INVESTIGATION OF A DIRECT READING DEPTH METER FOR "PILOTAGE" USING A NEW ULTRASONIC SOUNDING PRINCIPLE (QUASI "MODULATED FREQUENCY" PRINCIPLE)

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SUMMARY OF CONTENTS.

By making use of the new ultrasonic sounding principle (quasi "modulated frequency" principle) instead of the "impulse principle" (damped transmission), the following results are obtained when sounding in very shoal water in laboratory tanks, rivers and the sea, viz.-

1. An absolutely continuous depth indication by means of a steady pointer reading on the dial is obtained; a depth variation of even a few milliseconds being plainly detected.
2. Very small depths of less than 15 centimetres beneath the projector are readily indicated.
3. The indications are in strict linear proportion to the depth.
4. The absolute error is zero, and the relative error is less than 1 %.
5. The power consumption is only 12 watts, and the apparatus may measure depths of over 50 metres.

The above results indicate that this sounding apparatus is suitable for "navigation" and may be used as a substitute for sounding by hand-lead.

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1. INTRODUCTION.

The most important requirement for guiding ships safely into a harbour is an accurate and continuous knowledge of the depth of water beneath the ship's bottom. Usually, in harbours the depth of water rarely exceeds several score of metres at the outside. If the depth of water beneath the ship's hull approaches one to one-half of a metre there is danger of grounding, in critical cases. In such cases a most accurate and continuous knowledge of the depth is essential. However, the depth finders at present in use are hardly capable of meeting such requirements because they are built upon the "impulse principle" (damped transmission), *i. e.* the sound impulse is always of very short duration, for instance about 1/1000 of a second, and a sonic impulse of

1/1000 of a second duration represents a wave train of about 1.5 metres' length (as a result of the high velocity of sound in water of 1500 metres/sec. at normal temperatures). Moreover, the "impulse principle" does not furnish a continuous reading of the depth because the pulse emissions are not continuous.

By making use of the new Ultrasonic Sounding Principle (Modulated Frequency Principle), instead of the "Impulse Principle", I have obtained the following results in very shallow water in the laboratory and in actual field tests. These are described in detail below :–

2. The Principle of the "Modulated Frequency Depth Sounding".

Let the "beat" frequency produced between the emitted sound wave and the wave reflected from the sea-bed be a function of the depth of water, when using a modulated frequency ultrasonic emitter and receiver. It follows that the valve frequency-metre indication of the "beat" should provide a continuous indication of the depth.

For instance, let us assume that the frequency characteristic of the sound wave is directly proportional to the time t as shown in Fig. 1.

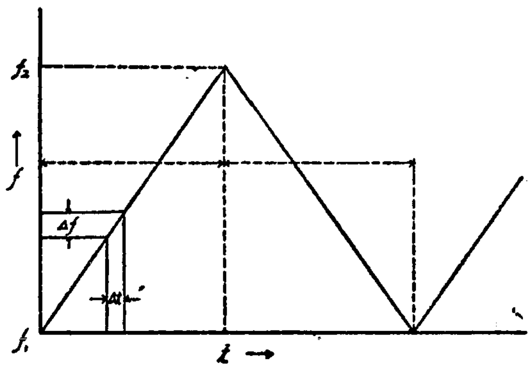

Fig. 1

In the figure the ordinates represent the frequency f. Therefore the "beat" frequency, between the sound wave transmitted by the emitter S (Fig. 2) and the reflected wave from the bottom B should be Δf, because there is a time interval Δt between the waves which is proportional to the depth of water D.

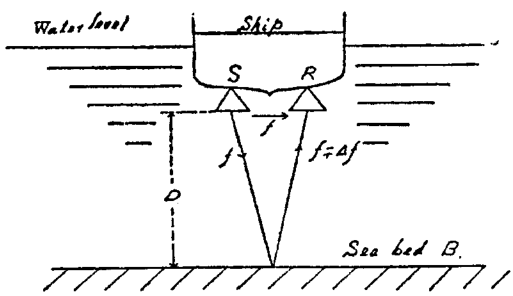

Fig. 2.

