

Mechanical Antenna Beam Steering

SubTitle

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Bachelor of Engineering in Electronics, Spring 24

Fifth Semester Project



add
colophon
as the last
thing!!

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STUDENT REPORT

Title:

Network Selection Algorithm

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Abstract:

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

The content of this report is freely available, but publication (with reference) may only be pursued due to agreement with the author.

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Preface

Aalborg University, March 11, 2024

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Chapter 1

Introduction

add abstract
(last thing to
do!!)

add intro-
duction (sec-
ond to last
step!!)

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 [5] [2]. This chapter explores the properties of antennas and beam steering methods, in order to understand antenna beam steering.

2.1 Fundamentals of Antennas

make short
introduction

2.1.1 Propagation

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

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

explain each
letter

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 polar coordinates are illustrated on figure 2.1 below.

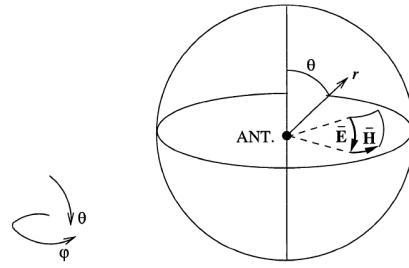


Figure 2.1: Electromagnetic field around a small antenna in far field range visualised in the polar coordinate system [1, p. 58].

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. Assuming that θ is kept approximately constant, that the electromagnetic waves propagate in free space and that the point of observation is at a large value of r , the electric and magnetic fields can be approximated with the planar coordinates (x, y, z, t) .

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

$$\mathbf{S} = \mathbf{E} \times \mathbf{H} \quad (2.2)$$

which points in the same direction as the wave propagation.

Multipath propagation

2.1.2 Polarization

2.1.3 Radiation Characteristics

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

$$R_2 = \frac{2D^2}{\lambda} \quad (2.3)$$

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

The radiation characteristics of an antenna can be described by the directivity, which doesn't depend on the distance r in the far field meaning that at the receiver the relation $r \gg R_2$ is assumed. Then the directivity is

$$D_t(\theta, \phi) = 4\pi r^2 \frac{S_t(\theta, \phi)_{max}}{P_{t,r}} \quad (2.4)$$

insert figure of planar coordinates and explain

add p4 rf antenna beam forming eq of power through area

expand maxwell eqs with frequency dependencies p4 rf antenna beam forming

describe multipath propagation and what issues it brings and how to mitigate. Also any advantages

describe polarization and what issues it brings and how to mitigate. Also any advantages

with $S_t(\theta, \phi)_{max}$ being the maximum power density and $P_{t,r}$ being the radiated power of the antenna. The fraction $\frac{P_{t,s}}{4\pi r^2}$ is also called the power density of the isotropic radiation of the antenna. The power of the source $P_{t,s}$ to the antenna might not equal the radiated power $P_{t,r}$ due to power loss $p_{t,l}$. Power loss can happen because of reflection loss in the input medium (typically cable), conductor loss and inductor loss. The efficiency of the antenna η is described as the ratio of the radiated power and the sourced power

$$\eta = \frac{P_{t,r}}{P_{t,s}} = \frac{P_{t,r}}{P_{t,r} + P_{t,l}} \quad (2.5)$$

The gain $G(\theta, \phi)$ of the antenna is defined as the efficiency η times the directivity D and can be calculated as

$$G(\theta, \phi) = \eta D(\theta, \phi) = 4\pi r^2 \frac{S_t(\theta, \phi)_{max}}{P_{t,s}} \quad (2.6)$$

or expressed in decibel with respect to the isotropic radiator

$$g_{dBi} = 10 \log_{10}(G) \quad (2.7)$$

The isotropic radiator is a theoretical antenna which radiates homogeneously in all directions, meaning that the magnitude of the power density vector \mathbf{S} at a distance vector \mathbf{r} is constant as

$$\left| \frac{S(r, \theta, \phi)}{S_{max}} \right| = 1 \quad (2.8)$$

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 [4, pp. 10-12].

