

Development of a Ferrite-Based Electromagnetic Wave Detector

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ABSTRACT

Direct detection of hydrocarbon by an active source using electromagnetic (EM) wave termed Sea Bed Logging (SBL) has shown very promising results. However, currently available electromagnetic wave technology has a number of challenges including sensitivity and lapsed time. Our initial response to this issue is to develop a ferrite-based EM wave detector for Sea Bed Logging (SBL). Ferrite bar and copper rings in various diameters were used as detector 1 (D1). For Detector 2 (D2), toroid added with copper wires in different lengths at the centre of it were used. The first experiment is to determine the inductance and resistance for both detectors by using LCR meter. We obtained the highest inductance value of 0.02530 mH at the ferrite bar when it was paired with a 15 cm diameter copper ring and 0.00526 mH for D2 using a 100 cm copper wire placed at the centre of the toroid. The highest resistivity for D1 was measured at ferrite bar paired with a 15 cm diameter copper ring and 1.099 Ω when using 20 cm length of copper wire. The second interest deals with voltage peak-to-peak (Vp-p) value for both detectors by using oscilloscope. The highest voltage value at the ferrite bar of D1 was 25.30 mV. While at D2, the highest voltage measured was 27.70 mV when using a 100 cm copper wire. The third premise is the comparison of sensitivity and lapsed time for both detectors. It was found that D1 was 61% more sensitive than D2 but had higher lapsed time than D2..

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Keywords: Sea Bed Logging, Detector, Sensitivity, Lapsed time

I. Introduction

In SBL, a mobile horizontal electric dipole (HED) source and an array of seafloor electric field receivers are utilised. The transmitting dipole emits a low frequency electromagnetic signal that propagates into the seabed [1]. The array of sea floor receivers measures both the amplitude and the phase of the received signal directly from the transmitter, and waves reflected and guided from the seabed. The received signal depends on the resistivity structure beneath the seabed [2]. Characterisation and detection of the reservoir using SBL are based on the electrical conductivity consisting in all geological media. The principle of conductivity difference in geological media is applied in this technology [3]. Besides its advantage in segregating a resistivity in a non-conductive layer and conductive formation beneath the sea floor, the electromagnetic method has a robustness characteristic against bad operating conditions such as high temperature and high pressure [4].

Many types of electromagnetic detectors have been developed for use in this type of hydrocarbon detection method. However, currently available detectors have a number of challenges and one of them is the reading instability that can result in a misinterpretation. This could lead to the loss of significant investments.

This paper describes the initial work to develop an EM detector with high sensitivity and short recovery time for SBL. The first part of this work is to compare the sensitivity for both detectors. Sensitivity of detectors is an important aspect for SBL method. In the previous work, electromagnetic detector was used to geophysically detect layer boundaries [5]. This work has been done because difficulties exist in magneto telluric and geomagnetic depth sounding method; these methods are geophysical methods sensitive to mantle melt. The selection of detectors plays a major role to gain good detection results. Since sensitivity was taken into account, another aspect that needs to be considered is lapsed time or recovery time.



The second premise dealt in this work is the determination of recovery time. In detail, EM detector for SBL needs a higher sensitivity with a shorter lapsed time that can prevent any error in SBL's further data processing. EM detection system used to detect buried metallic in the soil [6] found errors in the data caused by uncertainties in sensor height. As a result, a fluctuation in data occurred.] These two parameters are important for sensitive EM detectors because with the decreasing of recovery times, the efficiency of the detector will increase. Output of the EM wave detected was not affected by a pile-up caused by incoming EM wave. Now we can look thoroughly to the magnetic hysteresis element of the magnetic material used in this work. Hysteresis is a phenomenon in which the magnetic field lags behind the electric field [7]. Details about the hysteresis will be reviewed more comprehensively in the Results and Discussion section.

