

# User Manual

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**DOCUMENT HISTORY**

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## 1 Introduction

The purpose of this document is to inform the user of the system built in one of the 2015 year's CDIO projects in the course TSKS05, called *Zero Forcing*. This document will mainly give short descriptions of the different parts of the system and will mainly introduce how to use the actual system, as in how to setup and run the system. A more thorough description of the actual hardware and software parts of the system can be found in the project's *Technical Report*[1].

The built system's main usage is to demonstrate the Zero Forcing capabilities and possible applications of Massive Multiple Input Multiple Output (Massive MIMO). Zero Forcing is a type of beamforming technique used in Massive MIMO in a multi-user environment where the signal energy towards an intended user is maximised under the constraint that no interference is caused to the remaining users. The system can demonstrate these things on audio channels by using hardware designed in 2014 year's version of the TSKS05 course[2].

## 2 Components

The hardware and the components of the system has not been altered within this project. Thus, the description of the components here will heavily rely on the description from 2014 year's project's *User Manual*[3]. The different components listed below are also depicted in Figure 1.

1. The Computer with an AD card (Contec AD12-64, PCI), a D/A card (Contec DA12-16, PCI) and installed MIMO software.
2. The Distribution Box.
3. The power supply, University Power 3535.
4. Eight L/M-pairs.
5. Four USB power adapters.
6. One 37-pin D-sub connector cable.
7. One 96 pin PCA connector cable.
8. Eight 9-pin D-sub connector cables.

### 2.1 The Computer

The computer, together with its ordinary components, also have an A/D card of type Contec AD12-64 (PCI) and a D/A card of type Contec DA12-16 (PCI). Connections to these cards can be found on the lower back of the computer. The top slot is the D/A converter and the bottom one is the A/D converter. The computer runs Windows 7 and has MatLab installed in order to run the software programs. It also has a library called *ML-DAQ* which is used in order to fetch and send data, from and to the D/A and A/D cards.

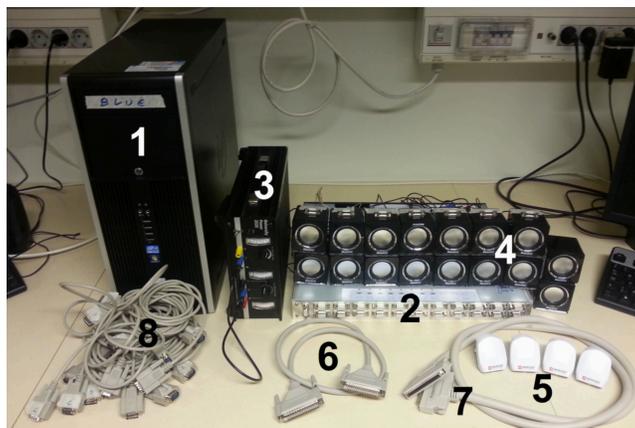


Figure 1: The components in the system. [3]

## 2.2 The Distribution Box

The Distribution Box provides connections between the computer and the L/M-pairs. On the front panel there are 23 connections, but only the top left eight connections are used. The rest of the connections can be used for future extensions.

On the backside, there are eight switches, one connection for the D/A-card and four cables to the Power Supply Unit. The switches control whether a L/M-pair belong to `TERMINAL_GROUP_G` or `ARRAY_GROUP_G` in the `initSWGlobalsScript` [1]. Thus, the switches control which pairs are used as terminals and which are used in the array.

- Switch down means `TERMINAL_GROUP_G`.
- Switch up means `ARRAY_GROUP_G`.

All L/M-pairs in the same group will always have the same mode of operation, that means receiving or transmitting data.

The mapping of the power cables can are described in Table 1.

Table 1: Mapping of power supply cables to voltage.

Color	Voltage
Yellow	+5 V
Black	Ground
Blue	-11 V
Red	+11 V

On the top of the Distribution Box there is a connection for the A/D-card.

## 2.3 The Power Supply Unit

The Power Supply Unit for the Distribution Box is named *University Power 3535* and has a total of five connections. Two belong to the output channel with output range [4, 6] V DC, where one connection is positive and one is ground. The other three connections belong to the other output channel consisting of one negative and one positive connection and one ground. The positive and negative channels has ranges [-16, -11] V and [11, 16] V respectively. The two grounds of the system of the power supply is connected so that both channels share a common ground.

The Power Supply Unit has two controls. They control each the levels of the output channels individually. The minus and the plus pole of the second channel is thus adjusted simultaneously by the second control.

