Buletin Pos dan Telekomunikasi Vol. 18 No.1 (2020): 17-28

Underwater Data Transmission Using Frequency Shift Keying (FSK) Modulation with Bit Rate of 2400 bps

Slamet Indriyanto[1], Anggun Fitrian Isnawati[2], Jans Hendry[3], Ian Yosef Matheus Edward[4]
[123]*Institut Teknologi Telkom Purwokerto*
[4]*Institut Teknologi Bandung*
[123]*Jl. D.I. Panjaitan No.128, Purwokerto, Jawa Tengah, Indonesia*
[4]*Jl. Ganesha No.10, Bandung, Jawa Barat, Indonesia*
email: [1]slamet@ittelkom-pwt.ac.id, [2]anggun@ittelkom-pwt.ac.id, [3]jans@ittelkom-pwt.ac.id, [4]ian@stei.itb.ac.id

ARTICLE INFORMATION

Received 26 August 2019
Revised 21 January 2020
Accepted 23 January 2020

Keywords:
Underwater Communication
FSK Modem
Binary FSK

ABSTRACT

Underwater acoustic communication is a technology that uses sound or acoustic waves and water as its propagation medium. This technology has been used in various fields, such as underwater wireless sensor networks, underwater monitoring system, and surveillance systems. An acoustic modem is required to facilitate communication between nodes. In this paper, an underwater acoustic modem using Frequency Shift Keying (FSK) modulation has been designed. This modulation is widely used because of its reliability and simple design. FSK modem was designed using M=2 level or known as Binary FSK (BFSK) with 40 kHz mark frequency and 43 kHz space frequency. This study tested data packets sending and its error rate against the distance variation. Testing for 70-bit data resulted in 1% error at 100 cm distance and 37% error at 170 cm distance. When compared with the previous testing at 1200 bps which resulted in 0% and 35% error, it can be seen that error at 1200 bps is better than at 2400 bps, but the data transmission was better at 2400 bps. Addition to the number of bits sent and distance has an influence on the error value, i.e. the greater the distance and the amount of data sent, the greater the error value.

1. Introduction

Underwater communication technology has been utilized in various fields, including for underwater wireless sensor networks (UWSN) (Akyildiz, Pompili, & Melodia, 2005), underwater monitoring (Mu et al., 2014), seismic monitoring (Zhu, Wu, Deng , Qin, & Wang, 2018), and surveillance systems (Grund, Freitag, Preisig, & Ball, 2006), etc.

Other studies on underwater communication technology discussed other medium than sound, namely radio frequency and optics (Yu, Jin, Sui, & Lan, 2011). However, researchers have made the acoustic signals use the primary choice for the development of underwater communication technology, considering the frequency selective fading which occurs under water. This will cause attenuation to certain frequencies. Radio frequency, for instance, will experience high attenuation regardless its short range (Wu et al., 2012). Communication systems using acoustics wave have advantages for long distance underwater data transmission, although some weaknesses persist, including acoustic carrier attenuation, multi-path reflection, and delay spread (Stojanovic, 2008). Several modulation schemes have been used by researchers in order to overcome the weaknesses. One of the schemes was modulation Frequency Shift Keying (FSK). FSK modulation is widely used by researchers for its reliability and simple design. However, one major disadvantage of FSK is that it has a slower bit rate when compared to other modulation schemes.

Underwater acoustic modem development using FSK modulation has an average bit rate of 200 bps to 400 bps (Wu et al., 2012) (Benson et al., 2010). A previous study on this matter used the modem in a speed of 1200 bps (Indriyanto & Edward, 2018). This study, however, will increase the speed to 2400bps using FSK modulation and analyze the modem’s performance. This study differs from the previous one from the use of increased speed up to t wo times to determine the capabilities of the modem made. Increased speed on the modem is obtained by calculating and changing the value of the filter capacitor in the demodulator circuit to match the speed used. Results of the study will be compared to that of the previous one to determine its performance. This study is expected to produce a low cost underwater acoustic modem with a variety of bit rate values which are suitable for short-range sensor network applications for Indonesian waters.

2. Literature Review

2.1. Previous works

There are a number of studies concerning underwater acoustic modem including on the adaptive underwater acoustic modem (Wu et al., 2012) which used adaptable modulation between FSK and DSSS with data rates of 200 bps and 400 bps. Bridget Benson et al. presented a design of a low-cost underwater acoustic modem (Benson et al., 2010) which uses FSK modulation with a frequency of 35 kHz, for short range, and low data rate applications with data rate up to 200 bps. J. H. Jeon, et. Al. studied mobile underwater communication system, underwater communication system with bio-inspired fish robots (Jeon, Lee, Kim, Ryuh, & Park, 2013). These researchers investigated mobile communication systems with a frequency of 74 kHz and a data rate of 1kbps. Based on previous research, namely ultrasonic underwater acoustic modem using FSK modulation (Indriyanto & Edward, 2018), modems have been made with FSK modulation and use ultrasonic frequencies, with 1200 bps speed used.

2.2. Underwater sensor network

Underwater network is one of the least explored sectors although underwater communication has been tested since World War II. In 1945, an underwater telephone was developed in the United States to communicate with submarines. Acoustic communication is physical layer technology in underwater networks. Figure 1 presents the architecture of underwater sensor network.

