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Magnetostriction Generator as Acoustic Wave Generator for Underwater Applications

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***Abstract* – At this time the research related to the effect of magnetostriction for underwater applications is still limited. Acoustic or sound waves are more easily propagated underwater than electromagnetic waves or light. An acoustic wave or sound can be generated by utilizing the magnetostriction effect, where this effect occurs when a rod of ferromagnetic material such as iron or nickel is magnetized and interacts with another magnetic field, resulting in vibration of the metal rod. This research aims to design and realize a magnetostriction generator as an acoustic wave generator at a frequency of 1 to 10 kHz for underwater applications, consisting of: a tuned LC oscillator circuit, and a ferromagnetic metal rod which is magnetized using a dc voltage. The results of measurements and testing of the magnetostriction generator show: (1) if it is equipped with a membrane, can work to emit an acoustic wave or sound at a frequency of ± 8.62 kHz in the air up to a distance of 15 cm without distortion with an average amplitude decrease of ± 0.648 dB for each the distance increased by 1 cm, and (2) if equipped with a membrane and enclosed in a waterproof casing, capable of transmitting the acoustic waves at a frequency of ± 8.31 kHz underwater up to a distance of 7 cm without distortion with an average amplitude decrease of ± 4.217 dB for each the distance up 1 cm. Overall the magnetostriction generator designed can work to generate and transmit the acoustic waves or sound underwater, as expected.**

Keywords: Acoustic waves, magnetostriction effect, magnetostriction generator, underwater.

I. INTRODUCTION

Naturally, electromagnetic wave are difficult to propagate in the water, so they are not suitable for underwater applications, such as: measurement, communication, and others. To overcome this, acoustic waves are used which because of their nature can propagate farther in the water [1]. Acoustic waves can be generated by a transducer, by converting an electrical signals into acoustic waves that can be emitted [2]. There are two methods of generating acoustic waves, namely using: magnetostriction and piezoelectric.

The working principle of the magnetostriction method is when a bar of ferromagnetic material such as iron or nickel is magnetized. Longitudinally the rod undergoes a very small change in length called the magnetostriction effect [3].

This magnetostriction effect will generate acoustic waves. One application of the magnetostriction effect is the sonar transducer, where the sonar transducer must have a large mechanical power at a small frequency [4].

Researches related to the generation of acoustic waves using magnetostriction, such as: modeling the strain generated by transducer using magnetostriction, the measured strain is influenced by the type of material [5], classification and utilization magnetostrictive materials in adaptive structures [6], and the process of magnetization and hysteresis loss for steel and identify the magnetization mechanism that occurs when a magnetic field is applied in a direction that is not aligned with the winding direction [7].

Meanwhile, researches related to magnetostriction applications, such as: the use of magnetostriction effects in the field of civil structures [8], nickel as a magnetostrictive material for ultrasonic conditions [9], development of a magnetostrictive transducers for detection of blockages in the salt pipe fluids [10], magnetostrictive sensors for generating and receiving longitudinal mode guided waves on a steel wire [11], and magnetostrictive materials that can convert magnetic energy into mechanical energy or vice versa which are used in the actuators, transducers, sensors, and energy harvesters [12]. Previous researches on the generation of acoustic waves based on the magnetostriction, generally for applications in the air.

Due to the importance of developing magnetostrictive applications to generate acoustic or sound waves, as discussed in: basic principles of magnetostriction and development of novel magnetostrictive materials [13], magnetostrictive sensor technology in various fields [14], and the design of rare-earth giant magnetostrictive ultrasonic transducers and their applications [15], as well as the limited research related to magnetostriction for underwater applications, which is the basis for this research.

The purpose of this research is to produce a magnetostriction generator as an acoustic wave generator at a frequency of 1 to 10 kHz, consisting of: an oscillator formed from a transistor amplifier and a feedback circuit in the form of a tuned *LC* as an ac wave generator, as well as a magnetized ferromagnetic metal rod. This

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magnetostriction generator circuit is expected to work underwater, and can be used for other applications that use acoustic waves. Acoustic waves at a frequency of 1 to 10 kHz were chosen, because at this frequency can be heard by the human ear and are easier to propagate underwater [1].

II. METHODOLOGY

The method used in this research is the design, realization, measurement and testing to produce a "magnetostriction generator" which can generate a sinusoidal acoustic wave at a frequency of 1 to 10 kHz. James Prescott Joule who first discovered the magnetostrictive effect or also called the Joule effect, and defined the concept of magnetostriction in 1842. He studied, measured, and characterized the change in length associated with iron as a result of magnetization. The inverse Joule effect, the permeability of ferromagnetic materials depending on the stress state, was observed by Villari in 1864. Studies on magnetostrictive and magnetostriction materials have been initiated since the discovery of these two effects [8].

The basic block diagram of a magnetostriction generator, as shown in Figure 1. Where: 1 = amplifier, 2 = ferromagnetic metal rod, 3 = dc source, 4 = vibration or acoustic wave, and (L = inductor and C = conductor) of tune circuit.