## 2.4 L/M-pairs

L/M stand for Loudspeaker/Microphone, since the two units in each L/M-pair are able to operate as both loudspeaker and microphone. One L/M-pair consists of two L/M-units, one master and one slave. The master has a 9-pin D-sub connector on top of it. Each L/M-pair is powered through a USB-cable and shines blue on the bottom of each unit when it is powered. The master loudspeaker has a volume control on the backside and this control alters the volume of both loudspeakers when they are acting in loudspeaker mode.

- The system is calibrated with all volume knobs set in the middle (at 12 o'clock).

## 2.5 USB Power Adapters

The USB Power Adapters for the L/M-pairs are simple *Skross USB travel chargers* with two outputs. They are connected to a wall outlet and delivers an output DC voltage level of 5 V per output.

## 2.6 Connection Cables

The connection cables between the L/M-pairs and the Distribution Box consists of D-sub cables with a 9-pin plugs on both ends, each of length 1.8 m. The cable between the D/A converter and the computer is a D-sub cable with a 37-pin plug on both ends. The connection between the Distribution Box and A/D converter of the computer consists of a 96 pin PCA connector cable.

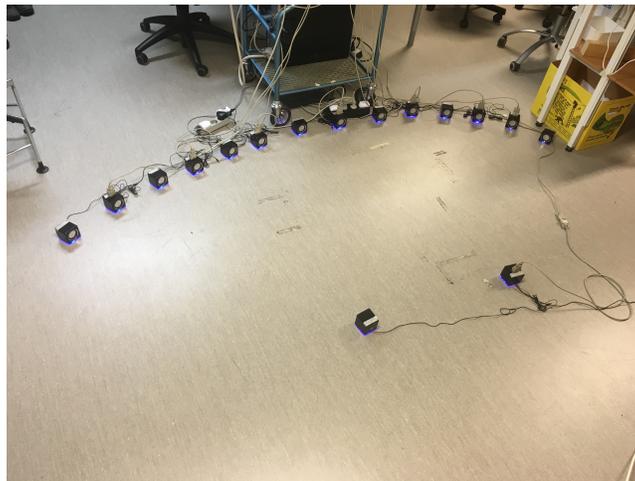
# 3 Setting up the System

The following must be carried out in order to set up the system:

1. Put all the L/M-pairs on the ground. This can be done in different layouts but we recommend setting the array units as an arc with the terminal units parallel to the arc. Ensure that no terminal unit is at the focus of the arc.

2. Connect the connection cables between the L/M pairs and the distribution box. The cables, ports on the L/M-pairs and the Distribution Box are labelled and should be connected accordingly.
3. Connect the D-sub connector cable and PCA connector cable between the Distribution Box and the CPU.
4. Connect all the USB cables of the L/M-pairs to the USB power chargers. The USB power chargers then need to be plugged in to a wall outlet. Make use of extension cords in order to get this done easily.
5. Ensure that the toggle switches behind the Distribution Box are set correctly for your system layout. The L/M-pairs that are being used as part of the transmitting array must have the switches toggled up and the remaining receiving terminal pair switches must be down.
6. Ensure that the power cables from the Distribution Box are connected to the Power Supply correctly and that the power supply unit has the right voltages as per table 1. The Power Supply unit must be turned on to run the system.
7. Turn on the computer and boot windows 7. The system is now ready and can be ran using the provided software.

For good results we recommend placing the L/M-units as shown in the below Figure 2. The array units should be 15-20cm apart from each other. The terminal units should be at least 50cm apart and between 1-2m away from the array.



*Figure 2: The recommended setup.*

## 4 Running the Software

To run the system the user should log in to the computer connected to the hardware. The system files can be found in the "GIT ZF 2015"-folder on the Desktop. To run the system, open the run the script `main.m` located in the controller folder. The user will then be presented with the choice if he wants to set the run parameters himself or if he wants to use the predefined parameters when running the system. The predefined parameters are described in section 4.1.

If the user chooses to do the setup manually he will be presented with a series of yes/no questions about which parameters that he wants to set. Some of the questions will have follow up questions prompting the user for input-values of the parameter in question.

### 4.1 Specifying Parameters

This section describes the parameters that the user can change for different system setups.

