



(43) International Publication Date
24 April 2014 (24.04.2014)

(10) International Publication Number
WO 2014/062826 A1

(51) International Patent Classification:
G01V 1/38 (2006.01)

(21) International Application Number:
PCT/US2013/065275

(22) International Filing Date:
16 October 2013 (16.10.2013)

(25) Filing Language: English

(26) Publication Language: English

(30) Priority Data:
61/714,308 16 October 2012 (16.10.2012) US
14/055,507 16 October 2013 (16.10.2013) US

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(81) Designated States (*unless otherwise indicated, for every
kind of national protection available*): AE, AG, AL, AM,
AO, AT, AU, AZ, BA, BB, BG, BH, BN, BR, BW, BY,
BZ, CA, CH, CL, CN, CO, CR, CU, CZ, DE, DK, DM,
DO, DZ, EC, EE, EG, ES, FI, GB, GD, GE, GH, GM, GT,
HN, HR, HU, ID, IL, IN, IR, IS, JP, KE, KG, KN, KP, KR,
KZ, LA, LC, LK, LR, LS, LT, LU, LY, MA, MD, ME,
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OM, PA, PE, PG, PH, PL, PT, QA, RO, RS, RU, RW, SA,
SC, SD, SE, SG, SK, SL, SM, ST, SV, SY, TH, TJ, TM,
TN, TR, TT, TZ, UA, UG, US, UZ, VC, VN, ZA, ZM,
ZW.

(84) Designated States (*unless otherwise indicated, for every
kind of regional protection available*): ARIPO (BW, GH,
GM, KE, LR, LS, MW, MZ, NA, RW, SD, SL, SZ, TZ,
UG, ZM, ZW), Eurasian (AM, AZ, BY, KG, KZ, RU, TJ,
TM), European (AL, AT, BE, BG, CH, CY, CZ, DE, DK,
EE, ES, FI, FR, GB, GR, HR, HU, IE, IS, IT, LT, LU, LV,
MC, MK, MT, NL, NO, PL, PT, RO, RS, SE, SI, SK, SM,
TR), OAPI (BF, BJ, CF, CG, CI, CM, GA, GN, GQ, GW,
KM, ML, MR, NE, SN, TD, TG).

Published:

— with international search report (Art. 21(3))

(54) Title: FLARED PSEUDO-RANDOM SPIRAL MARINE ACQUISITION

(57) Abstract: A method for acquisition of seismic data in a marine environment. The present invention relates generally to a meth-
od for acquisition of seismic data in a marine environment. More particularly, but not by way of limitation, embodiments of the
present invention include a method for acquiring seismic data in a marine environment using survey paths following spiral shooting
paths.



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FLARED PSEUDO-RANDOM SPIRAL MARINE ACQUISITION

FIELD OF THE INVENTION

[0001] The present invention relates generally to a method for acquisition of seismic data in a marine environment. More particularly, but not by way of limitation, embodiments of the present invention include a method for acquiring seismic data in a marine environment using survey paths following spiral shooting paths.

BACKGROUND OF THE INVENTION

[0002] Marine seismic exploration investigates and maps the structure and character of subsurface geological formations underlying a body of water. Marine seismic data is typically gathered by towing seismic sources (e.g., air guns) and seismic receivers (e.g., hydrophones) through a body of water behind one or more marine vessels. As the seismic sources and receivers are towed through the water, the seismic sources generate acoustic energy that travel through the water and into the earth, where they are reflected and refracted by interfaces between subsurface geological formations. The seismic receivers detect the resulting reflected and refracted energy, thus acquiring seismic data that provides seismic information about the geological foundations underlying the body of water.

[0003] Typically, large arrays of seismic receivers, often numbering in the thousands, are used to gather marine seismic data. The seismic receivers are generally attached to and spaced apart along streamer cables that are towed behind a marine vessel.

[0004] By way of illustration of such a system, Figure 1 shows a simplified depiction of a conventional marine seismic data acquisition system employing a marine vessel 10 to tow seismic sources 12 and a system 14 of steerable seismic streamers 16 through a body of water 18.