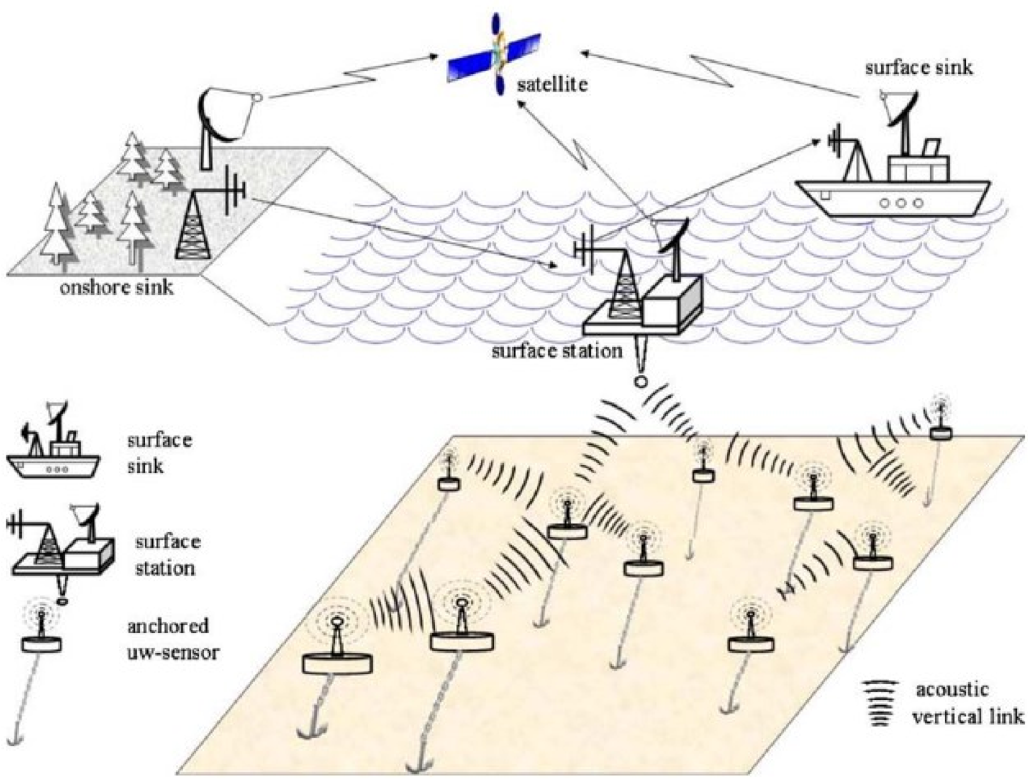

Figure 1. Underwater sensor network architecture (Akyildiz et al., 2005)

In practice, radio waves propagate over long distances through seawater only at extra low frequencies (30-300 Hz) that require large antennas and high transmission power. Berkeley Mica 2 Motes, the most popular experimental platform in the sensor network community, has reported having a transmission range of 120 cm under water at 433 MHz through experiments conducted at the Robotic Embedded System Laboratory (RESL) at the University of Southern California. Optical waves are not subject to high attenuation but are affected by scattering. In addition, optical signal transmission requires high precision in directing narrow laser beams. Thus, links for underwater networks are based on acoustic wireless communication (Akyildiz et al., 2005)

2.3. Modulation Scheme

This section will discuss the modulation scheme used, namely Frequency shift keying (FSK). FSK is a simple digital modulation technique that can provide reliable communication in harsh medium conditions. Many researchers use FSK modulation for its reliability and simple receiver design. However, the main disadvantage of FSK is the slower bit rate when compared to other modulation schemes. FSK is not ideal for high data rate applications such as Autonomous underwater vehicle (AUV) control and audio or video streaming.

Frequency shift keying was chosen to be implemented as a physical layer communication protocol because although simple, it is a strong modulation scheme and requires a small bandwidth (to match the characteristics of transducer and analog circuits used), and has been widely used in underwater communication in the last two decades for its resistance to frequency spreading from underwater acoustic channels (Benson et al., 2010). Mark frequency (binary 1) and space frequency (binary 0) used are 40 kHz and 43 kHz. An example of FSK modulation is shown in figure 2.

2.4. FSK Modem

2.4.1. Block Diagram of the Modulator Designed

Modulator is a circuit that is responsible for translating bit streams into signals that can be transmitted to physical media. For FSK modulation, digital data is transmitted through analog channels by shifting carrier frequency to mark frequency or space frequency on each period depending on whether the digit is 1 or 0.

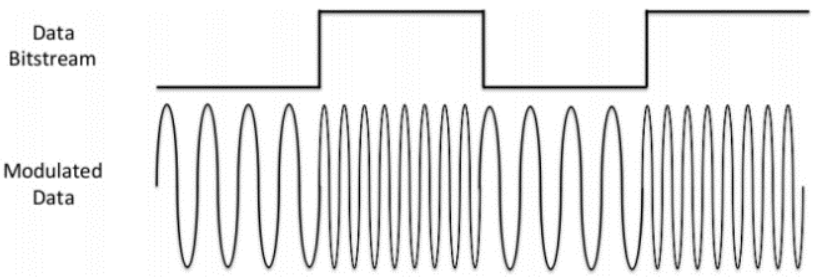

Figure 2. An FSK modulation

Figure 3 shows the block diagram of the designed modulator. IC XR 2206 consists of four functional blocks, a Voltage Controlled Oscillator (VCO), an Analog Multiplier and Shine Shaper, a gain buffer amplifier, and one set of current switches. A VCO produces an output frequency proportional to the input current set by a resistor connected from the timing terminals to ground. With two timing pins, two separate output frequencies can be independently generated for FSK generation applications using the FSK input control pins. This input controls the current switches that select one current through one of the resistor *timings* and routes it to the VCO (Exar Corporation, 2008).

