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(71) Ansøger: **Statoil ASA, N-4035 Stavanger, Norge**

(72) Opfinder: **Lars Ole Løseth, Veimester Kroghs gate 3, N-7043 Trondheim, Norge**
Lasse Amundsen, Hoeggveien 54, N-7036 Trondheim, Norge
Arne Johannes Kaaijk, Klostergata 72 E, N-7030 Trondheim, Norge

(74) Fuldmægtig: **Zacco Norway AS, P.O.Box 2003, Vika, NO-0125 Oslo, Norge**

(54) Benævnelse: **Improved CSEM Survey Method**

(57) Sammendrag:

There is disclosed a method of performing a controlled source electromagnetic survey, which includes in one embodiment deploying a receiver and an electric dipole source. The source defines a dipole axis. An electromagnetic field is transmitted from the electric dipole source. First and second horizontal components of an electromagnetic field response are detected using the receiver. A vertical component of the electromagnetic field response is then estimated using the detected first and second horizontal components of the electromagnetic field response.

fortsættes

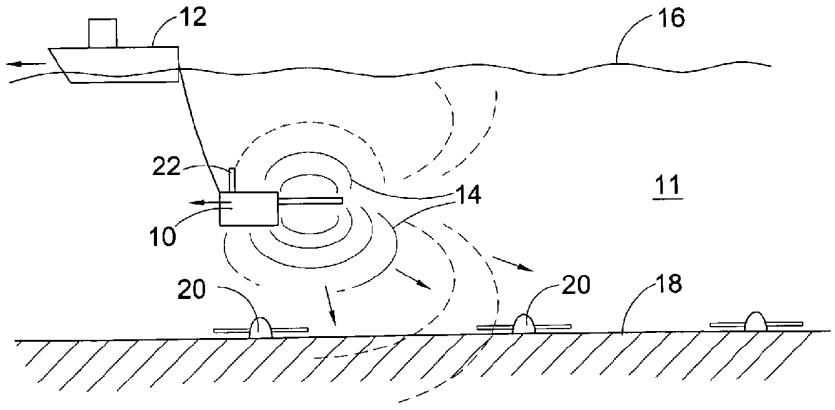


Fig.1

CLAIMS

1. A method of performing a controlled source electromagnetic survey, the method comprising the steps of:
   a. deploying at least one receiver and an electric dipole source;
   b. transmitting an electromagnetic field from the electric dipole source;
   c. detecting a first horizontal component and a second horizontal component of an electromagnetic field response to the transmitted electric field using the at least one receiver; and
   d. estimating a vertical component of the electromagnetic field response using the detected first and second horizontal components of the electromagnetic field response.

2. A method as claimed in claim 1, wherein step d comprises using a weighting factor and the detected horizontal field components to estimate the vertical component.

3. A method as claimed in claim 2, wherein the method includes determining the weighting factor in dependence on at least one property of the medium through which the transmitted electromagnetic field propagates.

4. A method as claimed in claim 3, wherein the at least one property of the medium includes seawater conductivity.

5. A method as claimed in claim 4, including the step of measuring the seawater conductivity.

6. A method as claimed in any one of the preceding claims, wherein step d comprises estimating a weighted difference or sum based on the detected first and second horizontal field components.

7. A method as claimed in any one of the preceding claims, wherein step d includes approximating a horizontal derivative of the electromagnetic field response.

8. A method as claimed in any one of the preceding claims, including the steps of: deploying at least one receiver in a first geographical location and at least one

receiver in a second geographical location; detecting two horizontal components of the electromagnetic field response using the at least one receiver in the first geographical location to form thereby a first set of horizontal components for the first geographical location; detecting two horizontal components of the electromagnetic field response using the at least one receiver in the second geographical location to form thereby a second set of field components for the second location; and estimating the at least one vertical field component by forming a weighted sum or difference using the first and second sets of detected first and second horizontal field components from the first and second geographical locations.

9. A method as claimed in claim 8, wherein the two detected horizontal components in each of the first and second sets are orthogonal components.

10. A method as claimed in claim 8 or 9, including the steps of: processing the detected first set of horizontal components of the field to form at least one first processed horizontal component of the field response for the first geographical location in a direction defined along a pre-determined axis; processing the detected second set of horizontal components of the field to form at least one second processed horizontal field component for the second geographical location in a direction defined along the same pre-determined axis; and forming the weighted sum or difference by forming a sum or difference between of the at least one first and second processed horizontal field components derived for the first and second geographical locations.

11. A method as claimed in any one of claims 8 to 10, wherein the at least one first processed field horizontal component of the field response comprises two first processed horizontal components which are orthogonal; and the at least one second processed component of the field response comprises two second processed horizontal components which are orthogonal, wherein the first and second processed horizontal components for the first and second geographical locations provide corresponding components of the field response.

12. A method as claimed in any one of claims 8 to 11, wherein the first and second geographical locations are spaced apart by a distance of more than around 100 m.

13. A method as claimed in any one of claims 8 to 12, wherein the first and second geographical locations are spaced apart by a distance of between around 200 to 1000 m.

14. A method as claimed in any one of the preceding claims, wherein the method includes deploying at least one receiver in at least three different geographical locations wherein the first and second locations are on a line extending at least between first and second locations and the third geographical location is located off said line; detecting at least two horizontal orthogonal components of the electromagnetic field response using the at least one receiver to thereby form a set of orthogonal components at each location; processing the detected set of components for each location to derive at least one processed set of orthogonal horizontal components for each location, such that the processed sets of orthogonal horizontal components comprise corresponding components of the electromagnetic field response for each location; and estimating vertical magnetic and vertical electric components of the electromagnetic field response includes differencing or summing the processed horizontal components from different geographical locations defined along the same axis direction.

15. A method as claimed in any one of the preceding claims, wherein the estimated vertical component of the electromagnetic field is selected from the group consisting of: a vertical electric (E_z) component; a vertical magnetic (H_z) component; a vertical derivative of the vertical electric field component; and a vertical derivative of the vertical magnetic field component.

16. A method as claimed in any one of the preceding claims, wherein the electric dipole source is a vertical or horizontal electric dipole source.

17. A method as claimed in any one of the preceding claims, deploying at least one receiver includes deploying first and second receivers to form a first receiver pair on a first receiver line extending at least between the first and second receivers, and deploying third and fourth receivers to form a second receiver pair on a second receiver line extending at least between the third and fourth receivers, and arranging the first and second receiver pairs so that the first and second receiver lines intersect.

18. A method as claimed in claim 17, including the step of deploying at least the first or second receiver and the third or fourth receiver in a common receiver unit at a first deployment locality.

19. A method as claimed in claim 17 or 18, including the step of arranging the first and second receiver pairs so that the first and second receiver lines are arranged orthogonally.

20. A method as claimed in any one of claims 17 to 19, including the step of detecting a first horizontal component of the electromagnetic field response in a direction defined along the first receiver line and detecting a second horizontal component of the electromagnetic field response in a direction defined along the second receiver line.

21. A method as claimed in any one of the preceding claims, wherein the source is a horizontal dipole source, the source defining a dipole axis, and the method includes the step of arranging the horizontal electric dipole source to form an acute angle between the dipole axis and a line extending between the source and the at least one receiver.

22. Apparatus for performing a controlled source electromagnetic survey, comprising:

an electric dipole source having a dipole axis and arranged to transmit an electromagnetic field;

at least one receiver adapted to detect a first horizontal component and a second horizontal component of an electromagnetic field response; and

a processing unit operative to estimate a vertical component of the electromagnetic field response the detected first and second horizontal components of the response.

23. A method of processing controlled source electromagnetic data, comprising the steps of:

a. providing data comprising first and second horizontal components of an electromagnetic field response detected by at least one receiver deployed in a controlled source electromagnetic survey in which an electromagnetic field is transmitted by an electric dipole source; and

b. processing the data to estimate a vertical component of the electromagnetic field response from the first and second horizontal components of the response.

