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High Gain Amplifier for Underwater Acoustic (UWA) Platform

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Abstract

Improved acoustic platform would allow more efficient transmission of information between Underwater Acoustic (UWA) equipment such as autonomous vehicles, piloted vehicles, and underwater profilers. A flexible and configurable UWA modem is required for easy modification in order to be employed for different UWA equipment. In this paper, we proposed an underwater acoustic platform using software defined radio (SDR) platform called GNU radio and universal software defined radio peripheral (USRP). The UWA modem design includes an amplifier that is designed for the USRP. The experiments shown that using the USRP amplifier the bit rate of the transmission is improved and a significant increment of the number of packet received.

Keywords

Underwater Acoustic, Acoustic Modem, GNU, USRP Amplifier

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1. Introduction

Underwater Acoustic (UWA) has become widely focused in the literature and it has surfaced as a powerful technique for aquatic applications, and it has attracted more and more attention from the research community recently. UWA communication improves our understanding of the physical world by providing fine resolution sampling of the surrounding underwater environment. The ability to have many small devices streaming real-time data physically distributed near the objects being sensed brings new opportunities to observe and act on the world which could provide significant benefits to mankind. For example, dense wireless sensor communication have been used in agriculture to improve the quality, yield and value of crops, by tracking soil temperatures and informing farmers of fruit maturity and potential damages from freezing temperatures [1]. These UWA system have been deployed in sensitive habitats to monitor the causes for mortality in endangered species [2]. UWA communications have also been used to detect structural damages on bridges and other civil structures to inform authorities of needed repair and have been used to monitor the vibration signatures of industrial equipment in fabrication plants to predict mechanical failures [3].

Underwater Acoustic (UWA) is a type of measuring and controlling system consisting of unmanned or autonomous underwater vehicles (UUVs/AUVs) and sensor nodes that have sensing, communication computing and moving capabilities. UWA, which have the features of distributed space, distributed time and distributed function, is a typical autonomous and intelligent system, which can independently accomplish specific tasks depending on the changing environment over a given volume of water. UWAs platform are envisioned to enable applications for oceanographic data collection, pollution monitoring, offshore exploration, disaster prevention, assisted navigation and tactical surveillance applications [1]. Multiple unmanned or autonomous underwater vehicles (UUVs/AUVs), equipped

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with underwater sensors, will also find application in exploration of natural undersea resources and gathering of scientific data in collaborative monitoring missions. To make these applications viable, there is a primary need to enable underwater communications among underwater devices.

Acoustic communications are the typical physical layer technology in underwater systems. Wire communications are difficult to deploy and are unsuitable for moving device or system. In fact, radio waves suffer from such high attenuation, while optical waves are affected by scattering and high precision in pointing the narrow laser beams. Acoustic wireless communications enable the UWA platform [2]. However, the complexity of underwater environment and acoustic communications are the challenges to UWA platform. Hence, UWA platform have become a widely focus research topic. The unique characteristics of the underwater acoustic communication channel are such as limited bandwidth capacity, high propagation delays and low reliability are time-variant, space-variant and frequency-variant [3]. Moreover, the ocean environment is dynamic and complex. Hence, theory analyses and precise simulation is difficult for UWA.

A few experimental implementations of underwater acoustic have been reported in the last few years. The Front-Resolving Observational Network with Telemetry (FRONT) project relies on acoustic telemetry and ranging advances pursued by the US Navy referred to as ‘telesonar’ technology [4]. The Seaweb network for FRONT Oceanographic Sensors involves telesonar modems deployed in conjunction with sensors, gateways, and repeaters, to enable sensor-to-shore data delivery and shore-to-sensor remote control. Researchers from different fields gathered at the Monterey Bay Aquarium Research Institute in August 2003 and July 2006 to quantify gains in predictive skills for principal circulation trajectories, i.e., to study upwelling of cold, nutrient-rich water in the Monterey Bay, and to analyze how animals adapt to life in the deep sea. However, experiment research on UWA is elementary and seldom work on developing platform for UWA is reported.

In this paper, we elaborate proposed a design and present the performance of the implemented physical experiment testbed for UWA platform. The experiment platform consists of system control of UWA connection, which can complete point-to-point communication performance tests and end-to-end connection experiments. This platform serves as the testing and evaluating system of UWA, which is convenient, flexible and scalable. This paper is organized as follows. The current acoustic modem is elaborate in section 2, followed by the proposed UWA System in section 3. Section 4 presents the experiment results. Last but not least, section 5 present the conclusion of the paper.