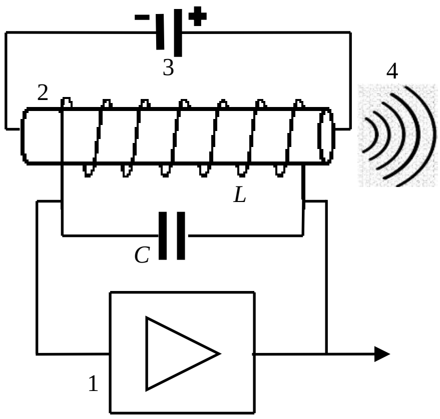
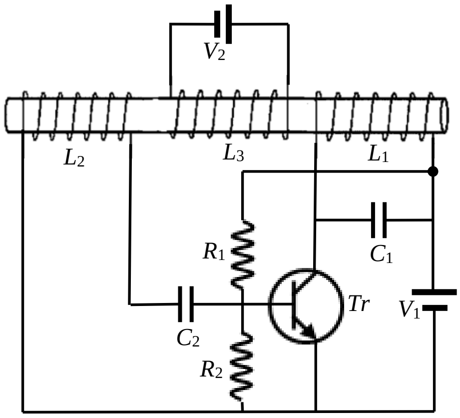


Figure 1. Block diagram of the magnetostriction generator

The magnetostriction generator consists of the following parts: (a). the oscillator as an ac generator composed of a transistor amplifier and feedback is in the form of tuned LC with an inductor L wrapped around a ferromagnetic metal rod, (b) a ferromagnetic metal rod magnetized by a dc voltage source. From the results of the interaction of the two magnetic fields, a magnetostrictive effect occurs in the form of vibrations in the metal rod as acoustic wave or audible sound.

In this research, the circuit used to generate acoustic or sound waves is based on the magnetostriction method as described in [3]. The complete circuit of the designed magnetostriction generator, as shown in Figure 2.

From Figure 2, the magnetostriction generator circuit is a "tuned LC oscillator" consisting of: transistor amplifier Tr, resonance device consists of inductor (L_1 and L_2) and capacitor (C_1 and C_2) where the inductor (L_1 and L_2) is wound on the core in the form of a ferromagnetic metal rods, and a ferromagnetic metal rods which is magnetized by a dc voltage through the inductor L_3.



Tr = TIP3055
R_1 = 10 kΩ, R_2 = 1 kΩ
$V_1 = V_2$ = 12 V_{dc}

Figure 2. The magnetostriction generator circuit as an acoustic wave generator

The resonant frequency f_0 of the tuned LC oscillator can be calculated using Equation 1 [16]:

$$f_0 = \frac{1}{2\pi\sqrt{LC}} \text{ Hz} \quad (1)$$

In realization, the installed capacitor C is (C_1 and C_2), and the inductor L is (L_1 and L_2), and without taking into account the emergence of mutual inductance M between adjacent inductors.

This alternating current at the resonant frequency f_0 produces an alternating magnetic field along the ferromagnetic metal rod, interacting with the magnetic field on the magnetized metal rod by a dc voltage source causing the metal rod to vary in length and vibrate due to the magnetostriction effect. If the metal rod has a length of l (meters), density ρ (kg/m^3), and Young's modulus γ (N/m^2) will produce a vibration frequency f_L according to Equation 2:

$$f_L = \frac{1}{2l}\sqrt{\frac{\gamma}{\rho}} \text{ Hz} \quad (2)$$

Young's modulus and density of some ferromagnetic materials for metal rods are shown in Table 1 [17].

Table 1. Young's Modulus and Density of some Ferromagnetic Materials

Material	Young's modulus (GPa)	Density (g/cm^3)
Copper	110	8.92
Iron	211	7.874
Nickel	170	8.908

In this research, the frequency of vibration f_L that planned is 1 to 10 kHz, so the length of the metal rod l is calculated using the Equation (2). The lengths of some ferromagnetic metals to produce the f_L are shown in Table 2.

Table 2. Length of The Metal Bar *l* for The Frequency of Vibration f_L = 10 kHz

Material	Young's modulus (GPa)	Density (g/cm^3)	Length (cm)
Copper	110	8.92	17.53870759
Iron	211	7.874	25.88951209
Nickel	170	8.908	21.85241611

From Table 2, iron metal with the rod length l = 25.88951209 ≈ 26 cm is sufficient to accommodate the inductor winding, so the iron metal is chosen.

The magnetostriction generator can generate an acoustic wave vibrations or sound maximally, if the frequency of vibration f_L of the ferromagnetic metal rod is matched with the resonant frequency f_o of the tuned *LC* oscillator circuit, or: the $f_L = f_o$. So according to Equations (1) and (2), on the tuned *LC* oscillator by installing an inductor *L* whose the value is fixed = 8.16 mH, to produce a resonant frequency f_o = 10 kHz, the minimum value of capacitor *C* is = 26 nF.

The realization of a complete magnetostriction generator circuit as an acoustic wave generator at a frequency of 1 to 10 kHz, as shown in Figure 3. the magnetostriction

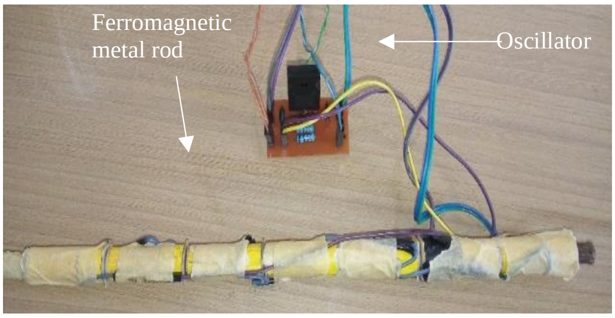


Figure 3. The realization of the magnetostriction generator circuit

generator circuit as an acoustic wave generator at a frequency of 1 to 10 kHz, consists of: tuned *LC* oscillator and ferromagnetic metal rods.