[0005] Each of seismic streamers 16 includes a streamer cable 20, a series of seismic receivers 22 and a series of steering devices 24 coupled to cable 20. Relative positions of the marine seismic receivers during seismic data acquisition can affect the quality and utility of the resulting seismic data. However, unpredictable environmental forces such as currents, winds, and sea states present in many marine environments can cause the relative positions of marine seismic receivers to vary greatly as they are towed through the water. Therefore, it is common for steering devices (commonly known as “birds”) to be attached to the streamer cables so that the relative positions (both lateral and vertical) of the seismic receivers can be controlled as they are

towed through the water. As depicted in Figure 1, during conventional marine seismic acquisition, steering devices 24 are used to maintain substantially constant lateral spacing between seismic streamers 16.

[0006] As a further illustration of typical marine seismic systems, Figure 2 illustrates a side view of marine vessel 10 towing one or more streamers 12 having seismic sources 12 () and/or seismic receivers 22 (O) through body of water 18 to acquire seismic data for a subterranean geological formation region of interest 26 of geological formation 25.

[0007] As marine vessel 10 tows seismic sources 12 and receivers 22 through body of water 18, seismic sources 12 are simultaneously excited, which generate acoustic wave energy that propagates down through water 18 and into geological formation 25. The acoustic wave energy is then reflected and refracted by interfaces between strata of geological formation 25. The resulting reflected/refracted seismic energy then passes upwardly through water 18 and is detected by seismic receivers 22. Additional passes are then conducted to survey additional points of interest. The seismic data detected by seismic receivers 22 then provides seismic information representative of subterranean geological formation of interest 26.

[0008] A common problem encountered with conventional marine seismic surveys is “gaps” in the acquired seismic data. These data gaps can occur when the spacing between adjacent acquisition passes is too large to provide sufficient resolution for proper data processing. Gaps in seismic data can be caused by a number of factors including, for example, skewing of the seismic streamers relative to the direction of travel of the towing vessel during data acquisition. Even when steerable streamers are employed, gaps in seismic data are common, particularly when strong crosscurrents are present. When strong crosscurrents are present during seismic data acquisition, it is not practical to maintain all the streamers in desired orientation, because fighting strong crosscurrents with steering devices may produce noise that dramatically reduces the quality of the gathered seismic data.

[0009] When gaps in marine seismic data are discovered, if the data gaps cannot be filled by post-acquisition interpolation methods, the areas corresponding to the data gaps must be resurveyed, a process commonly known as “shooting in-fill” or “in-filling.” Unfortunately, the existence of gaps in marine seismic data may not be discovered until the initial marine seismic survey has been completed and the resulting seismic data is being processed. Obviously, in-filling is highly undesirable because of the significant expense and time involved in resurveying

in-fill areas that may be located hundreds of kilometers from one another or even retransiting the same vessel pass again to make up coverage.

[0010] Traditionally, marine seismic surveys using the systems depicted in Figures 1 and 2 above are conducted using a series of straight line sail paths across a region of interest. That is, under conventional methods, a marine vessel and its corresponding streamers sail back and forth across a geological region of interest, incrementally moving each subsequent pass or sweep over slightly until all of the combined paths have covered the survey region of interest. In this way, traditional seismic surveys follow a survey path similar to the path followed by one mowing a rectangular section of lawn with a lawn mower, namely, a back and forth straight line path that is moved over incrementally each pass until the entire section of lawn is covered.

[0011] Referring again to Figure 1, traditional marine seismic survey systems employ a set of streamers where the lateral distance (d_f) of the forward-most seismic receivers is equivalent to the lateral distance (d_r) of the rearward-most seismic receivers. Thus, in surveying a region of interest, a marine vessel 10 will typically employ a back and forth path across a geological region of interest, moving each pass or sweep over by roughly a distance of $\frac{1}{2}d_f$ to a distance of about $1 d_f$ until the entire region of interest is surveyed. As will be seen below, this method of surveying suffers from a poor randomization and distribution of source point locations and receivers throughout the survey area. For example, for a ten streamer setup with dual sources towed by the streamer vessel, d_f might be about 900m but each sail line would move over about 500m. Accordingly, this poor randomization and distribution results in a decreased effectiveness of post-acquisition interpolation methods for filling in seismic data gaps in the acquired data.