2. Current Acoustic Modems

Research underwater acoustic modems have been designed with the objective of reducing power consumption or cost or with the objective of testing new communication algorithms to increase bit rate or better counter the effects of harsh environments. This section presents an overview of some of the research modems that have been designed in the past decade.

The University of Southern California's Information Sciences Institute designed a prototype modem for the Sensor Networks for Undersea Seismic Experimentation (SNUSE) project [5]. Their primary design goal was to provide an inexpensive, low power modem to operate over 50-500 meters for seismic monitoring applications. To accomplish their objective, the prototype included an inexpensive ultra low-power wake up receiver that consumes only 500 microWatts and an inexpensive off the shelf 8-bit microcontroller and radio frequency integrated circuit for control and frequency shift keying based communication. They did achieve a prototype costing less than $100 with a maximum transmit power of 2W, receive power of 25mW, and idle power of 500µW, but could only perform in open space testing.

Researchers at the University of California Irvine proposed the use of software acoustic modems running on generic speakers and microphones to establish acoustic communications for underwater sensor networks with the idea that the use of generic hardware can greatly reduce the cost of the modem design [6]. Their frequency shift keying based modem design implemented on the Tmote In- vent module can achieve a bit rate of 24 bps at a 10 meter range or 48 bps at a 3 meter range in water [7].

The AquaModem [11, 15], designed at the University of California Santa Barbara, was designed for short range (< 1km) eco-sensing applications in a shallow horizontal underwater channel. The AquaModem uses M-ary direct sequence spread spectrum signaling, with joint detection and channel estimation performed by matching pursuits to effectively handle multipath interference. It was implemented on a TI TMS320C6713 DSP. It is also made use of custom made $2500 transducers with a center frequency of 24kHz and a double-sided bandwidth of 7.8 kHz. The modem was field tested in a shallow water coral reef and achieved ranges up to 440 meters with a bit rate of 133 bps and an uncoded symbol error rate < 1% [9].

Researchers at Kookmin University, Korea, designed an underwater acoustic modem that makes use of four small air transducers to communicate to other nodes facing to the north, east, south, and west respectively and a fifth transducer to communicate to a surface node. The design uses an ATmega128 as its microcontroller unit which interfaces to an Arm PXA270 processor for medium access layer (MAC) control. It operates at 30 kHz and is capable of transmitting data up to 5 kbps at ranges up to 30 meters [10].

Vasilescu et. al developed the AquaNode that is dually networked: optically for point-to-point transmission at 330 kbps and acoustically for broadcast communication over ranges of hundreds of meters at 300 bps [13]. The acoustic modem is are built around an Analog Device Blackfin BF533 fixed point DSP processor and uses FSK modulation on a 30kHz carrier frequency. The nodes self-localize and can be used to form static undersea networks. With all the nodes running at full power, the battery provides 1-2 weeks of continuous operation.

Researchers at the University of Connecticut designed an orthogonal frequency division multiplexing based modem on a TMS320C6713 DSP with the goal of providing a higher data rate solution to other research modems [12]. The modem is capable of transmitting data at a raw data rate 3.1 kbps after rate ½ nonbinary LDPC coding and QPSK modulation. The modem has been tested in water in a lab test tank, but has not been field tested, thus no range information is available.

Researchers at Northwestern Polytechnical University in China also designed a DSP based OFDM modem, implementing the design on a ADSP-TS101 and achieving an uncoded bit rate of 1kbps in a lake (range not specified) [8, 14]. Sozer and Stojanovic developed a reconfigurable acoustic modem (rModem) [17] designed to act as a physical layer prototyping platform. This platform includes a high processing power floating point DSP for the implementation of various physical layer protocols and an FPGA that enables users to operate at any carrier frequency and bandwidth within the 1kHz - 100kHz band by setting carrier coefficients, filter coefficients, and interpolation/decimation rates. The current rModem design interfaces to a daughter card that can drive a Teledyne AT-408 transducer that operates in the 9-14kHz band. Because the rModem is intended to be used as a research tool rather than a commercial product, high processing power and cost is tolerated. The rModem hardware and software operability was field tested in Woods Hole, MA [16].

