1D Modeling of EM Waves using MATLAB

By

ABDUL FATTAH BIN BADROL

Dissertation

Submitted to the Electrical & Electronics Engineering Programme
in Partial Fulfillment of the Requirements
for the Degree
Bachelor of Engineering (Hons)
(Electrical & Electronics Engineering)

Universiti Teknologi Petronas
Bandar Seri Iskandar
31750 Tronoh
Perak Darul Ridzuan

CERTIFICATION OF APPROVAL

1D MODELLING ELECTROMAGNETIC (EM) WAVES FOR OFFSHORE APPLICATION

by

Abdul Fattah Bin Badrol

A project dissertation submitted to the
Electrical & Electronics Engineering Programme
Universiti Teknologi PETRONAS
in partial fulfilment of the requirement for the
Bachelor of Engineering (Hons)
(Electrical & Electronics Engineering)

Approved:

____

(Puan Hanita bt. Daud)
Project Supervisor

UNIVERSITI TEKNOLOGI PETRONAS
TRONOH, PERAK

December 2010

CERTIFICATION OF ORIGINALITY

This is to certify that I am responsible for the work submitted in this project, that the original work is my own except as specified in the references and acknowledgements, and that the original work contained herein have not been undertaken or done by unspecified sources or persons.

____

(Abdul Fattah Bin Badrol)

ABSTRACT

This project is to develop 1D plane modeling of Electromagnetic (EM) waves for seabed logging application using MATLAB. Seabed logging is a technique that utilizes EM waves to propagate signals to reservoir depths where the difference in resistivity levels of different regions under the seafloor will help to determine possible oil wells for future exploration. This report describes briefly on the advantages of this technique as well as the process on how the EM wave is implemented to distinguish the hydrocarbon from other elements. The data gathered can be used to develop the 1D plane layer modeling. EM imaging can identify reservoirs before seismic surveys are conducted. Where seismic methods indicate the presence of a suitable structure, EM data dramatically improves confidence in ranking the prospect. An EM has the potential to find hydrocarbons in traps that cannot be detected using seismic methods and would be overlooked by conventional workflows [5].

ACKNOWLEDGEMENTS

My utmost appreciation and gratitude is extended to Puan Hanita Daud, for the dedication of her time and effort, relentlessly teaching and guiding me despite her many other obligations.

Many thanks to my family back home for their sacrifices coupled with their continuous encouragement and support and heading me towards the star.

Special thanks to all members of the Electrical and Electronics Engineering Department, for providing continuous support.

My appreciation is also extended to my friends who encouraged and supported me throughout the successful completion of this project.

TABLE OF CONTENTS

LIST OF FIGURES

LIST OF TABLES

CHAPTER 1

INTRODUCTION

1.1 Background of Study

Measurements of electrical resistivity beneath the seafloor have traditionally played a crucial role in hydrocarbon exploration and reservoir assessment and development. In the oil and gas industry, sub-seafloor resistivity data has been obtained by various techniques including study of landforms and seismic analysis. The area where oil reservoir is thought likely to be located will be drilled by test wells. [1]

By using a technique of implementing Electromagnetic (EM) waves, also known as seabed logging, a clear advantage is seen as to provide the necessary information without resolving to invasive geophysical methods. This technique uses a mobile horizontal electric dipole transmitter and array of seafloor electric receiver. The HED transmitter will transmit the EM wave through the seafloor and the receiver will record data that has been reflected back.[2] This technique has the ability to distinguish between hydrocarbon and water.

1.2 Problem Statement

Simulation of SBL before this has been based on a single layered hydrocarbon. If another layer of hydrocarbon is present, it is not known whether the hydrocarbon can be detected by the simulator. This is more important when both layer of hydrocarbon is arranged above each other.

1.3 Objectives

The objectives of this project are:

i. To develop seabed logging simulator using MATLAB Graphical User Interface
ii. To develop modeling of more than one reservoir of different arrangements.
iii. To find the effect of Electromagnetic Waves to the receivers when salinity and hydrocarbon thickness is varied.
iv. To obtain graphical comparison between the simulation and scaled modeled experiment.

1.4 Scope of Study

1.4.1 Understanding seabed logging methods

The author needs to understand the processes involved for seabed logging, as well as the advantages and disadvantages of this technique.

1.4.2 Developing seabed logging simulator using MATLAB

The author needs to have knowledge on the software to develop the simulator. Knowledge on programming and the tools offered in the software will help assist to achieve the project objective. The simulator will then be used to model the Electromagnetic waves to detect the hydrocarbon when different variables are varied.

1.4.3 Performing scaled model experiments

The author needs to conduct scaled experiments based on seabed environments to obtain data which will then be compared to the data gained from the simulation.

CHAPTER 2

LITERATURE REVIEW

2.1 Seabed Logging Methods

From [2] Seabed logging method uses resistivity sensing method exploiting the fact that hydrocarbons and hydrocarbon reservoirs has more resistivity than surrounding water filled sediments. Changes in the electric field around the reservoirs can be measured and the data gained can be used to interpret the presence of hydrocarbon.

Seabed logging technique uses a horizontal electric dipole (HED) antenna as the source, emitting an alternating current. The HED source is towed above the receiver which is stationed on the sea bottom where they are placed at appropriate locations. The HED source transmits low-frequency EM energy into the subsurface. Low-frequency signals of 0.25Hz are used due to its characteristics which has low attenuation over long distances compared to high frequency EM wave. [3]

The EM wave propagates through the sea and subsurface to reservoir depths where it detects the contrast in subsurface resistivity. Due to the resistive nature of hydrocarbon filled rocks, the EM wave experiences little attenuation and leaks up energy up to the seafloor. The receivers will then record this leakage field. Hydrocarbon filled reservoir have high resistivity compared to water pools. The different resistivity of layers below seafloors enables this method to distinguish between these two layers. The data recorded from the receiver will then be used for modeling and mapping boundaries. [3]

From [9] the basic processing steps for real SBL data are demodulation, calibration, scaling, and inline rotation. Receiver data are recorded in the time domain. In the demodulation step, time-domain EM data are transformed to frequency domain through a Fourier transform and the frequencies of interest extracted. To relate the recorded signal to the physical field present at the receiver sensors at the time of measurement, the signal is calibrated. After calibration, the recorded data are converted to the EM field quantities. The phase of the source current is used to obtain absolute phase data.

The current amplitude is accounted for through normalization by the dipole current moment. The strength of the electromagnetic field at the antennas depends on their orientation relative to the transmitted field. For any given angle of the receiver sensors, they measure the legs of the total EM vector field.

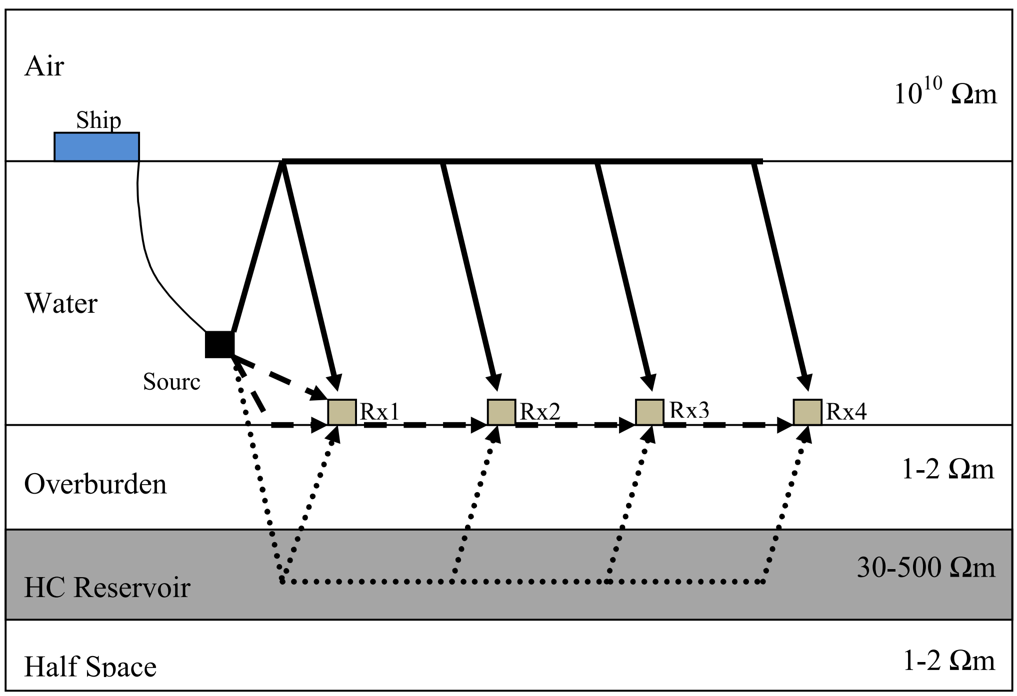


Figure 1: Seabed Logging Process

Each layer beneath the seafloor has different resistivity [3]. For example, oceanic crust has high resistivity around 100-1000Ωm. Sedimentary rocks can exhibit a wide range of resistivity around 0.2-1000Ωm and mainly controlled by variation in porosity. Hydrocarbon filled reservoir also have high resistivity around 30-500Ωm compared to water that is very conductive around 0.5-2Ωm. Due to different resistivity between water and hydrocarbon, therefore both of the layer can be distinguish by this method.

