Mechanical Antenna Beam Steering

SubTitle

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Bachelor of Engineering in Electronics, Spring 24

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STUDENT REPORT

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Abstract:

In this semester project an algorithm is developed, that ...

Contents

Preface

This project was developed by Rikke Udengaard in the Spring semester of 2024 at Department of Electronic System at Aalborg University.

Aalborg University, May 10, 2024

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Chapter 1

Introduction

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Chapter 2

Technical Analysis

The purpose of beam steering is to increase the antenna gain in a specific direction to achieve reduction in interference and to save power. This is enabled by having the main lobe of a radiation pattern of a directional antenna pointing towards the target of transmission and reception. Beam steering is purposeful for narrow directional beams. Beam steering can be performed using manual, mechanical or electronic with the main differences being type of implementation and increasing speed of change of directivity from manual to electronic [17] [6]. This chapter explores the properties of antennas and beam steering methods, in order to understand antenna beam steering.

2.1 Fundamentals of Antennas

In order to develop a beam steering device for antennas it is necessary to understand antennas and their properties. Propagation, polarization, radiation characteristics are all properties of antennas that can vary based on the type of antenna.

2.1.1 Propagation In Free Space

Propagation of radio waves can be described with Maxwell's equations using the spherical coordinate system (r, θ, ϕ, t) for antennas. The Maxwell equations in differential form are as follows

$$\begin{aligned}
\nabla \times \mathbf{E} &= -\frac{\partial}{\partial t}\mathbf{B} \\
\nabla \times \mathbf{H} &= \mathbf{J} + \frac{\partial}{\partial t}\mathbf{D} \\
\nabla \cdot \mathbf{B} &= 0 \\
\nabla \cdot \mathbf{D} &= \rho
\end{aligned} \tag{2.1}$$

with **E** being the electric field with unit [V m^{-1}], **B** being induction [T], **H** is magnetic field [A m^{-1}], **D** being dielectric displacement [A s m^{-2}], **J** being the current density [A m^{-2}] and ρ being electric charge density [C m^{-3}].

The electric field and the magnetic field are always connected; the electric field is created by the magnetic field and vice versa. The electric field and the magnetic field in spherical coordinates are illustrated on figure 2.1 below.

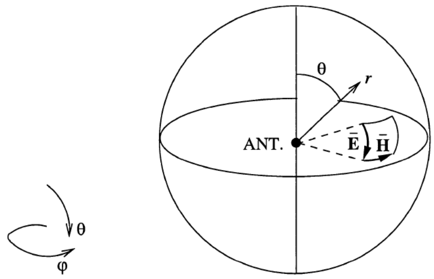


Figure 2.1: Electromagnetic field around a small antenna in far field range visualised in the spherical coordinate system [5, p. 58].

As visualised on figure 2.1 the electric field only depends on the θ-component and the magnetic field only on the ϕ-component when in the far field. The vector **r** is direction of the observation point. The length of **r** is the distance to the observation point ie. distance between transmitting and receiving antenna [5, p. 59].

The Poynting vector describes the power density and direction of the Electromagnetic flux and is the cross product of the electric and magnetic field

$$\mathbf{S} = \mathbf{E} \times \mathbf{H} \qquad [\mathrm{W\,m^{-2}}] \qquad (2.2)$$

which points in the same direction as the wave propagation [16, p. 3].

Multipath propagation

Because electromagnetic waves can reflect on surrounding surfaces, be changed by condition of the transmission medium or be Doppler shifted due to movement of objects, receiver or transmitter, the signal that reaches the receiving antenna can have travelled other paths than the direct line-of-sight path from the transmitter. The received signal is a summation of all input signals regardless of phase angles, phase shifts or direction and therefore the received signal might be distorted [12, pp. 1-2].

2.1.2 Polarization

Different antenna designs have different radiation patterns and polarization. Table 2.1 lists a number of different antenna designs and their polarization

Type	**Polarization**
Isotropic antenna	
Dipole antenna	Linear
Patch antenna	Linear, circular
Horn antenna	Linear, cicular
Helical antenna	Circular

Table 2.1: Table showing polarization of some typical antenna designs [16, p. 11].

Polarization describes the classification of the plane propagated wave, which is a electromagnetic wave that propagates with constant velocity in a specific direction. The direction of the propagation of the electromagnetic wave is always perpendicular to the direction of the electric field **E** and both are perpendicular to the direction of the magnetic field **H**. If the direction of the electric field is constant with time and position, the polarization of the propagated wave is classified as linear. If the direction of the electric field changes by rotating uniformly around the axis of the propagated wave, the wave has circular polarization. The polarization of the receiving and transmitting antennas affects how the signal is detected. The signal is best received when the polarization of the receiving antenna is the same as the polarization for the transmitting antenna. Mismatch in polarization will result is less received signal power or more signal noise [11, p. 82-84].

2.1.3 Radiation Characteristics

The electromagnetic waves are radiated to the near field and then far field. The far field is mathematically described as the distance $r > R_2$, with R_2 defined as

$$R_2 = \frac{2D^2}{\lambda} \qquad [\mathrm{m}] \tag{2.3}$$

with D being the largest dimension of the antenna or antenna array and λ being the wavelength of the carrier frequency [16, p. 4].

The radiation characteristics of an antenna can be described by the directivity, which is defined as the ratio of the maximum power density $S(\theta, \phi)_{max}$ radiated to the average power density $S(\theta, \phi)_{avg}$ radiated by an antenna. The directivity is unitless [11, p. 63]. An isotropic antenna is a theoretical antenna which radiates homogeneously in all directions, meaning that the magnitude of the power density vector **S** at a distance vector **r** is constant

$$D(\theta,\phi) = \left| \frac{S(r,\theta,\phi)}{S_{max}} \right| = 1 \tag{2.4}$$

It is this theoretical isotropic radiator that the gain of antennas are in respect to. The gain of a directive antenna in a certain direction is called the antenna gain G [16, p. 12]. The directivity doesn't depend on the distance r in the far field meaning that at the receiver antenna, the relation $r \gg R_2$ is assumed.