2.4.2. Block Diagram of Demodulator designed

Demodulator has the task to convert the received analog signal into a digital signal. In FSK modulation, the task is to detect mark and space frequencies of the received signal and converts it back to digital 1 or 0. The IC used to make the demodulator circuit is IC XR2211 which has a special function as an FSK demodulator. Figure 4 below shows a block diagram from IC XR2211.

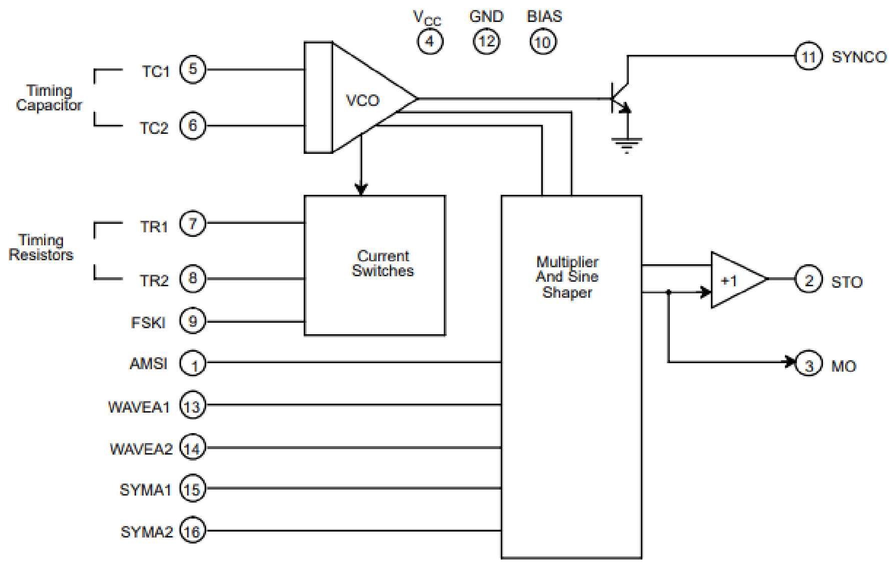

Figure 3. Block diagram of Modulator XR2206

IC XR2211 comprises an internal circuit block which works as the following description: The Preamplifier is used as a limiter such that input signals of above 10mV rms are amplified to a constant higher signal. The Voltage Controlled Oscillator (VCO) is a frequency generator (f0) determined by its input current, set by a resistor (R0) to ground and is driving current with a resistor (R1) from the phase detector. Quad phase detector serves to detect phases, carriers, and produce high output impedance. The output phase detector will produce the sum and difference from its input signal and from the VCO frequency that is connected internally. The Loop Phase Detector serves as phase detector feedback to provide a high impedance output. Internal Reference functions as a generator of reference voltage. Lock Detect Comparator is the logic complement of the lock detect output on pin 6. This output is also an open collector type that can sink 5mA of load current at “low” or "on" state. FSK Data Output is an open collector logic stage that requires an RL to VCC pull-up resistor. This can sink 5mA load current. When decoding FSK signals, the FSK data output is at "high" or "off" state for low input frequency, and at a "low" or "on" state for high input frequency (Exar Corporation, 1997).

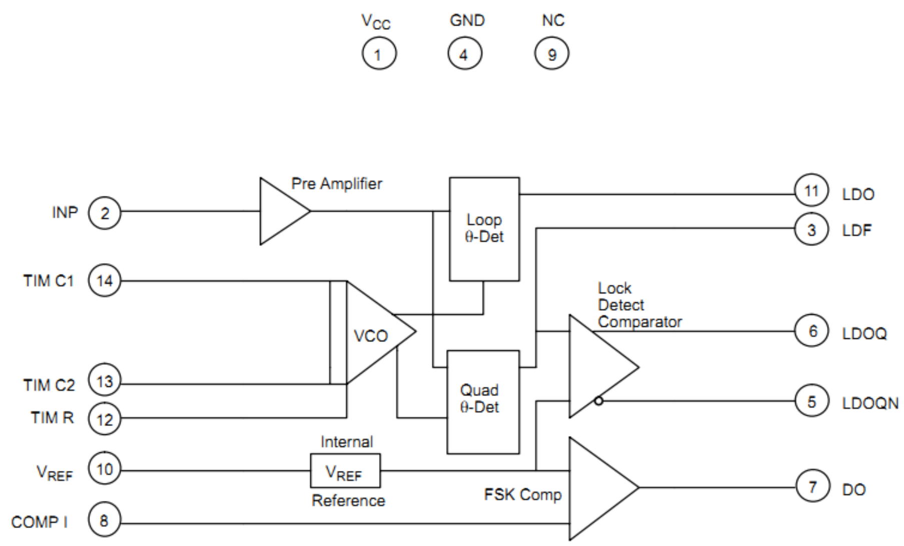

Figure 4. Block diagram for Demodulator XR2211

3. Research Method

This study applies the Research and Development (R&D) method with the following stages:

