REQUIREMENT SPECIFICATION

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Version 2.0

Status

Reviewed	Christoffer Ring	2014-12-02
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PRODJECT IDENTITY

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Linköping University, ISY

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Document History

Version	Date	Changes	Performed by	Reviewed by
0.1	2014-09-04	First draft.	All group members	Christoffer Ring
0.2	2014-09-14	Changes to all parts according to feedback from Customer and Supervisor.	All group members	Christoffer Ring
0.3	2014-09-17	Changes to all parts according to feedback from Supervisor.	All group members	Christoffer Ring
1.0	2014-09-26	Changes according to discussion at tollgate 2.	Fredrik Stenmark	Christoffer Ring
2.0	2014-12-02	Changes according to e-mail discussion.	Fredrik Stenmark	Christoffer Ring

1 INTRODUCTION

In the course TSKS05 – CDIO Communication Systems – the students are supposed to construct a system that demonstrates the concept of massive Multiple-Input Multiple-Output (MIMO) beamforming. MIMO is a widely used wireless cellular technology, where both ends of the communication link are equipped with multiple antenna elements. Massive MIMO is an evolution of this technique, where the base station of a cell is equipped with an unconventionally large number of antenna elements, typically an order of magnitude larger than the number of users served.

This product will apply the Massive MIMO principle on acoustic and not electromagnetic waves. Using a set of loudspeakers, which can also be used as microphones, the students shall be able to measure sound transmitted from a source and from that sound extract important channel and signal characteristics. With this information, the loudspeakers shall be able to preprocess a desirable sound such that the acoustic waves produced by the loudspeakers add up constructively at a particular spatial location and destructively essentially everywhere else.

One possible demonstration setup for presenting massive MIMO beamforming is to break a single wine glass among a set of similar glasses. Namely, a set of wine glasses will be placed sufficiently separated in various locations of an indoor area. One of the wine glasses will be selected and hit so that it produces a sound. The system should gather this information and form an acoustic wave field that will break the selected glass but leave the remaining glasses unaffected, see Fig. 1. However, this rather spectacular way of presenting massive MIMO beamforming will not be used in this product. For a description of the product setup, see section 2.

Figure 1. A possible setup for a demonstration of massive MIMO beamforming.

The purpose of this document is to give a detailed overview of the requirements of the product, functions and limitations that have been agreed upon with the customer.

The template, see Table 1, below is used across this document in order to present, in a compact view, the requirements of the product. The second column will take one of the two values, “Change” or “Original”. The value “Original” is used when the requirement, described in the third column, is unchanged from the approved version 1.0 of this document. In case of revision of a requirement the value "Change" shall be used together with the date of revision.

The last column states the priority of the requirement, i.e. in what order the requirements are to be fulfilled. There can only be 2 levels of priorities. Requirements with priority 1 shall be fulfilled by the time of delivery. The Project Group has a collective time budget of 1200 hours to spend on the product. If the Project Group has working hours, without exceeding the time budget, left to spend before the delivery of the product, suitable requirements with priority 2 shall be fulfilled. The total time available is defined in Chapter 6.

Table 1: Requirements template.

Requirement number X	Change	Description of requirement number X	Priority

1.1 Parties

Table 2: The table below specifies the various parties involved in the project.

Name	**Position**
Danyo Danev	Examiner
Christopher Mollén	Customer
Mikael Olofsson	Hardware Expert – Consultant
Antonios Pitarokoilis	Supervisor
The students (see Project Identity)	Project Group

1.2 Aim and Goal

The goal of the project is to demonstrate the capability of massive MIMO to focus energy towards a very precise point. In this project we are using loudspeakers and sound waves audible to human ears to present the latter ability of massive MIMO. The project also aims at giving the students a realistic opportunity to exercise their knowledge, acquired through previous studies in the telecommunication field, by constructing a system fulfilling the customer's requirements.

1.3 Usage

The usage of the product is to, in an intuitive manner, demonstrate massive MIMO beamforming for people that do not have any experience in the area of MIMO systems.

1.4 Background

Massive audio beamforming uses a technique called massive MIMO. With massive audio beamforming the department of Electrical Engineering, who provided the idea for the project, would like to show the effects of massive MIMO beamforming. MIMO systems employ multiple antenna elements both at the transmitter and the receiver side. When sufficient knowledge of the channel is available, the transmitter can use this information in order to steer the transmitted signals towards particular points. In addition, the receiver can also use this information to receive selectively from specific directions and suppress signals arriving from others.