The total radiated power P_r is found by the surface integral of the power density. Assuming a spherical surface, the total radiated power is described as

$$P_r = \int_0^{2\pi} \int_0^{\pi} S(\theta,\phi)\, r^2 \sin\theta \, d\theta \, d\phi \qquad [\mathrm{W}] \tag{2.5}$$

And further, averaging the radiated power over every direction in the sphere gives the relation

$$P_{avg} = \frac{P_r}{4\pi r^2} \qquad [\mathrm{W\,m^{-2}}] \tag{2.6}$$

Replacing the average power density $S(\theta,\phi)_{avg}$ by the average power in every direction P_{avg}, the directivity of an antenna $D(\theta,\phi)$ can be defined as

$$D(\theta,\phi) = 4\pi r^2 \frac{S(\theta,\phi)_{max}}{P_r} \tag{2.7}$$

with $S(\theta,\phi)_{max}$ being the maximum power density and P_r being the total radiated power of the antenna.

The power of the source $P_{s,t}$ to a transmitting antenna might not equal the radiated power $P_{r,t}$ due to power loss $p_{l,t}$. Power loss can happen because of reflection loss in the input medium (typically cable), conductor loss and inductor loss. The efficiency of the transmitting antenna η is described as the ratio of the radiated power to the sourced power

$$\eta = \frac{P_{r,t}}{P_{s,t}} = \frac{P_{r,t}}{P_{r,t} + P_{l,t}} \tag{2.8}$$

The gain $G(\theta,\phi)$ of the antenna is the effective directivity, meaning how well the receiving or transmitting antenna is able to convert, respectively, electromagnetic waves or power into the other. The gain of a transmitting antenna can be calculated as

$$G_t(\theta,\phi) = \eta D_t(\theta,\phi) = 4\pi r^2 \frac{S_t(\theta,\phi)_{max}}{P_{s,t}} \tag{2.9}$$

or expressed in decibel with respect to the isotropic radiator [16, p. 10] [19, pp. 1.8-1.10].

$$g_{dBi} = 10 \log_{10}(G) \qquad [\mathrm{dB}] \tag{2.10}$$

2.1.4 Friis Transmission Equation

The Friis transmission equation explains how the received power at a receiver antenna is related to the power of the transmitting antenna. The receiver antenna receives energy from the transmitting antenna and the effectiveness of this is described as the effective area $A_r(\theta, \phi)$ assuming that the antenna is placed in the origin of the spherical coordinate system. If the antenna has the property of reciprocity, the effective area and the gain of the receiver antenna is related by

$$A_r(\theta, \phi) = \frac{\lambda^2}{4\pi} G_r(\theta, \phi) \qquad [\mathrm{m}^2] \quad (2.11)$$

If the gain of the transmitting antenna G_t is in the direction of the receiver antenna G_r then the angular dependencies of the antenna properties can be surpressed. The power of the receiving antenna is equal to the power density $S_t(\theta, \phi)$ multiplied by the effective area of the receiver antenna A_r, expressed as

$$P_r = S_t A_r \qquad [\mathrm{W}] \quad (2.12)$$

As previously mentioned the directivity of an antenna does not depend on the distance r from the antenna, and likewise so with the power density S_t, so the value of S_t is equal regardless of the distance from the antenna in the far field with respects to the angular dependencies. Substituting S_t and A_r in equation 2.12 for S_t isolated in equation 2.9 and A_r from equation 2.11 yields

$$\begin{aligned} P_r &= \frac{G_t P_t}{4\pi r^2} \frac{\lambda^2 G_r}{4\pi} \\ &= G_t G_r P_t \left(\frac{\lambda}{4\pi r}\right)^2 \end{aligned} \qquad [\mathrm{W}] \quad (2.13)$$

Also called Friis transmission equation [19, pp. 1.10-1.11]. G_t is the gain of the transmitting antenna in the direction of the receiver and G_r is the gain of the receiving antenna in the direction of the transmitter. The radiation characteristics of an antenna in the far field is called the antenna radiation pattern and will look different depending on the design of the antenna. The radiatation pattern is dependent on the anglular properties θ and ϕ and is usually visualised in a plane parallel to the electric field and called an **E** plane pattern or elevation plane pattern, or parallel to the magnetic field and called a **H** plane pattern or Azimuth plane pattern [11, p. 79-80][16, p. 13-14].

2.1.5 S-Parameters

S-parameters are used to describe the input and output relationship of a system's ports at microwave frequency [18]. S-parameters are used because voltages and currents can be difficult to measure directly in the microwave frequency spectrum. S-parameters describe a network in waves instead of voltages and currents [15]. S-parameters can be used to describe a n-port, $n \geq 1$, system and are dependent on frequency [18]. Some typical systems are one-port and two-port systems, visualised in figures 2.2 and 2.3.

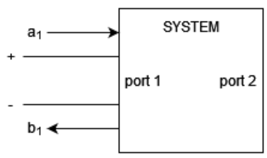


Figure 2.2: One-port system.

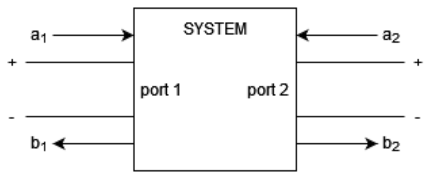


Figure 2.3: Two-port system.

The parameters a and b represent the wave flow in the system and they are a linear combination of the voltages and currents at the ports [15].Looking at a two-port system, such as a system with a receiver antenna and transmitter antenna, the S-parameter matrix looks as follows:

$$\begin{bmatrix} b_1 \\ b_2 \end{bmatrix} = \begin{bmatrix} s_{11} & s_{12} \\ s_{21} & s_{22} \end{bmatrix} \begin{bmatrix} a_1 \\ a_2 \end{bmatrix} \tag{2.14}$$

The S-parameters represent different information about the system.

