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바이오텔레메트리용 초음파 핑거의 소형화

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Miniaturization Pinger for Biotelemetry

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소형 핑거의 크기를 좌우하는 것은 진동자의 크기이며, 진동자의 크기는 주로 사용 주파수와 진동 모드에 의하여 정해진다. 이 연구에서는 핑거에 자주 이용되고 있는 링형 진동자와는 진동 모드가 다른 바이모르프형 진동자를 이용하므로써 소형 진동자의 개발이 가능하였으며, 이 진동자를 이용하여 핑거의 소형화를 이룩 할 수 있었다. 개발된 진동자의 크기는 50*kHz* 공진에서 직경 7.3*mm*, 두께 0.7*mm*이었으며, 소형화된 핑거는 직경 8.0*mm*, 길이 30*mm*의 크기이고, 공기중에서의 중량이 3.5*g*, 수중중량이 1.8*g*이었다. 음향 출력 레벨은 3*V*의 전지를 사용하여 147*dB* (re 1*μPa* at 1*m*)이었고, 약 3일간 사용 가능하였다.

Introduction

During the past decade miniature electronic transmitters have been developed in order to monitor the behavior or the heart rates of individual fish as well as the environmental information. For the tracking of fish behavior the acoustic or radio tags are required to be small. Many researchers have studied and tested how the acoustic tags (pingers or transponders) can be small in with a battery of longer lifetime, a long detection range and many information1)~9),11). Pinger size is determined by batteries, electric circuits and especially a transducer. Though the size of battery and electronic components depend upon the output power and the lifetime of the battery, the transducer size is decided nearly by the resonant frequency and the vibration mode of pingers.

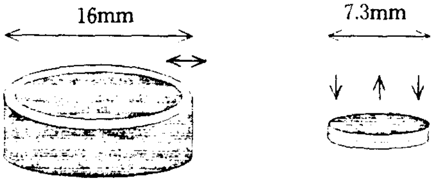
Acoustic energy loss due to absorption increases rapidly with frequency and it severely restricts the detectable range. Upward from about 70 *kHz* the ultimate limit to detection of signals is set by thermal noise5). The most significant noise in the sea at frequencies up to about 50 *kHz* is due to sea state related with the wind force5),10). Considering these factors the optimum frequency may be estimated 50 *kHz* to 70 *kHz* for the acoustic biotelemetry.

This paper describes the development of a miniature transducer for 50 *kHz* and the construction of the prototype pinger employing the bimorph type ceramic transducer.

Development of transducer

Transducer size and vibration

Fig. 1 shows the size and typical vibration mode of the ceramic transducer of both ring and bimorph types.



Ring type Bimorph type

Fig. 1. Size and vibration mode of transducer at 50 *kHz*.

The ring type ceramic transducers vibrate like a breathing so radiate the acoustic energy in omni-direction in water. They have been equipped frequently with a lot of pingers for biotelemetry, and their diameter and height is around 16 *mm* and 5 *mm* at 50 *kHz* respectively. On the other hand the bimorph type ceramic transducers vibrate as a bending; i.e., one sheet of the transducer element is expanded and then the other one is contracted in repetition.

To make a small sized transducer two techniques are effective. One is a high frequency use. The higher the frequency the smaller the size of the transducer but the more the absorption loss. The other is the use of a different vibration mode without changing the frequency. The authors adopted the latter to reduce the size of transducer. The transducer developed in this study has a diameter of 7.3 *mm* and thickness of 0.7 *mm* at 50 *kHz* resonant. A favorable feature of the developed transducer is that the resonant frequencies can be controlled manually by shaving its diameter.

The relationship between the resonant frequency f_r and the diameter D of the two transducers is shown in equation (1) and (2). Equation (1)[14] is for the ring type and the equation (2)[8),12)] for the bimorph type:

$$f_r = (1/\pi D)(E/\rho)^{1/2} \tag{1}$$

Where E is Young's modulus, ρ the density.

$$f_r = (1.65t/D)(E/\rho(1-\sigma^2))^{1/2} \tag{2}$$

Where t is thickness of transducer and σ the Poisson's ratio.

Moldings

Fig. 2 shows a molding method of the bimorph type. As seen in Fig. 2, the bimorph type transducer is molded with a fluid silicon rubber as softly as possible to make free vibration. Based upon this simple method we succeeded in making of a miniature pinger as a trial. An impedance of the molded transducer measured 800 ohms.

