Experimental Study of Measuring Radiation Patterns for VHF and UHF Antennas

E Marpanaji¹, K T Yuwono¹, M I Mahali¹, P T Aji¹ and N A B Nugrahà²
¹Electronics Engineering Education Department Universitas Negeri Yogyakarta, Yogyakarta, Indonesia
²Student Electronics Engineering Education Department Universitas Negeri Yogyakarta, Yogyakarta, Indonesia

Email: eko@uny.ac.id, arispra@uny.ac.id, izzudin@uny.ac.id, purno.tri@uny.ac.id and nikko.adji@gmail.com

Abstract. This paper discusses the experiment of measuring antenna radiation patterns using hardware and software that has been made previously. The antenna measured is the Half Wave Open Dipole antenna that works at VHF frequencies as Antenna Under Testing (AUT). The hardware used is Module-1 and Module-2 which have previously been tested for functionality, and the software is the Antenna Radiation Pattern application that is created using the Visual Basic programming language in the Microsoft Visual Studio package. Radiation pattern measurement experiments were carried out under various conditions, namely (1) without RF signals; (2) with RF signal and the position of the transmitting antenna is 0o with AUT; (3) with the RF signal and the position of the transmitting antenna at an angle of 90o to AUT; and (4) simulation of electromagnetic wave interference when making measurements. Based on the results of experiments conducted, it can be concluded that the Antenna Radiation Pattern application has functioned well and can describe the AUT radiation pattern. Future work of this research is the measurement of radiation patterns for other types of antennas and refinement of applications for the measurement of various antenna parameters.

1. Introduction
The current telecommunications system relies heavily on wireless communication technology. Cellular and mobile communication systems, Internet services via WiFi devices, communication services for monitoring aircraft, ships, and trains also use wireless telecommunications systems or telecommunications using radios. The use of wireless telecommunications systems in various types of communication services shows that wireless telecommunications technology or telecommunications using radios is still needed for telecommunications systems in the future.

Antenna is a very important component in building wireless telecommunications systems especially for radio communication systems. Antennas play an important role in carrying out electromagnetic wave radiation to the air at the transmitter, and receiving electromagnetic waves from the air for the receiver. The distance and direction of communication between the transmitter and receiver is largely determined by the characteristics of the antenna used. If the antenna used does not function properly, then the function of the radio telecommunications system also cannot function as expected.

Antenna characteristics are very important to consider because they determine the success of the radio communication process. Antenna characteristics are usually presented in the form of antenna parameter values that can indicate the performance of an antenna. Antenna parameters are needed to
obtain an overview of the performance of an antenna, including: radiation patterns, directionality, gain, bandwidth, efficiency, beamwidth, and aperture. Antenna parameter measurements are performed when testing an antenna design. One of the tools used in antenna measurement is the antenna radiation pattern measurement. This gauge can provide an overview of directivity, aperture, beamwidth, and gain through a graph displayed by this gauge.

This study conducts a study in the engineering of a measuring instrument that functions to measure antenna parameters, especially for antennas that work at Very High Frequency (VHF) and Ultra High Frequency (UHF) frequencies. This research includes observing the possibilities or technological opportunities that can be used in engineering measuring instruments as well as hardware and software components that can be used at relatively cheaper prices.

Hendrik, et al (2013) conducted research on the engineering of measuring instruments using the IC LT 5504 component as the front end of a Radio Frequency (RF) signal receiver, the microcontroller functions to convert analog signals to digital signals and transmit the results of the conversion to a computer via USB port, computer perform signal processing and display results using the Visual Basic programming language [1]. The front end component is actually widely available in addition to the components used in the study. Thus, a comparison can be made which components are most effective.

Another researcher, Kirbi, et al (2015) developed the antenna radiation pattern measurement tool but did not display the radiation pattern graph [2].

This research is looking for alternative solutions related to the components used in engineering the antenna parameter measurement tool. Thus, a measuring instrument can be obtained which is cheaper and can meet the needs of the laboratory for practical purposes and also as a learning medium for antenna measurement.