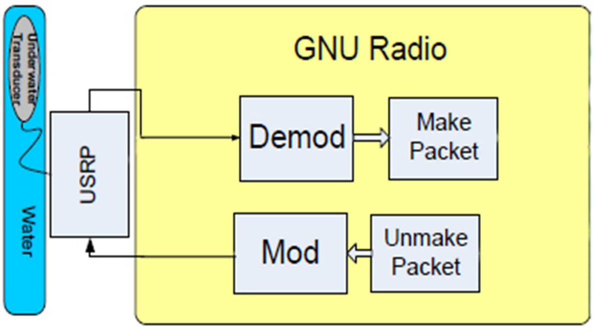
Numerous other researchers have implemented communication algorithms on a laptop computer and used commercially bought hardware to connect to the laptop and conduct in-water experiments. Examples include OFDM based implementations [17-22] and multiple-input, multiple-output (MIMO) based implementations [23-25]. These designs are useful for examining the capabilities of different modulation schemes, but are not designed for real-time deployment. Table 1 compares the described research modems in terms of platform, modulation scheme, bit rate, and range. `NS' denotes values not specified in the literature.

Table 1. Research Underwater Acoustic Modem Comparison.

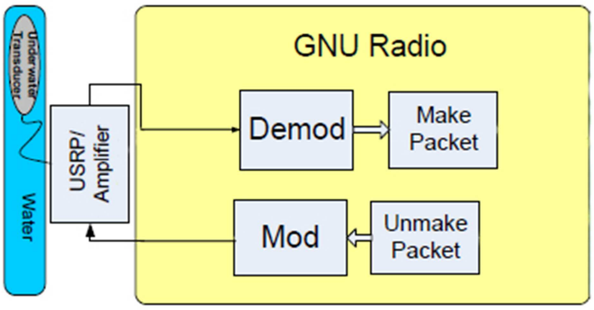
Modem	Platform	Mod	Bit Rate	Range(m)	BER
USC	MCU	FSK	NS	NS	10^{-5} (CODED)
UCI	Tmote	FSK	12	5	10%
uConn	DSP	OFDM	6200	NS	NS
rModem	DSP	varied	varied	200	NS
AquaModem	DSP	DSSS	133	440	1%
Kookmin	MCU	NS	5000	30	NS
AquaNode	MCU	FSK	300	400	NS
USRP	FPGA	Configurable	Configurable	Depends on daughter board	4%

3. Proposed UWA System

The underwater acoustic platform consists of several main modules such as USRP, USRP amplifier, GNU Radio and underwater transducer. To increase the performance of the system, a USRP amplifier is designed. The placement of the amplifier is shown in Figure 1 b). Apart from the implementation of the high gain USRP amplifier, Gaussian Minimum Shift Keying (GMSK) is use in the UWA platform underwater acoustic communication.



(a)



(b)

Figure 1. The Underwater Acoustic Platform Architecture (a) without amplifier and (b) with amplifier.

Theoretically, any type of acoustic signal can be generated using the GNU Radio and the USRP SDR. However, for prove of concept purposes, for our proposed UWA platform transmitted using a GMSK radio signal with the bit rate of 20kb/s. There are several advantages using GMSK for radio communication system. One of its advantage is it improves the spectral efficiency compared to other phase shift keying modes.

USRP Amplifier Design need a several requirements to be considered when designing the USRP amplifier for the receiver and transmitter such as:

- The USRP amplifier must amplify signals around the transducer's resonance frequency (75 kHz) and filter out all other frequencies.
- The USRP amplifier must provide high gain to be able to detect signals as small as a couple hundred microVolts.
- The design must be easily modifiable to accommodate different transducers with different resonance frequencies and bandwidths.

To meet the above design requirements of a highly sensitive, high gain, narrow band receiver, the amplifier consist a 40dB per decade rollover high-pass filter as shown in Figure 2.

Figure 2. Receiver Block Diagram.