24. A computer program for processing controlled source electromagnetic data, the data comprising first and second horizontal components of an electromagnetic field response detected by at least one receiver deployed in a controlled source electromagnetic survey in which an electromagnetic field is transmitted by an electric dipole source, whereby the data are read in and processed to estimate a vertical component of the electromagnetic field response from the first and second horizontal components of the response.

25. A computer loaded with machine-readable instructions for the computer to perform processing of controlled source electromagnetic data, the data comprising first and second horizontal components of an electromagnetic field response detected by at least one receiver deployed in a controlled source electromagnetic survey in which an electromagnetic field is transmitted by an electric dipole source, whereby data are read in and processed by the computer according to the instructions to estimate a vertical component of the electromagnetic field response from the first and second horizontal components of the response.

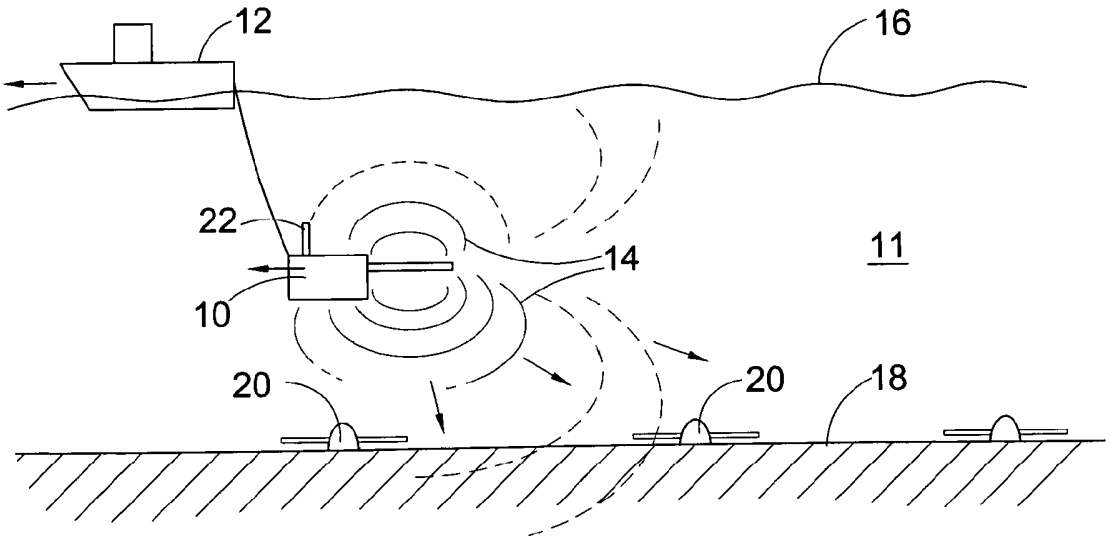


Fig.1

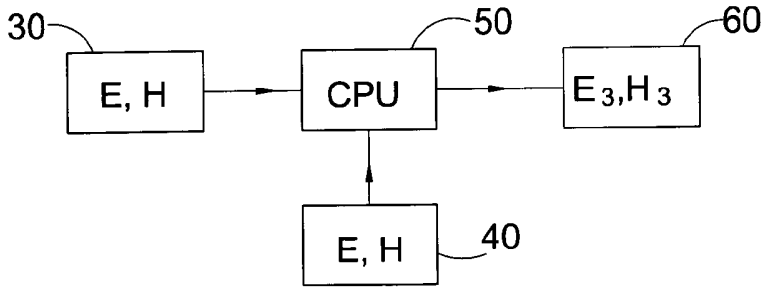


Fig.2

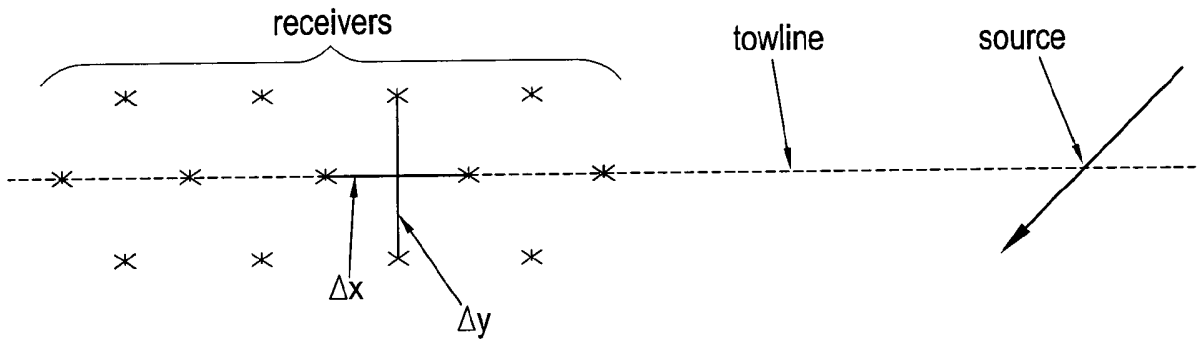

receivers
towline
source
Δx
Δy

Fig.3

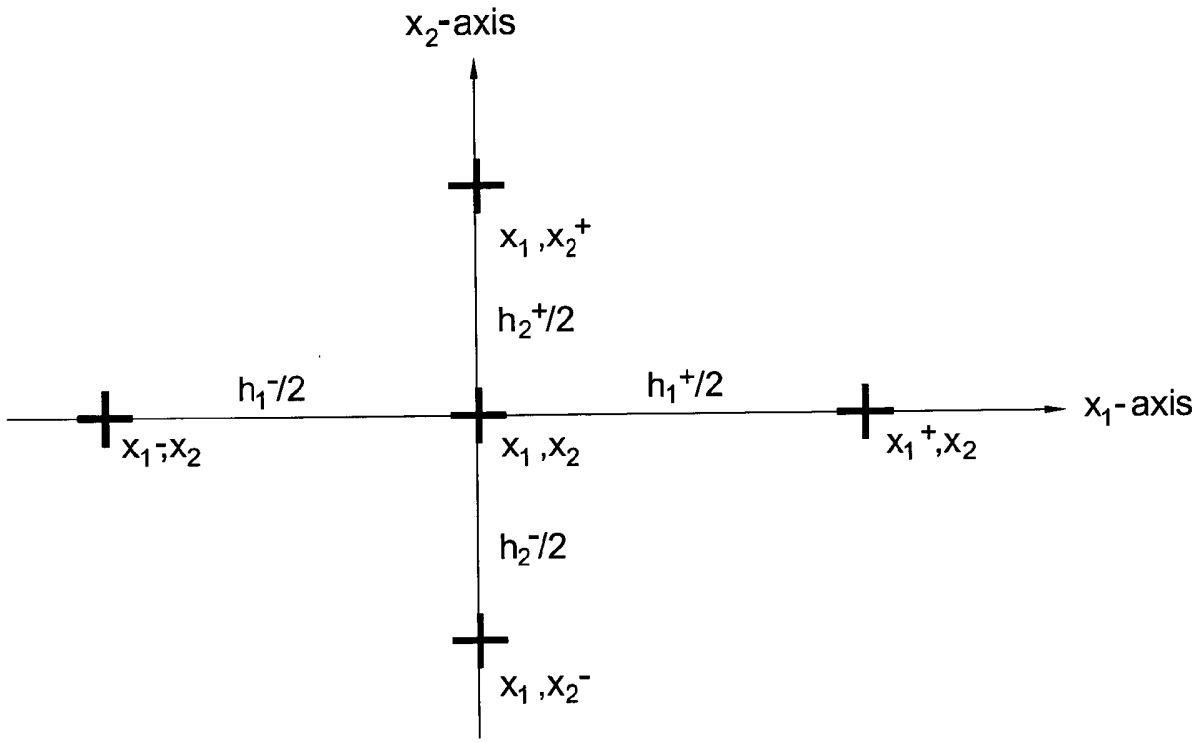

x2-axis
x1 ,x2+
h2+/2
h1-/2
h1+/2
x1-axis
x1-,x2
x1 ,x2
x1+,x2
h2-/2
x1 ,x2-

Fig.4

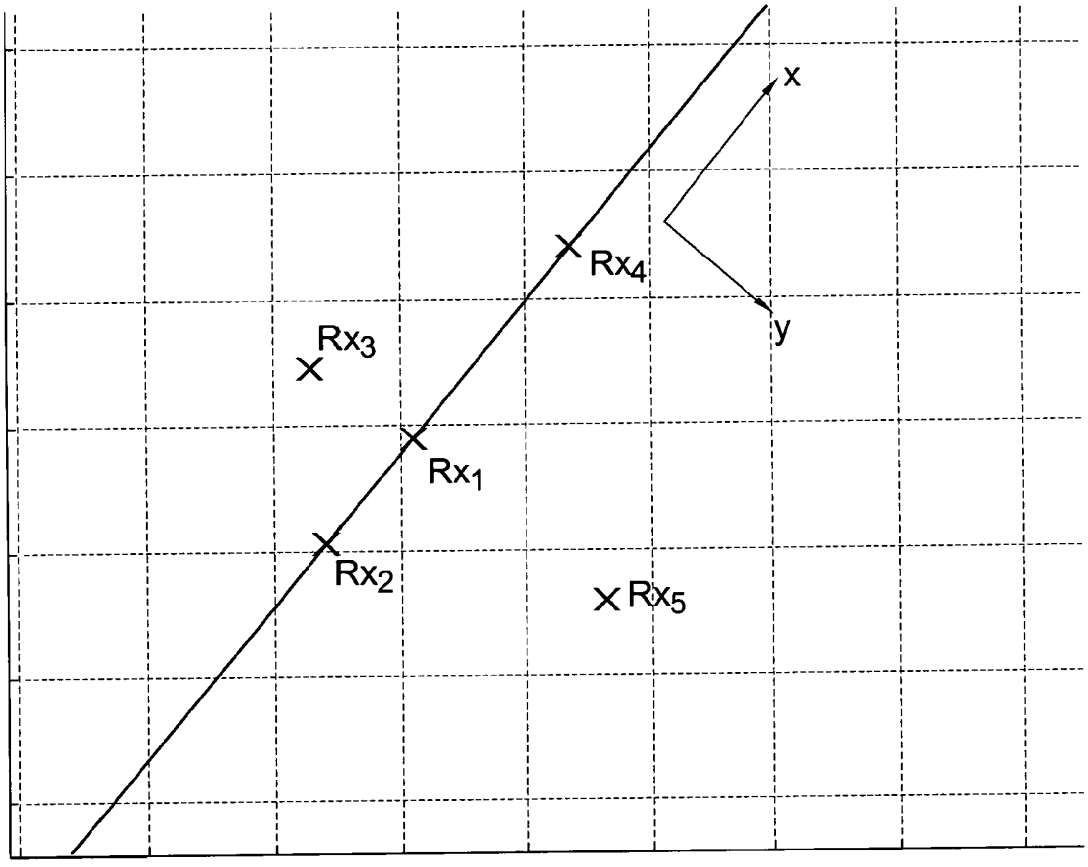


Fig.5

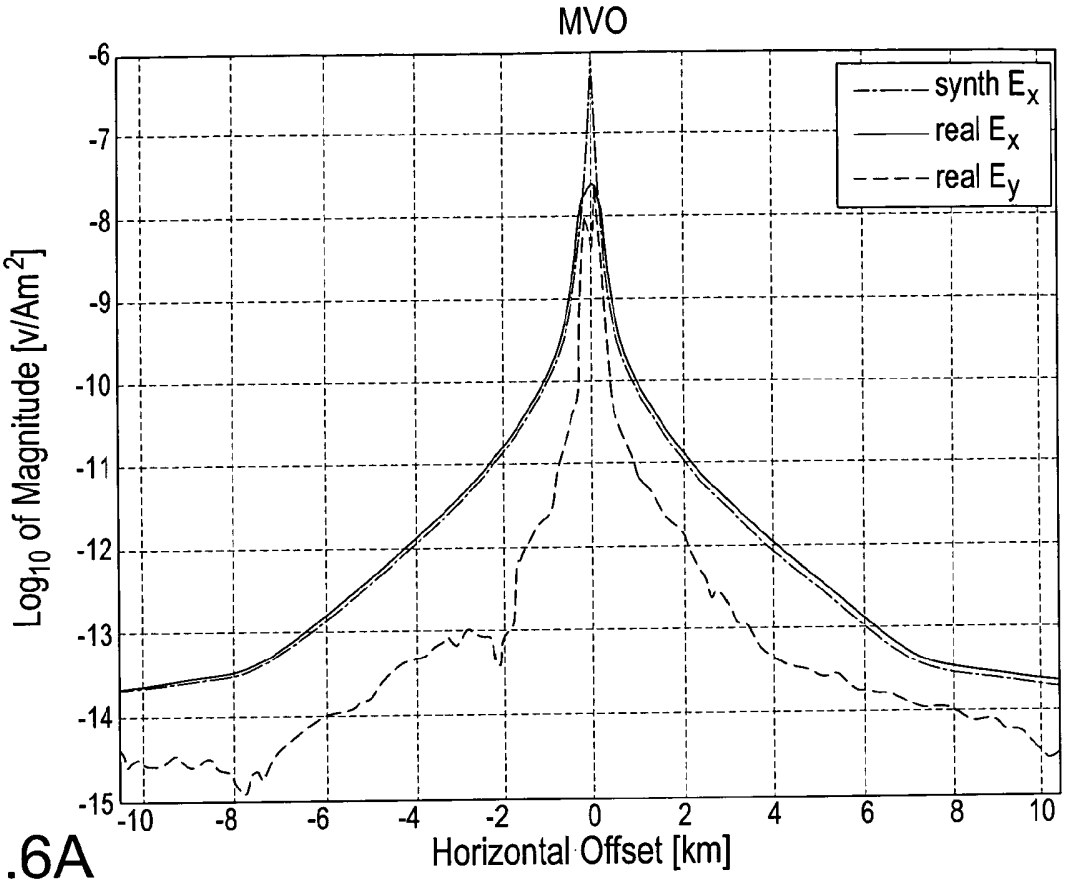

MVO
synth E_x
real E_x
real E_y
Log_{10} of Magnitude [v/Am^2]
Horizontal Offset [km]