Parameter	**Description**
S_{11}	$S_{11} = \frac{b_1}{a_1}$. Forward reflection coefficient. Describes the input return loss Γ i.e. what is reflected from the port rather than radiated or absorbed.
S_{12}	$S_{12} = \frac{b_1}{a_2}$. Reverse transmission coefficient i.e. how much is transmitted from port 2 to port 1.
S_{21}	$S_{21} = \frac{b_2}{a_1}$. The forward transmission coefficient i.e. how much is transmitted from port 1 to port 2.
S_{22}	$S_{22} = \frac{b_2}{a_2}$. Reverse reflection coefficient i.e. output matching.

Table 2.2: Explanation of S-parameters [18].

Ideally, an electrical load is designed to have the least possible absorbtion. This means the power transfer is maximised or the signal reflection is minimised, depending on the use case. This is done by matching the input impedance of the electrical load to the output impedance of the signal source, such as a cable. Minimal reflection is achieved when the complex output impedance is equal to the complex input impedance and maximum power transfer is achieved when the complex output impedance is equal to the complex conjugate of the input impedance. If the input impedance of an electrical load is denoted Z_L and the characteristics output impedance of a signal source is denoted Z_0 [18][15], the return loss can be calculated as

$$\Gamma = \frac{Z_L - Z_0}{Z_L + Z_0} \tag{2.15}$$

Using the reflection coefficient the output flow of the system's port one is equal to $b_1 = \Gamma a_1$ [15]. S_{11} and the reflection coefficient γ are related as follows:

$$S_{11} = 20 \log_{10} (|\Gamma|) \quad \text{[dB]} \tag{2.16}$$

2.1.6 Antenna Designs

The design of the antenna affect the radiation characteristics, the bandwidth and the range of frequencies that the antenna is able to transmit or receive [11, p. 76]. Bandwidth is the range of frequencies on which the antenna is expected to operate in the wanted manner. There are several criterias that can be used to decide on the bandwidth for an antenna, for example the range where the reflection coefficient (see 2.1.5) is less than a specified value or when the polarization fits a certain shape (see 2.1.2). The antenna design affects the operating frequency range of the antenna and so an antenna can also be designed to operate with a given bandwidth. The radiation pattern of an antenna varies with the frequency but the general shape is primarily decided by the design of the antenna [2]. The antenna types described in table 2.1 are some typical design types along with the isotropic antenna which is a theoretical antenna [16, p. 11].

A center-driven dipole antenna is two wires or rods pointing at the opposite direction of each other, for example towards positive and negative z in the spherical coordinate system. In the Azimuth plane the radiation pattern is a circle centered at the centre of the dipole antenna, whereas in the elevation plane, the radiation pattern is two ears extending from the centre to either side (see figure 2.4) [16, pp. 12-14]. The figure 2.4 shows a typical radiation pattern for a one-wavelength dipole antenna. As seen, the dipole antenna has a very uniform pattern, but increasing the length of the dipole can increase the directiveness. However, the length also affects the input impedance. The dipole antenna will always have linear polarization [3].

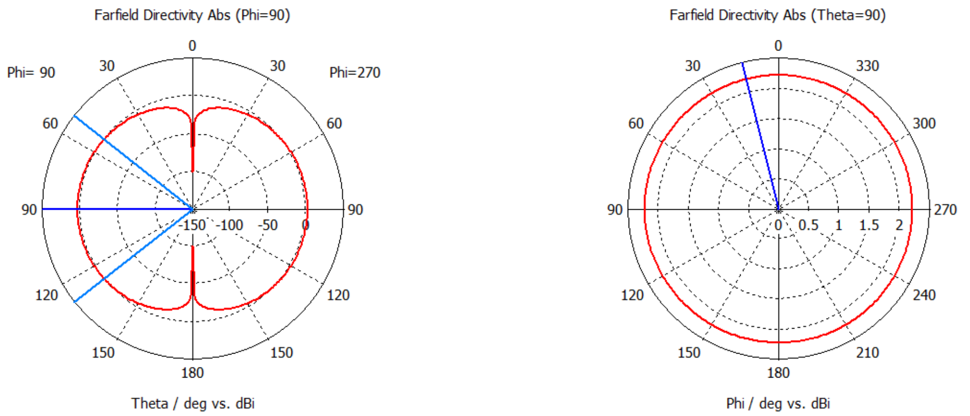


Figure 2.4: Dipole antenna radiation pattern. Figures generated with *CST Studio* dipole antenna example ($f = 2.4\,\text{GHz}$).

A patch antenna is in its simplest form a piece of metal on top of a grounded surface. The metal can have different shape and size to accomodate different operating frequencies, bandwidths and gains. The feeding of the patch can also affect the antenna parameters such as the impedance match. The patch antenna is usually only used for UHF applications, because the flatness of the antenna allows it to fit into narrow areas, where the patch size must also be small. The operating frequencies depend on the size of the patch. The patch antenna has lower efficiency than many other antenna design types, and a small bandwidth. The radiatation pattern depends, as in all cases, on the design of the patch, and can have a large variety of shape [19, p. 7.1-7.5]. An example can be seen in 2.5.