As underwater noise is concentrated in low frequencies the first stage which consist of a high pass filter, cancels out a majority of unwanted noise. The high pass filter consists of two cascaded filters, each with a 20dB per decade rollover. Each filter has a gain of 10 and a cutoff frequency of 16 kHz thus giving a total gain of 100 (40dB). The second stage is a band-pass filter used to further amplify signals in the transducer's operating band. It consists of two cascaded biquad filters, each with a 20 dBper decade rollover. The current configuration has the center frequency of the first and third filters set to 75 kHz and the center frequency of the second filters set to obtain a flatter frequency response in the pass band. Thus the combined pre-amplifier provides an ~100dB gain around 75 kHz while attenuating low frequencies at a rate of 20dB per decade, this is shown in Figure 3.

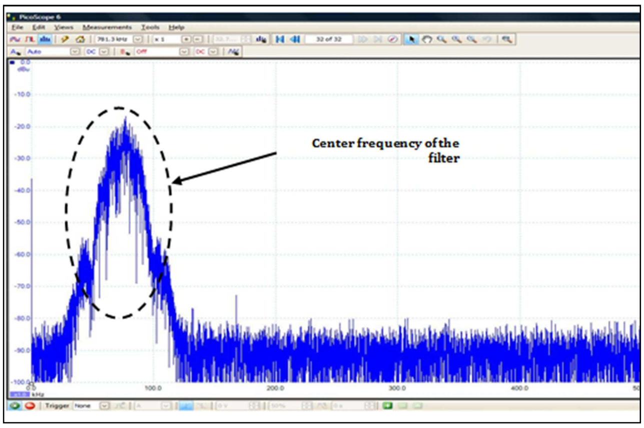


Figure 3. Estimated power coupled in the transmitting frequency.

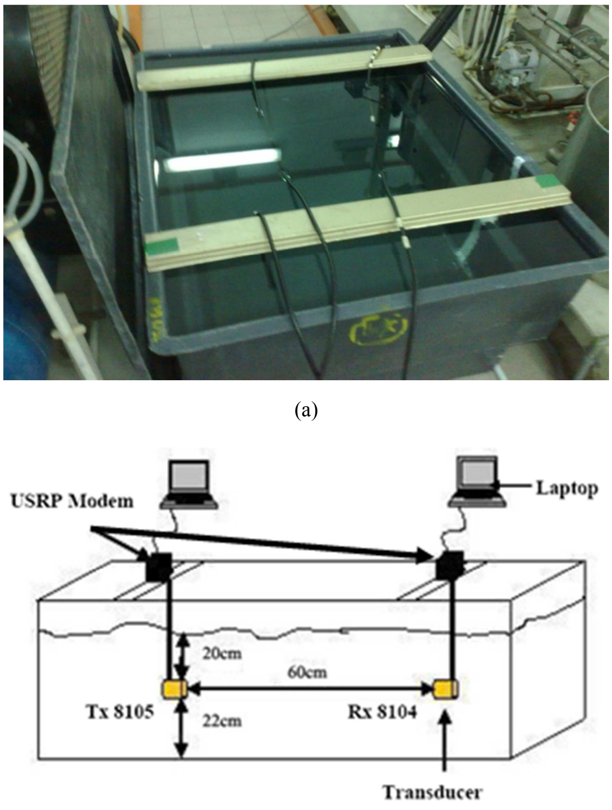
4. Experimental Work

The experiments was conducted in two stages, the initial stage where the setup does not include the USRP amplifier and the implementation of the USRP amplifier stage.

4.1. Initial Experiment

The experiment is set up as shown in Figure 4 for the testing of the GNU Radio and the USRP Modem with the hydrophone. The tank is 80cm long, 125 cm wide and the depth is 65 cm. The experiment consists of two USRP modem, two laptops and two transducers. The communication between the laptops and the USRP Modems are provided with serial ports. Figure 4 shows the underwater experiment setup in the lab and Figure 5 shows the GNU Radio and USRP setup of the initial experiment as well as the amplifier experiment. The performance of the platform with the chosen physical parameter is measured in term of the packet received ratio (PRR) versus the distance of the water tank. This is to determine the distance that the developed platform can support.

In the initial experiment the result of measurement testing the UWA platform without the USRP amplifier. This experiment is considering the distance between the transmitter and receiver, bit rate transmitted, time taken for transmission, transmitter gain and receiver gain in per packets received (PR).



(a)

(b)

Figure 4. Underwater Acoustic Platform experiment set up (a) the scenario in the lab (b) the illustration of the set up.