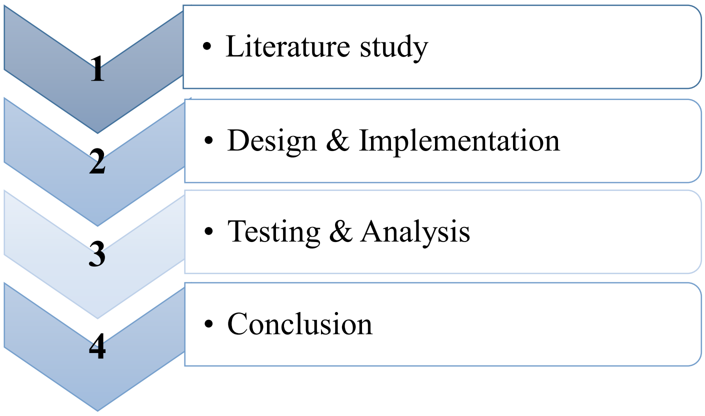

Figure 5. Research Stages

3.1. Literature Study

This stage is divided into two main steps, namely literature search and literature review. Literature search is a search from the already published papers of relevant research topic for references. References papers are found from the IEEE website. After finding numerous papers, some with relevant research topic are then selected. These selected papers were then reviewed to determine the state of the art of research and research contributions and formulate hypotheses to design the ways to conduct research. At this stage, the authors can obtain a clear picture for the research.

3.2. Design and Implementation

The stages and steps taken in formulating the research's design and implementation planning are as follows:

a. Creating FSK modulator and demodulator designs
b. Building FSK modulator and demodulator
c. Testing FSK modem with the frequency designed
d. Testing the working area of the transducer used
e. Matching the FSK modem's frequency with the transducer working frequency range
f. Configuring overall modem system.

3.3. Testing and Analysis

The testing stage is divided into two parts, basic and system testings. Each part of the testing was conducted in the following steps:

a. Basic Testing
   In the basic testing, the component and modem circuit were tested to find out whether they are running as desired through transducer and modulator circuit testing.
b. System Testing
   System testing is conducted to evaluate the overall performance of the system by sending data under water. The testing was conducted in a 1meter deep swimming pool.

3.4. Conclusions

In this stage, conclusions were drawn in based on the results obtained.

4. Research Results and Discussion

This section explains system block diagram, testing scenario and analysis of the system built. The testing stage is divided into two parts, namely basic testing and system testing.

4.1. System Block Diagram

The underwater acoustic modem is designed using FSK modulation, therefore an FSK modulator and demodulator circuit are needed. The microcontroller used is arduino Uno, and the transducer used is commercial ultrasonic waterproof sensor type JSN SR-04T. Figure 6 below is a block diagram of the system created.

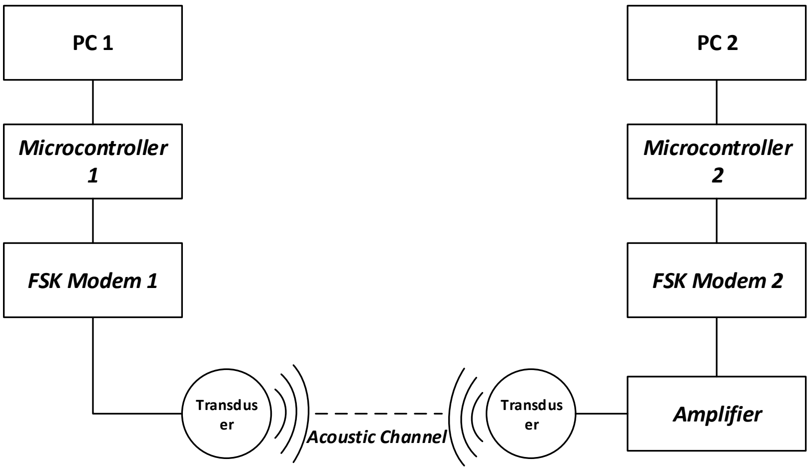

Figure 6. System Block Diagram

4.1.1. Modem

Modem is an acronym for modulator and demodulator. Modulator is a circuit that is responsible for translating bit streams into signals that can be transmitted into physical media. For FSK modulation, digital data is transmitted through analog channels by shifting the carrier frequency to mark frequency and space frequency each period depending on whether the digit is 1 or 0. The modulator circuit is designed using IC XR-2206 which is an Exar integrated circuit (IC) product that is able to produce high-quality sine, square, triangle, ramp, and pulse waves with high stability and accuracy (Exar Corporation, 2008).

Demodulator converts the received analog signal into a digital signal. In FSK modulation, this means detecting the mark frequency and space frequency of the received signal and converting it back to digital 1 or 0. The demodulator circuit is designed using IC XR-2211A which is also an Exar product (Exar Corporation, 1997).

Table 1. Modem Parameter

Properties	Assignment
Modulation	FSK
Mark Frequency	40 kHz
Space Frequency	43 kHz
Bandwidth	3 kHz
Speed	2400 bps

Table 1 shows the parameters of the modem designed. Mark frequency is used to represent digital bit “1”, and space frequency is used to represent digital bit “0”.

4.1.2. Transducer

Transducer is the component used to convert an electrical signal into an acoustic signal (at the transmitter) or convert an acoustic signal into an electricity signal (at the receiver). Commercial transducers are sold at high prices. In this paper, a more inexpensive transducer is used.

Figure 7. Waterproof ultrasonic sensor JSN SR-04T

Figure 7 shows the type of transducer used in this study. A Waterproof ultrasonik sensor JSN SR-04T transducer was selected to be used as part of the modem built. This sensor is an ultrasonic distance measuring module with a non-contact distance detection function. This product adopts an industrial-grade integrated ultrasonic design, which is waterproof with stable performance.

