# Geophysics 424 A1 Final exam
# Electromagnetic and Potential field methods

**Date :** Wednesday December 10th 2008, 2 - 5 pm
**Location** CEB 1-23
**Instructor :** Dr. Martyn Unsworth
**Time allowed :** 3 hours
**Total points = 105**

## Instructions

*Attempt all questions.*

*Notes and books may **not** be used.*

*Calculators may be used.*

*Cell phones and all other electronic devices must be switched off and stored.*

*All questions must be directed to the invigilator.*

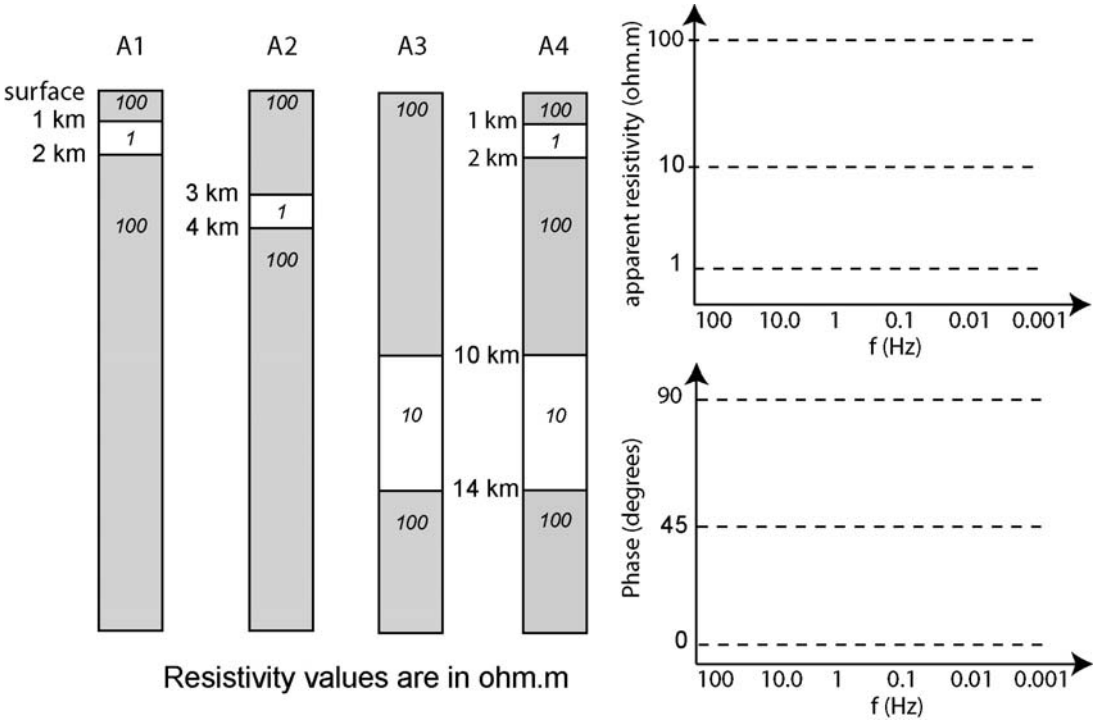
*A separate 2 page formula sheet is available.*

## Question 1 : Magnetotellurics (Total = 14 points)

The figures below shows four resistivity models.

Sketch the **apparent resistivity** and **phase** that would be measured at the surface.

Where possible, be **quantitative** in your answer. Explain your answers.




