



(51) International Patent Classification:

E21B 47/18 (2006.01) E21B 47/12 (2006.01)
E21B 21/08 (2006.01)

(21) International Application Number:

PCT/US2013/022089

(22) International Filing Date:

18 January 2013 (18.01.2013)

(25) Filing Language:

English

(26) Publication Language:

English

(30) Priority Data:

13/352,714 18 January 2012 (18.01.2012) US

(71) Applicant: **BAKER HUGHES INCORPORATED**
[US/US]; P.O. Box 4740, Houston, Texas 77210-4740
(US).

(72) Inventors; and

(71) Applicants : **MOGHADDAMNIA, Sanam** [DE/DE];
Leinstr. 33, 30159 Hannover (DE). **ZHENG, Feng**
[CN/DE]; Palmstr. 2, 47057 Duisburg (DE). **BRAHIM,**
Imed Ben [TN/DE]; Hildesheimerstr. 76, 30169 Hannover,

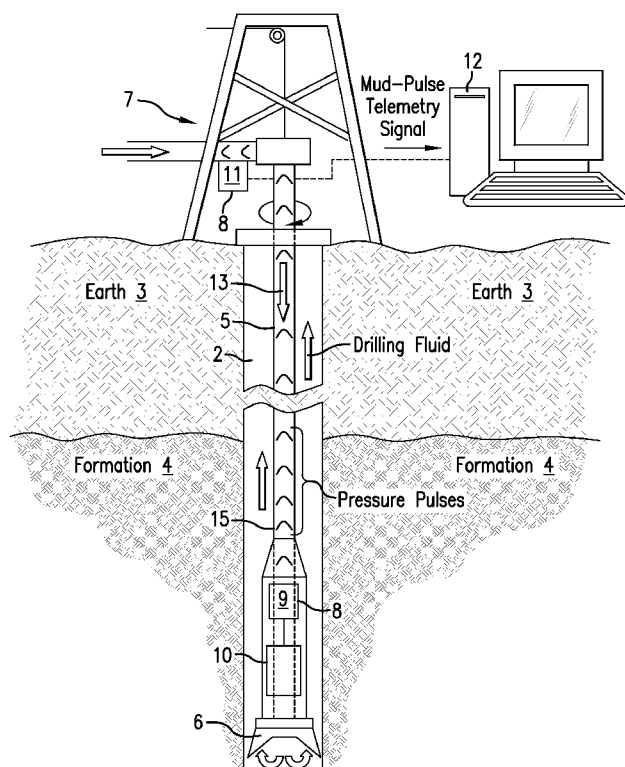
Lower Saxony (DE). **EMMERICH, Wojciech** [DE/DE];
Zur Jagerei 102, 29229 Celle (DE). **HANSEN, Christian**
[DE/DE]; Emil-Schwabe-Weg 7, 31319 Sehnde, Nieder-
sachsen (DE). **BRUNS, Jens-Uwe** [DE/DE]; Elsternstieg
4, 31303 Burgdorf, Niedersachsen (DE).

(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, IS, JP, KE, KG, KM, KN, KP,
KR, KZ, LA, LC, LK, LR, LS, LT, LU, LY, MA, MD,
ME, MG, MK, MN, MW, MX, MY, MZ, NA, NG, NI,
NO, NZ, OM, PA, PE, PG, PH, PL, PT, QA, RO, RS, RU,
RW, 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,

[Continued on next page]

(54) Title: INTERFERENCE REDUCTION METHOD FOR DOWNHOLE TELEMETRY SYSTEMS



(57) Abstract: A method for reducing interference in a re-
ceived downhole telemetry signal includes: segmenting a re-
ceived signal; windowing each signal segment; transforming
each windowed signal segment into a complex variable do-
main to generate a plurality of complex variable domain seg-
ments with an in-phase component vector I and a quadrature
component vector Q; calculating a real amplitude vector A
from the I and the Q vectors; filtering interferers in the am-
plitude vector A for each complex variable domain segment
to generate a filtered amplitude vector $\tilde{A}$; recalculating an am-
plitude of the amplitude vector A using the filtered amplitude
vector $\tilde{A}$ to generate an output amplitude vector $\hat{A}$; scaling
the I and the Q vectors by a factor $\hat{A}/A$ to generate an output
in-phase component vector I' and an output quadrature com-
ponent vector Q'; and transforming I' and Q' into the time do-
main to provide an interference-reduced output signal in the
time domain.



