coils in a 3-phase configuration (Star configuration), they are connected in sets. With three sets in total where every set represents a phase, as shown in the figure below.

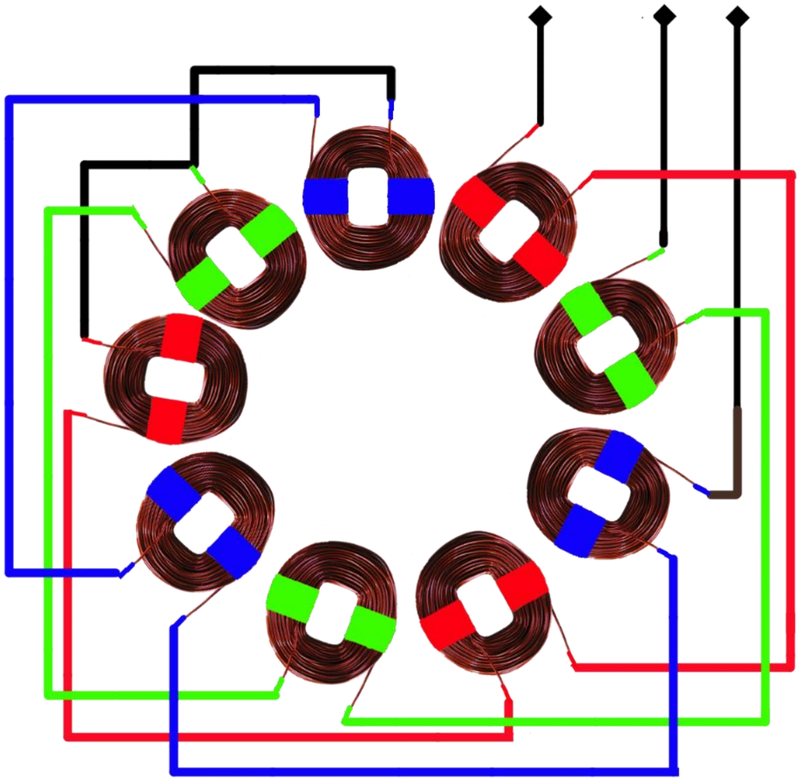

Figure 2: 3-Phase Generator Connectivity.

When connecting in 3-phase it has to be at least three coils or the multiple of 3, important to make sure all the coils have the same amount of windings. This to insure that all the 3 phases supplies the same amount of power. In our prototype we have chosen to use 6 coils, this is a multiple of 3 so it will be possible to convert from single phase to
3-phase at any time.

When connecting the rotor disk coils in a single-phase configuration, all the coils are connected in series.

2.4.2 Magneto generator

A magneto is an electrical generator that uses permanent magnets to produce periodic pulses of alternating current. It is classified as an alternator generator and built in the same way as an electromagnetic generator, where the magnet(s) work as the stator. The magnets do not need to be applied a current upon, while a stator with coils would need a current applied to it, to generate a magnetic field. This will in our case save us from the need of taping into the battery of the model helicopter.

Magnetos are often the simplest and the most reliable, but are limited in size because of magnetic flux available from its permanent magnets.

3. Generator Design Concepts

3.1 Vertical Coil

This concept will take more space vertically on our shaft, this is because of the permanent magnets which had to be mounted to the helicopter in a vertical configuration around the coil that is wrapped in a vertical fashion. We therefore decided to exclude this concept from further development.

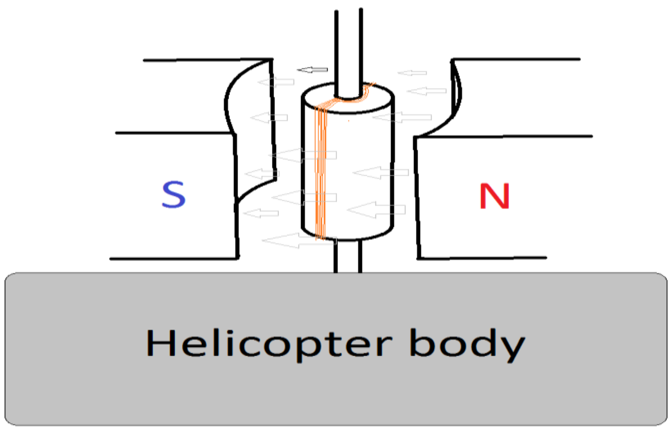

Figure 3: Vertical Coil Concept Drawing.

3.2 Stator Coil

This concept is based on the same concept of the single magnet disk, the difference is that the magnets would have to be swapped with a stationary stator with cobber coils connected to the battery.

It was also decided to exclude this solution because this concept needs to tap in to the battery of the model helicopter to generate the magnetic field at the stator coils. This is not desirable because it will decrease the battery lifetime.

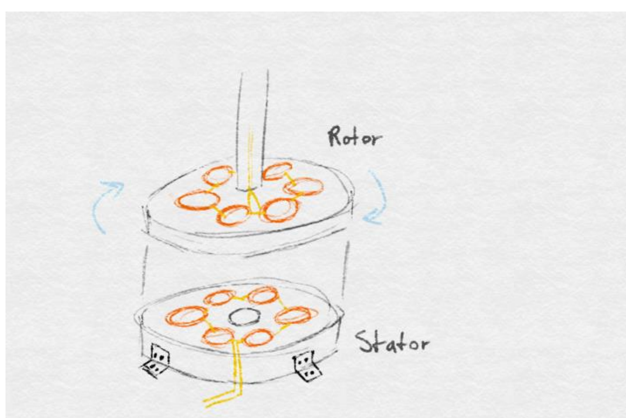

Figure 4: Stator Coil Concept Drawing.

3.3 Single Magnet Disk

In this concept, we will cast a resin disk with cobber coils integrated, this will work as the rotor of the generator and will rotate with the axel of the model helicopter. There will be a second disk under the rotor that will work as the stator in the generator. This disk will have two D601-N52 permanent magnets integrated, these are small 1cm diameter disk magnets, which are the strongest permanent magnets of this size. The magnet disk will be mounted down with epoxy and will not be rotating with the axle of the model helicopter.

Figure 5: Single Disk Generator 1st Version.

After some research we wanted to find out if it possible to implement the rotary transformer in the generator. For our first proof of concept this is the solution we want to further build on, if the concept proves feasible. It is expected that there will occur some interference due to the magnets and the generator coils, the solution for this would be to move the frequency spectre of the carrier signal to the transformer so it`s not in the same range than that of the generator.

We made a new design for the single magnet disk, which includes a rotary transformer in the same part. We did this by enlarging the diameter of the generator rotor and stator disks, and included the rotary transformer coils on the outer part of the disks. We found it was preferred to have the coils as close as possible to the edge to minimize the magnetic interference from the magnets and generator coils.

This design will be more efficient according to the space requirements on the axel, compared to the previous design, a separate construction for the rotary transformer is eliminated. As seen bellow in figure 5.

Figure 6: Single Magnet Disk Generator Final Version.

3.4 Dual Magnet Disk

This concept bases itself on 3 disks parallel to each other, the disk on top and bottom has the same D601-N52 permanent magnets as the single disk concept, and is stationary mounted. The rotor rotates in between the two disks and have coils in it, which will induce power when the magnetic force of the magnet is applied to the rotating coils.

Figure 7: Dual Magnet Disk Without Cover Top.

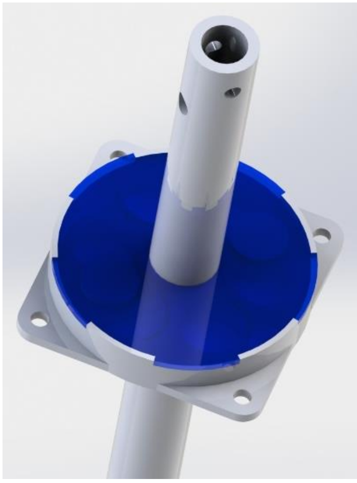

Figure 8: Dual Magnet Generator Housing.

We modulated the magnet disks in the new design, in order to add the possibility to change from a single magnet disk to a dual magnet disk design.

After some research, we followed up on the new design with the dual magnet disk configuration. The system includes a rotary transformer in the same assembly. We did this by enlarging the diameter of the generator disks and included the rotary transformer coil on the outer part of the disks, preferred to have coil closest to the edge to decrease magnetic interference from magnets and generator coils.

With this design there will be more possibilities regarding magnet configurations and how the rotary transformer can be set up.

This design will be more efficient according to space requirements on the axel, now that it's not needed to make a separate construction for the rotary transformer. As seen bellow in figure.

Figure 9: Dual Magnet Disk Generator/Rotary Transformer Final Version.

3.5 Design details

3.5.1 Rotor Cast Form

The rotor cast form is made in 3 parts. This is to be able to get the disk out when the cast is finished, and is made big to increase strength and robustness for re-use. The design enables us to cast several rotor disks with the same cast form.

It has a circle ledge that will make it possible to cast the coil for the rotary transformer, after casting the rest of the rotor disk. This will also insure that the rotary transformer coil is as close to the surface as possible.

Figure 10: Bottom Cast Form Plate, 1st Version.

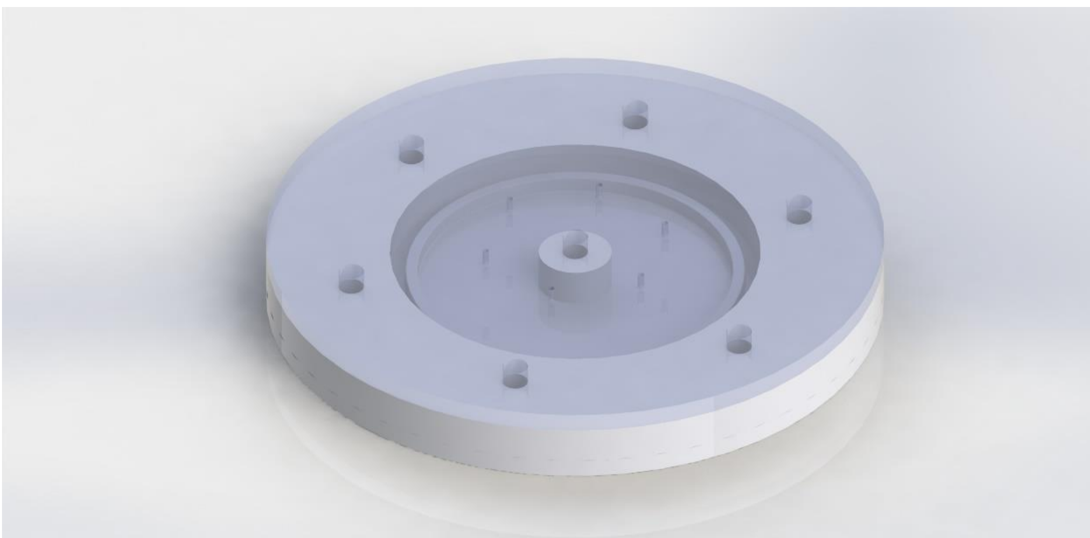

Figure 11: Rotor Cast Form 1st Version, All 3 Parts.

After having done a number of casts, we saw potential for improvements to enhance the strength of the cast form. This because we had a bottom plate that broke at the axel replacement cylinder in the center of the form, when trying to get the cast out. The solution to this could be to increase the width of the bottom plate. In addition, add a fillet at the axel replacement cylinder.

We also inserted small slot gaps in the center piece of the cast form to be able to jam in a screwdriver for disassembly. This was not essential for our prototype, and have been added to 3D-Models as seen bellow, for future builds. As seen in figures bellow.

Figure 12: Bottom Cast Form Plate, Final Version. With Filet On Axel Replacement Cylinder And Increased Width Of Plate.

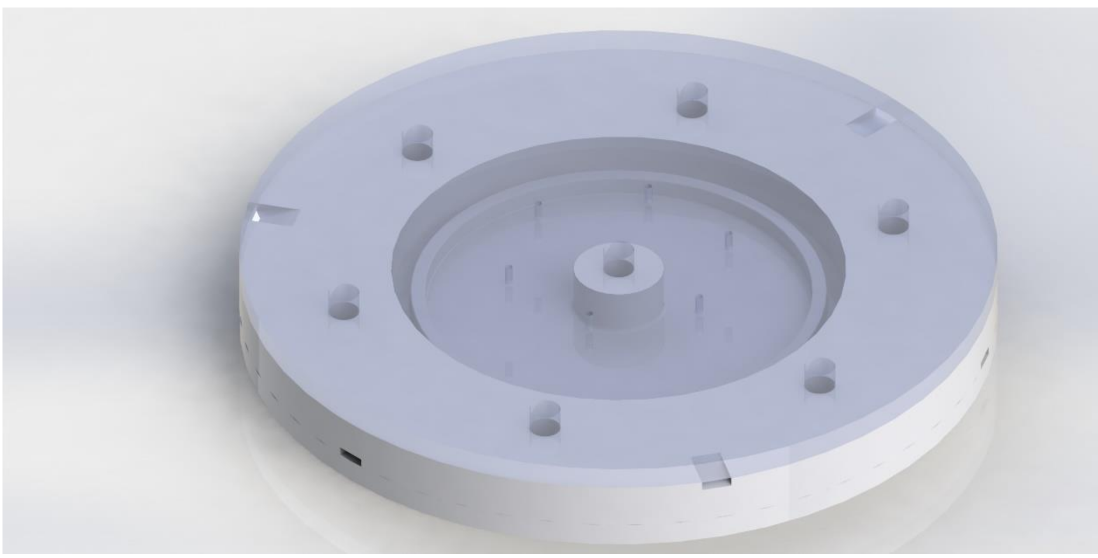

Figure 13: Rotor Cast Form, Final Version. With Slot Gaps In Centrepiece.

For the rotor disk cast itself we chose to use Crystal Resin, this is an epoxy with good robustness and strength. When hardened the cast also achieves a high stiffness and a level and transparent surface. We also used both ski wax and a dry lube in the cast form before casting the rotor disk, these work as a release agent for the cast. It was also found that poking around in the cast for air bubbles, before hardening would be beneficial for the finished cast.

When casting it is important to ensure that, all the coils are coiled and placed in the same direction.

3.5.2 Rotor Bushing

We have designed a hexagon shaped rotor bushing, which is possible to produce both mechanically (CNC) and with 3D-Printing, due to high cost on mechanically produced bushing we chose to go with the less expensive 3D-printed version. The inner diameter of the rotor bushing is set at 12mm that to be equal the outer diameter of the model helicopter axel. We found that the 3d printing process shrunk the parts a tiny bit so we got the preferred press-fit tolerance. Using a press-fit tolerance between the bushing and shaft we get a solid and balanced assembly that never moves. The rotor disk can now rotate with the axel of the helicopter. The hexagon star is not as high as the whole cast this to make the resin coat get well around it and reinforce it.

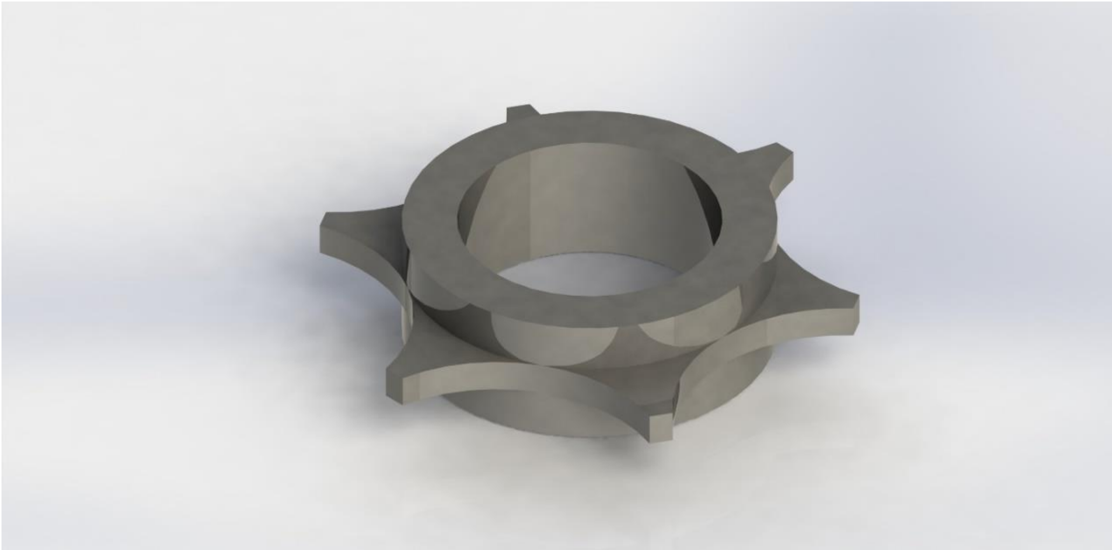

Figure 14: Rotor Bushing

The rotor bushing also work as a guide for the coil locations when casted in the "Rotor cast form", as seen below in figure 15.

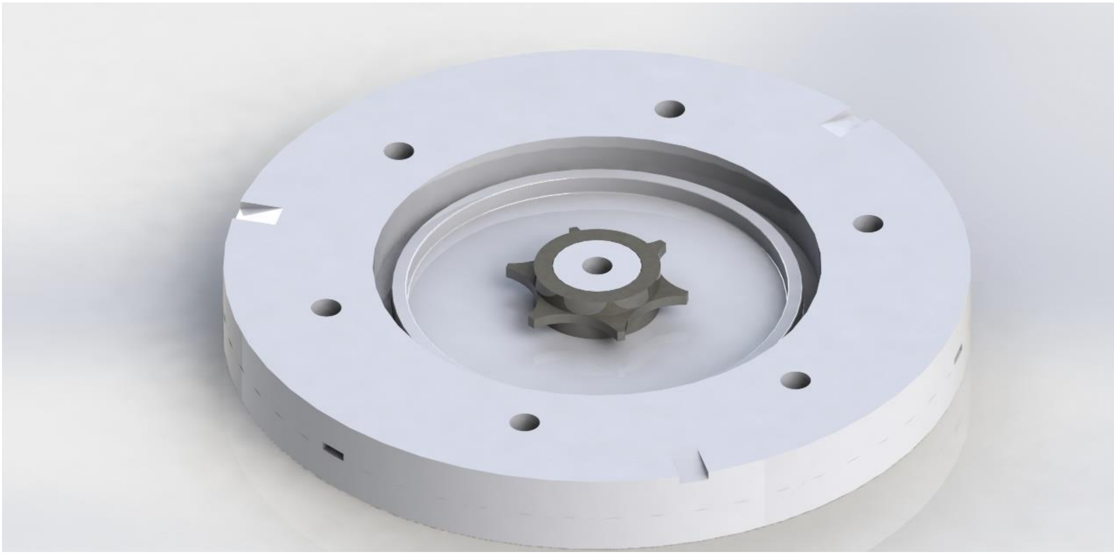

Figure 15: Rotor Bushing Mounted On Rotor Cast Form.

When finished casted we get a result like the figure bellow.

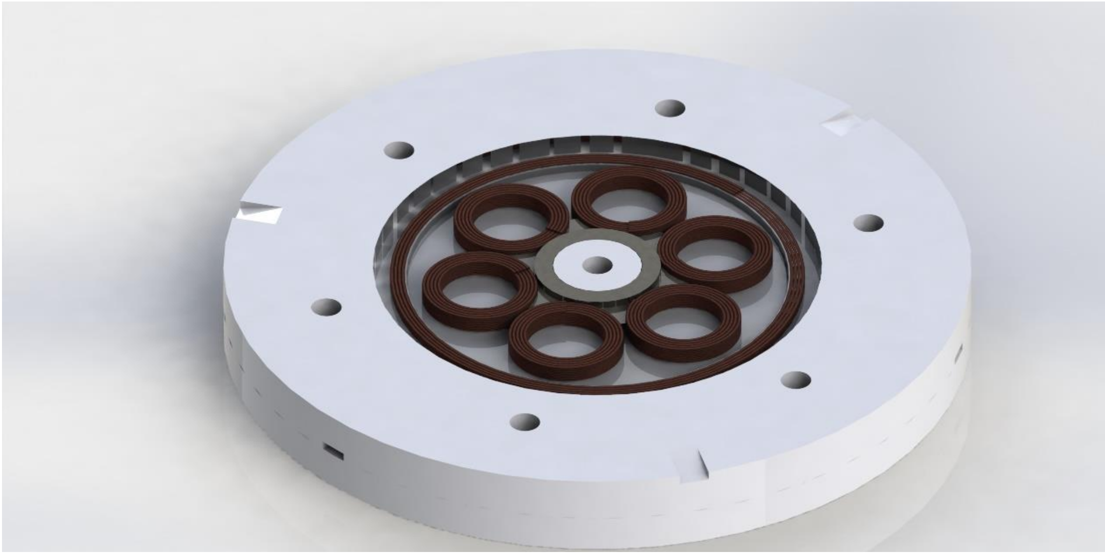

Figure 16: Complete Rotor Disk, In Resin Coating. Still In Cast Form.

3.5.3 Coils

To determine the number of coiling we have used the equations below.
Using an N52 grade disc magnet, we assume the following:

$$B = 1.43\,T$$

$$\emptyset_{magnet} = 0.01\,m$$

$$l_C = 0.0314\,m$$

$$r_{orbit} = 0.016\,m$$

$$O = 2\pi * 0.016\,m = 0.100\,m$$

$$2000\,rpm = 33.3\,rps$$

(6)

$$v_{orbit} = O * 33.3 = 0.100\,m * 33.3 = 3.33\,m/s$$

Given that the orbital velocity is 3.33 m/s and assuming maximum flux through coils, we get:

(7)

$$V_{ind} = B \perp lv$$

$$V_{ind} = 1.43\,T * 0.0314\,m * 3.33\,m/s \approx 0.15\,V$$

To achieve 6 volts at 2000 rpm,

(8)

$$n = \frac{6\ V}{0.15\ V} = 40$$

To produce 6Vac there will be needed 40 coiling per coil under ideal circumstances. We chose to increase this number of coiling to 50 per coil, this in order to meet requirement **SRS-05** and supply more than $7V_{AC}$. Which gives the equation.

$$n = \frac{7.5\ V}{0.15\ V} = 50$$

We chose to make the coils with a height of 5mm, which is half of the diameter of the D601-N52 magnet. As seen bellow on picture of the magnet, most of the magnetic flux is not emitted over a bigger area than less than half of the diameter of the magnet. We also chose to have the inner diameter of the coils to be equal to the diameter of the magnet which is 10mm, this design allows us to exploit the magnetic field with the highest possible efficiency.

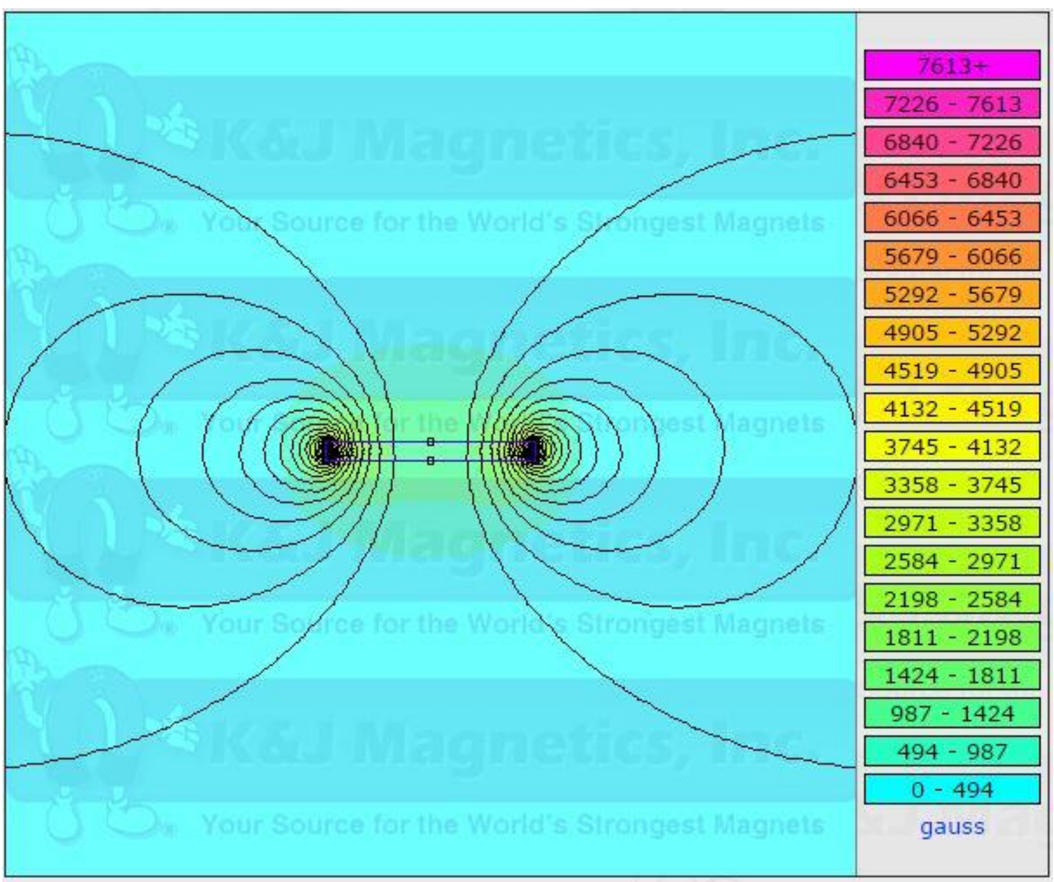

Figure 17: Magnetic Field Of D601-N52 Magnets.

For the production of the coils we made a contraption for effective coiling of the rotor coils as seen in picture bellow, it was produced after complications when trying to do it by hand from small spacing and tiny coils.

Figure 18: Coiling Contraption

To make the coiling stick together we used epoxy glue, for every 10-15 windings, we applied a small amount of epoxy glue on three places around the coil. We also used some ski wax on the contraption on the bearing, the coil centerpiece and the big hexagon shaped nut. This so we could get the coils loose when finished hardening. Coils are kept on the contraption until hardened.

