A Study on the Detection Algorithm of an Advanced Ultrasonic Signal for Hydro-acoustic Releaser

Young-Jin Kim, Kyung-Moo Huh*, and Young-June Cho

Abstract: Methods used for exploring marine resources and spaces include positioning a probe under water and then recalling it after a specified time. Hydro-acoustic Releasers are commonly used for positioning and retrieving of such exploration equipment. The most important factor in this kind of system is the reliability for recalling the instruments. The frequently used ultrasonic signal detection method can detect ultrasonic signals using a fixed comparator, but because of increased rates of errors due to outside interferences, information is repetitively acquired. This study presents an effective ultrasonic signal detection algorithm using the characteristics of a resonance and adaptive comparator Combined with the FSK+ASK modulator. As a result, approximately 8.8% of ultrasonic wave communication errors caused by background noise and transmission losses were reduced for effectively detecting ultrasonic waves. Furthermore, the resonance circuit's quality factor was enhanced (Q = 120 to 160). As such, the bias voltage of the transistor (Vb= 3.3 to 6.8V) was increased thereby enhancing the frequency's selectivity.

Keywords: Detection algorithm, marine instrument, probes, remote control system, ultrasonic signal.

1. INTRODUCTION

The first step to the exploitation of ocean resources should be the analysis based on exploration and measurement, and manned or unmanned submersibles and probes are frequently located to take precise analysis. Ordinarily, such marine instruments are put on the seabed and are recalled after a fixed duration, because vessels have difficulty in carrying out exploration when they are afloat for a long time. In the case of shallow water, divers place a probe on the bottom and recall it as desired. On the other hand, the hydro-acoustic releaser is used to handle a probe on the seabed in respect to exploration for deep sea mineral resources and ocean researches, because divers cannot otherwise carry out their work. The most important aspect in the control of hydro-acoustic releasers is the reliability of recalling probes as well as the recognize-ability of hydro-acoustic signals exercising the strongest influence [1]. Ultrasonic signals should be able to be stably transmitted to underwater regions regardless of external disturbances such as the variance of the media necessary to transmit hydro-acoustic signals, the temperature variance by depth, multi-path fading and otherwise. Furthermore, the hydro-acoustic releaser should be able to be remote-controlled [2,3]. In the existing methods, received control information has been recognized through hardware and has been compared with the reference information. The final control information is derived through repeating the same method scores of times [4]. The problem is that such a method is not effective for the hydro-acoustic releaser as the most important thing is controllability. Although the 'frequency shift keying' [5] has been used as it is effective for multi-path fading in shallow water, its information transfer rate per time is relatively low compared to other transfer systems (PSK : Phase Shift Keying, DPSK : Differential PSK, 16 QAM : Quadrature Amplitude Modulation) [6]. Thus, in the present study, a modulation system combined with FSK (Frequency Shift Keying) and ASK (Amplitude Shift Keying) was designed through intermittent controlling of the signal modulated into FSK under fixed protocols, in order that information transfer rate can be increased as well as the fact that ultrasonic signal recognition of the hydro-acoustic releaser can be advanced. The efficiency of hydro-acoustic signal recognition was ascertained through experiments, on the basis of the resonance characteristic and the adaptive comparator presented in this study.

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Young-Jin Kim and Young-June Cho are with the Korea Institute of Industrial Technology 35-3, Hongcheon-ri, Ipjang-myeon, Cheonan-si Chungcheongnam-do, Korea (e-mails: {yjk574, choyj}@kitech.re.kr).

Kyung-Moo Huh is with the School of Electronics Engineering, Dankook University, San #29, Anseo-dong, Cheonan-si Chungcheongnam-do, Korea (e-mail: huhkm @dku.edu).

* Corresponding author.

2. FSK + ASK COMBINED ULTRASONIC SIGNAL

2.1. The process of generating combinative information signals

Fig. 1 shows the process of generating combinative information signals and the constitutions of respective block.

2.2. Basic signal generating

To generate the signal for transmitting ultrasonic information, the following 'unit pulse function' was derived by using two functions '$u(t)$' and '$-u(t-a)$'.

$$f(t) = u(t) - u(t-a) \tag{1}$$

$$f(t) = \sum \{u[t - nT] - u[t-(n+0.5)T\} \tag{2}$$

The signal of the (1), generated in this manner, was repeated as shown in Fig. 2 and in (2), the digital signal, having the duty rate of 50% and the cycle (T), was generated. The basic signal generates a digitally modulated information signal in order to be used as a reference signal for verifying the basic operational characteristics of ultrasonic transducers. Based on this digitally modulated signal (50% duty ratio), the duty ratio was tuned (25~30%) so that the physical amplitude of the transducer can be at its maximum. In order to generate the max amplitude ultrasonic signal, a sine wave signal with a duty ratio of 50% must be detected at the voltage detected by the transducer. However, in order to change the square wave generated by the modulator into a high voltage (app. 600V, 5A) sine wave signal at its max amplitude using a circular transformer, the physical repetition oscillation characteristics of the transducer were taken into consideration to tune the duty ratio approximately 25~30%.

