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Design of Dipole Antenna at 433 Mhz ISM Band for Underwater to Land Communication

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ABSTRACT

This research has designed a dipole antenna which is intended for communication underwater to land that worked and was implemented into prototype form. Design using the software Ansoft High-Frequency Structural Simulator (HFSS) v13 and analyze parameters which are generated in simulation results, namely the Voltage Standing Wave Ratio (VSWR), reflection coefficient (S11), the radiation pattern of two-dimensional and three-dimensional. On its design was made of two dipole antennas that can work in a system as a transmitter and receiver. Both of these-dipole antenna operating at ISM 433 MHz frequency band and produce VSWR = 1.62 at the transmitter antenna and = 1.406 on the receiving antenna. In addition, has been measured radiation patterns by antenna performance. From the results of radiation patterns measurements, two pieces of Main Lobe in its field azimuth.

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1. INTRODUCTION

Antenna is defined in Webster's Dictionary as a metallic device which in general used for radiating or receiving radio waves in rod or wire form. Meanwhile, the IEEE Standard Definitions of Terms for Antennas (IEEE Std 145-1983)* defines an antenna or aerial as a device for radiating or receiving radio waves. [1]

Another definition states that an antenna (antenna or aerial) is a device that functions to transfer electromagnetic wave energy from the physical channel media to the air or vice versa from the air to the physical channel media. Because it is an intermediary device between the physical channel media and the air, the antenna must have properties that match the supplying physical channel media. [2] The antenna functions as a transition medium between free space and a transmission channel which can be in the form of a coaxial channel or guided wave which has the function of carrying electromagnetic energy from the transmitting source to the antenna or from the antenna to the receiving system. [3] In a system consisting of a sender and a receiver, of course an antenna is needed as a tool that will transmit information. This information signal will be processed into electromagnetic waves which are then emitted through the antenna. [4]

Underwater wireless communication is a form of communication that uses water as its propagation medium. In this case, communication from underwater to land is also included in underwater communication. Underwater communication with land control certainly has different characteristics. Because this communication is through transmission lines on two different mediums. This of course will affect the performance of the antenna. [5] Therefore, it is necessary to do good design and planning by

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reviewing two different media, namely water and air to make an antenna that can work optimally in the two media.

Wireless communication from underwater to land is utilized for various aspects. Communication for submarines uses underwater-to-ground wireless technology to determine the location of the submarine and facilitate the exchange of information from the submarine to headquarters on land. [6]

Submarine technology uses sonar as its communication. This is because at very low frequencies, the wavelength will also be greater. With a large wavelength, the frequency will be more resistant to attenuation so that the attenuation experienced by water becomes smaller. Thus, the transmission of information underwater becomes more possible using low frequencies. However, because it uses a low frequency, the dimensions of the antenna are getting bigger. In accordance with the wavelength formula (λ=c/f), the lower the frequency value, the greater the wavelength value. This wavelength value is directly related to the dimensions of the antenna. The greater the wavelength, the larger the dimensions of the antenna used. [7]

Radio Frequency (RF) describe as electromagnetic waves that have wavelengths which usually used in radio communications. [8] Radio frequencies range from very low frequency (vlf), which ranges from 10 to 30 kHz, to extremely high frequency (ehf), which ranges from 30 to 300 GHz. Radio waves propagate at a frequency of 100,000 Hz to 100,000,000,000 Hz, while audio waves propagate at a frequency of 20 Hz to 20,000 Hz. in radio broadcasts, audio waves are not transmitted directly but are superimposed on radio waves that will propagate through space. there are two methods of transmitting audio waves, namely through amplitude modulation (AM) and frequency modulation (FM). [9]
The frequency bands available for industrial, scientific and medical (ISM) applications are from 6.78 Mhz to 245 GHz. The study before recommendd the next research to using the RF module 433 operating at 433MHz to provide higher throughput, lower end-to-end delay and cheaper in case of Air-to-Air, Air-to-Water, and for long distance water-water communications with a low throughput. [10] According to the size of the antenna designed, the center frequency from the middle range was chosen as the frequency used. The frequency was 433 MHz.

2. RESEARCH METHOD

In this research, two dipole antennas have been made that function as transmitters and receivers through the water-to-land propagation medium. The two dipole antennas will be mounted on a ground-based receiving prototype and the transmitting antenna will be placed on a transmitter prototype that will be submerged in water.