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, ML, MR, NE, SN, TD, TG).

— *as to the applicant's entitlement to claim the priority of
the earlier application (Rule 4.17(iii))*

Published:

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

Declarations under Rule 4.17:

— *as to applicant's entitlement to apply for and be granted
a patent (Rule 4.17(ii))*

INTERFERENCE REDUCTION METHOD FOR DOWNHOLE TELEMETRY SYSTEMS

CROSS REFERENCE TO RELATED APPLICATIONS

[0001] This application claims the benefit of U.S. Application No. 13/352714, filed on January 18, 2012, which is incorporated herein by reference in its entirety.

BACKGROUND

[0002] Boreholes are drilled deep into the earth for many applications such as carbon dioxide sequestration, geothermal production, and hydrocarbon exploration and production. The boreholes are drilled using a drill tubular having a drill bit disposed at the distal end. A pump at the surface of the earth pumps drilling fluid sometimes referred to as drilling mud internally in the drill tubular to the drill bit to flush cuttings and lubricate the drill bit.

[0003] It is known in the drilling industry that a downhole tool may be used to characterize earth formations while a borehole is being drilled or during a temporary halt in drilling in operations referred to as logging-while-drilling (LWD) or measurement-while-drilling (MWD). Data obtained from the tool in one or more applications is transmitted uphole to the surface of the earth using mud-pulse telemetry. The data is then used for formation analysis or to monitor the drilling operation.

[0004] In mud-pulse telemetry, the data obtained from the tool is encoded and modulated into as an acoustic signal. The acoustic signal is transmitted using the drilling fluid as a transmission medium. Unfortunately, the drilling operation and especially the mud pump can cause interference with the mud-pulse data signals, which can lead to a loss of information or a signal delay. Hence, it would be well received in the drilling industry if the transmission of mud-pulse telemetry signals could be improved.

BRIEF SUMMARY

[0005] Disclosed is a method for reducing interference in a received downhole telemetry signal. The method includes: receiving a downhole telemetry signal in a time domain with a receiver; segmenting the received signal into a plurality of signal segments; windowing each signal segment in the plurality of signal segments to generate a plurality of windowed signal segments; transforming each windowed signal segment in the plurality of windowed signal segments into a complex variable domain to generate a plurality of complex variable domain segments, each complex variable domain segment having an in-phase component vector I and a quadrature component vector Q; calculating a real amplitude vector

A from the in-phase component vector I and the quadrature component vector Q for each complex variable domain segment; filtering interferers in the amplitude vector A for each complex variable domain segment to generate a filtered amplitude vector $\tilde{A}$ for each complex variable domain segment; recalculating an amplitude of the amplitude vector A using the filtered amplitude vector $\tilde{A}$ for each complex variable domain segment to generate an output amplitude vector $\hat{A}$ for each complex variable domain segment; scaling the in-phase component vector I and the quadrature component vector Q by a factor $\hat{A}/A$ for each complex variable domain segment to generate an output in-phase component vector I' and an output quadrature component vector Q' for each complex variable domain segment; and transforming I' and Q' for each complex variable domain segment into the time domain to provide an interference-reduced output signal in the time domain; wherein the segmenting, windowing, transforming each windowed signal segment, calculating a real amplitude vector A , filtering, recalculating, scaling I and Q , and transforming I' and Q' are performed using a processor.

[0006] Also disclosed is an apparatus for reducing interference in a received mud-pulse telemetry signal. The apparatus includes: a receiver configured to receive a downhole telemetry signal in a time domain; and a processor coupled to the receiver and configured to implement a method that includes: segmenting the received signal into a plurality of signal segments; windowing each signal segment in the plurality of signal segments to generate a plurality of windowed signal segments; transforming each windowed signal segment in the plurality of windowed signal segments into a complex variable domain to generate a plurality of complex variable domain segments, each complex variable domain segment having an in-phase component vector I and a quadrature component vector Q ; calculating a real amplitude vector A from the in-phase component vector I and the quadrature component vector Q for each complex variable domain segment; filtering interferers in the amplitude vector A for each complex variable domain segment to generate a filtered amplitude vector $\tilde{A}$ for each complex variable domain segment; recalculating an amplitude of the amplitude vector A using the filtered amplitude vector $\tilde{A}$ for each complex variable domain segment to generate an output amplitude vector $\hat{A}$ for each complex variable domain segment; scaling the in-phase component vector I and the quadrature component vector Q by a factor $\hat{A}/A$ for each complex variable domain segment to generate an output in-phase component vector I' and an output quadrature component vector Q' for each complex variable domain segment; and transforming I' and Q' for each complex variable domain segment into the time domain to provide an interference-reduced output signal in the time domain

