Project Plan for A Rock-solid Yagi-Uda Antenna

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CONTENTS

I. PROBLEM DEFINITION

The goal of this project is to develop an antenna operating at ultra-high frequency using our knowledge of electromagnetism and individual research, build it, and compare it to theoretical expectations and simulations.
Methods of testing and predefined requirements for the performance lead to a range of specifications. In turn, that defines the design choice for the antenna.

II. SPECIFICATIONS

The specifications of the antenna are based on the requirements defined in the project guidelines [1] and the requirements of the receiver used for the final antenna test [2].

A. Known parameters

The distance between the transmitter and receiver is approximated at 200m, using the Kick-Off slides [2].
The frequency f of receiving antenna is 433MHz. The signal wavelength at this frequency is $\lambda = c/f = 0.693m$, where c is the speed of light.

B. Receiver

According to the Kick-off slides, Yokogawa AQ6370 Optical Spectrum Analyzer [3] with a collinear antenna ANT433M [4] are used for receiving the signal. The spectrum analyzer has a sensitivity up to -90dBm. As there are many sources of noise in the area where the signal is received, the magnitude of the signal should not be too low. The average EM noise level of electromagnetic radiation is measured as radiation intensity for UH frequencies is -20dBm[5]. Thus, a signal from the transmitting antenna should be above the noise level to make sure it is detectable.
According to the specifications of the spectrum analyzer, level accuracy at an input level of -20dBm is ±0.4dBm. That means that signal at -19dBm will be twice above the minimum accuracy, thus, it will be detectable. Still, this is the minimum requirement, and having a higher magnitude of the signal is desirable.
The receiving antenna has a bandwidth of 428-437MHz.

C. Polarization

As it was already mentioned, receiving antenna is collinear. This type of antenna is vertical and usually they are able to receive plane-polarized signals [6]. Therefore, the polarization of the transmitted signal wave should also be linear. An example of antenna that can provide such radiation is a monopole antenna.

D. Directivity

The directivity[7] is about the maximum radiation intensity in a specific direction compared to the average radiation intensity. This means that a high directivity translates to less power loss because of side lobes. As the power provided by the signal generator is limited, it is crucial to make the antenna highly directional[7].

E. Gain of transmitting antenna

The gain[7] is mostly related to the effectiveness of an antenna compared to the omnidirectional radiation intensity emitted by a source of the same input power. Thus the gain of the transmitting antenna should be as high as possible, which means that most power is radiated out of the antenna.

The average TV antenna is designed for gains between 12dBi and 24dBi[8]. The frequency of the transmitting antenna is 433MHz which is between the frequencies of TV signal. TV antennas are operating at distances much larger than the distance at which the signal is received in this project. Therefore, it is sufficient to design the antenna to have a gain of 12dBi or higher.

F. Impedance matching

In order to minimize signal reflection and maximize the power transfer, the impedances of the transmitter, coaxial cable, and antenna need to be matched. The Quasar UK AM hybrid transmitter module QAM-TX1 will be used and has an output impedance of 50 Ohms [1]. To match this output impedance a 50 Ohms coaxial cable will be used. This means the antenna must also have an impedance of 50 Ohms [9].

G. Build difficulty

One of the goals of the project is to construct an antenna and test it. Given the time constraint and limited budget, the design of the antenna should be easily executable. Therefore, it should not require high precision while constructing, difficult geometries, or require sophisticated tooling and should not rely on trial-and-error to tweak the design.

H. Budget

The budget for this project is 25€. Therefore, the materials used to build the antenna should be widely accessible and the design should minimize material usage. That limits the design volume. The budget also implies the challenge of having a small error margin while building, as a replacement could exceed the budget.

III. Design ideas and choices

A. Choice of antenna type

The antenna type choice is based on the results of research shown in table 2 (see page 4). The loop and helical antenna will not be chosen, since they have circular polarisation. Moreover, the monopole will not be chosen, because the needed frequency cannot be transmitted with the monopole. The dipole is omnidirectional, which is unpreferable as mentioned in section II-D. The horn antenna, dish antenna and Yagi-Uda antenna have specifications, which can meet the requirements.

1) Horn antenna: It has suitable specifications as shown in table 2. The optimal horn aperture dimensions can be calculated by determining the frequency or wavelength needed, the gain and the possible dimensions of a waveguide used to operate the whole antenna. As the waveguides available online are expensive, it can be built using materials from the TCO workshop. However, to estimate the order of magnitude of the horn antenna, the dimensions of the waveguide are assumed to match the WR2100, used for a range of frequencies that match our frequency [10]. Consequently, the waveguide can be expected to be $0.54m \cdot 0.27m$. Considering the estimated gain range, the minimum expected gain of 12dB is used to calculate the final dimensions. Using these values, the optimal aperture surface is approximately 1.2 m^2 according to a sequence of calculations that can be performed according to the textbook Modern Antenna Design (pp.343ff.) [11]. This antenna has fulfilled most specifications. However, its size could cause problems with time management, storage, and building, as well as fitting the budget.