The antenna that has been designed is in the ism 433 MHz frequency band. The selection of this frequency band is based on the consideration that the desired antenna size is not larger than the size of the prototype submarine that is planned to be used. On conventional submarines, the antenna that is commonly used has very large dimensions because it is operated at a low frequency band (audio). This is because at very low frequencies, the attenuation experienced by the water becomes smaller. Thus, transmitting information underwater becomes more possible using low frequencies. According to the wavelength formula (λ=c/f), if the lower the frequency value, the greater the wavelength value. This wavelength value is directly related to the dimensions of the antenna. The greater the wavelength, the larger the dimensions of the antenna used. For more details, as in the following equation.

$$(\lambda=c/f) \tag{1}$$

$$(l=\lambda/2) \tag{2}$$

The antenna designed is projected to be used for diver robots that are not too large dimensions. The 433 MHz frequency is used because the dimensions of the antenna at this frequency are quite proportional to the size of the submarine and the attenuation because the water experienced at this frequency is not too large when compared to the higher frequency band of 433 MHz.

The antenna is implemented as a transmitting and receiving antenna that can be used for communication from underwater to land with a compact and proportional design for the prototype to be used and can meet the operating frequency for that communication. In this design, two dipole antennas have been made using the software AnSoft High Frequency Structural Simulator Version 11

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(HFSSV11). In addition, a dipole antenna prototype has been made so that direct testing can be carried out to compare the simulation results with direct testing.

2.1. Antenna Parameters

According to the IEEE Standard Definition of Terms for Antennas, the parameters to describe antenna performance are radiation pattern, radiation intensity, beam width, directivity, gain, bandwidth, polarization, and input impedance. Other parameters that also determine the success of the antenna performance are the Voltage Standing Wave Ratio (VSWR) and the reflection coefficient (S11). [11]

2.2. Radiation Pattern

Antenna radiation pattern is a diagram that describes the direction and magnitude of antenna radiation. Basically, the antenna radiation pattern has a ball-like shape, to make it easier to calculate and describe, it is arranged into two horizontal radiation patterns and a vertical radiation pattern. [12] Often, the radiation pattern is determined in the far field and is represented as a function of the directional coordinates.

Half Power Beam Width (HPBW) is the angular width that separates the two half power points on the main beam of the radiation pattern. HPBW can be calculated by finding the -3 dB point from the maximum value of the radiation pattern. Front To Back Ratio is the ratio between the maximum power emitted on the main lobe and the power on the back lobe [1]. Front To Back Ratio (FTBR) is the ratio between the maximum power emitted on the main lobe and the power on the back lobe.The value of the front to back ratio (FTBR) can be determined by comparing the antenna power at the maximum power reception level (position 00 on the main lobe) and in the opposite direction (position 1800 on the back lobe). However, it can also compare the power of the antenna when the position is 900 in the main lobe position and the power of the antenna when the position is 2700 in the back lobe position. So, thus comparing antenna power at a certain angular position is not an absolute (certain) thing and cannot be changed, but the determination of the angular position depends on the position of the main lobe and back lobe which are in the radiation pattern.

2.3. Radiation Intensity

Radiation intensity is defined as the power radiated from an antenna per unit space angle. Radiation intensity is a far field parameter and can be generated by multiplying the radiation density by the square of the distance Mathematically expressed as:

$$U = r^2 W_{rad} \tag{3}$$

where:

U	=	radiation intensity (W/space angle unit)
Wrad	=	radiation density (W/m2)
r	=	radiation radius (m)

2.4. Beamwidth

The beam width of an antenna radiation pattern is defined as the angle of separation between two points equal to opposite sides of the maximum pattern. In an antenna radiation pattern, there are several beam widths. One of the beamwidths used is Half Power Beamwidth (HPBW), which is defined by the IEEE that in a plane containing the direction of the maximum beam, the angle between the two directions is the radiation intensity half of the beam value. Another important beamwidth is the angle of separation between the first points of the pattern which is called the First Null Beamwidth (FNBW). In practice the term beamwidth is usually referred to as HPBW. [2]

2.5. Dipole Antenna Design

The dipole antenna that has been designed is used for communication purposes through two types of propagation which have very different characteristics, namely through the medium of seawater to land. This antenna is designed to operate in the unlicensed ISM 433 MHz frequency band. The design of this antenna is desired as an antenna whose radiation pattern is omnidirectional, that is, it has a pattern in a certain plane (azimuth) and a directional pattern in an orthogonal plane (elevation). The design of a dipole antenna has gone through three main stages. First, determine the specifications and dimensions of the dipole antenna design. The second is designing with Ansoft HFSSv11 software so that the

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expected results are obtained. The third is the prototyping process to test the success of the design.