[0007] Further disclosed is a non-transitory computer readable medium having computer executable instructions for reducing interference in a received downhole telemetry signal by implementing a method that includes: segmenting a received downhole telemetry signal in a time domain into a plurality of signal segments; windowing each signal segment in the plurality of signal segments to generate a plurality of windowed signal segments; transforming each windowed signal segment in the plurality of windowed signal segments into a complex variable domain to generate a plurality of complex variable domain segments, each complex variable domain segment having an in-phase component vector I and a quadrature component vector Q ; calculating a real amplitude vector A from the in-phase component vector I and the quadrature component vector Q for each complex variable domain segment; filtering interferers in the amplitude vector A for each complex variable domain segment to generate a filtered amplitude vector $\tilde{A}$ for each complex variable domain segment; recalculating an amplitude of the amplitude vector A using the filtered amplitude vector $\tilde{A}$ for each complex variable domain segment to generate an output amplitude vector $\hat{A}$ for each complex variable domain segment; scaling the in-phase component vector I and the quadrature component vector Q by a factor $\hat{A}/A$ for each complex variable domain segment to generate an output in-phase component vector I' and an output quadrature component vector Q' for each complex variable domain segment; and transforming I' and Q' for each complex variable domain segment into the time domain to provide an interference-reduced output signal in the time domain; wherein the segmenting, windowing, transforming each windowed signal segment, calculating a real amplitude vector A , filtering, recalculating, scaling I and Q , and transforming I' and Q' are performed using a processor.

BRIEF DESCRIPTION OF THE DRAWINGS

[0008] The following descriptions should not be considered limiting in any way. With reference to the accompanying drawings, like elements are numbered alike:

[0009] FIG. 1 illustrates an exemplary embodiment of a downhole tool disposed in a borehole penetrating the earth;

[0010] FIG. 2 illustrates a block diagram of a method to reduce interference in received mud-pulse telemetry signals; and

[0011] FIG. 3 depicts aspects of an amplitude spectrum before and after the interference reduction method is applied.

DETAILED DESCRIPTION

[0012] A detailed description of one or more embodiments of the disclosed apparatus and method presented herein by way of exemplification and not limitation with reference to the Figures.

[0013] FIG. 1 illustrates an exemplary embodiment of a downhole tool 10 disposed in a borehole 2 penetrating the earth 3, which includes an earth formation 4. The formation 4 represents any subsurface material of interest. The downhole tool 10 is conveyed through the borehole 2 by a carrier 15 such as a drill tubular 5 in one embodiment. Disposed at the distal end of the drill tubular 5 is a drill bit 6. A drilling rig 7 is configured to conduct drilling operations such as rotating the drill tubular 5 and thus the drill bit 6 in order to drill the borehole 2. In addition, the drilling rig 7 is configured to pump drilling fluid 13 internally through the drill tubular 5 in order to lubricate the drill bit 6 and flush cuttings from the borehole 2.

[0014] The downhole tool 10 is configured to perform measurements while the borehole 2 is being drilled or during a temporary halt in drilling. A mud-pulse telemetry system 8 is coupled to the downhole tool 10 and configured to transmit measurement data to the surface of the earth 3. The mud-pulse telemetry system 8 includes a transmitter 9 and a receiver 11. The transmitter 9 is configured to encode the measurement data into a series of acoustic pulses that are transmitted in the drilling fluid internal to the drill tubular 5. In another embodiment, the drilling fluid in the annulus external to the drill tubular 5 can be used to transmit the series of acoustic pulses. The receiver 11 disposed remote from the downhole tool 10 at or near the surface of the earth 3 is configured to receive the acoustic pulses (i.e., mud pressure pulses) and convert the acoustic pulses into an electrical (or optical) signal for processing. The electrical signal represents the acoustic pulses over a period of time in the time domain. A computer processing system 12 is coupled to the receiver 11 and configured to receive and process the electrical signal containing the measurement data. The processing includes extracting the measurement data for use by drilling operators and analysts. In order to accurately extract the measurement data, the computer processing system 12 is configured to reduce interference that is induced into the acoustic mud-pulse signals during transmission to the surface of the earth 3 or at the surface. Non-limiting examples of the interference include distortion and masking of the acoustic pulses. The interference is represented in the electrical signals received from the receiver 11. An interference reduction algorithm that implements an interference reduction method disclosed herein is executed by the computer processing system 12 to reduce the interference in order to obtain the measurement data.