## Question 2 : Marine EM methods (Total = 6 points)

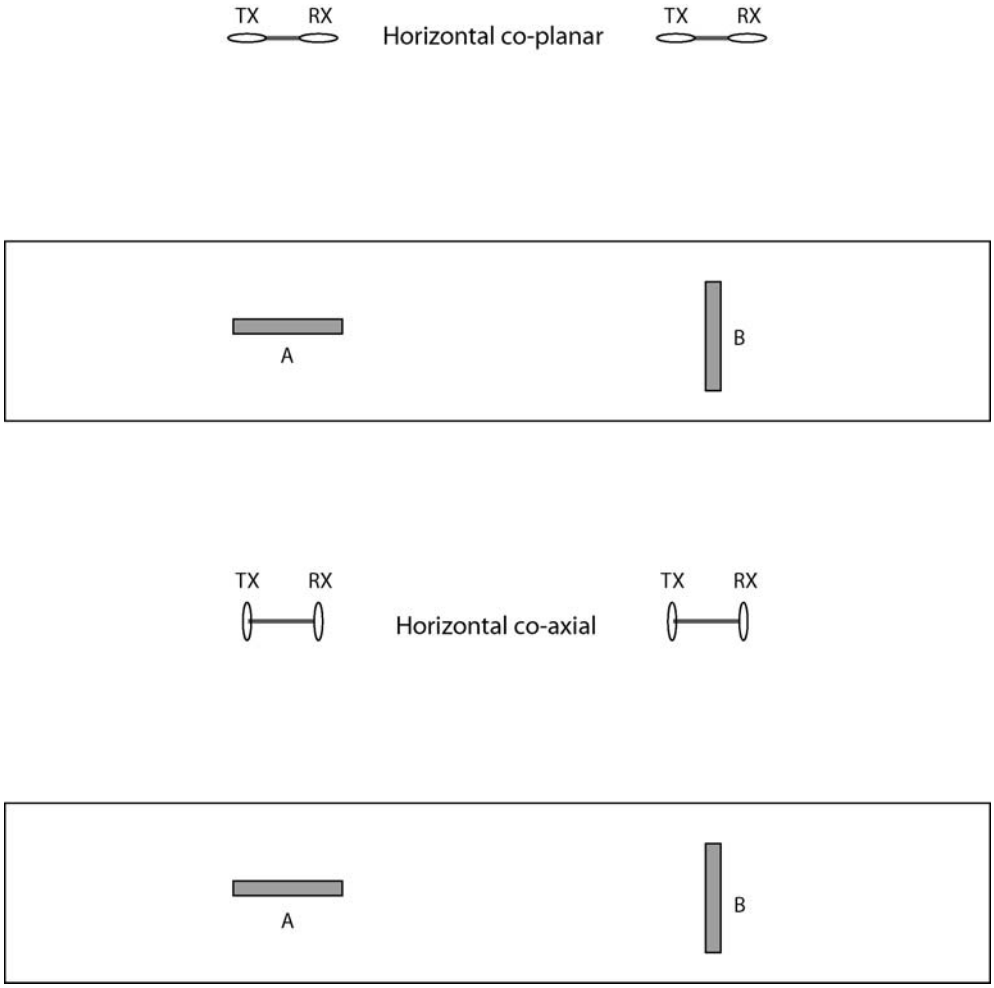
A survey is investigating a seafloor target in a location where the seawater is 2500 m deep. Seawater resistivity is 0.3 Ωm

The seafloor resistivity is 10 Ωm and the target is 100 m below the seafloor.

Would a seafloor MT or marine CSEM survey be most appropriate?

Explain your answer.

## Question 3 : Frequency domain EM surveys (Total = 12 points)




A frequency domain EM survey is flown over two buried conductors (A and B)

Two configurations of TX and RX are used.

The secondary magnetic field ($H^S$) is in-phase with the primary magnetic field ($H^P$).

(a) Sketch the **primary** and **secondary** magnetic field lines when the TX-RX is above each conductor. Sketch on figure above.

(b) For each TX-RX geometry, which conductor (A or B) will give the biggest response in $|H^T/ H^p|$?

(c) Indicate if $|H^T/ H^p| > 1$ or $|H^T/ H^p| < 1$ above each conductor for the co-axial and co-planar configurations.

**(12 points)**

## Question 4 : Maxwell's Equations (Total = 30 points)

A **plane** EM wave is travelling **vertically** downwards in the Earth in the *z*-direction.

The wave has an angular frequency, $\omega$, and time dependence $e^{i\omega t}$

The electric field is **polarized** in the *x*-direction.

At this location, the Earth has the following properties

| | | |
|---|---|---|
| Magnetic permeability | $= \mu = \mu_0$ | $= 4\pi \, x \, 10^{-7}$ H/m |
| Dielectric permittivity | $= \varepsilon = \varepsilon_0$ | $= 8.85 \times 10^{-12}$ F/m |
| Electrical conductivity | $= \sigma$ | $= 0.01$ S/m |
| Speed of light | $= c$ | $= 3 \, x \, 10^{8}$ ms$^{-2}$ |

(a) Show that Maxwell's equations reduce to an ordinary differential equation for $E_x$

$$\frac{d^2 E_x(z)}{dz^2} = i\omega\sigma\mu \, E_x(z) \; - \; \omega^2 \mu\varepsilon E_x(z)$$

Clearly explain all assumptions made in your derivation **(8 points)**

(b) Indicate the type of **electric current** that is represented by each term on the right hand side of this equation. At a frequency $f = 10$ Hz, which term is larger? Simplify this equation by discarding the **smaller term**.