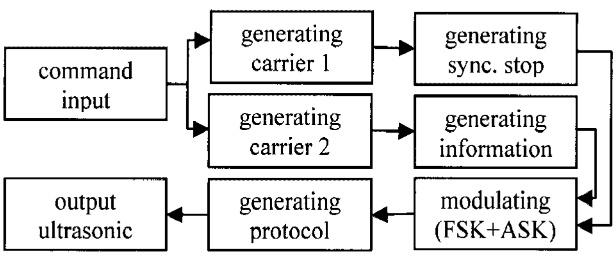

Fig. 1. A flow of generating FSK+ASK combined signals.

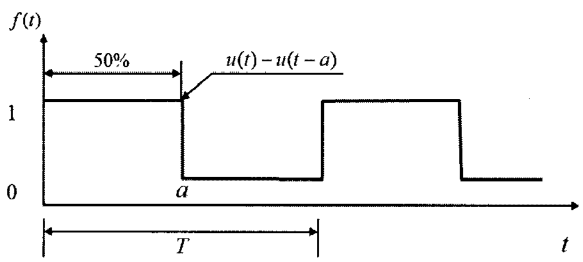

Fig. 2. Basic signal generating.

2.3. Carrier signal generating

In this system, two carriers were used in order to apply a FSK modulation system that is comparatively free from the influence of multi-path fading. In accordance with the maximum amplitude characteristic of a transducer, the first carrier has the basic signal cycle 'T' of 28 μs and the duty rate of 25% as well generating the carrier signal 1 as shown in Fig. 3 and (3), through repeating 'n' times. This signal should be the stop signal to discriminate the end between the synchronizing and information signal, which is to synchronize transmission and receipt, and the information signal. TSYNC is the cycle of synchronizing signals. The carrier signal 2 has the basic signal cycle 'T' of 32 μs. As well, the duty rate of 25% was generated by repeating 'n' times. It is used to generate the information signals such as ID (Identification), Action, and otherwise. The intervals of basic signals were selected as 28 μs and 32 μs in order to induce the transmission transducer's central frequency of 35.7kHz and 31.2kHz.

$$f_{SYNC}(t) = \sum \{u[t - nT_{SYNC}] - u[t-(n+0.25)T_{SYNC}]\} \tag{3}$$

2.4. Synchronizing signal generating

Cycles and duty ratio of the two carriers, generated in the previous step, are different from each other as to information content. In order to generate the modulated wave of the first synchronizing signal, the signal 2.5sec long is generated as shown in Fig. 4. The modulated signal 1 was generated by modulating this signal into the carrier signal 1 generated previously.

2.5. Information signal generating

Secondly, a pulse signal should be generated to produce information signals such as header, ID, and otherwise. A basic pulse signal is generated with the

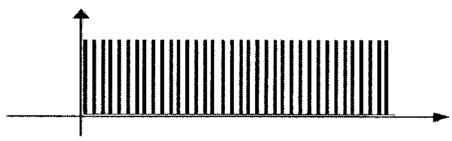

Fig. 3. Carrier signal 1 generating.

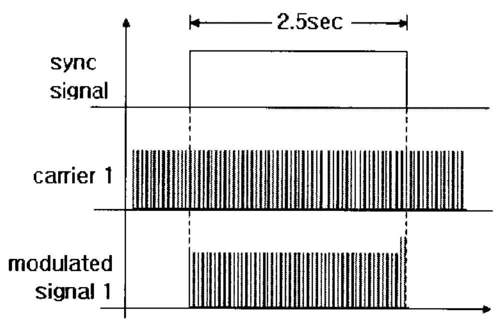

Fig. 4. Synchronizing signal generating.

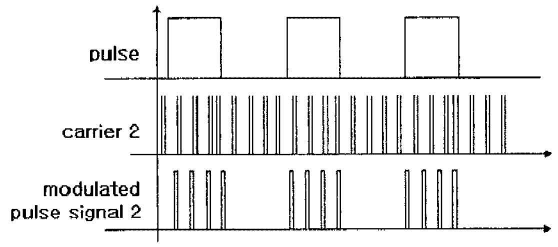

Fig. 5. Modulated signal 2 generating.

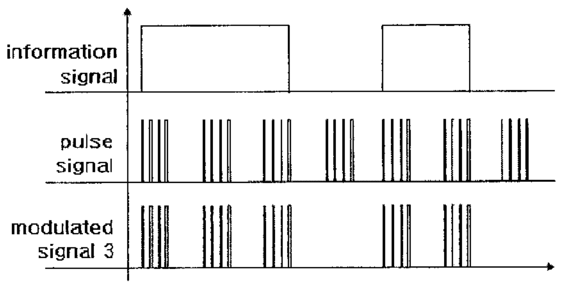

Fig. 6. Information signal generating.