#### System run parameters

- Array pairs – Which pairs that are used in the sender Array.  
Recommended value: [1 2 3 4 6 7 8]
- Terminal pairs – Which pair(s) that is positioned as terminal(s).  
Recommended value: 5
- Sample Frequency – Sample frequency used in the system, has a limit of  $6250\text{Hz}$ .  
Recommended value:  $6060\text{ Hz}$
- Carrier Frequency – Carrier frequency used in the system.  
Recommended value:  $505\text{ Hz}$
- Use Zero Forcing – If true Zero Forcing beamforming is used, if false Maximum Ration combining is used.
- Use power control – If true, power control is applied to the beamforming, so that the system sends equal amount of power to both terminals.
- Use Error Control – If true error control will be used, otherwise it will not be used.  
Recommended value: True
- Use root raised cosine – If true a root raised cosine filter will be used for the modulation, if false a rectangular filter will be used.  
Recommended value: False
- Use interleaver – If true an interleaver will be used in the modulation step, otherwise it will not be used.  
Recommended value: True

- Use K-mean clustering – If true K-mean clustering will be used in the demodulation step, otherwise it will not be used.  
Recommended value: True
- PSK - Value – What exponent should be used in the PSK, 1 for BPSK, 2 For QPSK.  
Recommended value: 1

### **Plot parameters**

- Plot passband signal before sending – True or false
- Plot received signal PSD – True or false
- Plot Inphase phase and quadrature phase plots – True or false
- Plot scatter plots – True or false
- Plot eye diagrams – True or false

## **4.2 Interpreting the Results**

This section describes and explains the results produced from running the system. The section is divided in two parts. One explains the various printouts of relevant metrics given after each run. The other part explains the resulting plots.

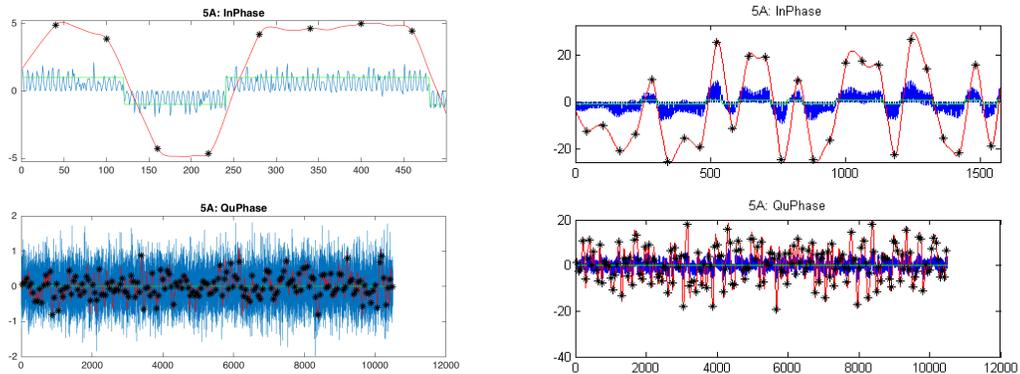
### **4.2.1 Interpreting metric results**

There are a few metrics presented after running the system that might be relevant to the user.

- Error rate – The percentage of bits that were erroneously received. Expected value: 0-10%.
- Total Sending Power – The sum of the power of the sent signal on all array units.
- Received Power – The received signal power at the receiving terminal units. In the format [Master, Slave].
- Estimated channel – Shows the length between each terminal and each array pair in centimeters.