1.5 Definitions

Word	**Definition**
MIMO	Multiple Input Multiple Output
A/D	Analog to Digital
D/A	Digital to Analog
L/M	Loudspeaker and microphone unit
L/M-pair	A pair of loudspeaker and microphone units

Word	Definition
OS	Operating System
Subsystem	A part of the whole system

2 OVERVIEW OF THE SYSTEM

The system consists of two subsystems called Software and Hardware. The user interacts with the Software, which in turn communicates with the Hardware, in order to steer the wave energy towards a selected point of focus, see Fig. 2. By measuring and comparing the signal power at the point of focus and at a point somewhere in the area around the point of focus, the system will be able to verify that constructive interference is achieved at the point of focus and that destructive interference is achieved essentially everywhere else. Thereby the system demonstrates the same concept of massive MIMO beamforming that the setup with the wine glasses do, Fig. 1, however in a more controlled manner.

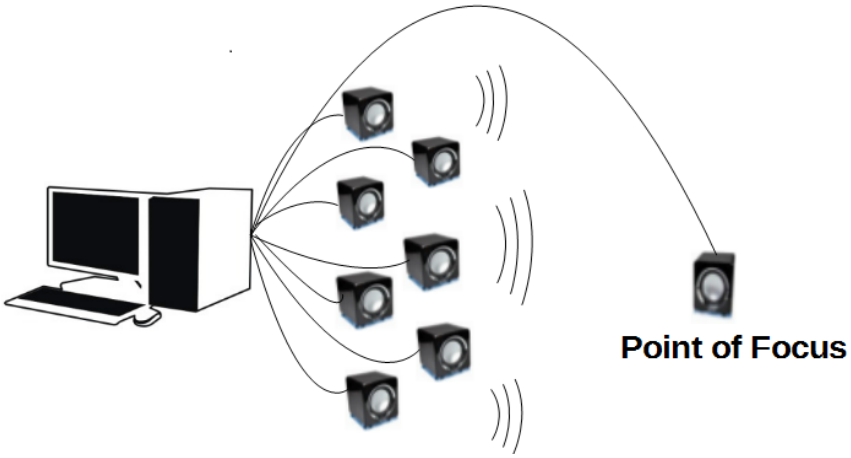

Figure 2. The system works by controlling the different L/Ms so that they transmit sound that add up constructively at the point of focus. The number and positioning of the L/Ms are not representative of the actual system.

2.1 General Description of the Product

The product will use massive audio beamforming in order to create constructive interference at a certain focus point and can therefore illustrate a case of operation of massive MIMO beamforming. The user is able to control the MIMO beamforming through the Software. The user will be able to change the amplitude, frequency, power and phase for each L/M-pair. Moreover, the user, will be able to control the operational modes of the L/M-pairs, i.e. if the L/M shall work as a loudspeaker or a microphone. The user can control two groups of L/M-pairs, one group consists of the L/M-pair in the point of focus and the other group consists of the remaining L/M-pairs. This means that all L/M-pairs included in one group will have the same operational mode at the same time.

2.2 Product Components

The following documents and deliverables are included in the product.

- A system focusing energy into one precise point and at the same time canceling energy in essentially every other point, therefore demonstrating one of the powers of massive MIMO beamforming.
- A poster presenting the system.
- A technical report, user manual and test protocols.

- A project conference.
- A web page presenting the product.

2.3 Included Subsystems

The product consists of two parts, Software and Hardware. The Software and the Hardware interact with each other through drivers on the computer. The Software consists of an OS, drivers and MATLAB code. The Hardware mainly consists of the following entities:

- Computer.
- A/D converter.
- D/A converter.
- Amplification circuits.
- L/M-pairs.

2.4 Limitations

The project does not include:

- Writing Windows drivers for the A/D and D/A converters.
- Being able to demonstrate MIMO at large outdoor areas.
- Using other OS than Microsoft Windows 7.

2.5 General System Requirements

1.	Original	The system shall be able to focus sound energy at a certain point so that the transmitted signals add up constructively.	1
2.	Original	The system shall be able to suppress sound energy so that the transmitted signals add up destructively around the point of focus.	1
3.	Original	The system shall be able to use real time recorded sound to estimate the channel between each L/M and the origin of the sound.	1
4.	Original	The Software shall be able to present information about the current operation. Such information will include visualizing the emitted signal characteristics and presenting the L/Ms operational mode.	1
5.	Original	The user shall be able to see an average value of the signal power received at the two L/M units, which constitute the L/M-pair located at the point of focus in the system setup, see Fig. 2.	1

3 SOFTWARE

The Software consists of a user interface, an OS, four modules and also drivers for the A/D – and D/A converters. Microsoft Windows 7 is used as OS and the modules are used to solve smaller tasks within the Software. Fig. 3 presents the architecture of the Software. The following sections in this chapter will describe the Software in more detail.