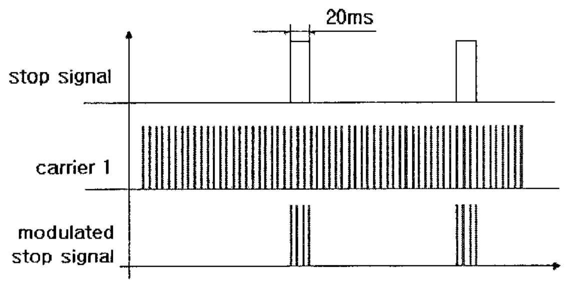

Fig. 7. Stop signal generating.

duty rate of 30% (on : 0.8ms, off : 1.8ms, T : 2.6ms); the modulated signal 2 was generated, as shown in (4) and Fig. 5, by modulating into carrier 2. The modulated signal 2 was again controlled as to the length of information signal, and as a result, the modulated signal 3 was generated as shown in Fig. 6.

$$f(t) = \sum \{u[t - nT_{SIG2}] - u[t - (n + 0.3)T_{SIG2}]\} \quad (4)$$

2.6. Stop signal generating

The stop signal, which is used to select out of information signals, was generated by controlling the carrier 1 at intervals of 20ms, as shown in Fig. 7.

2.7. FSK + ASK combined signal generating

Fig. 8 shows the signal process of the FSK + ASK combined signal and Fig. 9 shows the process in which the FSK + ASK modulated signal is generated and combined.

First, by synchronizing the carrier signal 2 with pulse signal to control ASK modulation, the modulated signal 2 (frequency 2) is generated for the ASK modulated signal. Then, according to the stop signal, carrier signal 1 controls ASK modulation to generate the modulated signal 4 (frequency 1). The FSK modulation generates the FSK modulated signal

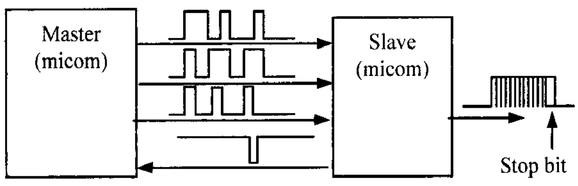

Fig. 8. Signal process of FSK+ASK combined signal.

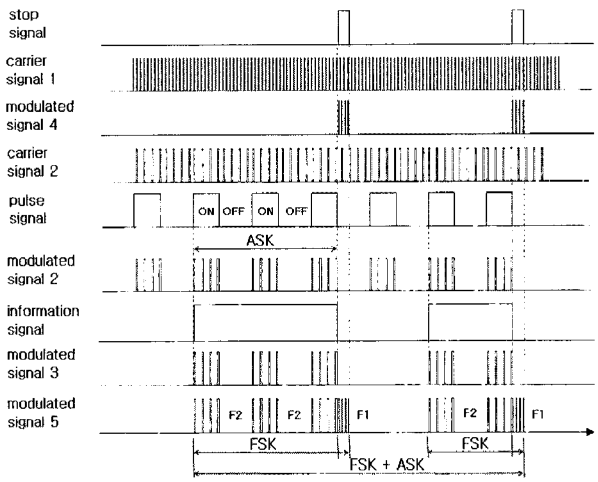

Fig. 9. FSK + ASK combined modulated signal.

by combining (F2+F1=FSK) modulated signal 3 generated according to the length of the information signal with the stop signal (Frequency 1). The FSK+ASK combined signal generates the FSK+ASK combined signal by controlling ASK modulation and differentiating the number of pulse signals according to the length and intervals of information signal.

3. ALGORITHM OF ADVANCED HYDRO-ACOUSTIC SIGNAL RECOGNITION

3.1. Hydro-acoustic signal recognizing

Fig. 10 shows a process of detecting submarine ultrasonic signals. The signal of the necessary frequency band (30~50kHz), including an input signal, should be filtered and necessary frequency components (32.0, 35.0, and 38.0kHz) should be extracted. Next, it should be recognized as a signal through the part of comparing defined variable reference voltages, and should be detected as an ultrasonic signal through the algorithm of analyzing sound waves.

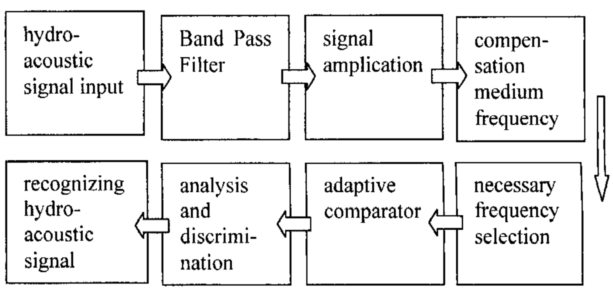

Fig. 10. A Process of detecting hydro-acoustic signals.