Table 2 shows the specifications of the JSN SR-04T transducer used. The working voltage is 5 volts with a frequency of 40 kHz. This sensor application is generally used for distance sensors or car parking sensor, therefore, a test and measurement are necessary prior to its use as an acoustic transducer.

Tabel 2. Transducer Specification

Properties	Assignment
Operating Voltage	DC 3 – 5.5V
Working Current	Less than 8mA
Probe Frequency	40 kHz
Measuring Angle	75^0
Operating Temperature	-20^0 to 70^0 C

Source: (Jahankit, n.d.)

In this test, the frequency response of the JSN SR-04T sensor is measured. The test is done by providing input frequencies from 20 kHz to 50 kHz from the function generator to transducer 1, and then an acoustic signal is received through transducer 2 and is measured with an oscilloscope. From this test, data on the range of frequency in which the JSN SR-04T sensor gives a good response is obtained. Figure 8 below shows the results of the transducer’s frequency response measurement.

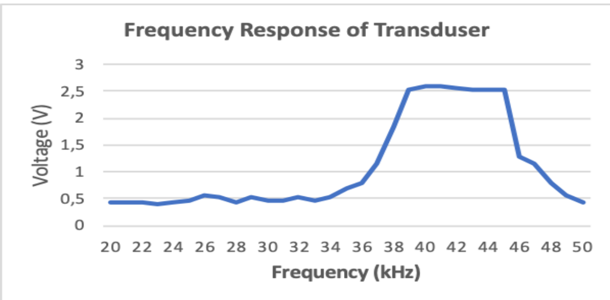

Figure 8. Transducer’s Frequency Response graph

4.2. FSK Modem Design

4.2.1. Modulator Circuit Design

The modulator circuit is designed using IC XR-2206 which is commonly used as FSK modulators and function generators with high stability and accuracy. The output waveforms can be both amplitude and frequency modulated by an external voltage. Frequency of operation can be selected externally between the range of 0.01 Hz to more than 1 MHz. This circuit is ideally suitable for communications, instrumentation, and function generators applications that require sinusoidal tone, AM, FM, or FSK generation. Figure 9 shows a basic FSK modulator circuit.

The XR 2206 can be operated with two separate timing resistors, R1 and R2, connected to Pin 7 and 8 respectively. Depending on the polarity of the logic signal at Pin 9. If Pin 9 is open-circuited or connected to a bias voltage of ≥ 2V, only R1 is activated and when the voltage level on pin 9 is $\leq 1V$, only R2 is activated. The modulator circuit's output frequency depends on the values of Resistor R1, R2, and the value of capacitor C which is an external component that must be added to IC XR2206. The output frequency value is calculated by equation 1).

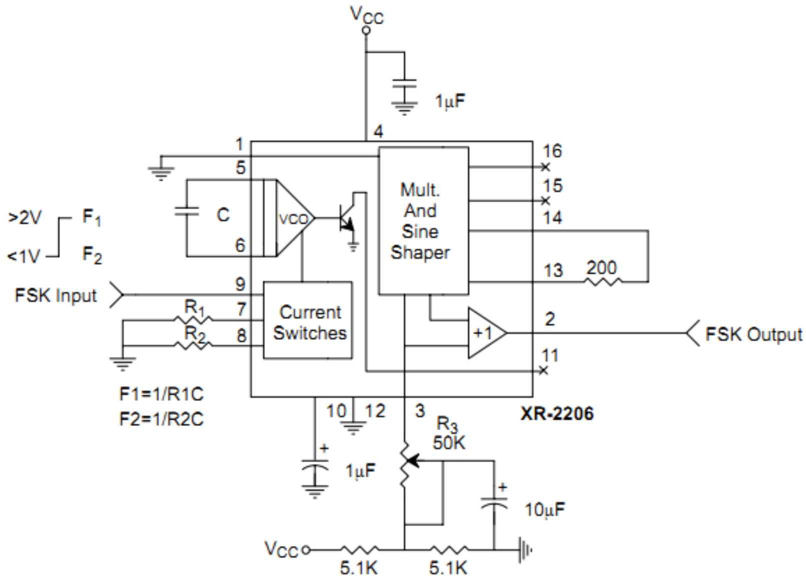

Figure 9. FSK Modulator circuit

$f1 = \frac{1}{R_1C}$ and $f2 = \frac{1}{R_2C}$ .... 1)

where:

f1 : mark frequency
f2 : space frequency
R1 : Modulator Resistor 1
R2 : Modulator Resistor 2
C : Timing Capacitor

F1 is the output mark frequency when the input is high logic data, while F2 is the output space frequency when the input is low logic data. The mark frequency and space frequency can be adjusted independently by selecting the timing resistors R1 and R2. The oscillation frequency of the modulator circuit is determined by the timing of the external capacitor C on Pin 5 and 6, and by the timing resistor R connected to Pin 7 or 8 and can be adjusted by varying the values of R or C. The recommended R value for a given frequency range is shown in Figure 10. It has the optimal temperature stability for 4kΩ <R <200kΩ. The suggested C values are from 1000pF to 100µF.

4.2.2. Demodulator Circuit Design

The demodulator circuit designed using IC XR-2211A is very suitable for FSK modem applications and can operate with a supply voltage range from 4.5V to 20V and a wide frequency range over 0.01 Hz to 300 kHz. This IC can accommodate analog signals between 10mV and 3V. This circuit consists of a basic PLL to track the input signal with a band pass, a quadrature phase detector that performs carrier detection, and an FSK voltage comparison that provides FSK demodulation. External components are used to set center frequency, bandwidth, and output delay independently. Figure 11 shows the FSK Demodulator circuit.