In high resistivity and relatively thin (20-200 m) subsurface media, such as hydrocarbon filled reservoirs (30-500 Ωm), the energy is guided along the layers and attenuated less depending on the critical angle of incidence [2]. Guided EM energy is constantly refracted back to the seafloor and is recorded by the EM receivers. Energy is also reflected and refracted via the air-water interface.

This energy is commonly termed the air-waves and dominates at far offsets depending on water depth. The refracted energy from high resistivity subsurface layers will dominate over directly transmitted energy when the source-receiver distance is large enough [8]. The detection of this guided and refracted energy from hydrocarbon is the basis of SBL

2.2 Forward SBL Modeling

Forward modeling is a technique of determining what a given sensor would measure in a given formation and environment by applying a set of theoretical equations for the sensor response. Forward modeling is used to determine the general response of most electromagnetic logging measurements such as reservoir detection and simulation.

Forward modeling is also used for interpretation, particularly in horizontal wells and complex environments. The set of theoretical equations (the forward models) can be modeled in one, two or three-dimensional modeling. The more complex the geometry, the more factors can be modeled but the slower the computing time [10].

When interpreting SBL data it is important to compare the EM response over the Hydrocarbon accumulation with the EM response in a reference area immediately outside the accumulation. It is also critical to understand SBL responses from high resistivity bodies other than the hydrocarbon reservoir itself which can potentially generate significant responses. Modeling has two main goals; firstly, to establish the optimal survey location and receiver geometry; and secondly, to quantify the expected SBL response from the subsurface hydrocarbon accumulation relative to that of a reference area outside the accumulation.

Important factors to consider when planning an SBL survey are water depth, water and seabed conditions, burial depth of the hydrocarbon accumulation, electrical properties of the overburden, geometrical and electrical properties of the reservoir, and electrical properties beneath the hydrocarbon accumulation [8].

2.3 Equations

2.3.1 Maxwell Equation

Modern electromagnetism is based on a set of four fundamental relations known as Maxwell's equations [11]. These equations hold in any material, including free space (vacuum), and at any spatial location *(x,y,z).* Together with some auxiliary relations, Maxwell's equations form fundamental tenets of electromagnetic theory. Maxwell's equations are:

$$\nabla \cdot \boldsymbol{D} = \rho\ v \tag{1}$$

$$\nabla \times \boldsymbol{E} = -\frac{\partial\ \boldsymbol{B}}{\partial\ \boldsymbol{t}} \tag{2}$$

$$\nabla \cdot \boldsymbol{B} = 0 \tag{3}$$

$$\nabla \cdot \boldsymbol{H} = \mathbf{J} + \frac{\partial\ \boldsymbol{D}}{\partial\ \boldsymbol{t}} \tag{4}$$

$$D = \varepsilon\ \boldsymbol{E} \tag{5}$$

$$\boldsymbol{B} = \mu\ \boldsymbol{H} \tag{6}$$

$$\boldsymbol{J} = \sigma\ \boldsymbol{E} \tag{7}$$

$$\varepsilon = \varepsilon_0 * \varepsilon_r \tag{8}$$

$$\mu = \mu_0 * \mu_r \tag{9}$$

Where,

B = Magnetic flux density (T)

D = Electric flux density (C/m2)

E = Electric-filed density (V/m)

H = Magnetic field intensity (A/m)

J = Current density (A/m2)

ε = Permittivity (F/m)

μ = Permeability (H/m)

σ = Conductivity (S/m)

ε_0 = 8.854 x 10^{-12} F/m

ε_r = Relative permittivity

μ_0 = 4π x 10^{-7} H/m

μ_r= Relative permeability

2.3.2 Wave related equation

$$\gamma = \alpha + j, \beta \tag{10}$$

$$\alpha = \omega\sqrt{\mu\ \omega}\left[\frac{1}{2}\left(\sqrt{1+\left(\frac{\sigma}{\omega\ \varepsilon}\right)^2}+1\right)\right]^{\frac{1}{2}} \tag{11}$$

$$\beta = \omega\sqrt{\mu\ \omega}\left[\frac{1}{2}\left(\sqrt{1+\left(\frac{\sigma}{\omega\ \varepsilon}\right)^2}-1\right)\right]^{\frac{1}{2}} \tag{12}$$

$$\eta = \sqrt{\frac{j\ \omega\ \mu}{\sigma + j\ \omega\ \varepsilon}} \tag{13}$$

Where,

γ = Propagation constant (m^{-1})

α = Attenuation constant (Np/m)

β = Phase constant (rad/m)

η=Intrinsic Impedance of medium (Ω)

ω=Angular frequency (rad/s)

μ = Permeability (H/m)

σ = Conductivity (S/m)

ε = Permittivity (F/m)

For magnitude of received waves,

$$E_x = E\, e^{(-\alpha)z} e^{(-j\beta)z} \qquad (14)$$

Where,

E_x= Magnitude of received EM waves (V/m)

α provides the amplitude of decay while β provide phase of propagation for the wave.

If $\sigma >> \omega\,\varepsilon$,

$$\alpha = \beta \approx \sqrt{\frac{\omega\,\mu\,\sigma}{2}} = \frac{1}{\delta} \qquad (15)$$

Where,

δ=Skin depth (m)

Skin depth characterizes how well an electromagnetic wave can penetrate into a conducting medium. The distance required to attenuate an EM signal by the factor e^{-1} (0.37) is about 551 m in seawater (0.3 Ωm), 1424 m in 2Ωm sediment and 108 m in air (1010 Ωm) for a 0.25 Hz signal. EM signals are rapidly attenuated in seawater and seafloor sediments saturated with saline water, and these signal pathways will dominate at near source-to-receiver offsets [8].

2.4 Electromagnetic wave reflection and refraction

From [6] electromagnetic wave reflection and refraction by transmission through planar boundaries can be divided into two parts which are normal incidence and oblique incidence.

2.4.1 Electromagnetic wave reflection and transmission at normal incidence

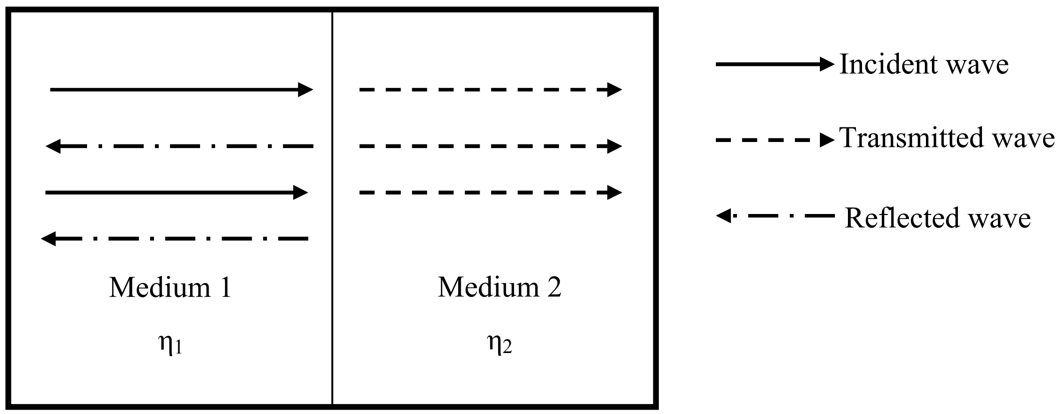


Figure 2 : A Normal Incidence

The wavenumber and intrinsic impedance of medium 1:

$$k_1 = \omega\sqrt{\mu_1 \varepsilon_1} \qquad (16)$$

$$\eta_1 = \sqrt{\frac{\mu_1}{\varepsilon_1}} \qquad (17)$$

Similarly to medium 2:

$$k_2 = \omega\sqrt{\mu_2 \varepsilon_2} \qquad (18)$$

$$\eta_2 = \sqrt{\frac{\mu_2}{\varepsilon_2}} \qquad (19)$$

Simultaneous solutions for E_0^r and E_0^t in term of E_0^i

$$E_0^r = \left(\frac{\eta_2 - \eta_1}{\eta_2 + \eta_1}\right) E_0^i = \Gamma\ E_0^i \qquad (20)$$

$$E_0^t = \left(\frac{2\ \eta_2}{\eta_2 - \eta_1}\right) E_0^i = \tau\ E_0^i \qquad (21)$$