3.2. Band pass filter

As the received hydro-acoustic signal component contains various kinds of noises as to ocean environment, suitable frequency components should be selectively filtered so that they can be applied to the input signal. As shown in Fig. 11, a RLC parallel resonance circuit was filtered by passing only the signal components of which bands are between 30 and 50kHz, after a Band Pass Filter was formed by coupling condensers. This is because the frequency band of an ultrasonic sensor is between 30 and 40kHz. A capacitive coupling band-pass filter was designed by coupling two resonators into a capacitor element, to steepen the resonance circuit's elimination characteristic out of the band. The capacitor was commonly used in two resonance circuits, and the component of capacitive reactance (X_C) was regularly fixed as it is difficult to be precisely controlled. Instead, inductive reactance (X_L) was applied as it is comparatively easy to be precisely controlled. In this manner, the bandwidth was set up and the resonance frequency was tuned.

Fig. 12 shows a block diagram of the band pass filter. The reason why the horizontal axis is measured with the time and frequency axes is because three frequencies are used and to simultaneously observe the signals of the band pass filter.

As shown in Fig. 13, resonance characteristics of the condenser coupled Band Pass Filter were used with respect to Quality factor (Q) and the load of two resonators coupled critically so that the load on one resonator, 'Qm', can be 0.707 times and also so the bandwidth of 3dB can be wider than one resonance

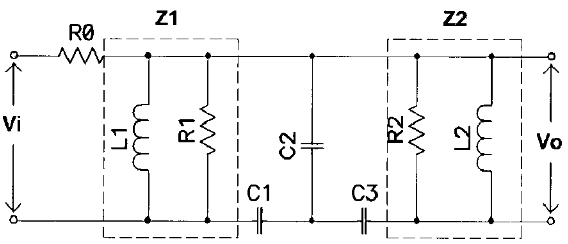

Fig. 11. A circuit of the band pass filter.

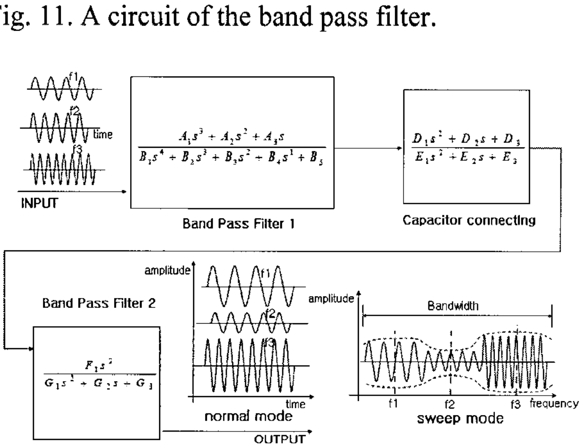

Fig. 12. A block diagram of the band pass filter.

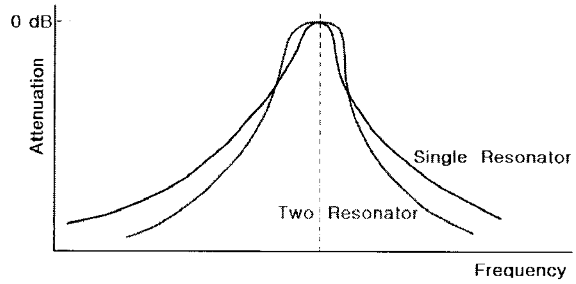

Fig. 13. Selectivity variance in the number of resonators.

circuit and the elimination bandwidth of frequency, excluding the bandwidth, can be steepened. As for the characteristic of a condenser coupled Band Pass Filter, in the low frequency, the reactance by two parallel inductors is decreased, the influence of two parallel capacitors is disregarded, and the reactance by one serial capacitor is increased. In the case of the high frequency, characteristics of the reactance and the capacitors are converted. Finally, it is attenuated at the rate of 18dB/octave as 6dB/octave is contributed to their respective characteristics.

3.3. Necessary frequency component selection

The output signal of a secondary signal amplifying circuit should be inputted to the input of a frequency selecting circuit. (5) shows the characteristics of a transfer function.

The input signal (V_i) in Fig. 15 is the two frequency components entered into the input part, and the output signal (V_o) represents the signal waveform after each input signal passes through the necessary frequency selection parts that have different resonance frequencies.

1) The Characteristic of a Transfer Function in the System

$$\frac{\frac{1}{CS}SL}{\frac{1}{CS}+SL}=\frac{\frac{L}{C}}{\frac{1}{CS}+\frac{CS^2L}{CS}}=\frac{\frac{L}{C}}{\frac{1+S^2CL}{CS}}=\frac{SL}{S^2CL+1}$$

$$\frac{\frac{SL}{S^2LC+1}}{R_S+\frac{SL}{S^2LC+1}}=\frac{\frac{SL}{S^2LC+1}}{\frac{S^2R_SLC+R_S+SL}{S^2LC+1}} \tag{5}$$

$$=\frac{SL}{S^2R_SLC+SL+R_S}$$

$$H(S)=\frac{S\frac{L}{R_SLC}}{S^2+S\frac{L}{R_SLC}+\frac{R_S}{R_SLC}}$$

As shown in Figs. 14 and 15, the characteristic, where impedance is culminated when a RLC parallel resonance circuit is resonated, was used for the bias to

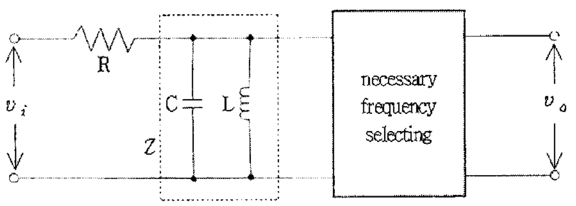

Fig. 14. Necessary frequency component selection circuit.