The direction in which coils are wound, clockwise or counter-clockwise, and the connections to the start or finish of each winding determines the instantaneous polarity of the ac voltages. All windings which are wound in the same direction will have the same polarity between start and finish ends. [4]

We coiled all the coils in the same direction, with the battery drill in reverse. This to ensure that the polarity of all the coils was the same between start and finish ends, when completed.

3.5.4 Magnet disk and magnets.

Our original design began with 2 magnet slots in the magnet disk (Stator), these where very small. After assembly of generator there occurred a great level of flux leakage with the D601-N52 magnets, and we were not able to induce current through the poor magnetic field.

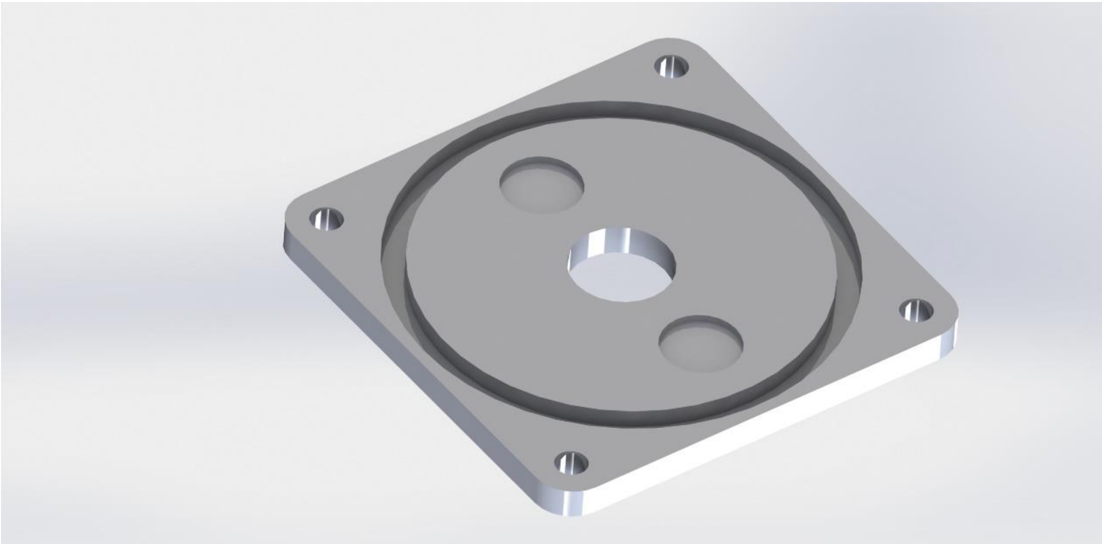

Figure 19: Magnet Disk, 1st Version.

We chose to use 4 magnets of the same family as the D601-N52 but with a greater height that increased the magnetic field. This had an immediate effect but could still not achieve more than $1V_{AC}$ This is not in line with requirement id; **SRS-05**. (Ref. Test report **T-SRS-05**)
The 4 magnets are aligned in a way that, magnets 1 and 3 have their north pole facing up. Magnets 2 and 4 have their south pole facing up, toward the generator coils.

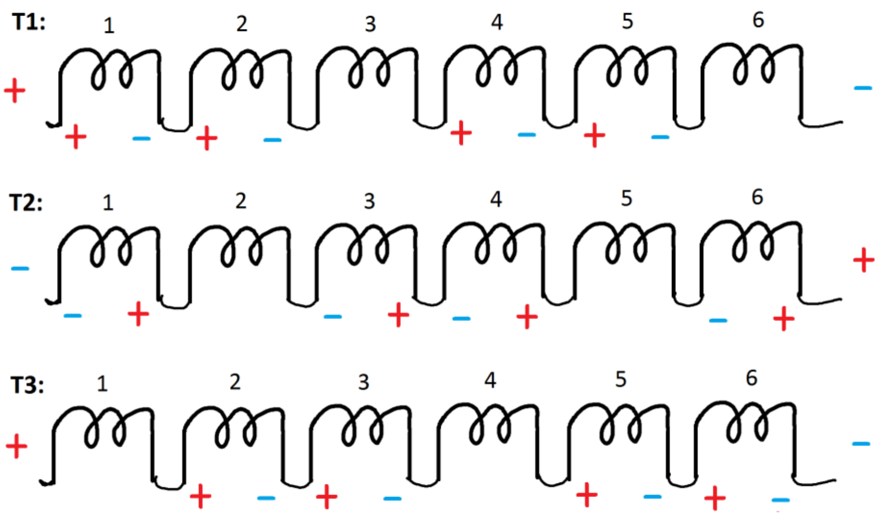

Figure 20: Single Phase, Polarity of Coils Rotating over Four Magnets.

The figure above shows the rotor coils connected in series, when in a single phase configuration. This setup is contemplated for using 4 magnets. The figure also shows how the polarity of the coils changes at times $T_1, T_2\ and\ T_3$ as the coils are passing the magnetic fields of the permanent magnets.

The coils are set up in pairs, in a way that coils 1 and 4 will enter the magnetic field of the south pole magnets simultaneously. At the same time coils 2 and 5 will leave the magnetic field of the north pole magnets. This results in all 4 coils having the same polarity.

To increase the voltage produced from the coils, the solution could be to increase the number of coiling on the copper coils and/or add iron cores within the coils. However, this would increase the weight and size of the construction.

For future development we have chosen to increase the number of magnets from 2 to 6 magnets, and have also inserted slots for them in the 3D-models. The disk in itself has been increased in height to be able to fit bigger magnets than first designed for.

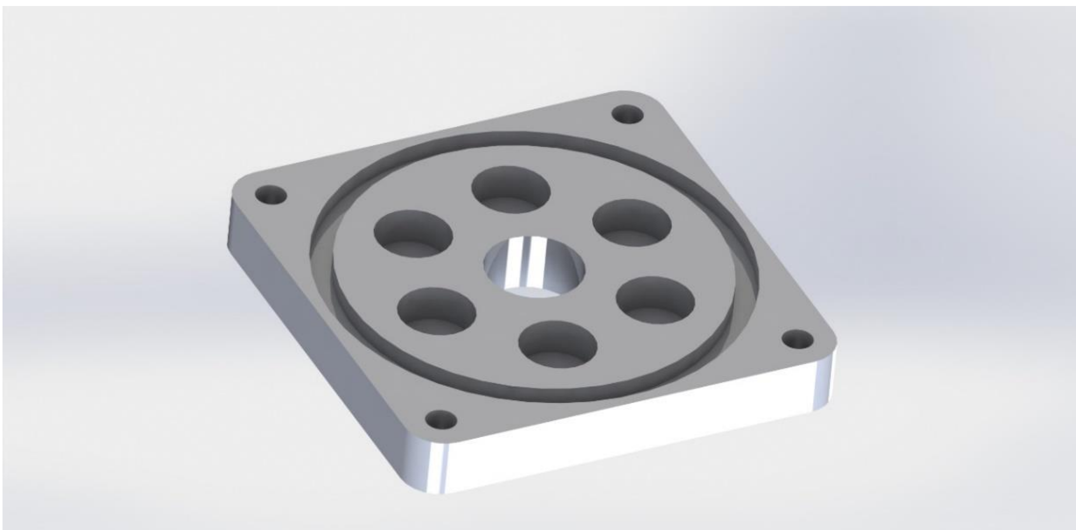

Figure 21: Magnet Disk, Final Version. Increased Height Of Whole Disk And Magnet Slots.

3.5.5 Rotor disk.

The rotor disk consists of seven coils, the rotary transformer coil is the one furthest from center in order to minimize noise. The other six coils are for the generator, the coils can be connected in both 3-Phase and single phase. The rotor bushing is located in the center of the resin cast. Generator coils are also mounted with equal spacing, this will increase balance to the rotor disk.

Figure 22: Generator Rotor Disk

3.5.6 Helicopter shaft simulator

We built a model helicopter shaft simulator, to be able to test the generator and the rotary transformer.

We started with buying a pipe that had the same dimensions as the actual shaft of the helicopter, but because of long delivery time on the shaft coupling from the motor axel to the helicopter shaft we chose to go with a produced shaft.

This shaft was designed to fit on the motor shaft with set-screws, this to make it rotate with the motor shaft with minimal friction. This fits both motors that we are using for prototyping. It has also been designed so that it is hollow, thru half the shaft. This is to be able to pull the wires from the rotor disk through 4 holes right above the rotor disk location and to the top of the axle.

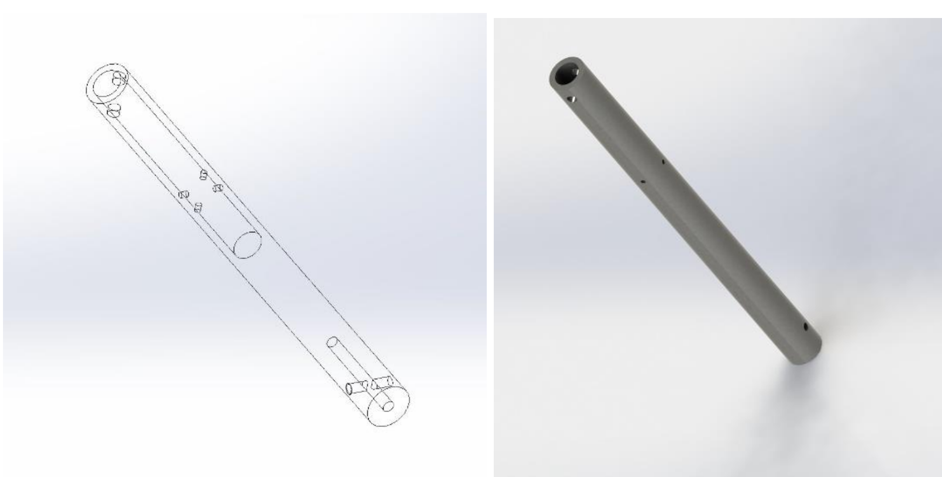

Figure 23: Shaft, 2D-Sketch & 3D-Design.

We also designed bearing holders, because of no other availability. The design of these was also made modular for design freedom, the bearing holders balances the system beautifully, makes everything in line and able to rotate without friction.

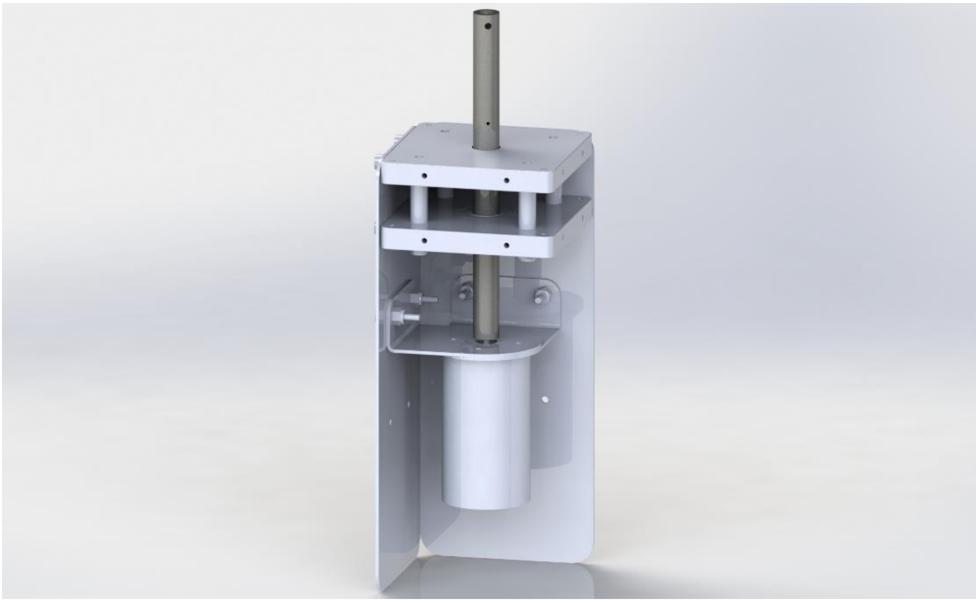

Figure 24: Helicopter Shaft Simulator.

The motor we are using is a synchronic motor, which has to be programmed to go at a certain speed. We chose to use this motor because it has a more accurate RPM controller that we could regulate at any time with software.

3.6 Completed Alternator generator/Rotary transformer

After assembly, this would be the result. A very space sufficient and efficient design, which satisfies requirement **SRS-08** and **SRS-16**. The figure shows the motor at the bottom, with our produced shaft to simulate the helicopter shaft. Then it shows two bearing holders with 12x28x10 bearings, embedded in the holders to maintain level and in balance shaft. On top of the bearing holder is the stator disk, with magnets embedded to it and a transformer coil. The disk is mounted on the bearing holder to increase stability.

The final part is the rotor disk; it has the generator coils and rotary transformer coil casted within. It has a press-fit solution to rotate with the shaft when motor is operational. It is also designed so that the shaft has small holes right over where the rotor disk will be mounted, for it to be possible to pull the wiring thru the shaft.

There has been added some plates to the design for the motor to be mounted, but is not included in the prototype.

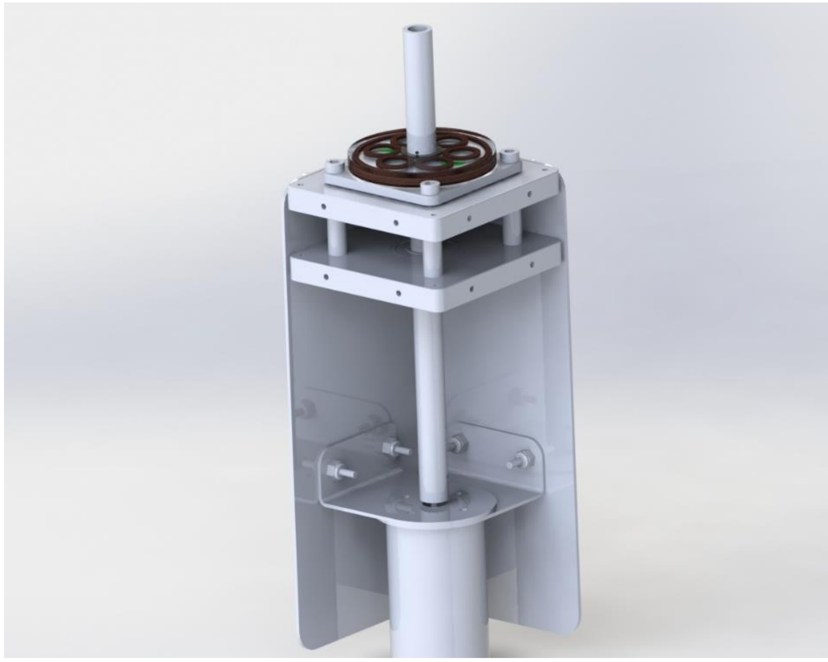

Figure 25: Generator & Transformer Mounted On Shaft Simulator.

Power Supply Module

The power supply module is a vital part of our system. Without a stable and reliable flow of current, the system will fail as its data signals must be delivered in real time and are highly sensitive to voltage changes. To be able to supply the system with stable power, we will use the rotational motion of the helicopter rotor to create enough electricity to feed the microcontroller and the strain gauge sensors. This way we can supply power without having the system to rely on its own batteries. As long as the helicopter is in operation, the system will produce its own power.

4. Theory

4.1 Full-wave rectifier

For converting an AC input to DC output, diodes can be used. Simply put, a diode only leads current in one direction. By using several diodes in certain configurations, we can create a half-wave rectifier, full-wave rectifier/rectifier bridge. A full wave rectifier includes both the positive and the negative amplitudes of the AC input, hence double the efficiency.

(9)

$$\eta = \frac{P_{out}}{P_{in}} = \frac{4}{\pi^2} = 40.6\ \%$$

$$\eta = \frac{P_{out}}{P_{in}} = \frac{8}{\pi^2} = 81.1\ \%$$

The equation (9) above show efficiency for a half-wave and full-wave rectifier.

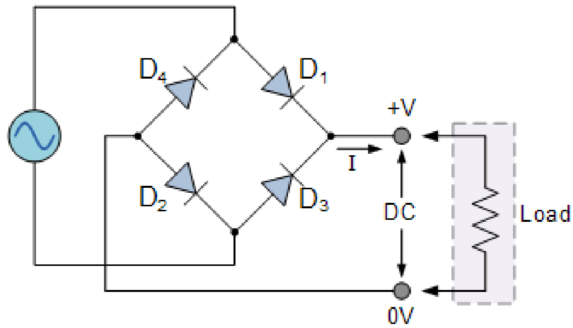

Figure 26: Full-wave rectifier bridge.

What happens here is that the alternating current is blocked by the diodes in one direction, and allowed through in the other. In a bridge configuration, the current is lead through two paths depending on the changing polarity. That way both amplitudes are included.

4.2 Capacitor-input filter

When using a rectifier, the AC input will be converted to a pulsating DC output. By using a capacitor parallel to the circuit load, the DC pulse can be reduced to a small ripple. Generally, the higher the capacity of the capacitor, the smaller the ripple. A higher frequency AC will also help reducing the ripple. [5]

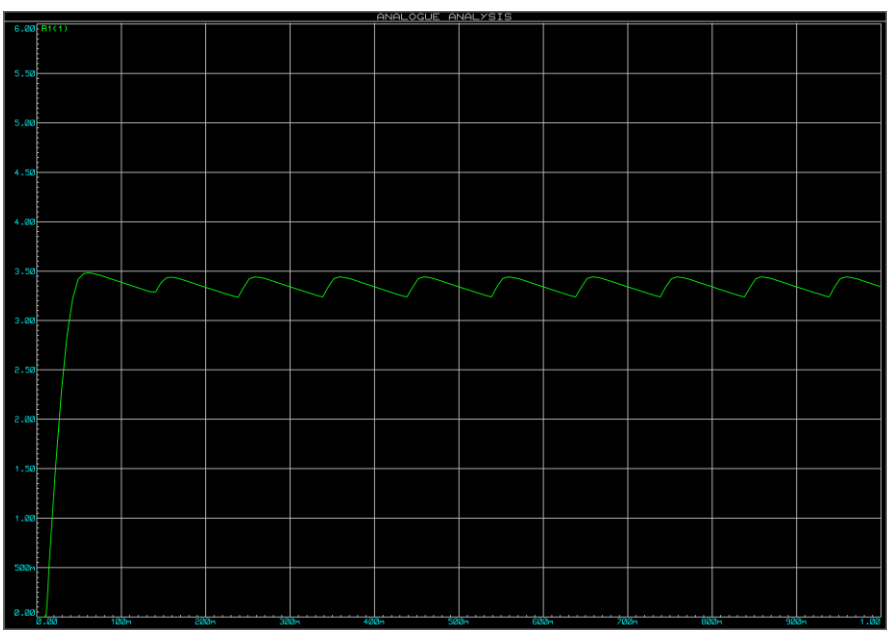

Figure 27: The DC-output of a full-wave rectified AC-input with a capacitor-input filter.

5. PSM Design Concepts

This section will elaborate our different designs for solving the power supply problem.

5.1 3-phase AC to DC converter

The 3-phase generator is an effective generator using coils divided into 3 phases. For that we need a number of coils that is a multiple of 3. A higher number of coils will produce alternating current at a higher frequency. When using a 3-phase generator, the size of the copper wire required can also be reduced. [6]

Our initial design uses 3 coils on a rotor disc, each coil 120 degrees apart from the two others. This is important, to make the voltage amplitudes of each phase evenly distributed over time.

A number 6 diodes will be used in pairs, in order to rectify the alternating current. This produces positive and negative voltage outputs of equal magnitude.

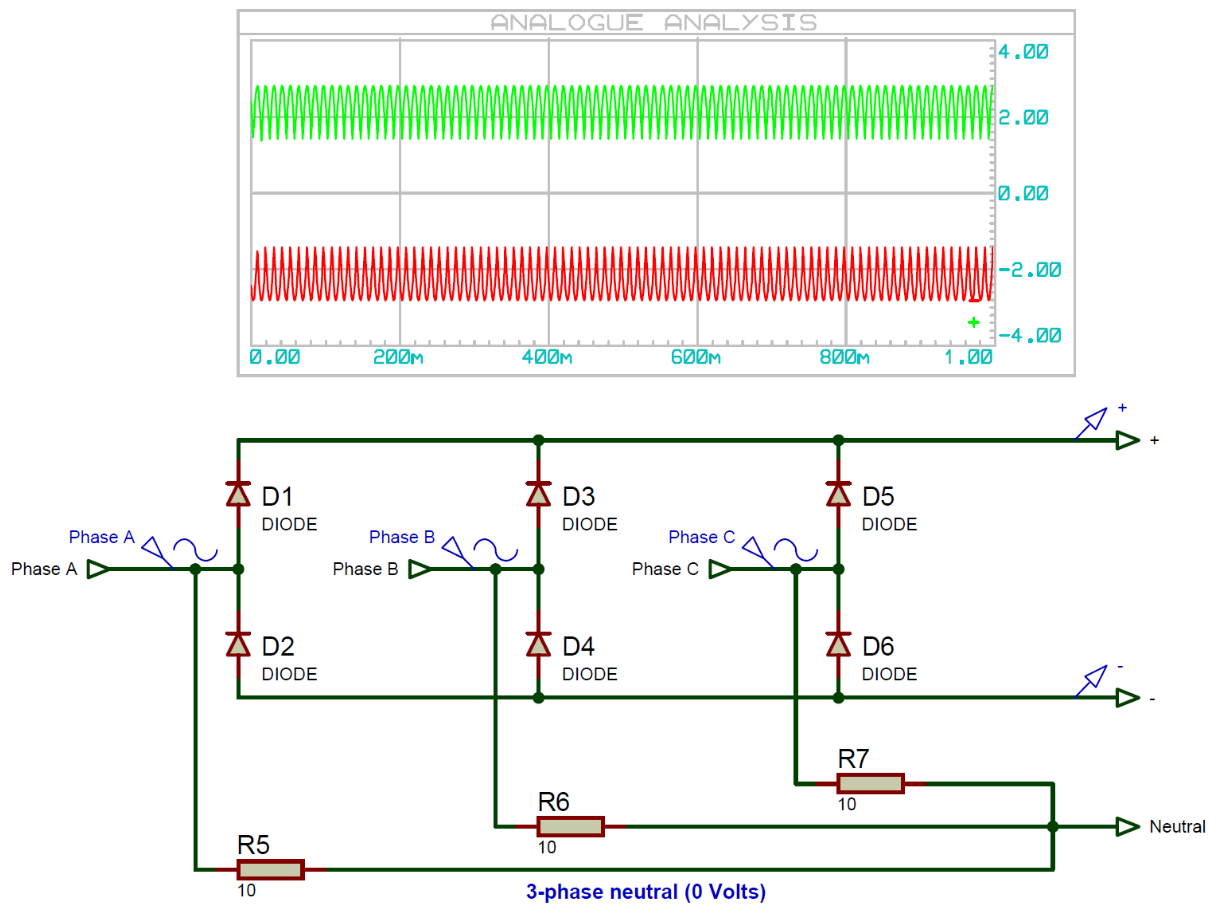

Figure 28: Circuit rectifying 3-phase alternating current (AC) to direct current (DC).

In this circuit we have 3 different phases of alternating current. Phase A is 0 degrees, while phase B is offset by 120 degrees and phase C by 240 degrees.

The circuit outputs +/- gives a positive and negative polarized DC, and both outputs should be of the same magnitude. However, as shown in the diagram in figure 1, this DC is very rippled. To reduce this ripple, we can introduce some capacitors into the circuit:

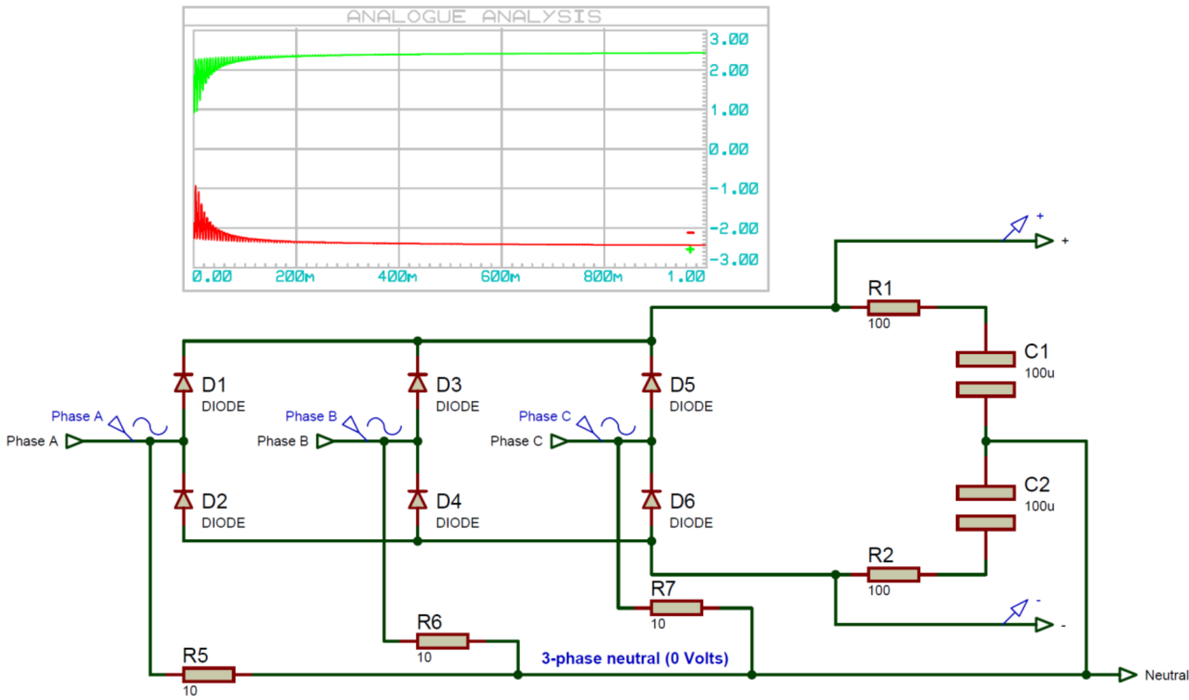

Figure 29: Circuit rectifying 3-phase alternating current (AC) to direct current (DC) w/ripple reduction.