Where

$$\Gamma\ = \frac{E_0^r}{E_0^t} = \left(\frac{\eta_2 - \eta_1}{\eta_2 + \eta_1}\right) \qquad (22)$$

$$\tau\ = \frac{E_0^t}{E_0^i} = \left(\frac{2\ \eta_2}{\eta_2 - \eta_1}\right) \qquad (23)$$

From the equation above, Γ is a reflection coefficient and τ is a transmission coefficient.

2.4.2 Electromagnetic wave reflection and transmission at oblique incidence

In oblique incidence there are two cases involving the polarization of incident wave which case 1 the E-field vector is perpendicular to the plane of incidence and case 2 where the E-field is parallel to the plane of incidence. For case 1 is called the horizontal polarization. For case 2 is called as vertical polarization.

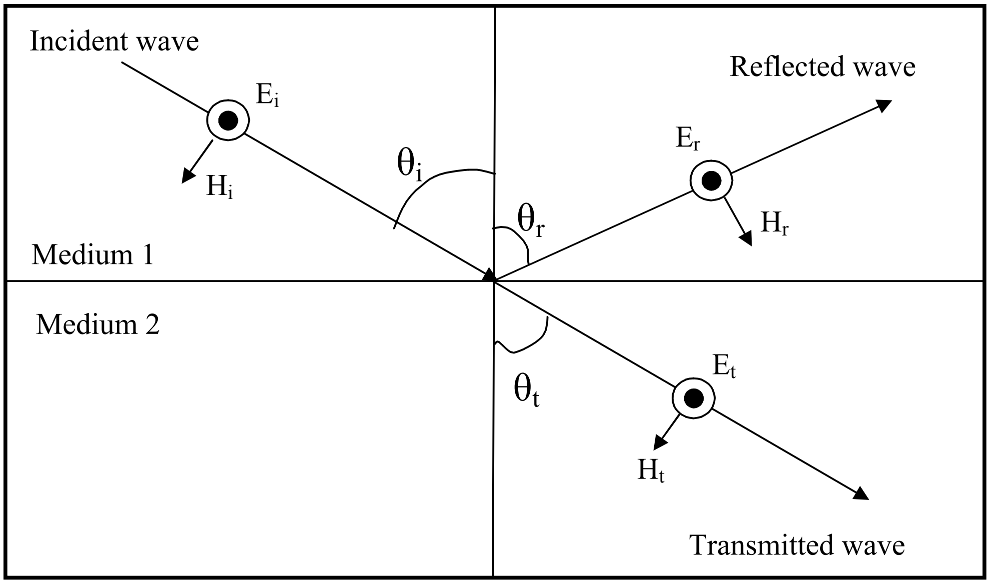


Figure 3: Incidence reflected and refracted rays and orientation of the E and H fields for perpendicular polarization.

$$\Gamma_{\pm} = \frac{E_r}{E_i} = \left(\frac{\eta_2 \cos\theta_i - \eta_1 \cos\theta_t}{\eta_2 \cos\theta_i + \eta_1 \cos\theta_t}\right) \qquad (24)$$

$$\tau_{\pm} = \frac{E_0^t}{E_0^i} = \left(\frac{2\eta_2 \cos\theta_i}{\eta_2 \cos\theta_i + \eta_1 \cos\theta_t}\right) \qquad (25)$$

From the equation above, Γ is a reflection coefficient and τ is a transmission coefficient.

2.5 Scale Model Calculation

The purpose of the experimental setup was to create a stratified structure with a sublayer of low-loss material (the "hydrocarbon" layer) embedded in a medium with high loss ("Overburden"). [7] It was important that the distances and frequencies used in the tank experiment could be scaled up to realistic distances and frequencies that can be encountered in a real SBL survey.

The ratio of the full scale and the laboratory scale dimensions is

$$\frac{d_{fs}}{d_{lab}} = n$$

If

$$\left(\frac{\rho}{\mu f}\right)_{fs} = n^2 \left(\frac{\rho}{\mu f}\right)_{lab}$$

The full scale and the laboratory scale both generally concerned with nonmagnetic conductors $\mu = \mu_o$ the permeability of the free space, so that

$$\left(\frac{\rho}{f}\right)_{fs} = n^2 \left(\frac{\rho}{f}\right)_{lab}$$

For the frequency

$$\left(\frac{1}{f}\right)_{fs} = n^2 \left(\frac{1}{f}\right)_{lab}$$

$$\boxed{n^2 f_{fs} = f_{lab}}$$

If the scale factor is n = 1500

a. **Wave length**

If full scale frequency is 0.1 Hz

$$(1500)^2 (0.1Hz) = f_{lab}$$

$$225KHz = f_{lab}$$

.

$$\lambda = 2\pi\sqrt{\frac{2}{\mu\sigma\omega}}$$

$$\lambda = \sqrt{\frac{8\pi^2}{\mu\sigma\omega}}$$

$$\lambda = \sqrt{\frac{1}{10^{-7}\sigma f}}$$

For sea water conductivity is σ = 5.2

$$\lambda = \sqrt{\frac{1}{10^{-7}\times 5.2\times 225\times 10^{3}}}$$

$$= 2.92m$$

b. **Skin Depth**

If full scale frequency is 0.1 Hz

$$(1500)^2(0.1Hz) = f_{lab}$$

$$225KHz = f_{lab}$$

.

$$\delta = \sqrt{\frac{2}{\mu\sigma\omega}}$$

$$\delta = \sqrt{\frac{1}{4\pi^2\times 10^{-7}\sigma f}}$$

For sea water conductivity is σ = 5.2

$$\delta = \sqrt{\frac{1}{4\pi^2\times 10^{-7}\times 5.2\times 225\times 10^{3}}}$$

$$= 0.46m$$

c. **Phase Velocity**

If full scale frequency is 0.1 Hz

$$(1500)^2(0.1Hz) = f_{lab}$$

$$225KHz = f_{lab}$$

.