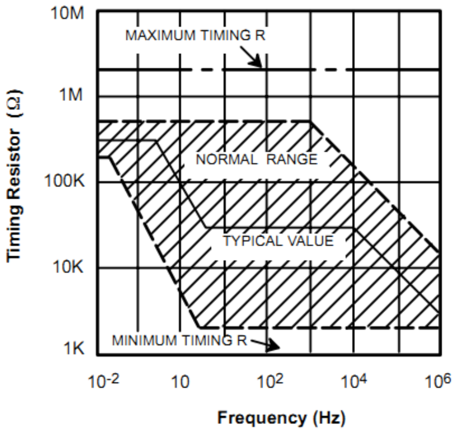

Figure 10. Resistor values proportional to oscillation frequency

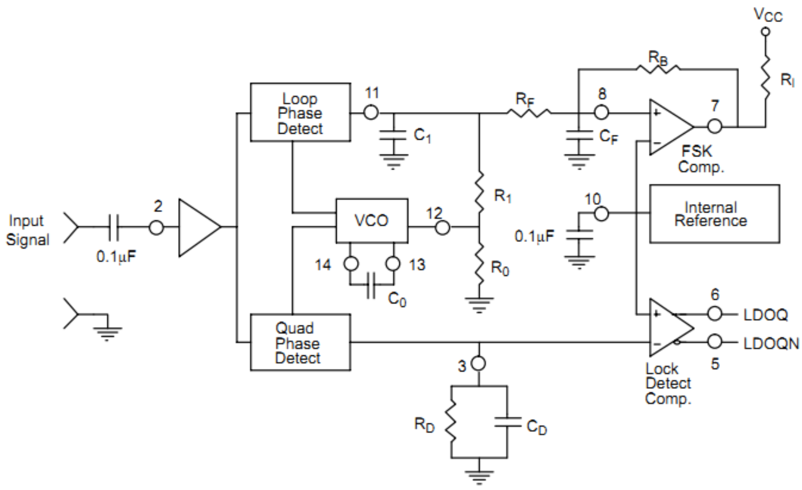

Figure 11. RFSK Demodulator circuit

The previous studies used similar modulator and demodulator circuit design with this current study. The modem used in the previous study had a limitation of only being able to transmit data with a 1200 bps bit rate, therefore this study attempts increase the data transmission speed to 2400 bps. This study differs from the previous one in its calculation and replacement of CF capacitor filter values in the demodulator circuit. The equation 2) shows a formula for obtaining the CF value.

$$C_F = \frac{0.25}{(R_{SUM}.Baud\ Rate)} \quad \text{.......... 2)}$$

Where:

CF : Capacitor Filter
R_{SUM} : Resistor
Baud Rate : data flow speed

4.3. System Implementation

After the system is designed, the next step is building the FSK modem circuit and conduct system integration. Arduino uno is connected to the FSK modem, amplifier and transducer. Following are the results of the implementation of the FSK modem circuit that has been designed. Figure 12 shows the system implementation.

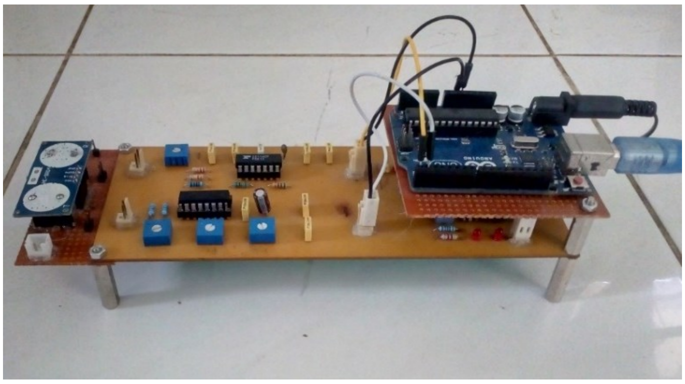

Figure 12. System Implementation

4.4. Basic Testing

In this testing, a measurement is conducted to find out whether the output of the modulator circuit matches the design made. This testing also aims to obtain the mark frequency and space frequency of the modulator circuit.