Since

Δt is proportional to $2D$

and from Fig. 2

Δf is proportional to Δt

consequently :

Δf is proportional to $2D$... (1).

Therefore Δf is directly proportional to the depth D.

In this principle the emitted sound wave is not discontinuous as in the "impulse principle" and therefore the depth indications are absolutely continuous.

If the values of f_1, f_2 and df/dt are properly chosen, then a depth of a few centimetres only can be easily indicated. Therefore this sounding principle is most suitable for "navigation".

This principle is not affected by the wave-length of the emitted sound impulse, and therefore the theoretical error is nil.

3. Determination of the carrier frequency.

Theoretically, any value whatsoever may be adopted for the carrier frequency. I have used, however, a frequency of 100 K.C. with a frequency modulation of $\pm$ 5000 cycles/sec. for the following reasons.

Thus, by using the high carrier frequency, we have :–

a) Maximum directional effect.

b) Great frequency variation, *i. e.* $f_2 - f_1 = f_d$ is comparatively large, and therefore measurements of very small depths may be obtained.

The attenuation of such high frequency waves is relatively great, nevertheless when used for "navigating" this drawback is negligible.

With such a rate of frequency modulation, the amplitude modulation is inappreciable.

4. Sound emitter and sound receiver.

For the emission of the above-mentioned high frequency sound energy, we may make use of the piezo-electric oscillation, magnetostriction oscillation, etc. I have preferred the former however, and have adopted quartz plates cut *Y*-shaped for the oscillating element. The external view is shown in Fig. 3.

The directional effects as calculated by Nukiyama's formula (1) are as follows :–

Angle of divergence	=	7°20'
Effective angle	=	6°5'
Directional efficiency	=	1075.

The sound receiver construction is identical in all respects to the above-mentioned sound emitter.

5. The Oscillator.

This is an ordinary valve oscillator.

It consists of two small receiving valves connected in "push-pull". Its input energy at the plate is only 12 watts. The wiring diagram is given in Figure 4.

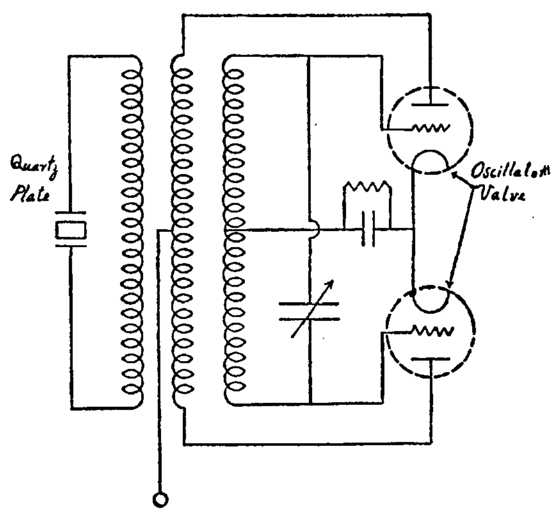

Fig. 4.

(1) Nukiyama, I. E. E., Japan, May 1934, p. 419.

6. THE RECEIVER.

The receiving set contains the detector, amplifier and limiter (and the output circuit).

6*a*. *Detector.* — As mentioned above this detector is designed to detect the mixed waves arriving simultaneously from the emitter and by reflection from the ocean bottom. The mixed waves are shown in Figure 5.