2. Antenna Parameters

Antenna is one of the main components in the process of radio communication or communication via un-guided media (wireless). Antenna can be defined as a structure associated with the transition region between guided waves and waves in free space or vice versa [3]. Waves are electromagnetic waves that are used in the process of radio communication. Guided waves are high-frequency electrical (current or voltage) waves that pass through the transmission line in the form of coaxial cables or other types of cables that are often used in wireless communication. While free space is free air between the transmitter and the receiver to transmit electromagnetic waves.

The main function of an antenna is to convert high-frequency electric waves into an electromagnetic wave with the same frequency to the transmitting antenna. Electromagnetic waves generated by the transmitting antenna will spread towards the receiving antenna. The function of the receiving antenna is to convert electromagnetic waves into electric waves (current or voltage) again, as shown in Figure-1.

The antenna parameters are generally used to explain the specifications or characteristics of an antenna. The characteristics of a transmitting antenna are identical to those of a receiving antenna.

![Figure 1. Antennas for radio communication](image-url)
Before discussing antenna parameters, it is necessary to convey first about the coordinate system that is often used in analyzing antenna parameters, which are spherical coordinates as shown in Figure 2.

![Figure 2. Spherical coordinate.](image)

The point P in spherical coordinates which has a distance $r$ from the center O, forming the angle $\theta$ of the z-axis line, and forming the angle $\phi$ of the x-axis can be denoted by P ($r$, $\theta$, $\phi$). The line $\overrightarrow{OP}$ can represent an electromagnetic field line issued by an antenna element located on the z-axis (one line with the z-axis). The notation in the form of spherical coordinates is then used in every calculation and analysis of the electromagnetic wave field emitted by an antenna to show the antenna's performance in the form of the parameters of an antenna.

The antenna parameters that are often used to describe the characteristics or performance of an antenna are: radiation pattern, directivity, gain, efficiency, antenna aperture, bandwidth, and beamwidth. The parameters discussed in this paper are focused on measuring the radiation pattern of a VHF antenna, especially the radiation pattern for the horizontal plane (horizontal pattern).

The radiation pattern of an antenna shows the amount of radiation energy released by the antenna at a certain distance according to the intensity of the field in the angular direction $\theta$ and $\phi$. The radiation pattern has a maximum radiation intensity towards the z-axis which is often referred to as the Main Lobe and smaller radiation intensities both towards the front and back of the antenna which is often referred to as the Minor Lobe or Side Lobe. Figure-3 shows the radiation pattern of an antenna [4].
Figure 3. The radiation pattern of an antenna in the z-axis direction

Antenna radiation pattern is a graph of far field radiation from an antenna. More specifically, the radiation pattern is a graph of power emitted from an antenna per unit of solid angle, or radiation intensity $U$ [watts per unit of solid angle]. The radiation pattern can be obtained by simply multiplying the power density at a certain distance by the square of the distance $r$, where the density or power density $S$ [watts per square meter] is given by the magnitude of the average Poynting vector $\mathbf{S}$:

$$U = r^2 S$$  \hspace{1cm} (1)

Equation (1) has the nature of the effect of distance on the intensity of $U$ radiation. To eliminate the effect of distance and to ensure that the radiation pattern is not affected by the distance from the antenna, measurements are made with the condition that $r$ is in a far field. The simplest example is an ideal antenna that radiates power in all directions equally or often referred to as an isotropic antenna.

If the total power emitted by the antenna is $P$, then the power is spread over the plane $r$ radius, and the power density at the distance $r$ for any direction can be stated:

$$S = \frac{P}{4\pi}$$  \hspace{1cm} (2)

Furthermore the radiation intensity can be determined by the equation:

$$U = r^2 S = \frac{P}{4\pi}$$  \hspace{1cm} (3)

Thus, equation (3) is independent of the distance value $r$.

