# Performance of Underwater Audio Transmission Based on Underwater Visible Light Communication (UVLC)

Arya Maulana Ibrahimy, Budi Ikhwan Fadilah, Dharu Arseno, Brian Pamukti

*Abstract*—**Currently, underwater communication is limited to sign language or additional tools such as a blackboard. Underwater voice communication itself is still becoming resistant due to acoustic waves, which have a propagation distance far but only have a small data rate (about kbps), and Radio Frequency (RF) which has a very short propagation distance, but with a high data rate (range up to Mbps). Underwater Visible Light Technology Communication (UVLC) was initiated to replace the role of waves carrier because besides having a long propagation distance, it also has a high data rate (up to Gbps). This research has tested the indoor and underwater channel tools with artificial seawater media. The transmitter uses Light Emitting Diode (LED) Super bright green LED or 500 nm wavelength, and the receiver uses a Positive Intrinsic Negative (PIN) photodiode of type BPW34. The experiment test scenario includes increasing the propagation distance and changing the angle. The output of this research is in the form of power received in dBm, internal sound level decibels a-weighting (dBA). After extensive testing, the result shows that the devices performance was stable, both indoor and underwater analysis. We also prove that the value of the received power and the sound level for excellent communication on the indoor channel is -6 dBm and 98.8 dBA. In addition, in the underwater channel, the value of transmit power and sound level is obtained at -10 dBm and 86.6 dBA.**

*Index Terms*—**UVLC; receive power; sound level.**

## I. Introduction

THE Visible Light Communication (VLC) is wireless communication that uses visible light to transmit data. The visible light wavelength starts from 400 nm up to 700 nm [1]. Nowadays, the VLC is initiated for future data communication. VLC has advantages in high data rate and high bandwidth because of the light speed and the terahertz frequency. The other advantage of using the VLC there is still no regulation of frequency use in terahertz frequency. The last advantage of the VLC because of its efficiency in lightning and communication.

The Underwater Visible Light Communication (UVLC) is the application of VLC that use in the underwater medium. It is purposed to make an underwater wireless communication with a high data rate with moderate to long-distance propagation. It is purposed for disaster mitigation communication, diver voice communication, and autonomous underwater vehicle.

The study [2] mentioned that the data rate of the resulting communication wireless optical with the LED as transmitter reaches 1 Gbps with a depth of 11 up to 31 m below the water. The data rate can reach up to 5 Gbps in a clear ocean with a laser as the transmitter. Meanwhile, with an experiment in the turbid harbor, the data rate can reach up to 1 Gbps.

Research [3] experiments a visible light audio transmission. These experiments make the received power and transmission loss as parameters. Based on this experiment, the maximum distance of propagation only reaches 20 cm in the indoor channel.

Research [4] explains that the crosstalk can happen in the underwater channel. This experiment uses RGB LED as the transmitter and uses a color filter in the receiver. The conclusion of this experiment crosstalk can happen while two VLC transmitters use the same wavelength. This experiment does in a freshwater channel.

The novelty of this paper is the underwater channel that is used. The underwater channel uses artificial seawater that contains calcium, magnesium and has to specify gravity around 1.024. The output of this paper is the sound level, received power, and the loss that is compared with an indoor channel. Moreover, the output of the experiment will be compared by the experiment result in the indoor channel. This method is done to prove the underwater channel effect on the device.

This research is managed as follows. Part II illustrates the design system for the UVLC system, including the channel model and prototype schematic. Part III describes the result and analysis of the experiment. Part IV conclusion that achieved by the result and analysis of this experiment.

## II. Research Method

This section discusses the basic theory in this paper. The transmitter that used in this paper use a green wavelength LED. Based on the research [2], [5], [6], wavelength around 500 nm until 520 nm has better performance on any condition underwater. On the received side, we used a silicon positive-intrinsic-negative (PIN) photodiode. Even the silicon PIN photodiode does not have amplification like the avalanche photodiode (APD) [7], the voltage operating is lower than the APD.