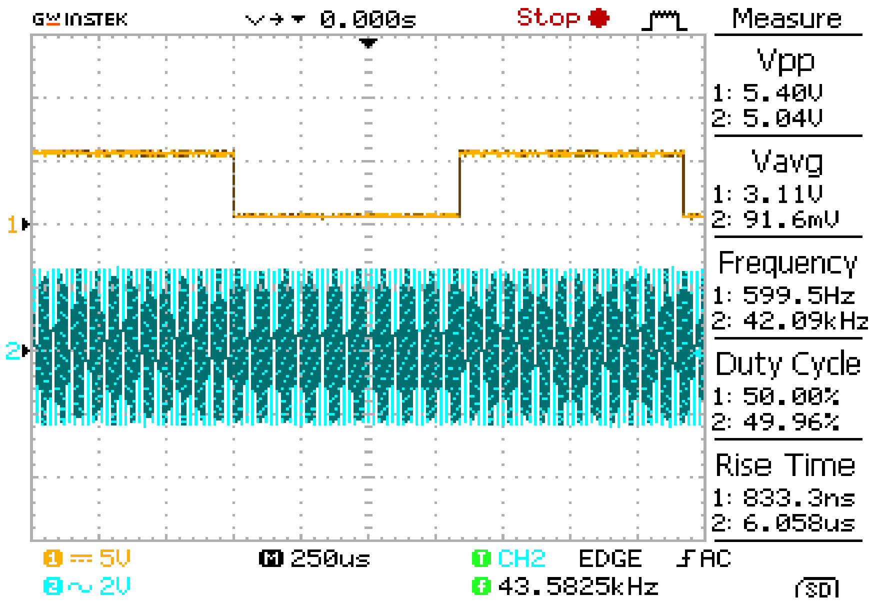

Figure 13. Modulator input and output measurement

Figure 13 shows the results of modulator circuit output measurement using an oscilloscope. Channel 1 on the oscilloscope is the input modulator which is still in a digital signal 1 and 0. Channel 2 on the oscilloscope is the modulator output that has been modulated using FSK modulation. When the input modulator signal is high or logic 1, the output modulator will generate a mark frequency with a frequency of 43 kHz. Whereas when the input modulator signal is low or has logic 0, the output modulator will produce a frequency space with a frequency of 40 kHz. So, if there is a variation of logic 1 and 0 in the input modulator, the output modulator will produce a frequency that varies between 40 kHz and 43 kHz.

4.5. System Testing

The system testing scenario is divided into two stages. The first system testing is done by sending the "hello world" text 10 times with a delay of 1 second. The testing is carried out in a swimming pool with a distance of 100 cm - 170 cm bit rate 2400 bps.

Figure 14 shows the system testing which is carried out in a swimming pool. Modem 1 functions as a sender and modem 2 functions as a receiver. Modem 1 is set to send the text "hello world" 10 times. Number 1 is the location of transducer 1 and number 2 is the location of transducer 2.

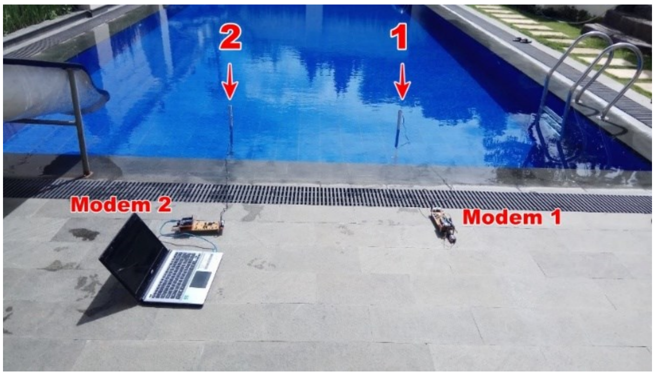

Figure 14. System testing in a swimming pool

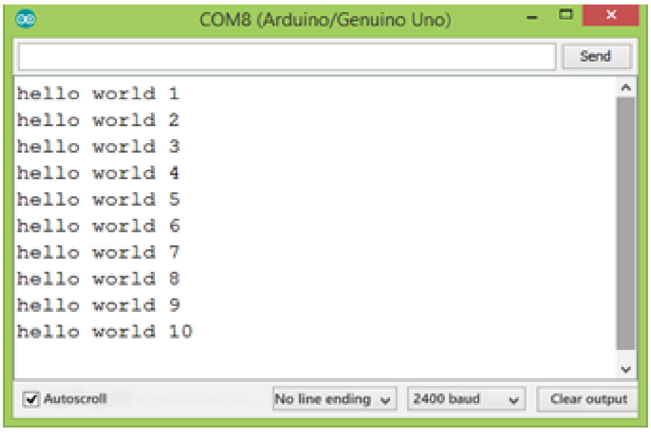

Figure 15. Display of serial monitor on the receiver

Figure 15 shows the Arduino IDE serial monitor display on the receiver. The text "hello world" was received well on modem 2 through water media.

The second scenario is testing the level of data transmission errors or errors in general based on distance. This test is done by sending data packets consisting of 7, 14, 35, and 70 data bits with a bit rate of 2400 bps, with testing distances of 100 cm, 130 cm, 150 cm, and 170 cm. Each data packet is tested 10 times and the average value is taken from the occuring errors. Figure 16 is a graph of errors by distance at a bit rate of 2400 bps.

Figure 16 shows that the testing results are: for 7 bit data, 0% error is obtained at a distance of 100 cm, 1% at a distance of 130 cm, 1% at a distance of 150 cm and 24% at a distance of 170 cm. For 14-bit data, 0% error is obtained at a distance of 100 cm, 1% at a distance of 130 cm, 5% at a distance of 150 cm, and 28% at a distance of 170 cm. For 35 bit data, 1% error is obtained at a distance of 100 cm, 2% at a distance of 130 cm, 6% at a distance of 150 cm, and 34% at a distance of 170 cm. Meanwhile, for 70-bit data, 1% error is obtained at a distance of 100 cm, 2% at a distance of 130 cm, 6% at a distance of 150 cm, and 37% at a distance of 170 cm.