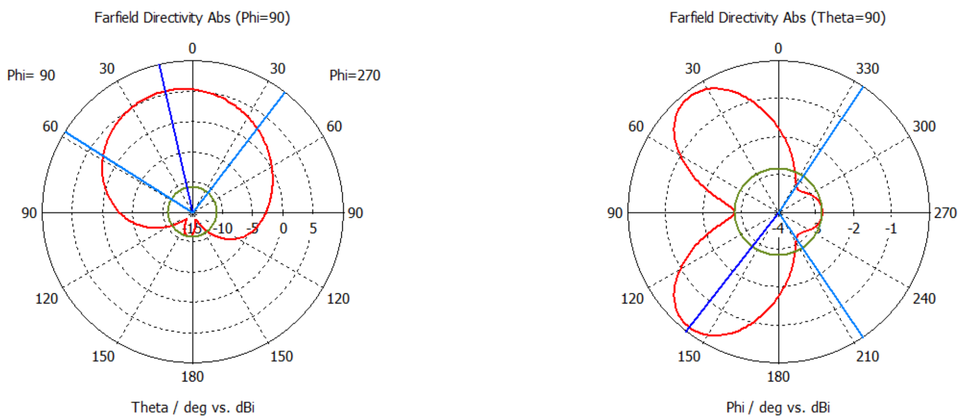


Figure 2.5: Patch antenna radiation pattern. Figures generated with *CST Studio* ($f = 2.4\,\text{GHz}$).

Horn antennas come in many shapes and sizes which affect the radiation pattern and gain but common amongst the different designs is high beam directivity.

A pyramidal, rectangular horn antenna is a common horn antenna, and has a fan-shaped radiation pattern. The gain can be calculated by knowing its dimensions and the beamwidths of the fan can be changed by the varying the aperture dimensions. Horn antennas can be designed to cover both wide and narrow bandwidths, linear or circular polarization and have a certain gain. It is therefore that horn antennas are regarded as being able to fulfill many different applications [19, p. 14.1-14.3].

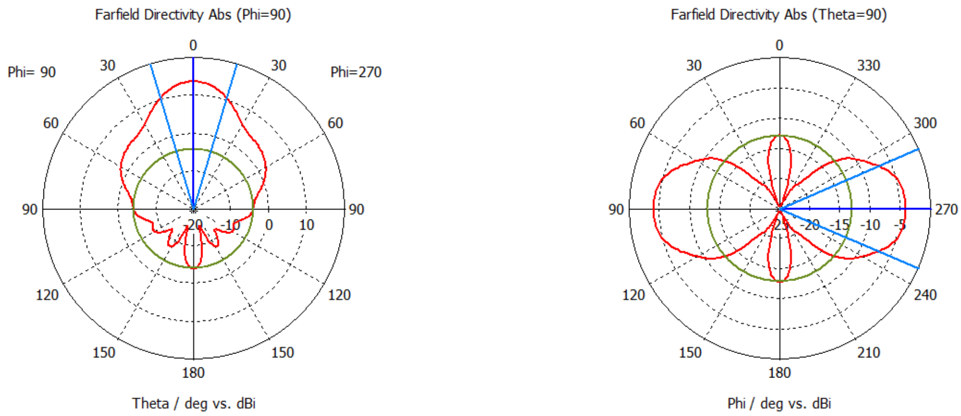
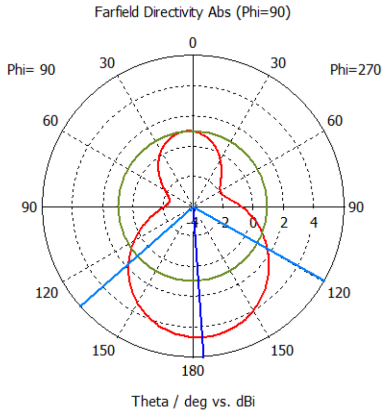


Figure 2.6: Horn antenna radiation pattern. Figures generated with *CST Studio* horn antenna example ($f = 2.4\,\text{GHz}$).

A helical antenna is one or several conductors in a helical shape connected to a ground plane and can be configured in many modes, usually *normal* or *axial* mode. Normal mode is achieved when the diameter of the helix is smaller than a wavelength and axial mode is when the circumference is close to the wavelength. A helix antenna has circular polarization in either right-hand or left-hand direction. A helix antenna has a wide spectrum for which impedance characteristics can be matched [19, p. 12.2].



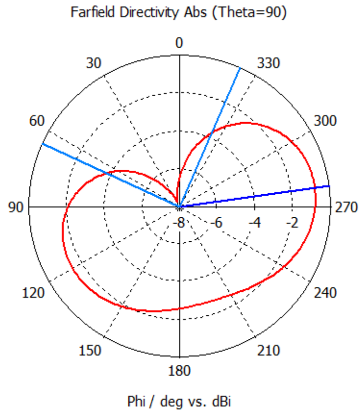


Figure 2.7: Helical antenna radiation pattern. Figures generated with *CST Studio* ($f = 2.4\,\mathrm{GHz}$).

Antennas can also be put together in arrays. This changes the characteristics of the radiation pattern and ??

arrays

2.2 Beam Steering Methods

Although the design of the antenna or antenna arrays decide the pattern of radiation, it is possible to modify this pattern or the direction of the pattern to achieve different directivities for other applications. The beam of the antenna can be steered in different directions for example, in order to cover a larger physical area with a single or few antennas. Beam steering can be done manually, mechanically or electrically.

2.2.1 Manual and Mechanical Steering

explain motor control and types of motors with type of control loops

2.2.2 Electrical Steering

Chapter 3

Requirements and Delimitations

The purpose of this project is to develop a setup where a receiving antenna is able to detect a transmitting antenna at a abitrary point in space and testing this setup. Detection of radio waves can for example be used for intruder detection or can be further developed to include data transmission and thereby achieving higher troughput if the transmitting antenna is able to locate and focus on the receiving device.

Concluding on these two scenarios, it is required that the receiving antenna must be able to be controlled ie. steered in any direction and the electromagnetic radiation in the area must be read.

3.1 Delimitations

The setup developed in this project will only be designed to be able to work in a two-dimensional plane. Moreover, in order to be able to reproduce the test results, the environmental variables such as objects in the space, size of space, temperature and humidity must be controlled and measurable.

