February 15, 2023

Letter of Transmittal

Dr. Mike Hegedus
School of Engineering Science,
Simon Fraser University,
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V5A 1S6

RE: ENSC 405W Requirement Specification

Dear Dr. Hegedus,

Please find attached a copy of a requirements specification document prepared by SyncLock for ENSC 405W/440. It describes the functionality of a digital lock-in amplifier (DLA) that we plan to develop for use as testing equipment. This device will be accurate, robust, and stable for testing carried out in laboratories and out in the field and can be used for learning and development purposes.

The DLA will be designed on a PCB with digital-to-analog converters, a microprocessor, and analog-to-digital converters that will receive an input signal and process it to extract a low-noise signal from the input. The system should allow parameters such as amplitude, phase, and frequency to be used to configure the device to allow it to be used for testing different applications in different environments.

This document will cover the general scope of the project, a system overview, functional requirements, and standards that will guide the development of the product. The requirements are also organized into a proof-of-concept stage, engineering prototype, and final product stage to show what will be delivered at each point.

Thank you for taking the time to review our requirements specification document for the digital lock-in amplifier. Should any questions or concerns arise, please do not hesitate to contact our Chief Communication Officer, Ese Dan-Aighewi, by email (adanaigh@sfu.ca).

Sincerely,

Ese Dan-Aighewi
Chief Communication Officer
SyncLock

Digital Lock-In Amplifier

Requirements Specification

SyncLock (Company #8)

Simon Fraser University
ENSC 405W - Capstone A

February 15, 2023

Sponsor:
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Abstract

The Digital Lock-in Amplifier aims to extract information carried by small signals from large noise while addressing the nonidealities accompanied by analog circuits. The requirement specification document outlines the functionalities of the Digital Lock-in Amplifier that will be introduced at the proof-of-concept stage, the prototype stage, and the production stage. The constraints as well as the engineering standards are listed to ensure the usability of the product.

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Glossary

Term	Definition
AC	Alternating Current. A signal which exhibits both positive and negative values.
ADC	Analog-to-Digital Converter
Buffer Amplifier	A buffer to provide protection circuitry
DAC	Digital-to-Analog Converter
DC	Direct Current. A signal which exhibits either positive or negative values
DLA	Digital Lock-In Amplifier
DSP	Digital Signal Processing
Microcontroller	A small computer to control the components of the device
PCB	Printed Circuit Board
UI	User Interface

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1 Introduction

Small signal measurement is often required in fields including electronics, biology, and many others. In the presence of large noise and wave interference due to multiple factors, the signal of interest may be too faint to be measured with accuracy. Extracting the information carried by small signals is important because it provides insights into the dynamics of the system being studied.

1.1 Solution Overview

SyncLock aims to design and assemble a digital lock-in amplifier that can be used in general laboratory settings as well as in the field with reasonable portability. A computer interface is used to configure the amplifier’s parameters including the reference signal’s amplitude, frequency, phase, and pre-amplifier gain. While receiving input, the signal is converted from analog to digital domain using an analog-to-digital converter (ADC). The amplifier filters the noise using digital signal processing techniques and the resulting target signal of interest is stored on the board with an SD card.

Figure 1 shows the high-level workflow of the digital lock-in amplifier. The board containing the amplifier has a size comparable to a cell phone. It is able to collect signal data without the controlling computer connected and the battery can support the board for two to three days of use between charges.

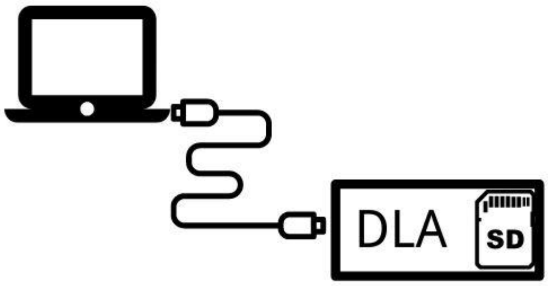

Figure 1. The high-level interaction between modules.

By turning away from using analog circuitry to design and construct the board, many challenges that an analog lock-in amplifier faces can be avoided. For instance, the analog multiplier that is used to mix the input signal with the reference signal is noisy, sensitive, and has a phase in itself.