**(6 points)**

(c) Find a solution to the equation in (a) of the form $E_x = Ae^{kz}$ where z increases positively into the Earth. Boundary conditions require that $E_x = E_o$ at $z = 0$ m

Derive values for $A$ and $k$. **(6 points)**

(d) The skin depth ($\delta$) is defined as the depth at which $E_x$ has fallen to 1/e it's value at the surface. Show that

$$\delta = \sqrt{\frac{2}{\omega\mu\sigma}} \sim \frac{503}{\sqrt{\sigma f}} \text{ (m)}$$ **(5 points)**

(e) A radio station transmits with wavelength of 740 m. You are listening to the radio in your car when you enter a tunnel.

The depth of the tunnel below the surface of the Earth slowly increases.

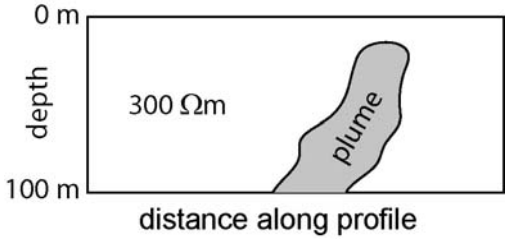
At what depth will you no longer be able to hear the radio? The ground has a resistivity of 100 ohm-m. Reception ceases when the signal is reduced to 0.1% of the surface value. **(5 points)**

## Question 5 : VLF (Total = 13 points)

VLF measurements with an EM16 are being used to locate a plume of saline groundwater that is leaking from a mine. The TX frequency is 21KHz

The plume has the following characteristics:

- Groundwater resistivity in plume = 0.5 Ωm
- Soil porosity = 5%
- Pore space is 50% saturated.




(a) Calculate the **bulk resistivity** in the plume (give possible range) **(5 points)**

(b) Sketch a map of the **ideal orientation** of the VLF profile, primary magnetic field and transmitter. **(4 points)**

(c) Sketch the **tilt angle** data recorded in this orientation. **(2 points)**

(d) The uncontaminated soil has a resistivity of 300 ohm-m. What is the **maximum depth** at which the plume could be detected with VLF. **(2 points)**

## Question 6 : Time domain EM methods (Total = 12 points)

(a) A GEOTEM survey is being conducted at a location where the Earth's magnetic field is **horizontal** and $B_E = 25000$ nT.

The z-axis receiver is in a towed bird that oscillates with an amplitude of $0.5^o$ at a frequency of 0.1 Hz. This receiver is a horizontal loop.

Show that the oscillation causes noise with amplitude = 137 nT/s in $\frac{dB_z}{dt}$ **(6 points)**

(b) The transmitter has a current $I = 1000$ amps and area $A = 100$ m$^2$.

The noise level is that computed in part (a). The Earth has a resistivity of 100 ohm-m. What is the **latest time** at which the decaying signal can be observed? **(4 points)**

(c) What **depth of exploration** does this represent? **(2 points)**

## Question 7 : Time domain EM methods (Total = 18 points)

A time domain survey is using a sawtooth transmitter waveform.

The primary magnetic field is shown on the next page (A)

The ore body ( a conductor) behaves as an inductor and resistor in series.

(a) The secondary voltage induced in the conductor is shown in B.

Explain how the voltage is related to the primary magnetic field. **(4 points)**

(b) Sketch the time variations of the secondary current.