II. Materials and methods

A 20-turn toroidal transmitter with an aluminium rod placed in the centre of the toroid was used in this work. It was supplied by 5 MHz frequency of square wave from a wave generator (Textronic AX493). The distance between the transmitter and the detector was fixed at one meter, as described in Figure 1 and Figure 2. The properties of the transmitter are summarised in Table 1. Two types of EM detectors were investigated. The responses from the detectors were then determined by measuring the induced voltage with an oscilloscope.

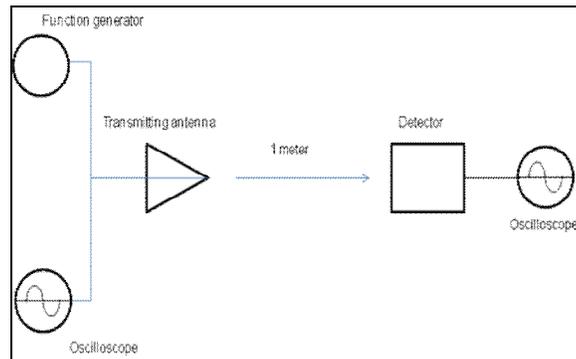


Fig. 1. Block diagram of transmitter-detector system

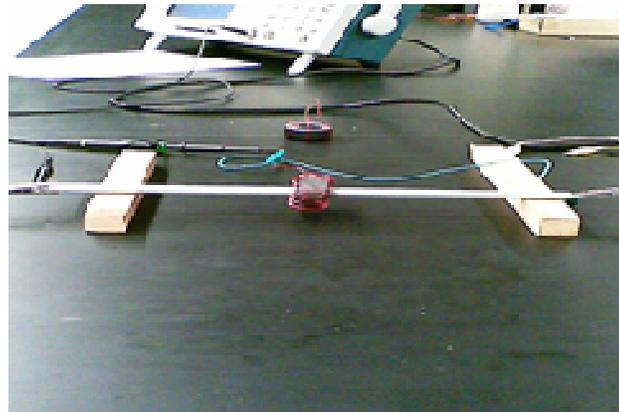


Fig. 2. Block diagram of transmitter-detector system

Table 1. Transmitter properties

Transmitter parameters	Properties
aterial	Toroid with 20 turns and aluminium rod in the centre of the toroid
Frequency	5MHz
Distance from detector	1 meter
Waveform	Square-shaped