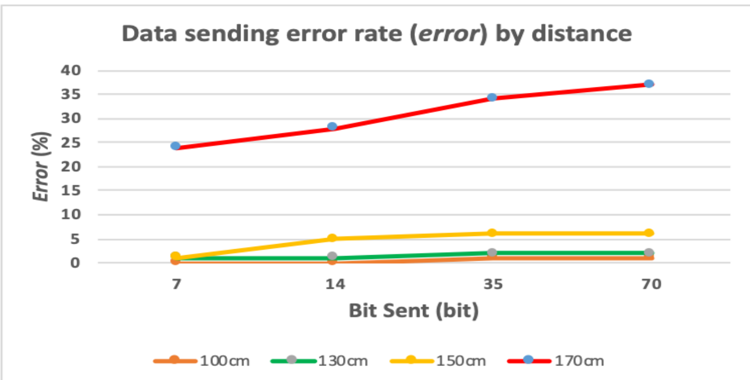

Figure 16. Graph of Dara sending error rate by distance

5. Conclusions and Recommendations

Underwater data transmission using FSK modulation with level M = 2 or referred to as BFSK with a bit rate of 2400 bps has been successfully carried out. Underwater data transmission testing was carried out in a swimming pool with a depth of 1 meter. The system testing was carried out by sending "hello world" text data and it was received well by the receiver at a 2400 bps bit rate. The next system testing is conducted by sending data using bit variations of 7, 14, 35, and 70 bits at distances of 100cm, 130cm, 150cm, and 170cm. The testing results show that for 7bit data, 0% error is obtained at a distance of 100 cm, 1% at a distance of 130 cm, 1% at a distance of 150 cm and 24% at a distance of 170 cm. For 14-bit data, 0% error is obtained at a distance of 100 cm, 1% at a distance of 130 cm, 5% at a distance of 150 cm, and 28% at a distance of 170 cm. For 35bit data, 1% error is obtained at a distance of 100 cm, 2% at a distance of 130 cm, 6% at a distance of 150 cm, and 34% at a distance of 170 cm. Meanwhile, for 70-bit data, 1% error is obtained at a distance of 100 cm, 2% at a distance of 130 cm, 6% at a distance of 150 cm, and 37% at a distance of 170 cm. From these results, it was found that the farther the distance and the greater the amount of data sent, the greater the error value. Thus, this study recommends that future study needs to develop the system to increase the transmission distance.

6. Acknowledgement

Authors would like to thank Research and Community Services Institute (LPPM) of Institut Teknologi Telkom Purwokerto for awarding grant to conduct this internal research

References

Akyildiz, I. F., Pompili, D., & Melodia, T. (2005). Underwater acoustic sensor networks: Research challenges. *Ad Hoc Networks*, *3*(3), 257–279. https://doi.org/10.1016/j.adhoc.2005.01.004

Benson, B., Li, Y., Faunce, B., Domond, K., Kimball, D., Schurgers, C., & Kastner, R. (2010). Design of a Low-Cost Underwater Acoustic Modem. *IEEE Embedded Systems Letters*, *2*(3), 58–61. https://doi.org/10.1109/LES.2010.2050191

Exar Corporation. (1997). *Datasheet XR-2211A FSK Demodulator/Tone Decoder*. Retrieved from https://www.exar.com/ds/xr2211av104.pdf

Exar Corporation. (2008). *Datasheet XR-2206 Monolitic Function Generator*. Retrieved from https://www.sparkfun.com/datasheets/Kits/XR2206_104_020808.pdf

Grund, M., Freitag, L., Preisig, J., & Ball, K. (2006). The PLUSNet Underwater Communications System: Acoustic Telemetry for Undersea Surveillance. *OCEANS 2006*, 1–5. https://doi.org/10.1109/OCEANS.2006.307036

Indriyanto, S., & Edward, I. Y. M. (2018). Ultrasonic Underwater Acoustic Modem Using Frequency Shift Keying (FSK) Modulation. *2018 4th International Conference on Wireless and Telematics (ICWT)*, 1–4. https://doi.org/10.1109/ICWT.2018.8527809

Jahankit. (n.d.). Datasheet JSN-SR04T-2.0, Ultrasonic Waterproof Range Finder. Retrieved from https://www.jahankitshop.com/getattach.aspx?id=4635&Type=Product

Jeon, J., Lee, D., Kim, C., Ryuh, Y., & Park, S. (2013). Research and development of an acoustic modem for underwater bio-mimetic fish robots. *2013 10th International Conference on Ubiquitous Robots and Ambient Intelligence (URAI)*, 432–435. https://doi.org/10.1109/URAI.2013.6677303

Mu, L., Chen, C., Liu, C., Yu, C., Yang, Y., Jang, J., … Paull, C. (2014). Underwater topography measurement and observation in Southwest Taiwan using unmanned underwater vehicles. *OCEANS 2014 - TAIPEI*, 1–6. https://doi.org/10.1109/OCEANS-TAIPEI.2014.6964394

Stojanovic, M. (2008). Underwater Acoustic Communications: Design Considerations on the Physical Layer. *2008 Fifth Annual Conference on Wireless on Demand Network Systems and Services*, 1–10. https://doi.org/10.1109/WONS.2008.4459349

Wu, L., Trezzo, J., Mirza, D., Roberts, P., Jaffe, J., Wang, Y., & Kastner, R. (2012). Designing an Adaptive Acoustic Modem for Underwater Sensor Networks. *IEEE Embedded Systems Letters*, *4*(1), 1–4. https://doi.org/10.1109/LES.2011.2180013

Yu, X., Jin, W., Sui, M., & Lan, Z. (2011). Evaluation of Forward Error Correction Scheme for Underwater Wireless Optical Communication. *2011 Third International Conference on Communications and Mobile Computing*, 527–530. https://doi.org/10.1109/CMC.2011.49

Zhu, Z., Wu, Z., Deng, Z., Qin, H., & Wang, X. (2018). An Ocean Bottom Flying Node AUV for Seismic Observations. *2018 IEEE/OES Autonomous Underwater Vehicle Workshop (AUV)*, 1–5. https://doi.org/10.1109/AUV.2018.8729726