Show both GOOD and BAD conductors on same graph. **(6 points)**

**(c)** Sketch the time variations of the secondary magnetic field at the RX.

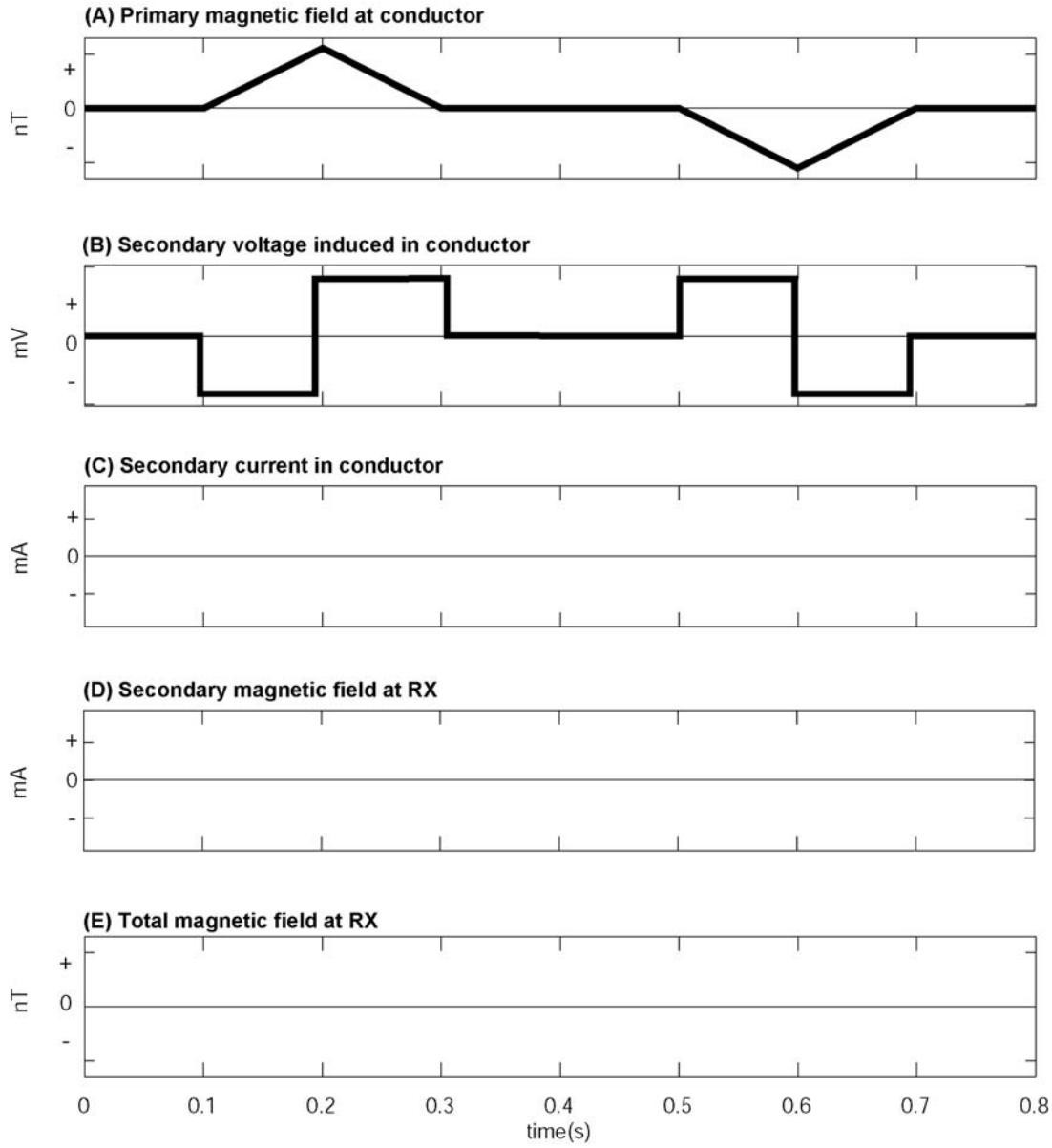
Show both GOOD and BAD conductors on same graph. **(4 points)**

**(d)** Sketch the time variations of the total magnetic field at the RX

Show both GOOD and BAD conductors on same graph. **(4 points)**

Your answer will be **qualitative** in (b) - (d).

Briefly explain how you obtained your answer.


(A) Primary magnetic field at conductor
nT
+
0
-
(B) Secondary voltage induced in conductor
mV
+
0
-
(C) Secondary current in conductor
mA
+
0
-
(D) Secondary magnetic field at RX
mA
+
0
-
(E) Total magnetic field at RX
nT
+
0
-
0
0.1
0.2
0.3
0.4
0.5
0.6
0.7
0.8
time(s)