1.2 Background

A lock-in amplifier is a type of electrical amplifier that can extract small signals from extremely noisy environments [1]. It works by unitizing the input signal time dependence. By controlling a reference signal that is synchronized in frequency with the target small signal, the lock-in amplifier outputs the amplitude and the phase parameters of the signal of interest [1, 2]. Figure 2 shows the block diagram of a typical analog lock-in amplifier. The basic operation contains the following steps [1]:

- A reference signal is generated at the same frequency as the input signal. The waveform of the reference is typically a sine or a square wave.
- The input signal is multiplied by the reference signal using active circuits, resulting in the amplitude and phase information of the signal to present at DC.
- The mixed signal is low-pass filtered to remove the noise, where X is the in-phase component and Y is the quadrature component.
- The filtered signal contains the instantaneous amplitude and phase information at each time stamp. It is demodulated to give the signal of interest.
- The resulting signal is amplified and fed toward the output of the lock-in amplifier.

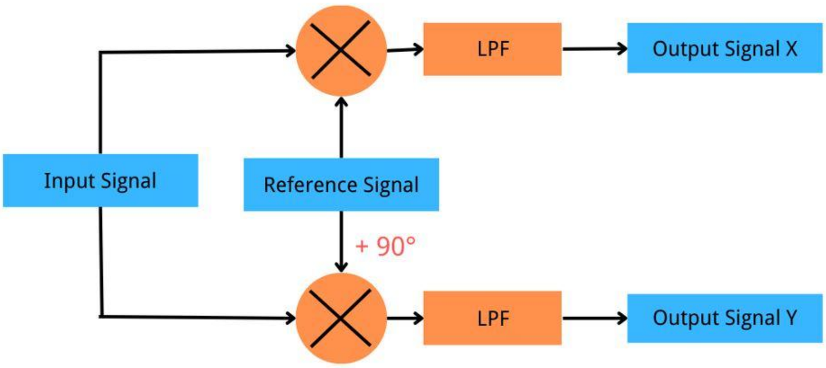

Figure 2. Block diagram of an analog lock-in amplifier.

By controlling the reference frequency, a lock-in amplifier rejects noise signals at other frequencies to reduce the noise effect on the signal measurement.

Lock-in amplifiers support science research in various ways. Scenarios that require small-signal measurements in the presence of large noise go from signals in electronic circuits to signals in biological systems. Examples include measuring the AC resistance of electrical circuits, analyzing noises emitted by certain sources at a particular frequency, characterizing electronic devices in response to large signal inputs, monitoring cellular activities, and bio-impedance, as well as measuring the small signals generated by biosensors [1, 3].

Nonetheless, analog lock-in amplifiers suffer from multiple non-idealities that can affect the accuracy of the signal measurement. The most common ones come from the frequency and phase responses of the circuit. The nonlinearity in the response can result in errors in obtaining signal parameters. The low-pass filter at the end of the analog circuit introduces the

1/f noise, which is an amplifier noise that reduces the signal-to-noise ratio. Here, f is the frequency and as the 1/f noise dominates the noise spectrum at low frequencies, the performance of the analog low-pass filter is negatively impacted. Furthermore, analog lock-in amplifiers have difficulty adapting reference signals generated with different parameters. One might work well with certain reference frequencies but not others. Consequently, extracting the small signal occurring at a different frequency would require redesigning the analog lock-in amplifier.

1.3 State of the art

Going from vacuum tubes in the 1930s, lock-in amplifiers continue to improve in performance, accuracy, and versatility [1]. One of the recent developments in lock-in amplifier technology is the transition from analog to digital circuitry [1]. As shown in figure 3, the input signal fed to a digital lock-in amplifier is converted to the digital domain using an analog-to-digital converter (ADC) before any mixing and filtering [1, 4]. This is accompanied by advancement in converting between the analog and the digital domains at increasing speed and resolution [1]. At the output, the measurement signal may be converted back to analog depending on the specific need.