[0015] The interference reduction method is particularly useful for canceling strong narrow band interferers (e.g., sine waves) from a broadband telemetry signal. The interference reduction method requires a sampled version of the mud-pulse pressure signal received by the receiver 11 at the surface.

[0016] FIG. 2 illustrates a block diagram that depicts aspects of an interference reduction method 20. In block 21, the mud-pulse telemetry signal (i.e., pressure pulses over time) is segmented into overlapping segments. The length of each segment and an amount of overlap are configurable. In one or more embodiments, the length of each segment is 25 seconds and the overlap is 60%. In the following discussion, the length of each segment is denoted by N .

[0017] In block 22, the signal in each segment is windowed and then transformed in block 23 into a complex variable domain (i.e., frequency domain). In one or more embodiments the windowing function is a Hamming window, but other windowing functions may also be used instead of the Hamming window. The main purpose of the windowing function is to reduce unavoidable spectral leakage of information from the signal caused by the transformation of the mud-pulse signal to the complex variable domain to a tolerable amount. The transformation is performed in blocks with a block length M . If M is greater than N , then zero padding may be used to fill in the difference. In one or more embodiments, windowing can include using the segmented signals as the windowed signals such that a “rectangular window” is used to segment the received telemetry signals.

[0018] After the transformation to the complex variable domain, the in-phase component vector I and the quadrature component vector Q of each segment are converted into an amplitude vector A , as shown in Block 24. The vector A contains real-valued elements. The I/Q signal is then directly fed into block 27 for I/Q scaling.

[0019] Next, in Block 25, the amplitude vector A is filtered by a non-linear filtering operation configured to cancel out (high) amplitude values caused by narrowband interferers. This operation results in filtered amplitude vector $\tilde{A}$. In one or more embodiments, the non-linear filtering operation is performed by a median filter. In one or more embodiments, the median filter is selected to have an order between 25 and 35 and is used with a DFT having a frequency resolution of 50 mHz. Alternatively, the interferer amplitudes may be detected by applying a peak detection algorithm to the amplitudes in A . In this case, the interferer amplitudes are replaced by their neighboring values in the amplitude vector A .

[0020] It can be appreciated that an advantage of Block 25 in the present method is that for the purpose of interferer cancellation no explicit knowledge of the interferer frequencies is necessary.

[0021] The next step, as depicted in Block 26, is to recalculate and update the amplitude vector A . The removal of the interferer amplitudes is performed in this block. For interferer cancellation or removal, only the input amplitude vector A and the filtered output vector $\tilde{A}$ are compared. The output amplitude vector leading out of Block 26 is denoted by $\hat{A}$.

[0022] There are many ways to remove the interferers from the amplitude vector A to form the output amplitude vector $\hat{A}$. One approach is to calculate the difference between the amplitude vectors A and $\tilde{A}$: $d1 = |A - \tilde{A}|$. If one element of the difference vector $d1$ is greater than a predefined threshold $t1$, then its corresponding amplitude element of the amplitude vector $\tilde{A}$ is used for calculation of the corresponding output amplitude element of vector $\hat{A}$. Instead of calculating a difference $d1$, another approach is to compare A against a predefined threshold vector $c = (t2 + 1)\tilde{A}$. The thresholds $t1$ and $t2$ are configurable. To allow fast signal level adaption, the thresholds are updated by using the complex valued domain signal. A third approach to remove the interferers from the amplitude vector A is to copy the vector A into the vector $\hat{A}$ and then replace the K largest values in the vector $\hat{A}$ with the corresponding values in vector $\tilde{A}$. The advantage of this approach is that no comparison against a threshold is necessary.