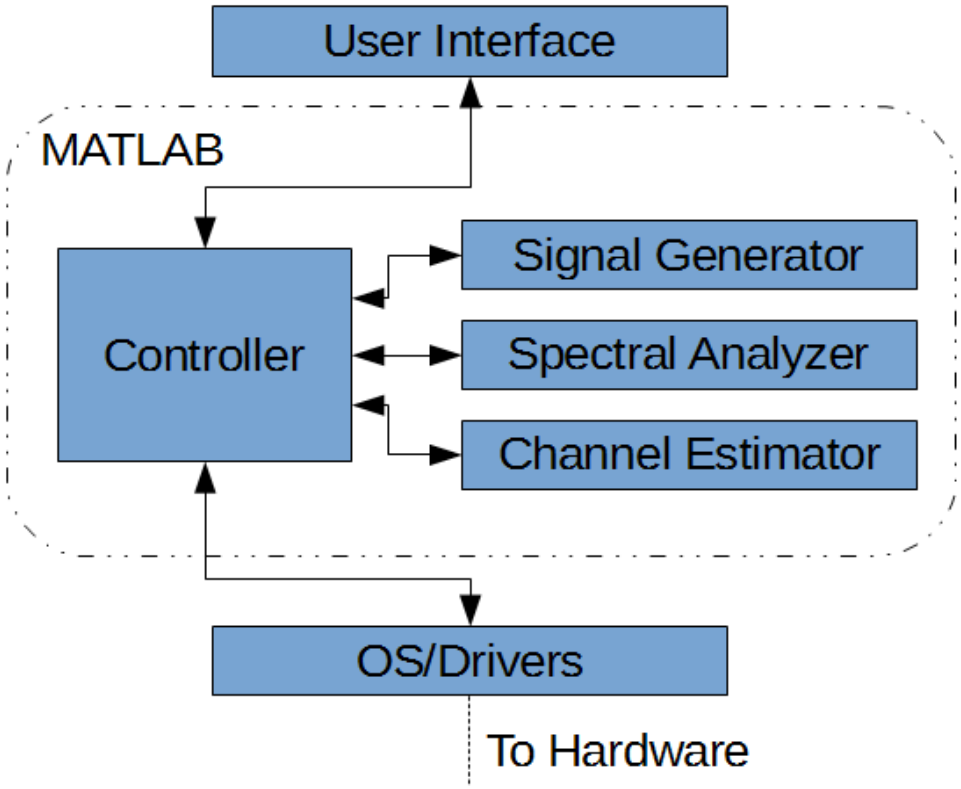

Figure 3. Structure of the Software subsystem.

3.1 Introductory Description

The user interface presents the data produced by the modules. The modules are used to receive, analyze, present and send sound data. The modules are called Controller, Signal Generator, Spectral Analyzer and Channel Estimator. All these modules are written in MATLAB. The user gives commands to the Controller, which in turn controls the communication with the interface and the drivers, employing the other modules when needed. The Channel Estimator performs the task of estimating the characteristics of the channel given sound data that has been exposed to the channel. The Spectral Analyzer will be able to calculate the frequency characteristics of the received signal. The Signal Generator will be able to produce the sound data that is to be sent to each L/M in the Hardware and then through the channel, given information such as impulse response of the channel.

3.2 Interface to Other Subsystems

6.	Original	Communication between Hardware and Software is realized through Windows drivers.	1

3.3 Design Requirements

7.	Original	The modules are written in MATLAB.	1

3.4 Functional Requirements for the Software

8.	Original	The Software shall be able to receive signals, representing sound data, from the Hardware.	1
9.	Original	The Channel Estimator shall be able to produce an estimate of the channel characteristics that is good enough to fulfill requirement 29, using sound data that is provided by the Hardware.	1
10.	Original	The Software shall be able to send signals, representing sound data, to the Hardware.	1
11.	Original	The Controller shall be able to control the operational mode of the L/Ms (see chapter 4.1).	1
12.	Original	The Spectral Analyzer shall be able to calculate the fundamental frequency of a tone, with frequencies between 300 Hz and 15 kHz, provided by the Hardware.	1
12.1	Change 2014-12-01	The Spectral Analyzer shall be able to calculate the fundamental frequency of a tone, with frequencies between 300 Hz and 3000 Hz, provided by the Hardware.	1
13.	Original	The Software shall be able to produce a tone with frequencies between 300 Hz and 15 kHz.	1
13.1	Change 2014-12-01	The Software shall be able to produce a tone with frequencies between 300 Hz and 3000 Hz.	1

4 HARDWARE

The Hardware consists of a number of entities. These are the Computer, D/A converter, A/D converter, amplification circuits and L/M-pairs. Fig. 4 presents the architecture of the Hardware. The following sections of this chapter further specify these entities.