The first stage of design is to determine the specifications and dimensions of the dipole antenna. The important parameters in designing a dipole antenna are as follows:

- Operating frequency *(f_o)* : The resonant frequency of the selected antenna is in the unlicensed ISM band, at 433MHz. So that the specified resonant frequency is 433 MHz
- Relative permittivity (ε_r): The conductor material used in this design is Aluminum (aluminum) which has a permittivity of ε_r = 1. The choice of this conductor material is based on the ease of obtaining it at a raw material store, as well as its closeness to the Perfect Electric Conductor (PEC), which also has a permittivity of the material ε_r = 1. While the insulating material used is Polyethylene with a permittivity of ε_r = 2.25 and a dielectric loss tangent of 0.001. The choice of this insulator material is based on its closeness to porcelain insulators with a dielectric loss tangent of 0.
- Antenna diameter: The width of the diameter used for this dipole antenna is 7 mm or with a radius (r) = 3.5 mm with the characteristics of a solid material. The reason for choosing this dimension is because it can be easily obtained on the market and is more capable of radiating waves in water when compared to those with holes.
- Impedance: The input impedance used in the design of this dipole antenna is 50 Ω.
- Selection of an insulating material of polyethelene or plastic that is resistant to water pressure as the material for wrapping the antenna and its transmitter device when submerged in water. The choice of this material is not only because it is easy to obtain, but also because of its ability to protect the device from water so that a short circuit does not occur due to exposure to water which can damage the prototype transmitter and its antenna.

The second stage is designing the dimensions of the dipole antenna using Ansoft High Frequency Structural Simulator Version 11 software. The length of the dipole antenna is greatly influenced by the wavelength. In theory, there are various length sizes of dipole antennas, including ($\ell = \lambda/4$), ($\ell = 3\lambda/4$), ($\ell = \lambda$), ($\ell = 3\lambda/2$), and half-wavelength dipole ($\ell = \lambda/2$) [3]. The type of dipole antenna used as a reference is a $\lambda/4$ dipole or in other words a dipole with a quarter-wave size ($\lambda/4$) on each pole. With fo = 433 MHz then λ = 0.693 m, so that the length of the Dipole Antenna l = 0.173 m or equal to 17.3 cm. The details show at the Table 1. The antenna design shown at the Figure 1.

Table 1. Dipole Antenna Design

	Pole length	Gap	Radius	Material type	Boundary type
Dipole Tx	17.3 cm x 2 pole	3 cm	3.5 mm	Aluminum Solid	*Fresh Water*
Dipole Rx	17.3 cm x 2 pole	3 cm	3.5 mm	Aluminum Solid	*Air*

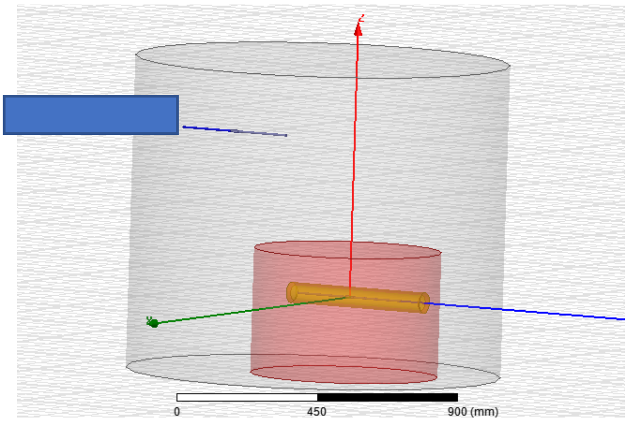

Figure 1. Antenna design simulation

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Because the designed antenna is made to operate on two propagation mediums, water and air, the HFSS software design uses two boundaries (water and air), by placing the transmitter antenna in water and the receiver antenna on land. However, because of the characteristic of water which is short circuit when it encounters a material that can conduct electricity, the Rx dipole antenna is placed in a waterproof plastic material. The following is a design simulation image on medium two boundaries.

3. RESULTS AND DISCUSSION

The data from the table 1 above were obtained from themathematical equations and then simulated in the HFSS v.13 software were obtsiner the S11 and S22 values of the two antennas at a frequency of 433 MHz are still far from the optimum antenna standard, which is -4dB on S11 (Tx antenna in water), and -3.54 dB on S22 (antenna receive on land). Because the size obtained from the calculation results after simulation has not yet obtained optimal results in terms of the S11/S22 and VSWR values of the two antennas above, optimization is carried out using the trial-and-error method to obtain more optimal results by considering the environmental correction factor.