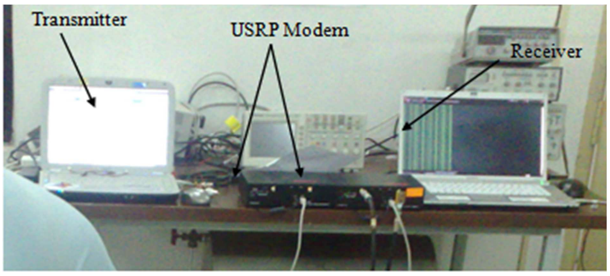


Figure 5. The test bed setup for the transmitter and the receiver.

The experiments use the following configuration. Note also that all the following experiments will have the same setup configurations. The carrier frequencies for the experiment are 25 kHz, 35 kHz, 45 kHz and 75 kHz referring to [26]. The modulation format used is GMSK. Each communication blocks included 200 training bits and 300 data bits. The length of preamble was 100 symbols (packets) and each symbol is equal to 1Mb. The bit rate used in the experiment are 20, 30, 40, 50, 60 and 70 kb/s.

4.2. Results

In this experiment, the bit rate, transmitted gain, received gain, amplitude and depth are fixed. The configurations of the experiment setup are as follows; bit rate 20 kb/s, Tx gain 0 dB, Rx gain 20 dB, Amp 378999 and depth 25cm. Figure 6 shows the graph of attenuation versus distance. The measurement shows that the attenuation increases with higher frequency and the four curves agree quite well at intermediate distances, whereas there are deviations at both ends of the range.

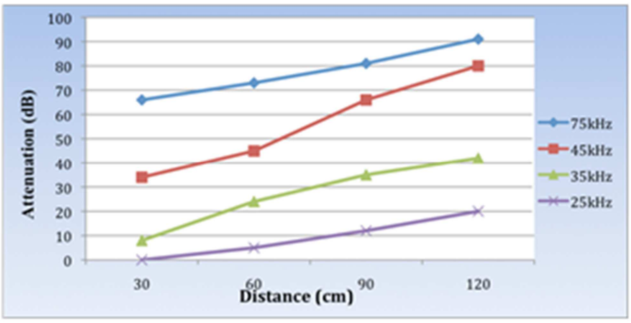


Figure 6. Attenuation within the distance.

Figure 7 shows the various bit rates for different frequencies. The transmitted gain, received gain and depth are maintained but the experiment was conducted for the distance (between the transmitter and receiver) of 120 cm. The measurement shows that the bit rate of 20 kb/s is able to receive up to 90 packets for all the low frequencies. However, higher bit rate such as 70 kb/s needs to compromise with lower packet receive rate.

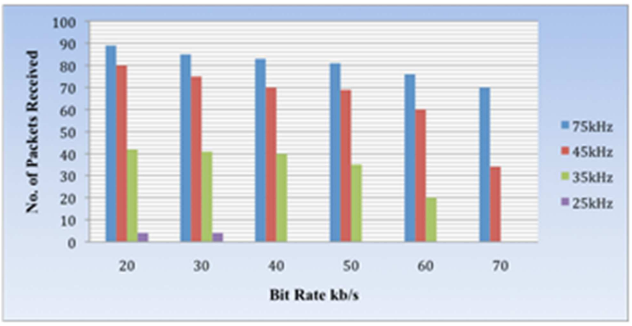


Figure 7. Packets received within the bit rate.

Figure 8 shows the results of the number of packets received when transmitted using different gain for USRP transmitter modem, the gain limit of the USRP transmitter, which starts from -20 to 0 dB. Observation shown that low transmitter gain will affect on the signal reaching the receiver and will cause packets lost. Figure 9 shows the results of the number of packets received when using different gain for USRP receiver modem. The graph shows the gain limit of the USRP receiver, which starts from 0 to 20dB. It shows that low receiver gain affects the sensitivity of the receiver to receive more packets. These measurements proved that the suitable gain for the USRP transmitter is 0dB for the transmitter and 20dB gain for the receiver.