2) Dish antenna: To estimate the area A of the parabolic dish antenna from the antenna gain requirement[12].

$$A = \frac{\lambda^2}{4\pi\eta} \cdot \frac{G_{dBi}}{10} \tag{1}$$

Where λ is the wavelength of the signal, η is the efficiency of the antenna and G_{dBi} is gain. With an efficiency of 50% and a gain identical to the gain of Yagi-Uda the required area is approximately $1.2m^2$. Finding a metal sheet of such area and correctly bending it to match the antenna requirements doesn't fit within the budget.

B. Yagi-Uda antenna design

Yagi-Uda was chosen as it has proved itself to be the most reliable in terms of directivity, polarisation, and operation at UH frequency. Parameters for this type of antenna can be derived both analytically and numerically, through simulations. It is made of several metal rods attached in a parallel manner to a single shaft (non-conductive). The first rod, the reflector, is the longest. The second one, the driven element, produces electromagnetic waves. The consecutive rods, the directors of the signal, get shorter and shorter. Yagi-Uda design example can be seen in the figure 1:

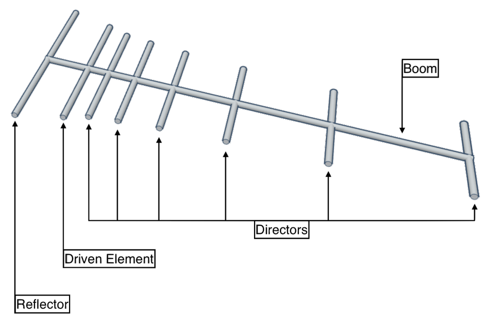

Fig. 1: Yagi-Uda antenna design [13].

Yagi-Uda antenna has several design configurations mentioned in multiple sources and used as a standard[7][14]. Due to specifications of impedance matching, dimensions for Yagi-Uda with 50 Ohms are chosen (see table below). These dimensions are provided by both D.K. Cheng and E.A. Jones. At the current stage of the project, this design is to be used, because it both follows the specifications and has a significant scientific background.

TABLE I: Optimal design of the Yagi-Uda antenna. Dimensions of elements of Yagi-Uda array antenna in terms of wavelength, which was determined previously.

Optimal design for $Z = 50$ Ohm		
Element	Length[cm]	Spacing[cm]
1	$0.478\lambda \approx 32.348$	-
2	$0.450\lambda \approx 30.453$	$0.182\lambda \approx 12.317$
3	$0.448\lambda \approx 30.318$	$0.152\lambda \approx 10.286$
4	$0.434\lambda \approx 29.37$	$0.229\lambda \approx 15.497$
5	$0.422\lambda \approx 28.558$	$0.435\lambda \approx 29.438$
6	$0.440\lambda \approx 29.776$	$0.272\lambda \approx 18.407$
Total	170.823	85.945

C. Materials

The next parameter to decide on is the material of the rods creating the Yagi-Uda array. It has to be a conductor which is easy to solder, as well as be at an affordable price, and commonly available. The diameter needs to be 4mm [14]. According to the calculations shown in section III-B a total of 1.3m of metal rods will be needed, and 0.65m in addition to account for potential mistakes, overall amounting to 2m of rod material. From the TCO workshop following prices were obtained:

- Copper only available at 5mm diameter, 13€/meter, overall 26€.
- Aluminium with 4mm diameter, 8€/meter, overall 16€.

The copper rods have an unsuitable diameter, too high price, but can easily be soldered. Aluminium has a suitable diameter and price, butise hard to solder. This can be solved by using one of the following connection techniques:

- Clamping, which involves using screws that potentially affect the signal.
- Threading, cutting out spiral edges that connect to the other metal like screws.

The holder for the rods, the handle for the antenna, and the stand are chosen to be made of wood, because it is lightweight, stiff, and has low electrical conductivity, therefore not interfering with the signal. Furthermore, in the Designlab some wood is available for free and many tools are available to modify the wood. For attaching the metal rods to the wooden construction 3D-printed clamps will be designed and used, which can position the rods precisely. For connection between the transmitter and driven element a coax cable splitter will be used.

D. A word on COMSOL simulations

Simulating the antenna using numerical methods saves building time and resources. COMSOL Multiphysics example file for the Yagi-Uda Antenna Wi-Fi Booster[15] was used to set up the simulations and obtain the results. One of the features of the geometry builder is that it's possible to make certain parameters dynamic. In our case, the lengths of the reflector, the driven element, and the directors are dependent on the desired transmitting signal's wavelength. Our desired design feature is to have four directors and a target transmitted signal frequency of 433 MHz. After modifying the study settings, the following result is obtained (figure 2), which displays a desirable directivity of the radiation pattern.