By connecting the two capacitors C1 and C2 to the neutral (0 volt) output from the 3-phase generator, we can use this as a ground earth reference point. This will be for ripple reduction only. Later in the circuit, we will be using the negative output as a ground earth reference point, as this allows for the highest possible voltage difference between the two poles.

5.2 Single phase AC to DC converter

This design uses only single phase alternating current and converts it through a diode bridge. In a single phase generator, the coils (if multiple) are connected together into a positive and negative pole. Therefore, in the following circuits we consider the generator coils as one single power source.

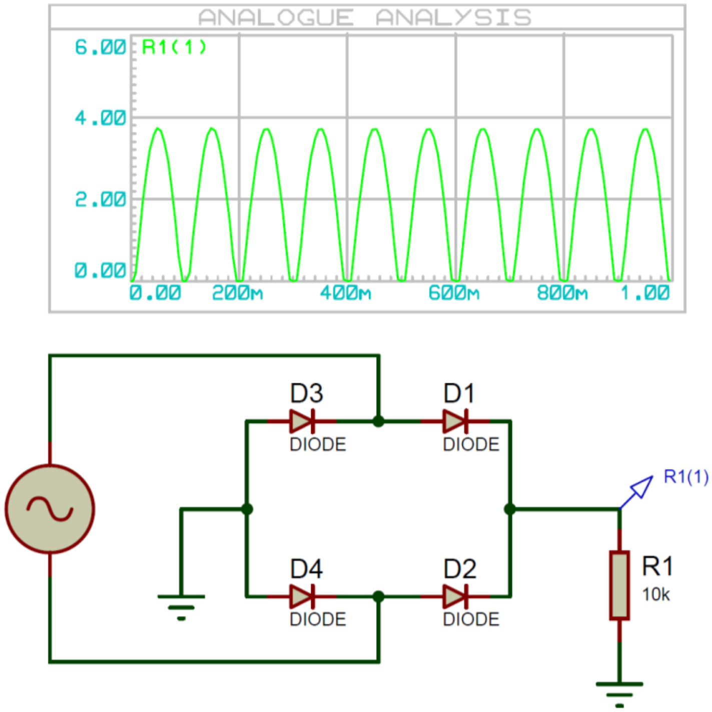

Figure 30: Single phase alternating current converted to direct current through a full-wave rectifying bridge.

A single phase generator allows for a simpler circuit, but does not produce voltage as effectively as a 3-phase generator. Ripple voltage is still an issue in this design as well, so a capacitor is required to reduce this.

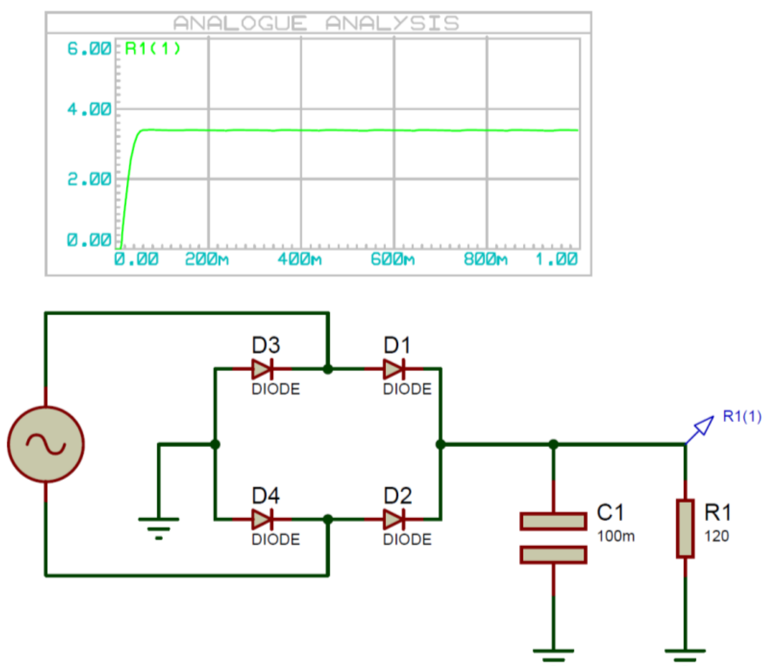

Figure 31: Single phase AC to DC with ripple reducing capacitor.

Analog Circuitry

6. Collecting the Signal

To collect bending data, we will use a strain gauges assembled in a Wheatstone bridge configuration.

6.1 Strain Gauge

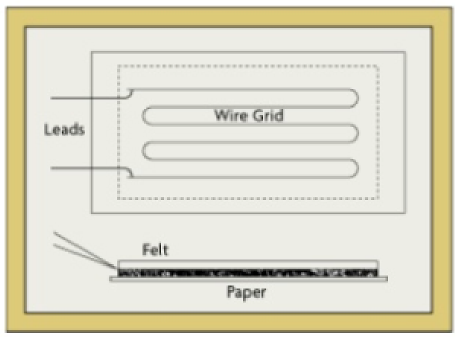

Figure 32: Bonded Strain Gauge

A strain gauge is a device used to accurately measure the deformation (strain) of an object. It is used extensively in industry in the manufacturing and testing of equipment. It can be used to measure force, pressure, weight and torque.

Strain gauges are passive sensors. They have no internal power supply and receive energy from an external source in order to produce a signal. The strain gauge is a transducer, transforming variations in a measured physical motion into a related electrical signal.

Strain gauges are made from metal alloy such as Constantan, Nichrome, Dynaloy, Stabiloy or Platinum alloy. For moderate temperature (and for most applications), they are made by forming the metal allow onto very thin mounting sheets by a photo etching process, resulting a "foil-type" bonded strain gauge [7]. For higher temperatures, they are made of wire.

Typical values of the resistance of strain gauges are between 120 and 1000Ω. High resistance strain gauge produce less heat due to their limited measuring current and are less sensitive to resistances within the connection cables. [8]

The output of the strain gauge is a low amplitude analogue voltage in the millivolt range. This is voltage can be considered the bending signal. This signal requires further processing before it can be used for analysis.

Advantages	Disadvantages
Small size	Careful installation procedure required
Low mass	Moisture effects can dissolve bonding glue
Low cost	Relatively low amplitude output signal
Resistance change is the circuit output	Thermal degradation over time
Excellent linearity over wide range of strains	Requires calibration after repeated usage.

Table 1: Advantages and disadvantages of Strain Gauges

6.2 Definition and equations

Strain is the amount of deformation of a body due to an applied force. This is measured in the fractional change in length of the object in the direction of the applied force. [9]

Stress is defined as force per unit area. The stress applied to an object along its transverse axis can also result in a deformation and resulting strain.

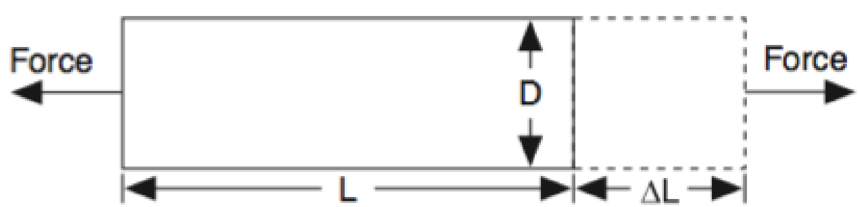

Figure 33: Force applied to an object

The equation for strain, ε of an object Is (10)

$$\varepsilon = \frac{\Delta L}{L}$$

where ΔL is the change in length of the object and L is the original length.

Strain is dimensionless, but sometimes expressed in units of mm/mm. The magnitude of measured strain is very small and is often expressed as microstrain (me), which is e x 10^{-6} [9]. Strain can be either positive (resulting from tension) or negative (resulting from compression).

6.3 Resistance and strain

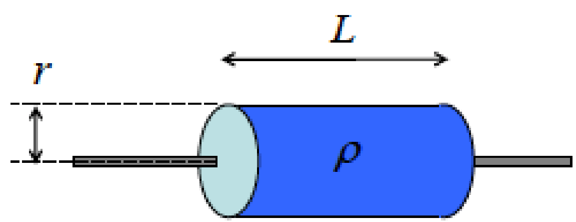

Figure 34: Wire in a Strain Gauge

The resistance of the wire in the strain gauge is given by (11)

$$R = \frac{\rho L}{A}$$

where L is the length of the wire, ρ is the resistivity of the wire and

where the A is the cross sectional area of the wire (12)

$$A = \pi r^2$$

The metallic wire in the strain gauge can be subject to either tension or compression.

Tension causes the length, L of the wire to increase and its radius, r to decrease. The reduced radius results in reduction of the area, A. The increased length and reduced area causes the resistance of the wire to increase.

Compression causes the length, L of the wire to decrease and its radius, r to increase. The increased radius results in increase of the area, A. The reduced length and increased area causes the resistance of the wire to decrease.
The resulting change in resistance linearly corresponds to the strain experienced.

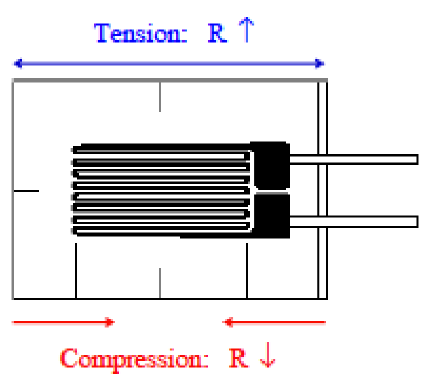

Figure 35: Effects of tension and compression on the resistance of a wire.

6.4 Applying the strain gauge

The direction, type and resolution of the strain to be measured must be considered in selecting a strain gauge. [10]

We intend to measure the bending strain of a rotor blade. This requires that the strain gauge be installed so that its grid pattern maximizes the amount of foil subject to strain in the parallel direction.

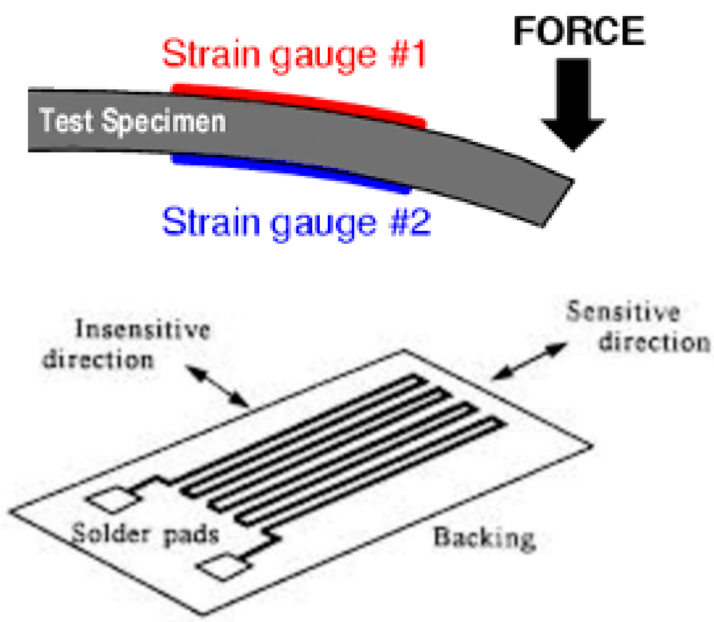

Figure 36: Applying the Strain Gauge to measure Strain in a particular direction caused by a bending force

In order to measure this strain, the “bonded” strain gauge is attached to the body whose strain is to be measured. It is carefully mounted so that its transverse axis lies in the same direction as the structure motion that is to be measured [7]. The surface of the body must be cleaned: degreased and neutralized of any chemical that could dissolve the glue which will attach the bonded strain gauge to the body of the object. [11]

The strain experienced by the body will transfer directly to the strain gauge. Strain gauges used in this way can be used to determine the vertical force which caused the bending. [10]

6.5 Strain Gauge in a Wheatstone Bridge

The resolution of the strain that we expect to measure is very small. To measure minute resistance changes we must place the strain gauge in a Wheatstone Bridge configuration. This converts the resistance change into a voltage change. Greater resolution and sensitivity are possible when more than one strain gauge is used in the bridge. [12]

Our design uses four strain gauges in the Wheatstone Bridge. This is called a full bridge configuration. However, two of the strain gauges will be arranged in a perpendicular direction to the strain that is expected.

Signal Modulation

Modulation is the process of varying one or more properties of a repetitive signals waveform – for example its amplitude or frequency. We will need to conduct signal modulation to guarantee that the bending data information is successfully transferred from the rotor blades through the rotating transformer and out into the dummy system.

7. Signal processing

In electronics, signal is defined as an electric current or electromagnetic field used to convey data. Electric current is either direct current (DC) or alternating current (AC), depending on the direction of the current flow in a circuit. In **direct current** (DC), the electric charge (current) can only flows in one direction centrally to electric charge in **alternating current** (AC), which change direction periodically. [13]

The voltage in **alternating current** circuits also periodically reverses as result of the current changing direction. Signal are classified into continuous time (analog signal), or discrete time (digital signal). The difference between analog and digital signals is that analog signals are continuous electrical signals, whereas digital signals are discrete electrical signals. [14]

8. Analog signal

An analog signal is a continuous signal containing time varying quantities such as flow of electric current or voltage, pressure, temperature, pneumatic energy or sound. Analog quantities vary continuously in frequency and amplitude. The analog technology uses the analog signals in their original forms. The figure below shows an example of a graph, which represents an analog signal in form of voltage.

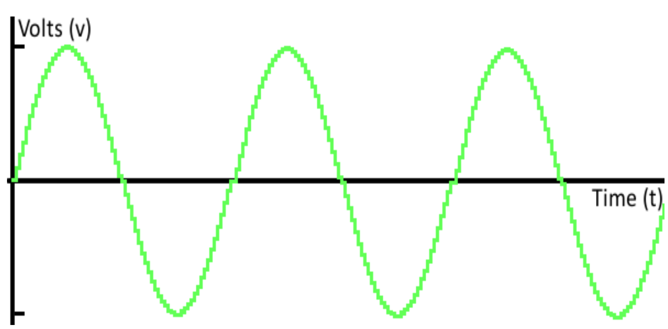

Figure 37: A continuous sine signal.

A continuous signal is usually continuous in both time and amplitude. This type of signal usually contains values for all real numbers along the time axis, contrary to discrete time signal, which is created by sampling a continuous time analog signal. [14] A digital signal is a type of signal whose original information is sampled (converted into string of bits), before being transmitted.

A digital signal is a type of signal whose original information is sampled (converted into string of bits), before being transmitted. Digital technology involves sampling analog signals at a certain interval and convert the analog quantities into binary numbers that can be stored in the digital devices like Hard Disk, CD, USB or Digital Books. The figure below shows a graph where a continuous analog signal is samples and represented in discrete form.

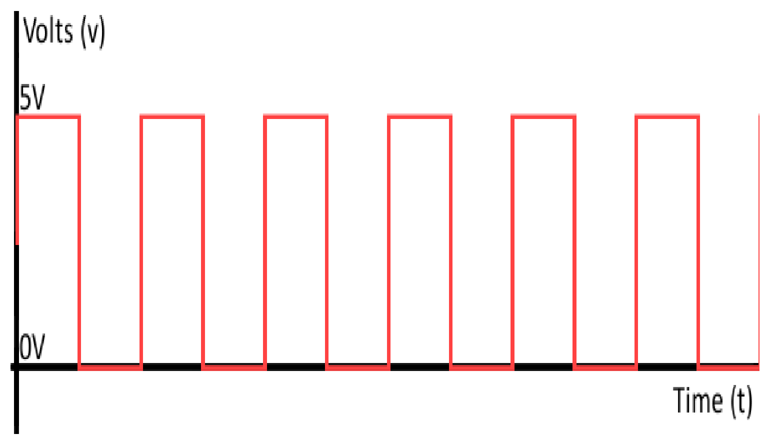

Figure 38: Digital signal.

A digital signal has a discrete value at each sampling point. The precision of the signal is determined by how many samples are recorded per unit of time. Discrete signals generally consist of on and off states, where binary numbers are used to represents the states with one representing the on state, while zero represents the off state.

9. Discrete signal Sampling

The sampling theorem, which is a relatively straightforward consequence of the modulation theorem, is elegant in its simplicity. It states that a bandlimited time function can be exactly reconstructed from equally spaced samples if the sampling rate is sufficiently high-specifically, that it is greater than twice the highest frequency present in the signal. [15]

A similar result holds for both continuous time and discrete time. One of the important consequences of the sampling theorem is that it provides a mechanism for exactly representing a bandlimited continuous-time signal by a sequence of samples, that is, by a discrete-time signal.

The reconstruction procedure consists of processing the impulse train of samples by an ideal low pass filter. Central to the sampling theorem is the assumption that the sampling frequency is greater than twice the highest frequency in the signal. Frequency-domain sampling typically arises when we would like to measure or explicitly evaluate numerically the Fourier transform. [3]

Although in general the Fourier transform for both continuous time and discrete time is a function of a continuous-frequency variable, the measurement or calculation must be made only at a set of sample frequencies. Because of the duality between the time and frequency domains for continuous time, the issues, analysis, and concepts related to frequency-domain sampling for continuous-time signals are exactly dual to those of time-domain sampling. [4]

In order for a signal to be transmitted from one place to another, the signal has to be coded and modulated to maintain the quality of the data being transmitted from one place to another. Signal modulation involves mapping data into a carrier signal such that the receiver can recover the conveyed data in useful way.

Coding and modulation provide the means of mapping information into waveforms such that the receiver (with an appropriate demodulator and decoder) can recover the information in a reliable manner. Signal encoding and decoding is sometimes used in reference to the process of analog to digital conversion and digital to analog conversion.

Generally, signal modulation is a process where a modulating signal or information m (t) is encoded into a bandpass signal s (t), where m (t) stands for modulating signal and s (t) stands for modulated signal. The process can be done in either of two main ways namely

Analog and digital modulation.

10. Analog Modulation

Analog signal modulation involves transmitting the information and data signal though a carrier signal. Usually the carrier signal is a high frequency sinusoidal signal represented by amplitude, frequency and phase. The analog modulation is performed varying one of the parameters of the carrier signal accordingly with the data to be conveyed. The modulation is performed by varying the frequency, amplitude or phase of carrier signal accordingly with the amplitude of the message signal to be transmitted. The three basic types of analog modulations are:

1. AM or Amplitude Modulation
2. FM or Frequency Modulation
3. PM or Phase modulation

Amplitude Modulation:

Amplitude modulation involves varying the amplitude of Carrier signal accordingly with the amplitude of the signal to be transmitted. Amplitude modulation is the simplest and cheapest of all the types of signal modulations. The hardware designed to perform the amplitude modulation are simpler, cheaper and less effective compared to the hardware designed to perform frequency and phase modulations.

Frequency modulation or FM on the other hand is a type of analog modulation, which involves varying the frequency of Carrier signal accordingly with the amplitude of the signal to be modulated. Phase modulation or PM is the process of varying the phase of Carrier signal accordingly with the amplitude of message signal.

Digital modulation has a band signal of discrete amplitude revel centrally to the analog modulation, which has a continuous band signal. The digital modulation involves modulating data in binary signal form, which has only 2 levels namely high or logic 1 or low or logic 0. The three basic types of digital modulation are:

1. Amplitude shift Key or ASK
2. Frequency shift key or FSK
3. Phase shift key or PSK

Analog modulation uses mainly analogous methods like Amplitude Modulation, Frequency Modulations and Phase Modulation. The modern mobile communication systems on the other hand use digital modulation techniques mentioned above. Digital modulation techniques are more sophisticated and efficient techniques compared to their analog counterparts. The modulation techniques offers many advantages like greater noise immunity, robustness and simpler multiplexing.

10.1 Amplitude shift key (ASK)

This method is digital to analogue version of Amplitude Modulation. The technique is Similar to AM and functions by dictating the binary value and only the amplitude changes while the frequency and phase stay the same. When the carrier amplitude is varied in proportion to message signal m (t).

We have the modulated carrier $m(t)cosw_ct$ where $cosw_ct$ is the carrier signal. As the information is an on-off signal, the output is also an on-off signal where the carrier is present when information is 1 and carrier is absent when information is 0. Thus, this modulation scheme is known as on off keying (OOK) or amplitude shift key. The problem with ASK is that it is not immune to noise interference and the entire transmissions could be lost due to this problem.

10.2 Frequency shift key (FSK)

Frequency shift keying (FSK) is one of the techniques used to transmit a digital signal on an analogue transmission medium. The frequency of a sine wave carrier is shifted up or down to represent a single binary value or a specific bit arrangement. The simplest form of frequency shift keying is called *binary frequency shift keying* (BFSK).

In this technique, the binary logic values one and zero are represented by the carrier frequency being shifted above or below the *center frequency*. When Data are transmitted by varying frequency of the carrier, we have the case of frequency shift key. In this modulation carrier has two predefined frequency w_{c1} and w_{c2}. When information bit is 1 carrier with w_{c1} is transmitted i.e. $\cos w_{c1}$ and When information bit is 0 carrier with w_{c0} is transmitted coswc0

PSK or Phase shift key

Phase-shift keying (PSK) is a digital modulation scheme based on changing, or modulating, the initial phase of a carrier signal. PSK is used to represent digital information, such as binary digits PSK is typically applied in wireless local area networks (WLAN), Bluetooth technology and radio frequency identification (RFID) standards used in biometric passport and contactless payment systems.

PSK is typically applied in wireless local area networks (WLAN), Bluetooth technology and radio frequency identification (RFID) standards used in biometric passport and contactless payment systems. The phase of the carrier is shifted for this modulation. If the base band signal m(t) =1 carrier in phase is transmitted. If m (t) = 0 carrier with out of phase is transmitted i.e. $\cos(w_c t+\emptyset)$. If phase shift is done in 4 different quadrants then 2bit of information can be sent at a time. This scheme is a special.

Manchester encoding

Manchester encoding has gained wide acceptance as the modulation scheme for low-cost radio-frequency transmission of digital data. This form of binary phase-shift keying is a simple method for encoding digital serial data of arbitrary bit patterns without any long strings of continuous zeros or ones, and having the encoding clock rate embedded within the transmitted data.

Manchester encoding is a form of binary phase-shift keying (BPSK) that has gained wide acceptance as the modulation scheme for low-cost radio frequency (RF) transmission of digital data. Manchester is a simple method for encoding digital serial data of arbitrary bit patterns without having any long strings of continuous zeros or ones, and having the encoding clock rate embedded within the transmitted data.

These two characteristics enable low-cost data-recovery circuits to be constructed that can decode transmitted data with variable signal strengths from transmitters with imprecise, low-cost, data-rate clocks. The encoding of digital data in Manchester format defines the binary states of "1" and "0" to be transitions rather than static values. For our system, we used FSK modulation technique to transmit our digitalized signal from the PIC12F1840 Microcontroller. The technique allows digital data to be transmitted by doing some changes in the frequency of the carrier signal.

This system commonly uses an analog carrier sine wave. There are two different binary states namely: zero (0) and one (1), each which is represented by an analog wave. The technique is robust to noise compared to other digital modulation techniques.

Microcontroller

11. General

The PIC12F1840 microcontroller is an 8-bit microcontroller, operating between 1.8 – 5.5 volts with a maximum frequency of 32 MHz. It has a number of modules that is put to use in our system, including:

10-bit analog to digital converter.
5-bit digital to analog converter.
Data signal modulator.
Comparator.
EUSART

These modules are configured by so called control registers consisting of 8-bits each. For example:

CONTROL REGISTER:

Bit 7	**Bit 6**	**Bit 5**	**Bit 4**	**Bit 3**	**Bit 2**	**Bit 1**	**Bit 0**
DACEN	DACLPS	DACOE	-	DACPSS<1:0>		-	DACNSS

Table 2: Example of an 8-bit control register.

The greyed out columns are bits that are unimplemented and have no function. These bits cannot be set, and will always appear as 0.

This chapter aims to elaborate only the features and modules that are being used in our system, and also justify why we chose the PIC12F1840. Despite some minor variations, the PIC12F1840 and PIC12LF1840 are basically the same and therefore share datasheet. For further details and specifications, refer to the PIC12(L)F1840 datasheet. [16]

12. Pin layout

The PIC12F1840 has 8 pins, where 6 pins are I/O and the remaining 2 pins are power (V_{DD}) and ground (V_{SS}).

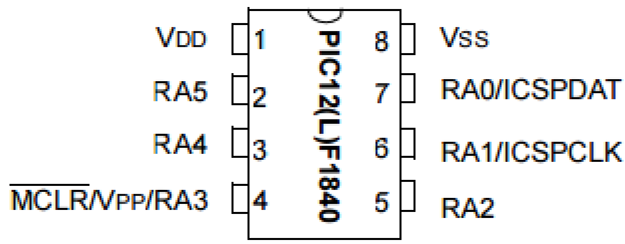

Figure 39: 8-pin diagram for PIC12F1840.

In general, pins 2, 3, 5, 6 and 7 are programmable I/O pins, while pin 4 is input only. This is also a high-voltage input pin capable of receiving a 12 V signal, but this is not a feature used in our application.

Certain features are limited to only a single or few pins, and in some cases two or more features need to share I/O pin. This occurs in our application of this microprocessor, and more details on the process of module switching will be elaborated in the software chapter.

13. Programming the PIC12F1840

When programming the PIC12F1840, the following is required:

Microcontroller with suitable packaging
Computer with programming software + IDE
USB connected ICD (In-circuit debugger)
Pin connection interface

In our case, we used respectively the following:

PIC12F1840 with DIP-packaging (pin-through)
MPLAB X IDE v3.26 (free from Microchip Technology Inc. [17])
MPLAB ICD 3
Suitable breadboard

The code written can be downloaded onto the PIC12F1840 through the ICD, by connecting it to the following pins:

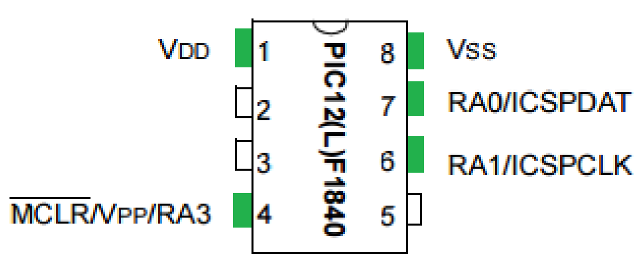

Figure 40: Pins required for programming the PIC12F1840.