Fig.6A

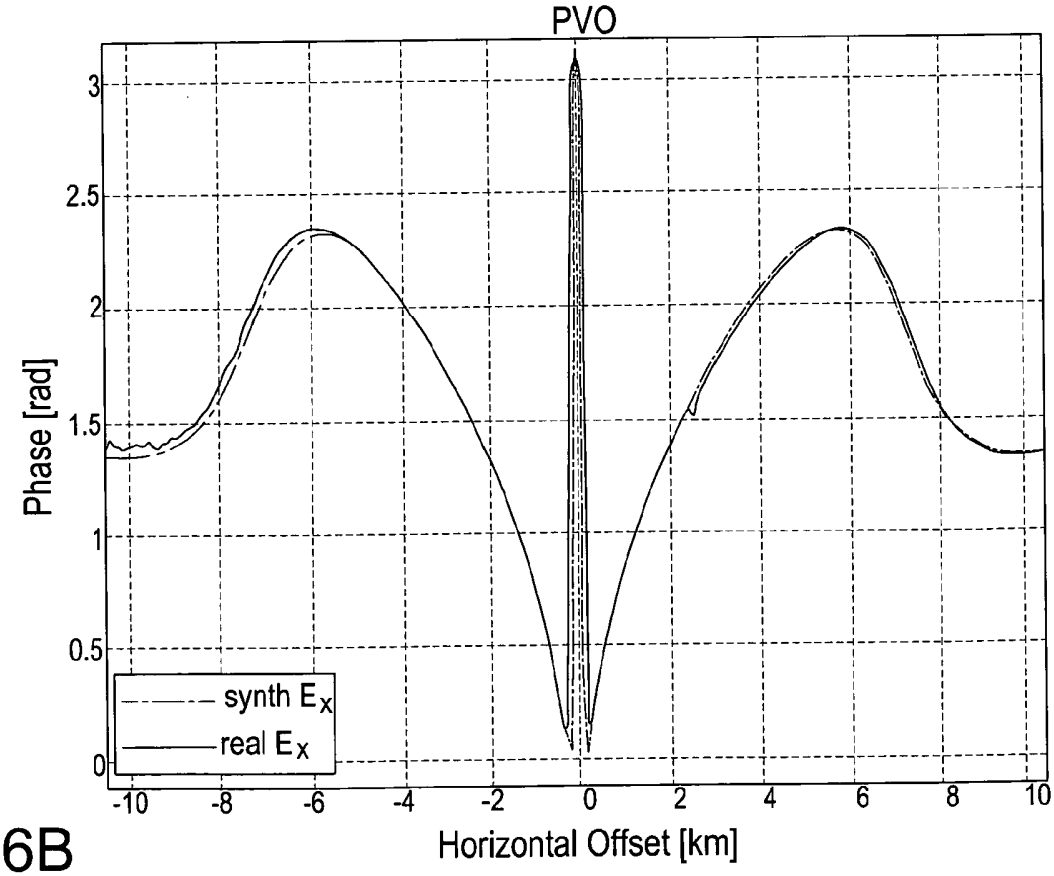

PVO
synth E_x
real E_x
Phase [rad]
Horizontal Offset [km]

Fig.6B

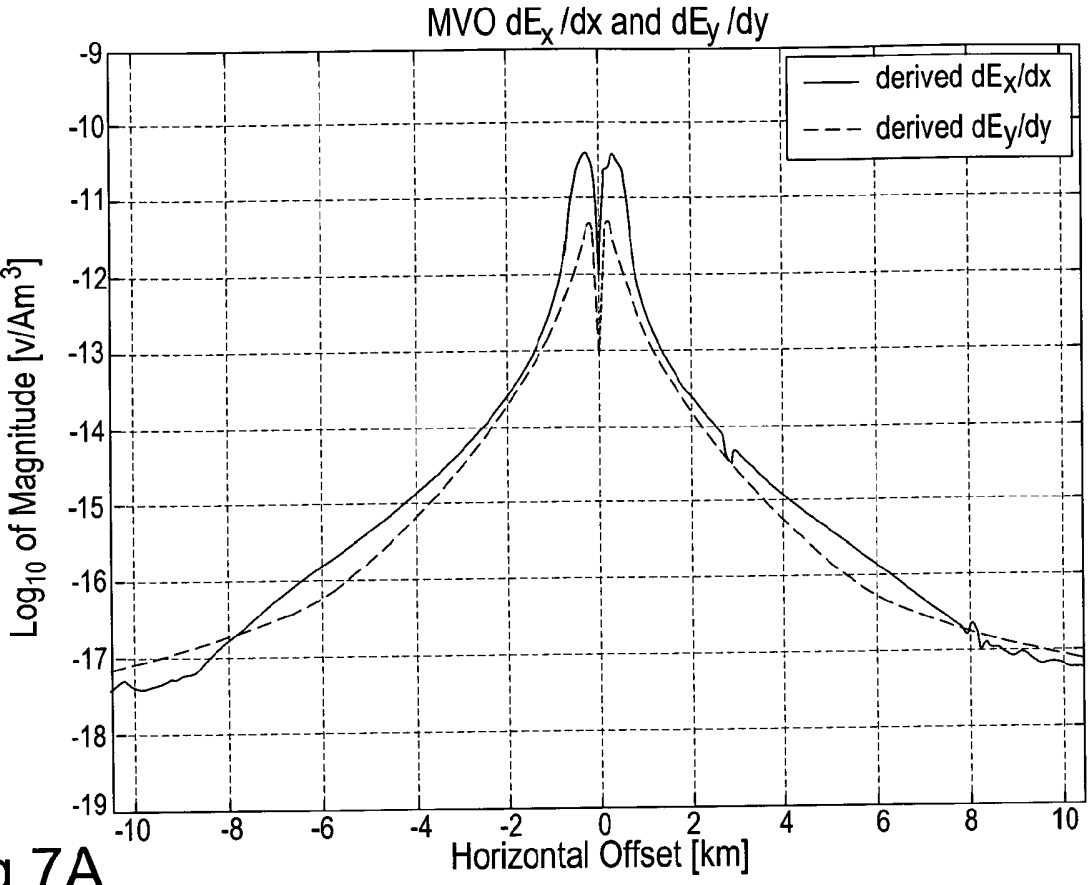

MVO dEx /dx and dEy /dy
derived dEx/dx
derived dEy/dy
Log10 of Magnitude [v/Am3]
-9
-10
-11
-12
-13
-14
-15
-16
-17
-18
-19
-10
-8
-6
-4
-2
0
2
4
6
8
10
Horizontal Offset [km]

Fig.7A

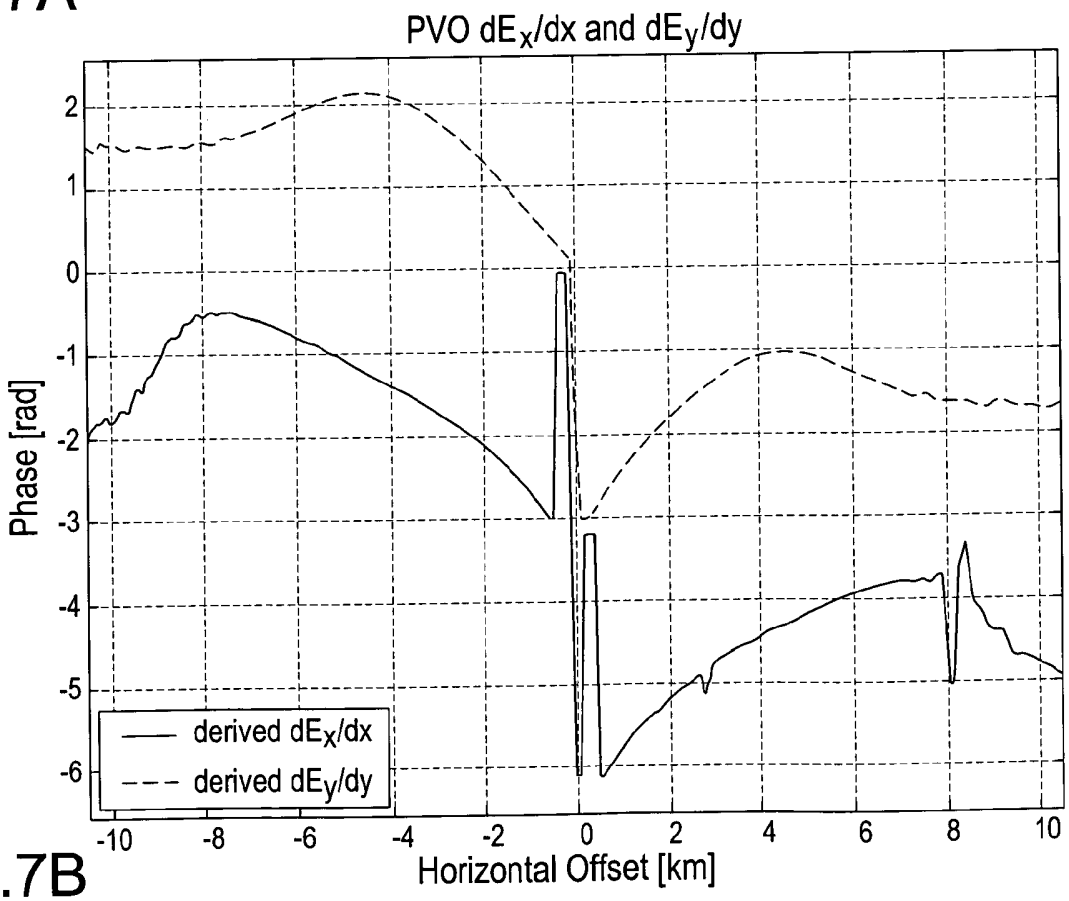

PVO dEx/dx and dEy/dy
Phase [rad]
2
1
0
-1
-2
-3
-4
-5
-6
derived dEx/dx
derived dEy/dy
-10
-8
-6
-4
-2
0
2
4
6
8
10
Horizontal Offset [km]