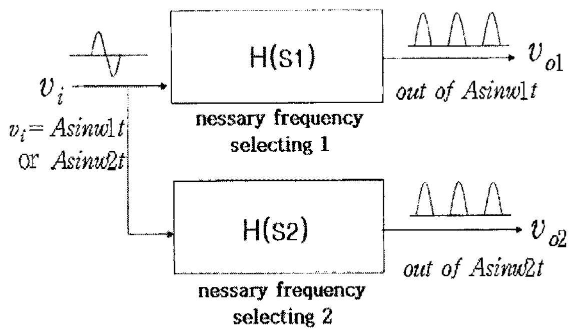

Fig. 15. A block diagram of a necessary frequency selection part.

operate a transistor so that only three frequency components out of the frequency components of the necessary bandwidth can be selected. In this manner, a high acuity necessary frequency selecting circuit was designed. An algorithm, which is able to interpret and judge various influences caused by reflected waves and variances of media, was performed in order that necessary frequency components can only be extracted at the receiving part after the transmission of information [7]. Three different frequencies should be used for the hydro-acoustic releaser, but the difference between those frequencies is very slight. Thus, selecting the necessary frequency is all important to the instrument. For this reason, the characteristic, where impedance is culminated when a RLC parallel resonance circuit is resonated, was used for the bias of a transistor as shown in (6).

$$Z_T = R + Z = R + \frac{j\omega L}{1-\omega^2 LC}[\Omega] \quad (6)$$

In this case, Resistance 'R' is Fig. 14's resistance for voltage distribution according to the resonance characteristic at the parallel resonance circuit and impedance 'Z' is the combined impedance of inductive reactance 'X_L' and capacitive reactance 'X_C'. Additionally, three necessary frequency components, whose amplitude of output voltage corresponds with (7), were extracted.

$$V_0 = V_P \frac{1}{\sqrt{1+(\frac{R}{\omega L})^2(1-\omega^2 LC)^2}}[V] \quad (7)$$

Here, the voltage(V_P) is the peak voltage of the input signal supplied to the input terminal of the parallel resonance circuit as seen in Fig. 14.

3.4. Hydro-acoustic signal detection comparing part

3.4.1 Setting the reference voltage (V_{ref}) of non-inverting comparator

As shown in Fig. 16, a non-inverting comparator was used to detect input signal information and the reference voltage of the comparator was set. Equation (8) provides the results of the calculation based on the comparator. Here, '*Vcc*' was based on 5V.

$$V_{ref1} = (\frac{R48}{R48+R50})v_{cc} = (\frac{10K}{10K+470K})5 = 0.10[V] \quad (8)$$

3.4.2 Detecting the input signal voltage (Vs) of a non-inverting comparator

The input signal of a non-inverting comparator can be detected as shown in (9). The value of the designed comparator was varied as to the strength of input signals. However, that result is not an error in respect that it is recognized as signal voltage in case it is higher than the reference voltage (V_{ref}) Thus, the result calculated through the designed comparator (V_S= 0.41V) can be recognized as signal voltage.

$$V_S = (\frac{R47}{R52+R47})i_c R52 = (\frac{10K}{1K+10K})0.45X1 = 0.41[V] \quad (9)$$

However, the signal component, attenuated due to variances of media, had difficulty in being amplified as well as the fact that its voltage was lower than the reference in case the reference voltage in (8) was highly set to the level (2/3V) of input voltage. Likewise, operational failures were increased due to disturbing noise components in case the reference voltage was lower to the level of 1/3V.

3.4.3 Designing a variable reference voltage setting circuit

As shown in Fig. 18, a variable reference voltage comparison part was designed and the reference

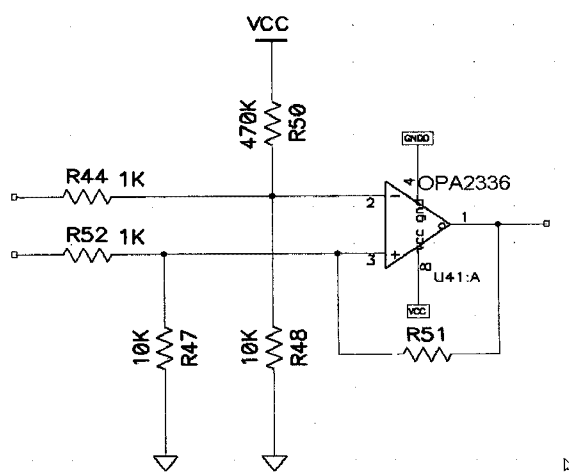

Fig. 16. A detector for non-inverting voltage level.