The several factors that led to the optimization of the dimensions of the antenna are as follows:

1. Environmental correction factor.
2. After simulating the antenna parameters (S11, VSWR, and radiation pattern), the results are not as expected.
3. Dimensional factors and characteristics of other devices that want to be integrated with the antenna that has been made.

Optimization is carried out by changing the dimensions of the poles and the size of the gap between the two poles of each antenna using the trial-and-error method so that an operating frequency of 433 MHz is obtained. The dipole diameter is set at 7mm. Optimization data shown in Table 2 below.

Table 2. Optimization Data on Dipole Antenna Design

No.	Pole Length (cm)	Receiver Antenna		Transmitter Antenna	
		S11 (dB)	VSWR	S11 (dB)	VSWR
1	17.3	-4.8	3.8	-4.5	4.7
2	16.5	-6	2.75	-5	3.5
3	16	-8	2.3	-6.25	3
4	15	-11	1.85	-8	2.4
5	15.5	-14.5	1.5	-10.5	1.9
6	14.7	-15	1.45	-12.5	1.6
7	**14.4**	**-16**	**1.4**	**-15**	**1.4**
8	14.0	-15	1.5	-12.5	1.7

According to S11 and VSWR which obtained from the 7^{th} simulation result for receiver antenna and transmitter antenna, thus the final dimensions of the two dipole antennas are chosen as follows at Table 3.

Table 3. Dipole Antenna Design After Optimization

	Pole length	Gap	Radius	Material type	Boundary type
Dipole Tx	14.4 cm x 2 pole	3 cm	3.5 mm	Aluminum Solid	*Fresh Water*
Dipole Rx	14.4 cm x 2 pole	3 cm	3.5 mm	Aluminum Solid	*Air*

After designing, a simulation process is carried out to obtain antenna parameters such as reflection coefficient (S11/S22), VSWR, HPBW, and radiation pattern. The results shown at Figure 9.

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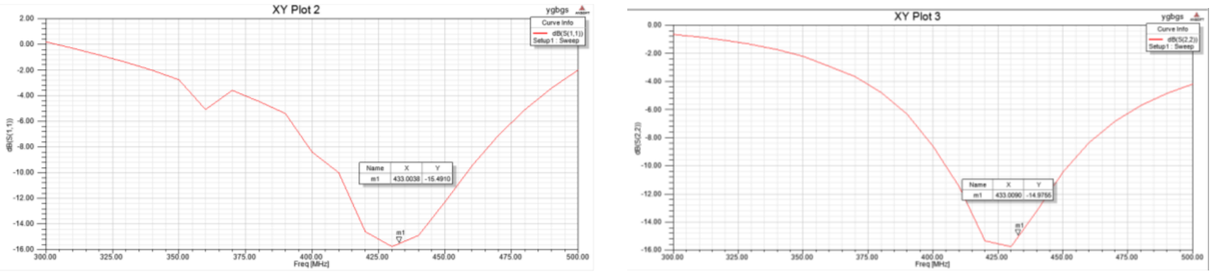


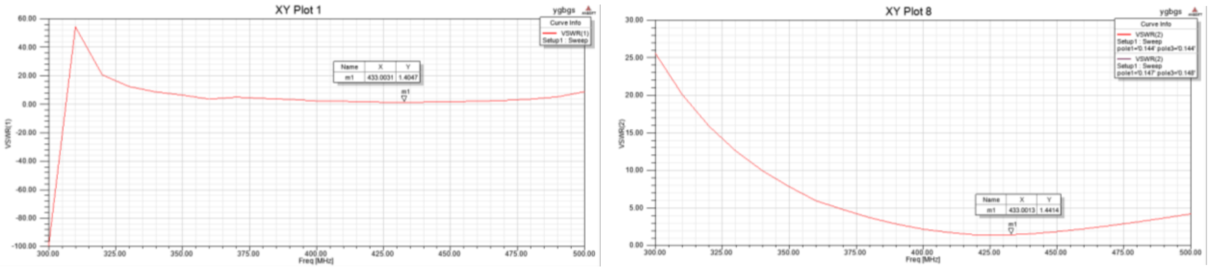
(a) (b)

Figure 9. (a) Reflection Coefficient (S11/S22) and (b) Return Loss Value of S11

From the simulation results, the return loss value of S11 on the underwater transmitting antenna reaches -15.5 dB at a frequency of 433 MHz and has almost fulfilled the desired results. Meanwhile, from the simulation results of the return loss value of S22 on the receiving antenna on the ground, it is -15dB at a frequency of 433 MHz This value is sufficient to meet the standard requirements for the allowable return loss value for each antenna. By using the trial-and-error method, this value is closest to the desired value.