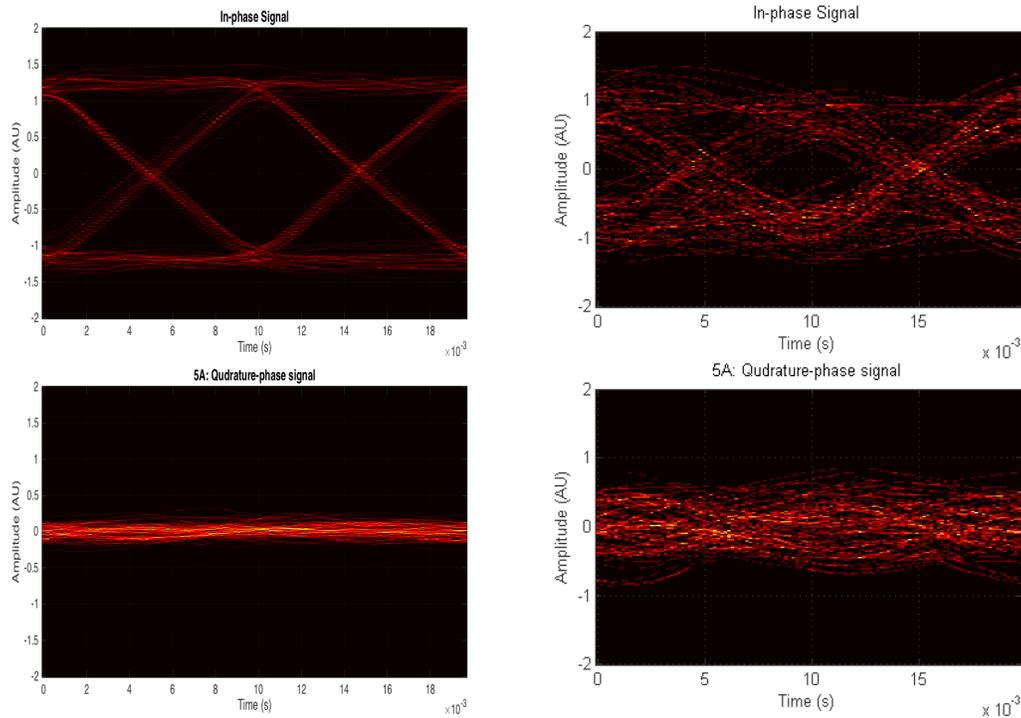
### **4.2.2 Interpreting plot results**

This section explains how to interpret the resulting plots. The plots on the left hand side in this section are created using a simulated AWGN channel model, those on the right hand side using the actual system. As these are plotted using a BPSK modulation, i.e. only in-phase component containing information, the descriptions focus on the in-phase parts.



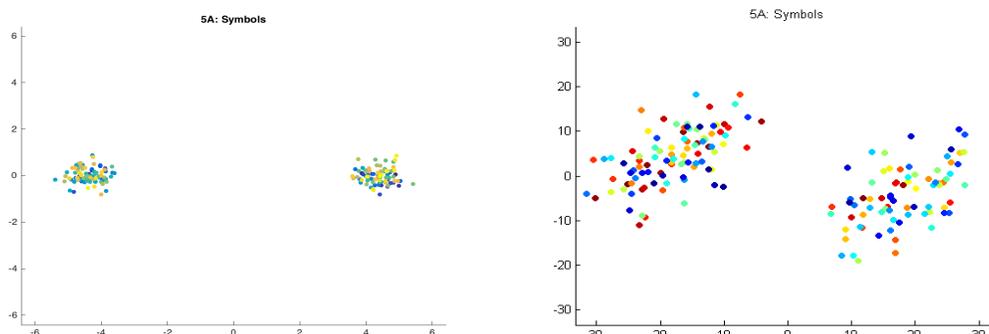
*Figure 3: Left: IQ phase plot of a simulated run. Right: IQ phase plot of a run on the real system*

In figure 3 three curves and some stars can be seen. The blue curve is the received signal down converted using a cosine at the carrier frequency. This gives the blue line both the DC-offset of the original message and a component oscillating at twice the carrier frequency. This signal is then filtered which results in the red curve, which is the one used to make decisions on symbols. The black stars marks the sampling points. The green curve represents the actual sent symbols. In the simulated result one can see both blue and red curve holding still when a symbol is repeated, this unfortunately not true for the real system and indicates that there is some level of memory in this particular channel.



*Figure 4: Left: Eye diagram plot of a simulated run. Right: Eye diagram plot of a run on the real system*

In figure 4 one can see an eye diagram of the filtered version of the received signal, i.e. the red curve in figure 3 (though the amplitude in the eye diagram is scaled to fit between  $\pm 1.5$ ). In the eye diagram all the transitions between symbols are plotted on top of each other, with the sampling points placed in the middle and at the side borders. Ideally the result should look as the plot to the left, but will look more likely the one to the right (in the case of a successful run). In the case of a really bad channel the plots will be just red lines all over the place.



*Figure 5: Left: Scatter plot of a simulated run. Right: Scatter plot of a run on the real system*

Figure 5 shows scatter plots of the received symbols. Each sample point in the filtered in-phase component is matched with corresponding point in the filtered quadrature-phase component and then plotted. From the simulated case it is clear that the system is well behaved - nothing else than noise is added. In the plot from the actual system a slight phase shift can be seen. This is probably due to the system only syncing on a sample level. A K-mean clustering algorithm is used to mitigate this. It draws a line between the centroids of the two clusters and calculates the phase shift from that.

### 4.3 Hints for a Successful Demonstration

If the system gives poor results then it might be due to the physical setup of the L/M units. First try and move the terminals that exhibit bad performance about 10 centimeters. If the results are still not satisfactory try and position the units in the MIMO array in a wide parabola and so that the distance to the individual units from a terminal does not differ by more than one wavelength ( $\sim 70$  centimeters if recommended values are used for the parameters).

Needless to say background noise in the room also affects the results negatively. It is beneficial, but not necessary, to use the system in an open space to reduce reflections and scattering.

Two important things to look out for is that the hardware switches mentioned in the beginning of section 2.2 are set up correctly according to the software variables. The user also has to make sure that the power supply unit mentioned in section 2.3 is turned on.

## References

- [1] Mikael Karlsson et al., *Technical Report*. ISY, Linkoping University, 2015.
- [2] Fredrik Stenmark et al., *Technical Report*. ISY, Linkoping University, 2014.
- [3] Fredrik Stenmark et al., *User Manual*. ISY, Linkoping University, 2014.