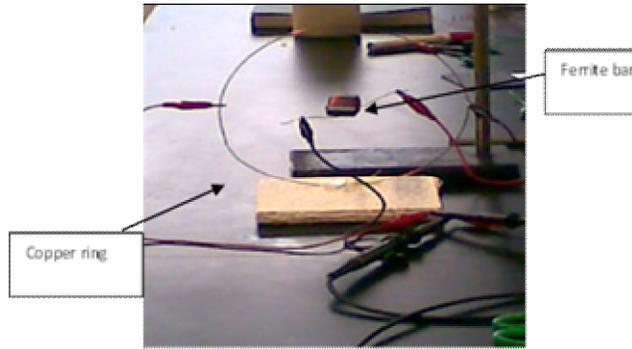


Fig. 3. Detector 1 (D1) set up consisting of a of a ferrite bar and copper wire

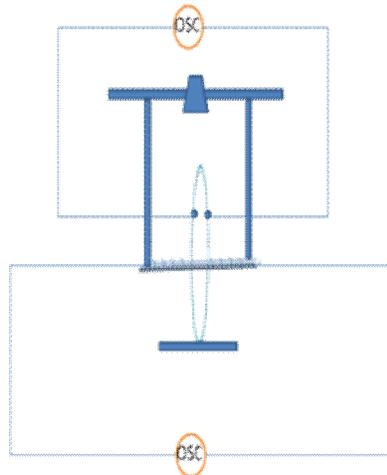


Fig. 4. Schematic diagram of D1

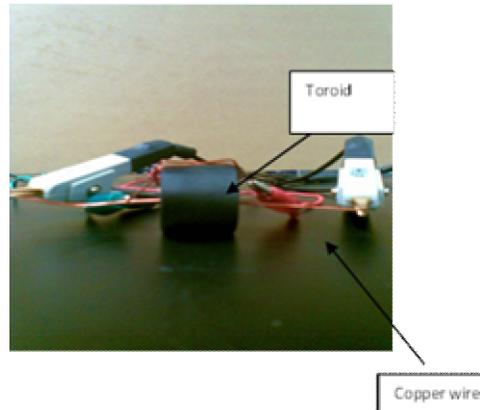


Fig. 5. Detector (D2) set up consisting toroid and copper wire

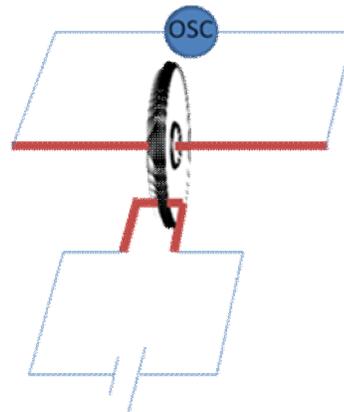


Fig. 6. Schematic diagram of D2

Table 2. Properties of ferrite material manufactured by ACME Ferrite Products Sdn Bhd (Source: www.acme.com.my)

Term	Symbol	Conditions	Value	Unit
Initial Permeability	μ_i	10kHz 25°C	800 ± 25%	
Max. Magnetic Flux density	Bm	50Oe 25°C	3100	Gauss
Residual Magnetic Flux density	Br	25°C	1/00	Gauss 25°C
Coercive Force	Hc		0.65	
Relative Loss factor	$\tan \delta / \mu_i$	25°C	0.15 MHz	10 ⁻³
Electrical Resistivity	ρ	DC 25°C	≥10 ⁸	Ωcm
Temperature Coefficient		20°C.80°C	≤5	10 ⁻⁶ K ⁻¹
Curie Temperature	Tc		>150	°C
Density	ρ		5000	Kg/m ³

Two types of EM wave detectors were selected in the present work. Figure 2 and Figure 3 show the arrangements of the two types of detectors used. In addition, their schematic drawings are presented in Figure 4 and Figure 5.

Table 3. Properties of detector (D1 and D2).

Detector 1 (D1)		Detector 2 (D2)	
Copper wire	Shape	Ring-shaped with variable diameter	Wire
	Thickness	0.8mm with variable diameter	0.8mm with variable length
	Location	Placed vertically around the ferrite bar	Placed at the centre of toroid
Toroid		None	ID
			OD
			Type
			Type D28 with constant electric source applied
Ferrite Bar	Type D28 with 20 wind by copper wire (thickness 0.8mm)		None

Table 3. describes the properties of both detectors. The diameter of copper ring in D1 varies from 7.5mm, 8.0mm, 9.0mm, 11.0mm, 13.0mm, 15.0mm, to 20.0mm.

Measurements of parameters for both detectors have been performed by using oscilloscope and LCR meter (Instex LCR-16). Parameters that we have put into consideration for both detectors were voltage peak to peak (V_{p-p}), inductance (L), resistance, (R) and recovery time (t). Moreover, measurements of V_{p-p} have been carried out by using two oscilloscopes at the ferrite bar and copper ring; single function and both function operations were performed. Table 3 shows the clear method of operating oscilloscope during the measurement of V_{p-p} for D1.

Measurements of inductance (L) and resistivity (R) during detection period have been performed by using LCR meter at each ferrite bar and copper ring.

Detector 2 consisted of a small toroid as a magnetic feeder with a copper wire in the centre of it. A constant magnetisation was supplied by connecting 9V dry-cell battery to the toroid. Copper wires (0.8mm thickness) with different set of length varying from 10cm, 20cm, 30cm, 40cm, 50cm, 60cm, 70cm, 80cm, 90cm to 100 cm were placed in turn at the centre of magnetic feeder. The measurement of V_{p-p} for detector 2 have been taken by using oscilloscope at both ends of copper wire which had been placed at the centre of toroid during receiving an electromagnetic wave from the transmitter. By using the LCR meter, the inductance and resistance value have been determined during the detection period of EM wave.

