Preliminary design of the implementation of automatic antenna radiation pattern measurement: Study of Yagi antenna radiation pattern

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Abstract. The radiation pattern is an important parameter of the antenna performance. This parameter needs to be measured not only accurately but also as fast as possible. For this purpose, the automatic measurement system has been developed. In this research, the system is implemented to analyze the radiation characteristic of a Yagi antenna by measuring its radiation pattern. The measurement result of the patterns is compared to those of the table characteristics of the Yagi antenna as well as a computer simulation. For this purpose, a Yagi antenna is designed and realized as the radiation pattern measurement object. Then, the students experiment to measure and analyze the effect of parasitic elements on the radiation pattern performance of the antenna. The questionnaire is carried out as the method of the research and directed to the students of the Telecommunication Study Program, Bandung State Polytechnic, to get the perception of the object performance.

1. Introduction

It is well known that the antenna radiation pattern and polarization are two important parameters of the antenna performance. Hence, the students have to attempt to get an understanding of these parameters which are fundamental for them. The radiation pattern is the main antenna parameter which is the response of the antenna to the electromagnetic power rate surrounding it. The antenna radiation pattern as stated by Warren L. Stutzman is a graphical representation of the radiation field (far-field) properties of an antenna [1,2]. This parameter determines the system coverage of wireless communication.

In the course of Antenna and Propagation, the radiation pattern of the antenna becomes the major topic. Since the function of the antenna is to direct the electromagnetic power rate to certain coverage areas, the analysis and measurement of the radiation pattern are importantly conducted. This parameter contributes to the relatively high number of learning objectives in the Antenna and Propagation course.

Though the radiation pattern is a three-dimension in nature, for the practical reason this pattern is measured and plotted in two planes, namely principal planes. The measurement of the radiation pattern has to be accomplished in an efficient, fast, and accurate way. To do this, an automatic antenna radiation pattern measurement system has been developed [3]. The measurement time has to be fast since there are some antenna configurations to measure. Some preceding researches relating to the study of the antenna radiation pattern have been accomplished both simulation [4,5] and measurement [6,7].
To study radiation patterns, some kinds of antennas are needed as the objects that their radiation pattern to be measured and analyzed. Yagi antenna is one of the topics whose radiation pattern is interesting to study [8]. In this research, this antenna is designed so that its configuration can be varied to examine the changes in the radiation pattern.

2. Method
The general procedure to conduct this research is:
- Study literature and design the Yagi-Uda antenna
- Design and provide learning module Yagi-Uda antenna including the job sheet
- Realize the designed physical antenna
- Conduct the treatment and demonstrate the radiation pattern performance
- Provide a questionnaire to get the student perception about the designed learning module [4].

Yagi antenna is one of the listed topics that are presented in the learning module. The theory of the Yagi antenna is reviewed before proceeding to the design step. Here, the Yagi parameters are studied including the use of the Yagi table as the important one to design and examine the parameters.

To conduct the measurement in the practical laboratory, a Yagi antenna is designed and realized. The design is such that the elements are subject to change in composition, i.e., we can add and remove the parasitic elements as well as we can change the space between elements. In this case, the input impedance is designed to prevent it from loading the effect of the parasitic elements. Figure-1 is a six-element Yagi configuration that consists of a driven element, a reflector element, and 3 director elements. LR, L, LD, and s are reflector length, driver length, director length, and spacing between elements respectively.

![Figure 1. Six element Yagi antenna.](image)

3. Result and discussion

3.1. Study literature and design of Yagi-Uda antenna
Yagi antenna is well-known around the world since this antenna is widely used as a TV receiving antenna and invented in 1926 [9]. It is composed of an active dipole (about a quarter wavelength in length) and called driven element, a passive reflector dipole which is slightly longer than the driven element, and one or more passive director elements which are slightly less than the driven element. The optimum sizes of the elements and spacing elements are designed according to the Yagi table provided in [10].

From the table, it can be chosen the Yagi configuration for a certain number element, for which the length of each element and the spacing between elements are presented as a function of the wave-length. The table is a numerical table which provides the basic antenna parameters which are (1) input impedance of the antenna, (2) directivity, (3) front-to-back ratio (FBR), (4) half power beamwidth on
In this research, the six-element Yagi is designed and this antenna operates in the center frequency of 924 MHz. Based on the Yagi table the corresponding parameters are decided and calculated, and the result is presented in Table 1.

| No | Parameter                           | Value     |
|----|-------------------------------------|-----------|
| 1  | Frequency range                     | 890 – 930 MHz |
| 2  | Element number                      | 6         |
| 3  | Gain                                | 11 dB     |
| 4  | System impedance                    | 50 ohm    |
| 5  | Wave length                         | 32.79 cm  |
| 6  | Driven element length               | 14.95 cm  |
| 7  | Reflector element length            | 15.80 cm  |
| 8  | Director element length             | 14.33 cm  |
| 9  | Element spacing                     | 6.56 cm   |
| 10 | Front-to-back ratio                 | 9.20 dB   |
| 11 | Half-power beam-width on H-plane    | 68°       |
| 12 | Half-power beam-width on H-plane    | 58°       |
| 13 | Side lobe level in H-plane          | -9 dB     |
| 14 | Side lobe level in E-plane          | -20 dB    |

3.2. Design and provide learning module Yagi antenna

The learning module is designed theoretically and practically. The learning module consists of theory one and accompanied by a training kit and job sheet. The training kit is an Antenna Radiation Pattern System to measure the antenna radiation pattern automatically. The training kit accompanied by the job sheets is already provided [3].

