Mechanical Antenna Beam Steering

SubTitle

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Bachelor of Engineering in Electronics, Spring 24

Fifth Semester Project

STUDENT REPORT
AALBORG UNIVERSITY

add colophon as the last thing!!

AALBORG UNIVERSITY
STUDENT REPORT

Electronics and IT
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Title:
Network Selection Algorithm

Theme:
Communication Technology

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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 2023 at Department of Electronic System at Aalborg University.

Aalborg University, March 18, 2024

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Chapter 1

Introduction

add abstract (last thing to do!!)

add introduction (second 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

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

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

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

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

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 polar coordinates are illustrated on figure 2.1 below.

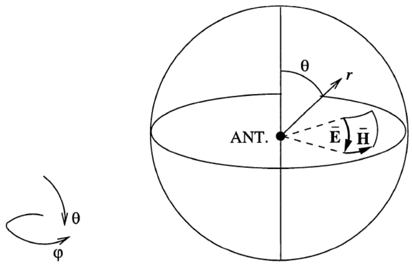

Figure 2.1: Electromagnetic field around a small antenna in far field range visualised in the polar coordinate system [1, p. 58].

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).

insert figure of planar coordinates and explain

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

$$\mathbf{S} = \mathbf{E} \times \mathbf{H} \tag{2.2}$$

which points in the same direction as the wave propagation.

add p4 rf antenna beam forming eq of power through area

expand maxwell eqs with frequency dependencies p4 rf antenna beam forming

Multipath propagation

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

2.1.2 Polarization

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

Type	Polarization
Isotropic antenna	
Dipole antenna	Linear
Patch antenna	Linear, circular
Horn antenna	Linear
Helix antenna	Circular

Table 2.1: Table showing polarization of some typical antenna designs.

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

$$R_2 = \frac{2D^2}{\lambda} \tag{2.3}$$

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 characterstics 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

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

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

$$\eta = \frac{P_{t,r}}{P_{t,s}} = \frac{P_{t,r}}{P_{t,r} + P_{t,l}} \tag{2.5}$$

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

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

or expressed in decibel with respect to the isotropic radiator

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

The isotropic radiator 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 as

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

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

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

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 surpressed. 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

$$P_r = S_t A_r \tag{2.10}$$

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

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

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 characterstics 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 a **E** plane pattern or parallel to the magnetic field and called a **H** plane pattern.

Antenna Design Types

describe typical antenna designs. see p11 rf antenna beam forming

2.2 Beam Steering Methods

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

make short introduction

3.1 Functional Requirements

outline in table functional requirements

3.2 Technical Requirements

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

3.3 Delimitations

explain delimitations 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

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

elaborate and do test

5.2 Test of Radiation Pattern

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

elaborate and do test

5.3 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 frenquecy
- 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 % [3].

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

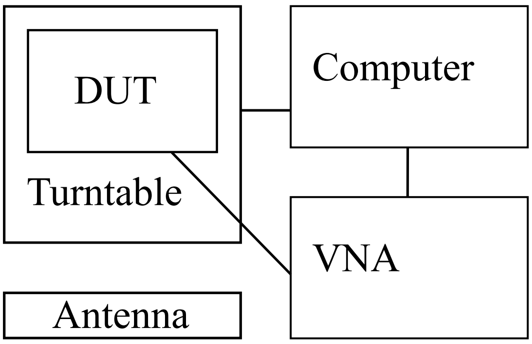

Figure 5.1: Setup for test of functionality of beam steering device.

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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