Lapsed time measurement was performed to determine hysteresis effect by the following methods. When the detectors were exposed to EM wave, the signal detected at the oscilloscope showed a proportional response (due to the properties of the detector). Time taken by a signal detected at oscilloscope at the peak value (when the EM source transmitter was on) was dropped off to the base line when EM wave source (transmitter) is off were measured.

III. Results and discussion.

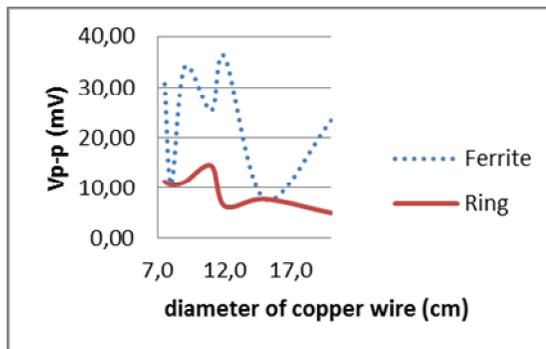
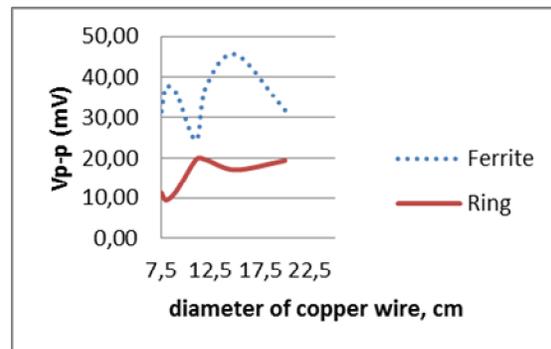
Measurements of sensitivity and lapsed time for the two detectors (D1 and D2) were carried out using a ferrite-core material [11]. Table 4 shows the results of V_{p-p} gained from D1 with the changing of diameter of the copper ring. The experiment conducted with oscilloscopes was divided into two sections, i.e. single function operation and both functions operation. During the single function operation of oscilloscope at the ferrite bar, the highest V_{p-p} value recorded was 45.60mV, which was using a 15.0-cm-diameter copper ring. However, it was drastically decreased when both functions operation of oscilloscopes was operated.

Table 4. V_{p-p} measurement method for D1 using oscilloscope.

	Oscilloscope function	
	Single operation	Both operation
Ferrite Bar	Operated	Operated
Copper ring	Non-operated	Operated
Ferrite Bar	Non-operated	Operated
Copper ring	Operated	Operated

Table 5. V_{p-p} values for D1

Diameter of copper ring (cm)	V_{p-p} (mV) single function operation		V_{p-p} (mV) both function operation	
	Ferrite	Ring	Ferrite	Ring
20.0	31.80	19.40	23.40	5.04
15.0	45.60	17.10	7.79	7.79
12.0	37.60	19.60	36.00	6.41
11.0	24.40	19.60	25.30	14.50
9.0	36.20	11.60	34.00	11.20
8.0	37.80	9.43	10.70	10.70
7.5	31.20	11.30	31.20	11.30

Fig. 7. Graph pattern for V_{p-p} values for ferrite bar and copper ring from D₁ during single operation of oscilloscopeFig. 8. Graph pattern for V_{p-p} values for ferrite bar and copper ring from D₁ during both operations of oscilloscope.Table 6. L, R and V_{p-p} values for D1