VSWR

VSWR Antenna Transmitter and Receiver



(a) (b)

Figure 10. VSWR (a) Antenna Transmitter and (b) after Optimization

From the simulation results at Figure 10, the value of the Voltage Standing Wave Ratio or VSWR of the two dipole antennas at a frequency of 433 MHz is below 2 so that the VSWR value is 2: 1. This value is as expected because the good VSWR value in signal reception is below 2 and close to 1.

HPBW

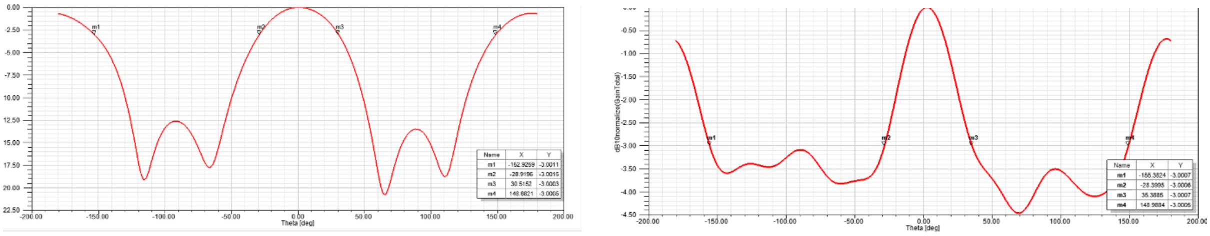


Figure 11. Simulation Results of Azimuthal Radiation Patterns in (a) Rectangular Coordinates and (b) Elevation Field in Rectangular for Dipole Antenna Design

From the simulation results at Figure 11, the -3 dB value in the normalization of the radiation pattern in rectangular coordinates is obtained at around -28° and 30° angles from the maximum radiation direction, so the azimuthal HPBW of the simulated field is 28° + 30° = 58°. This value indicates a large beamwidth. Meanwhile, the radiation pattern for the elevation plane is obtained at an angle of -28° and 35° from the maximum radiation direction, so the HPBW of the azimuthal plane from the simulation results is 28° + 35° = 63°. This value indicates a large beamwidth.

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Radiation Pattern

- Duo boundary (Water and Air)

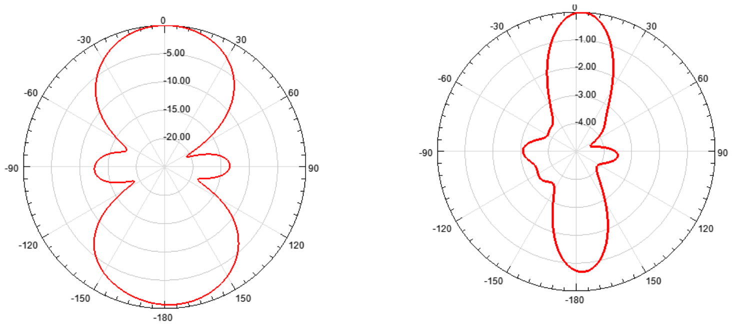

Figure 12. Azimuthal Elevation Duo boundary

- One boundary (Air)

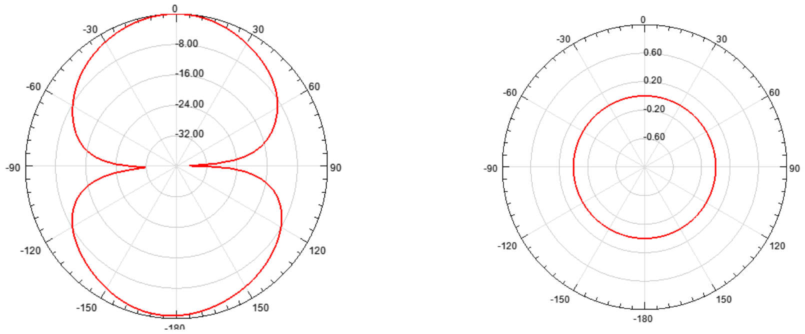

Figure 13. Azimuthal Elevation One Boundary

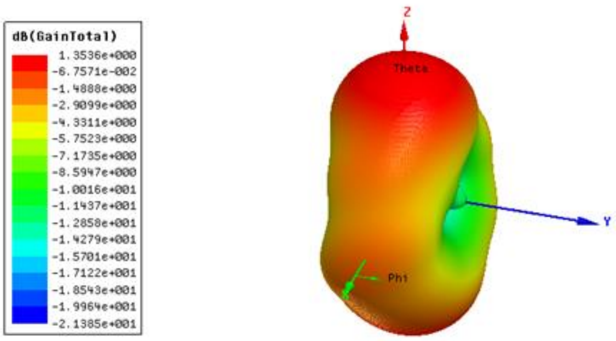

Figure14. Dipole Antenna 3D radiation pattern

Figure 112, Figure 13, and Figure 14 shows that the designed antenna is a directional antenna. Where the antenna radiates electromagnetic waves with a total gain of the antenna from the simulation results of 1.3536 dB. theoretically the maximum gain of a λ/2 dipole antenna is 10 log 1.66 or 2.2 dBi.