An external power source is also required. For this we use 3 x AA batteries connected to the breadboard delivering 4.75 V_{DC}. As mentioned earlier, the PIC12F1840 requires 1.8 – 5.5 V_{DC} to operate.

Software for the PIC12F1840 is written in C, using MPLAB X IDE.

14. Pin- and module configuration

When programming the PIC12F1840, modules can be configured to different I/O pins by setting a number of 8-bit registers. Each module has one or more of these configuration registers associated to it. Features of that module can be enabled, disabled and configured by writing to the register, either as an entire 8-bit byte or each bit individually. Overview of the different register configurations of each module can be found in the associated section in the datasheet [16]. They will also be discussed in this chapter.

15. Interrupts

The PIC12F1840 has the ability to branch off from the regular program execution whenever an interrupt flag is raised. What this means is that whenever an interrupt flag bit is set, the program execution will halt. An interrupt function will be called, which the developer must define in software. The regular program execution will continue whenever the interrupt flags are cleared.

There will only be one interrupt function, and all modules that causes interrupts must share this section of code. By using if-statements and comparing interrupt flag bits, the different interrupts can easily be separated.

16. Clock frequencies

16.1 Internal clock oscillator

The PIC12F1840 has an internal crystal oscillator block and acts as the source for all frequencies derived within then microcontroller. This includes the system clock, as well as a series of modules that require a clock source (i.e. the modulator or AD-converter). The oscillator frequency is controlled by the **OSCCON** control register:

OSCCON:

Bit 7	Bit 6	Bit 5	Bit 4	Bit 3	Bit 2	Bit 1	Bit 0
SPLLEN	IRCF<3:0>				-	SCS<1:0>	

Table 3: OSCCON control bits for the internal oscillator.

The **SPLLEN** bit controls the 4x PPL feature, which is necessary to achieve 32 MHz clock frequency. Our system is not using this feature.

The **IRCF<3:0>** bits control the oscillator frequency.

The **SCS<1:0>** bits controls the system clock source. This can be the internal oscillator block, Timer1 oscillator or a clock determined by **FOSC<2:0>** bits in configuration word 1. Our system is using the internal oscillator block.

Our microcontroller has been configured to operate with a frequency of 8 MHz, by setting the **IRCF<3:0>** bits to 1110.

16.2 Timer0

Our system uses the Timer0 module to create a looping program that executes on timer interrupts. The Timer0 module will keep incrementing the 8-bit **TMR0** register. Whenever this register overflows, the interrupt bit for the timer is set and the register starts over at 0. This feature allows us to easily adjust the frequency of which the program is executed, which is useful for controlling the sampling rate. The timer0 module is enabled by bits in the **OPTION_REG** control register.

OPTION_REG:

Bit 7	Bit 6	Bit 5	Bit 4	Bit 3	Bit 2	Bit 1	Bit 0
$\overline{\text{WPUEN}}$	INTEDG	TMR0CS	TMR0SE	PSA	PS<2:0>		

Table 4: OPTION_REG control bits for the Timer0 module.

The **TMR0CS** bit controls the Timer0 clock source. If set to 1, the timer uses the RA2/T0CKI pin for an external clock source. If cleared to 0, the timer uses the internal instruction cycle clock, F_{OSC}/4 (fourth fraction of the oscillator frequency).

The **TMR0SE** bit controls whether the timer increases on a rising edge or falling edge of the clock. This is only valid for external clock sources, and not the internal instruction cycle clock that our software uses.

The **PSA** bit enables the prescaler of the timer. If set to 1, prescaler is enabled. If cleared to 0, prescaler is disabled and increments happen at the clock frequency provided.

The **PS<2:0>** bits control the prescaler, if enabled. The timer increment rate can be scaled from 1:2 to 1:256. This is useful for slowing down the timer rate.

Another possibility to control the increment rate is to write to the **TMR0** register that holds the 8-bit counter value. For instance, setting this to 00001111 should increase the rate by a factor of 2. However, when this register is written to, the increments will pause for 2 instruction cycles. This must be accounted for if accuracy is important, meaning that a value of 00010001 will correctly double the increment rate. This register must be written every time the interrupt flag is cleared.

17. EUSART module

17.1 Technical specification

The PIC12F1840 has an integrated EUSART protocol (Enhanced Universal Synchronous Asynchronous Receiver Transmitter). Often known only as UART, this is a bit-serial data transfer protocol much used in telegraphy that dates back to 1971 [18].

The EUSART module is configured by 3 control registers:

TXSTA controlling the transmitter (TX).
RCSTA controlling the receiver (RC).
BAUDCON controlling the baud rate at which data is transferred.

For our system only the transmitter is used in asynchronous mode to send data to the data signal modulator (DSM) module. The receiver is not used.

TXSTA:

Bit 7	Bit 6	Bit 5	Bit 4	Bit 3	Bit 2	Bit 1	Bit 0
CSRC	TX9	TXEN	SYNC	SENDB	BRGH	TRMT	TX9D

Table 5: TXSTA control bits of the EUSART module.

Only the bits that are being specifically set in our software will be discussed here. The bits not elaborated are left with their default values. For information on default values, refer to the "Special Function Register Summary" in the PIC12(L)F1840 datasheet, p. 24-33 [16].

The **TXEN** bit controls the state of the transmitter. If set to 1, the transmitter is enabled. If cleared to 0, the transmitter is disabled.

The **SYNC** bit controls the operation mode of the transmitter. If set to 1, synchronous mode is selected. If cleared to 0, asynchronous mode is selected.

RCSTA:

Bit 7	Bit 6	Bit 5	Bit 4	Bit 3	Bit 2	Bit 1	Bit 0
SPEN	RX9	SREN	CREN	ADDEN	FERR	OERR	RX9D

Table 6: RCSTA control bits of the EUSART module.

The **SPEN** bit controls the serial port. If set to 1, the serial port is enabled and RX/DT and TX/CK pins are configured as serial port pins. If cleared to 0, the serial port is disabled and pin configuration released.

The **SREN** bit controls the receiver state. If set to 1, the receiver is enabled. If cleared to 0, the receiver is disabled.

The rest of the bits will not be configured by our software, and will remain in their default state.

For transmitting data, the EUSART module uses the **TXREG** register. This 8-bit register is writeable, and whatever data the software writes here is moved by hardware to the transmit shift register (TSR). From here, the bits are serially read and transmitted to a control buffer and then forwarded to the TX/CK output pin.

BAUDCON:

Bit 7	Bit 6	Bit 5	Bit 4	Bit 3	Bit 2	Bit 1	Bit 0
ABDOVF	RCIDL	-	SCKP	BRG16	-	WUE	ABDEN

Table 7: BAUDCON control bits of the EUSART module.

The **BRG16** controls the baud rate generator mode. If set to 1, the 16-bit baud rate generator is selected. If cleared to 0, the 8-bit baud rate generator is selected.

The **ABDEN** controls the auto-baud detection feature in asynchronous mode. If set to 1, the auto-baud detect is enabled and automatically sets the baud rate. The bit is cleared when auto-baud is completed.

17.2 Asynchronous transmit configuration

For asynchronous transmission, the following bits needs to be set/cleared:

TXEN = 1
SYNC = 0
SPEN = 1

Our software uses the auto-baud feature to detect the baud rate, by setting the **ABDEN** bit of the **BAUDCON** control register.

Data can then be loaded into the **TXREG** register, 8 bits at a time, and transmission starts immediately.

18. Analog to digital converter (ADC)

18.1 Technical specification

The PIC12F1840 has a 4-channel 10-bit analog to digital converter. It uses two 8-bit registers, ADRESH and ADRESL to store the conversion result, where one of the registers holds only the two remaining bits. These can be left-shifted or right-shifted by setting the ADFM bit of the ADCON1 control register. This means that either the two least significant bits are stored in the lower register, or the two most significant bits are stored in the higher register.

The AD-converter requires a reference voltage (V_{REF}) representing the maximum sample value. The analog input signal to be converted must have a voltage value between this V_{REF} and V_{SS} (ground) for the converter to be able to read and store it. The voltage reference can be provided from the V_{DD} input, the V_{REF+} pin or from the fixed voltage reference module providing either 2.048 V or 4.096 V (configured in the FVRCON register). In our system we are using the provided 5 V from the V_{DD} pin as voltage reference. This should compensate for any unforeseen voltage changes, as the entire system is supplied with the same voltage. If a change to this supply occurs, the analog signal will change accordingly and the converted digital value should be unaffected.

18.2 Data sampling

The analog signal can come from 4 input channels, internal temperature indicator, internal digital-to-analog converter or a fixed voltage reference buffer. The analog signal is lead to an integrated sample and hold circuit. The conversion happens relatively fast, and one complete conversion cycles consists of 11 so called T_{AD}-cycles, each with a period of between 1 – 4 µs, depending on the internal clock frequency. Assuming a T_{AD} period of 1 µs gives us a total of 11 µs, plus a 100 ns for capacitor recharge/discharge that must be accounted for. This means one single conversion takes 11,1 µs at minimum.

This gives a theoretical maximum sampling rate of approximately 90 kHz, at either 32, 16, 8 or 4 MHz clock frequencies. In other words, meeting the required 833,33 Hz sampling rate for our system is well within reach.

ADC Clock Period (TAD)		Device Frequency (FOSC)					
ADC Clock Source	ADCS<2:0>	32 MHz	20 MHz	16 MHz	8 MHz	4 MHz	1 MHz
Fosc/2	000	62.5ns[2]	100 ns[2]	125 ns[2]	250 ns[2]	500 ns[2]	2.0 µs
Fosc/4	100	125 ns[2]	200 ns[2]	250 ns[2]	500 ns[2]	1.0 µs	4.0 µs
Fosc/8	001	0.5 µs[2]	400 ns[2]	0.5 µs[2]	1.0 µs	2.0 µs	8.0 µs[3]
Fosc/16	101	800 ns	800 ns	1.0 µs	2.0 µs	4.0 µs	16.0 µs[3]
Fosc/32	010	1.0 µs	1.6 µs	2.0 µs	4.0 µs	8.0 µs[3]	32.0 µs[3]
Fosc/64	110	2.0 µs	3.2 µs	4.0 µs	8.0 µs[3]	16.0 µs[3]	64.0 µs[3]
FRC	x11	1.0-6.0 µs[1,4]	1.0-6.0 µs[1,4]	1.0-6.0 µs[1,4]	1.0-6.0 µs[1,4]	1.0-6.0 µs[1,4]	1.0-6.0 µs[1,4]

Legend: Shaded cells are outside of recommended range.

Note 1: The FRC source has a typical TAD time of 1.6 µs for VDD.

2: These values violate the minimum required TAD time.

3: For faster conversion times, the selection of another clock source is recommended.

4: The ADC clock period (TAD) and total ADC conversion time can be minimized when the ADC clock is derived from the system clock FOSC. However, the FRC clock source must be used when conversions are to be performed with the device in Sleep mode.

Figure 41: ADC clock period (TAD) vs. device operating frequency, with explanatory legend.

The AD converter is able to create an interrupt whenever a conversion cycle completes, meaning a flag bit will be set and the program execution will be interrupted. The interrupt function will be called and executed before returning to regular program execution. This is useful for effectively making sure that the conversion result is handled immediately after a conversion is completed and before a new conversion is started. For more detail on interrupts, refer to the “Interrupts” section.

18.3 Configuring the ADC

The AD converter is configured by two 8-bit control registers, ADCON0 and ADCON1.

ADCON0:

Bit 7	Bit 6	Bit 5	Bit 4	Bit 3	Bit 2	Bit 1	Bit 0
-	CHS<4:0>					GO/ $\overline{\text{DONE}}$	ADON

Table 8: ADCON0 control bits of the ADC module.

The **CHS<4:0>** bits control which channel the analog signal is acquired from. While these 5 bits allows for 32 different values, only 7 of them are implemented resulting in 7 selectable input channels.

The **GO/** $\overline{\textbf{DONE}}$ bit is 0 whenever the AD converter is idle and not in progress. Setting this bit to 1 will immediately start a conversion cycle, and the bit remains set until the cycle is completed. It is then cleared by hardware.

The **ADON** bit is the enable bit of the AD converter module. It is enabled by setting this bit to 1. If this bit is cleared, the AD converter is disabled and consumes no operating current.

ADCON1:

Bit 7	Bit 6	Bit 5	Bit 4	Bit 3	Bit 2	Bit 1	Bit 0
ADFM	ADCS<2:0>			-	-	ADPREF<1:0>	

Table 9: ADCON1 control bits of the ADC module.

The **ADFM** bit controls the conversion result formatting. Setting this bit to 1 will right justify the result, meaning the two most significant bits are stored in the ADRESH register. Setting this bit to 0 will left justify the result, meaning the two least significant bits are stored in the ADRESL register.

The **ADCS<2:0>** bits control the conversion clock frequency. This frequency is either derived from the system clock or provided from a dedicated reference clock oscillator. There are 7 different selectable clock options.

The **ADPREF<1:0>** bits control the voltage reference source configuration. As described earlier, this can either come from the power supply, an external voltage or the fixed voltage reference module.

19. Digital to analog converter (DAC)

19.1 Technical specification

The PIC12F1840 has an integrated 5-bit rail to rail digital to analog converter, able to provide 32 different output voltage levels. It uses a resistor ladder to produce these values, together with positive and negative reference voltages. The negative reference voltage can be selected to either V_{SS} or V_{REF} pin, while the positive reference voltage can be selected to V_{DD}, V_{REF} or a fixed voltage reference buffer (FVR). The DAC can be set in a low-power voltage state when not in use. This is recommended for consuming the least amount of power.

The DAC uses two control registers, DACCON0 and DACCON1, for configuration.

DACCON0:

Bit 7	Bit 6	Bit 5	Bit 4	Bit 3	Bit 2	Bit 1	Bit 0
DACEN	DACLPS	DACOE	-	DACPSS<1:0>		-	DACNSS

Table 10: DACCON0 control bits of the DAC module.

The **DACEN** bit is the enable bit of the DAC. If this is set to 1, the DAC is enabled.

The **DACLPS** bit is the low-power state select bit, and determines which source the DAC clamps to when set in low-power state. If this bit is set, the positive reference voltage is selected and the negative reference voltage is disconnected. If it is cleared, the negative reference voltage is selected and the positive reference voltage is disconnected.

The **DACOE** bit controls the DACOUT pin. If the bit is set to 1, then the output voltage of the DAC is also connected to the DACOUT pin. If the bit is cleared to 0, then the DACOUT pin is released from the DAC output and can be used for other purposes. The DAC output is always available for other modules, regardless of whether this bit is set or not.

The **DACPSS<1:0>** bits control the selection of positive reference voltage for the DAC.

00 = V_{DD}
01 = V_{REF} pin
10 = FVR buffer output

The **DACNSS** bit controls the selection of negative reference voltage for the DAC. If the bit is set to 1, then V_{REF} is selected as negative reference voltage. If the bit is cleared to 0, then the V_{SS} of the microcontroller power supply is set as negative reference voltage.

DACCON1:

Bit 7	Bit 6	Bit 5	Bit 4	Bit 3	Bit 2	Bit 1	Bit 0
-	-	-	DACR<4:0>				

Table 11: DACCON1 control bits of the DAC module.

The **DACR<4:0>** bits control the analog output level of the DAC. These bits actually control a multiplexer connected to the resistor ladder between the positive and negative reference voltages, consisting of 2^5 or 32 selectable resistors.

To set the DAC in a low-power state when not in use, the **DACEN** bit must be cleared to 0. The next step is to select the resistor closest to the clamped reference voltage selected by the **DACLPS** bit. If this bit is set to 1, the **DACR<4:0>** bits should be set to 11111. If it is cleared to 0, then the **DACR<4:0>** bits should be set to 00000.

19.2 Offset calibration

In our analog circuitry, the integrated DAC of the microcontroller is used to provide a custom voltage value to the reference voltage of the AD8237 as an offset correction.

For now, this value is hardcoded in the software. This takes care of any permanent offset error, but a more agile solution to this is necessary to account for drift error.

19.3 Synthesized sine wave and FSK-modulation

Since the data signal modulator module only generates square waves, it is not quite suitable for the purpose of sending a signal through a transformer. The result will only be an AC pulse on the other side of the transformer on each edge rise and fall of the original square signal. A solution to this can be to generate a synthesized sine wave by using the 5-bit DAC module. To reduce processor load, the values of the sine wave have been calculated in advance by using the following function:

(13)

$$f(x) = 15.5 * \sin\frac{2\pi x}{31} + 15.5$$

This gives a sine wave oscillating around 15.5 with amplitudes of 15.5, covering all values in the 0 to 31 range. Since the DAC can only output voltage levels represented by binary values from 00000 to 11111, it is necessary to offset the sine wave with +15.5, and multiply the amplitudes to cover the whole range. The following x-values are then inserted into (1):

(14)

$$x \in \mathbb{N}, [0, 31]$$

In other words, all natural numbers from 0 to 31 is inserted for x. The values this function gives are then rounded to closest whole number.

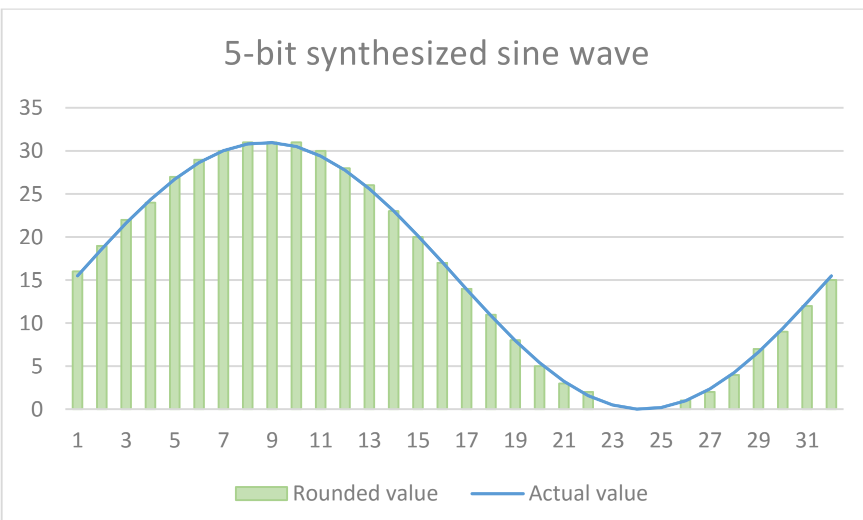

Figure 42: Synthesized sine wave with 5-bit resolution.

Even though 5-bits might seem like a low resolution, the synthesized sine wave is quite satisfying and close to the original wave, relatively speaking. The calculated values are hard coded as an array.

Having a resolution of 5 bits gives 32 different values. This means that a full period of this wave requires at least 32 instruction cycles to complete. In other words, the frequency of this wave can never be greater than 1/32 of the instruction cycle frequency.

The clock frequency of our microcontroller has been set to 8 MHz, which gives a maximum sine wave frequency of

$$f_{sine} = \frac{8\ MHz}{32} = 250\ kHz. \quad (15)$$

However, we must take into account that the interrupt function responsible of generating the sine wave is only triggered every second instruction cycle. This means the maximum frequency of the sine wave is

$$f_{sine} = \frac{1}{2} * \frac{8\ MHz}{32} = 125\ kHz. \quad (16)$$

By adjusting the timer0 counter register, the interrupt function can be set to trigger every fourth instruction cycle, giving a frequency of

$$f_{sine} = \frac{1}{4} * \frac{8\ MHz}{32} = 62.5\ kHz. \quad (17)$$

These two frequencies of 125 kHz and 62.5 kHz will be used to represent 1-bits and 0-bits, giving a theoretical bitrate of 125 kb/s through the rotary transformer [19]. This is the FSK (frequency shift keying) modulation, where a bit-serial signal is represented by analog sine waves.

20. Pin budget

The PIC12F1840 is limited to 6 I/O pins, where one pin is input only. Some modules are also limited to only one pin, and this means some features need to share pins by switching modules in software.

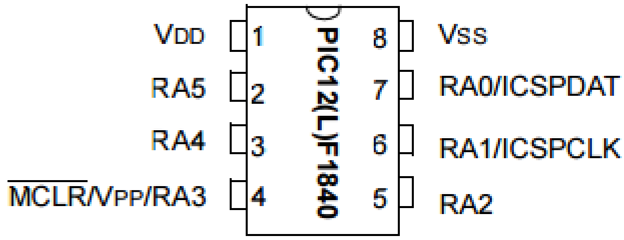

Figure 43: 8-pin diagram for PIC12F1840.

For instance, the DAC is limited to the DACOUT pin. This is pin 7/RA0, as specified in the datasheet. The DSM module is also limited to this pin only, so if both the DAC and the DSM were to be used, they would have to take turns on using the output pin. Our software takes this issue into account, and switches modules as needed to deliver the functionality required to fulfil the system.

In our final build system, it is envisioned that the functionality is distributed on the pins as the following:

Pin	Input/output	Function
RA0	Out	DAC
RA1	Out	DEMUX select bit
RA2		
RA3	In	AD-converter: Strain gauge bridge 1
RA4	In	AD-converter: Strain gauge bridge 2
RA5		

Table 12: Pin budget table.

The DAC output from the **RA0** pin will be sent to a 1:2 demultiplexer, where channel 1 connects to the signal transformer and channel 2 connects to the feedback circuitry of the AD8237 amplifier. The **RA1** pin controls the switching between these channels. This is necessary as the DAC only operates on the **RA0** pin.

21. Software

This section will aim to sequentially explain the source code of the PIC12F1840. It is intended that you read this while looking at the code. Please refer to appendix B for the full source code for our microcontroller unit.

21.1 Sequential explanation of the source code

Firstly, the header file "main_header.h" declares functions and variables used in the code in "main.c". This is standard C code syntax. In addition to declarations, various configuration words configure the microcontroller. This code is generated automatically by the MPLAB X IDE.

The main()-function starts with configuring the internal oscillator, the 8-bit timer, interrupts, DA-converter and AD-converter. I/O-pins are also configured. The code up to this point is only executed once at system start.

Next, the while-loop running the program starts. The demux select pin is raised high, selecting channel 1. This connects the DAC output to the analog circuitry. It is important to switch to this channel before setting the DAC output value, to avoid sending any unwanted voltage to the rotary transformer. The AD conversion cycle is then started, by calling the ADC()-function. What this function does is to enable the AD-converter and start the conversion cycle. An empty loop is set to run as long as the conversion cycle is running. Immediately after the conversion is complete, the results are stored and the AD converter is disabled to reduce power consumption. The ADC()-function call is now complete.

The next step is to disable the DAC to stop the DAC output voltage before switching to channel 0 of the demux. Again, this is to avoid sending unwanted voltage to the rotary transformer. The timer0 interrupts are enabled and a for-loop is then executed, where the idea is to iterate through the bits of the AD-conversion result. Bits are then masked out and individually passed as a parameter to the sine_output()-function.

The sine_output()-function sets the timer_scaleup bits depending on the databit that was passed as an argument. The DAC is then enabled.

At the same time, the timer0-interrupts will start to occur as the interrupt bit was enabled earlier. The interrupt-function is then called, the DAC output is updated by iterating through the sine-array, generating a synthesized sine wave. The **TMR0** register is updated with the value of timer_scaleup. This is to alter the rate of which timer-interrupts occur, thus controlling the frequency of the sine wave.

The for-loop will execute until all 10 bits of the conversion result has been passed. A delay of 1 ms is added, to let the sine wave oscillate for a short period of time. When completed, the timer-interrupts are disabled and the while-loop starts over.

Rotary transformer

The rotary transformer is essentially the same as a conventional transformer, except that the geometry is arranged so that the primary or secondary can be rotated, with respect to each other with negligible changes in the electrical characteristics. This makes it possible to transmit a signal wirelessly from the primary to the secondary side of the transformer even when one side is in rotation, this by using the magnetic field produced from the primary coil when applied a current upon.
As with any transformer, an AC current is required to power the system.

For our proof of concept we have chosen to go with the flat plane rotary transformer, shown in figure 24. The power transfer is accomplished, electro-magnetically, across an air gap. There are no wearing contacts, noise, or contamination problems due to lubrication or wear debris.

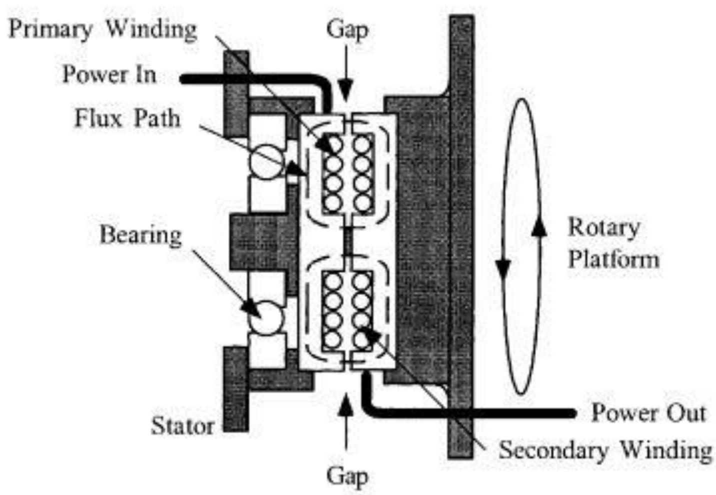

Figure 44: Flat Plane Rotary Transformer. [20]

To design a converter transformer to have a minimum of leakage inductance, the primary and secondary must have a minimum of distance between them

The rotary transformer has an inherent gap and spacing of the primary and secondary. The gap and spacing in the rotary transformer result in a low primary magnetizing inductance. This low primary inductance leads to a high magnetizing current. The leakage inductance, L_p can be calculated for flat plane using Equation. [20]

(18)

$$L_p = \frac{4\pi(MLT)N_p^2}{a}(c + \frac{b_1+b_2}{3})(10^{-9}) \text{ , [henrys]}$$

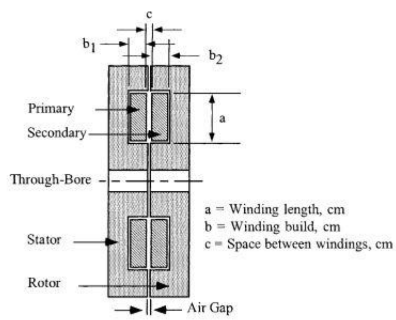

Figure 45: Flat Plane Rotary Transformer, Winding Dimensions [20]

For further improvement of transmission efficiency, which means high coupling coefficient, consists in how much amount of the AC magnetic flux due to the AC current impressed on the primary coil is made to interlink with the secondary coil. [21]

22. Transformer Construction

We chose to implement the rotary transformer with the generator in the same construction. By doing this, we had to take to consideration that the carrier signal from the MCU would have to be moved out of the frequency spectre of the generator. This to be able to read the bending data signal without noise generated from the generator coils on the same frequency as the carrier signal.