[0023] After having calculated the new amplitude vector $\hat{A}$, the next step, as depicted in Block 27, is to scale each element of the original I/Q signal with its corresponding amplitude factor $\hat{A}/A$ phase vector PHI and calculate the in phase component I' and the quadrature component Q' .

[0024] In the final step, as depicted in Block 28, the complex values $Z = I' + jQ'$ are transformed back to the original domain (i.e., the time domain). In one or more embodiments, this transformation is accomplished using an inverse discrete Fourier transform (IDFT). As the original signal has been segmented in Block 21 with a selected overlap (e.g., 60%), the final output signal is calculated using the same amount of overlap. In one or more embodiments, the output signal is calculated using the efficient Overlap-Add method.

[0025] After applying the interference reduction method 20 to the sampled mud-pulse telemetry signals corresponding to the received mud pressure pulses, the output signal does not contain strong narrowband interferers (i.e., individual sine waves) and still contains the measurement data transmitted by the transmitter 9.

[0026] FIG. 3 demonstrates the results of applying the interference reduction method 20 to a mud-pulse telemetry signal. The amplitude spectrum of the input signal and the amplitude spectrum of the output signal having reduced interference are illustrated in the frequency domain. The received baseband mud-pulse telemetry signal (i.e., input signal) shown at 31 is heavily disturbed by strong co-channel interferers. As can be seen, the strong co-channel interferers are removed from the output signal shown at 32.

[0027] It can be appreciated that the interference reduction method 20 has inherent flexibility that allows its use in various deployments. This inherent flexibility is achieved by proper selection or configuration of the following parameters: (i) the sampling rate f_s (i.e., rate at which the incoming signal is sampled (not shown in block diagram)); (ii) the segmentation (window) length N ; (iii) the transformation block length M ; (iv) the length of the segment overlap (e.g., percent overlap); (v) the length of the median filter, if median filtering is used as the non-linear filtering technique; and (vi) any of the threshold values for calculation of output amplitude vector $\hat{A}$ from vectors A and $\tilde{A}$.

[0028] It can be appreciated that the disclosed interference reduction method has several advantages. In contrast to existing interference cancellation methods, the disclosed interference reduction method does not need a signal from a second receiver or sensor or signals from special noise measuring sensors such as, for example, mud pump strobe sensors mounted at the mud pumps. Furthermore, it is advantageous that the disclosed interference reduction method does not need manual calibration and can be used automatically on any mud-pulse telemetry signal. Moreover, the disclosed interference reduction method can be combined with existing interference cancellation methods.

[0029] The method flow diagram depicted herein is just an example. There may be many variations to this diagram or the steps (or operations) described therein without departing from the spirit of the invention. For instance, the steps may be performed in a differing order, or steps may be added, deleted or modified. All of these variations are considered a part of the claimed invention.

[0030] In support of the teachings herein, various analysis components may be used, including a digital and/or an analog system. For example, the transmitter 9, the receiver 11, or the surface computer processing 12 may include the digital and/or analog system. The system may have components such as a processor, storage media, memory, input, output, communications link (wired, wireless, pulsed mud, optical or other), user interfaces, software programs, signal processors (digital or analog) and other such components (such as resistors, capacitors, inductors and others) to provide for operation and analyses of the apparatus and

methods disclosed herein in any of several manners well-appreciated in the art. It is considered that these teachings may be, but need not be, implemented in conjunction with a set of computer executable instructions stored on a computer readable medium, including memory (ROMs, RAMs), optical (CD-ROMs), or magnetic (disks, hard drives), or any other type that when executed causes a computer to implement the method of the present invention. These instructions may provide for equipment operation, control, data collection and analysis and other functions deemed relevant by a system designer, owner, user or other such personnel, in addition to the functions described in this disclosure.

[0031] Further, various other components may be included and called upon for providing for aspects of the teachings herein. For example, a power supply (e.g., at least one of a generator, a remote supply and a battery), cooling component, heating component, magnet, electromagnet, sensor, electrode, transmitter, receiver, transceiver, antenna, controller, optical unit, electrical unit or electromechanical unit may be included in support of the various aspects discussed herein or in support of other functions beyond this disclosure.