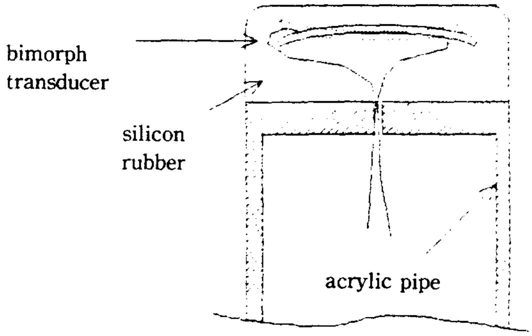


Fig. 2. Molding of bimorph transducer.

Miniaturization of pinger

Designs of electric circuits

Fig. 3 shows a circuit of the prototype pinger to get a positioning information only. If an information for the water temperature and the depth is desired, then each sensors can be replaced

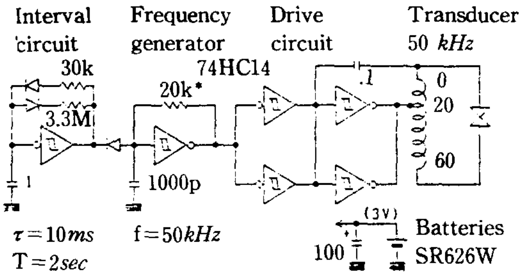


Fig. 3. Circuit diagram of prototype pinger.

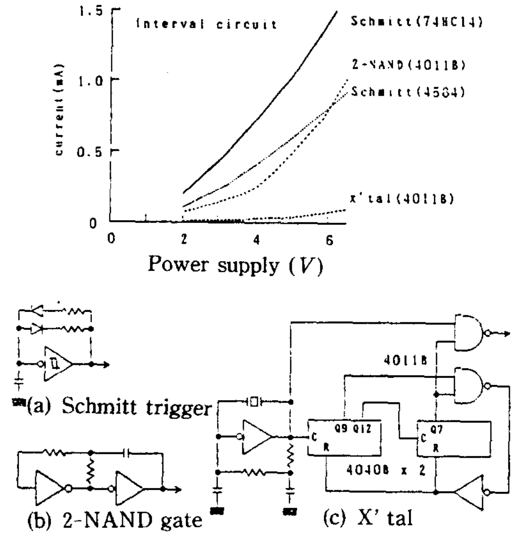


Fig. 4. Currents drawn by each interval circuit when pulse duration was 10*ms* and pulse interval 2*sec.*

instead of the two registers in the interval circuit.

In Fig. 3, the pinger circuit is composed of a C-MOS IC (HEX Schmitt trigger inverter, 74HC14, miniaturized flat type) and a few other electronic parts. The interval circuit which decides both the pulse duration and the pulse interval is operated by one inverter. Similarly, the frequency generator triggered from the interval circuit throughout a switching diode is operated by one inverter. The drive circuit was designed to increase the driving power and to get double voltages of pulse signal by the use of four inverters, which supplies it to the transformer. In the transformer a ferrite torus type core FT-23-75, 1.5 *mm* high by 5.8 *mm* in diameter, is wound with enameled copper wire of 0.5 *mm* diameter. equation (3) shows how the first hand turn N_1 was decided:

$$N_1 = E_{rms}(4.44\times f\times A_e\times B_{max}\times 10^{-8})^{-1} \qquad (3)$$

where the E_{rms} is rms value of the voltage input onto $N_1(V)$, f the transmitting frequency (Hz), A_e the effective cross section area (cm^2) and B_{max} the maximum magnetic flux density (Gauss). The input signal onto the transformer of first hand was 6 V_{p-p} square waves of 50 *kHz*, and the FT-23-75 core has the A_e 0.0213 cm^2 and the B_{max} 3000 Gauss. From these factors the N_1 was calculated. The second one N_2 can be decided by the equation (4):

$$(N_2/N_1)^2 = Z_2/Z_1 \qquad (4)$$

where Z_2 is the impedance of the transducer and Z_1 the optimum driving load. The measured Z_1 was about 100 ohms.

In general, the interval circuit draws most of the current of pingers as it operates in analog. Fig. 4 shows a comparison of currents with other interval circuits used in measuring of it. The current of the 74HC14 shows the highest value among them. However, we choose it inevitably considering both the driving power and the number of electronic parts related closely to the pinger size.