The coil that is driven by an electrical source is called the primary and the other is called the secondary. The ratio of the number of turns on the primary to the number of turns on the secondary is called the turns ratio. Since essentially the same voltage is induced in each turn of each winding, the primary to secondary voltage ratio is the same as the turns ratio. [4]
For example, for our case with 20 turns on the primary and 40 turns on the secondary, the turns ratio is 1:2. Therefore, if 2 volts were applied to the primary, 4 volts would appear at the secondary.
This kind of transformer is called a step-up transformer, since its secondary voltage would be twice that of the primary.

A transformer with a 1:2 turns ratio exhibits a impedance ratio of 1:4. Transformers always reflect impedances from one winding to another by the square of the their turns ratio or, expressed as a formula:

$$\frac{Z_p}{Z_s} = (\frac{N_p}{N_s})$$

Where Z_p is primary impedance, Z_s is secondary impedance, and $\frac{N_p}{N_s}$ is turns ratio (which is the same as the voltage ratio). [4]

We chose not to use ferrite cores, because the magnetic field produced by the transformer primary coil when applied the signal, was great enough to transfer a signal. This would also overcomplicate the construction regarding balance and size. Which would not satisfy requirement: **SRS-08** & **SRS-09**

It is anticipated that instantaneous transmission of electric signal by means of rotary transformer to the external dummy system is subject to the following restraints.

Gap distance between Rotary transformer coils: Gap distance between transformer coils should desirably be in the order of mm, taking the assembling accuracy and vibration during System in use. [21]

Transformer diameter: Structurally, the transformer diameter has to be larger than that of shaft.

22.1 Noise

Electrical noise is always present, and affects performance (signal-to-noise-ratio) in two areas:

Magnetic susceptibility and E-Field induced noise.

Conducted noise (Cable induced).

Magnetic susceptibility begins once the gap between transformers coils increases. The larger the gap the more the magnetic flux leakage increase, this reduces the transformers efficiency. This allows E-field noise to enter the transformer coil set.

Conducted noise, is typically induced via the instrument cable. A fully differential transformer is most suitable to maximize the signal to noise ratio. Transformer coils that are center tapped (tied to ground), to establish a zero reference on the signal side of the transformer, can compromise the noise rejection. [22]

For further development, it would be possible to add a ferrite core to the rotary transformer to expand the magnetic field, thus this can aggravate the problem of electrical field noise. Because any magnetic susceptible metal contacting the ferrite core set, aggravates and increases the magnetic flux leakage. Could also be possible to convert the transformer to a fully differential transformer, for maximum noise rejection.

22.2 Signal Amplification

The amplifier that amplifies the signal before the rotary transformer should have a low output impedance. While the load for the rotary transformer should be 10 times greater or more, than the output impedance of the amplifier before the transformer.

The amplifier after the rotary transformer should have a high input impedance.

The rotary transformer should have a galvanic isolation between the primary- and secondary-side of the rotary transformer. This means that both the primary and secondary-side cannot be grounded at the same ground point.

We chose to make the transformer a step-up transformer (1:2 ratio), this because of the low voltage bending signal we get out from the MCU. To be able to more easily see the change when applied a force of bending on the strain gauges. The signal from the strain gauges will have a change that it is so minimal, that a step up transformer would help to get more accurate measures of bending.

The 2 ± 2 V analog bending data signal will be transferred from the MCU thru the rotary transformer with a 1:2 ratio. Which will be translated into a digital representation of 8-bits, meaning a varying value between 0 and 255 is to be expected.

PCB Design

Strain gauges are commonly used to monitor and measure the metallic surface deformation. These resistive sensors are used to measure and test the deformation of structure made out of metal materials. One of the most challenging problems in monitoring the deformation of materials is developing the required signal conditioning circuit and the software codes needed to interface the resistive sensors to the digital data analyzing systems. This document describes the development of Wheatstone bridge signal conditioning Printed Circuit Board (PCB).

23. Schematic Creation

The system can be divided into five subsystems namely: Power suppling module, Analog signal conditioning, Microcontroller, multiplexer and connectors. This chapter describes the development of the schematic of the signal conditioning Printed Circuit Board (PCB).

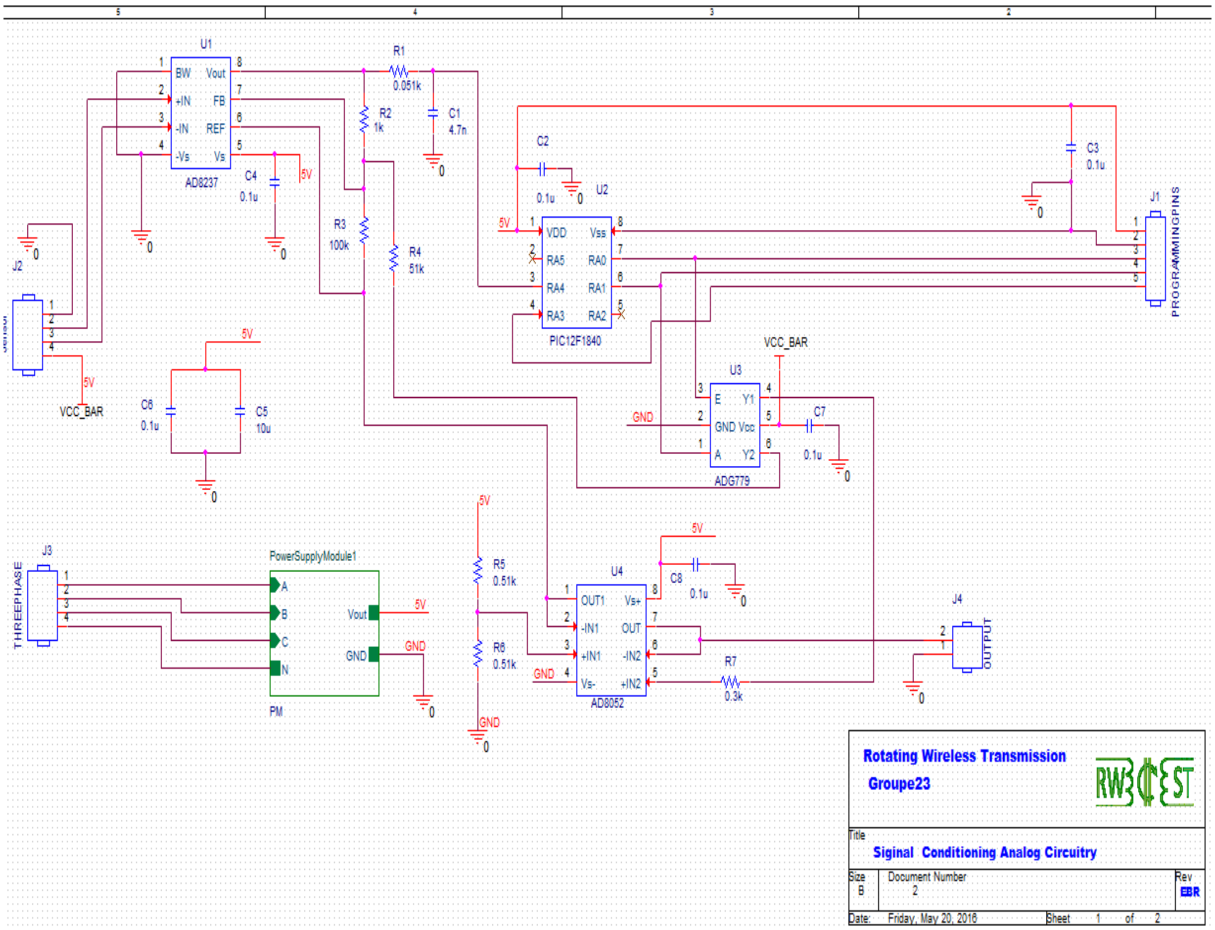

Figure 46: Complete schematic

24. The Power-supplying module

Firstly, our Wheatstone bridge sensory system will need to be powered up with an excitation power. The system will need a constant and regulated power supply to provide power to all the components. Our PCB system consist of different Integrated Circuit components(IC), which can only operate on constant and regulated power supply.

We have decided to use a common power supply for all the -active components of our system. We developed a power-supplying module capable of supplying the needed voltage to all the devices used in our system. One of our system requirement is to supply a constant and regulated voltage within range of 7Volts, while supplying sufficient current. We want to have an ideal power supply, which maintains the same voltage for possibly varying current draw.

Varying current may result in our PCB may result from a change in current associated with noise coursed by one of the devises. A change in current due to noise in one device, affects all the other devices attached to the same power with the noise producing devise. This means that a change in current draw affects the whole voltage power network.

We decided to avoid such scenario happening to our PCB by using a voltage regulator of type LM7805 that maintains the voltage within the required voltage range while supplying enough current to all the devices of the system. The figure 2.2 shows the schematic drawing of the power-supplying module. The power-supplying module is connected to linear regulator LM7805 as suggested by datasheet.

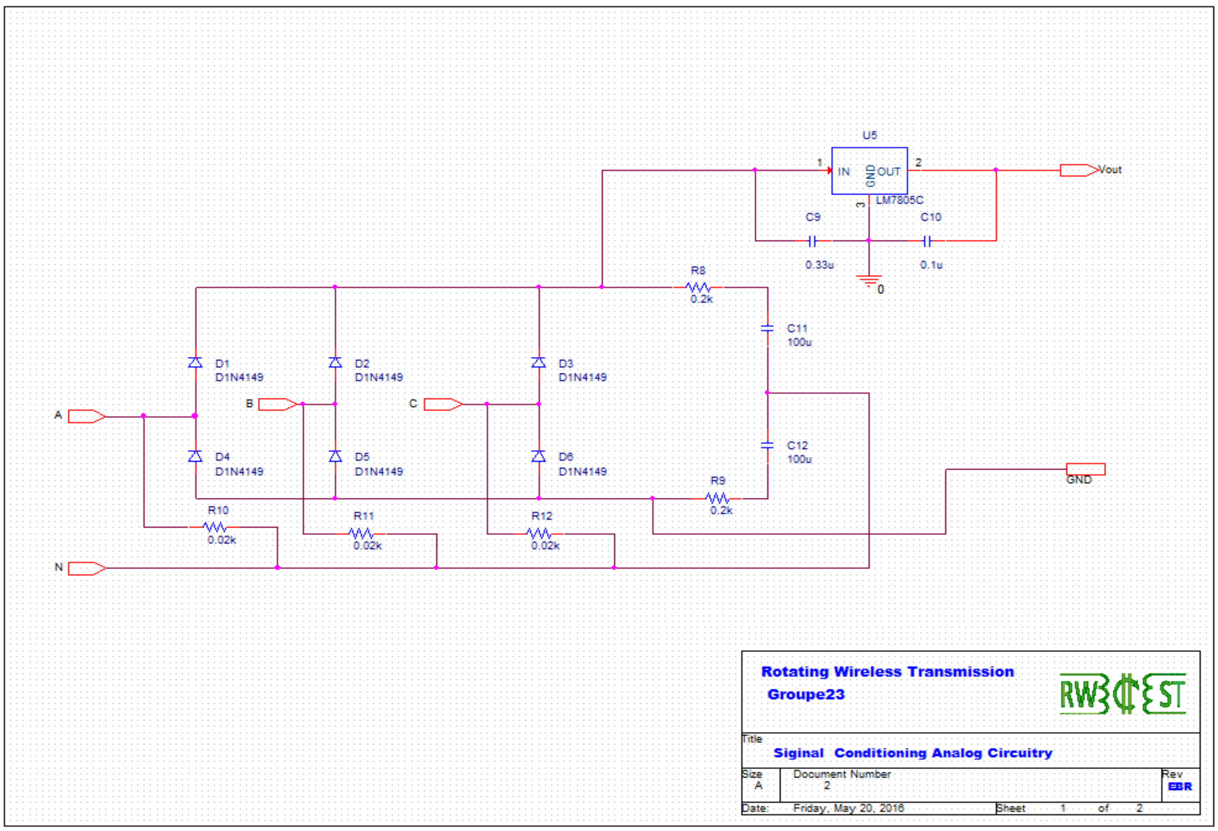

Figure 47: Power Supply Module (PSM) Schematic

25. Decoupling and Bypassing Capacitors

Usually components whose output change from one state to another generate transient current. When the transient current is drawn directly from the power supply, transient voltage is created because of power source's impedance. Transient voltage can be also created as result of material inductance associated PCB traces and wires

Transient current is likely to cause serious problems to components meant to drive high capacitance or low resistance loads. Law resistance transient currents, while high capacitance loads can lead to extremely oscillation in the power line. Oscillation in the power line can lead to the failure of the PCB performance.

The transient current problems can be resolved by bypass capacitors. Capacitors are widely used for this purpose because they have abilities to store charge, which may be necessarily supplied to Integrated Circuits (ICs) with low resistance and inductance. This means that the transient current can be drawn from the bypassing capacitor instead from the power line.

We bypassed our PCB system by connecting a 0.1µF ceramic capacitor closer to every power pin of every integrated circuits (IC). The capacitor is connected to the ground (GND) pin thereafter. The 0.1µF ceramic capacitor are meant to oppose voltage transition in the power line of our PCB by charging and disc arching. The figures below show some of our IC components are bypassed [23].

26. The Voltage Regulator LM7805

The voltage regulator operates by delivering the appropriate output voltage to the components such as micro controller, Op Amps etc. This series of fixed-voltage integrated-circuit voltage regulators is designed for a wide range of applications. These applications include on-card regulation for elimination of noise and distribution problems associated with single-point regulation [24].

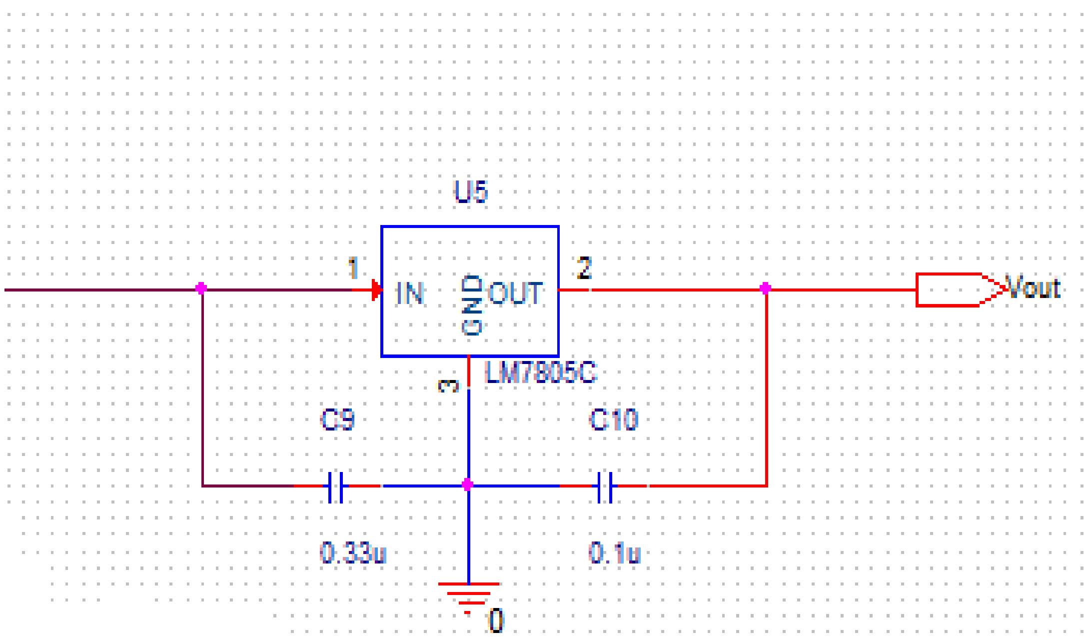

Figure 48: LM7805 Voltage Regulator

The regulator is bypassed by two ceramic capacitors. The first capacitor C9, the 0.330.33uF ceramic capacitor is connected up after the voltage source input of the LM7805 regulator. The bypassing capacitor is there to filter out any noise coming from the voltage source. The capacitor bypasses the LM7805 by shorting the AC signal of the voltage to ground (GND).Only the DC signal goes into the LM7805 regulator *[25]*.

Pin Number	Pin Name	Function Descriptions
1	INPUT	For Input Voltage
2	COMMON	Connected Ground (0 V) Reference.
3	OUTPUT	For the Output voltage

Table 13: Voltage Regulator LM7805 Pin Description

The second capacitor C10 is 0.1Uf ceramic capacitor, which is connected after the voltage regulator. The C10 is there to filter high frequency noise signals that may be on the DC voltage line. Both capacitors are needed to bypass the LM7805 regulator and avoid the transient current that may lead to the failure of our PCB layout [23].

27. The Analog Signal Conditioning System

The analog signal conditioning system consists of bridge amplification system, differential amplifier, low pass filters and a connection to DAC. This subsystem is connected to the Wheatstone bridge sensory system though a four pin connector header as shown by figure 5. Two inputs pins are on this header for the two signals from the Wheatstone bridge of the strain gauge. The inputs pins are numbered 2 and 3, while the pin number 1 is connected to the ground and pin number 4 is meant to supply the sensory bridge with 5Volts excitation power.

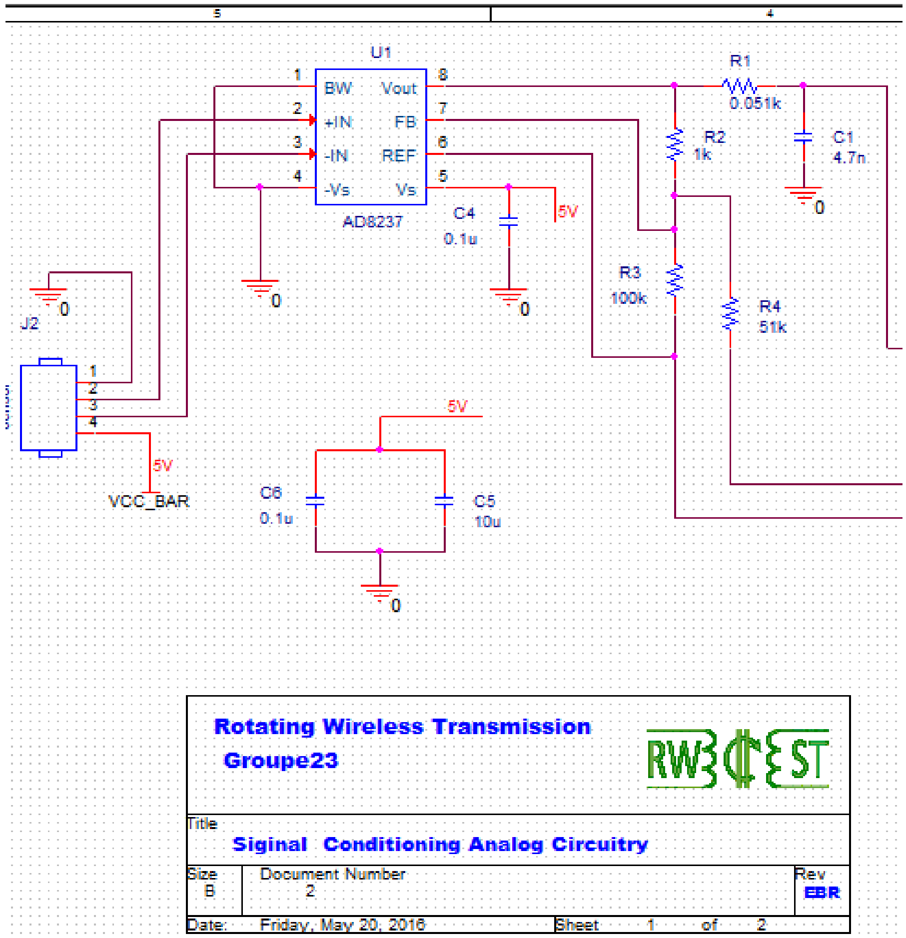

Figure 49: Analog Signal Conditioning System

28. Bridge amplification system

The signals generated by the sensory Wheatstone bridge, usually have weak amplitudes. For the signal to be process accurately, and for the system to be more robust to the effect noise, the signal needs to be amplified. Additionally the signal has to be as free of noise as possible. This makes it very necessary to use bridge amplification system.

The bridge amplification system of our PCB design consists of an instrumentation amplifier (AD8237), a differential amplifier (AD8052) and a number of loop resisters and capacitors. The instrumentational amplifier AD8052 is a special class of closed-loop amplifier with differential inputs, accurate and stable gain, between 1 and 1000, extremely high input impedance and extremely low output impedance. Moreover, the AD8052 has extremely high common mode rejection ratio (CMRR).

The AD8237 is a micro power, zero drift, rail-to-rail input and output instrumentation amplifier. The relative match of two resistors sets any gain from 1 to 1000. The AD8237 has excellent gain accuracy performance that can be preserved at any gain with two ratio-matched resistors. The characteristics of AD8052 make it suitable for using in our Signal conditioning printed circuit board PCB. Figure 6 shows how the AD8237 is configured on our PCB.

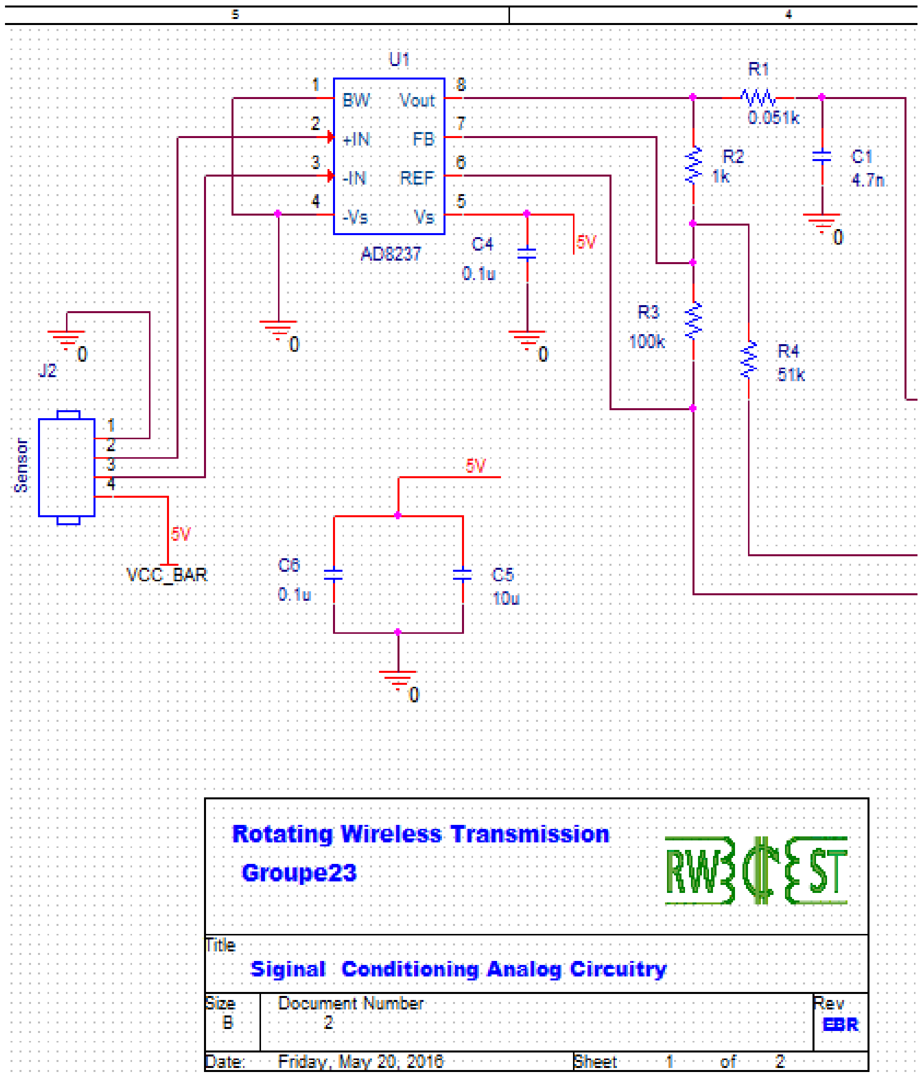

Figure 50: Instrumentational Amplifier AD8237

29. The Pin Function Descriptions for AD8237

The eight inputs and output pins are BW, +IN, −IN, −VS, +VS, REF, FB and VOUT. The + IN represents, the voltage signal entering the amplifier's non-inverting input from Wheatstone bridge, whereas –IN corresponds to the voltage signal through the inverting input of the amplifier [26]. The +VS represents the 5 Volts biasing voltage, while the −VS represents the ground GND. The table below table 4.1 give a detailed Pin Function Descriptions for the instrumentational amplifier.

Pin Number	Pin Name	Function Descriptions
1	BW	For high bandwidth mode, connect this pin to +VS, or for low bandwidth mode, connect this pin to −VS. Do not leave this pin floating.
2	+IN	Positive Input.
3	−IN	Negative Input.
4	−VS	Negative Supply
5	+VS	Positive Supply
6	REF	Reference Input
7	FB	Feedback Input
8	VOUT	Output.