3.2 Functional Requirements

The following table 3.1 outlines the functional requirements:

ID	Requirement	Traceability
F.1	Mechanically controlled turning along Azimuth angle ϕ	Chapter 3 introduction, section 3.1
F.2	Data reading of electromagnetic radiation in the surrounding space	Chapter 3 introduction, section 3.1
F.3	Controlled test environmental variables	Section 3.1

Table 3.1: Table of functional requirements.

3.3 Technical Requirements

outline in table technical requirements. Remember environmental requirements temp and hum

ID	Requirement	Traceability
T.1	Operating temperature of ??	?
T.2	Operating humidity of ??	?
T.3	Matching antenna polarization	?
T.4	Automatic, (speed?) control	?

Table 3.2: Table of technical requirements.

Chapter 4

Design of Antenna Beam Steering

The full system that will be designed includes a VNA, a turntable, two antennas and a computer. This chapter will describe the interfaces between these and their individual functionalities. In order to get an overview of the full system consider the figure 4.1

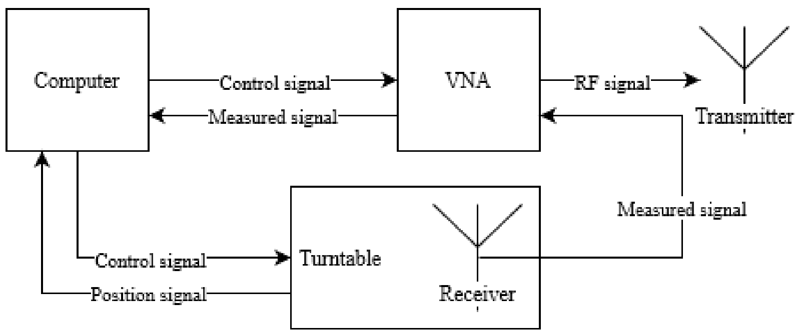


Figure 4.1: Overview of system design.

The system composes of three integrated modules and two antennas. The first antenna is a transmitter antenna and the second antenna is a receiver antenna, which is meant to be able to measure the gain in a wide area. This wide area is determined by the turning of the turntable on which the receiver antenna is mounted. Both the transmitter antenna and receiver antenna are connected to a VNA, but for the transmitter antenna, the functionality of the VNA used is the RF generator. For the receiver antenna, the received signal measured is then further sent to the computer for data analysis. The computer controls the turntable and the VNA. This includes defining settings before the analysis and taking decisions based on the returned data: the position of the turntable and the measured antenna signal from the VNA.

4.1 Antenna Design

explain design of horn antenna and why

4.2 Choice of Turntable

explain choice of turntable and how it meets reqs

4.3 Choice of Vector Network Analyzer

explain choice of vna and how it meets reqs

4.4 Design of Software Control Program

Using one computer for the control of every aspect of the system allows for the devices to be programmed to work concurrently. Both the VNA and the turntable are known to be able to be controlled in Python, there the control of the turntable and VNA is programmed in Python. The control of the turntable is implemented as adviced by the manual (see [8]), with the supplied software *RC-HRT I*. However, in order to control the turntable concurrently with the VNA, the *RC-HRT I* software is interfaced via Python with the module *pywin32*, which provides access to the Windows APIs [10]. *Rohde & Schwarz* have published a Python module for control of the VNA which is used. The module adds an API for the remote control of the VNA, which is communicated with over TCP using SCPI-commands *(Standard Commands for Programmable Instruments)*. Finally, thread parallelism is achieved with the module *threading*, which is what allows for the design of the control flow to work more efficiently.

4.4.1 Communication Interfaces

The communication interfaces of the program is limited by the choice of the VNA and the turntable. The *HEAD Acoustics, HRT I* turntable that has been chosen can be controlled by serial communication using the RS485-standard [7]. However, it can also be controlled by its accompanying Windows driver and software control program, which can be interfaced to Python with the *Pywin32*-module that accesses the Windows APIs. This requires the Windows registry to be updated with the UUID found in the control interface manual. With the Windows APIs accessible, the turntable can be controlled with predefined methods [9].

The *R&S ZVB8* VNA has a LAN type interface for control and data transfer [14]. LAN allows for mutual communication between devices. LAN covers both the physical layer in the form of cabling and network cards, the latter which also contains part of the link layer in the form of logic decisions, and the link layer which includes the link protocol [4, p. 153]. In order to communicate across a LAN the computers must be connected to the same network and know each other's addresses. Using the TCP/IP protocol the communication can be extended further outside the LAN to the wider internet. Even on the same LAN, two computers can communication with each other using their IP addresses [4, p. 174-175]. On top of this, TCP ensures a connection between the two applications running on the computer and the VNA. At each end of the connection a port number is used to identify the applications. Moreover, the TCP header includes an acknowledgement number which the applications use to acknowledge to each other, that the previous message was correctly received [4, p. 313]. The content of the TCP packets is SCPI commands and device-specific commands that follow the SCPI-standard [13, p. 5.4].

4.4.2 Concurrency

The turntable is controlled via serial communication while the data from the VNA is read via a network cable. Because communication with the turntable and the turning process and communication with the VNA are both I/O bound tasks, there is a possibility for some waiting time instead of CPU time in a control program. Therefore, in order to achieve real-time communication and data processing, the wait time is exploited by use of the Python module *Threading*. *Threading* uses a single processor and pre-emptive multitasking to acheive concurrency [1]. This means that at any time one thread is not using CPU computation the processor can switch to another thread and continue computation here. The processor also saves the current state of each thread so that it can return to the exact same place. However, this also means that reading and writing to global variables must be protected, because the processor can switch in the middle of a statement [1]. Likewise, if a thread needs to wait for another thread to execute a specific task, it is necessary that the user defines a wait flag, which synchronises the wait between relevant threads.

Chapter 5

Implementation

In this chapter the implementation of the software to control the turntable and the VNA is described based on the design principles laid out in chapter 4. The bacjground for the implmentation is to fulfill the requirements set out in chapter 3. In the project a Windows computer is used to interface to the turntable and VNA, and the software implementation is heavily influenced by this choice.