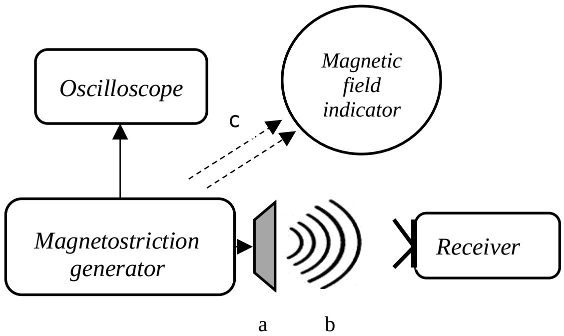
To be able to be used in applications of communications in the air or underwater, it is necessary to install a membrane (from the former loudspeaker cone with diameter of < 10 cm) attached to the ferromagnetic metal rod to convert the vibration energy of the metal rod into acoustic or sound waves, so that the sound which can sound louder. As for underwater applications, the circuit is completely wrapped in a waterproof non-metallic case to prevent short circuits and the membrane is coated with latex material so that it can transmit the vibrations into the water.

III. Results and Discussion

From the results of the design of the magnetostriction generator as an acoustic wave generator at a frequency of 1 to 10 kHz, carried out: measuring each part of the magnetostriction generator circuit, and testing the magnetostriction generator to generate acoustic waves in the air and underwater. This test does not involve and take into account the presence of noise or interference from other signals. Measurements and tests were carried out in the telecommunications laboratory of the Institut Teknologi Nasional Bandung.

A. Measurement of Magnetostriction Generator as Acoustic Wave Generator at Frequency 1 to 10 kHz

The block diagram for measuring the magnetostriction generator as an acoustic wave generator at a frequency of 1 to 10 kHz, as shown in Figure 4.



a = membrane, b = acoustic wave,
c = magnetic fields

Figure 4. Block diagram of measuring magnetostriction generator as acoustic wave generator at a frequency of 1 to 10 kHz

From Figure 4, carried out: (1) measuring the electric signal output of the tuned *LC* oscillator from the magnetostriction generator using a digital multimeter SANWA CD800a and an oscilloscope GW INSTEK GDS-1102A-U, (2) measuring the magnetic field strength of ferromagnetic metal rod magnetization using a magnetic field indicator TEST product by Wayne Kerr & Associates Inc., and (3) measuring the acoustic waves due to vibration of the ferromagnetic metal rods using the receiver of research [18]. The tuned *LC* oscillator and the ferromagnetic metal rod are each supplied by 12 V_{dc} from a separate source.

1. Tuned LC Oscillator

The oscillator on the magnetostriction generator consists of: transistor amplifier of TIP 3055 and tuned *LC*. Tuned *LC* consists of a capacitors (C_1 and C_2) and an inductors (L_1 and L_2) wrapped around a ferromagnetic metal rod. The measurement realization of the tuned *LC* oscillator, as shown in Figure 5. The output signal of the oscillator on the collector of the transistor, and the resulting acoustic or sound waves, are shown in Table 3.

From Table 3, the output of the tuned *LC* oscillator on the magnetostriction generator is shown. The best signal form is a sinusoidal wave with amplitude = 1.62 V_{pp} and frequency = 42.85 kHz obtained when a capacitor (C_1 = 4 nF and C_2 = 1 nF) is installed, as shown in Figure 6a. However, this signal wave has a frequency far above the planned one, which is between 1 to 10 kHz, and no acoustic waves or sound are heard. The acoustic waves or sound produced is loud when the amplitude of the signal wave = 15.6 V_{pp} and the frequency = 10.04 kHz, obtained when a capacitor (C_1 =10 nF and C_2 =10 nF) is installed, as shown in Figure 6b. The signal wave with the largest amplitude = 15.6 V_{pp} indicates that there has been a resonance in the tuned *LC* oscillator, and the resonant frequency of 10.04 kHz is as planned.

In furthermore measurements and tests, inductors (L_1

Table 3. Output Signal of The Tuned *LC* Oscillator and The Generated Acoustic Wave or Sound for The L_1 = L_2 = 8.16 mH