Figure 1 is the system design in this paper. The 1 kHz frequency act as information and starts from the source. After

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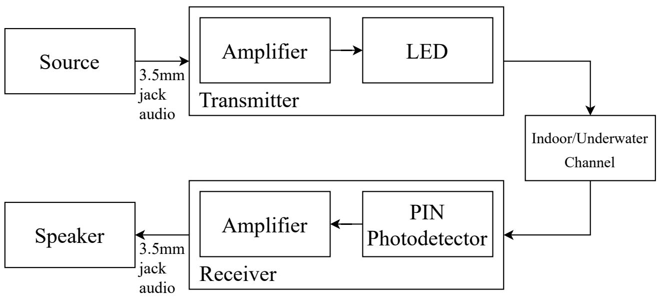


Fig. 1. Diagram block for communication.

that, there is amplification by the transistor and modulated by the LED. The information will be modulated by a light pulse and sent through the channel. Then, the light pulse will be received by the photodiode and converted to electrical information. Before the speaker produces the sound, the electrical pulse will be amplified again by the transistor.

### A. Light Emitting Diode (LED)

LED is a type of semiconductor diode often used in UVLC as the light source [8]. The LED consists of three parts: a p-junction contains the hole, an n-junction containing electrons, and a depletion region. LED works with the principle of forward bias. Forward biased is when the positive pole (+) met with the cathode, and the negative pole (-) met with the anode. Current will flow from the source of electric current to the p-region and n-region [9]. The merger of the electron and hole will occur on space depletion, so it comes out photons from space depletion. The illustration of LED can be seen in Figure 2.

### B. Positive-intrinsic-negative (PIN) Photodiode

The photodiode is a device that converts the light signal into an electrical signal. The PIN photodiode is a type of photodiode that consists of a p-region, intrinsic region, and n-region. PIN photodiode utilizing the principle of reverse bias, where the negative pole (-) will be connected with the cathode, and the positive pole (+) will be connected with the anode. Reverse bias resulted in the widening of the intrinsic region, as shown in Figure 3.

### C. Bipolar Junction Transistor(BJT)

BJT is a device that can function as an amplifier and switching [10]. Based on the pin, BJT has three pins [11].

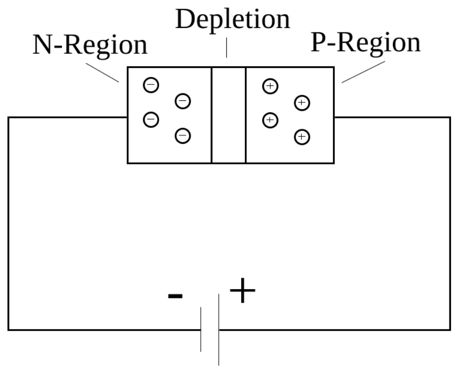


Fig. 2. The illustration of LED.

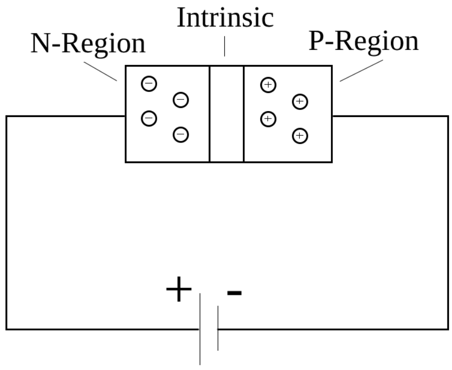


Fig. 3. Illustration of PIN photodiode.

TABLE I
CLASSIFICATION OF SEAWATER.

| Water Type | Particle Concentrate | Operating Wavelength |
|---|---|---|
| Pure sea/ clear ocean | Less | 450 - 500 nm |
| Coastal ocean | High | 520 - 570 nm |
| Turbid harbor | Very high | 520 - 570 nm |

The base is the first pin that has a positive pole. The second pin is the collector that has a negative pole. Moreover, the last is the emitter which has a negative pole. The symbol of BJT Negative-positive-negative can be seen in Figure 4.