5.1 Software Implementation

The VNA and the turntable are controlled in Python. The code is set up to have a module for each device and a main control program.

5.1.1 Turntable Control

```
    def set(self, rpm: int, func: EAccelerationFunction, start_pos:
   float) -> None:
    """ Establish basic settings: rpm, acceleration function and start
     position. """
    cur_pos: int = round(self.position)
    try:
        self.tt.Velocity = rpm
        self.tt.AccelerationFunction = func.value
    except Exception as e:
        logger.error(f"Unable to set settings for turntable {self.
   instance}, exiting with error code {e}.")
        exit()
    if self.tt.DisplayPolarity == EPolarity.epolBipolar.value:
        try:
            self.tt.DisplayPolarity = EPolarity.epolUnipolar.value
        except Exception:
            self.angle_max = 180.0
```

```python
            logger.error(f"Unable to set polarity to unipolar for turntable {self.instance}.")
    while cur_pos != round(start_pos):
        logger.info(f"Current position is {cur_pos} not start position {round(start_pos)}. Moving {self.instance} to start position.")
        if self.clockwise:
            self.go_to_CW(start_pos)
            self.wait_while_driving()
        else:
            self.go_to_CCW(start_pos)
            self.wait_while_driving()
        cur_pos = round(self.position)
    logger.info(f"Settings are velocity: {round(self.tt.Velocity)}, function: {EAccelerationFunction(self.tt.AccelerationFunction)}.")
    logger.info(f"Current position for {self.instance} is {cur_pos}.")
```

Listing 5.1: Python example

5.2 VNA Control

5.3 Concurrency in Main Control Flow

Chapter 6

Tests

This chapter includes test descriptions and results to validate the design against the requirements. First, the two directional antennas are tested to find their gain and ensure, that the transmitter and receiver have their maximum gain at the same frequency. Finally, the full test of the beam steering and transmitter locator is tested with the transmitter fixed at a known location in the test area.

6.1 Test of S-Parameters

The aim of this test is to test the reflection coefficient of the receiving antenna. The measurement will be used to choose the resonance frequency for the acceptance test.

Equipment

To perform the test the following equipment is needed:

- Rohde & Schwarz ZNA Vector Network Analyzer (10 MHz-43.5 GHz)
- Rohde & Schwarz ZN-Z54 Calibration Unit (9 kHz-40 GHz)
- Antenna cable

Procedure

The test is performed once. The following explains the procedure for the test:

1. Add power to VNA, connect antenna cable to VNA and Calibration unit.
2. Make calibration test by choosing *Cal* → *Quick Start Calibration* → *Apply* on the VNA.

3. Disconnect antenna cable and reconnect to DUT.
4. Set start and stop frequencies.
5. Ensure that VNA measures S_{11}-parameter by choosing *Meas* $\rightarrow S_{11}$.

The receiver antenna is a horn antenna which is designed to work in the spectrum from 4 GHz to 7 GHz. The measurement is performed in the spectrum 3 GHz to 8 GHz in order to encaosulate the entire antenna frequency spectrum, with steps of 25 MHz.

Result

The following figure shows S_{11} at the measured frequencies

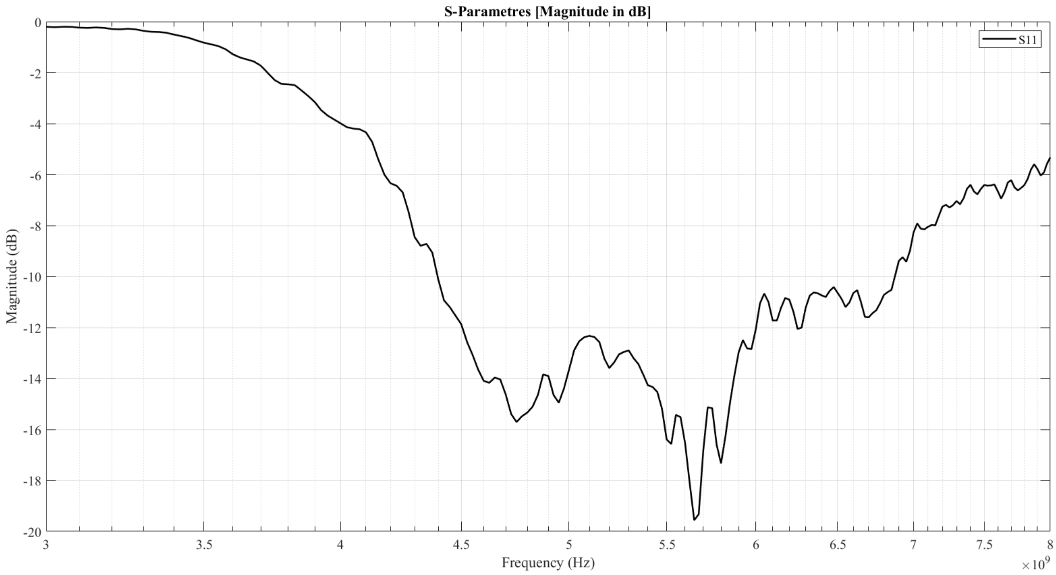


Figure 6.1: Measured S_{11}-parameter from 3 GHz to 8 GHz.

It can be seen that the antenna has a maximum S_{11} magnitude of -19.56 dB at 5.65 GHz. This gives a reflection coefficient of $\Gamma = 10^{-19.56/20} = 0.11$. Almost 1 GHz away at 4.75 GHz the magnitude of S_{11} is -15.71 dB which equals a reflection coefficient of $\Gamma = 10^{-15.71/20} = 0.16$.

6.2 Test of Radiation Pattern

The aim of this test is to know the directiveness of the receiving antenna. The measurement is used in the evaluation of the angle step of the turntable.