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Comparison of Simulation Results with Measurement Results
Receiving Dipole Antenna Prototype
Reflection Coefficient (S11)

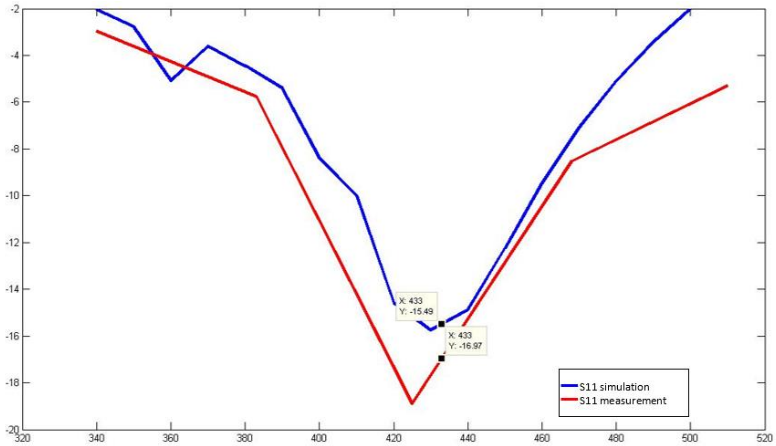

Figure 15. Comparison of S11 measurement results with simulation results receiving antenna

In Figure 15, it can be seen that there are similarities in the S11 graphic pattern between the measurement results and the simulation results. In the simulation, the S11 value tends to reach a frequency of 430 MHz. Meanwhile, in the measurement results, the S11 value tends to decrease to a frequency of 425 MHz. From the measurement results, it was found that the return loss value at the 433 MHz frequency was greater, namely -16.97 dB, while the return loss value in the simulation results was -15.49 dB, so the difference between the two was -1.48 dB. The bandwidth obtained from the measurement results is greater than the simulation results where in the measurement results s11 ≤ -10dB is at a frequency of 398 Mhz to 460 Mhz and in the simulation results at a frequency of 410 Mhz and 458 Mhz. There are differences in measurement results in the image because the area around the measurement room is not free from the influence of electromagnetic wave interference or reflected signals from the transmitting antenna.

VSWR

Figure 16 shows that the VSWR graphic pattern is similar between the measurement results and the simulation results. In the simulation, VSWR has a value of ≤2 starting from a frequency of 410 MHz to 430 MHz. Meanwhile, measurements start from a frequency of 410 MHz to 425 MHz. From the measurement results, it was found that the VSWR value at the 433 MHz frequency was smaller, namely 1.406, while the VSWR value in the simulation was 1.456. Where the difference in VSWR values from measurement results and simulation results is 0.050 dB. The difference between the measurement is due to the area around the measurement room not being free from the influence of electromagnetic wave interference or reflected signals from the transmitting antenna.

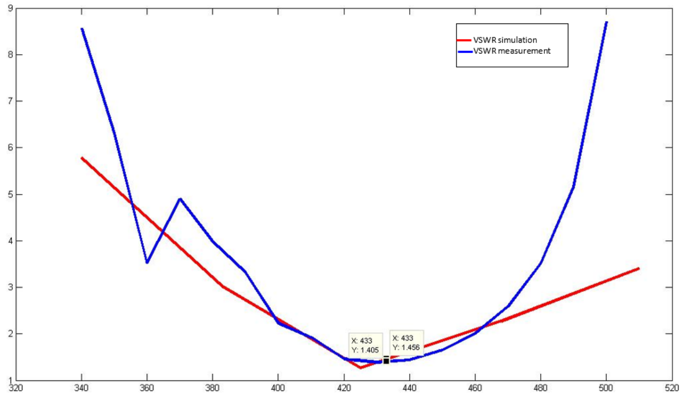

Figure 16. Comparison of VSWR Measurement Results with Simulation Results Receiving Antenna

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Transmitting Dipole Antenna Prototype
Reflection Coefficient (S11)