Capacitor		Signal wave		Acoustic wave or sound	Capacitor		Signal wave		Acoustic wave or sound
C_1 (nF)	C_2 (nF)	Frequency (kHz)	Amplitude (V_{pp})		C_1 (nF)	C_2 (nF)	Frequency (kHz)	Amplitude (V_{pp})	
1	1	-	-	x	**11**	1	-	0.24	x
	5	23.64	10.10	x		5	16.13	4.96	x
	10	16.72	10.60	x		10	13.84	5.44	x
	15	14.05	11.00	T		15	13.33	5.44	T
	20	12.29	11.60	T		20	11.99	5.92	T
2	1	33.33	5.40	x	**12**	1	-	0.16	x
	5	21.28	8.80	x		5	16.02	4.88	x
	10	17.36	9.39	x		10	13.44	5.36	T
	15	13.77	9.39	T		15	13	5.28	T
	20	12.05	9.80	T		20	12.44	5.44	T
3	1	41.32	3.07	x	**13**	1	-	0.16	x
	5	23.45	6.63	x		5	15.8	4.71	x
	10	17.53	8.19	x		10	13.16	5.28	T
	15	13.72	8.19	T		15	12.77	5.19	T
	20	12.05	8.39	T		20	12.23	5.36	T
4	1	42.85	1.62	x	**14**	1	-	0.24	x
	5	22.28	6.15	x		5	15.53	4.63	x
	10	16.78	7.59	x		10	12.94	5.19	T
	15	15.18	7.84	x		15	12.35	5.11	T
	20	11.98	7.67	T		20	11.57	5.44	T
5	1	-	0.16	x	**15**	1	-	0.16	x
	5	18.52	6.32	x		5	15.29	4.55	x
	10	15.83	7.03	x		10	12.69	4.96	T
	15	14.67	7.28	x		15	12.2	5.03	T
	20	13.32	7.51	T		20	11.57	5.11	T
6	1	-	0.005	x	**16**	1	-	0.16	x
	5	18.04	6.23	x		5	15.1	4.48	x
	10	15.46	6.8	x		10	12.17	4.96	T
	15	14.53	7.03	x		15	12.2	4.88	T
	20	13.12	7.44	T		20	11.23	5.19	T
7	1	-	0.16	x	**17**	1	-	0.16	x
	5	18.11	5.76	x		5	14.87	4.32	x
	10	15.56	6.23	x		10	12.38	4.71	T
	15	14.88	6.15	x		15	11.67	4.8	T
	20	13.70	6.63	T		20	11.21	4.88	T
8	1	-	0.16	x	**18**	1	-	0.16	x
	5	17.46	5.44	x		5	14.45	4.23	x
	10	14.85	6	x		10	12	4.71	T
	15	26.3	4	x		15	11.4	4.63	T
	20	13.31	6.55	T		20	10.96	4.71	T
9	1	-	0.16	x	**19**	1	-	0.08	x
	5	17.17	5.28	x		5	14.79	4.15	x
	10	14.62	5.67	x		10	12.11	4.63	T
	15	14.08	5.76	x		15	11.44	4.63	T
	20	12.89	6.15	T		20	11.19	4.63	T
10	1	-	0.16	x	**20**	1	-	0.08	x
	5	16.86	5.19	x		5	14.66	4.15	x
	10	10.04	15.6	T_K		10	11.99	4.55	T
	15	14.22	5.44	x		15	11.19	4.63	T
	20	12.11	6	T		20	10.85	4.63	T

Note: x = sound not heard, T = sound is heard, T_K = sound is loud and L_2) and L_3 = 57.12 mH were installed, and the capacitor C_2 was varied. The purpose of this inductor and capacitor installation is to obtain an output signal of the tuned *LC* oscillator at the resonant frequency f_0 that is matched with the vibration frequency of the ferromagnetic metal rod f_L, and to produce a magnetic field strength so that the acoustic wave or sound output from the magnetostriction generator is larger. The signal wave, and the acoustic wave or sound output of the magnetostriction generator with inductor $L_1 = L_2 = 57.12$ mH, are as shown in Table 4.

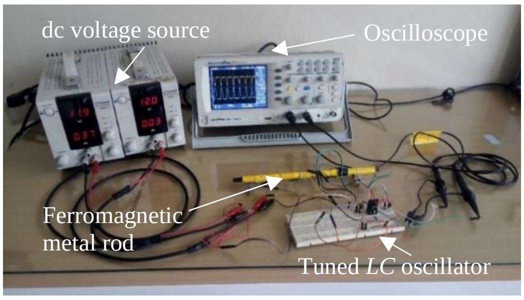
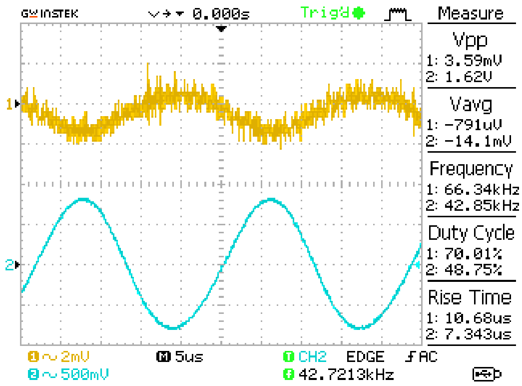
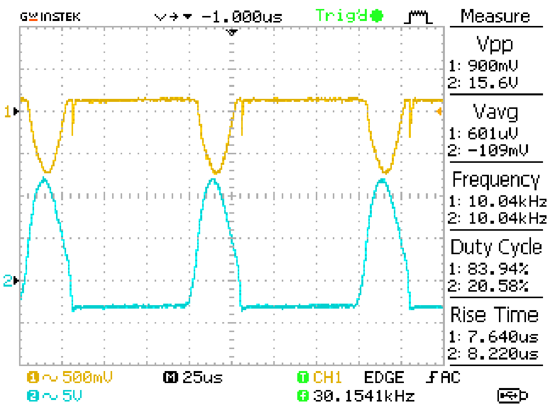


Figure 5. Realization of the measurement of tuned *LC* oscillator



(a)



(b)

Figure 6. Output signal waveform of the tuned *LC* oscillator when capacitor is installed: (a) C_1 = 4 nF, C_2 = 1 nF and (b) C_1 = 10 nF, C_2 = 10 nF

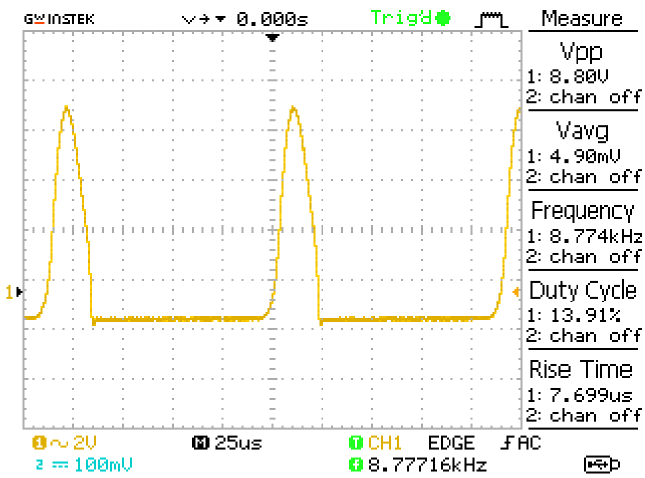
From Table 4, the output of the magnetostriction generator circuit produces a signal with an amplitude between 4.40 to 8.80 V_{pp}, and a frequency between 8.2368 to 21.8392 kHz.