Battery lifetime

Equation (5)[5] shows how the battery lifetime N may be calculated:

$$N = (C_b\times T)((I_p\times \tau\times 10^{-3}) + I_0)^{-1} \qquad (5)$$

where C_b is the battery capacity (mAh), T the pulse interval (sec), I_p the current drawn by circuit during the pulse emitting (mA), τ the pulse duration (ms) and I_0 the current when the pulse emitting is in quiescent state (mA). In accordance with the equation (5) the battery lifetime of 96 hours was calculated when the C_b is 26 mAh, $T=$

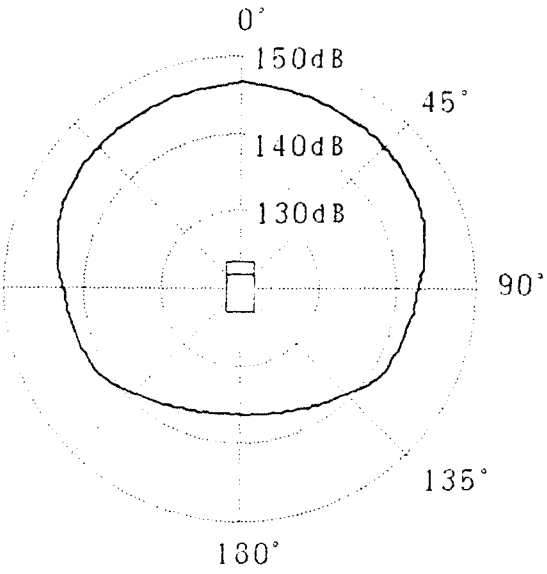


Fig. 5. Acoustic source level and beam pattern of prototype pinger in horizontal.

2 sec, $I_p=8.75$ *mAh*, $\tau=10$ *ms* and $I_0=0.45$ *mA*, but the measured value of it was 70 hours. The difference between the calculation and the measurement may be caused by an efficiency of the battery.

Fig. 5 shows both the acoustic source level and the beam pattern in the horizontal direction of the pinger. The vertical beam pattern may be same as the horizontal one for the transducer with the shape of a disc. These were measured in a pond of 5 meters depth having sufficiently clear water. The acoustic source level was 147 *dB* (re 1 μPa at 1 meter).

Efficiency

Equation (6) shows how the electric to acoustic efficiency η of the transducer calculates:

$$SL=170.8+10\ log \eta P+DI_t \qquad (6)$$

where SL is acoustic source level (*dB*), P the output electric power (*Watt*) calculated by the current during pulse and impedance of the transducer, and DI_T the transmitting directivity index in *dB*. The directivity index DI_T is:

$$DI_T=10\ log\ (\pi D\lambda^{-1})^2 \qquad (7)$$

where D is the diameter of the transducer (*mm*) and λ the wavelength (*mm*). If D is 7.3 *mm* and the sound velocity is 1500 *m/s*, DI_T will be -2.3 *dB*. η will be obtained by the equation (6). The efficency η was 11.7% when the output power is 0.06 Watts.

Efficiency of the driving circuit was 60 percents when the 18 V_{p-p} of square waves were supplied on to the transducer. It is, of course, possible to increase the efficiency up to more than 90 percents if the size of pinger is not critical. But the purpose of this study is to miniaturize the pinger itself keeping the practical use at the cost of some factors related to the optimum disign.

Construction of prototype pinger

Fig. 6 shows a construction of the prototype pinger.

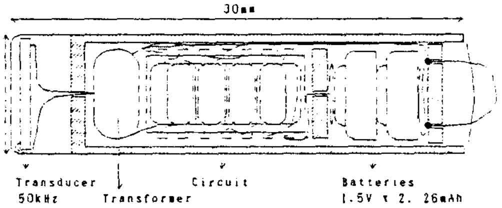


Fig. 6. Construction of prototype pinger.

In Fig. 6 the electronic components and two 1.5 volts silver oxide batteries (SR626W) are contained within a acrylic pipe, and are separated by a separator. The cap pressing down the battery cells were sealed with "5-Minute" epoxy or silicon rubber for the easy exchange of cells. A pressure test of the pinger was done up to 100 meters depth and there was no problem in the waterproof when the cap was sealed with "5-Minute" epoxy.