### D. Underwater Channel

This paper uses an underwater channel for the experiment. The underwater channel is one of the Non-Line of Sight (NLOS) channels. NLOS is the channel where there are obstacles between the communication transmitter and receiver. In this channel, obstacles can be happened by the particles and microscopic substances. This can cause the scattering, absorption, and refraction of light [12], [2]. Figure 5 illustrates the underwater channel that we used in this research.

Based on the seawaters particle and turbidity, three types of classification are explained in Table I [2].

### E. Indoor Channel

The other channel that uses in this experiment is the Line of Sight (LOS) indoor channel. LOS is a channel model where there is no obstacle of communication between the LED and photodetector. The LOS communication has a higher data rate due to no noise as the light of the other [8]. Figure 6 is the LOS channel.

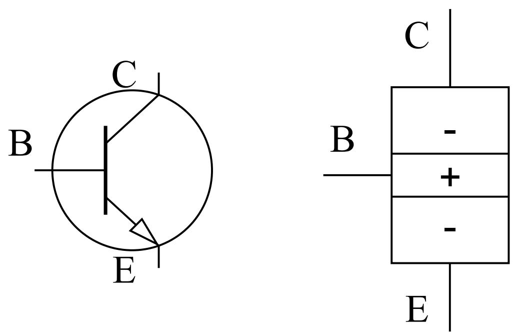


Fig. 4. The Negative-positive-negative Bipolar Junction Transistor.

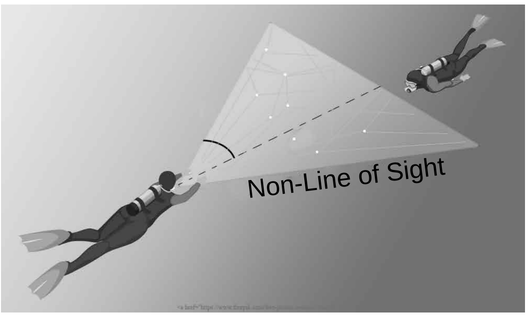


Fig. 5. Illustration of NLOS underwater channel.

### F. A-weighting

A-Weighting is the standard sound level measurement based on the "American Tentative Standards for Noise and Other Sounds" [13]. A-weighting can use as a sound level from 20 Hz to 20 kHz. The average human can hear unit is 0 dBA with a frequency of 1 kHz [14].

### G. Experiment Models

The purpose of the experiment was to obtain the received power and the sound level. Meanwhile, the environment sound level value is around 45 dBA. The condition of the light intensity is around 0 lux. The audio that used in this experiment has a 1 kHz frequency sourced from a smartphone. The uses of 1 kHz frequency to avoid the adjustment of the a-weighting dBA that sourced.

The testing includes a shift distance of propagation from 10 cm to 100 cm with the increment of 10 cm on the underwater channel and will be carried out measurements of the lux meter and sound meter on any increase in distance. Testing also includes the variation of the angle of information delivery, namely 0°, 10°, and 20°. The underwater channel does in Aquarium with 40-liter artificial seawater that has been explained in Section I. Meanwhile, the indoor channel measurement-do in the same room as the underwater experiment. The measurement illustration can see in Figures 7 and 8. Based on the experiment method, several parameters have been used in this experiment. Table II describes the parameters.

### H. Transmitter

The circuit of the transmitter can see in Figure 9. As for the in this circuit is the audio input through the audio jack of 3.5 mm. This signal then moves through the base of the transistor as the input signal. If there is no information, then the switch on the transistor will be closed, resulting in currents flowing to the ground from emitters. If there is information on the base, then the transistor's switch will open, resulting in information flowing from the base toward the emitter to the collector [11]. VCC by 9V will be used as enhancers voltage bias on the signal information, which will increase the signal's amplitude. The signal will be forwarded to LED and will modulate on the light pulse. Figure 10 is the transmitter device used in this paper.