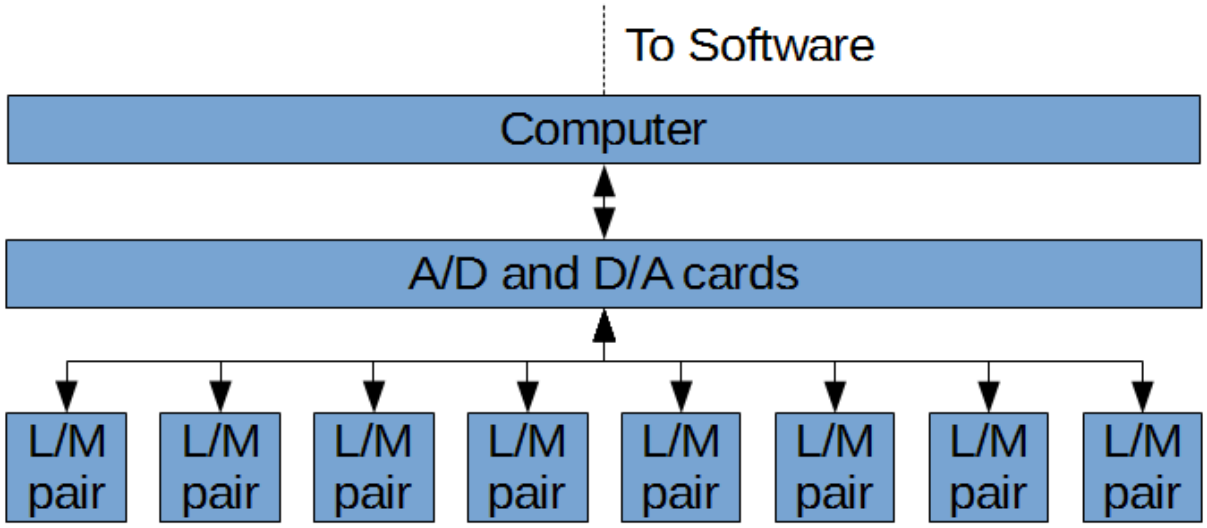

Figure 4. Structure of the Hardware subsystem.

4.1 Introductory Description

The D/A converter and A/D converter are connected to the Computer. Each amplification circuit is connected to both converters, as well as one L/M-pair. Parallel to the converters, there is also a line of communication between the computer and the switches on the amplification circuits. These switches are used to change the operational mode of the L/M-pairs. There are two operational modes for the L/M-pairs, loudspeaker mode and microphone mode. When an L/M-pair operates in loudspeaker mode, both L/Ms in the pair works as loudspeakers, meaning they transmit sound. When an L/M-pair operates in microphone mode, both L/Ms in the pair works as microphones, meaning they receive sound.

14.	Original	There shall be 8 amplification circuits, where each amplification circuit is capable of amplifying a signal 2000 times.	1
15.	Original	There shall be 8 L/M-pairs that can transmit and receive sound. This means converting electrical signals into sound waves and the other way around.	1
16.	Original	There shall be 32 working amplification circuits, where each amplification circuit is capable of amplifying a signal 2000 times.	2
17.	Original	There shall be 32 L/M-pairs that can transmit and receive sound. This means converting electrical signals into sound waves and the other way around.	2

4.2 Interface to Other Subsystems

The interface towards the Software is through the A/D converter, D/A converter and the parallel communication lines used for the switches.