Table 14: Pin Function description For AD8237.

30. The RC Low- pass filtering

To reduce the noise, harmonic distortion and high frequency disturbances, a first order RC low-pass filter was placed at the output of the instrumentational amplifier AD8237. This RC low pass-filter is meant to provide an attenuation of 3 dB per decade.

The information needed for our system lies between 0 and 10kHz, we therefore need to terminate everything above the frequency of 10 kHz. We have decided to use a first order RC low pass filters to filter out disturbance signals with the frequency above the maximum frequency. The used low pass filter has a cut-off frequency of 12.5 kHz.

The chosen cut-off frequency of the low-pass filter is higher than the maximum frequency, because we want to preserve the information with the frequency of 10 kHz. Figure 7 shows the low pass filter simulation in P spice capture.

31. Microcontroller PIC12F1840

In addition to filtering and amplification, the need to convert the signal into digital form using an Analog-to-Digital Converter, or ADC, adds some more signal conditioning needs. Besides amplifying the signal, the signal might also need to be translated to suit different ADC voltage references.

In addition, many ADCs, especially those contained inside an MCU or DSC, only operate on unipolar inputs; that is, the input voltage cannot alternate between positive and negative levels with respect to the Ground. In such cases, a Level Shifter is required. We chose to solve the above-mentioned problems using software. The software were done using the PIC12F1840. The figure (figure 8) below shows how the PIC12F1840 Microcontroller is implemented on our PCB.

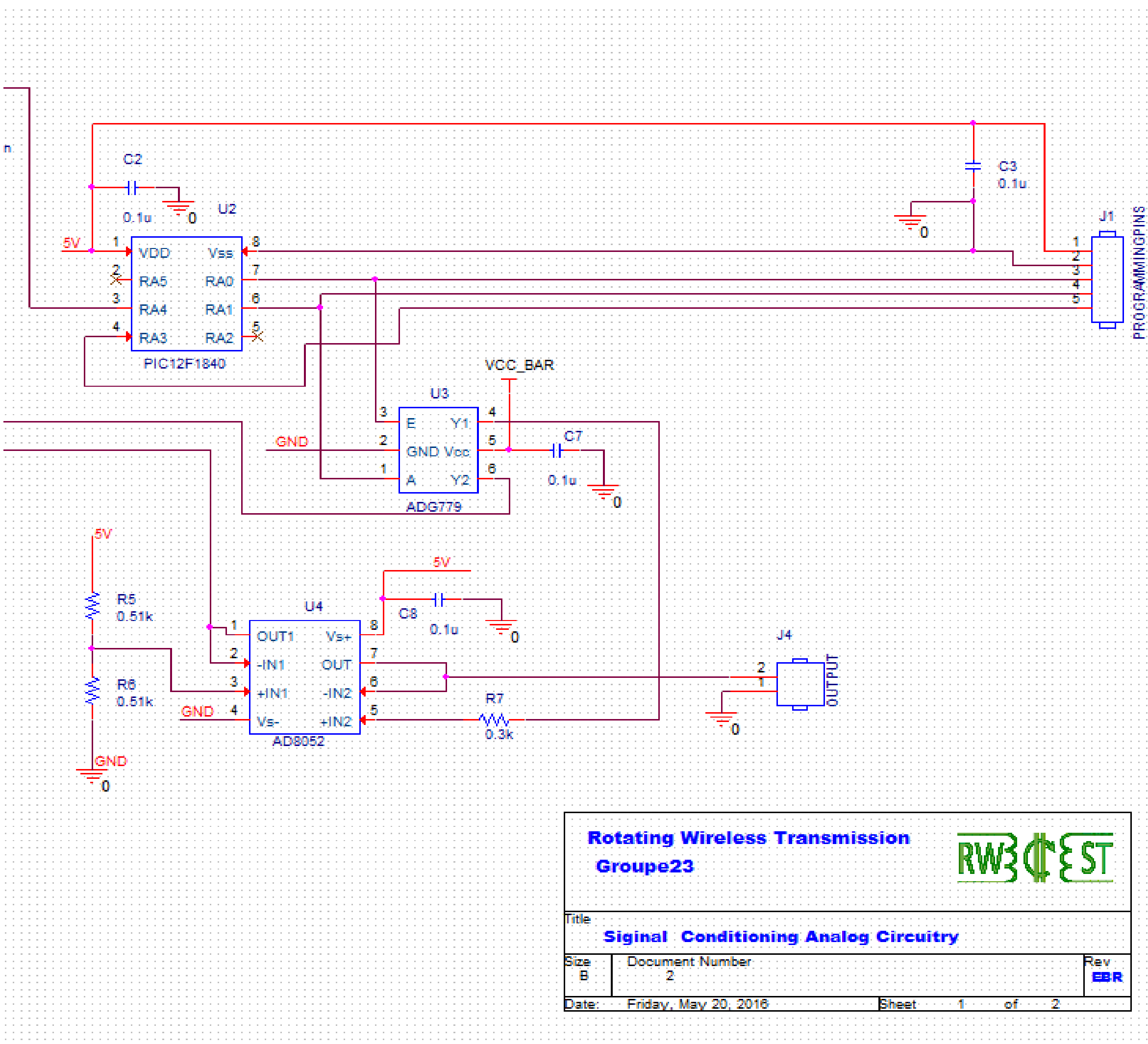

Figure 51: Microcontroller PIC12F1840

The ADC sampling is controlled by the microcontroller and the sampled data is processed internally in the microcontroller. The data is then modulated and transferred to a multiplexer before being transmitted through a two pins header. The table below shows the pin configuration of the PIC12F1840 Microcontroller [27].

Pin No	Pin Name	Function Descriptions
1	VDD,	Positive 5 Volts Power Supply
2	RA5	Interrupt, SR Latch, Timers, EUSART, Pull-up and Basic
3	RA4	A/D, Cap Sense, Comparator, Timers, ECCP, EUSART, Interrupt and Modulator
4	RA3	Timers, MSSP, Interrupt, Pull-up and Basic
5	RA2	A/D,SR Latch, Cap Sense, Comparator, Interrupt, Modulator and Pull-up
6	RA1	A/D, VREF, Comparator, SR Latch, Cap Sense, Interrupt and Modulator
7	RA0	A/D, VREF, Cap Sense ,Comparator, EUSART, Interrupt ,Modulator and Basic
8	VSS	Ground GND

Table 15: Pin Function for the PIC12F1840 Microcontroller.

32. Connection and Interfaces

A four pins header provides connectivity between the PCB system and the outer power Supplying system. The header provides the system with voltage power from an inductive power system. The header has four pins connected as shown by the figure below [28].

A four pins header shown by the figure below provides the connectivity between Wheatstone bridge sensory system and the PCB. One of the pin is meant to provide the needed 5Volts excitation power to the sensory system. The table below shows the pin configuration of the connector [28].

The programming header is a 5pins connector providing a way to program the microcontroller. The programming connector is a straight plug socked for card to card or cable to card connections. The header uses Stiftlister 1x5P, 4030-05A-102/2203-2051, Molex from: elfadistrelec. The table below shows the pin configuration for the programming header [28].

Pin Number for Connector	**Pin Number Pic12F1840**	**Pin Name Pic12F1840**
1(+5V)	1	VDD
2(GND)	8	VSS
3	7	RA0
4	6	RA1
5	4	RA3

Table 16: Pin Configuration for Programming Header

33. The Multiplexer ADG779.

The ADG779 Demultplexer operates from a single supply range of 1.8 V to 5.5 V. The component's Pin Function Descriptions table is shown below. The component uses an SMD footprint and is connected to both the ground, bypassing capacitor and the 5Volts power supply [29].

The ADG779 is a monolithic CMOS SPDT (single-pole, double-throw) switch. This switch is designed on a submicron process that provides low power dissipation yet gives high switching speed, low on resistance, and low leakage currents.

The ADG779 operates from a single supply range of 1.8 V to 5.5 V, making it ideal for use in battery-powered instruments and with the new generation of DACs and ADCs from Analog Devices, Inc. Each switch of the ADG779 conducts equally well in both directions when on. The ADG779 exhibits break-before-make switching action [29].

Pin Number	Pin Name	Function Descriptions
1	IN	Logic Control Input.
2	VDD	Most Positive Power Supply Potential.
3	GND	Ground (0 V) Reference.
4	S1	Source Terminal. Can be an input or an output
5	D	Drain Terminal. Can be an input or an output
6	S2	Source Terminal. Can be an input or an output.

Table 17: Pin Configuration for ADG779

During the final programming of our PIC12F1840 microcontroller, we found out that the demultplexer used was not functioning as expected. We therefore decided to replace the ADG779 with NLAS1053-D. The NLAS1053 is an advanced CMOS analog switch fabricated with silicon gate CMOS technology. It achieves very high speed propagation delays and low ON resistances while maintaining CMOS low power dissipation.

The device consists of a single 2:1 Mux/Demux (SPDT), similar to ON Semiconductor's NLAS4053 analog and digital voltages that may vary across the full power supply range (from VCC to GND). The inhibit and select input pins have over voltage protection that allows voltages above VCC up to 7.0 V to be present without damage or disruption of operation of the part, regardless of the operating voltage [30].

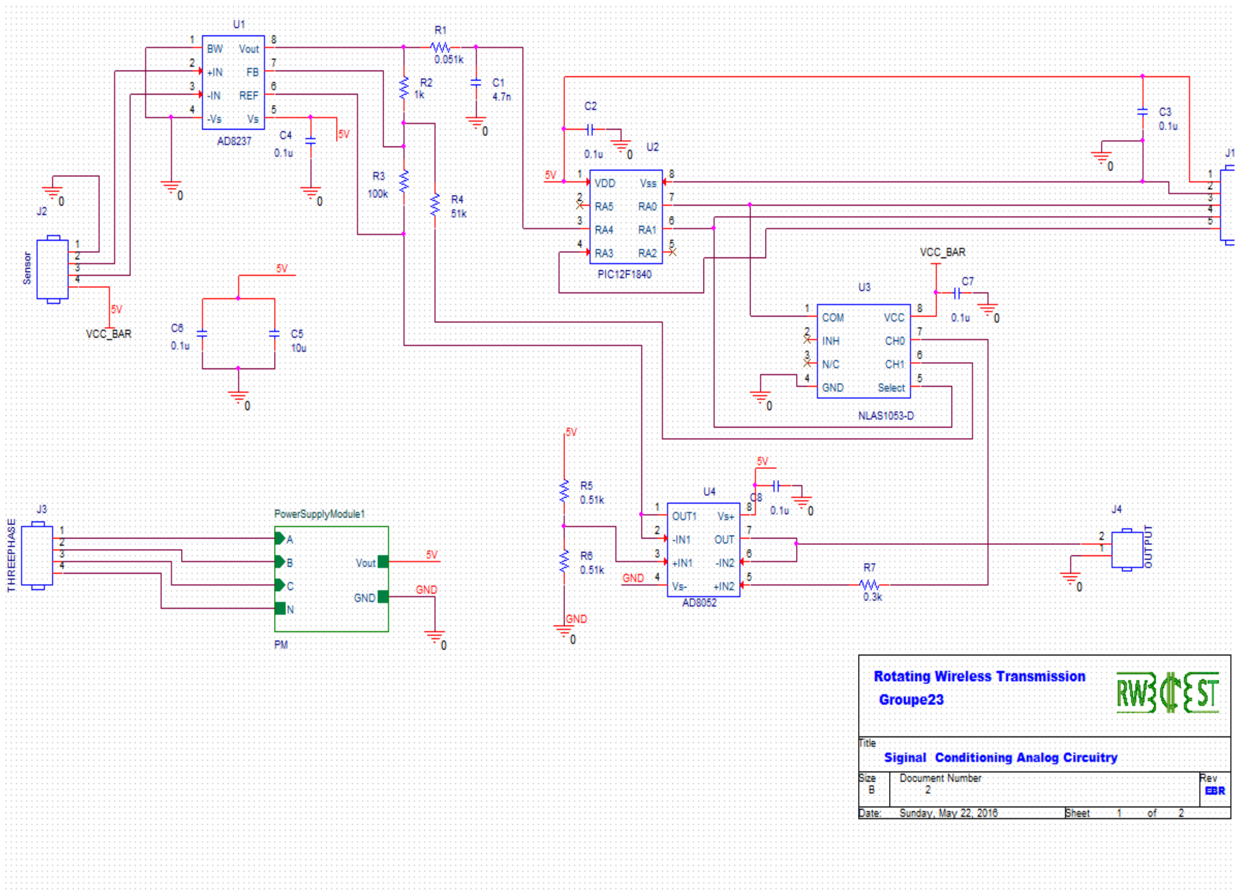

Table 18: Complete Schematic with NLAS1053-D

34. The Differential Amplifier AD8052.

The Ad8052 provides the two differential amplifiers needed for drift offset and modulated signal amplification. The AD8051 (single), AD8052 (dual), and AD8054 (quad) are low cost, high speed, voltage feedback amplifiers. The amplifiers operate on +3 V, +5 V, or ±5 V supplies at low supply current [31].

They have true single-supply capability with an input voltage range extending 200 mV below the negative rail and within 1 V of the positive rail. Despite their low cost, the AD8051/AD8052/AD8054 provide excellent overall performance and versatility. The output voltage swings to within 25 mV of each rail, providing maximum output dynamic range with excellent overdrive recovery [32].

Pin Number	Pin Name	Function Descriptions
1	OUT1	The Output Siginal1
2	–IN1	The Negative Imput1
3	+IN1	The Postive Input.
4	OUT	Negative Supply
5	–IN2	The Negative Feedback
	+IN2	Iput2, From The Multiplexer
7	+VS	The Output Siginal2
8	–VS	GND

Table 19: Configuration for AD8052

35. The Printed Circuit Board PCB

The process of designing the printed circuit board for the strain gauge Wheatstone bridge, involved several steps. The PCB was created using OrCAD Capture and PCB Editor. The OrCAD Capture is schematic editor tool, while the OrCAD PCB Editor is used to edit footprints and the Printed Circuit Board [33].

The process of designing the PCB of the resistive sensor Analog Circuitry using OrCAD software are: designing the schematic, designing the footprints of each component, dimensioning of the board, importing the schematic to PCB Editor, placing the components on the board, routing all the traces and generate Gerber and NC drill files [33].

36. Manufacturing Footprints

Each component used in strain gauge analogy circuitry mast have a footprint design. The dimensions for a given footprint are specified in the components datasheet [33]. Some footprints are standard, which means that they are already designed and present in PCB Editor Library.

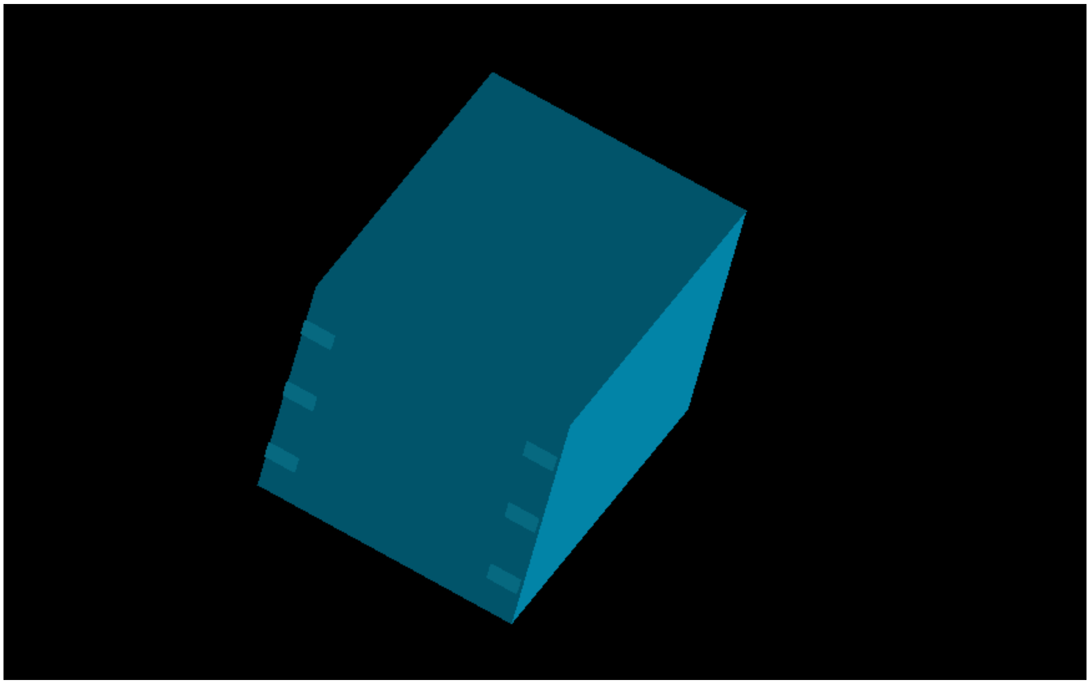

Figure 52: Footprint of ADG779.

We had to design most of our footprints, apart from footprints for Diodes, resistors and capacitors that are standard. We created a number of the needed footprints manually and assigned them to their corresponding components. Figures below figures below display some created footprints [33].

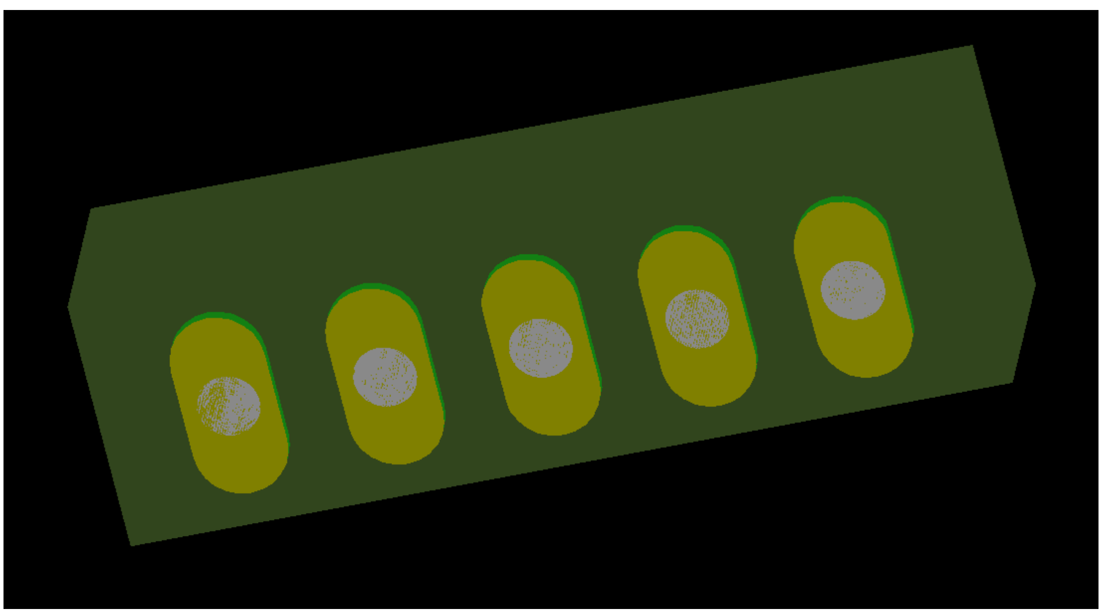

Figure 53: Footprint of 5-Pins Programming Header

The standard size resisters, capacitors and diodes uses the 1206 packages [34]. Most of the other components use SMD type of footprints, except for the connectors and headers that pin-through-hole components. The AD8052 provides the two differential amplifiers needed for drift offset and modulated signal amplification.

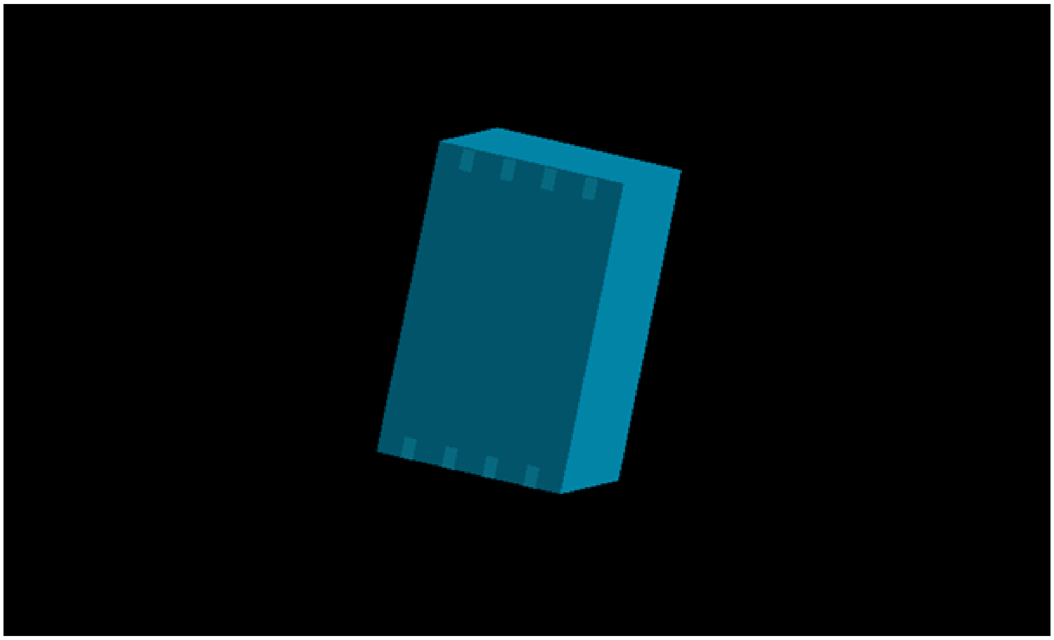

Figure 54: Footprint of AD8052

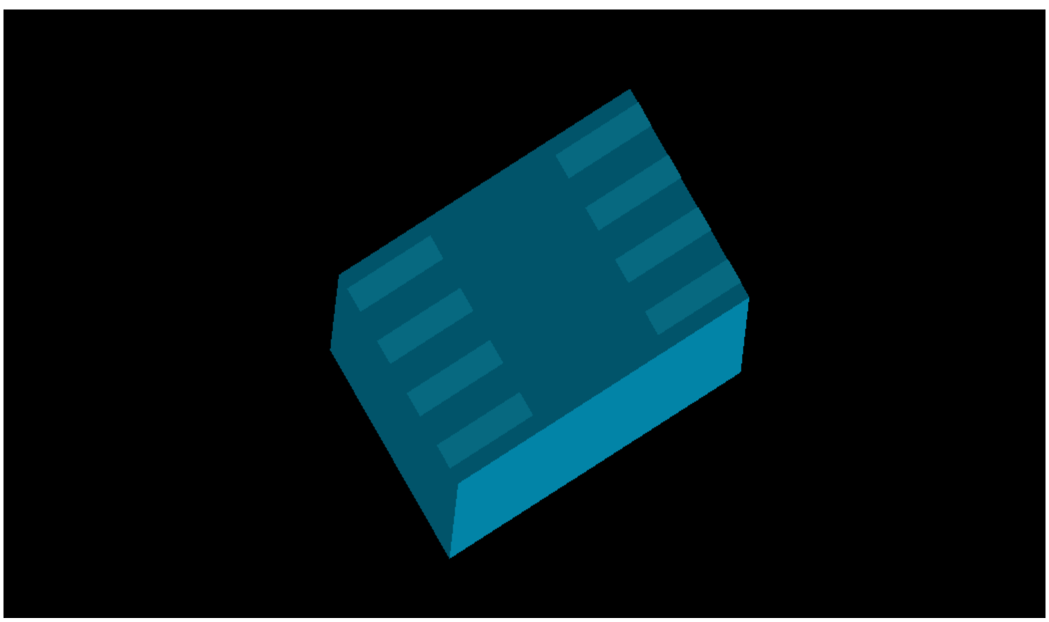

Figure 55: Footprint of ADG779

37. Board Dimensioning

The Printed Circuit Board for the Stain Gauge Analog Circuitry will be mounted on top of the rotor of a model helicopter. To be able to easily balance the PCB on the system we decided to create a quadratic circuit board. The dimensions of the outlines of the circuit are 6x6 centimeters and the PCB has two routing layers [35].

All the restrictions, such as maximum dimensions, rout keeping spacing, via and pad keeping spacing were defined before the board was created. There was no height restrictions on the board and the locations of components were chosen to facilitate the routing of the board. The PCB need to be mounted inside a piece of equipment at the top of the rotor system of a helicopter.

This makes it necessary to have mounting holes on the PCB for fixings. We placed four mounting holes of type MTG156 near each corner of the PCB. The MTG156 are holes of diameter 156 mils or 3.96 millimeters [33]. The below is image of the PCB layout created to perform signal conditioning. The figure below shows the bareboard of our PCB.

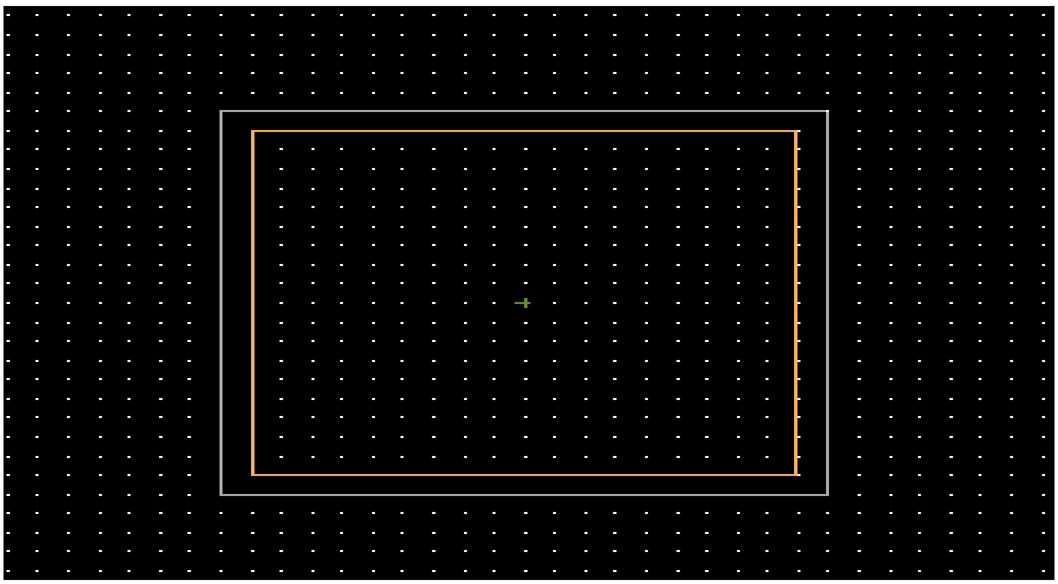

Figure 56: Bare Board

The above image shows the bare board of our PCB Design. The dimension of the board's outline are 5.5x5.5 inches. The board has two routing layers, but our plan was to signal routing tracks and components on the top layer. The ground will necessarily occupy the bottom layer to reduce noise and disturbances of the components. This is also done to increase the flexibility and make it easier to route the board.