Fig.7B

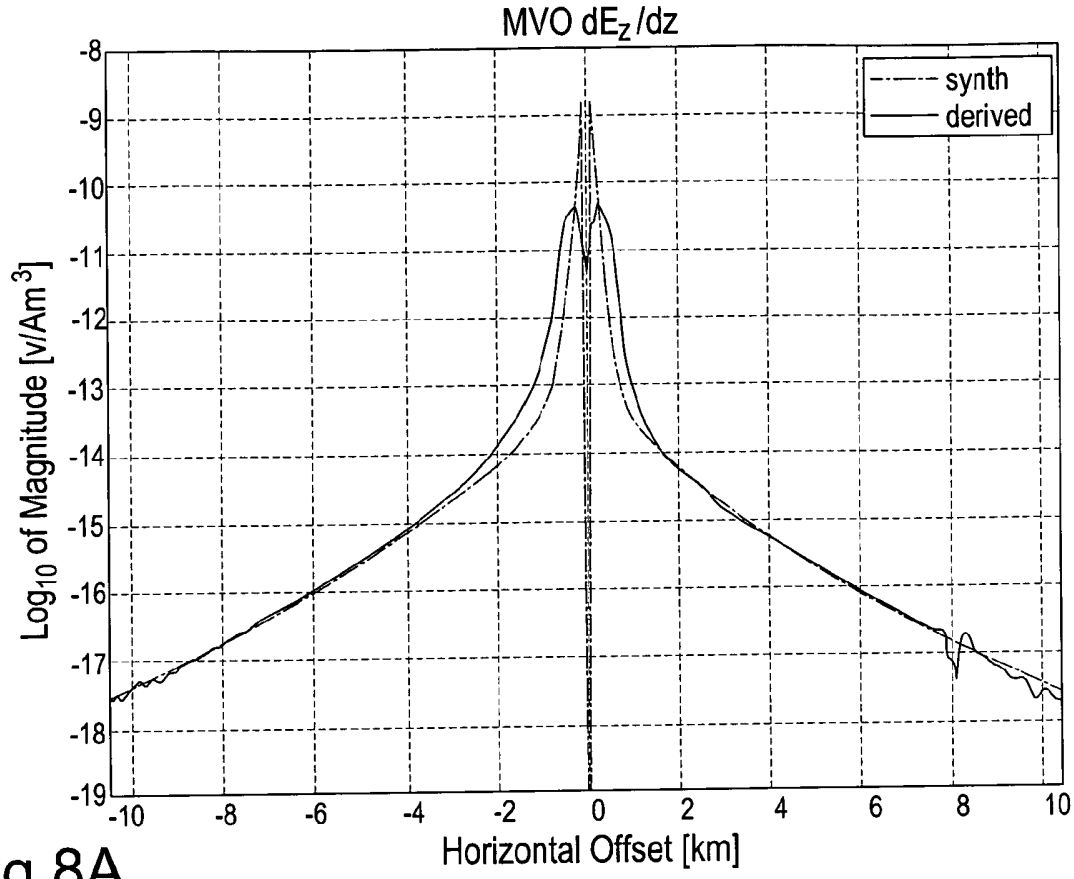

MVO dE$_z$/dz
synth
derived
Log$_{10}$ of Magnitude [v/Am^3]
-8
-9
-10
-11
-12
-13
-14
-15
-16
-17
-18
-19
-10
-8
-6
-4
-2
0
2
4
6
8
10
Horizontal Offset [km]

Fig.8A

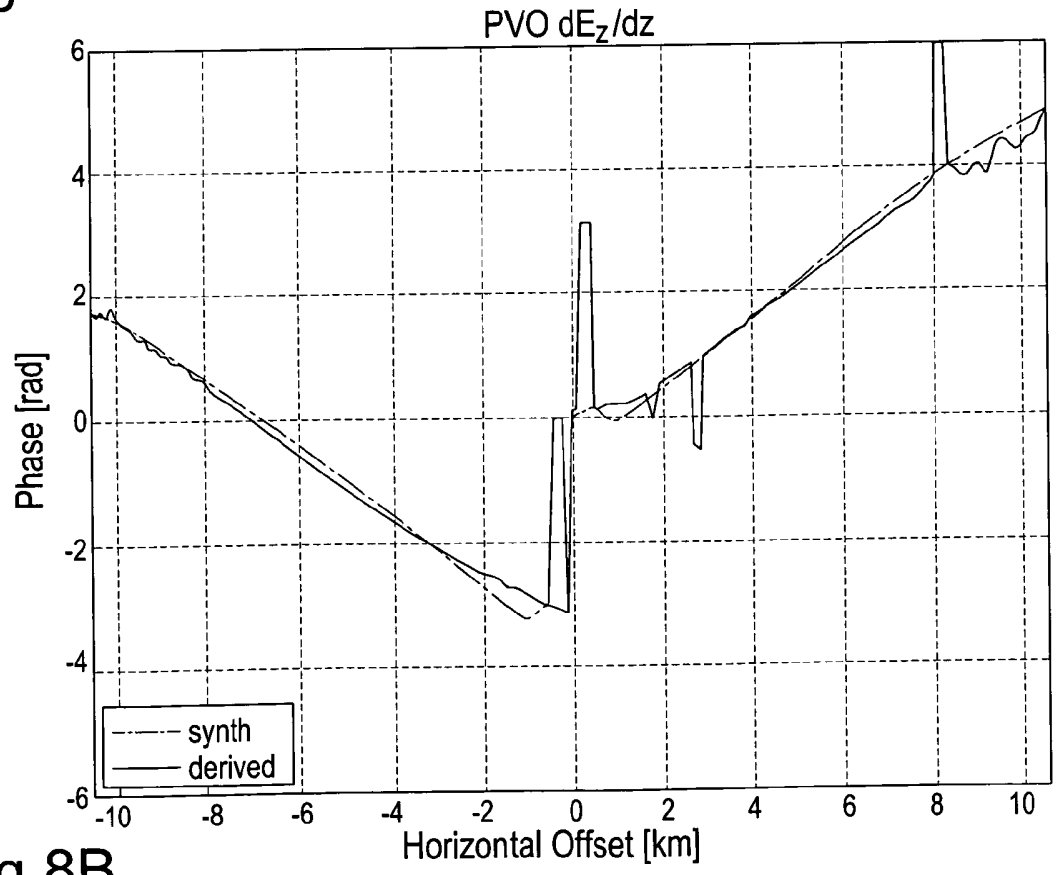

PVO dE$_z$/dz
Phase [rad]
6
4
2
0
-2
-4
-6
synth
derived
-10
-8
-6
-4
-2
0
2
4
6
8
10
Horizontal Offset [km]