$$C_p = \sqrt{\frac{2\omega}{\mu\sigma}}$$

$$C_p = \sqrt{\frac{10^7 \times f}{\sigma}}$$

For sea water conductivity is σ = 5.2

$$C_p = \sqrt{\frac{10^7 \times 225 \times 10^3}{5.2}}$$

$$= 1.50 \times 10^6 \; m/s$$

CHAPTER 3

METHODOLOGY

3.1 Procedure Identification

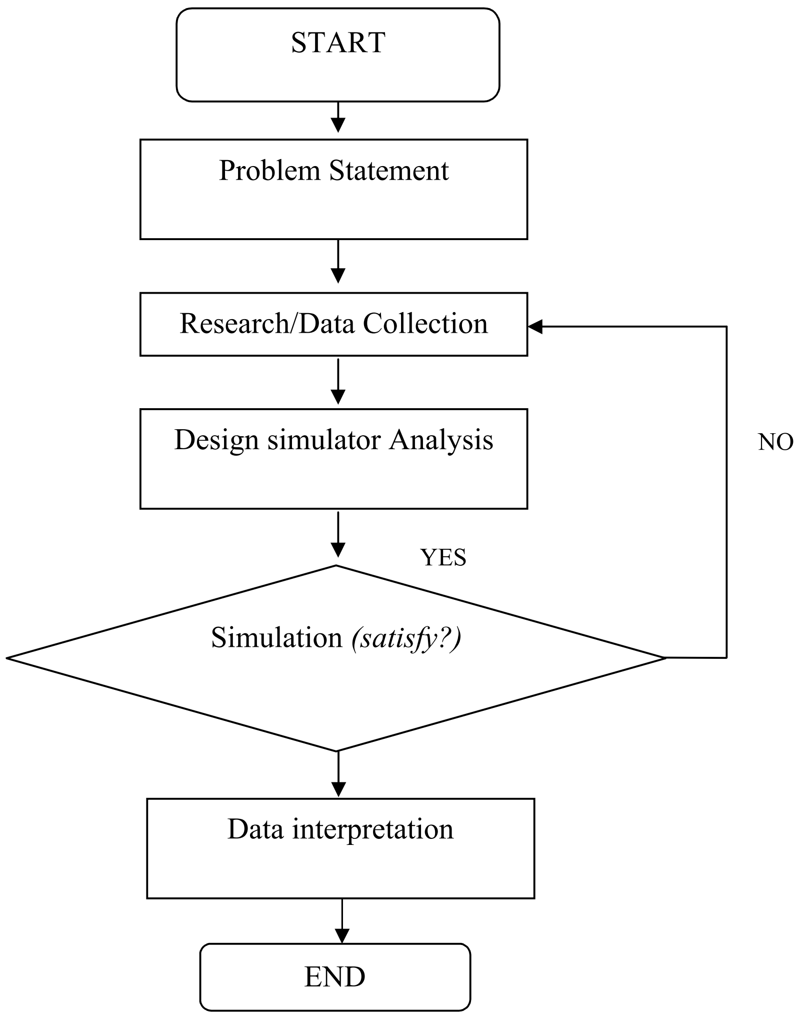


Figure 4: Flow Diagram for Project Work

3.2 Tools Required

3.2.1 MATLAB R2007a

The software will be the main tool for developing the simulation of the Electromagnetic wave in seabed logging application due to its user friendly interface and the amount of resources available.

3.2.2 Bartington Workstation

This workstation can be used to collect informative data from the receivers connected to it through an experiment setup.

3.2.3 Receivers

This device is used to retrieve signals from the transmitter and convey it back to the workstation.

3.2.4 Transmitter and Function Generator

The transmitter is connected to the function generator which will generate the signal with a predetermined frequency to the receivers.

3.2.5 Tank

This container is used to hold the water, transmitter and receivers. It will be the main area to conduct the experiment.

CHAPTER 4

RESULTS AND DISCUSSION

4.1 Simulator

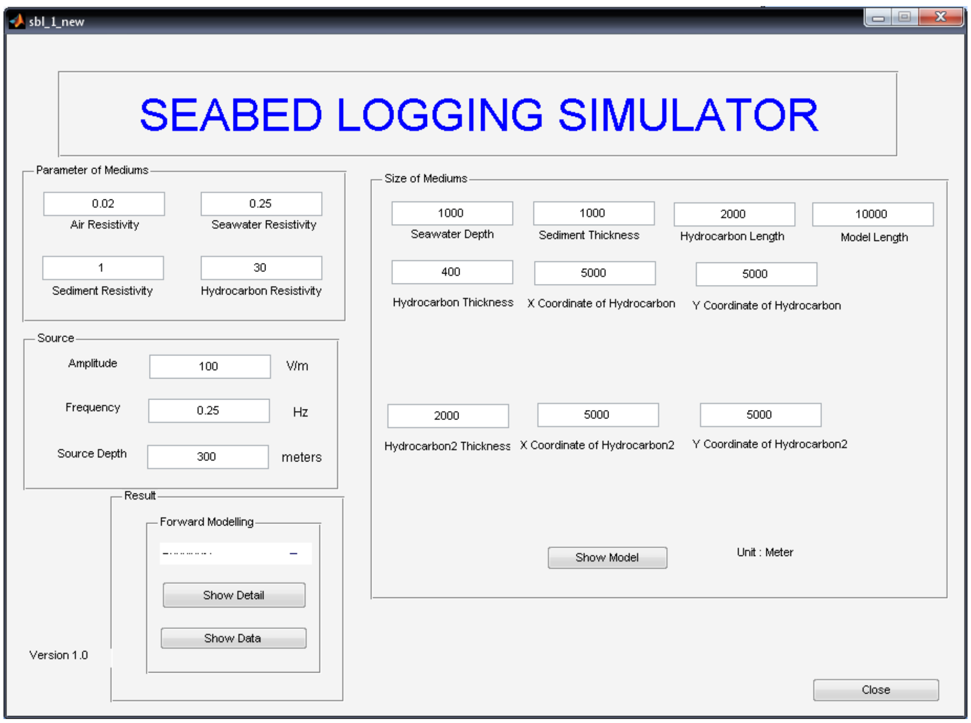


Figure 5: Seabed Logging Simulator

Figure 5 shows the simulator developed from MATLAB Graphical User Interface (GUI). It enables the user to input the values for the parameters that will display the seabed model. Since the simulation is to find the effects of the EM wave on different hydrocarbon arrangement, parameters of mediums are set to as in **Table 1** while the position and thickness of the hydrocarbons are varied. All simulations use source amplitude of 100V/m, frequency of 0.25Hz and source depth of 960m.

4.2 Simulation

Three arrangements were set to see the results of the two hydrocarbons in different arrangements. For Arrangement 1, two hydrocarbons are placed 4000m apart with the same Y coordinate to see the ability of the simulator to detect the presence of the two reservoirs. For Arrangement 2 the two hydrocarbons are placed above each other with the same thickness while for Arrangement 3, the thickness of the top layer hydrocarbon is reduced to see the effect of the EM wave on the hydrocarbons.

4.2.1 Arrangement 1

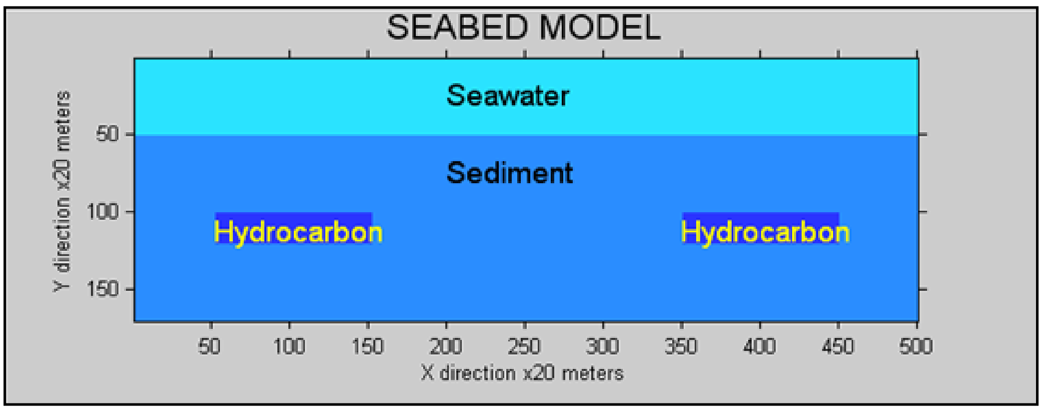


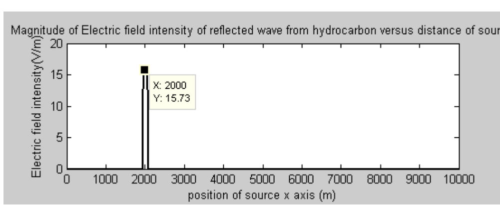
Figure 6: Arrangement 1

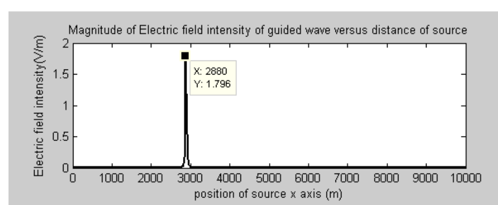
For demonstration purposes, the result will display from receiver 3 and 9 where the hydrocarbons are placed directly beneath the receivers, and receiver 6 where there are no hydrocarbon. The parameters are set as in **Table 1**.