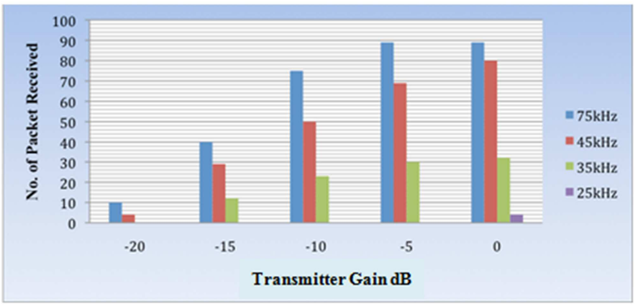


Figure 8. Packets received with various USRP modem transmitting gain.

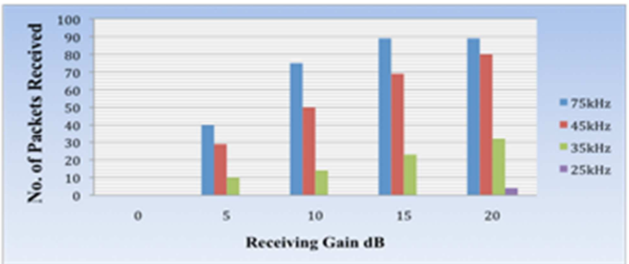


Figure 9. Packets received with various USRP modem receiving gain..

4.3. Implementation of the USRP Amplifier Experiment Stage

The USRP amplifier, consist of a power amplifier and a pre-amplifier. The power amplifier is responsible for amplifying the modulated signal from the digital hardware platform. It sends the signal to the pre-amplifier circuit which further amplifies the signal to a power level that matches the actual distance between the transmitter and receiver. The pre-amplifier amplifies the signal that is detected by the transducer so that the digital hardware platform can effectively demodulate the signal and analyze the received data. This section explain the design of the power amplifier, and pre-amplifier of the analog transceiver. Experimental measurement is carried out to evaluate the performance of the constructed GMSK acoustic test bed with USRP amplifier. The detail of physical parameters is given in Table 2.

Table 2. Parameters used in Implementation of the USRP amplifier experiment.

Parameter	Transmitter	Receiver
Frequency	75kHz	75kHz
Modulation	GMSK	GMSK
Bitrate	20kb/s	20kb/s
Amplitude	32767 (The Maximum DAC Value for USRP)	-

The performance evaluation when implementing USRP amplifier is done by measuring the GMSK signals when the USRP transmitter and receiver are connected to the pre-amplifiers. This experiment is carried out using frequency of 75 kHz. Figure 10 shows the receiver measurement of the GMSK. The signal gain is set to 40dB for the signal through the amplifier. The blue signal is the received signal, and the red signal is the output of the amplifier for the USRP modem. Figure 11 shows the transmitter measurement of the GMSK. The signal gain is set to 20dB for the signal through the amplifier. The red signal is the output from the USRP, and the blue signal is the output from the amplifier to the hydrophone.

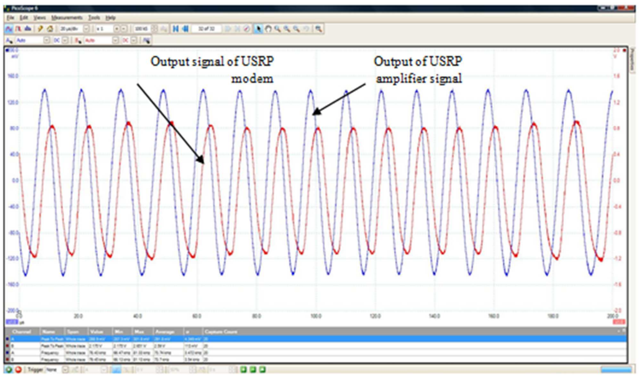


Figure 10. Receiver measurement for GMSK.

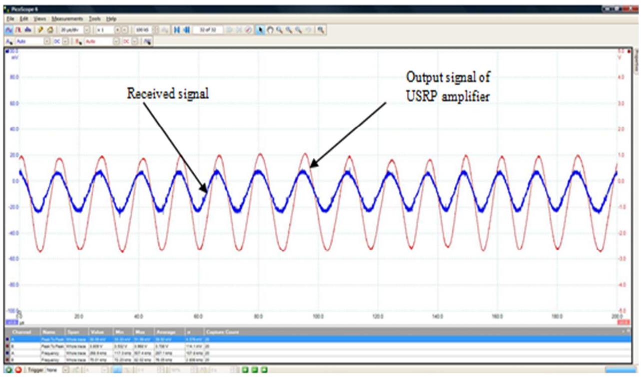


Figure 11. Transmitter measurement for GMSK.