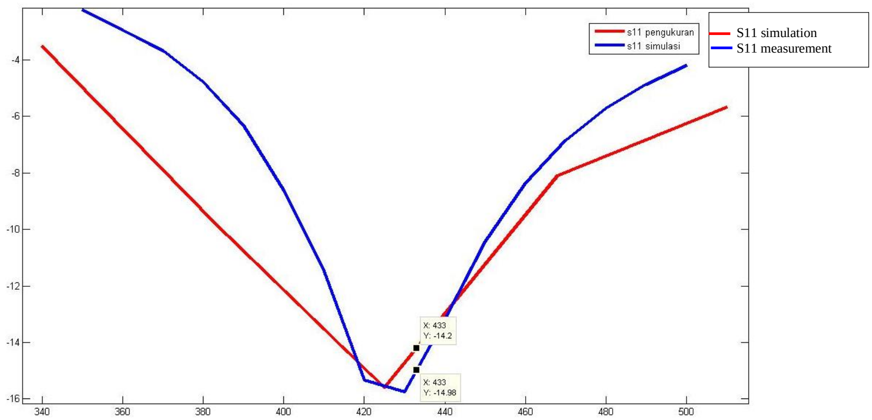

Figure 17. Comparison of S11 Measurement Results with Simulation Results Transmitting Antenna

In Figure 17, it can be seen that there are similarities in the S11 graphic pattern between the measurement results and the simulation results. In the simulation, the S11 value tends to decrease to a frequency of 430 MHz. Meanwhile, the measurement results start from a frequency of 385 MHz to a frequency of 425 MHz. From the measurement results, it was found that the return loss value at the 433 MHz frequency was smaller but still ≤ -10 dB, namely -14.2dB, while the return loss value in the simulation results was -14.98 dB so the difference between the two was -0.78 dB. The bandwidth obtained from the measurement results is greater than the simulation results where in the measurement results s11 ≤ -10dB is at a frequency of 385 Mhz to 458 Mhz and in the simulation results at a frequency of 405 Mhz and 455 Mhz. There are differences in measurement results in the images because the area around the measurement room is not free from the influence of electromagnetic wave interference or reflected signals from the transmitting antenna.

VSWR

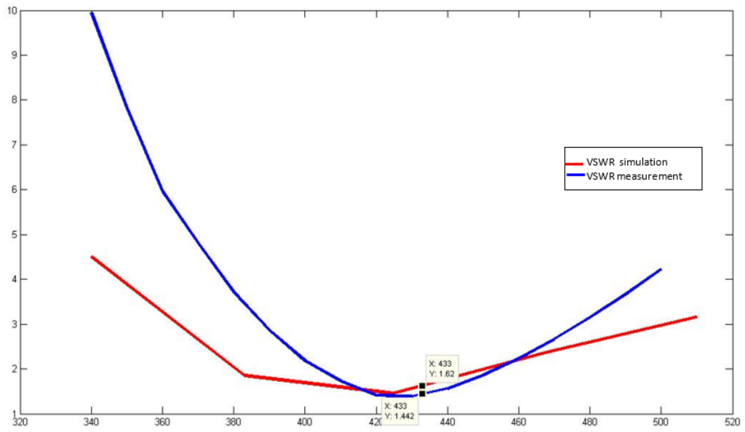

Figure 18. Comparison of VSWR Measurement Results with Simulation Results Transmitting Antenna

From Figure 18, it can be seen that the VSWR graphic pattern is similar between the measurement results and the simulation results. In the simulation, VSWR has a value of ≤2 starting from frequencies 405 MHz to 455 MHz. Meanwhile, measurements start from a frequency of 382 MHz to 450 MHz. From the measurement results, it was found that the VSWR value at the 433 MHz frequency was greater but still had a value of ≤2, namely 1.62, while the VSWR value in the simulation was 1.442. Where the difference in VSWR values from measurement results and simulation results is 0.020 dB. The differences in measurement results in Figure 21 are due to the area around the measurement room not being free from the influence of electromagnetic wave interference or reflected signals from the transmitting antenna.