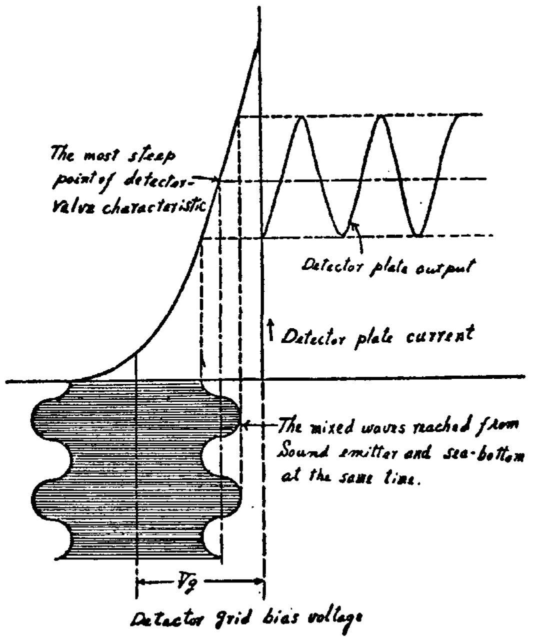

Fig. 5

In this case the wave form is very slightly modulated by the "beat" frequency (less than a few per cent) since the reflected wave is very weak in comparison with the emitted wave. The detection of such a wave form might be considered very difficult. However, this is not only quite easy but can be accomplished with great accuracy — and, further, absolute linear detection is possible. These results were first arrived at by theoretical considerations and were later easily confirmed in practical experiments. In