Fig.8B

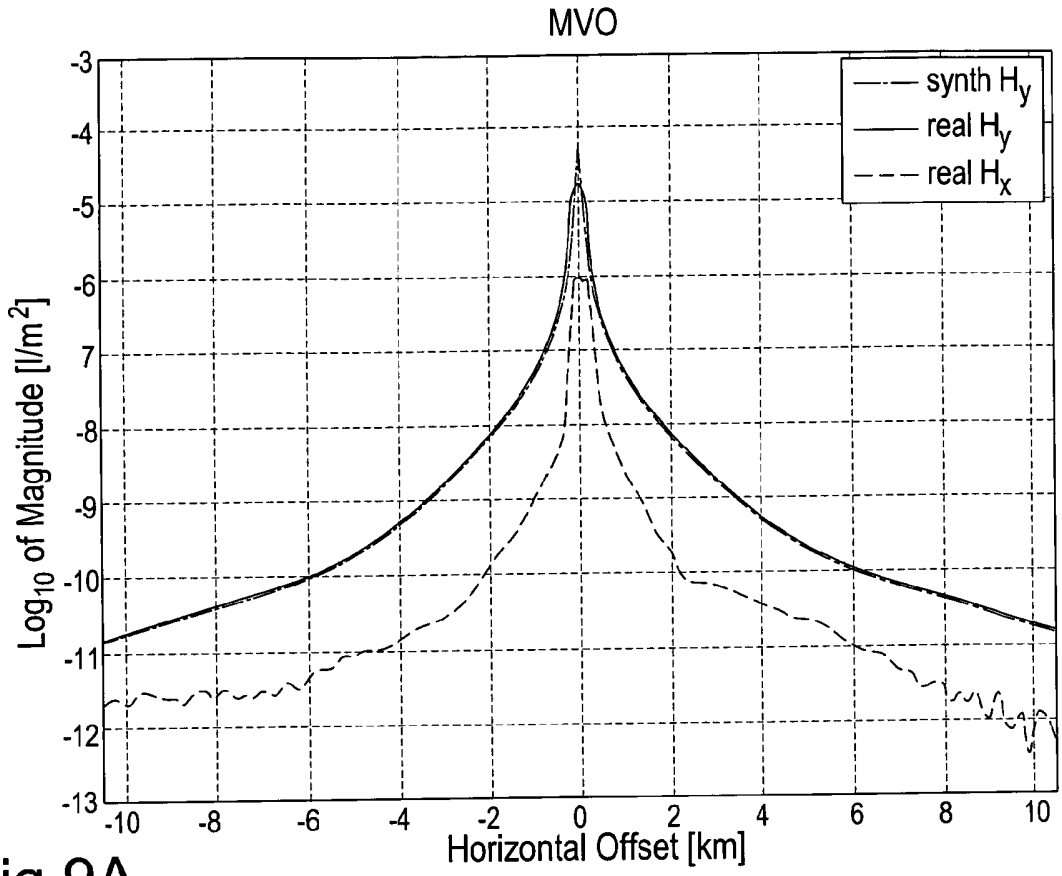

MVO
synth H_y
real H_y
real H_x
Log_{10} of Magnitude [I/m^2]
Horizontal Offset [km]

Fig.9A

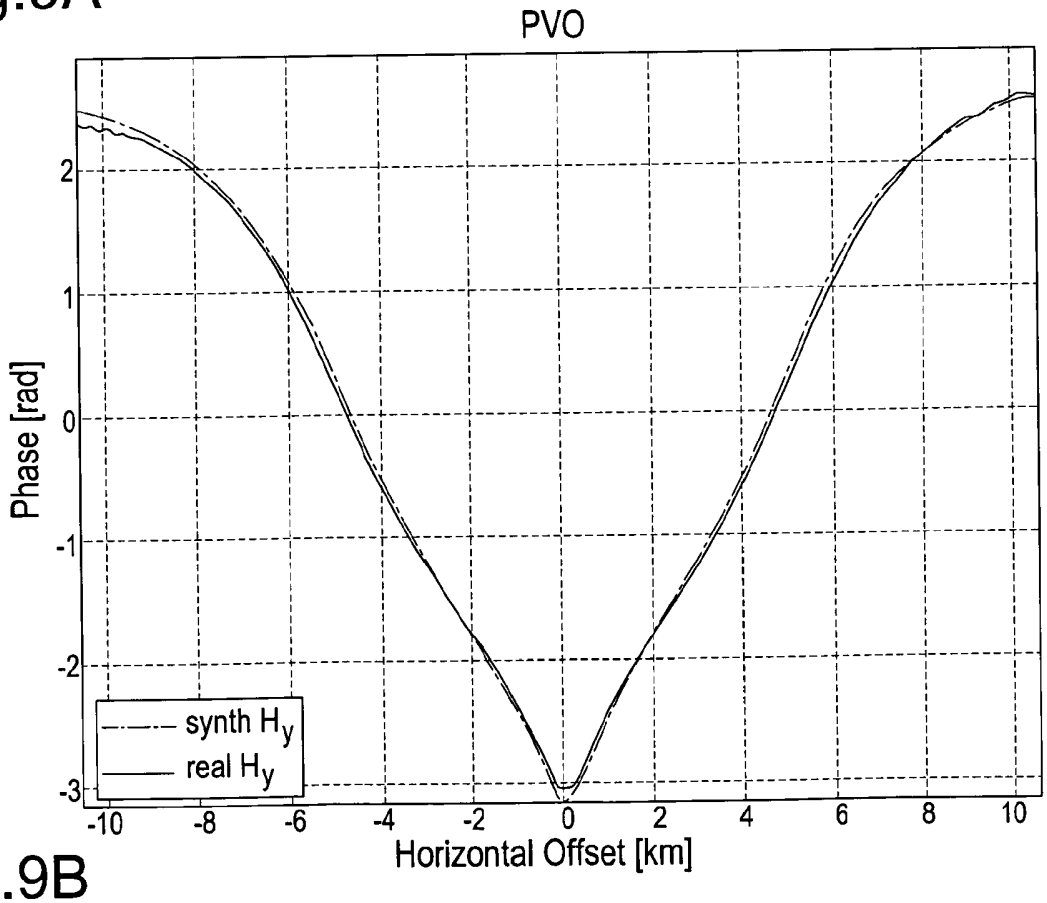

PVO
synth H_y
real H_y
Phase [rad]
Horizontal Offset [km]