The radiation pattern is usually described in the form of normalized values or described by the value divided by the maximum value of the radiation pattern itself [6]. Thus, the radiation pattern graph has an outer circle with a maximum value equal to 1. These normalized planar pieces are transformed into the two-dimensional domain as shown in Figure-4. The figure shows a radiation pattern of a half-wave open dipole antenna with the antenna element stretching on the $0^\circ - 180^\circ$ horizontal axis, so that the most radiant energy lies at an angle $\emptyset = 90^\circ$ dan $\emptyset = 270^\circ$ in the plane horizontal. The azimuthal angle
∅ (angle moving from 0° to 360° in the horizontal plane) rotates in a direction around the circle of vertical planes (vertical axis). The amplitude of the electric field is plotted along the radius of the horizontal plane circle. Typically, the elevation angle \( \theta \) (the angle that moves from 0° to 360° in the vertical plane) is determined for the image of the radiation pattern that will be displayed. However, the radiation pattern of the half-wave open dipole antenna rotates symmetrically for the entire elevation angle from 0° to 360° in the vertical plane, so all the pieces are identical [7]. The shape of the radiation pattern of the transmitting antenna will be identical to the shape of the radiation pattern of the receiving antenna.

![Figure 4](image)

**Figure 4.** Radiation pattern of a half-wave open dipole antenna in two dimensional shapes in a horizontal plane is common to illustrate the antenna radiation pattern.

### 3. Area of Antenna Electromagnetic Field

An antenna measurement must pay attention to the electromagnetic field of an antenna, so that the measurement results truly represent the electromagnetic field emitted by the antenna. In principle, the electromagnetic field area of an antenna can be divided into 2 (two) electromagnetic field regions, namely: (1) the area that is close to the antenna or often referred to as the near field region or the Fresnel Zone; and (2) areas with long distances with antennas or often referred to as far field regions or the Fraunhofer Region (Fraunhofer Zone) [3]. The boundary area of this field is determined by the distance (radius) and length of the antenna as shown in Figure-5 below.

The equation used to determine the radius limit of the Fresnel Region with the Fraunhofer Region is:

\[
R = \frac{2L^2}{\lambda}
\]

(4)

Where:

- \( R \) is the Fresnel area Radius boundary (m)
- \( L \) is the maximum size of the antenna (m), and
- \( \lambda \) is the electromagnetic wavelength (m).
Figure 5. Antenna field area (Fresnel Region and Fraunhofer Region).

Field components that can be measured in the Fraunhofer area will be transversal in the radial direction of the antenna and all the power flow is directed out radially as well. The shape of the terrain pattern in the Fraunhofer area (far field) is independent of distance. Whereas in the Fresnel area, the longitudinal component of the electric field may be more significant and the power flow is not entirely radial. The shape of the field pattern in the Frensnel area is generally very dependent on the measurement distance with the measured antenna. Thus, if we are going to measure the antenna parameters, the location of the antenna to be measured with the measurement point must be located in the Fraunhofer area or the measurement distance meets the equation [3][6]:

\[ R \geq \frac{2L^2}{\lambda} \]  

(5)

Where:
\( R \) is the distance of the measurement point in the Fraunhofer area (m)
\( L \) is the maximum size of the antenna (m), and
\( \lambda \) is the electromagnetic wavelength (m).

4. Research Method
4.1. Antenna Measurement Configuration
The system configuration for measuring the antenna parameters used in this study is shown in Figure-6. Antenna parameter measurements use a high-frequency electromagnetic wave source (a transmitter or oscillator with sufficient output power) along with a transmitting antenna that functions to radiate electromagnetic waves into the air. The antenna to be tested (AUT = Antenna Under Testing) is placed on a mechanical system that can rotate the AUT at an angle of \( \phi \). The radio frequency band used is Very High Frequency (VHF), so that the transmitter system, receiver system, and antenna used in this measurement also work on the VHF frequency band.
Mechanical system in principle is an antenna rotator or electric motor with enough torque to rotate the AUT. Furthermore AUT is connected to the receiver system and the receiver system output is connected to an indicator that can show the amount of power received by AUT. The value displayed by the indicator for a certain angle $\phi$ is the value of the electromagnetic wave power received by AUT at that angle. AUT rotation by rotator is $\phi = 0^\circ$ s.d. $360^\circ$ will produce an indicator value that can represent the radiation pattern of an antenna or other parameters as explained in the previous section.