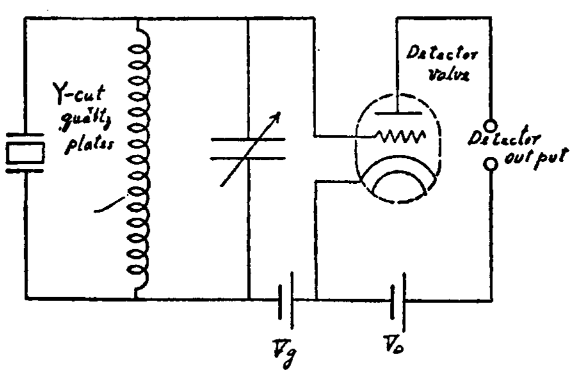

Fig. 6

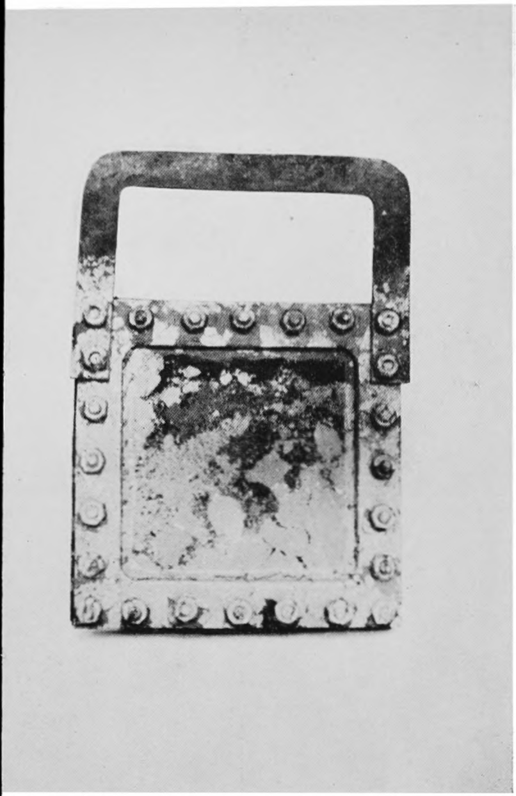

Fig. 3

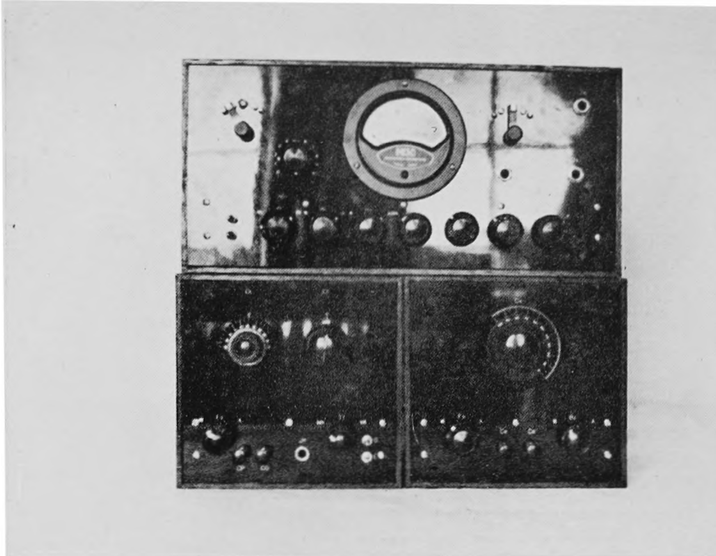

Fig. 8

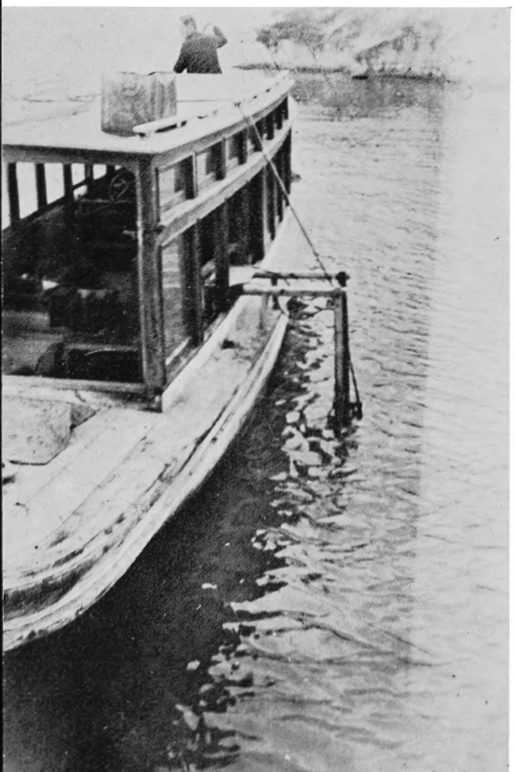

Fig. 15

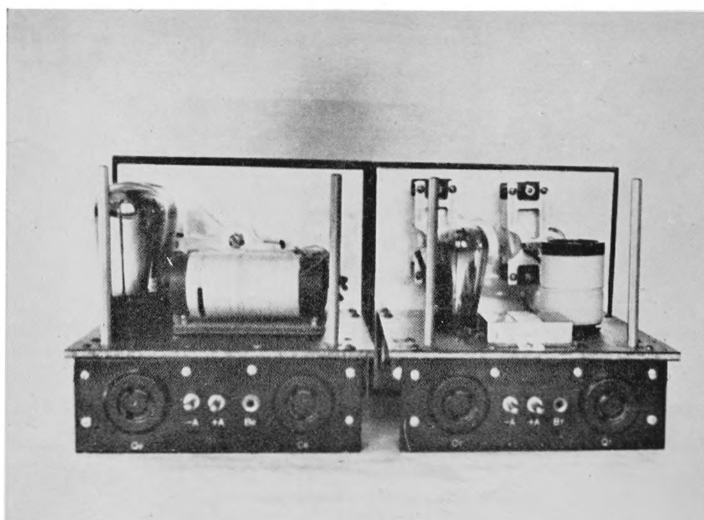

Fig. 9

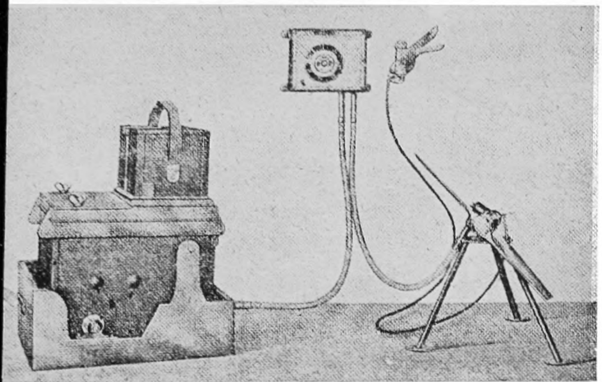

Fig. 2 *Chambre aérophotogrammétrique* Nistri *à plaques*
Nistri *aerophotogrammetric chamber for plates.*