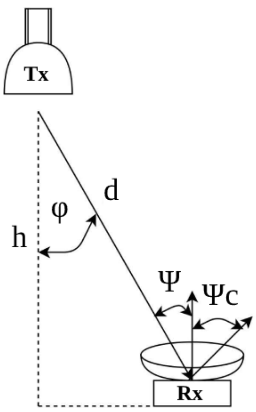


Fig. 6. LOS channel mode propagation.

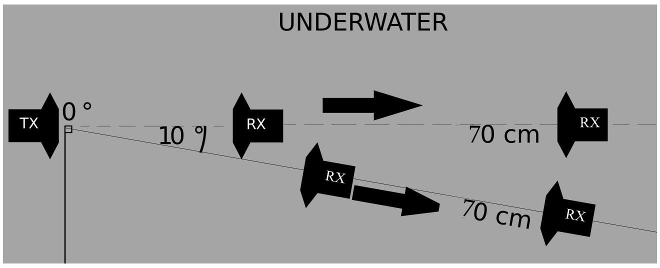


Fig. 7. Underwater channel measurement.

TABLE II
EXPERIMENT PARAMETER.

| Parameter | | Value |
|---|---|---|
| **Transmitter** | Type | LED 10 mm YSL-R1042G2C-D16 |
| | Number of LED | 4 |
| | Wavelength operation | 515-520 nm |
| **Receiver** | Type | Silicon PIN Photodetector BPW34 |
| | Wavelength operation | 400-1100 nm |
| | Area Photodetector | 7 mm |
| **Media** | Channel mode | Artificial seawater (NLOS) |
| | | Indoor (LOS) |
| | The water component | Calcium 450 ppm Magnesium 1300 ppm Specivy Gravity 1.024 in 19-litre water |
| **Dimensions of the aquarium** | Width | 40 cm |
| | Height | 40 cm |
| | Length | 100 cm |
| **Audio** | Frequency | 1 kHz |
| **Battery** | Voltage | 9 V |
| **Environment value** | Lux | 0 Lux |
| | Sound level | 45 dBA |
| **Measurement device** | Lux meter | HS1010 |
| | Sound meter | GM1351 |
| | AVO meter | A830 |

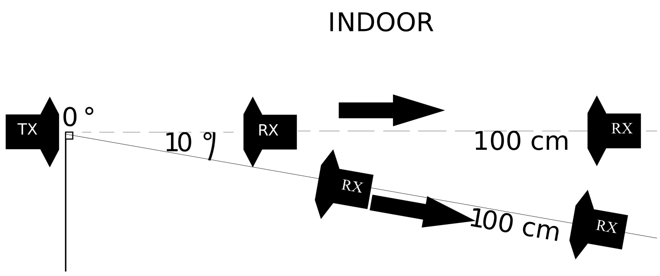


Fig. 8. Indoor channel measurement.

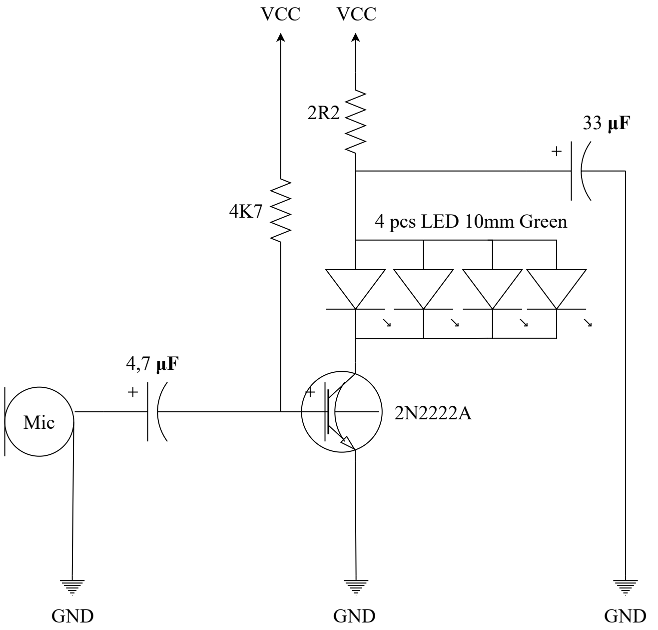


Fig. 9. Transmitter circuit.