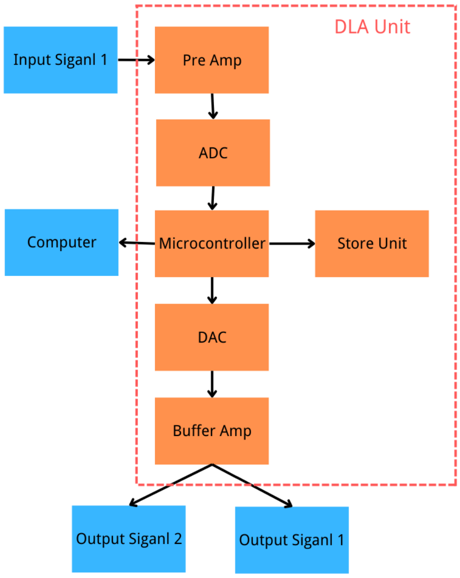

Figure 3. Schematics of a digital lock-in amplifier.

Digital lock-in amplifiers use digital signal processing techniques to extract the target small signal buried in noise. They are more accurate than analog components and are more flexible in terms of the input frequency range [1]. The reference signal parameters can be adjusted to suit the need for a particular measurement. Also, digital lock-in amplifiers make it possible to analyze an input signal at multiple frequencies simultaneously without losing the signal-to-noise ratio, directly obtaining the different frequency components of the measured signal [1].

1.4 Intended Audiences

The specifications document describes the requirement aspect of the Digital Lock-in Amplifier outlined by Dr. Behraad Bahreyni and will serve as a reference while in communication with the Intelligent Sensing Laboratory.

2 Requirements

2.1 Requirements Classification

The requirements for this project can be classified into five categories: general, hardware, firmware, software, safety and sustainability. The hardware, firmware, and software categories follow the operation process of the device, where the data is collected and processed in the hardware, transmitted by firmware, and received by the software application. Whereas the general category includes non-technical and integration requirements for our product.

The project requirements vary in different stages. In this document, the project stages consist of proof-of-concept, engineering prototype, and production version. Each stage is assigned to a letter as shown in the table below for better tracing.

Tag	**Project stage**
A	Proof-of-concept
B	Engineering Prototype
C	Production Version

Table 2.1. Project stage convention

Each requirement will be identified in the following format for better reference.

Req {Section}.{Requirement Number}

2.2 General Requirements

The general requirements involve non-technical aspects of the project, such as size and cost. They also highlight some integration requirements between different components. The goal of general requirements is to create a commercializable product that is reasonable to operate.

ID	Tag	Requirement Description
Req 2.2.1	B	The engineering prototype should cost less than 1000 dollars
Req 2.2.2	B	The device must be able to run without the computer connected
Req 2.2.3	C	The device will not exceed an average power consumption of 1W

Req 2.2.4	C	The device will cost no more than $200 including PCBs, components, and mechanical enclosures, but excluding batteries and cabling calculated based on a 100-piece production batch
Req 2.2.5	C	The device will not exceed a size of 16cm x 9cm x 3cm
Req 2.2.6	C	The device will not exceed a weight of 200g
Req 2.2.7	C	The device will not exceed a temperature of 50 degrees celsius under normal use
Req 2.2.8	C	The device will be water resistant
Req 2.2.9	C	The device will be drop-proof to a height of 1m
Req 2.2.10	C	The device will be shock-proof to a maximum shock of 30kV
Req 2.2.11	C	The device will be capable of withstanding temperatures from -40 degrees celsius to 100 degrees celsius
Req 2.2.12	C	The circuit board should have four screw holes for mounting

Table 2.2. General requirements

Many requirements mentioned above are according to professor Behraad's needs. He is looking for the final product to be compatible with his other PCBs, portable, and low power consumption for field usage. Our group also added several other requirements, so the final product can withstand certain damages.

2.3 Hardware Requirements

The hardware is the cornerstone of the DLA project, it consists of many components, such as ADC, DAC, and microcontroller. All these components need specific parameters to meet the user's requirements, such as sampling rate, SNR, and frequency response. The goal of hardware requirements is to provide high-resolution and low SNR digital signals for firmware and software.