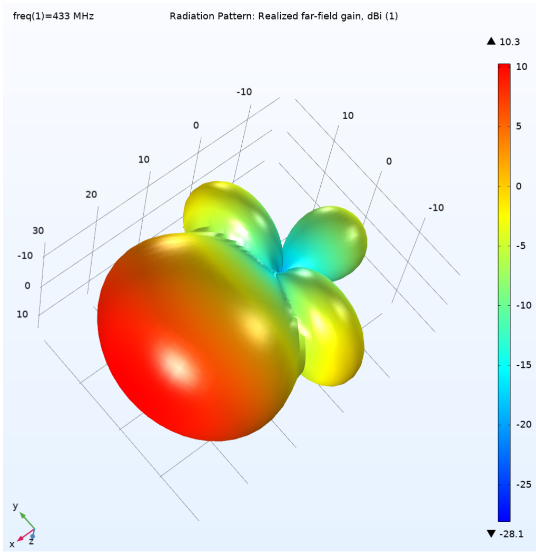

Fig. 2: Yagi-Uda radiation pattern from the COMSOL simulation.

IV. Block Diagram

The block diagram in figure 3 illustrates the different phases and steps needed to succeed in the project. The arrows represent steps. For example, after constructing the antenna, experiments will be done to determine its impedance, such that it can be matched which will again be a part of the construction.

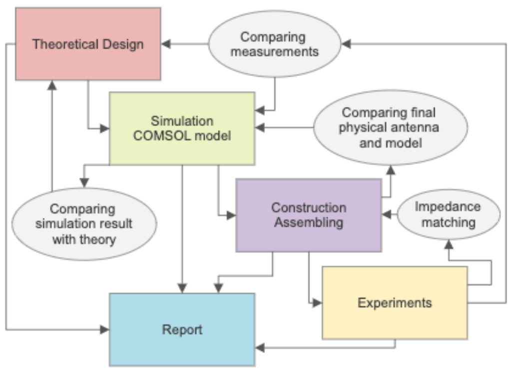

Fig. 3: Block diagram of the project. The colors of the big blocks match the colors in the Gantt Chart VIII.

TABLE II: Comparison between selected antennas types across different parameters

Antenna[16]	Yagi-Uda[17]	Loop[18]	Monopole[19]	Helical [20]	Horn[21]	Dish[22]	Dipole[23]
Directivity	High[24]	High[24]	Omni[25]	High[26]	High[27]	High[28]	Omni[24]
Polarization [29]	Linear	Circular	Linear	Circular	Linear	Linear	Linear
Build diff-ty	Moderate[24]	Easy[24]	Easy[25]	Hard[26]	Moderate[27]	Hard[28]	Easy[24]
Frequency	HF-UHF	HF	LF-HF	VHF-UHF	UHF	VHF	HV-UHF
Distance range	Long	Depends	Long	Long	Long	Long	Long

V. Division of tasks and team roles

Every team member comes with a unique set of skills and learning goals. As a team, we examined those in order to make the task division. During the project, everyone will be connected to everything, but we assigned a manager to each phase. This does not mean they will be to blame for these parts, or it will be their fault when it goes wrong, we are still a team. It does mean that during the phase they have to make sure they have an overview of what is being done and report how the phase is going during the meeting. For every task we will have a head of execution, this person makes sure the task is being done, and in case of hick ups reports to the manager of the phase. This is especially useful when phases are going to start being parallel to each other. Since the different phases of the project will not always be parallel, we are sure that everyone gets to help on all the parts of the project, making sure everyone reaches the learning aims of the project. Every project session starts with a quick meeting, such that everyone knows what they have to do and how far we are.

Our chairman, **Ivan**, may struggle with time management, but he is great at keeping an overview of the project. With the right plan and clear deadlines, we believe Ivan will be our perfect chairman. He has to make sure the managers report to him and to others during our meetings and the team stays focused. Furthermore, he will mainly assist the design team.

As a first-time **secretary**, it will be a challenge for **Selina** to make accurate and precise notes, that will help identify remaining tasks or changes that were decided on. She sometimes struggles with combining ideas and listening carefully, but when being secretary we are sure she will learn how to combine listening to others and still sharing her insights. She is good at setting deadlines and communicating which makes it easy for her to plan deadlines and make sure everyone is up-to-date. Furthermore, she will mainly be assisting the building team, preferably the electronics part.

As a **head of communication**, **Timur** will contact the TA and teachers if necessary. Timur had some communication delays in the past, this role will help him to learn the essence of efficient communication. Furthermore, he loves the theoretical side of projects. Therefore, he will mainly focus on the design.