Table 4. Output Signal of the Magnetostriction Generator for $L_1 = L_2 = 57.12$ mH and C_2 is Varied

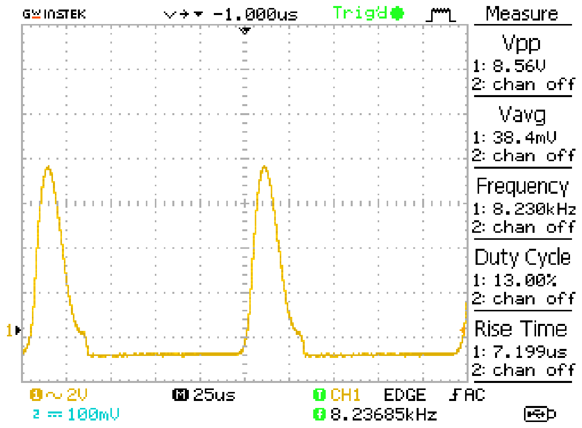
Magnetostriction generator output			
C_2 (nF)	Signal wave		Acoustic wave or sound
	Amplitude (Vpp)	Frequency (kHz)	
1	4.40	21.8392	x
2	8.39	10.3966	T_L
3	8.64	9.1924	T
4	8.80	8.7771	T
5	5.28	15.6723	x
6	5.48	14.9993	T_L
7	5.63	14.3321	T_L
8	5.96	13.6586	T
9	6.11	13.0854	T
10	8.56	8.2368	T_K
11	5.23	14.6174	T_L
12	6.44	12.9505	T
13	4.80	16.4100	x
14	4.88	15.7686	x
15	4.84	15.7062	x
16	4.96	15.2642	x
17	5.00	14.9497	T_L
18	5.00	14.9616	T_L
19	5.15	14.9405	x
20	5.19	14.4826	T_L

Note: x = sound not heard, T = sound is heard, T_K = sound is loud

The signal wave with the largest amplitude = 8.80 V_{pp} and frequency = 8.7771 kHz is obtained when a capacitor C_2 = 4 nF is installed, as shown in Figure 7a. While the signal wave with amplitude = 8.56 V_{pp} and frequency = 8.2368 kHz, produces an acoustic waves or sound that loudest sounding, obtained when capacitor C_2 = 10 nF is installed, as shown in Figure 7b. So that it can be said that there is a match between the frequency f_0 of the tuned *LC* oscillator and the frequency f_L of vibration of the ferromagnetic metal rod at a frequency of 8.2368 kHz which is in the 1 to 10 kHz range. When recalculated using Equation (1) with C_2 = 10 nF and L_2 = 57.12 mH, and without taking into account the mutual inductance *M* that occurs between the inductors, we get f_0 = 6.666 kHz. This result is close to the measurement results.



(a)



(b)

Figure 7. The output signal waveform for: (a) C_1 = 10 nF, C_2 = 4 nF and (b) C_1 = 10 nF, C_2 = 10 nF

2. Ferromagnetic Metal Rod

The inductors L_1 and L_2 are powered by ac which is wrapped around the ferromagnetic metal rod to create a magnetic field, and on the metal rod through the winding of the inductor L_3 a voltage of 12 V_{dc} is applied for magnetization so that a magnetic field also arises. Due to the interaction of the two magnetic fields, there will be a magnetostriction effect in the form of vibrations in the metal rod as an audible acoustic wave or sound. Measurement of the magnetic field strength that occurs around ferromagnetic metal rods uses a magnetic field indicator, as shown in Figure 8, while the magnetic field strength for various inductors *L*, as shown in Table 5.

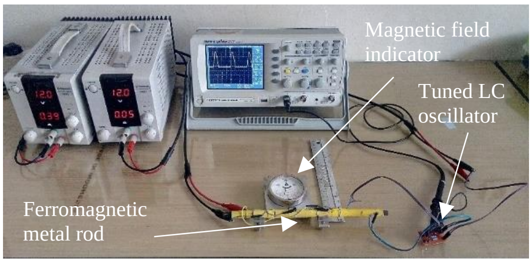


Figure 8. Measurement of the magnetic field strength around a ferromagnetic metal rod

Table 5. Magnetic Field Strength Around the Ferromagnetic Metal Bars in the Magnetostriction Generators

Inductor L_1, L_2 (mH)	Distance (cm)	Magnetic field strength (gauss)	Acoustic wave or sound
57.12	< 1	3	T_K
	1	2	T
	2	1.5	T
	3	1.2	T
	4	1	T
	5	0.5	T
	6	< 0.2	T_L
123.3	< 1	0.5	x
	1	0.2	x
	2	< 0.2	x
	3	< 0.2	x
	4	< 0.2	x

Note: x = sound not heard, T_L = sound weak, T = sound is heard, T_K = sound is loud
1 gauss = 1×10^{-4} T (100 μT); 1 T = 1 Wb/m^2

From Table 5, the magnetic field strength around the ferromagnetic metal rod at a distance of < 1 cm (the magnetic field indicator almost touches the metal rod) to 6 cm, the farther away from the metal rod, the magnetic field strength seems to decrease. When the inductor *L* = 57.12 mH is installed, it reads a magnetic field strength of 3 to 0.5 gauss and an acoustic wave or sound can be heard due to the magnetostriction effect. Meanwhile, if an inductor *L* = 123.3 mH is installed, it reads a magnetic field strength of 0.5 to 0.2 gauss and no acoustic wave or sound can be heard. So, it can be said that the magnetic field strength of a ferromagnetic metal rod affects the loudness or weakness of the acoustic wave or sound produced by the magnetostriction generator, so that the greater the magnetic field strength, the louder the acoustic wave or sound heard.