38. Creating a Netlist

The information about your design is sent from Capture to PCB Editor in the form of a netlist, which contains a description of the circuit and its components. Creating netlist is a way of importing the schematic drawn in capture to the PCB editor [33].

After we were done with making all the needed Footprints, we defined board dimensions and made sure that we have a complete and errorless schematic. From here, we proceeded to the next stage of designing the PCB of Stain Gauge Analog Circuitry. This stage involves importing schematic design from the schematic editor to the PCB Editor (Allegro).

We double-checked that each of our components in our design had the correct footprint, by inspecting each component and the corresponding footprint. We then performed annotation of all the symbols and proceeded creating netlist [35]. The design we belt and the footprint window is shown in figure.

39. Placing and arranging the Components.

This a stage where the just imported components can be placed on the board. There a number of restrictions regarding placing parts on the board. The factors needing special considerations are electrical functions, temperature characteristics, minimum spacing and route ability of the part to be placed on the board [35].

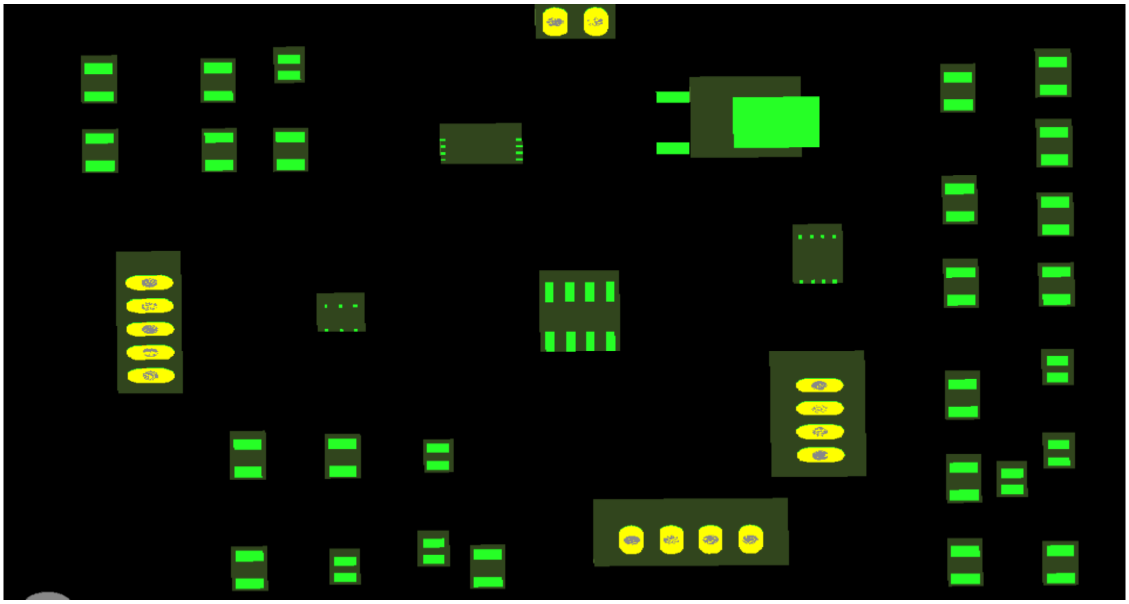

Figure 57: Placed Components without Rats nest.

We started by placing the terminal connectors respectively on the board. The remaining components were placed according to their route ability and as to reduce the amount of vias and trace length. The figure below show the components placed on the board.

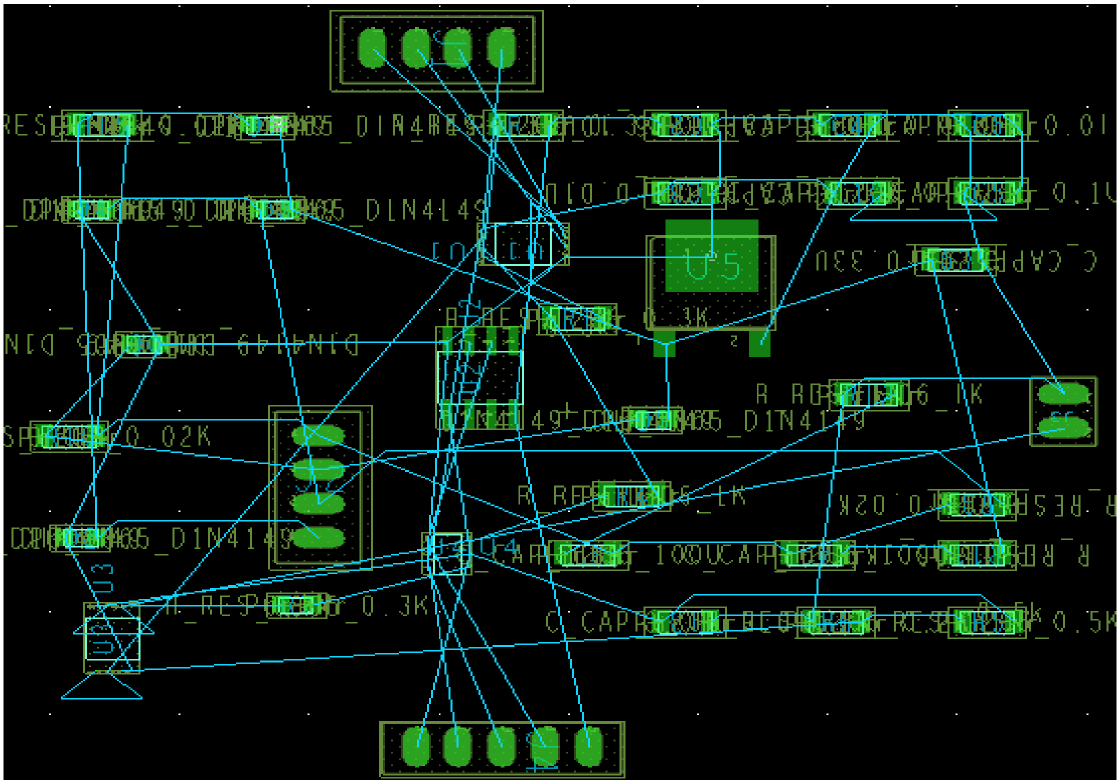

Figure 58: Placed Components with Rats Nest

The first aspect we did to our design was to investigate our components. To make sure that our all footprints are what we expect them to be, we printed the entire PCB layout with all the footprints with printing ratio of 1:1 of the board we wished to produce after manufacturing [33].

We then placed our components over the printed components paper to make sure that the real components corresponded the created footprint. The components we had paced well with their corresponding footprints and we therefore decided to go ahead and rout the traces [33].

40. Routing the Board

Routing the board involves connecting the electrical connections between components with copper tracks on the PCB. The connectivity between the components is blue lines called ratsnest before routing. Ratsnest must be replaced by copper tracks during routing [33].

Power tracks of our PCB were made wider than signal tracks because they have to carry more current. Our footprints which are of MSOPP Package made it impossible to make power tracks wider enough.

We are therefore forced to use the minimum width of 15 for the power nets and minimum width of 10 for the rest of the other nets. We decided to connect the traces manually to avoid violating the trace restrictions. The figures 14 and 15 show the routed PCB layout of the top and bottom sides respectively [35]. Due to the small physical size of the board and the nature of our schematic, routing the board's traces without using vias was impossible. We therefore made sure that we use via holes where necessary, but using as few as possible vias holes was one of our main goals. A via hole is a hole in a circuit board used where there is a need to pass a signal from one routing layer to another routing layer. Usually the more vias a circuit board have the more it become expensive to produce. This is the reason we wanted to minimize the numbers of vias holes on our circuit board.

To avoid increased inductance, we decided to avoid the increased width of the routing conductor. A special care should be taken during routing of the traces. Because the inductance creates a voltage drop, we made a plan that we make sure that a make sure that where possible we route the power and ground above each other, while the ground is routed on the bottom layer and the power routed on the top layer.

Figures bellow show our finished routed PCB layout of the top and bottom sides.

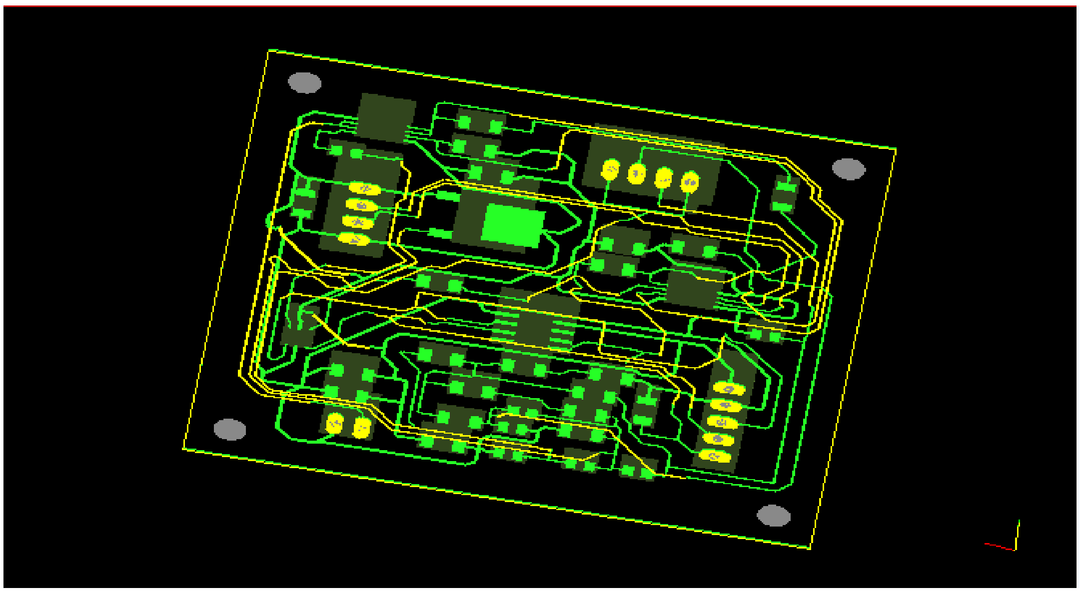

Figure 59: Bottom of Circuit Board

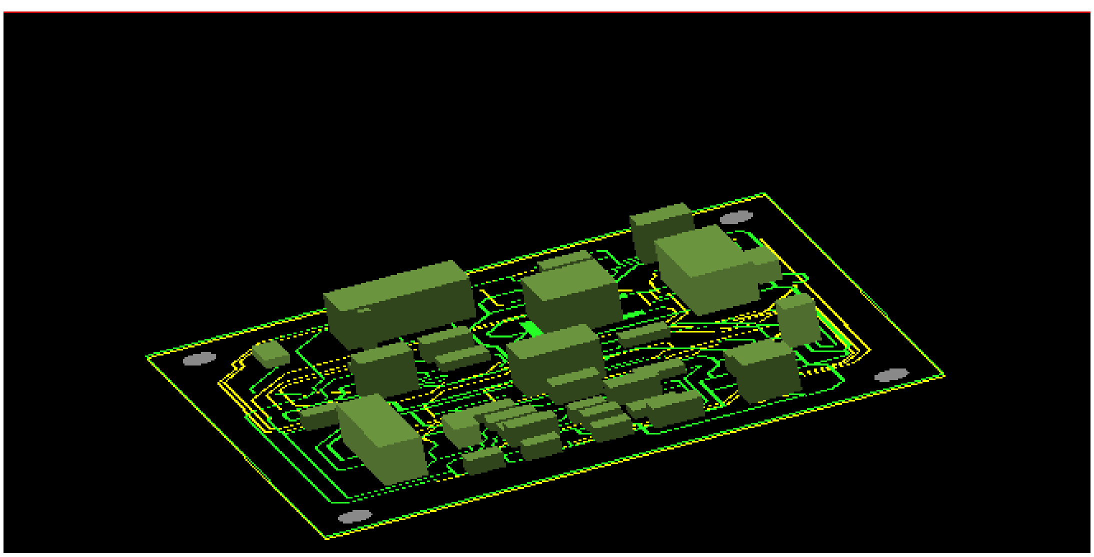

Figure 60: Top of Circuit Board

41. Creating Gerber and NC drill files

Gerber files are electrical files used by PCB manufactures use to describe the electrical connections of a Printed Circuit Board. These files describe the trace, vias, pads and corresponding footprints and plane. The Gerber files are collection of different layers and the designs that makes those files [35].

The NC Drill files contains information regarding holes and vias that are drilled through the board. Before generating, the two mentioned file types, it is important to make sure that the design rule check is done and verify that all the footprint match the real components [33].

The Gerber files contain of the following information:

An image containing the copper conductor information for the top side of the circuit board.

An image containing the copper conductor information for the bottom side of the circuit board.

An image containing the information of where solder mask is to be applied on the top layer of the board.

An image containing the information of where solder mask is to be applied on the bottom layer of the board.

An image containing information about where silkscreen is to be applied on the top layer.

An image containing information about where silkscreen is to be applied on the bottom layer.

Description of the properties of the drilled holes and Information about the locations of the drilled holes

The outlines of the board, including internal cutouts and other machining operations to mention few.

Generally, Gerber files contain all the necessary information corresponding the layers in the physical board. The information needed by manufactures vary from manufacture to another. It is therefore recommended to consult with your board fabricator before generating the Gerber files to make sure that the correct information is generated.

Initially we had a plan to develop this Circuit Board for strain gauge sensor conditioning. Our customer recommended a system with components having as small as possible footprints. The main objective of our PCB was to make Prototype. The manufacturer of our PCB suggested that the circuit we produced had smaller footprints than they can produce her at HSN.

This means that the footprints we produced are too small to be produced by the producer recommended by our customer. We manufactured both pads footprints and Circuit board as required by the customer. Very small PCB designs like we made are generally meant to be produced by pick and place machines, which is absent at HSN.

This resulted in changing the way of showing our porotype to connecting components on a breadboard. We therefore did not generate Gerber files, as we had to concentrate on documenting and finding other solutions.

42. Transmitting the signal through a rotary transformer

The most objective goal of our Printed Circuit board is to Linearize, amplify, Filter and digitalize the bending data which we correct from the sensory Wheatstone bridge. The signal read will undergo some signal processing and modulations. After signal modulation the digital signal will have to be amplified by the operation amplifier 8052 before being transmitted through a rotary transformer.

A rotary transformer is a type of a transformer that is used to deliver power. This type of transformer transfers power between two stationary coupling elements on the stationary side of the transformer and some rotating coupling elements located on the rotating side of the transformer. Our rotary transformer includes a primary and a secondary winding. The windings of the transformer are configured in the ratio of 1:2 and our modulated signal will be transmitted through the first and the second winding coils of the transformer.

Usually when two conductors are put closer to each other, a significant mutual inductance between them is created. An alternating current in the power circuit then induces a series mode interference voltage in the input circuit. This inductance depends on the geometry of the two circuits, namely on the overlapping length and separation. They exists capacitance between any two conductors in a system.

This kind of inducing and interfering create one of the biggest problem of our signal transmission through a rotating transformer. They may be some signal interference of our digital signal a solution to isolate the signal is not put in place. Inducing can lead to signal disturbance which can result in reduced effectiveness of our modulated signal digital signal.

We have therefore decided to create a simple isolating method to mitigate and avoid the disturbance which may occur when the signal goes through the magnetized rotating transformer. We created the simple circuitry system shown by the figure below to condition the circuit.

The simple conditioning system is implemented before and after the transformer. A signal from the PI12F1840 is amplified by AD8052 differential amplifier before going through the 2pins outputting header. The amplified signal is then fed to the input of the rotating transformer.

The AD8052 is connected as a buffer, which means that it also function as the Isolating system and amplification system for the signal which is fed on the first coupling coil of the rotating transformer. The signal to be transferred has then to pre conditioned and have an AC form to avoid the interference. The figure below shows the simple signal conditioning circuit.

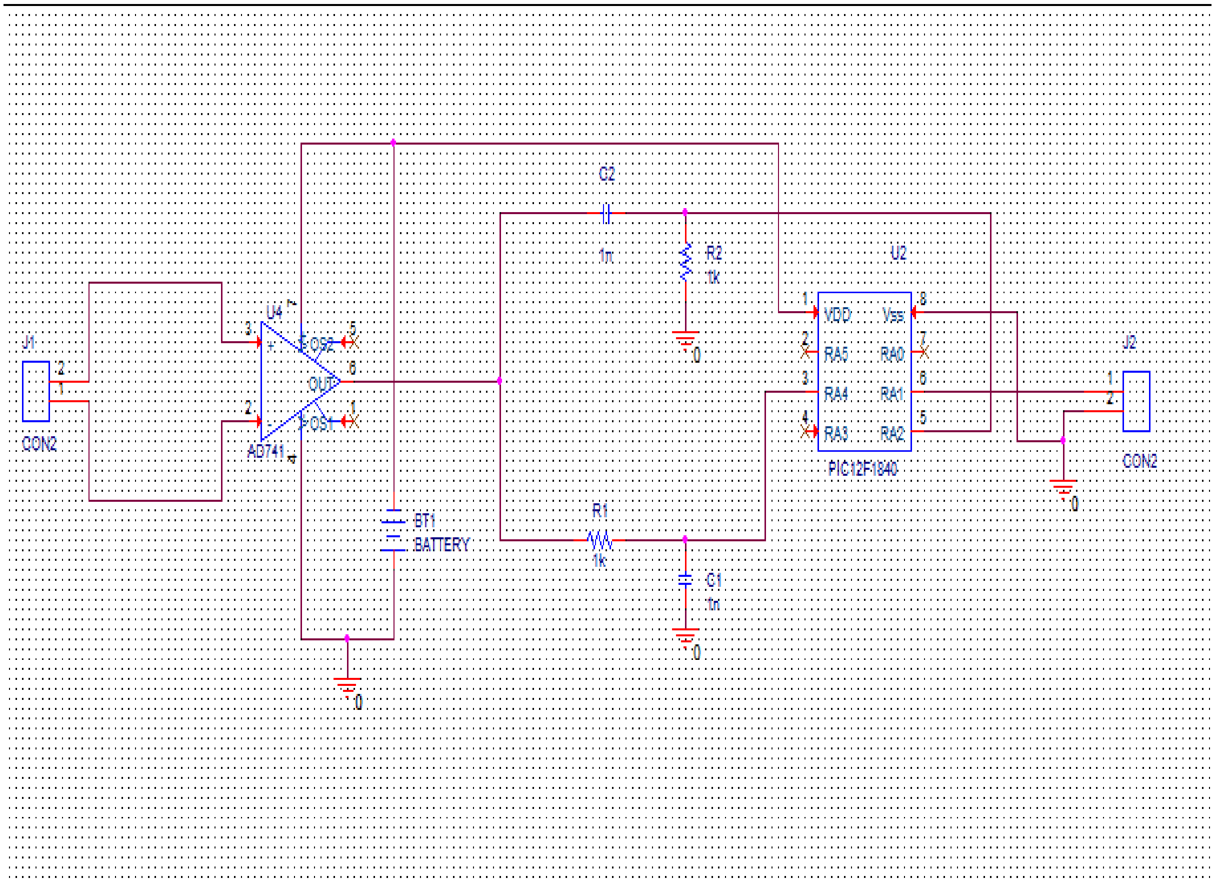

Figure 61: Amplifying Circuit after Transformer

While the rotary transformer’s output which is a sine wave is connected to another amplifier of type AD741. The first buffer is meant to amplify the digital modulated signal before it reach the rotary transformer, while the second amplifier is meant to amplify the signal after the rotary transformer.

The circuit includes also an RC band filter. Unlike a low pass filter that only pass signals of a low frequency range or a high pass filter which pass signals of a higher frequency range, passes signals within a certain band or spread of frequencies without distorting the input signal or introducing extra noise.The signal is finally demodulated by software in PIC12F1840 Micro controller.

43. Conclusion

Our technical solution covers the most essential challenges of making data available from a system rotating at high speeds. Unfortunately, we have not been able to test all of our concepts. However, the tests that we *have* performed shows proof-of-concept for our designs.

The alternator generator prototype that was built works, but is far from efficient enough to power our system. Improvements can be to increase the number of coil windings, increase the number of magnets, replace them with magnets of larger size or introduce a kind of ferrite cores to the coils.

Once the system has a sufficient power supply, the rest of the aspects can be tested and verified or improved.

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```
/*
 * File:   main_header.h
 * Author: Carl-Henrik Kristoffersen
 */

#pragma config FOSC = ECH       // Oscillator Selection (High-power mode)
#pragma config WDTE = OFF       // Watchdog Timer Enable (WDT disabled)
#pragma config PWRTE = OFF      // Power-up Timer Enable (PWRT disabled)
#pragma config MCLRE = ON       // MCLR Pin Function Select
#pragma config CP = OFF         // Flash Program Memory Code Protection
#pragma config CPD = OFF        // Data Memory Code Protection
#pragma config BOREN = ON       // Brown-out Reset Enable
#pragma config CLKOUTEN = ON    // Clock Out Enable
#pragma config IESO = ON        // Internal/External Switchover
#pragma config FCMEN = ON       // Fail-Safe Clock Monitor Enable
#pragma config WRT = OFF        // Flash Memory Self-Write Protection
#pragma config PLLEN = ON       // PLL Enable (4x PLL enabled)
#pragma config STVREN = ON      // Stack Overflow/Underflow Reset Enable
#pragma config BORV = LO        // Brown-out Reset Voltage Selection
#pragma config LVP = OFF        // Low-Voltage Programming Enable

#define USART_BAUD_RATE 9600
#define USART_DELAY 10 ms
#define USART_BLOCKING
#define _XTAL_FREQ 4000000 // Frequency value for __delay_ms() function.

// Pin definitions
#define PIN0_TRIS   TRISAbits.TRISA0
#define PIN0        LATAbits.LATA0
#define PIN1_TRIS   TRISAbits.TRISA1
#define PIN1        LATAbits.LATA1
#define PIN2_TRIS   TRISAbits.TRISA2
#define PIN2        LATAbits.LATA2
#define PIN3_TRIS   TRISAbits.TRISA3
#define PIN4_TRIS   TRISAbits.TRISA4
#define PIN4        LATAbits.LATA4
#define PIN5_TRIS   TRISAbits.TRISA5
#define PIN5        LATAbits.LATA5

// Global variables
int dac_fbref; // DAC feedback reference to analog circuitry.
int databit;
int dac_count = 0;
int timer_scaleup;
int res_high;
int res_low;

// Sine wave values from 0 to 31.
int sine[32] = {16, 19, 22, 24, 27, 29, 30, 31, 31, 31, 30, 28, 26, 23, 20,
                17, 14, 11, 8, 5, 3, 2, 0, 0, 0, 1, 2, 4, 7, 9, 12, 15};
```

```c


void ADC();
void DAC(int enable);
void sine_output(int enable, int bitvalue);
```

```c
/*
 * File:   main.c
 * Author: Carl-Henrik Kristoffersen
 *
 * Created on 15. mai 2016, 02:21
 */

#include <xc.h>
#include <stdio.h>
#include <stdlib.h>
#include "main_header.h"


int main(int argc, char** argv) {
    // PROGRAM START

    OSCCON = 0b01110000; // 8 MHz

    // Use Timer0 interrupts to iterate through the array
    OPTION_REG = 0b11001000; // No prescaler
    INTCONbits.T0IF = 0;
    INTCONbits.T0IE = 0; // Do not start timer interrupts yet.
    INTCONbits.GIE = 1;
    INTCONbits.PEIE = 0; // Disable peripheral interrupts.

    // Configure DAC
    DACCON0 = 0b10100000; // Enabled, LP ref negative, +Vdd, -Vss, DACOUT = 1.

    // Set feedback value
    dac_fbref = 0b01100; // Must be a value between 0 and 31.

    // Configure ADC
    ADCON0 = 0b00001100; // AN3 (RA4) pin selected. ADC not enabled.
    ADCON1 = 0b00000000; // AD result left-justified, freq = Fosc/2, Vdd is ref.

    //Configure pins
    ANSELAbits.ANSA4 = 1; // RA4 to analog.

    PIN0_TRIS = 0;  // RA0 to output.
    PIN1_TRIS = 0;  // RA1 to output.
    PIN2_TRIS = 0;  // RA2 to output.
    PIN4_TRIS = 1;  // RA4 to input.

    // Loop
    while(1){

        // DEMUX select pin. Select channel 1.
        PIN1 = 1;

        // Set feedback value
```

```
        DACCON1 = dac_fbref;

        // Execute AD-conversion and store result.
        ADC();

        // Disable DAC, switch DEMUX to channel 0. DAC enabled by sine_output()
        DACCON0bits.DACEN = 0;
        PIN1 = 0;

        INTCONbits.T0IE = 1; // Enable timer interrupts.

        // Iterate through result bits, output FSK-modulation.
        for(int i = 0; i < 10; i++){

            // Shift bits and mask LSB
            if(i < 8){

                //First 8 bits
                databit = ((res_high >> i) & 0x01);
                sine_output(1, databit); // Enable sine wave.
                res_high = ADRESH; // Revert the shift

            } else{

                // Last 2 bits
                databit = ((res_low >> (i-1)) & 0x01);
                sine_output(1, databit);
                res_low = ADRESL; // Revert the shift
            }
            __delay_ms(1); // Let sine wave oscillate for a short time.