Equipment

The test is performed in the anechoic chamber at Aalborg University with the provided setup equipment at the site. This includes

- Computer with relevant *MVG software*
- *MVG StarMIMO* in anechoic chamber

The *MVG StarMIMO* has a measurement bandwidth of 400 MHz to 6 GHz. As seen in the results in the test of S-parameters in section 6.1 the maximum reflection coefficient magnitude is at 5.65 GHz, therefore the step size of frequency spectrum for the radiation characteristics measurement is chosen to be 0.05 GHz.

Procedure

The following explains the procedure for the test:

1. Measure known antenna *(MVG SH800)* with known radiation characteristics. Use for gain reference.
2. Secure DUT to test platform.
3. Perform automated test by activating the measurement equipment outside the chamber.

Since the antenna is not designed for use below 4 GHz, this is set as the start frequency. The measurement equipment cannot measure above 6 GHz, therefore this is the end frequency. The StarMIMO measures at angles of 15° in both planes.

Result

The data collected is imported into *Matlab* for visualization. The figure 6.2 shows the elevation plane of the measured horn antenna in the anechoic chamber. The red line shows the radiation pattern for the horn antenna at $f = 4.75$ GHz. The blue line shows the radiation pattern for the horn antenna at $f = 5.65$ GHz. The antenna has a higher gain at $f = 5.65$ GHz of 12.99 dB, whereas at $f = 4.75$ GHz the highest gain is 11.41 dB. The 3 dB-bandwidths are also plotted at 19° for $f = 5.65$ GHz and at 22.5° for $f = 4.75$ GHz.

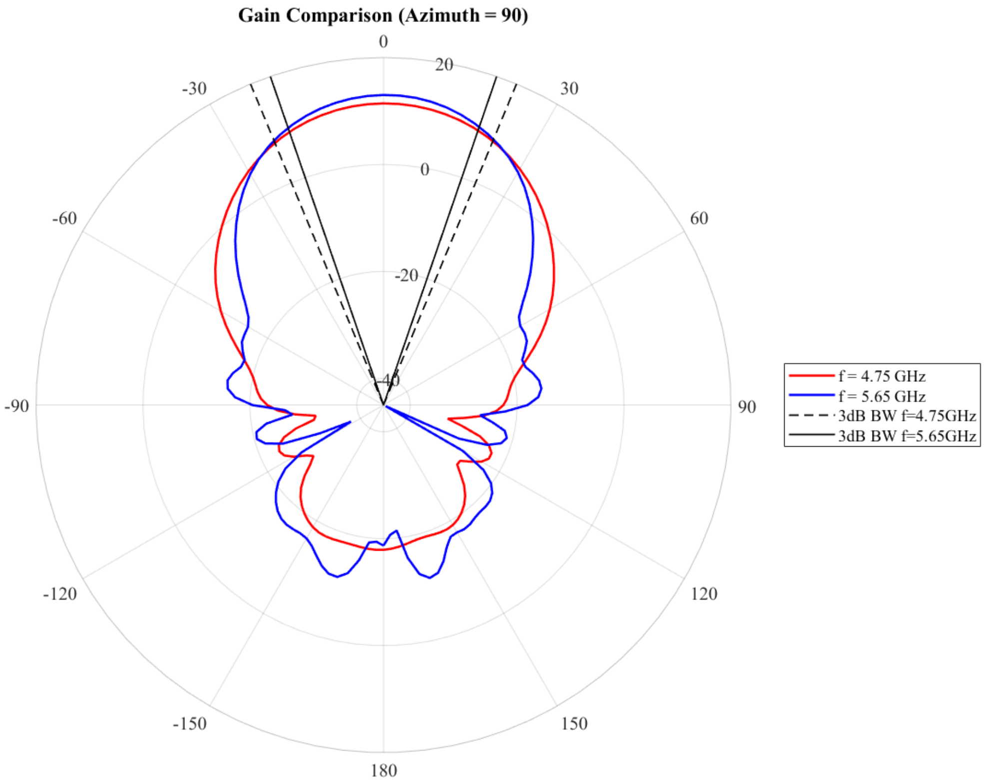


Figure 6.2: Measured gain in the farfield at 4.75 GHz and 5.65 GHz (elevation plane).

The figure 6.3 below shows the azimuth plane of the horn antenna as measured in the anechoic chamber. The red line shows the gain for the antenna at $f = 4.75\,\text{GHz}$ and the blue line shows the gain for the antenna at $f = 5.65\,\text{GHz}$. The maximum gain is 12.99 dB at 0°.