18.	Original	There shall be a line of communication from the Software to the Hardware through a D/A converter, which constitutes the interface between the Software and the Hardware.	1
19.	Original	There shall be a line of communication from the Hardware to the Software through an A/D converter, which constitutes the interface between the Hardware and the Software.	1
20.	Original	Through the Software, the user shall be able to switch between the two operational modes that are defined for the L/M-pairs in section 4.1.	1

4.3 Design Requirements

21.	Original	Maxxtro mini speaker 4 W shall be used as L/M.	1
22.	Original	Contec AD12-64 shall be used as A/D converter.	1
23.	Original	Contec DA12-16 shall be used as D/A converter.	1
24.	Original	There shall be a distance of at least half a wavelength of the sent signals between each L/M.	1
24.1	Change 2014-12-01	There shall be a distance of at least a quarter of a wavelength of the sent signals between each L/M.	1

4.4 Functional Requirements

The Hardware shall be able to receive and transmit sound. The L/M-pairs shall therefore be able to switch mode through the use of the switches. Each L/M-pair can operate as either a microphone or a loudspeaker.

25.	Original	The operational mode of the L/M-pairs shall be changed when requested by the Software.	1
26.	Original	The L/Ms shall be able to produce any derived audible sound within the frequency range specified in requirement 13.	1
27.	Original	The L/Ms shall be able to receive sound data and convert the sound data into electrical signals with an SNR no lower than 35 dB.	1
28.	Original	The L/Ms shall be able to send the converted electrical signals, mentioned in requirement 27, to the Software.	1

5 PERFORMANCE REQUIREMENTS

29.	Original	The product shall be able to produce a sound intensity of at least 64 dB in the point of focus, where the point of focus is at a distance of at least one meter to the closest L/M unit.	1
30.	Original	The product shall be able to suppress the sound intensity with at least 6 dB compared to a point, located at least half a wavelength from the point of focus, where the point of focus is at a distance of at least one meter to the closest L/M unit.	1
31.	Original	The product shall be able to crack a single wine glass among a total of 4 wine glasses, given that the glasses are placed in a line with at least 0.3 meters between each glass.	2

6 ECONOMY

32.	Original	Every member of the Project Group shall put 240 hours of work into the development of the product.	1
33.	Original	The Project Group shall not use more than 15 hours of supervision provided by the Supervisor.	1
34.	Original	The Project Group shall not use more than 25 hours of expert consultancy provided by the Hardware Expert.	1

7 DELIVERABLES

The following deliveries shall be made by the Project Group. The description of each delivery can be found in table 3 and table 4.

35.	Original	Requirement Specification	1
36.	Original	System Design Sketch	1
37.	Original	Project Plan	1
38.	Original	Time Plan	1
39.	Original	Design Specification	1
40.	Original	Test Plan	1
41.	Original	Test Protocols	1
42.	Original	Protocols from tollgates	1
43.	Original	Individual and collective Time Reports	1
44.	Original	Status Reports	1
45.	Original	User Manual	1
46.	Original	Technical Report	1
47.	Original	Afterstudy	1
48.	Original	Poster	1
49.	Original	Project Conference	1
50.	Original	Web Page	1
51.	Original	The Product	1

Table 3: This table describes some of the deliverables in more detail.

Delivery	**Contents/Definition**
Poster	A collection of informative pictures and paragraphs describing the resulting product and its capabilities.
Project Conference	A conference where the Project Group presents the product.

Delivery	Contents/Definition
Web Page	A web page containing information about the product and its capabilities.
The Product	The system demonstrating the capability of massive MIMO to focus energy towards a very precise point, including nicely written and good commented code for the Software.

8 DOCUMENTATION

Table 4: Listing over all the documents that will be produced within the project.

Document	Language	Contents	Format
Requirement Specification	English	Defines all requirements on the product.	pdf
System Design Sketch	English	Describes the initial thoughts on the design of the product.	pdf
Project Plan	English	Describes how the project shall be performed.	pdf
Time Plan	English	Details when and by whom the various activities in the project will be performed.	pdf
Design Specification	English	Details how the product shall be designed.	pdf
Test Plan	English	Details how the product shall be tested.	pdf
Test Protocols	English	Specifies the outcome of the tests specified in the Test Plan.	pdf
Individual and collective Time Reports	English	Contains individual and collective time reports, per activity and per person, weekly.	pdf
Protocols from milestones	English	Protocol to describe the progress of the product development.	pdf
Protocols from tollgates	English	Protocol to describe the tollgates.	pdf
User Manual	English	Specifies how the user shall use the product.	pdf
Technical Report	English	Details how the product is implemented.	pdf
Afterstudy	English	Presents a retrospective discussion about results and time planning.	pdf

9 EDUCATION

52.	Original	The user manual shall be detailed enough to be the only educational material needed for the user to use the product.	1
53.	Original	The customer shall be provided a guided demonstration of the product in order to know how it is used.	1