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4. CONCLUSION

Based on the analysis of the simulation results and the results of measurements of the dipole antenna prototype for underwater to ground communication using Ansoft HFSS and MATLAB software, it can be concluded as follows:

1. The selection of the ISM 433 MHz frequency is based on considerations of the propagation conditions encountered and considerations of the size and dimensions of the antenna expected as well as the availability of devices and materials on the market.
2. In determining the dimensions of an antenna, it is very important not only to focus on the theoretical formulation but also to pay attention to the environmental correction factor. In a dipole antenna, a change in the length of the antenna causes a change in the working frequency. In addition, the diameter size and the type of antenna material affect the S11 and VSWR values. The condition of the propagation medium also greatly affects the radiation pattern of the antenna.
3. Optimization of the best size for transmitting and receiving dipole antennas obtained for propagation in water and air mediums is to use a solid aluminium antenna with a diameter of 7 mm and a length of 144 mm for each pole.
4. The VSWR obtained in the antenna design simulation with Ansoft HFSS v13 software meets the ideal standard (VSWR $\leq$ 2). The VSWR at a working frequency of 433 MHz for the receiving dipole antenna is 1.456 for the simulation results and 1.406 for the measurement results. While the VSWR at the working frequency of the transmitting dipole antenna is 1.442 for the simulation results and 1.62 for the measurement results.
5. S11 obtained in the antenna design simulation with Ansoft HFSS v13 software meets the ideal standard (S11 $\leq$ -10 dB). S11 at a working frequency of 433 MHz for the receiving dipole antenna is -15.49 dB for the simulation results and -16.97 dB for the measurement results. Whereas S11 at a working frequency of 433 MHz for the transmitting dipole antenna is -14.98 dB for the simulation results and -14.2 dB for the measurement results.
6. The results of measurements of the radiation patterns of the two transmitting and receiving dipole antennas while in the air show almost the same results as the simulations in the azimuth and elevation planes. In the azimuth plane the radiation pattern of the two dipole antennas resembles the figure 8 and in the elevation plane they are circular.

REFERENCES

[1] Electronics Engineers, “IEEE Std 145-1983 IE E E Standard Definitions of Terms for Antennas,” *Publ. by Inst. Electr. Electron. Eng.*, vol. 145, 1983.

[2] H. A. Alsawaf and A. E. Kanaan, “Rectangular and circular antennas design for Bluetooth applications,” *Telkomnika (Telecommunication Comput. Electron. Control.*, vol. 21, no. 1, pp. 8–17, 2023.

[3] Y. Li, S. Wang, C. Jin, Y. Zhang, and T. Jiang, “A Survey of Underwater Magnetic Induction Communications: Fundamental Issues, Recent Advances, and Challenges,” *IEEE Commun. Surv. Tutorials*, vol. 21, no. 3, pp. 2466–2487, 2019.

[4] C. E. Santosa, J. T. S. Sumantyo, S. Gao, and K. Ito, “Broadband Circularly Polarized Microstrip Array Antenna with Curved-Truncation and Circle-Slotted Parasitic,” *IEEE Trans. Antennas Propag.*, vol. 69, no. 9, pp. 5524–5533, 2021.

[5] T. Shaneyfelt, M. A. Joordens, K. Nagothu, and M. Jamshidi, “RF communication between surface and underwater robotic swarms,” in *2008 World Automation Congress*, 2008, pp. 1–6.

[6] O. Aboderin, L. M. Pessoa, and H. M. Salgado, “Wideband dipole antennas with parasitic elements for underwater communications,” *Ocean. 2017 - Aberdeen*, vol. 2017-Octob, pp. 1–6, 2017.

[7] A. Massaccesi and P. Pirinoli, “Preliminary results on cylindrical antennas for underwater communication,” *2016 IEEE Antennas Propag. Soc. Int. Symp. APSURSI 2016 - Proc.*, pp.

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1895–1896, 2016.

[8] Z. Wang, S. Zhou, and Z. Wang, "Underwater Distributed Antenna Systems: Design Opportunities and Challenges," *IEEE Commun. Mag.*, vol. 56, no. 10, pp. 178–185, 2018.

[9] G. P. Joshi, S. Y. Nam, and S. W. Kim, *Cognitive radio wireless sensor networks: Applications, challenges and research trends*, vol. 13, no. 9. 2013.

[10] S. M. Maher, Z. M. Ali, H. H. Mahmoud, S. O. Abdellatif, and M. M. Abdellatif, "Performance of RF underwater communications operating at 433 MHz and 2.4 GHz," *Proc. 2019 Int. Conf. Innov. Trends Comput. Eng. ITCE 2019*, no. February, pp. 334–339, 2019.

[11] Pahrurrozi, C. M. O. Muvianto, and S. Ariessaputra, "DESAIN MODIFIKASI CANTENNA UNTUK OPTIMASI FEED ANTENA GRID 2 . 4 GHz," *J. Bakti Nusa*, vol. 1, no. 2, pp. 49–57, 2020.

[12] A. Aoad, "Design and manufacture of a multiband rectangular spiral-shaped microstrip antenna using EM-driven and machine learning," *Elektron. ir Elektrotechnika*, vol. 27, no. 1, pp. 29–40, 2021.