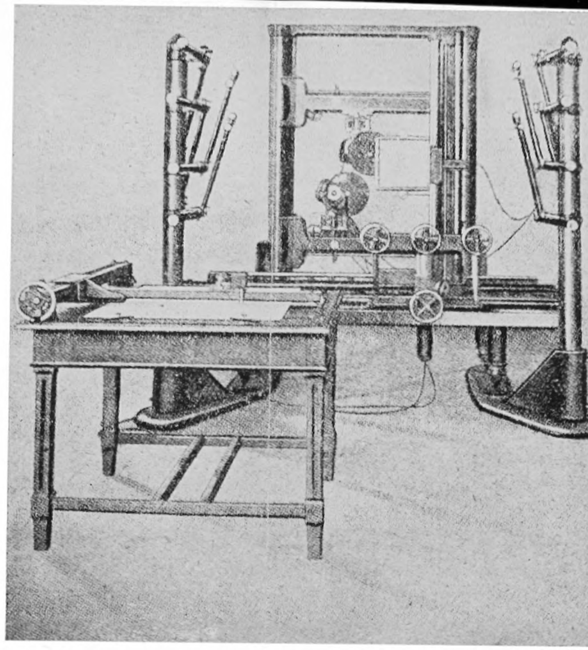

Fig. 4
Le Photocartographe Nistri, *modèle "Aéronormal"*
Nistri *photocartograph : "Aeronormal" type.*

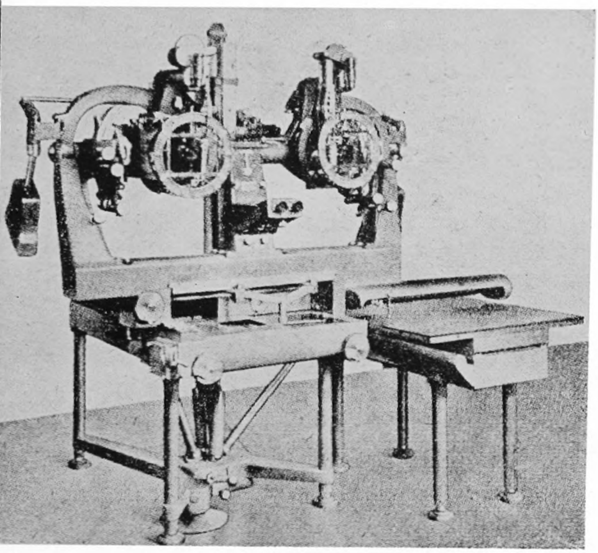

Fig. 5 *Le Stéréocartographe* Santoni, *modèle III*
Santoni *stereocartograph, model III.*