4.2. Equipment used

The process of measuring radiation patterns using hardware that has been developed previously. The equipment that has been made is Module-1 in the form of a mechanical rotator antenna and Module-2 which contains a Radio Frequency (RF) to Direct Current (DC) signal modifier and an Arduino Uno microcontroller system that will be connected to a PC or Laptop computer. The hardware function testing of Module-1 and Module-2 had been carried out the previous year.

This experimental study of radiation pattern measurement at the same time testing software created using the Visual Basic programming language in the Microsoft Visual Studio package to display graphs of radiation patterns based on the work functions of Module-1 and Module-2. The Visual Basic application runs on a PC computer that is connected to Module-2 using a USB cable. The software engineering method used is the Water Fall method [8]. In general the block diagram of a system measuring antenna radiation pattern is shown in Figure 7.

![Block diagram of an antenna radiation pattern gauge.](image-url)
Module-1 is used to put AUT and rotate to the right in the horizontal direction from 0° to 360° and back to its original position (position 0°). Whereas Module-2 functions to start and end rotator motor rotation, adjust the direction of rotation and turn angle of Module-1, convert the RF to DC analog signal voltage into digital RF to DC signal voltage, and then send the results of this conversion to a computer via the port USB. The graphic display application is created using the Visual Basic programming language, with a display as shown in Figure-8 below. The application created is titled Antenna Radiation Pattern.

![Figure 8. The front page of the Antenna Radiation Pattern application.](image)

5. Result and Discussion
5.1. Specifications Devices used in the measurement of radiation patterns
The specifications of the devices used in the radiation pattern measurement experiment are:

- The transmitter uses a 2 meter band aircraft brand Icom IC-2200H with 5 Watt power at a frequency of 143,250 MHz;
- The transmitter antenna uses a DP-LS2E D quarter-lambda antenna with a ring in the middle;
- The measurement distance between the transmitting antenna and the receiving antenna (AUT) is 4 meters;
- The measurement time is daytime, with fine weather;
- The antenna being tested or AUT is a type of Half Wave Open Dipole antenna;

Measurement of the radiation pattern of Half Wave Open Dipole antennas is done with various conditions, namely (1) without a transmitter signal; (2) with a transmitter signal where the position of the transmitting antenna is located 90° in front of the Half Wave Open Dipole antenna stretch (the transmitter antenna is perpendicular to the axis of the Half Wave Open Dipole stretch); (3) with a transmitter signal where the position of the transmitting antenna is 0° in front of the Half Wave Open Dipole antenna stretch (the transmitter antenna is in line with the axis of the Half Wave Open Dipole antenna); (4) simulation of electromagnetic wave interference by turning on a motorized vehicle near the measurement area (the effect of spark plugs on motorized vehicles on the measurement results).

5.2. Radiation pattern measurement results
Based on the results of the measurement of the radiation pattern by running the Antenna Radiation Pattern application without the RF signal from the transmitter shown in Figure-9.
Measurement of radiation patterns without RF signals from the transmitter is used to describe the noise received by AUT and is used to describe the noise in the radiation pattern graph. The measurement results in Figure-9 show that the noise signal is spread evenly to all angles (from 0° to 360°), with a minimum value of 127 and a maximum value of 132. These values are used as a reference in the process of eliminating noise when signal processing is carried out by the application Radiation Pattern Antennas.

The next measurement is to place the transmitting antenna located 90° from the axis of the Half Wave Open Dipole antenna. The results of the measurement of the radiation pattern are shown in Figure-10. The minimum and maximum values for the RF signal quantization are 104 and 188, respectively. The maximum value is much higher than the maximum value when there is no RF signal as shown in Figure 9 previously.

Based on Figure-10 it appears that the maximum radiation pattern is at an angle of 0° and 180°. This is due to the position of 0° and 180° perpendicular to the Half Wave Open Dipole antenna. Thus, the Half Wave Open Dipole antenna will receive the largest signal according to the characteristics of the Half Wave Open Dipole antenna having a maximum radiation pattern in front of and behind the stretch of the antenna element. The results of this measurement show that the function of RF to DC components, the microcontroller ADC quantization process, the data sent by Module-2 to the computer, and the application in displaying a radiation pattern graph are in accordance with the AUT characteristics of the Half Wave Open Dipole antenna.