[0012] Consequently, this method of surveying with a series of straight paths across a region is a highly inefficient way of gathering off-set and azimuth distributions. Using conventional methods to acquire wide azimuth distributions requires multiple passes down the same line with multiple boats, usually a single streamer vessel and multiple source vessels or two streamer vessels and multiple source vessels. Even using multiple passes and multiple vessels, the azimuth distribution acquired is still limited in certain directions. In this way, conventional methods of seismic surveys fail to provide full offset and azimuth data and further fail to optimize the randomization of the offset and azimuth data available. Accordingly, conventional methods of surveying a region are unnecessarily more costly in terms of both time and direct survey costs. Indeed, the cost of acquiring wide-azimuth data essentially increases by the cost of

the number of passes required down each sail line to obtain the azimuth range required. For conventional marine surveys that are not wide azimuth, costs can be increased by as much as 50% by infill needs.

[0013] Accordingly, there is a need in the art for improved seismic survey method that address one or more disadvantages of the prior art.

SUMMARY OF THE INVENTION

[0014] In an embodiment, a method for acquiring seismic data for a subsea region of the earth includes: providing a marine seismic vessel and a plurality of steerable seismic streamers, wherein the plurality of steerable seismic streamers are coupled to the marine seismic vessel for towing, wherein each steerable seismic streamer comprises a plurality of marine seismic receivers spaced apart along the length of each steerable seismic streamer; providing a plurality of marine seismic sources; towing the steerable seismic streamers through the marine environment such that the marine seismic vessel and the steerable seismic streamers travel substantially along a continuous spiral paths; exciting at least one of the marine seismic sources simultaneously with the step of towing the steerable seismic streamers so as to cause acoustic wave energy to travel through the marine environment into the subsea region of the earth; allowing the acoustic wave energy to reflect and refract from the subsea region so as to form reflected and refracted wave energy; and detecting the reflected and refracted wave energy with the marine seismic receivers as to form detected seismic data.

BRIEF DESCRIPTION OF THE DRAWINGS

[0015] The invention, together with further advantages thereof, may best be understood by reference to the following description taken in conjunction with the accompanying drawings in which:

[0016] FIG. 1 illustrates a simplified overhead depiction of a conventional marine seismic acquisition system where the lateral spacing between the streamers is substantially constant over the entire length of streamers.

[0017] FIG. 2 illustrates a side view of a marine vessel towing a plurality of marine seismic sources and a plurality of marine seismic receivers for conducting seismic surveys of a subsea region of the earth.

DETAILED DESCRIPTION OF THE INVENTION

[0018] Reference will now be made in detail to embodiments of the present invention, one or more examples of which may be illustrated in the accompanying drawings. Each example is provided by way of explanation of the invention, not as a limitation of the invention. It will be apparent to those skilled in the art that various modifications and variations can be made in the present invention without departing from the scope or spirit of the invention. For instance, features illustrated or described as part of one embodiment can be used in another embodiment to yield a still further embodiment. Thus, it is intended that the present invention cover such modifications and variations that come within the scope of the appended claims and their equivalents.

[0019] The present invention relates generally to a method for acquisition of seismic data in a marine environment. More particularly, but not by way of limitation, embodiments of the present invention include methods for acquiring seismic data in a marine environment using survey paths following a continuous spiral path.

[0020] A method is provided for acquiring wide azimuth seismic data over a subsurface target. In certain embodiments, at least one marine streamer vessel towing multiple seismic streamers may be equipped with a marine seismic source in either a single or a dual source configuration. The marine streamer vessel may be equipped to outfit the deployed seismic streamer with a full complement of steering, depth and lateral devices for each seismic streamer, i.e., steerable seismic streamers. In certain embodiments, a source vessel may be utilized containing one or more sources. The source vessel may have a marine seismic source in either a single or dual source configuration. The method may include a single streamer vessel or may include multiple streamer vessels and multiple source vessels.

[0021] The marine streamer vessel sails along a continuous spiral path while acquiring seismic data. The shape of the continuous spiral path may be roughly circular and may be optimized to meet objectives required to adequately image the subsurface target. The continuous spiral path can take the form of a circular path, an elongated elliptical path, or any combination

thereof. The continuous spiral paths shape and size can vary within the survey. Since the continuous spiral paths will be continuous there will be no line change time from one to another. The seismic acquisition will occur continuously across the survey. Breaks in the acquisition will be based on time instead of sail line length and location.

[0022] As the marine streamer vessel travels along the continuous spiral path, one or more sources may be excited so as to introduce acoustic wave energy in the marine environment and subsequently into the subsea region of the earth. The acoustic wave energy then reflects and refracts from the subsea region so as to form reflected and refracted wave energy, which is detected by marine seismic receivers that are spaced along the length of the seismic streamers. The detected seismic data is then interpreted to reveal seismic information representative of the surveyed subsea region of the earth.