[0032] The term “carrier” as used herein means any device, device component, combination of devices, media and/or member that may be used to convey, house, support or otherwise facilitate the use of another device, device component, combination of devices, media and/or member. Other exemplary non-limiting carriers include drill strings of the coiled tube type, of the jointed pipe type and any combination or portion thereof. Other carrier examples include casing pipes, wirelines, wireline sondes, slickline sondes, drop shots, bottom-hole-assemblies, drill string inserts, modules, internal housings and substrate portions thereof.

[0033] Elements of the embodiments have been introduced with either the articles “a” or “an.” The articles are intended to mean that there are one or more of the elements. The terms “including” and “having” are intended to be inclusive such that there may be additional elements other than the elements listed. The conjunction “or” when used with a list of at least two terms is intended to mean any term or combination of terms. The terms “first” and “second” are used to distinguish elements and are not used to denote a particular order. The term “couple” relates to coupling a first component to a second component either directly or indirectly through an intermediate component.

[0034] It will be recognized that the various components or technologies may provide certain necessary or beneficial functionality or features. Accordingly, these functions and features as may be needed in support of the appended claims and variations thereof, are

recognized as being inherently included as a part of the teachings herein and a part of the invention disclosed.

[0035] While the invention has been described with reference to exemplary embodiments, it will be understood that various changes may be made and equivalents may be substituted for elements thereof without departing from the scope of the invention. In addition, many modifications will be appreciated to adapt a particular instrument, situation or material to the teachings of the invention without departing from the essential scope thereof. Therefore, it is intended that the invention not be limited to the particular embodiment disclosed as the best mode contemplated for carrying out this invention, but that the invention will include all embodiments falling within the scope of the appended claims.

CLAIMS

What is claimed is:

1. A method for reducing interference in a received downhole telemetry signal, the method comprising:
 - receiving a downhole telemetry signal in a time domain with a receiver;
 - transforming the telemetry signal into a complex variable domain to generate a complex variable domain signal, each complex variable domain signal having an in-phase component vector I and a quadrature component vector Q;
 - calculating a real amplitude vector A from the in-phase component vector I and the quadrature component vector Q for the complex variable domain signal;
 - filtering interferers in the amplitude vector A for the complex variable domain signal to generate a filtered amplitude vector $\tilde{A}$ for the complex variable domain signal and to generate an output in-phase component vector I' and an output quadrature component vector Q' in the complex variable domain signal using the filtered amplitude vector $\tilde{A}$; and
 - transforming I' and Q' for the complex variable domain signal into the time domain to provide an interference-reduced output signal in the time domain;
 - wherein the transforming the telemetry signal, calculating a real amplitude vector A, filtering, and transforming I' and Q' are performed using a processor.
2. The method according to claim 1, further comprising:
 - segmenting the received signal into a plurality of signal segments; and
 - windowing each signal segment in the plurality of signal segments to generate a plurality of windowed signal segments;
 - wherein the segmenting and the windowing are performed using a processor.
3. The method according to claim 2, wherein each signal segment in the plurality of signal segments overlaps an adjacent signal segment.
4. The method according to claim 3, wherein an amount of overlap is expressed as a percentage of a length N of the signal segment being overlapped.
5. The method according to claim 2, wherein the windowing is performed using a Hamming window.
6. The method according to claim 2, wherein windowing comprises using the plurality of signal segments as the plurality of windowed signal segments.
7. The method according to claim 2, wherein transforming comprises transforming each windowed signal segment in the plurality of windowed signal segments into a complex variable domain to generate a plurality of complex variable domain segments,

each complex variable domain segment having an in-phase component vector I and a quadrature component vector Q .

8. The method according to claim 7, wherein the transforming each windowed signal segment is performed using a discrete Fourier transform.

9. The method according to claim 7, wherein a length of a signal segment is N , the transformation is performed in blocks having a block length M , and if M is less than N then padding the block with zeros.

10. The method according to claim 7, wherein calculating comprises calculating a real amplitude vector A from the in-phase component vector I and the quadrature component vector Q for each complex variable domain segment.

11. The method according to claim 10, wherein filtering comprises filtering interferers in the amplitude vector A for each complex variable domain segment to generate a filtered amplitude vector $\tilde{A}$ for each complex variable domain segment.

12. The method according to claim 11, further comprising:
recalculating an amplitude of the amplitude vector A using the filtered amplitude vector $\tilde{A}$ for each complex variable domain segment to generate an output amplitude vector $\hat{A}$ for each complex variable domain segment; and

scaling the in-phase component vector I and the quadrature component vector Q by a factor $\hat{A}/A$ for each complex variable domain segment to generate an output in-phase component vector I' and an output quadrature component vector Q' for each complex variable domain segment;

wherein the recalculating and the scaling are performed using a processor.