Diameter of copper ring (cm)	L (mH) x 10 ⁻²		R (Ω)		V_{p-p} (mV)	
	Ferrite	Ring	Ferrite	Ring	Ferrite	Ring
20.0	2.36	2.08	1.90	5.00	23.40	5.04
15.0	2.53	1.86	8.97	7.24	7.79	7.79
12.0	2.33	1.80	2.61	2.69	36.00	6.41
11.0	2.35	1.66	3.02	3.20	25.30	14.50
9.0	0.19	23.50	1.37	1.80	34.00	11.20
8.0	2.35	1.63	1.91	2.55	10.70	10.70
7.5	2.34	1.75	1.21	2.35	31.20	11.30

In another work done on EM wave logging system for determining resistivity and dielectric constant of earth formations [8], it was proved that the resulting magnetic fields produced by electromagnetic induction from a high frequency alternating current in the earth formations surrounding the well bore were detected at the spaced receiver coil by sensing the induced currents or voltages in the receiver coil caused by the secondary currents flowing in the formations. Another former research found that when the copper ring and ferrite bar were exposed to an EM wave, their existing electric fields were found to be proportional with EM field [7]. The electric fields from ferrite bar and copper ring are supposed to enhance each other and lead to a higher value of V_{p-p} during both function operations than during single function operation of oscilloscope. However, when both function of oscilloscope test was conducted, there was a significant decrease in V_{p-p} at ferrite bar and copper ring to 7.76 mV both. This result (Figure 3 and 4) showed that during detection period, the magnetic field from copper ring and ferrite bar could not enhance each other. Besides, the testing result of wider diameter of copper ring was expected to meet a threshold limit at

a certain diameter of copper ring. The achieved threshold limit led to a conclusion that magnetic field at the ferrite bar is not affected by magnetic field of the copper ring.

Generally, the results of inductance (L), resistivity (R), and Vp-p values for D1 are presented in Table 4. The table shows the results obtained from measurements by using oscilloscope and LCR meter. Figure 7 and Figure 8 show the results of inductance and resistivity values obtained from D1.

As shown in Figure 7 and Figure 8, the average value of the inductance (L) and resistance (R) at the ferrite was higher than the one of L and R at copper rings.

In measurement of electromagnetic and electric field for D2, Figure 5 shows that resistivity was increased when the length of copper wire was increased as well. From the resistivity value, we concluded that an electric field existed. One important difference between electromagnetic poles and electric charges is that electric charges can be isolated, but magnetic poles always exist in pairs [9]. This was proven by inductance values indicating the strength of the magnetic field in D2.

Figure 12 shows the inductance values gained from LCR meter when electromagnetic field was applied. Inductance can be described as a measurement of how much magnetic energy stored in the detector [10]. The use of 100cm copper wire in the centre of toroid generated the highest value of inductance (0.00526 μH), resistivity (0.9001 Ω), and Vp-p (27.70mV)

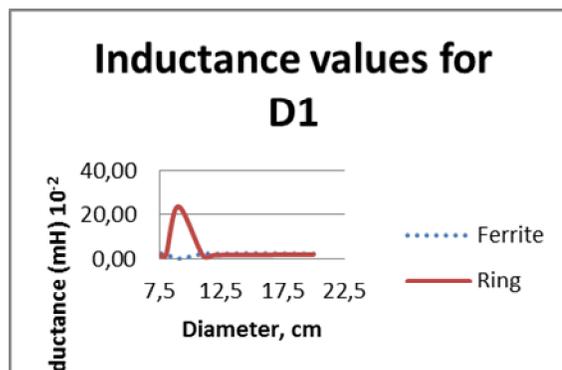


Fig. 9. Graph pattern for inductance values for ferrite bar and copper ring from D1

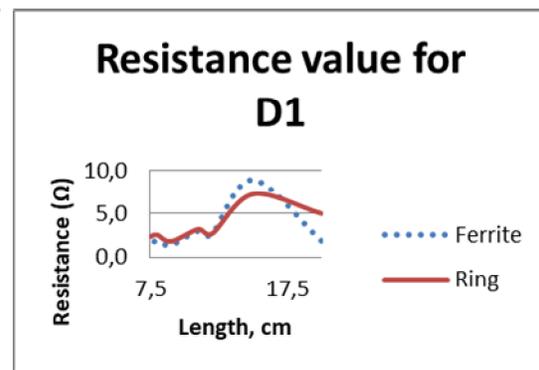


Fig. 10. Graph pattern for resistance values for ferrite bar and copper ring from D₁

Table 7. Inductance, capacitance, resistance and voltage v_{p-p} (V_{p-p}) values of detector 2 (D2).