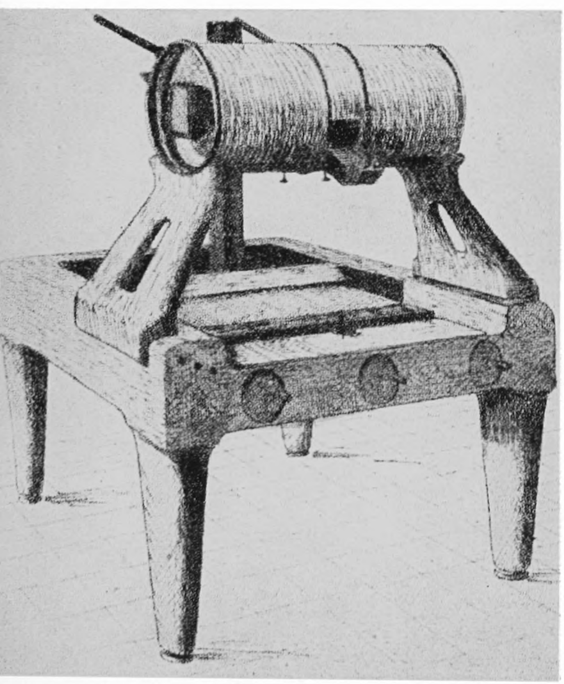

Fig. 6 *Schéma de construction du photostéréographe* Nistri

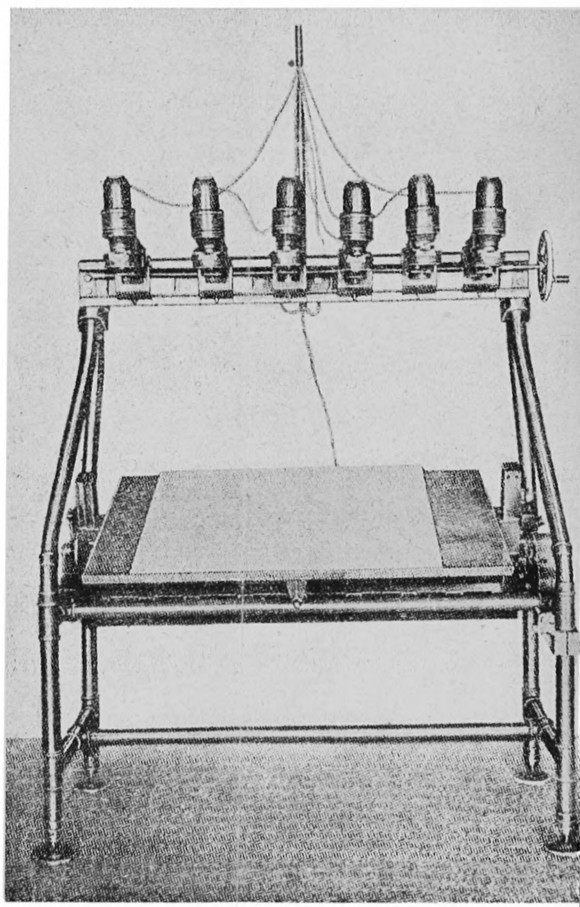

Fig. 7
Le Photocartographe multiple Nistri

such cases the detection is accomplished by plate detection with a proper grid bias voltage. For this purpose use is made of the steepest part of the slope of the detector valve characteristic curve. This is clearly shown in Fig. 5. Thus the detection is quite good and of a high order of efficiency. Fig. 6 shows one example of such detector connections.

6b. *Amplifier.* — For this purpose a resistance capacity coupled amplifying set was used which has such characteristics that it is capable of amplifying low frequencies. For the amplifying valve the high frequency pentode was used on account of its great amplification and freedom from noise which would disturb the microphone. The actual voltage amplification with single valve is about 200.

6c. *Limiter (and output circuit).* — The amplitude of the reflected wave varies in inverse proportion to the square of the depth to be measured. Therefore the "beat" frequency voltage should be limited to a constant level. As a limiter I used the heated type of triode which functioned at the same time as the output valve.

7. Depth Indicator.

Above the "constant level" the beat frequency may be indicated by any type of indicating frequency meter. After experiments with various types the most appropriate one was found to be that described below. The principle is shown in Fig. 7.

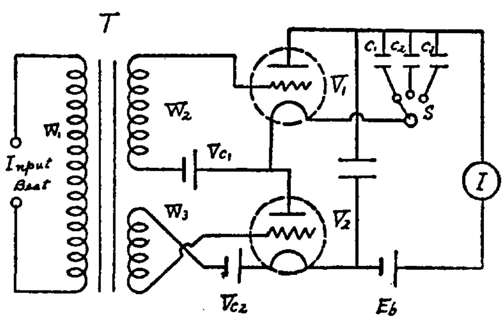

Fig. 7.