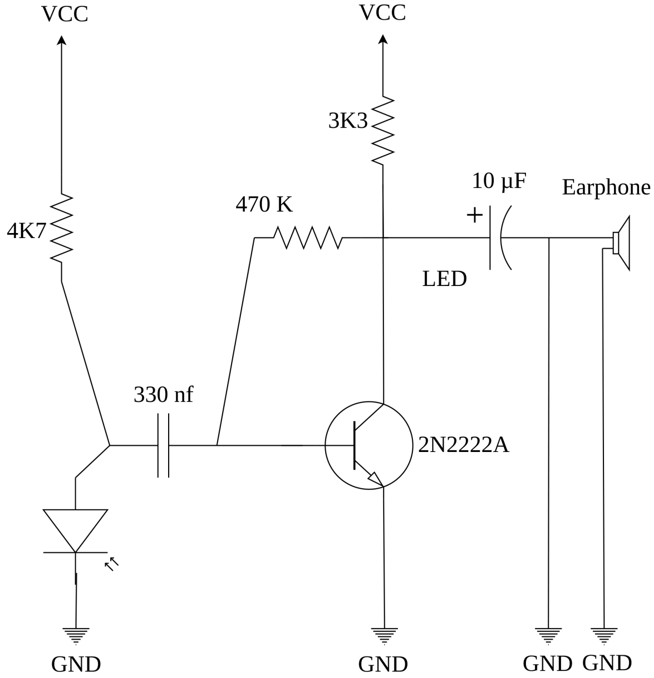


Fig. 11. Receiver circuit.

*I. Receiver*

Figure 11 is the receiver circuit. Meanwhile, the light pulse received by a PIN photodetector will be converted into electrical signals and information forwarded by reverse bias on the receiver. The amplifying and switching process will same as the transistor before the speakers generate the voice. The information signal with a voltage above 0.7 V will result in a switch in the transistor will work, then VCC will increase the bias voltage on the audio signal before it is generated on the device speaker. The receiver device can see in Figure 12.

## III. Result and Discussion

This section discussed the results and analysis of the testing tools that do according to the parameters specified. The results and analysis are divided into three parts, sound level, received power, and the relation of sound and power received. Each analysis was performed on two different channels, indoor and underwater. The results obtained in this chapter are sound level generated at the receiver device with an output frequency of 1 kHz and also the power received from the receiver device.

*A. Sound Level Measurement*

The results of this measurement are done by recording the output of the speaker by sound meter GM1351. The measurement unit is decibel a-weighting (dBA) with a threshold of the environment's sound level (45 dBA).

Based on Figure 13 shows that the distance of propagation affects the audio output that is produced by the speaker, this is evidenced by the value of the sound level produced continuing to be degraded from a distance of 10 cm to 100 cm. At an angle of 0°, there is an attenuation of the sound level around 30 dBA from 10 cm to 100 cm. At an angle of 10° the degradation value around 20 dBA at a distance of 60 cm, and then followed with the disappearing of output sound. Then at an angle of 20° the output of sound only achieves up to 20 cm with the reduction of sound level by 5 dBA, and at a distance further distinguished with the threshold level of environmental sounds. The angle changes from 0° to 10° and 20° lead changes in the value of sound level in a row of 30 dBA 40 dBA. The decline in the value of sound level is due to the beamwidth of the LED only having a full width at half maximum (FWHM) value in a 20°.