Figure 12 shows the difference in the packet received within the distance of 30 to 120 cm using the system with and without the USRP amplifier. The result of these two experiments shows that the USRP amplifier gives better performance to the underwater acoustic communication system. Figure 13 shows the comparison of the packet received within the bit rate for the system communication of USRP amplifier and without it. Figure 13 shows USRP amplifier gives better number of packet received for various bit rate.

The power amplifier is linear in the 10-100 kHz band for inputs greater than 500 mVpp. The USRP amplifier provides a flat, high gain for frequencies 25-75 kHz matching the operating frequency of the transducer and allowing for reception of a signal as low as 200 microVolts. Finally we elaborate the integrated system tests used to evaluate the functionality and performance of the complete composites design. These tests prove that a short-range underwater acoustic USRP Platform can be designed from low-frequency and high gain to long distance. The experiment also indicate that the USRP Modem can support data rates of 200 bps for long distance.

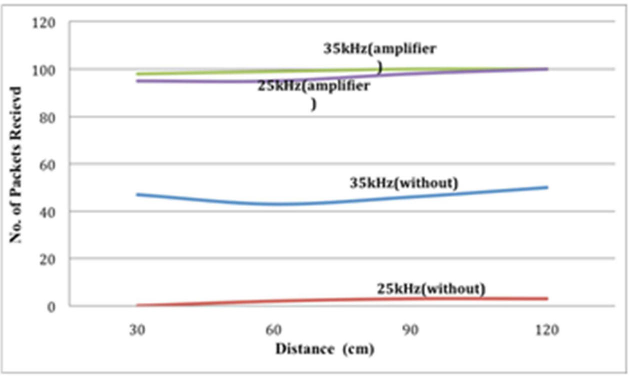


Figure 12. Compare the packet received within the distance for the system with USRP amplifier and without it.

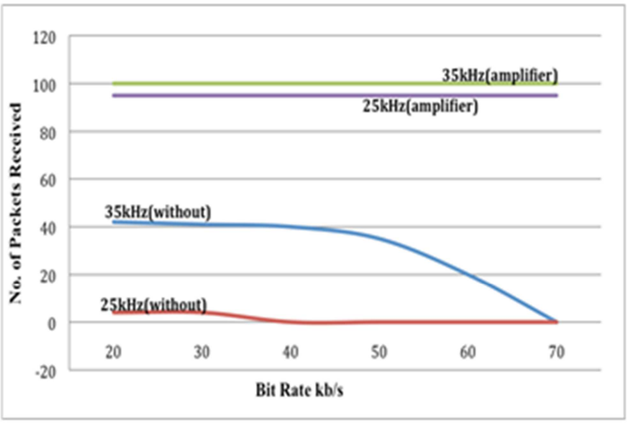


Figure 13. Comparison of variable bit rate value for the acoustic modem with and without USRP amplifier.

5. Conclusion

In the late twentieth century, Underwater acoustic communication system is growing rapidly hence increasing the demand for the acoustic wave. Nowadays, most of the acoustic wave is fully allocated and it is difficult to accommodate a new service. Therefore, new regulation, policies and standard have to be defined in order to support this rapid growth underwater acoustic network technology.

In this paper, an underwater acoustic communication platform has been proposed and implemented. The UWA system consisting USRP and GNU SDR is a UWA system that is flexible and configurable. This paper also describes the system of underwater acoustic modem with most critical component of the system, which is the USRP amplifier design circuit. The USRP amplifier provides a flat, high gain for frequencies 25-75 kHz matching the operating frequency of the transducer and allowing for reception of a signal as low as 200 microvolt. The implementation of the USRP amplifier had improved the utilization of the underwater communication in terms of bit rate and number of packet received.

The experiment study of GNU Radio and USRP with hydrophones, shows that whenever the distance is increase, the packets received will increase with the increase of frequency. Again if we increase the gain in USRP, then the packet receives will increase as well. Low gain will effect on the signal reaching and the packets will be lost. In general, the Underwater utilize GNU radio and USRP SDR has been successfully implemented. It is proved that by implementing GNU radio and USRP SDR in the new generation of underwater acoustic network technology, it will not only improve the utilization of the underwater network, but it also will improve the PRR of underwater acoustic network itself.

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