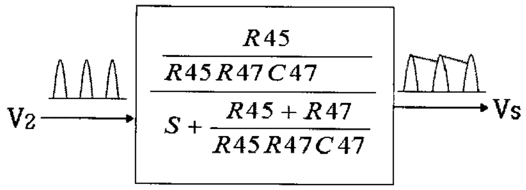

Fig. 17. A model of input signal voltage(V_s).

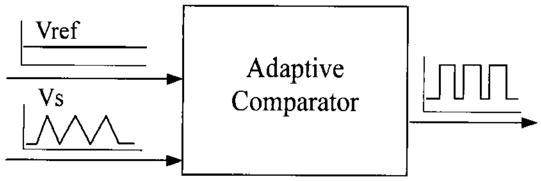

Fig. 18. Variable reference voltage-comparison part.

voltage was variably designed in order that it cannot be influenced by noises and the attenuation of input signals. In that case, the malfunction by disturbing noises can be removed because the voltage component (Ic x R44) in Fig. 16 is simultaneously reduced in proportion to the reduction of input signals. Moreover, the reference voltage can be heightened because voltage components are simultaneously increased in case input signal components are sufficiently amplified in the event that the phenomenon, in which noises are treated as input signals under low reference voltage, can be resolved as well as the phenomenon, where the input signal detected in high voltage level cannot come to the reference voltage level, can be resolved. In this regard, stable operation can be secured.

Fig. 17 shows a model of input signal voltage, and (10) was derived by calculating after setting the reference voltage.

$$\begin{aligned} V_{ref2} &= \left(\frac{R48}{R48+R50}\right)v_{cc} + i_c R44 \\ &= \left(\frac{10K}{10K+470K}\right)5 + 0.45mA = 0.54[V] \end{aligned} \quad (10)$$

4. EXPERIMENTS

4.1. System configuration

As shown in Fig. 19, a function controller that can act as a transmitter and can visually display transfer states and answer signals through wave forms, a voltmeter, a DC 12V battery that supplies power to the system, and a bi-direction transducer, were used to constitute the transmitting part. The receiving part was constituted by a function simulator that can visually display receipt states and voltage and current, a DC 18V battery, a function checker that can display receipt states in each step visually and numerically, a transducer that converts answer signals into ultrasonic signals, and a small water tank (W:2000mm x D:1500mm x H:1000mm). It was set so that acoustic signals can be generated in the transducer in case control information is inputted by using the mode switch in the function controller. Likewise, it was set so that the ultrasonic signal received through the function checker can be made into data visually and numerically.

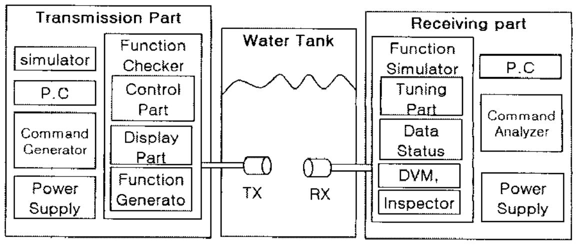

Fig. 19. The configuration of an experimental Instrument.

4.2. Assessing the characteristics of band pass filter

The wave form of Fig. 20(a) is characterized by low resonance in the band of intermediate frequency due to outstanding selectivity of resonance circuit. Fig. 20(b) is the wave form of which characteristics of band pass filter of intermediate frequency were improved by amplifying the whole signal through the stage of amplification, and by filtering intermediate frequency components again. Consequently, the security of control information and the stability of amplitude can be ensured by reason that it can be set

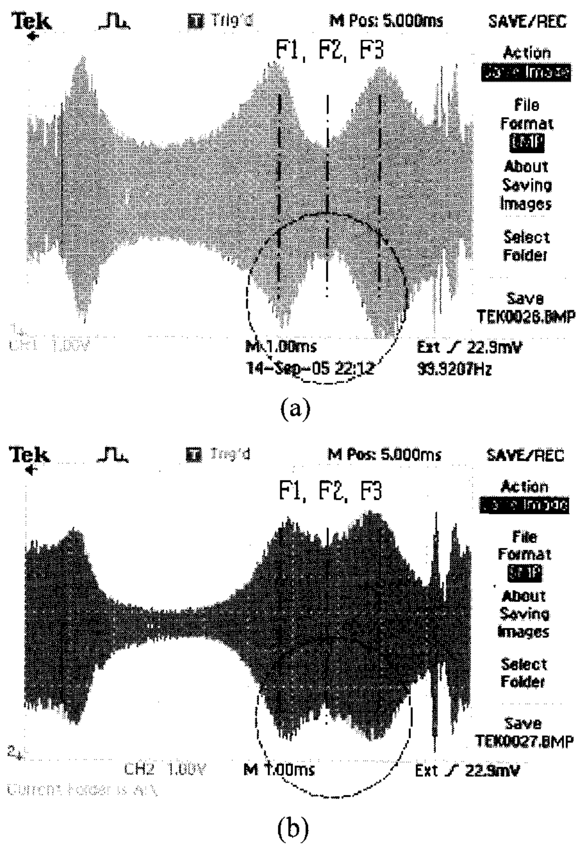

Fig. 20. Comparing the characteristics of a band pass filter.

to the control information signal by using three frequency components of which amplitudes of hydro-acoustic signals are the same.