In the diagram T is the triple winding transformer with the windings W_1, W_2 and W_3. The secondary windings W_2 and W_3 are connected (the latter in the inverse sense) to the triodes V_1 and V_2. The plate voltage E_b and the grid bias Vc_1 and Vc_2 are so adjusted that no current flows in the milliammeter "I" when the input beat voltage is not impressed on the primary winding W_1. In the case where the beat Δf is applied to the winding W_1, then V_1 and V_2 become either conductors or non-conductors alternately with respect to each other. At the moment that V_1 is a non-conductor and V_2 a conductor, the condenser C_1 becomes charged by the voltage E_b. Its charge Q is

$$Q = C_1 E_b$$

On the other hand when V_1 is a conductor and V_2 a non-conductor, the condenser is discharged. This action is repeated Δf times per second and thus the milliammeter current is

$$I = \Delta f Q = \Delta f C_1 E_b$$

If, in the above equation, we hold C_1 and E_b to a constant value,

$$I = K \Delta f \ldots\ldots\ldots\ldots \quad (2)$$

(where $K = C_1 E_b$ = a constant). Therefore the value of I should indicate directly the input beat frequency.

As shown by the above formulae (1) and (2), the meter indication of the depth is in strict linear proportion to the measured depth. Thus we have an absolutely continuous indication of the depth with a pointer giving a steady reading on the dial.

This depth indicator was fully adequate for the purposes intended, owing to its high input impedance, low power consumption and constant indication, regardless of whether the input voltage varies from a few volts to several hundred volts — a condition which is not realized with any other type of frequency meter. In fact, all the requirements for the research were satisfied.

Further, by switching to C_1 C_2 or C_3, the greatest accuracy may be obtained regardless of the variations in depth. For use in "navigating" this would offer great convenience and is a strong point in favour of the device.

8. EXPERIMENTAL SET.

Figure 8 shows the external view of the Experimental Set.

In the illustration are shown :– the oscillator at the lower right; detector at the lower left; and amplifier, limiter, depth indicator at the top.

Fig. 9 shows the side view of the oscillator (left) and the detector (right).

Fig. 10 shows the amplifier, limiter, depth indicator (inside views).

9. EXPERIMENTS CONDUCTED IN LESS THAN 12 METRES' DEPTH.

9*a*. *Laboratory tank*. — The laboratory tank was made of concrete: 4 m. wide, 4 m. deep and 100 m. long. It is shown in Fig. 11 The end *A* of the tank corresponds

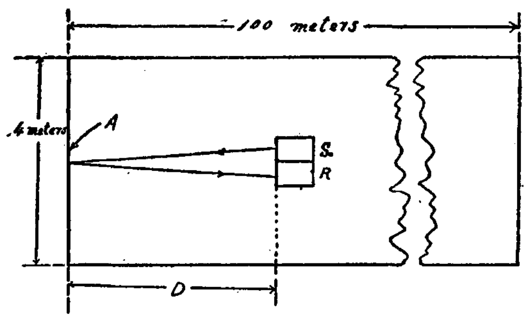

Fig. 11.

to the sea-bed; *D* to the variable depth which is shown by the depth recorded on the current indicator *I*.

9*b*. *Oscillator*. — The oscillator has been described under Para. 5. Its plate input is 100 volts; 25 milliamps.; 2.5 watts.

9*c*. *Results*. — The results are given in Table I and Fig. 12.

TABLE I.

Depth in Metres.	*Indicator*
0.15	2
0.5	4
1.0	6.5
1.5	8.5
2	11.2
3	16
4	20.5
5	26
6	30
7	35
8	40
9	45
10	50
11	55
12	60

As shown by these, the indication is in strict linear proportion to the depth, and the theory is thus adequately proved. The error is less than 1 % and the minimum depth indicated is 15 cm. In these experiments the interesting fact was brought out that depth variations of even a few milliseconds are clearly indicated. In other words the depth indications are absolutely continuous.