[0023] Other enhancements to the methods herein include, but are not limited to, configuring the steerable streamers in a flared configuration, wherein the lateral spacing increases rearwardly over the length of the seismic steerable streamers or a trumpet-shaped system of variable length seismic streamers exhibiting lateral streamer spacing that increases rearwardly at an increasing rate over the length of the seismic streamers. U.S. Patent Application serial no. 12/167,683, filed July 3, 2008, titled "Marine Seismic Acquisition with Controlled Streamer Flaring," the entire disclosure of which is incorporated by reference, describes a number of possible streamer configurations, streamer elements, and devices, all of which may be used in combination with embodiments of the present invention. For example, the separations between each streamer at the tails of the streamers can be greater than the separation 1. The steerable stream and software may be used to maintain a smooth transition from the streamer separation distance at the front to the streamer separation distance at the tail, while maintaining a spiral segment curved shape.

The steerable streamers may also be used to put a sinusoidal shape into the streamers. Each streamer may have a sinusoidal shape similar to the streamer adjacent to it. The streamer vessel may sail a generally sinusoidal path along each spiral survey. The sinusoidal course may be overlain on the general spiral course with the center of the sinusoid shape falling along the path sail line. If additional streamers and source vessel are being utilized they may also follow a sinusoidal course in a similar fashion as the streamer vessel.

[0024] The sinusoidal paths of the streamer vessels and streamers will randomize the locations of the source point and the receivers throughout the survey. This randomization may

reduce the effect of the acquisition footprint in the final processed data. It may also increase the effectiveness of the interpolation methods already in use to fill holes in the data acquired.

[0025] Advantages of certain embodiments of the present invention include, but are not limited to, a reduction of the number of marine vessel runs or paths required to complete a survey area, increased survey efficiency and coverage, a more effective randomization of the locations of source point and receivers throughout the area, a reduction of the acquisition footprint in the final processed data, an increase of the effectiveness of post-acquisition interpolation methods used to fill holes or gaps in the acquired data, lower survey costs, decreased survey times, and maximization of the available offset and wide azimuth data.

[0026] In closing, it should be noted that the discussion of any reference is not an admission that it is prior art to the present invention, especially any reference that may have a publication date after the priority date of this application. At the same time, each and every claim below is hereby incorporated into this detailed description or specification as a additional embodiments of the present invention.

[0027] Although the systems and processes described herein have been described in detail, it should be understood that various changes, substitutions, and alterations can be made without departing from the spirit and scope of the invention as defined by the following claims. Those skilled in the art may be able to study the preferred embodiments and identify other ways to practice the invention that are not exactly as described herein. It is the intent of the inventors that variations and equivalents of the invention are within the scope of the claims while the description, abstract and drawings are not to be used to limit the scope of the invention. The invention is specifically intended to be as broad as the claims below and their equivalents.

References

[0028] All of the references cited herein are expressly incorporated by reference. The discussion of any reference is not an admission that it is prior art to the present invention, especially any reference that may have a publication data after the priority date of this application. Incorporated references are listed again here for convenience:

1. US 2012/0002503 (Janiszewski; Brewer; Shan; Eick) "Seismic Acquisition in Marine Environments using Survey Paths following a Series of Linked Deviated Paths and Methods of Use." (2010).

CLAIMS

1. A method for acquiring seismic data for a subsea region of the earth comprising the steps of:
 - a. providing a marine seismic vessel and a plurality of steerable seismic streamers, wherein the plurality of steerable seismic streamers are coupled to the marine seismic vessel for towing, wherein each steerable seismic streamer comprises a plurality of marine seismic receivers spaced apart along the length of each steerable seismic streamer;
 - b. providing a plurality of marine seismic sources;
 - c. towing the steerable seismic streamers through the marine environment such that the marine seismic vessel and the steerable seismic streamers travel substantially along a continuous spiral paths;
 - d. exciting at least one of the marine seismic sources simultaneously with the step of towing the steerable seismic streamers so as to cause acoustic wave energy to travel through the marine environment into the subsea region of the earth;
 - e. allowing the acoustic wave energy to reflect and refract from the subsea region so as to form reflected and refracted wave energy; and
 - f. detecting the reflected and refracted wave energy with the marine seismic receivers as to form detected seismic data.
2. The method according to claim 1, further comprising the step of maintaining the plurality of steerable seismic streamers in a flared configuration.
3. The method according to claim 1, wherein the continuous spiral path substantially form a sinusoidal wave.
4. The method according to claim 1, wherein one or more of the plurality of marine seismic sources are coupled to the marine seismic vessel.
5. The method according to claim 1, further comprising the step of providing a second marine vessel wherein one or more of the plurality of marine seismic sources are coupled to the second marine vessel.