Fig.9B

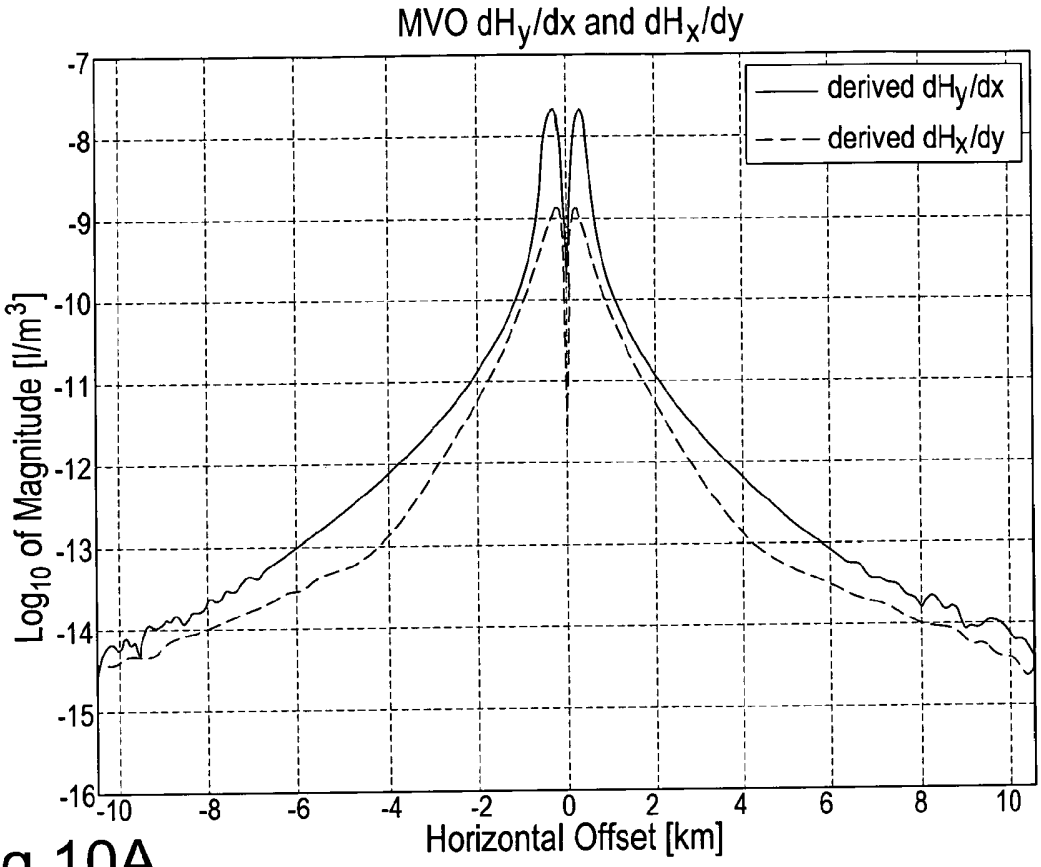


Fig.10A

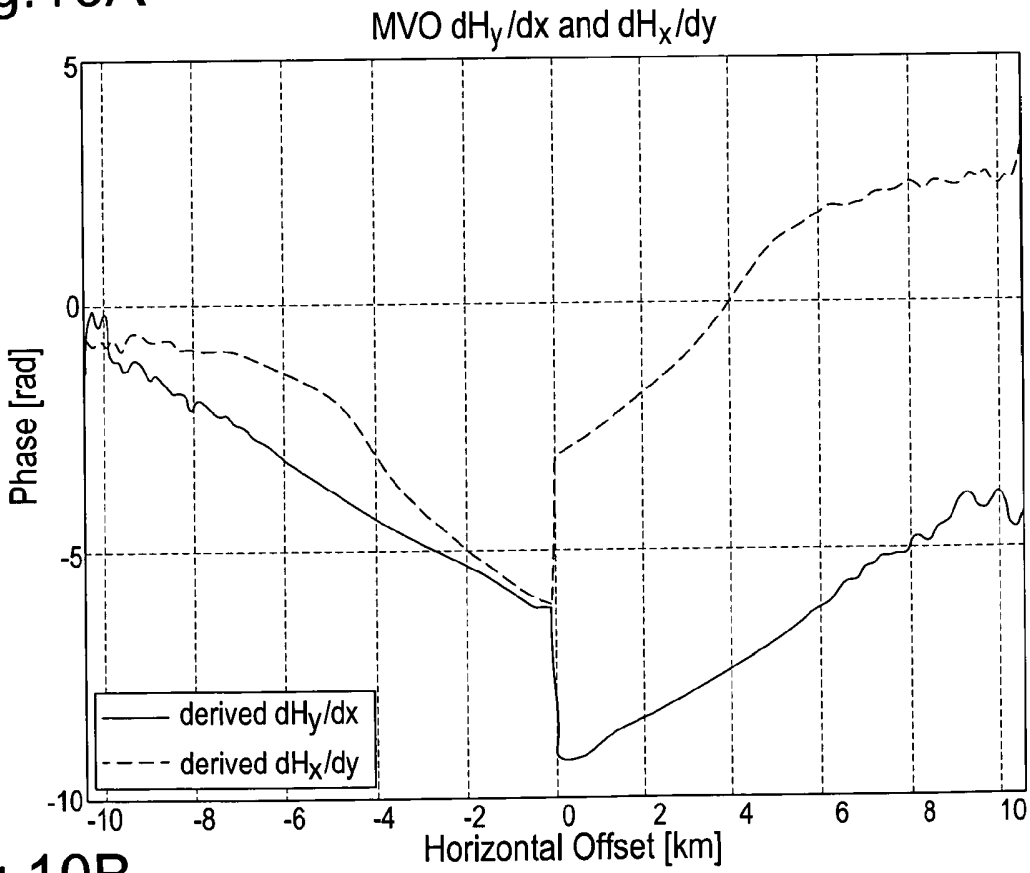


Fig.10B

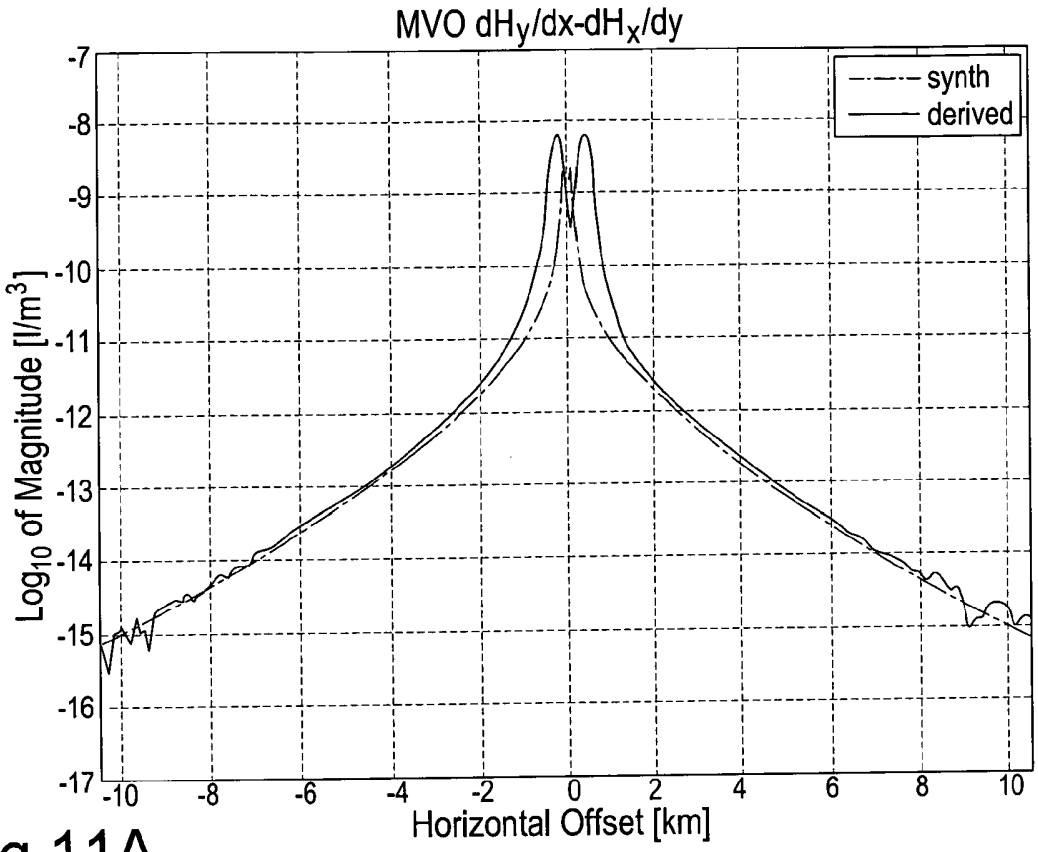