Table 1 : Parameters for Arrangement 1

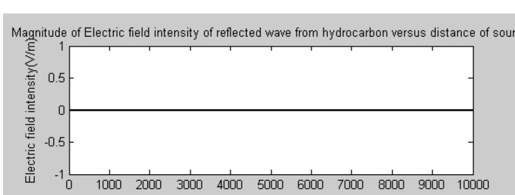
Parameters	Value
Seawater Resistivity	0.33 Ω
Seawater Depth	1000 m
Sediment Thickness	1000 m
Hydrocarbon Thickness	400 m
Hydrocarbon1 Length	2000 m
X Coordinate Hydrocarbon1	1000 m
X Coordinate Hydrocarbon2	7000 m
Y Coordinate Hydrocarbon1	2000 m
Y Coordinate Hydrocarbon2	2000 m

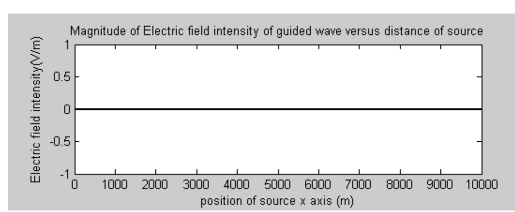
Magnitude of Reflected and Guided Wave from Hydrocarbon



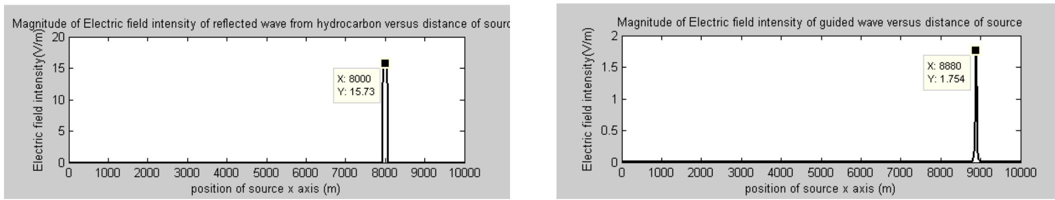


Receiver 3





Receiver 6



Receiver 9

Figure 7: Graphical Simulation Result for Arrangement 1

Table 2 : Magnitude of Captured EM Waves for Arrangement 1

Waves component	Magnitude of captured EM waves (V/m)		
	Receiver 3	Receiver 5	Receiver 9
Reflected Waves from Hydrocarbon	15.73	0	15.73
Guided Waves from Hydrocarbon	1.80	0	1.75

Based on **Figure 7** and **Table 2**, receiver 3 and 9 obtained data from reflected and guided wave of the EM signal due to the hydrocarbon which is placed directly under the receivers. No data is recorded for receiver 5 since there is no hydrocarbon beneath the receiver. Receiver 3 and 9 recorded a magnitude of 15.73V/m for the reflected waves which can confirm the existance of hydrocarbon beneath the sediment. This also shows that the simulator is able to generate two hydrocarbons in one model simulation.

The same simulation was generated with the same parameters except the seawater resistivity is increased to 4.33Ω. The results are shown in Table 3.

Table 3 : Magnitude of Captured EM Waves for Arrangement 1 with Seawater Resistivity Increased

Waves component	Magnitude of captured EM waves (V/m)		
	Receiver 3	Receiver 5	Receiver 9
Reflected Waves from Hydrocarbon	15.73	0	15.73
Guided Waves from Hydrocarbon	1.80	0	1.75

Salinity relates to seawater resistivity and corresponds to the conductiveness of the seawater. High salinity or low resistivity of seawater will produce a large affective conductivity of the resevoirs and consequently a low EM detectability. However, from **Table 3**, the results are the same as in **Table 2**. This may be due to the low resisitivity of the water (0.5-2Ωm) which produces a low effect to the conductivity of the EM wave.

4.2.2 Arrangement 2

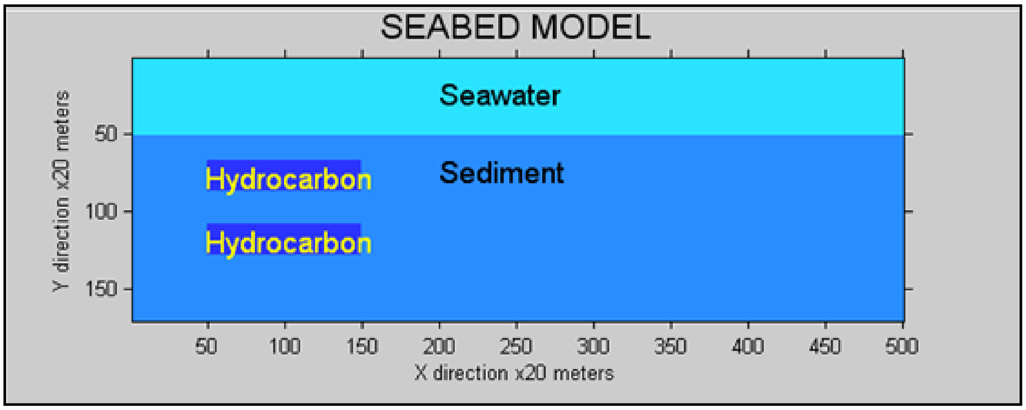


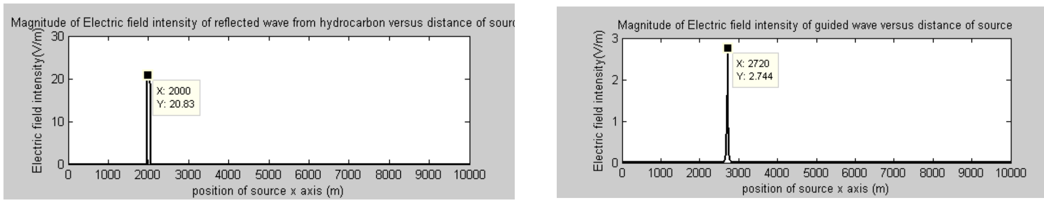
Figure 8: Arrangement 2

The arrangement was set to determine the effect of the EM waves when two layer of hydrocarbons are stacked above each other. The data gained can be used to determine wether the EM wave contain information to validate the existance on the bottom layered hydrocarbon. Analysis will be based on receiver 3 with the parameters set as in **Table 4**

Table 4: Parameters for Arrangement 2

Parameters	Value
Seawater Resistivity	0.33 Ω
Seawater Depth	1000 m
Sediment Thickness	1000 m
Hydrocarbon Thickness	400 m
Hydrocarbon Length	2000 m
X Coordinate Hydrocarbon1	1000 m
X Coordinate Hydrocarbon2	1000 m
Y Coordinate Hydrocarbon1	1200 m
Y Coordinate Hydrocarbon2	2100 m

Magnitude of Reflected and Guided Wave from Hydrocarbon



Receiver 3

Figure 9: Graphical Simulation Result for Arrangement 2

Table 5: Magnitude of Captured EM Waves for Arrangement 2

Wave Component	Magnitude of captured EM waves (V/m)
	Receiver 3
Reflected Waves from Hydrocarbon	20.83
Guided Waves from Hydrocarbon	2.74

From **Table 5**, when the hydrocarbon is closer to the receiver, the magnitude of reflected and guided wave is increased. This is because of the shorter distance needed to travel by the transmitted EM signal before being refracted by the hydrocarbon layer. The data shows the EM wave being reflected by the first high resistive layer of hydrocarbon. There is no information to indicate the existence of another layer of hydrocarbon beneath.

4.2.3 Arrangement 3

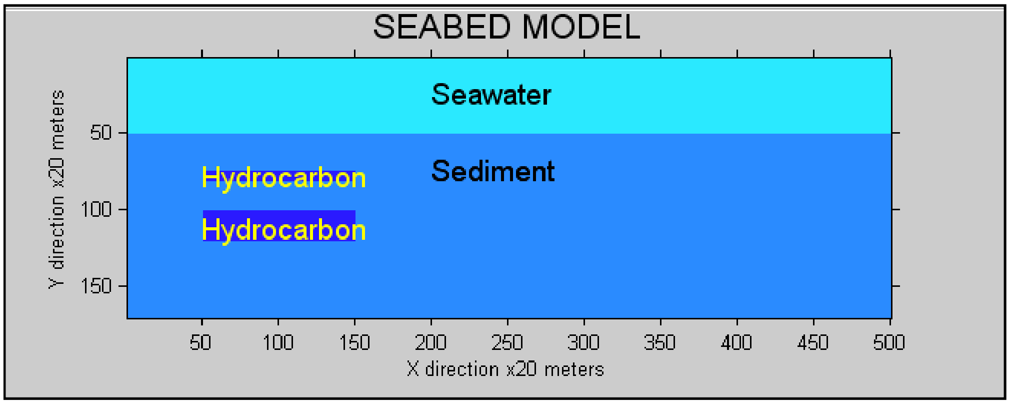


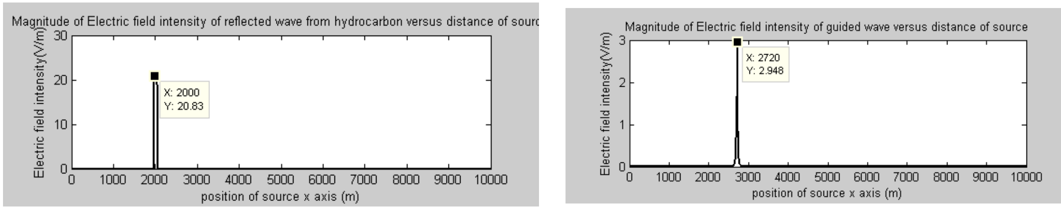
Figure 10: Arrangement 3

For the arrangment in **Figure 10**, the thickness of the top layer hydrocarbon is reduced to the most possible minimum value of 20m to see the effect of the transmitted EM signal on the bottom layer hydrocarbon. Receiver 3 is used to analyze the data with the parameters in **Table 6**.