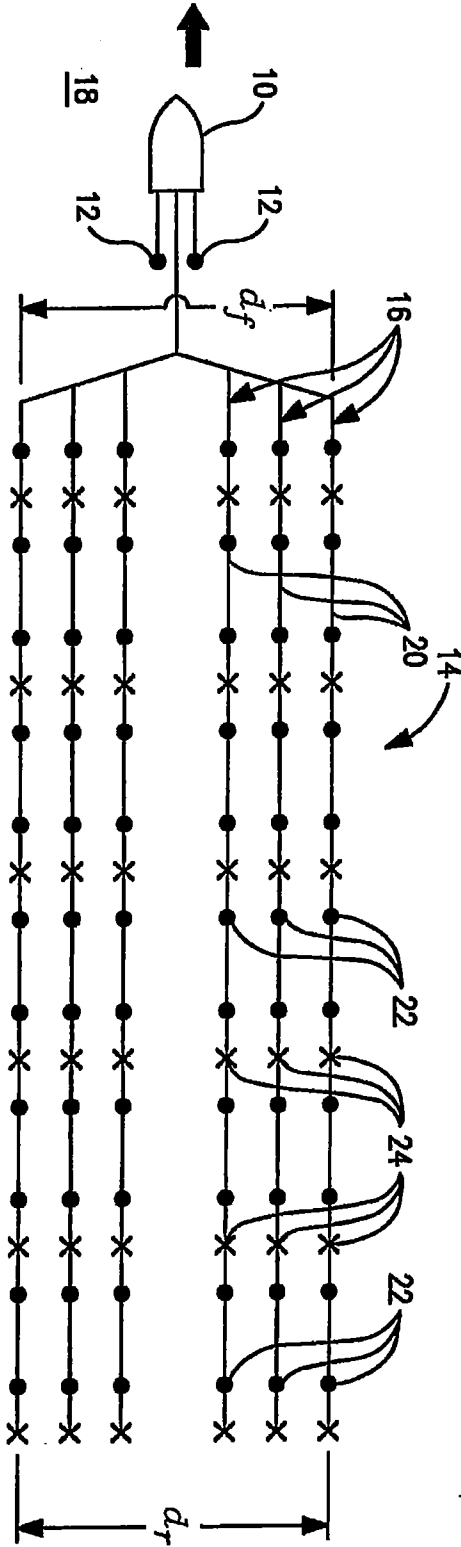


FIG. 1
(Prior Art)