As a **design manager**, **Omar** ensures all the theory is figured out and a suitable design is created. Omar thinks out of the box and explores different directions, which is essential when choosing an antenna design. He may struggle with prioritizing one specification over the other, but the team will help him with this.

Viktor will be our **manager of modeling**, so his task will be to keep an overview of the model of our antenna. He has a natural love for modeling and is already skilled in multiple programs. COMSOL will be a nice addition to his skill-set. He can struggle with online communication, but this will not be a problem, since we mostly work on campus.

Brunon will mainly be making the scripts to calculate essential parameters. This will be a big support for both the COMSOL model and the physical antenna. He has some struggles with theory but is eager to learn about COMSOL, and as he is already a skilled builder. So, if any problem occurs, he can fix them. We think he will also be a great middleman between the modeling and the building part of the project.

Kanan will be our **manager of assembling**, as building can get chaotic when everyone is creating different components, Kanan will keep an overview of the situation. It is his first time taking on main building responsibility, but with his great communication skills and will to learn about antennae, we are sure he will manage.

As **head of materials**, **Yasmin** makes sure we obtain suitable materials on time. She has a great eye for detail, which is essential for our antenna, as the building will be really precise. So we think, even though this is her first time on the building side of a project, she will be the key to making the building of the antenna a success.

VI. Time planning

For the time planning it was decided to create a Gantt chart, which can be found in the appendix VIII. This chart was created using the template of Vertex42 [30]. It shows who is assigned to be the manager of a phase, the head of execution, and the people assigned to help them. Every task has a day overlap with the task that follows up to that task, such that in case of setbacks, there is an extra day, or in case of unexpected success we can continue. The light orange represents exam days, during which we expect to achieve less. The red days are deadlines for the project. The purple boxes show the span of days for a certain task. They turn gray as progress is being made, if they are fully gray it means a task is done. Furthermore, the yellow days are days on which we expect to achieve milestones, which are also listed below.
Milestones:
- 03-21 Tuesday: Finished final design
- 03-24 Friday: Model shows the design is feasible
- 03-30 Thursday: First prototype
- 04-04 Tuesday: First experiment results
- 04-06 Thursday: Finished all experiments
- 04-11 Tuesday: First version of report

VII. Process control

As this project includes multiple assignments and deadlines, it is crucial to stay on track. Also, there are several directions of the project that will be done simultaneously, so people will split into groups to focus on their task. Weekly meetings and working sessions are proposed, so everyone in the project can share his progress and ask for assistance if needed. It is important to keep communication with each member and request information in case it is not provided. In addition, regular TA meetings should give certain feedback on work done and help define/correct further steps.

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VIII. Appendix

Fig. 4: Catastic antenna [2]

Planning A Rock-Solid Antenna

Group 8 Stone Stone
Module 7 AT

Project Start: 2-6-2023 (mm-dd-yyyy)
Display Week: 1

TASK	Manager of phase	Head of execution	ASSISTING	PROGRESS	START	END
Phase 1 Everything on paper	Ivan					
Project plan		The team	All	100%	2-6-23	3-23-23
Project report		The team	All	10%	3-21-23	4-11-23
Finishing the writing of the final report		Ivan	All	0%	4-3-23	4-11-23
Phase 2 Design	Omar					
Defining specifications/parameters of the antenna		Timur	All	100%	2-9-23	2-23-23
Defining design options		Omar	All	100%	2-19-23	3-7-23
Choosing antenna type		Ivan	All	100%	3-7-23	3-14-23
Assigning values to parameters		Timur	Brunon, Ivan, Yasmin	60%	3-14-23	3-28-23
Designing experiments for both the model and physical antenna		Selina	Viktor, Kanan	0%	3-28-23	3-31-23
Phase 3 Modelling	Viktor					
Creating a basic Yagi-Uda COMSOL model		Viktor	Brunon	100%	3-14-23	3-19-23
Creating a MATLAB script to determine parameters		Brunon	Timur, Ivan, Selina	60%	3-19-23	3-24-23
Creating a working COMSOL model		Viktor	Brunon, Yasmin, Timur, Kanan	0%	3-22-23	3-30-23
Performing experiments with model (earlier designed)		Viktor	Brunon, Selina	0%	3-30-23	4-3-23
Phase 4 Assembling	Kanan					
Defining materials		Yasmin	Kanan, Viktor	100%	3-14-23	3-21-23
Choosing how to assemle the antenna (mechanics)		Kanan	Yasmin, Brunon	100%	3-14-23	3-21-23
Assembling the antenna		Kanan	Yasmin, Brunon, Selina	0%	3-25-23	3-31-23
Impedance matching and electronics		Selina	Timur, Ivan	0%	3-30-23	4-4-23
Performing experiments with antenna (earlier designed)		Yasmin	Kanan, Selina	0%	4-2-23	4-6-23

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