        } // End for
        INTCONbits.T0IE = 0; // Disable timer interrupts.

    } // End while

    return (EXIT_SUCCESS);
}

// Interrupt function
void interrupt timer0_isr(void){
    // Executed on any interrupt
    if(dac_count > 31){
        dac_count = 0;
    }

    DACCON1 = sine[dac_count];
    dac_count++;
    TMR0 = timer_scaleup;
    INTCONbits.T0IF = 0; // Clear interrupt flag.
```

```
}

void ADC(){

    ADCON0bits.ADON = 1; // Enable ADC
    ADCON0bits.GO_nDONE = 1; // Start conversion

    while(ADCON0bits.GO_nDONE == 1){ }; // Do nothing during conversion

    // Conversion complete, store results.
    res_high = ADRESH;
    res_low = ADRESL;

    ADCON0bits.ADON = 0; // Disable ADC
}

void sine_output(int enable, int bitvalue){

    if(enable == 1){
        if(bitvalue == 1){
            timer_scaleup = 0b11111110; // Interrupt every instruction cycle.
        } else{
            timer_scaleup = 0b11111100; // Interrupt every 2nd instruction cycle
        }

        DAC(1); // Enable DAC.

    } else{
        DAC(0); // Disable DAC.
    }
}

void DAC(int enable){

    if(enable == 1){
        DACCON0bits.DACEN = 1;
    } else{
        DACCON0bits.DACEN = 0;
    }
}
```

Komponent:	Antall:	Leverandør:	Pris per stk:	Total pris:
Aksel til model	1	Clas Ohlson	159,00	159,00
Magnet 1cm Diameter	10	Kjmagnetics.com	3,00	30,00
Kulelager 12x28x8	2	Biltema	40,00	80,00
Harpiks(Resin) 1.5dl	1	Sløyd-Detaljer AS	155,00	244,00
Likeretterdioder	10	HSN	0,00	0,00
Likeretterdioder (Surface mount)	10	HSN	0,00	0,00
Spenningsregulator L7805 (Surface mount)	1	Onsemi.com	180,00	180,00
Spenningsregulator L7805ACV	10	ELFA Distrelec/HSN	4,31	43,10
Aluminiumelektrolytter 100 uF 25 VDC	20	ELFA Distrelec/HSN	2,11	42,20
Kondensatorer (Suface mount)	10	HSN	0,00	0,00
AD623ANZ Amplifier (Thru-hole)	4	ELFA Distrelec	0,00	0,00
DAC AD5601	4	Mouser Electronics	12,26	49,04
AD8237ARMZ instrumentation Amplifier (Surface mount)	6	ELFA Distrelec	0,00	0,00
AD8052ARMZ Amplifier (Surface mount)	6	ELFA Distrelec	0,00	0,00
Digitalt potmeter (Surface mount)	5	RS Online	12,40	62,00
Glassfiberduk	1	WESTSystem	159,00	159,00
Axel coupling 6mm-12mm	2	Ebay	99,00	198,00
Stiftlister 1x5P, 4094-05A-102/2205-2051, Molex	4	ELFA Distrelec/HSN	3,99	15,96
Skruer og div.	1	Monter	48,00	48,00
MCU PIC12F1840	6	microchip.com	0,00	0,00
Produksjon av aksel	1	Magnus HSN	500,00	500,00
DeMUX	2	Texasinstruments.com	0,00	0,00
Total:				1810,30

	Status:	Levert:	Link:
	Bestilt	Ok	
	Bestilt	Ok	https://www.kjmagnetics.com/proddetail.asp?prod=D601-N52
	Bestilt	Ok	http://www.biltema.no/no/Bil---MC/Laste-og-Trekke/Tilhenger/Reservede
Eks mva + 89,-frakt	Bestilt	Ok	http://www.sloyd-detaljer.no/kategorier/bild-kunst/leire-gips/stope-i-plas
	Trengs Utlevert	Ok	
	Trengs utlevert	Ok	
Samplet men kostet å levere	Bestilt sample	Ok	http://www.onsemi.com/PowerSolutions/product.do?id=MC7805
Eks mva	Trengs Utlevert	Ok	https://www.elfadistrelec.no/no/spenningsregulator-to-220-st-l7805acv/p
Eks mva	Trengs Utlevert	Ok	
	Trengs Utlevert	Ok	
Eks mva	Bestilt sample	Ok	https://www.elfadistrelec.no/no/instrumenteringsforsterker-dil-100-khz-a
150,- Frakt	Trengs ikke til prototype	----	http://no.mouser.com/ProductDetail/Analog-Devices/AD5601BKSZ-REEL7/
Eks mva	Bestilt sample	Ok	https://www.elfadistrelec.no/no/instrumenteringsforsterker-msop-200-kh
Eks mva	Bestilt sample	Ok	https://www.elfadistrelec.no/no/operasjonsforsterker-dobbel-110-mhz-m
Eks mva + 110,- frakt	Trengs ikke til prototype	----	http://no.rs-online.com/web/p/digital-potentiometers/1000157/
	Bestilt	Ok	http://www.westsystem.no/p/11376/glassfiberduk-dobbelvevet-200-gm
Inkludert levering i pris	Bestilt	Ok	
Eks mva	Bestilles av Dag**	Ok	https://www.elfadistrelec.no/no/stiftlister-1x5p-molex-4094-05a-102-220
	Bestilt	Ok	
	Bestilt sample	Ok	http://www.microchip.com/wwwproducts/en/PIC12F1840
	Bestilt	OK	
	Bestilt sample	Ok	
kr			

:ler/Kulelager-2000019337/
t-resin/crystal-resin-pid0589

/17313140?q=L7805ACV&page=1&origPos=1&origPageSize=50&simi=97.6

nalog-devices-ad623anz/p/17322142?q=AD623ANZ&page=1&origPos=1&origPageSize=50&simi=97.71
/?qs=sGAEpiMZZMswix2y39yldfRSUiTQKynFSPHLOc7VicY=
z-analog-devices-ad8237armz/p/30058170?q=AD8237ARMZ&page=1&origPos=1&origPageSize=50&simi=95.1
sop-analog-devices-ad8052armz/p/30058157?q=8052ARMZ&page=1&origPos=1&origPageSize=50&simi=90.43

5-2051/p/14300471?q=stiftlist%201x5&page=3&origPos=8&origPageSize=50&simi=96.51

Report 02/09/2016 11:33

Created by Chadi Chehade

Projects for client	Høgskolen i Sørøst-Norge
Users	All
Time interval	12/21/2012 — 05/25/2016

Total	**1856 hrs 33 min**
Carl-Henrik Kristoffersen	**486 hrs 28 min**
Rotary Wireless Signal Transmission	486 hrs 28 min
Administrative Tasks	243 hrs 40 min
Budgeting (Task nr. 117)	2 hrs 30 min
Document Verification (Task nr. 111)	20 hrs 18 min
Documentation (Task nr. 110)	78 hrs 39 min
Gantt-Diagram (Task nr. 105)	19 hrs 14 min
General Activities (Task nr. 112)	2 hrs
Meetings (Task nr. 113)	26 hrs 44 min
Practice & Execute Presentation (Task nr. 119)	33 hrs 15 min
Preliminary Research (Task nr. 104)	2 hrs 16 min
Project Management (Task nr. 122)	8 hrs 25 min
Project Model (Task nr. 102)	1 hrs 15 min
Project Plan (Task nr. 103)	1 hrs 29 min
Requirement Specification (Task nr. 101)	5 hrs 22 min
Risk Analysis (Task nr. 107)	2 hrs 15 min
Time managment / PAYMO (Task nr. 116)	5 hrs 34 min
Website (Task nr. 114)	34 hrs 6 min
Weekly Report (Task nr. 115)	15 min
Design Activities	173 hrs 27 min
AC/DC Converter (Task nr. 211)	8 hrs 30 min
AD Converter (Task nr. 205)	13 hrs 30 min
Amplifier	2 hrs
Circuit Board Design (Task nr. 204)	7 hrs 45 min

DAC (Task 212)	13 hrs
Microcontroller (Task 210)	45 hrs 8 min
Permanent Magnet Alternator (Task nr. 202)	6 hrs 50 min
Power Supply Module (Task nr. 207)	14 hrs 30 min
Programming (Task nr. 208)	23 hrs 30 min
Rotary Transformer (Task nr. 203)	12 hrs 30 min
Technical Research (Task nr. 209)	26 hrs 13 min
Implementation Activities	59 hrs 49 min
Assembly (Task nr. 302)	11 hrs 30 min
Prototype (Task nr. 305)	30 hrs 50 min
Purchasing (Task nr. 301)	3 hrs 59 min
SW / HW-Implementation (Task nr. 304)	13 hrs 30 min
Test Activities	9 hrs 30 min
A-Requirement Test (Task nr. 401)	9 hrs 30 min
Chadi Chehade	**545 hrs 42 min**
Rotary Wireless Signal Transmission	545 hrs 42 min
Administrative Tasks	307 hrs 56 min
Budgeting (Task nr. 117)	14 hrs 15 min
Document Verification (Task nr. 111)	18 hrs 45 min
Documentation (Task nr. 110)	69 hrs 45 min
Finalizing (Task nr. 121)	19 hrs 45 min
General Activities (Task nr. 112)	8 hrs 30 min
Meetings (Task nr. 113)	29 hrs 32 min
Practice & Execute Presentation (Task nr. 119)	26 hrs 15 min
Preliminary Research (Task nr. 104)	18 hrs 11 min
Prepare Presentations (Task nr. 118)	21 hrs 45 min
Project Model (Task nr. 102)	15 hrs 30 min
Project Plan (Task nr. 103)	15 hrs 31 min
Requirement Specification (Task nr. 101)	23 hrs 36 min
Test Specification (Task nr. 109)	3 hrs 49 min

Time managment / PAYMO (Task nr. 116)	17 hrs 15 min
Weekly Report (Task nr. 115)	5 hrs 30 min
Design Activities	165 hrs 16 min
AD Converter (Task nr. 205)	8 hrs 15 min
Amplifier	9 hrs 30 min
Circuit Board Design (Task nr. 204)	11 hrs 30 min
Microcontroller (Task 210)	6 hrs 30 min
Permanent Magnet Alternator (Task nr. 202)	52 hrs 30 min
Power Supply Module (Task nr. 207)	10 hrs 15 min
Rotary Transformer (Task nr. 203)	12 hrs 15 min
Strain Gauge & Wheatstone-bridge (Task nr. 201)	17 hrs 31 min
Technical Research (Task nr. 209)	37 hrs
Implementation Activities	63 hrs 15 min
Assembly (Task nr. 302)	10 hrs
Component Analysis (Task nr. 303)	6 hrs
Prototype (Task nr. 305)	26 hrs
Purchasing (Task nr. 301)	15 hrs 15 min
SW / HW-Implementation (Task nr. 304)	6 hrs
Test Activities	9 hrs 15 min
A-Requirement Test (Task nr. 401)	7 hrs 45 min
Alpha Testing (Task nr. 405)	1 hrs 30 min
Egide Bampo Rubusa	**502 hrs 10 min**
Rotary Wireless Signal Transmission	502 hrs 10 min
Administrative Tasks	303 hrs 10 min
Budgeting (Task nr. 117)	2 hrs 30 min
Document Verification (Task nr. 111)	32 hrs 15 min
Documentation (Task nr. 110)	119 hrs 15 min
Finalizing (Task nr. 121)	7 hrs 15 min
General Activities (Task nr. 112)	13 hrs
Meetings (Task nr. 113)	22 hrs 40 min

Practice & Execute Presentation (Task nr. 119)	20 hrs 15 min
Preliminary Research (Task nr. 104)	29 hrs
Prepare Presentations (Task nr. 118)	21 hrs 15 min
Project Model (Task nr. 102)	2 hrs 30 min
Risk Analysis (Task nr. 107)	5 hrs 45 min
Test Plan (Task nr. 108)	19 hrs 45 min
Test Specification (Task nr. 109)	7 hrs 45 min
Design Activities	188 hrs 30 min
AC/DC Converter (Task nr. 211)	12 hrs 30 min
AD Converter (Task nr. 205)	10 hrs 45 min
Amplifier	23 hrs
Circuit Board Design (Task nr. 204)	70 hrs
Microcontroller (Task 210)	11 hrs
Power Supply Module (Task nr. 207)	8 hrs 15 min
Strain Gauge & Wheatstone-bridge (Task nr. 201)	33 hrs
Technical Research (Task nr. 209)	20 hrs
Implementation Activities	10 hrs 30 min
Component Analysis (Task nr. 303)	7 hrs 15 min
Prototype (Task nr. 305)	3 hrs 15 min
Eton Williams	**322 hrs 11 min**
Rotary Wireless Signal Transmission	322 hrs 11 min
Administrative Tasks	223 hrs 41 min
Document Verification (Task nr. 111)	7 hrs 30 min
Documentation (Task nr. 110)	12 hrs 25 min
Finalizing (Task nr. 121)	1 hrs
General Activities (Task nr. 112)	7 hrs 30 min
Meetings (Task nr. 113)	21 hrs 20 min
Practice & Execute Presentation (Task nr. 119)	17 hrs
Preliminary Research (Task nr. 104)	28 hrs 12 min
Prepare Presentations (Task nr. 118)	39 hrs 45 min

Project Management (Task nr. 122)	26 hrs 17 min
Project Plan (Task nr. 103)	35 hrs 28 min
Requirement Specification (Task nr. 101)	11 hrs 45 min
Risk Analysis (Task nr. 107)	3 hrs
Test Specification (Task nr. 109)	3 hrs
Time managment / PAYMO (Task nr. 116)	9 hrs 27 min
Design Activities	98 hrs 30 min
AD Converter (Task nr. 205)	15 min
Circuit Board Design (Task nr. 204)	28 hrs 30 min
Microcontroller (Task 210)	9 hrs 30 min
Rotary Transformer (Task nr. 203)	15 min
Strain Gauge & Wheatstone-bridge (Task nr. 201)	13 hrs 15 min
Technical Research (Task nr. 209)	46 hrs 45 min
Total	**1856 hrs 33 min**

Iteration reports

Iteration 1	
Initial goals	1. Start preliminary research. 2. Determine project model. 3. Create project plan. 4. Create requirements specification and define key requirements. 5. Create test specification document based on requirements specification.
Results	1. Preliminary research was done. Starting to understand the scope of the project. 2. Decided to go for unified process project model. 3. Project plan v1.0 was created. 4. Requirements specification v1.0 was created. 5. Test specification document was not created.
Postponed	Test specification will be postponed to next iteration.
After-analysis	Good project start. Need to schedule new meeting with Dag to elaborate the requirement specification before test specification can be created. We chose Unified Process as project model for its flexible and agile properties. We will study the model further to better understand how to apply it.

Iteration 2	
Initial goals	1. Continue preliminary research 2. Finish Project Plan v2.0 3. Finish Requirement Specification v2.0 4. Create and finish Test Specification v2.0 5. Prepare for 1st presentation.
Results	1. Better understanding scope and boundaries of the project, as well as the project model. 2. Project Plan v2.0 was published in time. 3. Requirement Specification v2.0 was published in time. 4. Test Specification v1.0 was created, v2.0 was later published in time. 5. PowerPoint presentation was created.
Postponed	
After-analysis	We have been doing further studies on the project model, and better understanding how to implement it. Each iteration, we will go through and revise our documentation making sure the project plan and requirements are updated frequently. We imagine applying this project model will be very beneficial, especially when we work on our designs and implementation. We prepared thoroughly for the first presentation, got good constructive feedback.

	A technical document was also created and delivered as part of our documentation.
Iteration 3	
Initial goals	1. Concept elaboration. - Start making concept ideas and designs. 2. Get familiarized with strain gauges and Wheatstone-bridge configuration. 3. Study op-amp and create/improve technical documentation. 4. Study and design generator and power supply module. 5. Revise requirements specification.
Results	1. Several conceptual drawings have been created. 2. Acquired some strain gauges and did some experimentation. 3. EBR improved technical document based on feedback from Sigmund. 4. CHK has been studying generators/PSM and started creating designs. 5. CC has revised and improved requirement specification.
Postponed	Generator/PSM design alternatives must be developed next iteration. Risk analysis must be revised and improved. PUGH-matrixes must be created as we get more design concepts.
After-analysis	We have taken the feedback from 1st presentation into consideration and improved some of our requirements. Risk analysis has been postponed. We are starting to get some designs on generators and circuitry, as well as loose concept ideas on the rotary transformer and alternatives to transmit the signal. We have asked Dag about a list of components that are available to us from HSN.

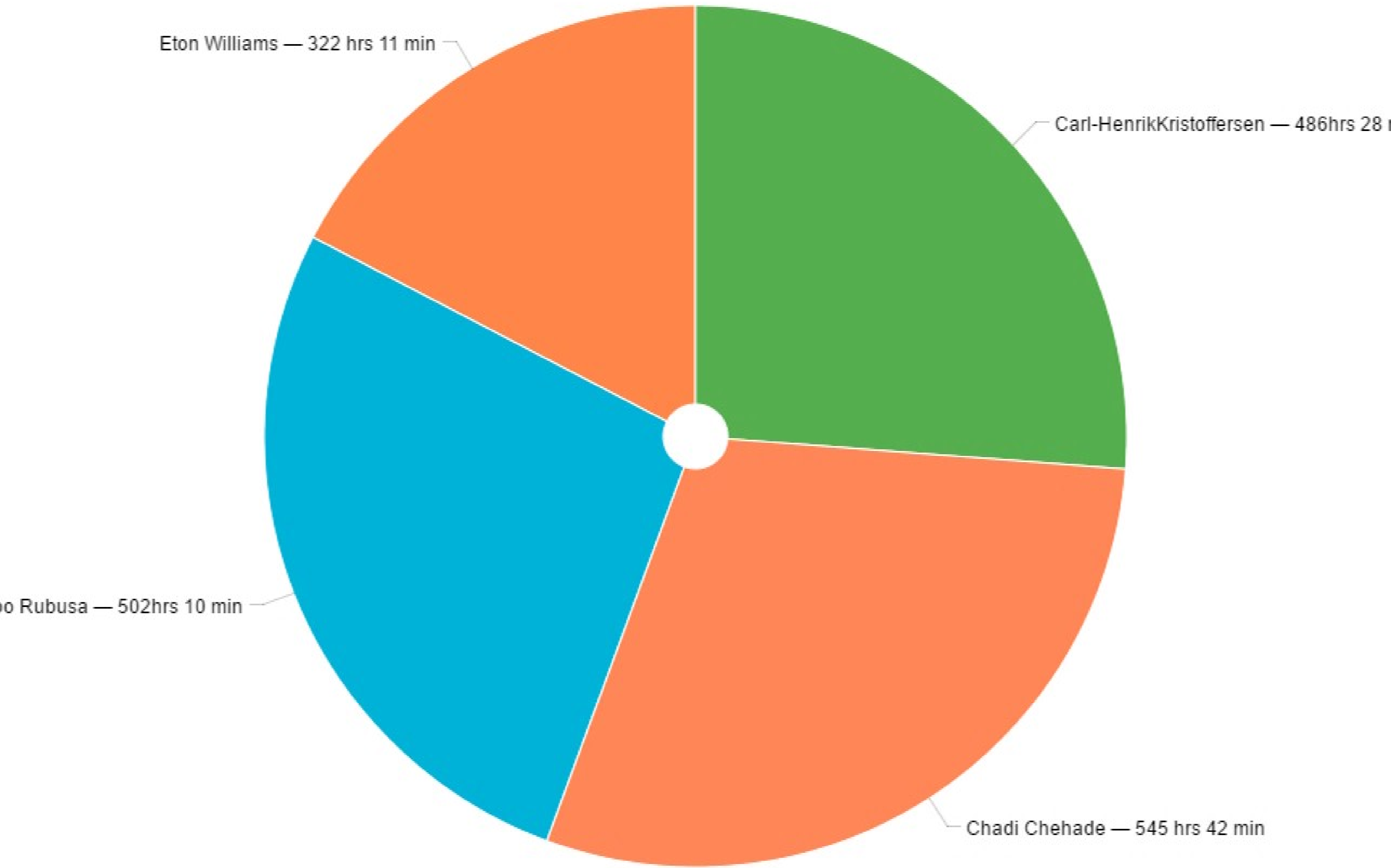
Iteration 4	
Initial goals	1. Revise and improve Project Plan (risk analysis) 2. Alternative designs to generator/power supply module. 3. Research and order microcontroller. 4. Create 3D-models of designs that are ready. 5. Research filtering and make a design. 6. Acquire components and start testing. 7. Revise documentation and publish v3.0.
Results	1. Risk analysis has been improved. 2. We now have multiple concepts for generator and power supply module. 3. We have ordered samples of two different PIC12 microcontrollers. 4. 3D drawings of one generator concept has been created. 5. Filtering designs have not been made. 6. Due to sickness, Dag has been away and not able to provide components. 7. Project Plan v3.0 revised and published. Requirement Specification v3.0 revised and published. Test Specification v3.0 has not been completed.
Postponed	Due to sickness amongst employer and supervisors, we have not yet received any components. After speaking with Dag, we agreed to provide a list of what we need. Test Specification need to be revised and changed according to the requirements specification as soon as possible.
After-analysis	Due to sickness, we have suffered some setbacks regarding components. Although we have been able to simulate our designs, we cannot proceed with until we get all the components we need. Microcontroller samples are on their way. Due to some internal issues within the group, we have not been able to publish a v3.0 of the Test Specification. These issues need to be addressed immediately. After speaking with Rolf Longva, we have gotten our hands on some very useful equipment. As soon as we get more components, we are ready to start implementing our designs.

Iteration 5	
Initial goals	1. Continue developing more concepts (PCB, signal filtering/conditioning). 2. Create more 3D-drawings. 3. Construct generator prototype. 4. Construct “helicopter” prototype (rotor shaft). 5. Construct power supply module prototype.
Results	1. Analog circuitry design not finished. 2. 3D-drawings were improved, casting shape was made. 3. Prototype not constructed, but design is ready. 4. Rotor shaft not designed. 5. PSM prototype not produced. Waiting for PCB-design.
Postponed	Generator prototype has been postponed due to 3D-drawings not printed. Rotor shaft has not been designed yet and postponed. PSM module is postponed, due to pending PCB design.
After-analysis	Although we did not accomplish everything we had hoped for, we made good progress on the design of the prototype. Microcontroller samples was received. Spoke to Richard Thue about 3D-printing our models. The group issues from earlier has been handled, and Carl-Henrik has now taken the role as group leader. Most of this iteration was spent on preparing 2nd presentation.

Iteration 6	
Initial goals	1. Gather components, look for samples. 2. Work on PSM prototype. 3. Research signal transformer. 4. Test system. 5. Program microcontroller.
Results	1. Samples of op-amps has been ordered. Awaiting analog circuitry design for more components. PCB-design was continued, started making footprints. 2. A simple PSM-circuit was successfully configured on a breadboard. 3. Consulted with supervisor Sigmund on signal transformers. 4. Only PSM has been tested. 5. Equipment for programming microcontroller has been acquired from Dag.
Postponed	More samples must be ordered during next iteration. 3D-printing was postponed due to Richard being away. Must be printed in order to build prototype.
After-analysis	After informative meetings with Dag, some breakthroughs regarding analog circuitry has been accomplished. Eton’s technical work has proved very useful.

Iteration 7	
Initial goals	1. Programming microcontroller. 2. Analog circuitry and PCB design. 3. Finalize prototype. 4. System testing. 5. Finalize analog circuitry design.
Results	1. Making good progress on programming of microcontroller. 2. Analog circuitry is still a work in progress. Looking at multiple solutions. 3. Parts have been 3D-printed. Started producing coils for casting. 4. No additional testing has been possible. Waiting for prototype. 5. All components has been sampled and are on their way.
Postponed	Microcontroller software is not finished, must be completed next iteration. Analog circuitry design must be finished as soon as possible, so that PCB design can be completed and a circuit board can be produced. Finalize prototype next iteration. System testing must be done next iteration.
After-analysis	Researching signal modulation for the rotary transformer, and it seems that FSK-modulation is a good choice. Microcontroller has integrated FSK-modulator. Production of prototype has proven very time consuming. Still looking for a solution on how to attach the motor. Rotor shaft design in progress and axle coupler has been ordered. Looking at multiple solutions. Prototype concepts must be tested and demonstrated individually. Requirement spec and test spec was revised and improved.

Iteration 8	
Initial goals	1. Finalize prototype. 2. System testing. 3. Finalize software for microcontroller. 4. Revise and verify old documentation. 5. Finalize all documentation.
Results	1. Rotor disc with coils has been casted with good results. Simple trafo-coils were produced. Production of PCB will not be possible. Rotor-shaft has been produced. 2. Experimented with trafo-coils. Finally assembled and tested prototype of PMA-generator. Tests was unsuccessful. 3. Software for microcontroller was completed. Integrated modulator was not suitable for our system. 4. Requirement spec and test spec has been finalized. Project plan was revised. Technical documentation merged to one document. 5. Most documentation has been completed except for analog circuitry.
Postponed	Last iteration, postponing not possible.
After-analysis	Very stressful and hectic iteration, as many obstacles has occurred. There is no equipment available to produce our PCB. Solution has been to solder components onto adapter chips, and connecting everything on a breadboard. Generator prototype concept works, but is not efficient enough to power our system. See test reports. The microcontroller's FSK-modulation was unsuitable for use with the transformer, since it was only able to generate square functions. The solution was to create a synthesized sine wave in software using the DAC module. Issues within the group similar to the ones before has reoccurred. One member being absent is very problematic, as essential documentation is missing.



Eton Williams — 322 hrs 11 min
Carl-HenrikKristoffersen — 486hrs 28
po Rubusa — 502hrs 10 min
Chadi Chehade — 545 hrs 42 min