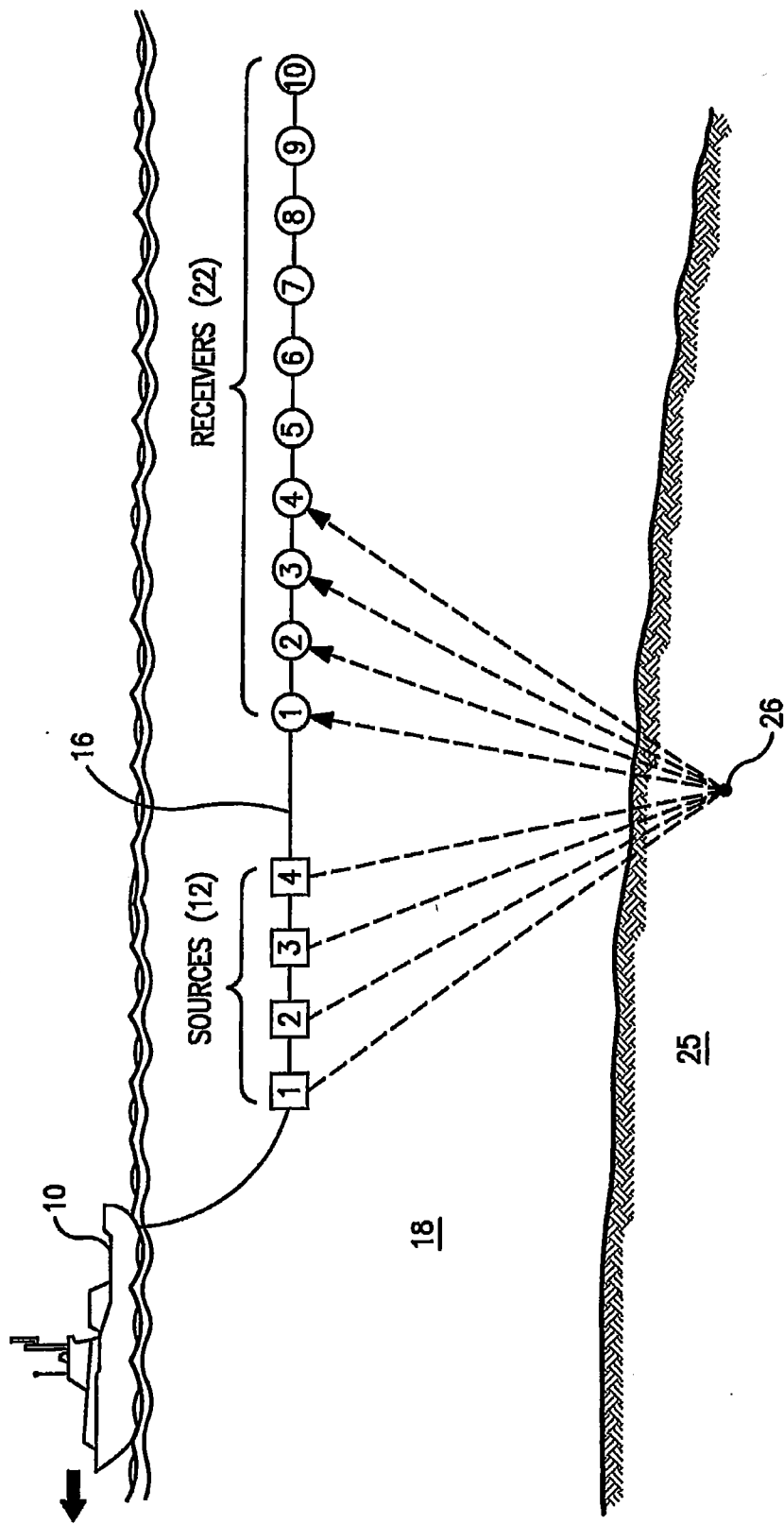


FIG. 2
(Prior Art)

INTERNATIONAL SEARCH REPORT

International application No.

PCT/US2013/065275

A. CLASSIFICATION OF SUBJECT MATTER

IPC(8) - G01V 1/38 (2013.01)

USPC - 367/20

According to International Patent Classification (IPC) or to both national classification and IPC

B. FIELDS SEARCHED

Minimum documentation searched (classification system followed by classification symbols)

IPC(8) - G01V 1/02, 16, 20, 30, 38 (2013.01)

USPC - 367/15, 16, 20; 702/14

Documentation searched other than minimum documentation to the extent that such documents are included in the fields searched

CPC - G01V 1/38, 3808, 3817, 3826, 3843 (2013.01)

Electronic data base consulted during the international search (name of data base and, where practicable, search terms used)

PatBase, Google Patents, Google Scholar

C. DOCUMENTS CONSIDERED TO BE RELEVANT

Category*	Citation of document, with indication, where appropriate, of the relevant passages	Relevant to claim No.
X	US 2009/0122640 A1 (HILL et al) 14 May 2009 (14.05.2009) entire document	1, 3-5
Y		2
Y	US 2011/0305107 A1 (EICK et al) 15 December 2011 (15.12.2011) entire document	2
A	US 2012/0002503 A1 (JANISZEWSKI et al) 05 January 2012 (05.01.2012) entire document	1-5
A	WO 2011/057324 A1 (MACNEILL) 19 May 2011 (19.05.2011) entire document	1-5

☐ Further documents are listed in the continuation of Box C.


* Special categories of cited documents:

"A" document defining the general state of the art which is not considered to be of particular relevance

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Date of the actual completion of the international search

16 January 2014

Date of mailing of the international search report

31 JAN 2014

Name and mailing address of the ISA/US

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