Figure 14 is the measurement of the underwater channel. The measurement farthest distance only reaches 70 cm because the volume of the aquarium limits it. The sound level difference in all angles with the indoor channel has a value of around 10 dBA. This difference is caused by the presence of scattering, refraction, and absorption on the underwater channel. Same as the indoor channel, the addition of the

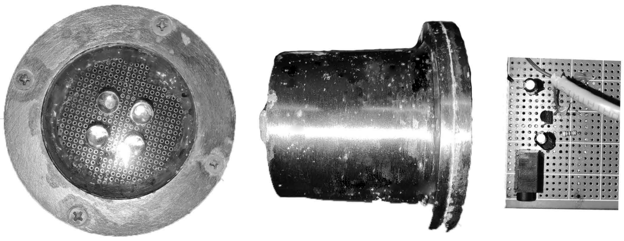

Fig. 10. Transmitter device.

Fig. 12. Receiver device.

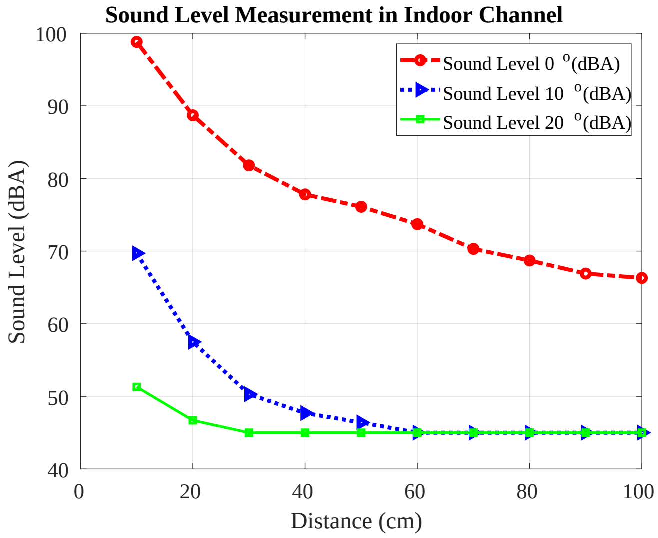


Fig. 13. Sound level in indoor channel.

TABLE III
SOUND LEVEL COMPARISON.

| Sound Level in Indoor Channel (dBA) | | | |
|---|---|---|---|
| Distance (cm) | Sound level 0° | Sound level 10° | Sound level 20° |
| 10 | 98.8 | 69.7 | 51.3 |
| 20 | 88.7 | 57.5 | 46.7 |
| 30 | 81.8 | 50.3 | 45 |
| 40 | 77.8 | 47.7 | 45 |
| 50 | 76.1 | 46.4 | 45 |
| 60 | 73.7 | 45 | 45 |
| 70 | 70.3 | 45 | 45 |
| 80 | 68.7 | 45 | 45 |
| 90 | 66.9 | 45 | 45 |
| 100 | 66.3 | 45 | 45 |
| **Sound Level in Underwater Channel (dBA)** | | | |
| Distance (cm) | Sound level 0° | Sound level 10° | Sound level 20° |
| 10 | 86.6 | 50.5 | 45 |
| 20 | 81.5 | 46.5 | 45 |
| 30 | 75.1 | 45 | 45 |
| 40 | 70.6 | 45 | 45 |
| 50 | 66.5 | 45 | 45 |
| 60 | 65.6 | 45 | 45 |
| 70 | 60.5 | 45 | 45 |

distance make the value of the sound level decrease. At an angle of 0°, the sound level value decreased around 20 dBA in 70 cm. Then at 10° degrees with a reduction of the sound level around 5 dBA in just 30 cm. At 20° degrees, there is no sound output in this measurement. Table III is a comparison of the sound level on each channel.