ID	Tag	Requirement Description
Req 2.3.1	A	The device will accept one input signal
Req 2.3.2	A	one input ADC and one output DAC
Req 2.3.3	A	ADC has a minimum sampling frequency of 200 KHz
Req 2.3.4	A	ADC has 18 bits resolution
Req 2.3.5	A	Pre amplifiers need to be set at the input

Req 2.3.6	A	DAC has 14 bits resolution
Req 2.3.7	A	Buffer amplifiers need to be set at the analog outputs
Req 2.3.8	B	Two inputs ADC
Req 2.3.9	B	Two independent outputs DAC
Req 2.3.10	B	DAC needs to be polar, positive and negative
Req 2.3.11	B	SNR should be controlled around 100dB
Req 2.3.12	B	The device will protect against inserting batteries in the reverse polarity
Req 2.3.13	B	The device will protect against under and over voltage
Req 2.3.14	C	The device will protect in the event of multiple inputs being plugged in simultaneously

Table 2.3. Hardware requirements

Professor Bahreyni introduced his hardware requirements in the previous meetings. Table 3 shown above is created based on his speech from a higher level. And those requirements are necessary to meet Professor Behraad's research purpose.

2.4 Firmware Requirements

The firmware in this project acts as an intermedium to transmit data between hardware and software. The goal of firmware requirements is to transmit data losslessly and in sync, and also correctly pass parameter settings from software to hardware.

ID	Tag	Requirement Description
Req 2.4.1	A	Processed data can be stored on an SD card
Req 2.4.2	A	Data can be sent to a connected computer device via USB

Table 2.4. Firmware requirements

Professor Bahreyni requires the device to display real-time signals when it's connected through USB or store signal data into an SD card during in-field research. Table 4 is created based on those two high-level requirements.

2.5 Software Requirements

The requirements below outline the software specifications of the system that will enable the user to interact with the device. The user interface will be straightforward, as its primary purpose will be to set the frequency and phase values of the reference signal. A stand-alone application that lays out the different visual components and easily allows for integration with signal processing capabilities that can be used to view, as well as manipulate the output from the device should be implemented.

The application should be run on a computer that has USB capabilities. It should be able to take in and store the frequency and phase values from the user, pending when they reconnect the device to process the signals captured from the field tests.

The application should be programmed to manage edge cases and exceptions to avoid crashing and should recover from critical failure, interruptions, or any power failure that occurs with the PCB.

ID	Tag	Requirement Description
Req 2.5.1	A	Software will be able to adjust the amplitude, frequency, and phase of reference signal
Req 2.5.2	A	Software will be able to configure amplifier parameters
Req 2.5.3	A	Software will be able to read the data from SD card or the device directly
Reg 2.5.4	B	Software should plot frequency spectrum of chosen signal
Req 2.5.5	B	Software will be able to report faults from the PCB
Req 2.5.6	C	User will be able to save data for the further applications

Table 2.5. Software Requirements

During an in-person meeting with Professor Behraad, we took a close look at the functionalities and UI design of a Zurish instrument. To minimize learning costs, our software requirements are set to have similar features to that of the Zurish instrument.

2.6 Safety and Sustainability Requirements

Safety requirements aim to protect people from harm, injury, or damage. Electronic components and circuit designs take a major part of our project, electric shocks, overheating, and loose components should be prevented. We need to set safety requirements, so users can operate the device safely.

Sustainability requirements focus on reducing the environmental impact. This can involve reducing resource consumption, minimizing waste and emissions, and promoting the use of environmentally friendly materials. In our case, most electronic components are not recyclable but can be reused. Besides electronic components, we can use recyclable materials for casing and packaging in the final product.

ID	Tag	Requirement Description
Req 2.6.1	A	The electronics and wiring should not present any shock hazards
Req 2.6.2	A	Current and voltage should be within the desired ranges
Req 2.6.3	A	The electric components and wire should be mounted firmly on the PCB
Req 2.6.4	B	The battery and wiring must not pose a fire or explosion hazard under normal operating conditions
Req 2.6.5	B	There must be no current flow once the device is turned off with the off switch.
Req 2.6.6	B	The PCB must not be completely enclosed to prevent overheating with adequate airflow.
Req 2.6.7	B	The PCB shall be enclosed in a secure casing to protect the board components and secure the sharp edges of the board.
Req 2.6.8	C	The packaging should be recyclable.
Req 2.6.9	C	The packaging and device must be labeled appropriately, using ISO 28219:2017

Table 2.6. Safety and sustainability requirements

Since Professor Behraad didn't mention any safety and sustainability issues, we write those requirements by imaging the safety and sustainability aspects of a Raspberry Pi and applying those aspects to our device.