B. Testing the Magnetostriction Generator as an Acoustic Wave Generator at a Frequency of 1 to 10 kHz

The purpose of the test is to determine the propagation ability of acoustic waves or sound produced by the magnetostriction generator in the air and under water. In the implementation of the test, on the transmitting side (*Tx*) is a magnetostriction generator as a generator of acoustic waves at a frequency of 1 to 10 kHz which is equipped with a membrane as a mediator of acoustic waves into the air. While on the receiving side (*Rx*), an acoustic wave receiver is used from the result of research [18]. We tested the magnetostriction generator as a generator of acoustic waves in the air shown ini Figure 9.

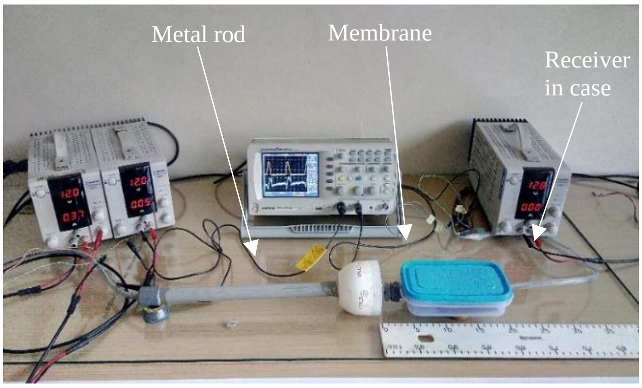


Figure 9. Testing the magnetostriction generator as a generator of acoustic waves in the air

From Figure 9, the test carried out in the air as the transmission medium, the location of the membrane at the transmitter (*Tx*) and the transducer at the receiver (*Rx*) are in a straight line facing each other, shifted farther apart every 1 cm. The output signal wave sent from the magnetostriction generator has an amplitude of ± 15 V_{pp} at a frequency of ± 8.5 kHz. The results of the magnetostriction generator test in the air are in the form of signal waves at the *Rx* output, as shown in Table 6.

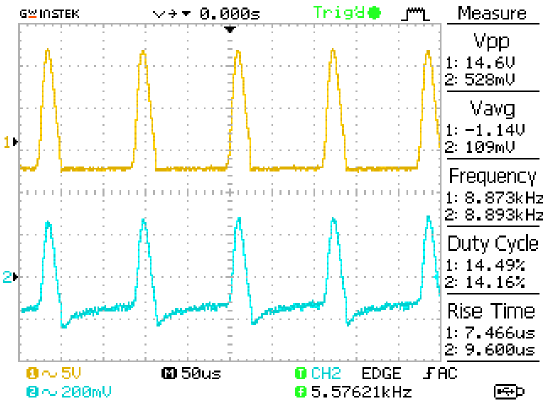
Table 6. Signal Waves at the *Rx* Output for The Testing in the Air

Signal wave of the *Rx* output		
***Tx*-*Rx* distance (cm)**	**Amplitude (mV_{PP})**	**Frequency (kHz)**
< 1	528	8.893
1	68	8.803
2	66	8.863
3	61	8.818
4	58	8.916
5	56	8.661
6	52	8.646
7	50	8.295
8	47	7.951
9	45	9.017
10	40	8.669
11	35	7.068
12	32	7.2847
13	30	7.755
14	28	5.10394
15	25	7.807

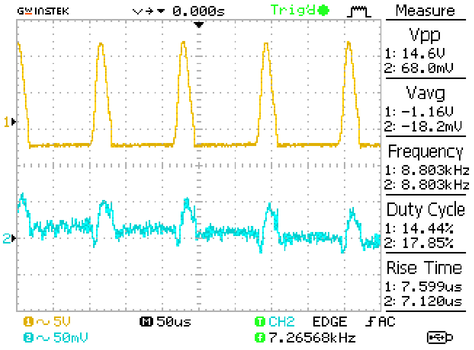
Note: the test is carried out until the distance of *Tx* – *Rx* = 15 cm

From Table 6, with an average amplitude of ± 14.97 V_{pp} and a frequency of ± 8.62 kHz the signal wave is transmit, at the *Rx* output a signal wave is obtained: at the closest *Tx* – *Rx* distance (< 1 cm) the received signal wave has an amplitude = 528 mVpp and a frequency = 8.893 kHz, at a distance of 1 cm has an amplitude = 68 mV_{pp} and a frequency = 8.803 kHz, at a distance of 5 cm it has an amplitude of 56 mV_{pp} and a frequency of 8.661 kHz, and so the amplitude decreases. The signal waves transmitted at *Tx* and the output of *Rx* at a distance of <1 cm, 1 cm, and 5 cm, as shown in Figure 10. It is said that the farther the distance *Tx* – *Rx*, the amplitude of the acoustic wave or sound in the air decreases, with an average rate of decreasing of ± 1.0775 or 0.648 dB every 1 cm increase in the distance starting from 1 cm.