### *B. Power Received*

The measurement of received power using the method of the conversion of lux and converted into the power with an area photodetector. As for the device lux meter used in this test is the lux meter HS1010. Scenario testing devices are the same by testing the level of sound. The formula of conversion lux to power is [15]

$$P_{(W)} = \frac{E_{v(lx)} \times A_{(m^2)}}{\eta_{(lm/W)}}, \qquad (1)$$

Where $Ev$ is the value of light illuminance in lux. $A$ is the value of the surface area of the photodiode. $\eta$ is the value

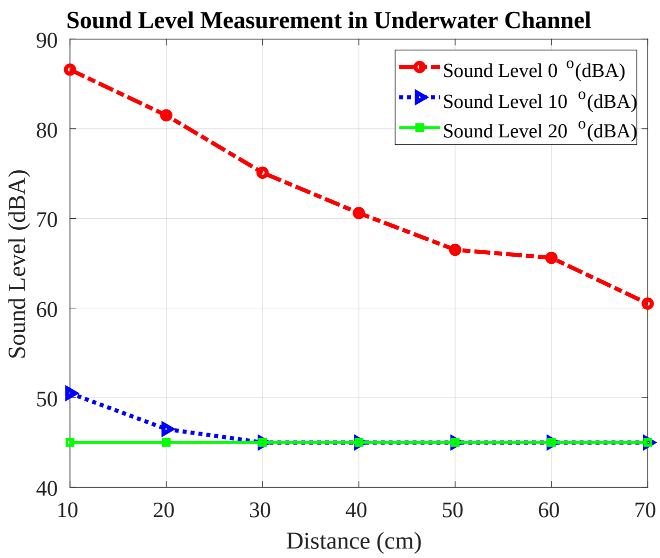


Fig. 14. Sound level in underwater channel.

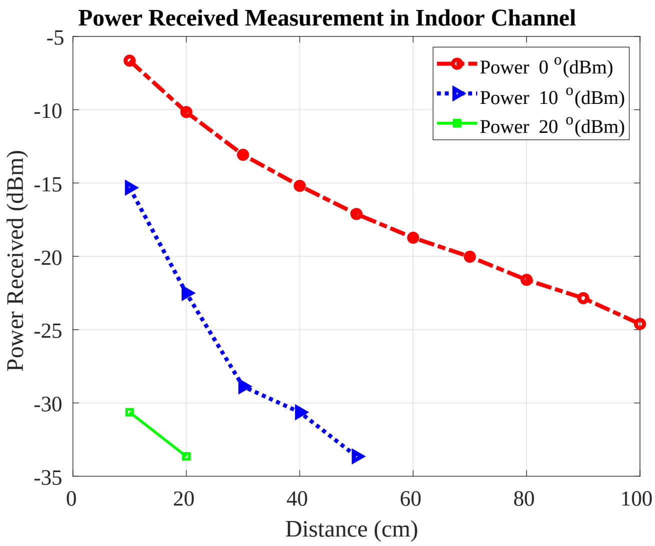


Fig. 15. Received power in indoor channel.

of luminous efficiency per watt. LED has an efficiency value of around 90 lm/W.

Figure 15 shows the performance of the received power in the indoor channel. Based on the measurement, the value of received power with the angle of propagation 0° has the best-received power with -6,65 dBm and degrade over 18 dBm at a distance of 100 cm. Meanwhile, with the angle of propagation of the 0° obtained, the value of the received power -15,32 dBm, and the degradation power of 18 dBm at a distance of 50 cm, and no light is received at a distance of 60 to 100 cm. On corners, 0° light are accepted only up to a distance of 20 cm with the value in the distance 10 cm by -30.63 dBm and decreased to -33,64 dBm at a distance of 20 cm.

Figure 16 shows the performance of the received power device on the Underwater channel. Received power at an angle of 0° has a value of -10,97 dBm and is degraded by 15 dBm at a distance of 70 cm. At 10°, received power was obtained by -30,63 dBm at a distance of 10 cm and decreased to -33,64 dBm at 20 cm. At the angle of 20°, no light is received. The comparison of the received power