4.3. Frequency selectivity experiment

Fig. 21 shows the method of extracting necessary frequencies. Through that method, three frequency components in which the characteristic, where impedance is culminated when a resonance circuit is resonated, was used for the bias to operate transistors, and the three frequency components, mixed with each other, were simultaneously extracted. The internal wave form in Fig. 21 shows what the selectivity of frequency was lowered to due to the low quality factor of the resonance circuit ($Q = X_L / r$). The dotted circle indicates the resonance circuit of which selectivity was improved as the value of 'Q' was heightened from 120 to 160.

4.4. Assessing the influence of multi-path fading

In order to assess the recognize-ability of hydro-acoustic signals under the multi-path fading that exercises the strongest influence on hydro-acoustic signals [8], the wave form of tone burst, whose amplitude is varied in length of time, was authorized and was assessed. As shown in Fig. 22, the power control mode (hydro-acoustic signals should be detected over 8ms for 20ms per second) was normally performed by receipt waiting mode in the first part. And, it is regarded as a noise component and is treated

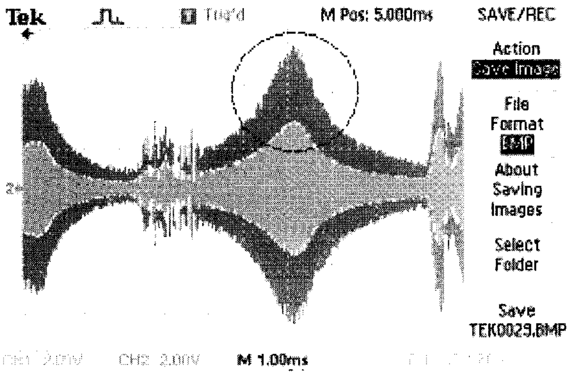

Fig. 21. Comparing the selectivity of frequency.

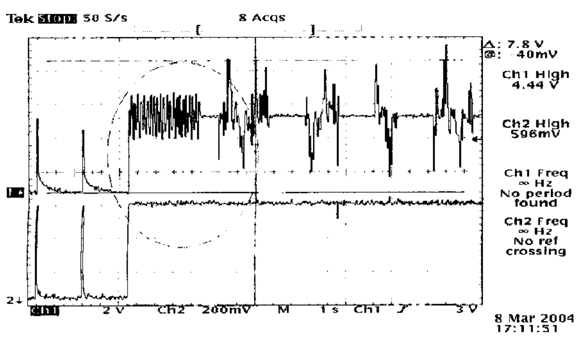

Fig. 22. Assessing the influence of multipath fading.

as a fog signal like the lower wave from shown in Fig. 22 in case noise components are delivered before the delivery of the information corresponding to octal information while the synchronizing signal (the signal in the circle) is being inputted. As a result, the influence of multi-path fading can be resolved.

4.5. Assessing the characteristics of hydro-acoustic signal based on ambient noises

In case the strength of hydro-acoustic signals is weakened by reason that the distance is lengthened in submarine environment, the noise components caused by ambient noises affect the control system and so the recognize-ability of hydro-acoustic signal is affected [9]. As shown in Fig. 23, the influence of distance was decreased and the performance of hydro-acoustic releaser was remarkably improved because signal components were detected by amplifying weak signals and correcting the damaged information in comparison with octal reference information. On the other hand, the attenuation rate of signals was increased in case ambient noise components are included in hydro-acoustic signals. Nevertheless, the output signal was recognized within the stable range (pulse: 160 ~ 170).

4.6. Assessing the operational failure by the delivery loss of hydro-acoustic signal

Table 1 is the test results from comparing the operational error rates caused by transmission loss [10] due to increased distance. Because the transmitted input signal level decreases in fixed comparator starting at distances from approximately 300[m], after the detected signal is integrated to find the signal voltage (V_S) at the peak, it becomes lower than the reference voltage (V_{ref}) and thus, in many cases, it is recognized as no signal. However, according to tests results for the adaptive comparator, the signal lowered due to increased distance was amplified and the resonance circuit's quality factor was enhanced (Q = 120 to 160). In addition, by using the FSK modulating method and adaptive comparator,

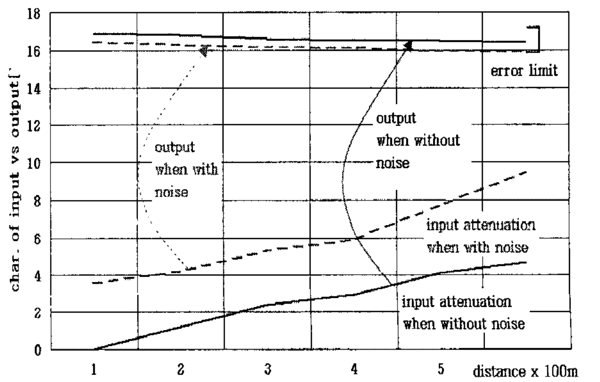

Fig. 23. Assessing the sound source based on ambient noises.