Table 6: Parameters for Arrangement 3

Parameters	**Value**
Seawater Resistivity	0.33 Ω
Seawater Depth	1000 m
Sediment Thickness	1000 m
Hydrocarbon1 Thickness	200 m
Hydrocarbon2 Thickness	400 m
Hydrocarbon Length	2000 m
X Coordinate Hydrocarbon1	1000 m
X Coordinate Hydrocarbon2	1000 m
Y Coordinate Hydrocarbon1	1600 m
Y Coordinate Hydrocarbon2	2000 m

Magnitude of Reflected and Guided Wave from Hydrocarbon



Receiver 3

Figure 11: Graphical Simulation Result for Arrangement 3

Table 7: Magnitude of Captured EM Waves for Arrangement 3

Wave Component	Magnitude of captured EM waves (V/m)
	Receiver 3
Reflected Waves from Hydrocarbon	20.83
Guided Waves from Hydrocarbon	2.95

From **Table 7**, the magnitude of the reflected EM wave is the same as the results for **Figure 8**. This is because resistivity does not depend of the size and shape of the material. Due to this, the data captured was solely from the top layer hydrocarbon and the EM wave failed to identify the presence of the bottom layer hydrocarbon.

4.2.3 Arrangement 4

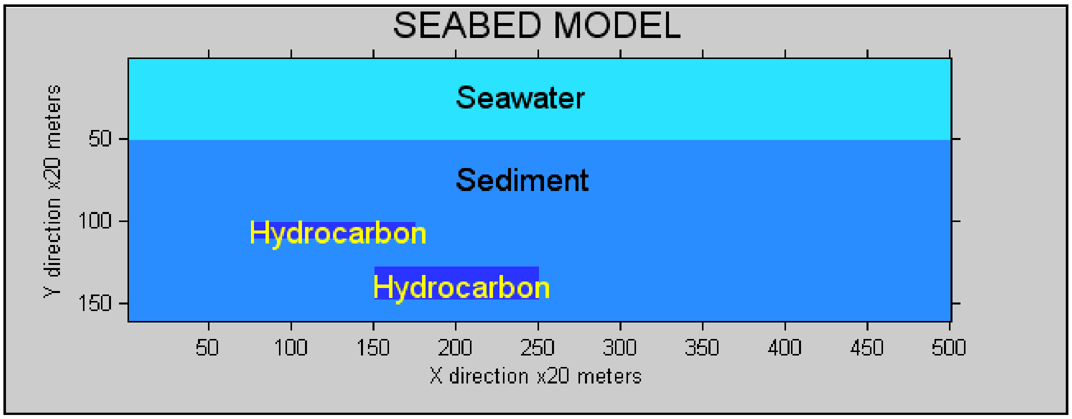


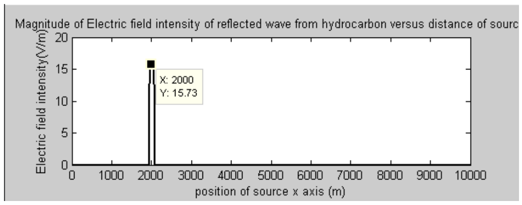
Figure 12: Arrangement 4

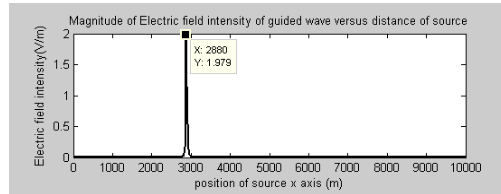
For this arrangement, the thickness of the top layer hydrocarbon is set to 200m and is positioned at 1500m, while the bottom layer hydrocarbon is 400m thick and is placed at 3000m. The parameters are shown in **Table 8**. Receivers 3, 4, 5, and 6 are used to obtain the data.

Table 8: Parameters for Arrangement 4

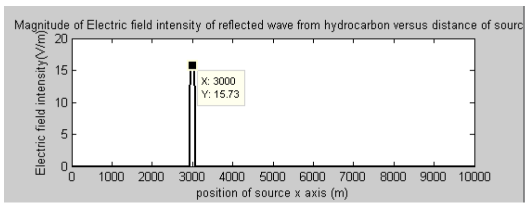
Parameters	**Value**
Seawater Resistivity	0.33 Ω
Seawater Depth	1000 m
Sediment Thickness	1000 m
Hydrocarbon1 Thickness	200 m
Hydrocarbon2 Thickness	400 m
Hydrocarbon Length	2000 m
X Coordinate Hydrocarbon1	1500 m
X Coordinate Hydrocarbon2	3000 m
Y Coordinate Hydrocarbon1	2000 m
Y Coordinate Hydrocarbon2	3500 m

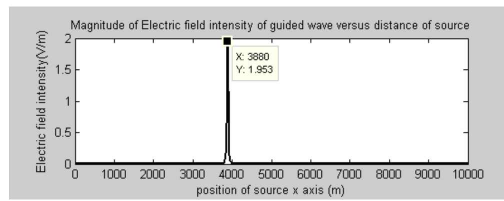
Magnitude of Reflected and Guided Wave from Hydrocarbon



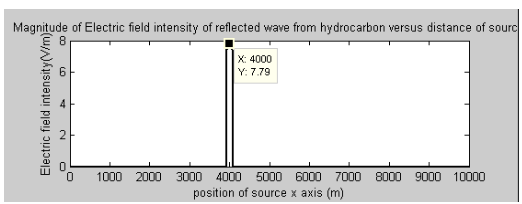


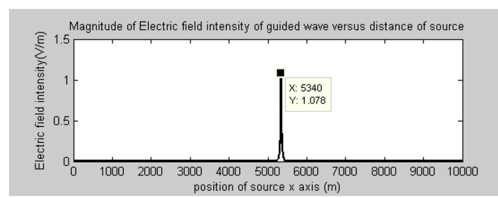
Receiver 3



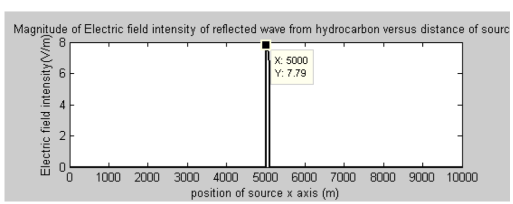


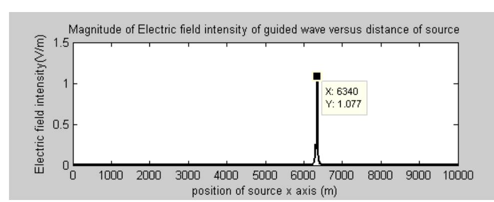
Receiver 4





Receiver 5





Receiver 6

Figure 13: Graphical Simulation Results for Arrangement 4

Table 9: Magnitude of Captured EM Waves for Arrangement 4

Waves component	Magnitude of captured EM waves (V/m)			
	Receiver 3	Receiver 4	Receiver 5	Receiver 6
Reflected Waves from Hydrocarbon	15.73	15.73	7.79	7.79
Guided Waves from Hydrocarbon	1.979	1.953	1.078	1.077

Table 9 shows that receiver 3 and 4 recorded the same magnitude of 15.73V/m while receiver 5 and 6 both recorded a magnitude of 7.79V/m. The point of interest is at receiver 4 where the hydrocarbons are overlapped. Again, the simulator only recorded the data from the top layer hydrocarbon. This arrangement shows the area that are overlapped is undetectable to the simulator.