The learning module is designed to facilitate the students for self-learning [11] as well as for the teaching-learning process to be effective. Working with learning modules, students will gain experience and responsible for their learning, and actively learn to achieve the objectives of learning [12]. Besides, they also are enabled by self-test [13] to evaluate if they have accomplished the material. The module will shift the teacher learning-centered to the student learning-centered. The theoretical background and working principles as well as how to design the Yagi antenna are all discussed in the module.

3.3. Realize the designed physical Yagi antenna

The physical antenna is one in Figure-1 but with the element number of 6: a driven element (14.95 cm), a reflector element (15.80 cm),and four director elements (14.33 cm). The element spacing is 6.56 cm. This composition is matched to 50 ohm the transmission line, but not balanced. This is because the dipole elements are the balanced antenna, while the coaxial transmission line is not balanced wire. This condition causes power loss in the input antenna.

This problem can be overcome by utilizing a balun (balanced-to-unbalanced) system. Using this balun, the port input of the antenna becomes high impedance, and at the same time will minimize the
loading problem. This is important since in the experiment the number of the element is changed. Without the balun, the change in the number of elements will change the input impedance of the antenna.

3.4. Conduct the treatment and demonstrate the radiation pattern performance

The treatment is intended to overcome the drawback of the learning process in the antenna radiation pattern. In the treatment, the students are facilitated by the learning module of the Yagi Antenna and training kit. The training kit is automatic measuring equipment to measure antenna radiation patterns. Using this equipment, the measurement time is fast, the measured data is accurate, and the data is automatically plotted on a computer monitor.

The learning module is designed so that the students are supposed to learn by themselves with minimal assistance from the teacher. In the class, the students split into several groups, each group consists of 3-4 students. Each group works in cooperative learning.

In this stage, the radiation performance of the Yagi antenna is analyzed as well as measured step by step. Since the antenna under test is a six-element Yagi antenna, there would be 6 steps to analyze theoretically and 6 steps in measurement as well. The procedure is presented in Table-2.

Table 2. Calculated parameters of the designed antenna.

| Step | Construction                  | Analyze                                      | Measure                                      |
|------|-------------------------------|----------------------------------------------|----------------------------------------------|
| 1    | Driven element                | HPBW-E, HPBW-H, gain, FBR, SLL, pattern     | E-plane radiation                            |
|      |                               | sketch on E-plane and H-plane                | data and plot                                 |
| 2    | Driven plus reflector element | HPBW-E, HPBW-H, gain, FBR, SLL, pattern     | E-plane radiation                            |
|      |                               | sketch on E-plane and H-plane                | data and plot                                 |
| 3    | Driven plus reflector plus 1| HPBW-E, HPBW-H, gain, FBR, SLL, pattern     | E-plane radiation                            |
|      | director element              | sketch on E-plane and H-plane                | data and plot                                 |
| 4    | Driven plus reflector plus 2 | HPBW-E, HPBW-H, gain, FBR, SLL, pattern     | E-plane radiation                            |
|      | director element              | sketch on E-plane and H-plane                | data and plot                                 |
| 5    | Driven plus reflector plus 3 | HPBW-E, HPBW-H, gain, FBR, SLL, pattern     | E-plane radiation                            |
|      | director elements             | sketch on E-plane and H-plane                | data and plot                                 |
| 6    | Driven plus reflector plus 4 | HPBW-E, HPBW-H, gain, FBR, SLL, pattern     | E-plane radiation                            |
|      | director elements             | sketch on E-plane and H-plane                | data and plot                                 |

The objective of the experiment is to examine the changing of radiation pattern as the function of the element number and composition in the Yagi antenna. The procedure is based on Table-2. In step-1, the antenna is the driven element which is a half-wavelength dipole. The exact dimensions of the length are provided in the Yagi table, in this case for six-element composition. Then the radiation pattern for both
H-plane and E-plane is measured. The student has to inspect this pattern and compared it to that of the theory.

The step-2, a reflector element is inserted parallel to the driven element. The dimension of the reflector element as well as space between the driven and reflector element is presented in the Yagi table. The student will see and analyze the radiation changing affected by this composition. This examination should refer to the theory.

The step-3, add a director element to the configuration of step-2, so we have three-element Yagi configuration. The dimension of the reflector element as well as the space between elements is presented in the Yagi table. Again, the student will work the same as that in the preceding steps, and this investigation should refer to the theory. The remaining steps, step-4 through step-6, are the same as those of the previous steps.

3.5. Provide a questionnaire to get student perception and interview to teacher opinion
The interview is imparted to the teachers to gain their opinion and suggestion. This is needed to complete and correct the deficiencies contained in the module. From the student’s side, the questionnaire is directed to obtain their perception about the usefulness of the designed topic. Some of the questionnaires to deliver are

- Hands-on experiment (measurement) make me easier to understand the concept and establishment of radiation pattern as well as E-plane and H-plane
- Through the experiment, I acquire a clear picture of how the effect of the reflector and director elements to the radiation pattern changes and compare it with that of theory
- Through the experiment I can grasp the effect of inter-element space to the changes of radiation pattern and relate this to those of theory
- I delight working and talking with my friends about the experiment

4. Conclusion
In this research, the flexible composition of the Yagi antenna is realized. The composition is subject to change as intended in learning objectives in the experiment to measure and analyze the radiation pattern performance. The feedback from the lecturers of Antennas and Propagation is expected to resolve the lack and weakness of the course material. The perception of the student satisfaction to this preliminary research shows a positive opinion since this process gives the learning experience both in measurement technic and data analyzing.

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