13. The method according to claim 12, wherein recalculating an amplitude comprises calculating a difference between amplitude vector A and filtered vector $\tilde{A}$ and if the difference is greater than a predefined threshold, then using corresponding elements of $\tilde{A}$ as the output amplitude vector $\hat{A}$.

14. The method according to claim 12, wherein recalculating an amplitude comprises comparing the amplitude vector A against a predefined threshold vector $(t_2+1)\tilde{A}$ where t_2 is a configurable threshold, and if the threshold is exceeded, then using corresponding elements of $\tilde{A}$ in the output amplitude vector $\hat{A}$.

15. The method according to claim 12, wherein recalculating an amplitude comprises copying the amplitude vector A and then replacing placing all values exceeding a threshold value with corresponding values from the filtered amplitude vector $\tilde{A}$.

16. The method according to claim 12, wherein transforming I' and Q' comprises transforming I' and Q' for each complex variable domain segment into the time domain to provide an interference-reduced output signal in the time domain.

17. The method according to claim 16, wherein transforming I' and Q' comprises using an inverse discrete Fourier transform.

18. The method according to claim 16, wherein transforming I' and Q' comprises using an overlap-add method to account for any overlap in adjacent signal segments in the plurality of signal segments.

19. The method according to claim 1, wherein the complex variable domain is a frequency domain.

20. The method according to claim 1, wherein filtering interferers in the amplitude vector A comprises a non-linear filtering operation.

21. The method according to claim 20, wherein the non-linear filtering operation comprises using a median filter.

22. The method according to claim 1, wherein the downhole telemetry signal comprises a mud-pulse telemetry signal.

23. An apparatus for reducing interference in a received downhole telemetry signal, the apparatus comprising:

a receiver configured to receive a downhole telemetry signal in a time domain; and
a processor coupled to the receiver and configured to implement a method comprising:

receiving a downhole telemetry signal in a time domain with a receiver;

transforming the telemetry signal into a complex variable domain to generate a complex variable domain signal, each complex variable domain signal having an in-phase component vector I and a quadrature component vector Q;

calculating a real amplitude vector A from the in-phase component vector I and the quadrature component vector Q for the complex variable domain signal;

filtering interferers in the amplitude vector A for the complex variable domain signal to generate a filtered amplitude vector $\tilde{A}$ for the complex variable domain signal and to generate an output in-phase component vector I' and an output quadrature component vector Q' in the complex variable domain signal using the filtered amplitude vector $\tilde{A}$; and

transforming I' and Q' for the complex variable domain signal into the time domain to provide an interference-reduced output signal in the time domain.

24. The apparatus according to claim 23, wherein the method further comprises:
segmenting the received signal into a plurality of signal segments; and
windowing each signal segment in the plurality of signal segments to generate a plurality of windowed signal segments.

25. The apparatus according claim 24, wherein transforming comprises transforming each windowed signal segment in the plurality of windowed signal segments into a complex variable domain to generate a plurality of complex variable domain segments, each complex variable domain segment having an in-phase component vector I and a quadrature component vector Q .

26. The apparatus according to claim 25, wherein calculating comprises calculating a real amplitude vector A from the in-phase component vector I and the quadrature component vector Q for each complex variable domain segment.

27. The apparatus according to claim 26, wherein filtering comprises filtering interferers in the amplitude vector A for each complex variable domain segment to generate a filtered amplitude vector $\tilde{A}$ for each complex variable domain segment.

28. The apparatus according to claim 27, wherein the method further comprises:
recalculating an amplitude of the amplitude vector A using the filtered amplitude vector $\tilde{A}$ for each complex variable domain segment to generate an output amplitude vector $\hat{A}$ for each complex variable domain segment; and

scaling the in-phase component vector I and the quadrature component vector Q by a factor $\hat{A}/A$ for each complex variable domain segment to generate an output in-phase component vector I' and an output quadrature component vector Q' for each complex variable domain segment.

29. The apparatus according to claim 28, wherein transforming I' and Q' comprises transforming I' and Q' for each complex variable domain segment into the time domain to provide an interference-reduced output signal in the time domain.