Fig.11A

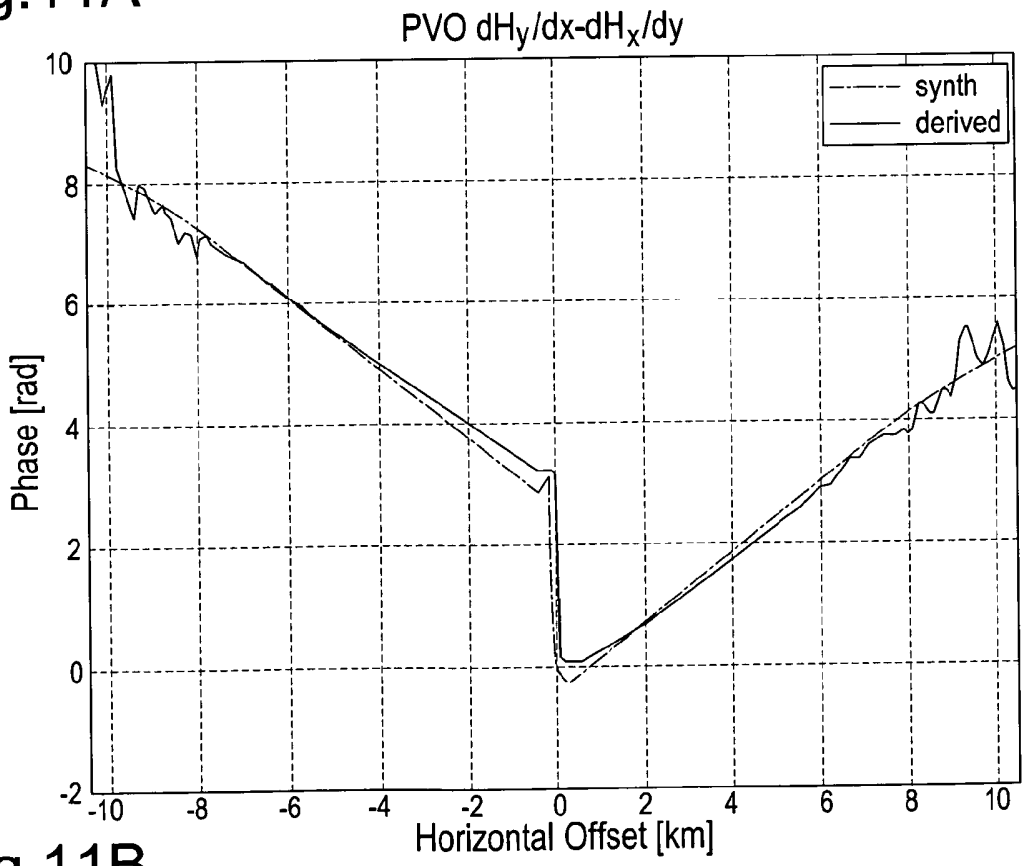


Fig.11B

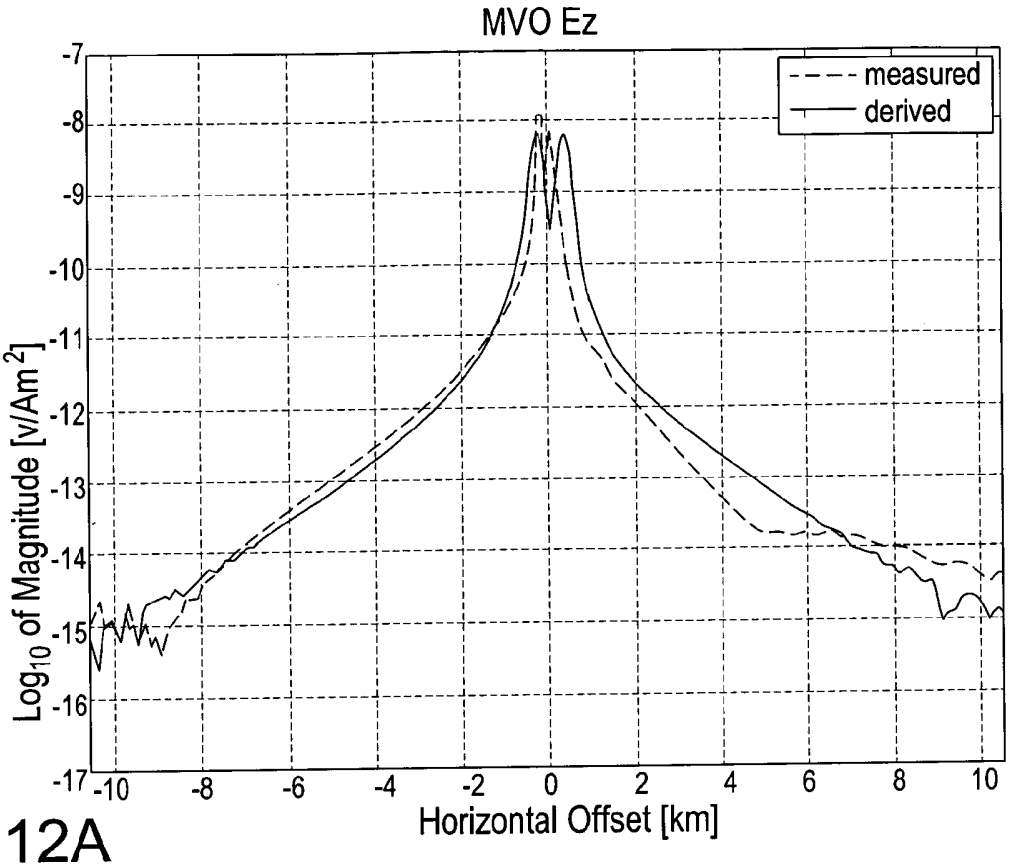


Fig.12A

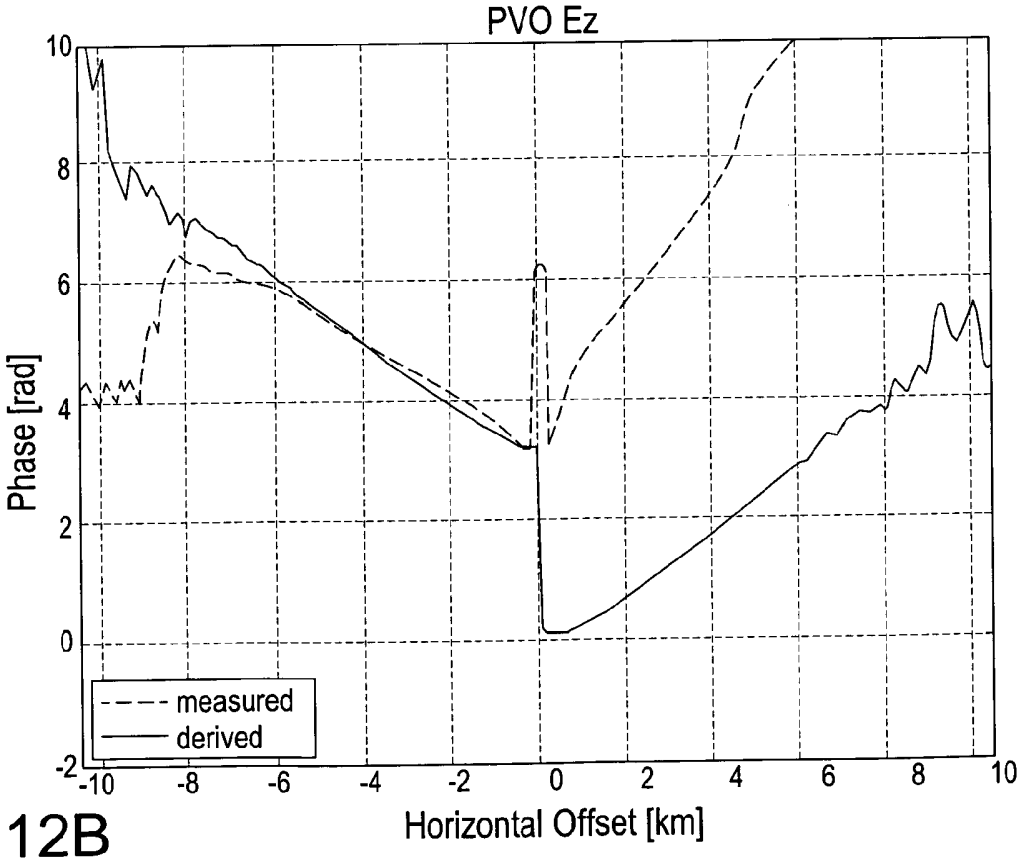


Fig.12B