Table 1. Assessing the hydro-acoustic Failure Caused by Delivery Loss.

distance (×10)		input (mV)	Amp. (V)	Ref. Spec.	Result of signal output {volt.(Vs), pulse}										Success (%)
					1	2	3	4	5	6	7	8	9	10	
Fixed Comp.	5	2.32	5.00	Vref= 3.0[V]	4.9	4.9	4.7	4.8	4.9	4.7	4.7	4.9	4.8	4.9	100
	10	1.64	4.59		4.6	4.5	4.4	4.6	4.5	4.7	4.5	4.4	4.7	4.6	100
	20	1.25	3.36		4.3	4.4	4.1	4.1	4.3	4.2	4.3	4.1	4.2	4.3	100
	30	**0.81**	**2.27**		**4.0**	**4.0**	**3.9**	**3.8**	**3.9**	**4.1**	**4.0**	**2.9**	**3.8**	**3.9**	**90**
	40	**0.46**	**1.29**		**3.6**	**2.7**	**3.3**	**3.4**	**2.7**	**3.7**	**3.6**	**3.7**	**2.6**	**3.5**	**70**
	50	**0.08**	**0.22**		**3.2**	**3.3**	**2.6**	**3.2**	**3.2**	**3.3**	**2.6**	**2.7**	**3.2**	**2.6**	**60**
Adaptive Comp	5	2.32	4.87	160-170 pulse	170	170	170	170	170	170	170	170	170	170	100
	10	1.64	3.44		169	170	169	168	168	169	168	169	170	170	100
	20	1.25	2.63		167	169	167	167	168	168	168	167	167	169	100
	30	0.81	1.70		166	167	167	166	165	166	167	165	166	166	100
	40	**0.46**	**0.97**		**165**	**164**	**163**	**158**	**165**	**164**	**164**	**165**	**163**	**164**	**90**
	50	**0.08**	**0.17**		**163**	**161**	**157**	**162**	**162**	**163**	**161**	**162**	**158**	**163**	**80**

the submarine ultrasonic communication errors were reduced by 8.8%, verifying that the effects from transmission losses were low up to approximately 400m.

5. CONCLUSIONS

In this study, the recognize-ability of hydro-acoustic signals was presented by using the characteristics of resonance and adaptive comparator for hydro-acoustic releasers, which are used to explore for ocean resources. The FSK+ASK combined modulator, which can stably transmit hydro-acoustic signals regardless of environmental variances and external disturbances, was designed. The condenser coupled Band Pass Filter was applied to the receiving part by using RLC parallel resonance characteristics in order that the signal components in a suitable frequency band can only be passed. Three frequency components were detected stably and effectively, by using the characteristic where impedance is culminated when the RLC parallel resonance circuit is resonated. In addition, an adaptive comparator was designed so that information detection performed through the comparator was varied as to the strength of input signals. Simultaneously, the influence of multi-path fading was effectively corrected and so the success rate of communication was improved. As a result, approximately 8.8% of ultrasonic wave communi-cation errors caused by ambient noise and transmission losses were reduced for effectively detecting ultrasonic waves.

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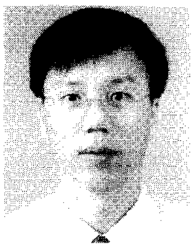

Young-Jin Kim received the M.S. degree in Electronic and Computer Eng, from Dankook University in 2002, and his Ph.D. in Electronic and Computer Eng, from Dankook University in 2006. He is currently working for the Korea Institute of Industrial Technology (KITECH), Cheonan, Korea. His research interests include control systems of marine equipment, application of ultrasonic sensors, and motor control.

Kyung-Moo Huh received the B.S. degree in Electronic Engineering from Seoul National University, Seoul, Korea, in 1979, and the M.S. and Ph.D. degrees in Electrical and Electronic Engineering from the Korea Advanced Institute of Science and Technology (KAIST), Korea, in 1981 and 1989, respectively. He is currently a Professor in the Department of Electronics Engineering, Dankook University, Cheonan, Korea, and also a Director of Dankook University's RIC (Regional Innovation Center) for Electronic Parts Inspection Automation. His research interests include System Control, Inspection Automation, Robot Control, Learning Control, and Machine Vision.

Young-June Cho received the B.S. degree in Mechanical Engineering from Hanyang University in 1979, and the M.S. and Ph.D. degrees in Mechanical Eng, from Korea Advanced Institute of Science and Technology (KAIST) in 1981 and 1986, respectively. He is currently working for the Korea Institute of Industrial Technology (KITECH), Cheonan, Korea. His research interests include automation control, application of optical parts, and marine equipment.