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 polar coordinate system. If the antenna has the property of reciprocity, the effective area and the gain of the receiver antenna is related by

$$A_r(\theta, \phi) = \frac{\lambda^2}{4\pi} G_r(\theta, \phi) \quad (2.9)$$

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 suppressed. The power of the receiving antenna is equal to the power density S_t multiplied by the effective area of the receiver antenna A_r , expressed as

$$P_r = S_t A_r \quad (2.10)$$

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 2.10 for S_t equation isolated in 2.6 and equation 2.9 yields

$$\begin{aligned} P_r &= \frac{G_t P_t}{4\pi r^2} \frac{\lambda^2 G_r}{4\pi} \\ &= G_t G_r P_t \left(\frac{\lambda}{4\pi r} \right)^2 \end{aligned} \quad (2.11)$$

Also called Friis transmission equation [6, pp. 8-10]. 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 radiation pattern is dependent on the angular properties θ and ϕ and is usually visualised in a plane parallel to the electric field and called a **E** plane pattern or parallel to the magnetic field and called a **H** plane pattern.

Antenna Design Types

Different antenna designs have different radiation patterns.

2.2 Beam Steering Methods

2.2.1 Manual and Mechanical Steering

2.2.2 Electrical Steering

describe typical antenna designs. see p11 rf antenna beam forming

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

Chapter 3

requirements and Delimitations

make short
introduction

3.1 Functional Requirements

outline in
table func-
tional re-
quirements

3.2 Technical Requirements

outline in
table techni-
cal require-
ments. Re-
member en-
vironmental
requirements
temp and
hum

3.3 Delimitations

explain de-
limitations
based on
available
equipment
and time

Chapter 4

Design of Beam Steering

	short introduction
4.1 Antenna Design	explain design of patch 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	explain design principles of software
4.4.1 Communication Interfaces	explain communication to and from vna and tt in depth
4.4.2 Concurrency with Threading	explain how program runs

Chapter 5

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.

5.1 Test of Gain in Frequency Spectrum

elaborate
and do test

The aim of this test is to test both directive antennas in a frequency spectrum to ensure they operate at the same frequency.

5.2 Test of Radiation Pattern

elaborate
and do test

The aim of this test is to know the directiveness of the two directional antennas.

5.3 Accept Test

elaborate
introduction

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.

Equipment

To perform the test, the following equipment is needed:

- HEAD Acoustics Remote-operated Turntable, model HRT I 6498, with 24 V 60 W power supply

- D-sub 9-pin to USB-A cable
- PC with one USB-A port and XX port
- VNA ???
- VNA cable ???
- Two 50Ω directional antennas with XX frequency
- power supplies to the antennas ????

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 % [3].

find exact values and names

add VNA environmental conditions

Test Execution

The following steps outline how to perform the test:

1. Do this. Refer to figure 5.1 to visualise the setup.

elaborate on the how

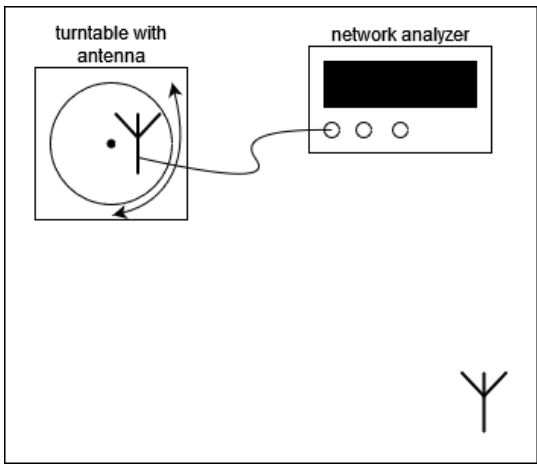


Figure 5.1: Setup for test of functionality of beam steering device.

improve this figure because it is ugly. Needs more names

5.4 Test Results

add table for test results and describe

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