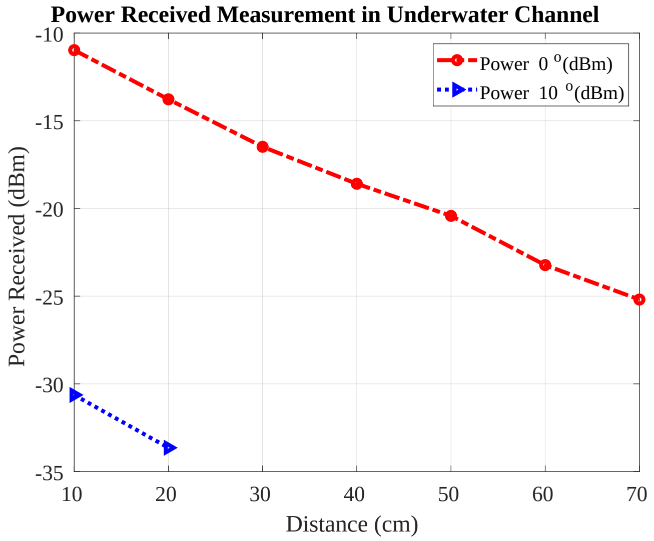


Fig. 16. Received power in underwater channel.

TABLE IV
RECEIVED POWER COMPARISON TABLE.

| Received Power in Indoor Channel (dBm) | | | |
|---|---|---|---|
| Distance (cm) | Power 0° | Power 10° | Power 20° |
| 10 | -6.654469702 | -15.31908062 | -30.63386979 |
| 20 | -10.16112111 | -22.50473622 | -33.64416975 |
| 30 | -13.07512123 | -28.8729572 | No value |
| 40 | -15.19318935 | -30.63386979 | No value |
| 50 | -17.11204461 | -33.64416975 | No value |
| 60 | -18.73055281 | No value | No value |
| 70 | -20.02689139 | No value | No value |
| 80 | -21,60296992 | No value | No value |
| 90 | -22,85235728 | No value | No value |
| 100 | -24,61326988 | No value | No value |
| Received Power in Underwater Channel | | | |
| Distance (cm) | Power 0° | Power 10° | Power 20° |
| 10 | -10.97245246 | -30.63386979 | No value |
| 20 | -13.7764524 | -33.64416975 | No value |
| 30 | -16.48413631 | No value | No value |
| 40 | -18.59266996 | No value | No value |
| 50 | -20.4219768 | No value | No value |
| 60 | -23.23024289 | No value | No value |
| 70 | -25.19318935 | No value | No value |

in the channel in the indoor and underwater can be seen in Table IV.

### C. Relation of Sound and Power Received

Based on the [16], the average human conversation sound level is around 50 to 60 dBA. In the experiment, the average human conversation is shown in Table V. The power needed to produce the sound level is around -30 up to -22 dBm. If the power receives more than -22 dBm, the sound is not safe for normal human hearing. Meanwhile, if the power received below -30 dBm, the output would sound tiny, like a human whisper.

TABLE V
RELATION OF POWER AND SOUND.

| Position | Power (dBm) | Sound Level (dBA) |
|---|---|---|
| Underwater, 70 cm, 0° | -25.19318935 | 60.5 |
| Indoor, 20 cm, 10° | -22.50473622 | 57.5 |
| Indoor, 10 cm, 20° | -30.63386979 | 51.3 |
| Underwater, 10 cm, 10° | -30.63386979 | 50,5 |
| Indoor, 30 cm, 10° | -28.8729572 | 50.3 |

## IV. CONCLUSION

This paper proposes the audio transmission on the underwater channel for future underwater voice communication. Based on the experiment, the obtained result of the power received, and sound level on the underwater is lower than the indoor. This condition occurs because underwater, there is the presence of absorption, scattering, and refraction effects caused by the particles in the underwater channel. Changing the angle of propagation leads to a decreased value in the experiment. This research proves that with the results at an angle of 10 the underwater, the received power declines to 20 dBm. At an angle of 20, there is no light received. These results also occur in the indoor channel, but there is still receiving power at an angle of 20. This result is caused by the angle of the half-wave luminous LED only reaching 20 degrees. This problem was overcome by using a wide-angle LED. In addition, this research can be experimented with by changing a different light source and photodetector.

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