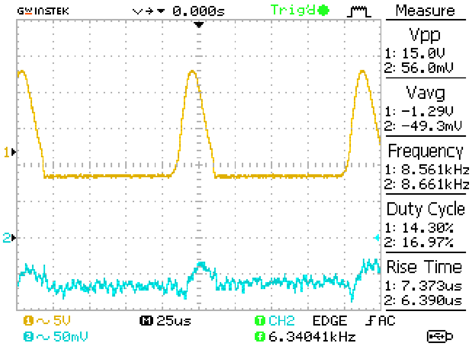
From the results of testing, it can be said that the magnetostriction generator as an acoustic wave generator at a frequency of 1 to 10 kHz that designed, can work and propagate the acoustic waves or sounds that are heard at a frequency of ± 8.62 kHz in the air.



(a)



(b)



(c)

Figure 10. The signal wave transmitted at *Tx* and the output at *Rx* for a distances: (a) <1 cm, (b) 1 cm, and (c) 5 cm

Testing the magnetostriction generator as an acoustic wave generator underwater, as shown in Figure 11.

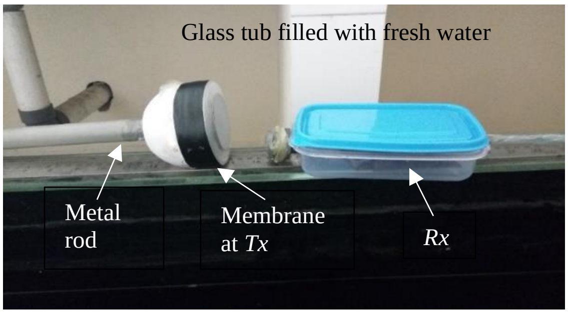


Figure 11. Testing the magnetostriction generator as an acoustic wave generator underwater

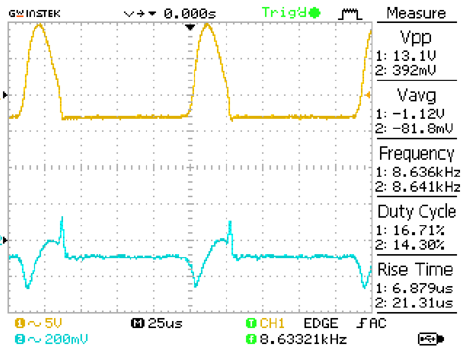
From Figure 11, the testing underwater was carried out in a glass tub of 2 m that filled with fresh water as the transmission medium, at a depth of about 20 cm. Where the magnetostriction generator as *Tx* and *Rx* of acoustic waves are each inserted into a casing, the position of the membrane at *Tx* and the transducer at *Rx* are in a straight line facing each other, shifted farther apart every 1 cm. The output signal wave transmitted from the magnetostriction generator has an amplitude of ± 13.5 V_{pp} at a frequency of ± 8.5 kHz. The results of testing the magnetostriction generator underwater are in the form of signal waves at the *Rx* output, as shown in Table 7.

Table 7. Signal Wave at the *Rx* Output for Testing Undewater

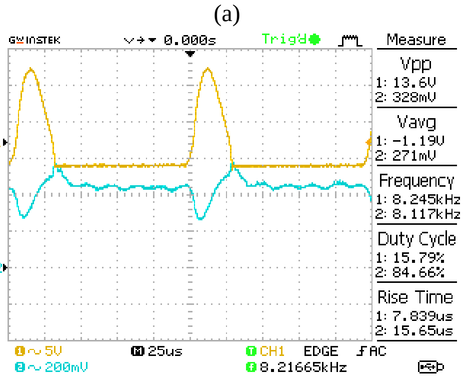
***Tx-Rx* distance (cm)**	**Signal wave of the Rx output**	
	Amplitude (mV_{PP})	**Frequency (kHz)**
< 1	392	8.641
1	328	8.117
2	280	8.278
3	250	8.278
4	200	9.208
5	184	8.587
6	92	8.146
7	32	8.361

Note: the test is carried out until the distance of *Tx* – *Rx* = 7 cm

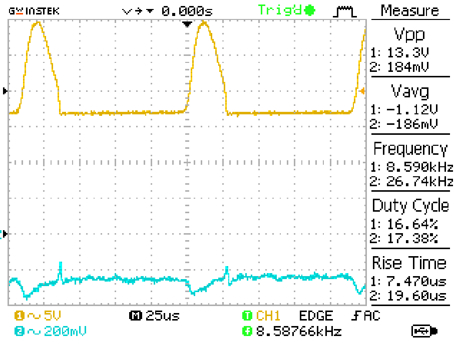
From Table 7, with an average amplitude of ± 13.55 V_{pp} and a frequency of ± 8.31 kHz the signal wave is transmit, at the *Rx* output a signal wave is obtained: at the closest *Tx* – *Rx* distance (< 1 cm) the received signal wave has an amplitude = 392 mV_{pp} and a frequency = 8.641 kHz, at a distance of 1 cm it has an amplitude = 328 mV_{pp} and a frequency = 8.117 kHz, at a distance of 5 cm it has an amplitude of 184 mV_{pp} and a frequency of 8.587 kHz, and so the amplitude decreases. The signal waves transmitted at *Tx* and the output of *Rx* at a distance of <1 cm, 1 cm, 5 cm, and 7 cm, as shown in Figure 12. It is said that farther the distance *Tx* – *Rx*, the amplitude of the acoustic wave or sound in the air decreases, with the average rate of decreasing of ± 1.625 or 4.217 dB for every 1 cm increase in the distance starting from 1 cm. At a distance of 7 cm there was a significant decrease in the amplitude of the signal wave, where the amplitude drops to 32 mV_{PP} while the frequency is around 8.361 kHz, as shown in Figure 12d.