4.3 Scaled Model Experiment

Experiments were conducted to see the effect of Seabed logging method on a scaled level. The objective of the experiment is to gather data to validate and compare with the result of the simulation. The specifications for the experiment are shown in **Figure 14**

Three receivers, a signal source and two representations of hydrocarbons are used. The source transmitter will be moved from origin until the end of the tank. A basic experiment was conducted first where no hydrocarbons are placed in the tank as a controlled result. Next, the experiment is repeated with the hydrocarbons arrangement as in **Figure 14** and again with the salinity increased.

4.3.1 Experiment 1

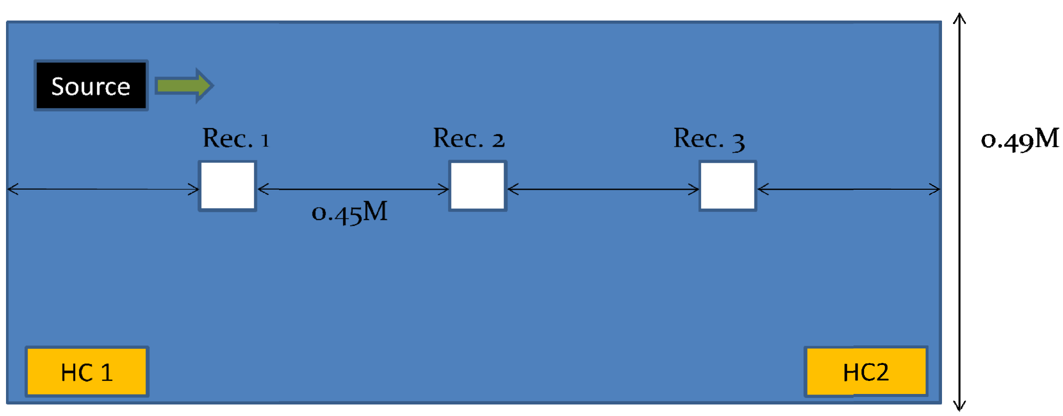


Figure 14: Experiment 1 Setup

Two hydrocarbons are placed in the tank. Hydrocarbon 1 is located at the left hand side of receiver 1 while hydrocarbon 2 is placed on the right hand side of receiver 3. Resistivity is measured to be 1.42 Ω, while the frequency is set to 1 KHz. The transmitter distance is 0.37m from the floor with its amplitude at $23.2V_{p-p}$. Analysis of the data will be focused on the tails of the graph which shows the difference in magnitude from the refracted transmission electromagnetic signal of the hydrocarbons.

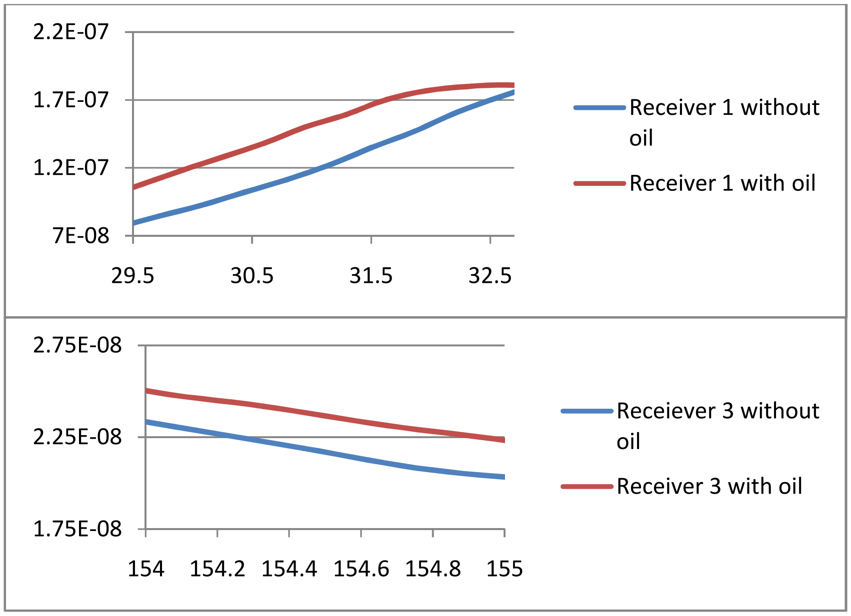


Figure 15: Magnitude of EM wave at Receiver 1 and 3

The higher incline of magnitude compared to the control data without the hydrocarbon indicates that hydrocarbon is presence on the left hand side of receiver 1. Receiver 3 recorded a higher magnitude compared to the data without hydrocarbon on the right hand side of the receiver which indicate hydrocarbon is present.

The same experiment was repeated with the salinity increased to resistivity of 1.15Ω. When salinity is increased, conductivity also increases which will make the EM wave experience attenuation. Higher salinity will result in lower magnitude of received EM waves.

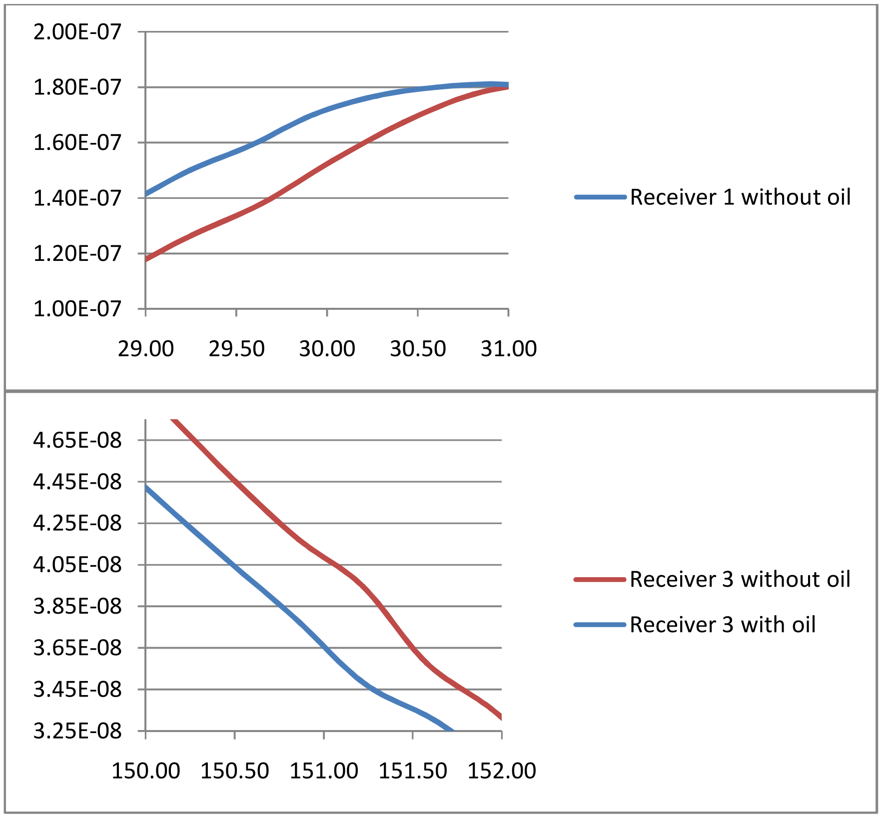


Figure 16: Magnitude of EM Wave at Receiver 1 and 3 with Increased Salinity

Based on the data in **Figure 16**, it is seen that when salinity is increased, the magnitude of the EM wave with the presence of oil reduces. This is because the EM signals experience more attenuation in a conductive environment.

4.3.2 Experiment 2

Another experiment was conducted where two hydrocarbons are placed above each other. Resistivity was measured to be 1.42Ω, and the transmitter was configured to have amplitude of 23.2 $V_{p\text{-}p}$, frequency of 1 KHz and transmitting 0.37m from the bottom of the tank. The result is shown in **Figure 18**.

Resistivity is then decreased to 1.15Ω by adding salt into the tank and the experiment is repeated. The result is shown in **Figure 19**.