The next measurement is to place the transmitter antenna (RF signal source) at an angle of 0° (in line with the stretch of the Half Wave Open Dipole antenna element). The results of measurements of radiation patterns with these positions are shown in Figure-11 below.
Based on Figure 11 it appears that the maximum radiation pattern occurs when the AUT rotates as far as 90° and 270°. The results of this measurement indicate that the maximum radiation pattern occurs when the transmitting antenna is perpendicular (90° or 270°) to the stretch of the Half Wave Open Dipole antenna element. The minimum radiation pattern occurs when the transmitting antenna is located next to the stretch of the Half Wave Open Dipole antenna (at an angle of 0° or 180°). The results of this radiation pattern measurement are consistent with the characteristics of the Half Wave Open Dipole antenna, which has maximum radiation in front of or behind the stretch of the antenna element and has minimum radiation on the left or right side of the stretch of the Half Wave Open Dipole antenna. Thus, the hardware functions of Module-1, Module-2, and the Antenna Radiation Pattern application are functioning properly.

The last improvement of the Antenna Radiation Pattern application is a facility to eliminate very high amplitude surges due to the arrival of noise whose value exceeds the maximum value of the RF signal. This phenomenon can be conditioned by giving a disturbance signal originating from the spark plugs of motor vehicles located near the AUT during the process of measuring the radiation pattern. Correction facility is needed to eliminate values that far exceed the average RF signal received, namely by setting the Maximum Limit value when displaying images of radiation pattern measurements. Thus, if interference occurs when taking radiation measurements, then the display of radiation pattern images can be corrected by eliminating noise that interferes with the measurement process.

Figure 11. AUT radiation pattern when RF signal source is located 0°

Figure 12. Improving the application by adding the Maximum Limit adjustment facility as a data correction factor in displaying the radiation pattern graph.
In addition to the correction facility, the application is enhanced with other accessories to complement the appearance of the Antenna Radiation Pattern application so that users can more easily understand the values of radiation pattern measurements. Improvements to the Antenna Radiation Pattern application appearance are shown in Figure 12.

Based on the results of experiments measuring antenna radiation patterns as a testing process for developing Module-1 hardware, Module-2, and Antenna Radiation Pattern application software with AUT using the Half Wave Open Dipole antenna, it can generally be stated that the hardware and software created have suitable for use in measuring radiation patterns. Testing should be continued for other types of antennas for further exploration of the performance of Antenna Radiation Pattern hardware and software, as well as testing the reliability and validity of Antenna Radiation Pattern hardware and software.

6. Conclusion and Future Works
6.1. Conclusion
Based on the experimental results of radiation pattern measurements using the Antenna Radiation Pattern device that has been made, it can be concluded as follows:

1. Antenna Radiation Pattern device consisting of hardware Module-1 and Module-2 as well as application software for displaying radiation pattern graphs have functioned well for the measurement of radiation patterns.

2. Measurement of the radiation pattern is strongly influenced by environmental conditions where the measurement is carried out, especially the interference of electromagnetic waves generated by devices other than the RF signal transmitter (RF signal source) used, for example noise signals due to spark plugs in motor vehicles.

3. Display of radiation patterns in accordance with the ideal radiation pattern graph (according to theory) can be obtained by processing digital signals resulting from the quantization of RF to DC signals before being displayed in the form of radiation patterns.

6.2. Future Works
Further work based on the results of this study are:

1. Improvement of digital signal processing resulting from RF to DC signal quantization so that the graphical display of the antenna radiation patterns measured is more accurate.

2. It is necessary to test various types of antennas to test the reliability and validity of measurements of antenna radiation patterns.

3. Further development of the Antenna Radiation Pattern device for measuring antenna parameters other than radiation patterns, such as Gain, Beam Width, Directivity, and Aperture.

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