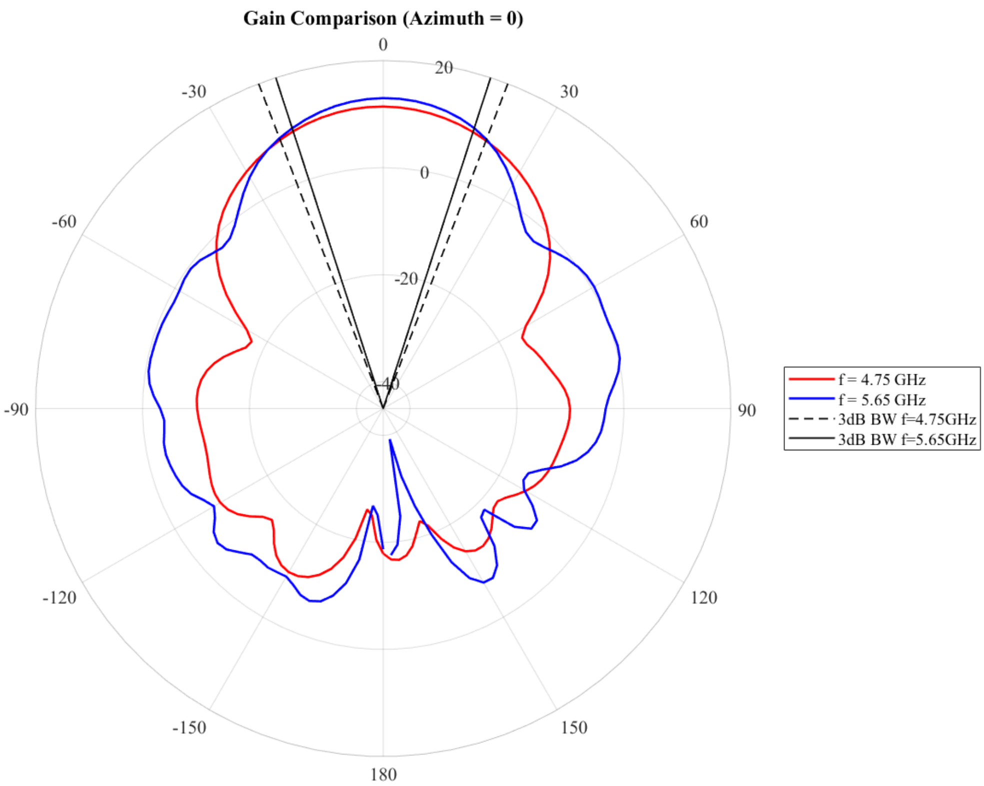


Figure 6.3: Measured gain in the farfield at 4.75 GHz and 5.65 GHz (azimuth plane).

Simultaneously the maximum gain of the antenna over the frequency spectrum at any measured angle was measured as seen on the figure 6.4. The measurement shows that the gain, generally, increases as the frequency increases.

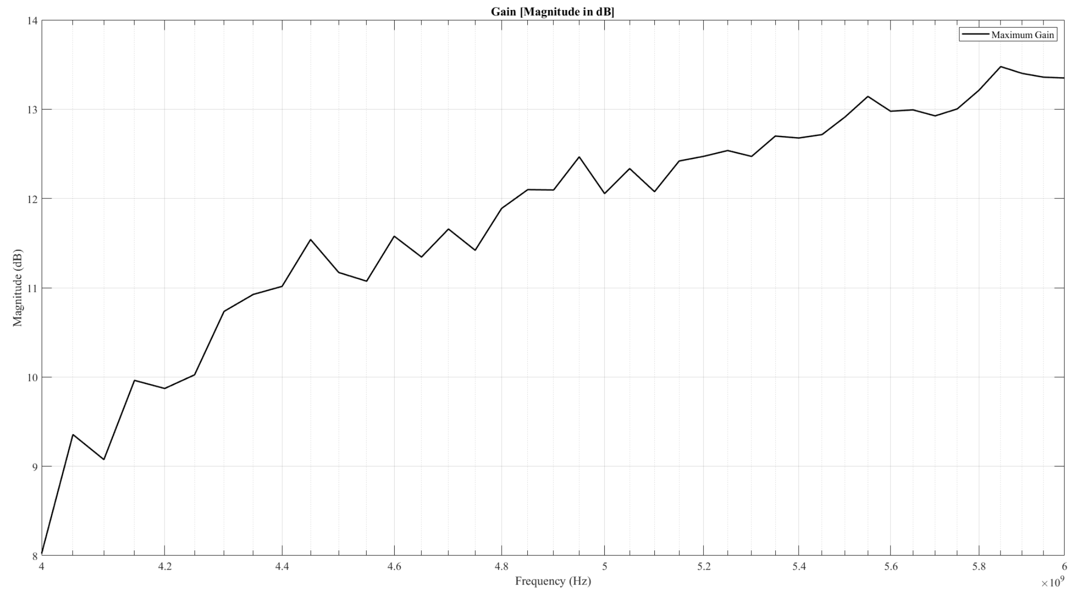


Figure 6.4: Measured maximum gain at any measured angle in the frequency spectrum from 4 GHz to 6 GHz.

6.3 Accept Test

The aim of this test is to test the full function of the developed product. The test must show that the receiver antenna on the turntable is able to scan the test area and measure the received power at fixed angles, before selection the location with the maximum received power and focusing its beam on that location.

elaborate introduction

Equipment

To perform the test, the following equipment is needed:

- HEAD Acoustics Remote-operated Turntable, model HRT I 6498, with 24 V DC 60 W power supply
- D-sub 9-pin to USB-A cable
- PC with one USB-A port and one LAN port
- Rohde & Schwarz ZVB 8 Vector Network Analyzer
- Network cable (8-pin RJ-45 connector)
- Two 50 Ω directional antennas with XX frequency

- power supplies to the antennas ????

find exact values and names

Moreover, the test must be performed in a controlled environment, where the temperature is not below 0 °C or above 50 °C with a relative humidity in the range 20 % - 80 % [7].

add VNA environmental conditions

Test Execution

The following steps outline how to perform the test:

1. Do this. Refer to figure 6.5 to visualise the setup.

elaborate on the how

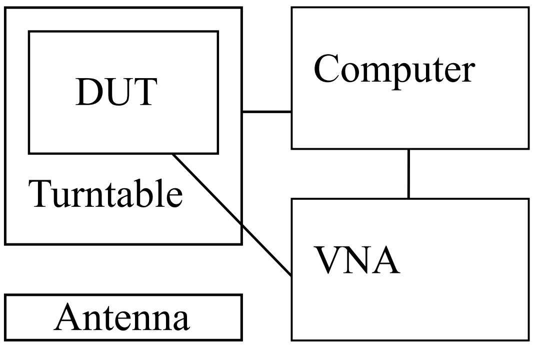


Figure 6.5: Setup for test of functionality of beam steering device.

improve this figure because it is ugly. Needs more names

Test Results

add table for test results and describe

Test errors

While the turntable is turning the cable connected to the horn antenna will move with it. This will affect the phase of the signal. However, since the purpose of the test is to measure magnitude, this error is will not effect the test result.

6.4 Summary of Tests

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