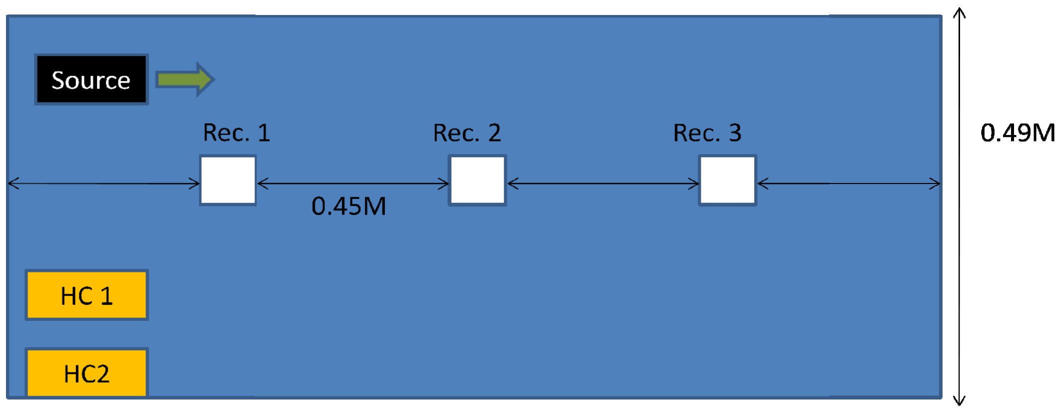


Figure 17: Experiment 2 Setup

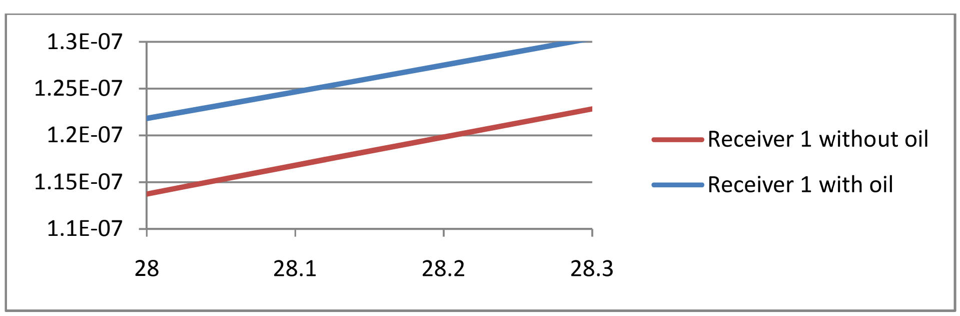


Figure 18: Magnitude of EM Wave at Receiver 3

The increased magnitude of the EM wave compared to the data without the oil indicates that a hydrocarbon is presence on the left side of receiver 3. Comparing with the results in experiment 1, the magnitude is similar to that of experiment 2. Due to that, there is no indication that another layer of hydrocarbon exists below the top layer.

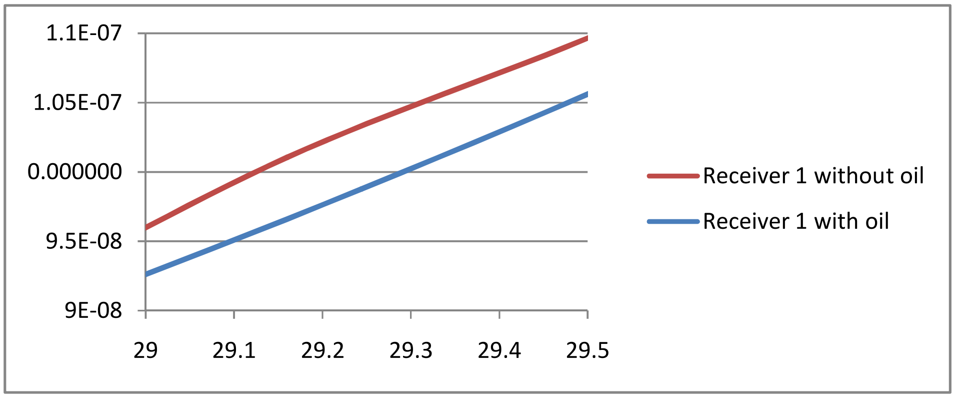


Figure 19: Magnitude of EM Wave at Receiver 3 with Increased Salinity

The result in **Figure 19** shows that the data with oil presence is lower in magnitude compared to the data without the oil. The magnitude is similar to that in experiment 1 and there is no information to indicate the existence of 2 layer hydrocarbon in the tank.

4.4 Simulation and Scaled Model Experiment Comparison

Based on the Simulation generated and the experiment conducted, the results obtained can be used to compare to validate both methods on the EM waves. Two conditions are used which is with the two hydrocarbons placed above each other and another with the salinity increased. Both method shows an increment of magnitude when hydrocarbon is present.

Due to some error in the programming codes, the simulator was not able to generate results when resistivity is increased. However, from the results in the experiment, a result can be predicted where resistivity changes the conductivity of the water. The higher the salinity, the more conductive the water becomes which will result in a reduced magnitude of the EM wave.

CHAPTER 5

CONCLUSION AND RECOMENDATION

5.1 Conclusion

By using electromagnetic waves, potential hydrocarbon reservoirs can be detected under the seabed. The existence of the hydrocarbon can be determined by the results of the reflected and guided wave from the hydrocarbon. Through the simulation, when hydrocarbons are overlapped, the EM waves can only detect the top layer of hydrocarbon. The data obtained did not have information to suggest the existence of the bottom layered reservoir. The same pattern occurred when conducting the scaled modeled experiment.

5.2 Recommendation

There are a few recommendations that can be done to improve this project

- To develop 2D modeling in the same environment by varying the X axis
- To include other components into the simulator such as porosity of sediment/hydrocarbon, lithology, seawater density, and temperature.

REFERENCES

[1] http://www.searchanddiscovery.net/documents/2008/08008ridyard/index.htm

[2] **EN Kong H. Westerdhal** 'Seabed Logging': A possible direct hydrocarbon for deep sea prospects using EM energy [Journal]. - Oslo : Oil & Gas Journal, 2002. – May 13, 2002 edition

[3] **Janniche Iren Nordskag, Lasse Amundsen** Asymptotic airwave modeling for marine controlled-source electromagnetic surveying [Journal].-Trondheim, Norway: Geophysics, 2007 –VOL.72,NO.6

[4] **Khairul Ihsan Bin Talib** 1D Modeling Electromagnetic (EM) Waves for Offshore Application [Final Project Report]. – Bandar Seri Iskandar: Universiti Teknologi PETRONAS, 2009.

[5] **Ståle Johansen,* Ketil Brauti, Stein Fanavoll, Hans Amundsen, Tor Atle Wicklund, Jens Danielsen, Pål T. Gabrielsen, Lars Lorentz, Michael Frenkel, Benjamin Dubois, Ole Christensen, Kathrine Elshaug and Stig A. Karlsen**. 2008, "How EM survey analysis validates current technology, processing and interpretation methodology" ***Journal Leveraging Technology, First Break*** 26: 83-88

[6] **Ulaby Fawwaz T.** Electromagnetics for Engineers [Book]. - New Jersy :Pearson Education, 2005.

[7] **L.O. Løseth, H.M. Pedersen, T. Schaug-Pettersen, S. Ellingsrud and T. Eidesmo** A scaled experiment for the verification of the SeaBed Logging method [Journal]. - Trondheim, Norway, 24 November 2006

[8] **Johansen, S. E., Amundsen, H. E. F., Rosten, Ellingsrud, S., Eidesmo, T., Bhuyian, A. H**., (2005). Subsurface Hydrocarbons Detected by Electromagnetic Sounding. *First break,* 23, 31-36.

[9] **STÅLE E. JOHANSEN and TOR A. WICKLUND**, Interpretation example of marine CSEM [Journal] - dataElectroMagnetic GeoServices as (emgs), Trondheim, Norway

[10] The Oilfield Glossary- Forward Modeling (n.d). Retrieved March 17, 2010 Retrieved from http://www.glossary.oilfield.slb.com/Display.cfm?Term=forward%20modeling

[11] Basic Electromagnetic Theory, Retrieved from http://media.wiley.com/product_data/excerpt/89/04714381/0471438189.pdf

APPENDICES

APPENDIX A

Suggested Milestone for the Second Semester of 2-Semester Final Year Project

No	Detail/ Week	1	2	3	4	5	6	7		8	9	10	11	12	13	14
1	Project Work Continue															
2	Submission of Progress Report 1															
3	Project Work Continue															
4	Submission of Progress Report 2															
5	Seminar (compulsory)															
6	Project work continue															
7	Poster Exhibition															
8	Submission of Dissertation (soft bound)															
9	Oral Presentation															
10	Submission of Project Dissertation (Hard Bound)															