Detectable range

Most of the detectable range of pingers is variable with a receiver and wind speed as far as the acoustic source level *SL* is same. The detectable range *r* can be calculated by equation (8), (9) and (10):

$$SNR = SL - TL - NL \qquad (8)$$

where *SNR* is a signal to noise ratio at the face of transducer (*dB*), *TL* a transmission loss (*dB*) and *NL* a noise level (*dB*). In telemetry the *SNR* may require a margin level of at least 12 *dB* against the *NL*.

$$TL = 20\ log\ r + \alpha r \times 10^{-3} \qquad (9)$$

where $\alpha (= 0.22f + 0.000175f^2$, f is frequency in *kHz*) is the absorption loss (*dB*/*km*)[14]. At 50 *kHz* the absorption loss is about 11.5 *dB*/*km*. The noise level received by a receiver depends upon a band width of the receiver and can be calculated using the following equation (10):

$$NL = SPL + 10\ log\ BW \qquad (10)$$

where *SPL* is the spectrum pressure level per 1 *Hz* and *BW* the band width of the receiver (*Hz*). Assuming the *SPL* to be 42 *dB*[10] approximately at 50 *kHz*, the wind speed of 12 knots and the receiving band width of 1000 *Hz*, then the *NL* will be 72 *dB*, So, if the *SL* is 147 *dB*, *NL* 72*dB* and *SNR* 12 *dB*, then the detectable range *r* becomes about 600 meters. But the detectable range measured about 400 meters in Tateyama Bay of 30 meters depth when the receiving band width was 3300 *Hz*.

Conclusion and discussion

Development of the small size transducer was carried out successfully with an idea that the bimorph type transducer used in the air is much smaller than the other type of same frequencies and has an availability as a transducer for pingers by molding of it. Several different methods of the molding were tried before the above mentioned one was chosen. For example some kind of baffles were made using a material of brass, aluminum, etc. A 1/4 wavelength point of the transducer is supported upon inside the baffles and molds it with the silicon rubber. As the results the molding method shown in Fig. 2 was turned out to be better among them. The molded size of the bimorph type transducer was no bigger than 8.0 *mm* in diameter

Table 1. Specifications of the commercial pingers and prototype one

Maker	VEMCO (canada)		SMITH-ROOT (Am.)	KODEN (Japan)	Prototype pinger
Model	V2	V3	SR-74	MBK	—
Diameter (*mm*)	8.5	16	14.5	18	8
Length (*mm*)	33~38	48~103	63.6	84	30
Weight (air) (*g*)	4.3~5.1			28	3.5
in water (*g*)	2.7~3.5		9.1	12	1.8
Transd. type	ring	ring	ring	ring	bimorph
resonant	no	yes	yes	yes	yes
Frequency (*kHz*)	69~77	50~77	74±1.5	50	50
generated by	x'tal	x'tal	x'tal	RC	RC
SL (*dB*/*μPa*)	136~147	146~159		160	147
Range (*km*)	.2~1	.5~1.5	.5	1	.6
Lifetime (*days*)					
tracking only	1.5~12	6~200	—	5	3
with temp.	—	1.6~1500	30	5	—
with depth	—	1.4~ 43	—	5	—
Pulse					
duration (*ms*)	15	15	2% intv.	20	15
interval (*sec*)	1	1~3	.5~4.0	1~3	2

and 5.0 *mm* in height. Consequently by the use of this transducer a making of a miniature pinger which can be attached to a small fish of 20 *cm* body length was possible. Specifications of the prototype pinger compared to the commercial ones are shown in Table 1.

We succed in a field test of the prototype pinger attached to a salmon and followed it about two hours with a directional hydrophone to prove its practical use in October 1988, Hokkaido.

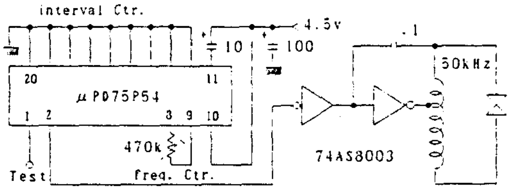


Fig. 7. Circuit diagram of a new pinger using 4-bit single chip microcomputer.

To extend the battery lifetime and to control accurately both the pulse interval and the pulse duration, we have tried another circuit (Fig. 7) using a single chip microcomputer (μPD75P54, 4 bits PROM)[13]. Though we have not completed yet for the writing a program into the PROM, it will be done in near future. If it completed, the battery lifetime of a new pinger may be quite longer than the prototype in spite of similar size of the pinger.

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