3 Constraints

The constraints describe the non-functional aspects of the project to ensure proper functionality and reliability. Unlike requirements, constraints will specify restrictions at a high level.

ID	Tag	Requirement Description
Cons 3.1.1	A	UI should be clean and easy to use
Cons 3.1.2	A	UI's text and font should be reasonable to read and consistent
Cons 3.1.3	A	UI's color should be simple and easy to distinguish
Cons 3.1.4	A	UI should have a clear distinction between primary and secondary buttons
Cons 3.1.5	B	Consider PCB space constraint when designing PCB

Cons 3.1.6	B	The device should be compatible with common power supply or battery
Cons 3.1.7	B	The device should have clear indicators for ports
Cons 3.1.8	B	The delay from input to output should be small when using in real-time mode
Cons 3.1.9	C	The device should be protected to withstand certain damage

Table 3.1 Constraints

4 Engineering Standards

Before this device can be used in the field, the engineering standards below should be used as a directive to ensure that the final product is fit and safe for use. We shall reference several international and Canadian electronics and safety standards while building the product.

ID	Code	Description
Req 4.1	IEC 62680-2-3:2015	Universal serial bus interfaces for data and power - Part 2-3 [6]

Table 4.1. Connection Protocol

ID	Code	Description
Req 4.2	ISO 28219:2017	Packaging — Labeling and direct product marking with linear bar code and two-dimensional symbols [6]
Req 4.3	CAN/CSA-ISO/TR 14062-03	Environmental Management - Integrating Environmental Aspects into Product Design and Development [5]

Table 4.2. Environmental and Packaging standards

ID	Code	Description
Req 4.4	CAN/CSA-C22.2 NO. 61010-1-12/A1:18	Safety requirements for electrical equipment for measurement, control, and laboratory use - Part 1: General requirements [5]
Req 4.5	CSA C22.2 NO. 61508-1:17 (R2022)	Functional safety of electrical/electronic/programmable electronic safety-related systems — Part 1: General requirements [5]

Req 4.6	IEC 61188-1-1	Printed Boards and Printed Board Assemblies - Design and Use - Part 1-1: Generic Requirements - Flatness Considerations for Electronic Assemblies [6]
Req 4.7	CSA C22.2 NO. 0.23:15 (R2020)	General requirements for battery-powered appliances [5]

Table 4.3. Electrical standards

ID	Code	Description
Req 4.8	ISO/IEC 29138-1:2018	User interface accessibility - Part 1: User accessibility needs [6]
Req 4.9	ISO 9241-161:2016	Ergonomics of human-system interaction — Part 161: Guidance on visual user-interface elements [6]

Table 4.4. Software standards

5 Conclusion

In conclusion, the digital lock-in amplifier is a powerful tool used in many fields to extract weak signals from a noisy environment. Our device will be robust, user-friendly, safe, and portable meeting all the engineering standards listed above. As a company, we also strive to produce a product that is cost-efficient, intuitive, and affordable. Under the supervision of Dr. Behraad Bahreyni, our team of open-minded engineers will make a product that meets all of our proposed requirements above suitable for the Intelligent Sensing Laboratory.

Appendix

For the proof of concept deliverables which will be presented by the end of the semester in April. Company 8 will have the following deliverables:

- Computer software interface controlling the reference signal's frequency and amplitude
- 18-bit sampling resolution and minimum 200 kHz ADC with one channel input
- Microprocessor with the programmed digital logic on mixing and filtering working on a raspberry pi board
- One digital output with the option to data dumped onto an SD card
- One channel analog output for the DAC
- The range of the reference and output signals will cover a range of +/- 5V

Some key problems that need to be addressed in order to meet our proof of concept deliverables include:

- The ADC needs to have a high enough resolution
- SNR needs to be strictly controlled for small signal measurements.
- The raspberry pi board needs to have all of the modules we desire including the preamplifier, ADC, Microprocessor, DAC, and op-amp.
- Providing all the above requirements consuming less than 1W of power

References

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