Length of wire (cm)	Inductance (μH)	Resistance (R)	Voltage (mV)
0	2.53	0.00	0.0
10	3.95	0.00	4.0
20	4.00	1.10	11.2
30	4.11	1.05	17.3
40	4.50	0.88	13.2
50	4.48	0.78	18.3
60	4.80	0.58	22.4
70	4.97	0.67	23.8
80	5.15	0.70	24.6
90	5.18	0.78	25.7
100	5.26	0.90	27.7

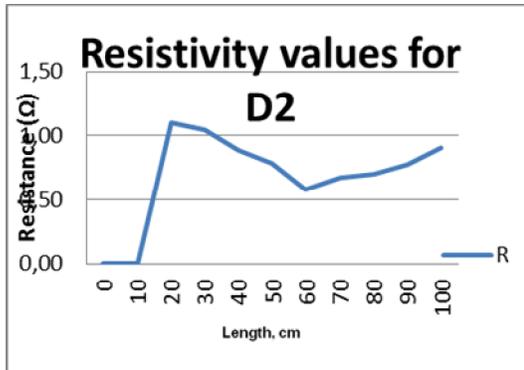


Fig. 11. Graph pattern resistivity values from D2

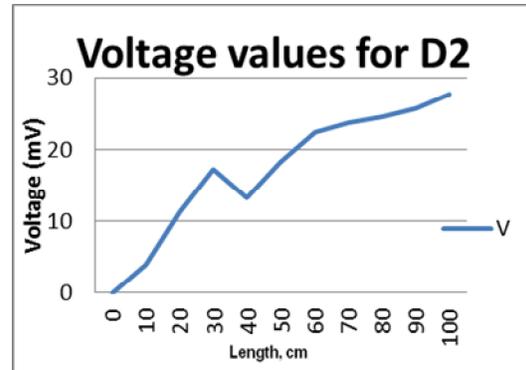


Fig. 12. Graph pattern Vp-p Values from D2

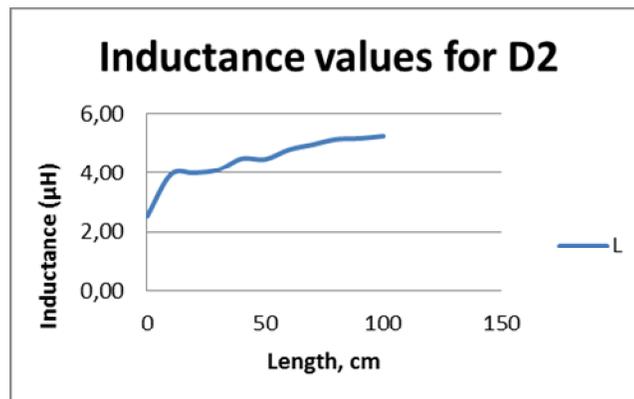


Fig. 13. Graph pattern for inductance values from D2

The results of magnetic after-effect lapsed time measurements conducted in this work shows that D1 had a higher lapsed time than D2. It took more than 15 minutes to have Vp-p decreased to zero value when the EM wave was switched off. It significantly affected the performance of the D1 even though it had a high sensitivity. D2 took 2 seconds to return to a zero voltage. One important mechanism to result in a short lapsed time for detector is to avoid incoming continuous electromagnetic wave to pile up.

IV. Conclusions

We have constructed a novel ferrite-based EM wave detector for SBL application. From the two experiments conducted, we found that the sensitivity of D1 was much higher than D2 by 61%. On the other hand, D2 had a lower lapsed time than D1, making it an important aspect for SBL application.

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