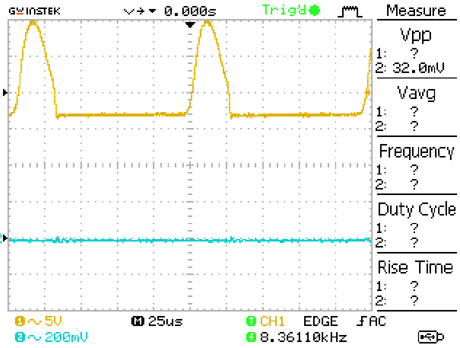
(a)



(b)



(c)



(d)

Figure 12. The signal wave transmitted at *Tx* and the output at *Rx* for a distances: (a) <1 cm, (b) 1 cm, (c) 5 cm, and (d) 7 cm

From the results of testing, it can be said that the magnetostriction generator as an acoustic wave generator at a frequency of 1 to 10 kHz that designed, can work and propagate the acoustic wave or sound at a frequency of ± 8.31 kHz under water.

C. Discussion

The overall results of the design and realization, measurement and testing are in accordance with what was planned, namely the "magnetostriction generator" which functions to generate an acoustic waves at a frequency of 1 to 10 kHz. This is in accordance with researches of the acoustic wave generation by [2], [19]-[22], and the magnetostriction effects by [3]-[6].

This research has produced a generator as an acoustic wave generator based on the magnetostriction effect without being equipped with a transmit transducer, there is an novelty compared to the results of previous researches which are based on an electronic oscillator and must be equipped with an acoustic transducer [2], [18], [22].

The resulting "magnetostriction generator" circuit is relatively simple with the dimensions of *l* less than 30 cm in length, and can use a 12 V battery as a power source. The tuned *LC* oscillator with one transistor amplifier, is able to generate the signal waves at the resonant frequency of ± 8.2368 kHz which is in the range frequency 1 to 10 kHz as planned. This is in accordance with the working principle of the tuned *LC* oscillator [16].

The ferromagnetic metal rod made of iron with a length of 26 cm which is magnetized by a voltage of 12 V_{dc} produces the magnetic field strength of 3 gauss at a distance of 1 cm, can vibrate due to the magnetostriction effect so as to produce an acoustic waves or sound that are loud enough to be heard by the ear and can still be detected at a distance 15 cm through the receiver [18]. This is in accordance with the research of magnetization by [7], [12].

In the test: (1) the acoustic waves or sound at a frequency of ± 8.2368 kHz generated by the magnetostriction generator through a medium of membrane (note: the membrane used with a diameter of < 10 cm, from the former loudspeaker cone) can propagate in the air, the sound is quite loud , and the wave amplitude only experienced attenuation or decreased by ± 0.648 dB for every 1 cm increase in distance compared to the results of the study [23] which was 6 dB for every two times the distance increased. (2) the acoustic waves or sound at the frequency of ± 8.62 kHz; as expected, its characteristics are suitable for propagation in the air and can be detected by the receiver [18] up to 15 cm away without distortion. (3) on testing underwater, the magnetostriction generator as a generator of acoustic waves or sound at the frequency of ± 8.31 kHz which is equipped with the membrane and placed in the waterproof casing, can work as expected. The transmitted acoustic waves can propagate underwater, and only experience attenuation or decrease of ± 4.217 dB for every 1 cm increase in distance. Compared to when propagation in the air, there is a difference in the attenuation of (4.217 – 0.648) or 3.569 dB.

A summary of the results of research obtained, as shown in Table 8. So, the results of this research can prove/show that the magnetostriction generator can work underwater to generate the acoustic waves or sound at a frequency of ± 8.31 kHz which is in the frequency range of 1 to 10 kHz.

Table 8. The Summary of the Results of Research Obtained

Spesifications	Planned	Obtained
Type of generator	magnetostriction generator	magnetostriction generator
Type of the output wave	acoustic	acoustic (sound is heard)
Shape of the output wave	sinusoid	sinusoid
Frequency of the output wave	1 to 10 kHz	± 8.2368 kHz (at the air), ± 8.31 kHz (underwater)
Wave attenuation each distance increases 1 cm.	-	± 0.648 dB (at the air), ± 4.217 dB (underwater)
Acoustic transducer	none	membrane (to amplify sound)
Work at	in the air and underwater	in the air and underwater

IV. Conclusion

From this research; the magnetostriction generator has been produced as a generator of acoustic waves or sound at a frequency of ± 8.2368 kHz which functions as a generator of acoustic waves or sound. The magnetostriction generator can work to transmit the acoustic waves or sound at the frequency of ± 8.62 kHz in the air up to a distance of 15 cm without distortion, with an attenuation of ± 0.648 dB for every 1 cm increase in distance. The magnetostriction generator which is enclosed in a waterproof casing can work to transmit acoustic waves at a frequency of ± 8.31 kHz underwater up to a distance of 7 cm without distortion, with an attenuation of ± 4.217 dB for every 1 cm increase in distance. The results of this research are novelty compared to the results of the previous acoustic generator researches based on electronic oscillators and must be equipped with an acoustic transducers, and furthermore these results can be used for research related to magnetostriction generators for underwater applications.

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