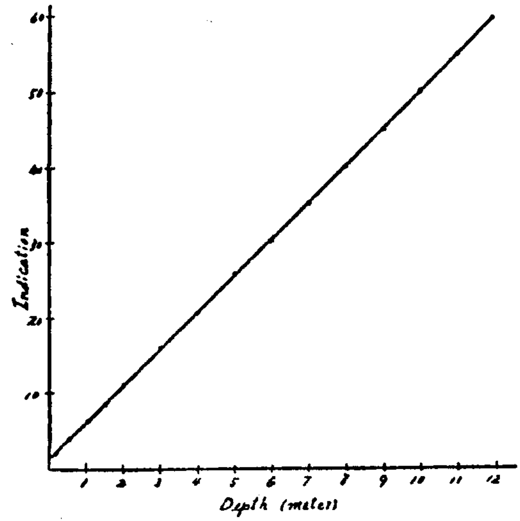

Fig. 12

10. EXPERIMENTS IN DEPTHS OF OVER 12 METRES.

10*a*. *Laboratory tank*. — As described in Para. 9*a*. Experiments were conducted in the same tank using the same methods.

10*b*. *Oscillator*. — The oscillator has been described in Para. 5. The plate input was 200 volts ; 60 milliamps. ; 12 watts.

10*c*. *Results*. — The results are given in Table II and Fig. 13.

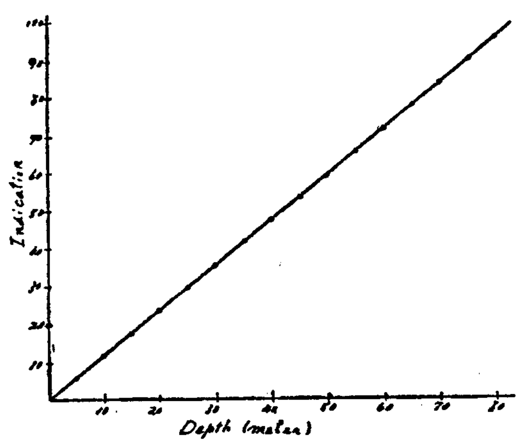

Fig. 13

TABLE II.

Depth in Metres.	*Indicator.*
5	6
10	12
15	18
20	24
25	30
30	36
35	42
40	48
45	54
50	60
55	66
60	72
65	78
70	84
75	90

In this case depths of over 80 m. could not be measured owing to the dimensions of the tank.

11. Actual Field Tests.

Actual field tests were conducted many times in the Hirose River at Sendaishi from a small sounding boat and from a motor boat at Port Shiogama. The views are given in Figs. 14, 15 and 16.

The results of these field tests were in complete agreement with the above-mentioned laboratory tests.

12. Conclusions.

By making use of the new Ultrasonic Sounding Principle (Quasi "Modulated Frequency" Principle) instead of the "Impulse Principle" the following results have been obtained in very shoal water in the laboratory tank, in the river, and at sea:–

1. An absolutely continuous depth indication is obtained with steady readings of the pointer on the dial — depth variations of even a few milliseconds are clearly detected.
2. Very small depths down to 15 cm. of water beneath the projector are readily indicated.
3. The indication is in exact linear proportion to the depth.
4. The absolute error is zero, and the relative error is less than 1 %.
5. The power consumption is only 12 watts, and the machine can measure depths of over 50 metres.

The above results show that this sounding device is most suitable for navigating and may replace the hand lead.

13. Acknowledgments.

This research was carried on at the Tohoku Imperial University (Sendaishi), and was aided by financial grants from the Invention Bounty of the Commercial and Industrial Ministry, the Oi Fund of the I. E. E. of Japan and the Saito Gratitude Foundation. Dr. Honda, the President of the Tohoku Imperial University and Dr. Mitsuda, Chief of the Electrical Research Laboratory of the Communications Ministry, furnished valuable suggestions.

I am glad to have this opportunity to express my appreciation of their generous support and assistance.