30. The apparatus according to claim 23, wherein the downhole telemetry signal comprises a mud-pulse telemetry signal.

31. The apparatus according to claim 30, wherein the receiver is configured to receive a series of pressure pulses in drilling fluid and convert the series of pressure pulses into the mud-pulse telemetry signal, the mud-pulse telemetry signal comprising data obtained from a downhole tool disposed at a drill tubular.

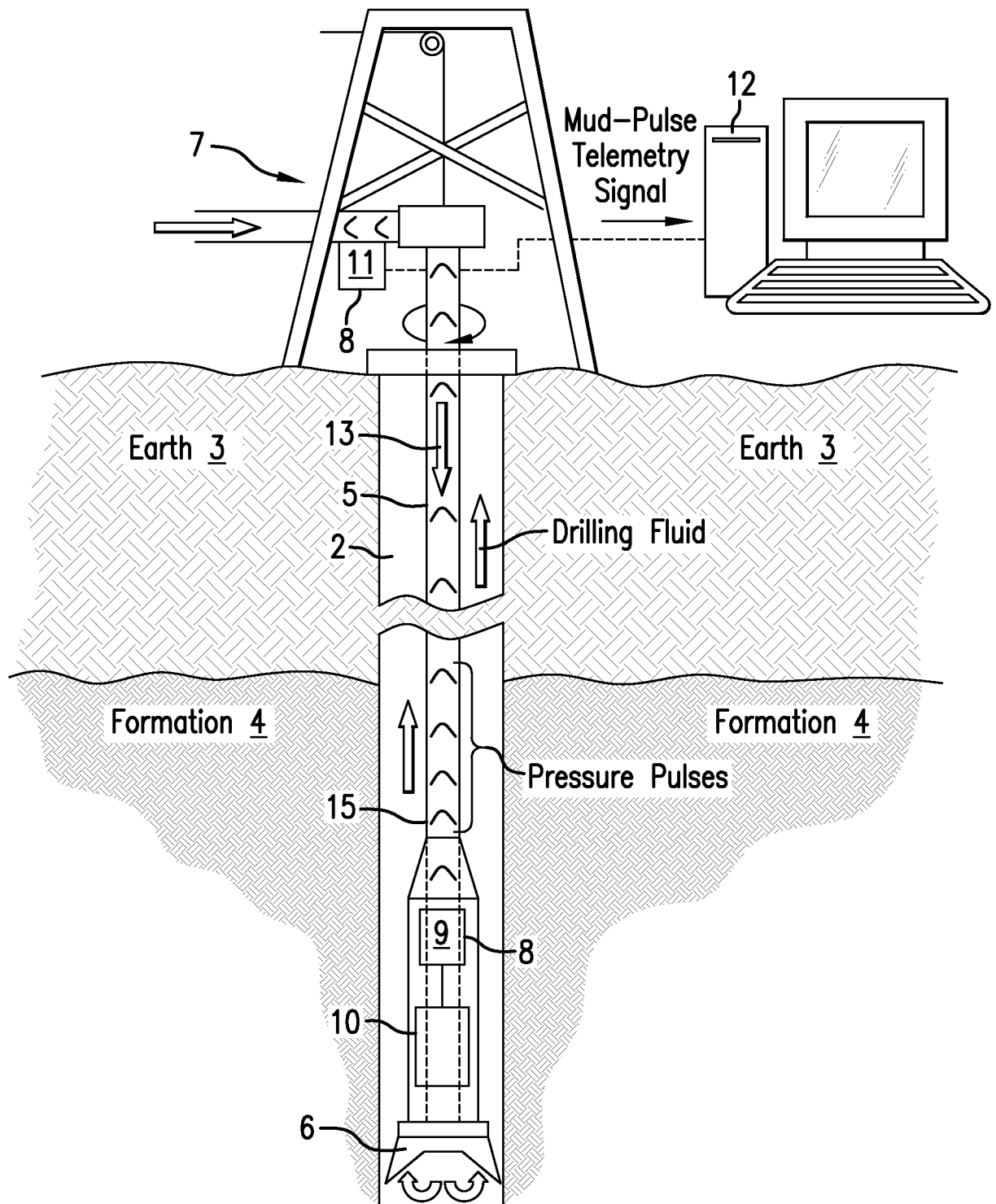


FIG. 1

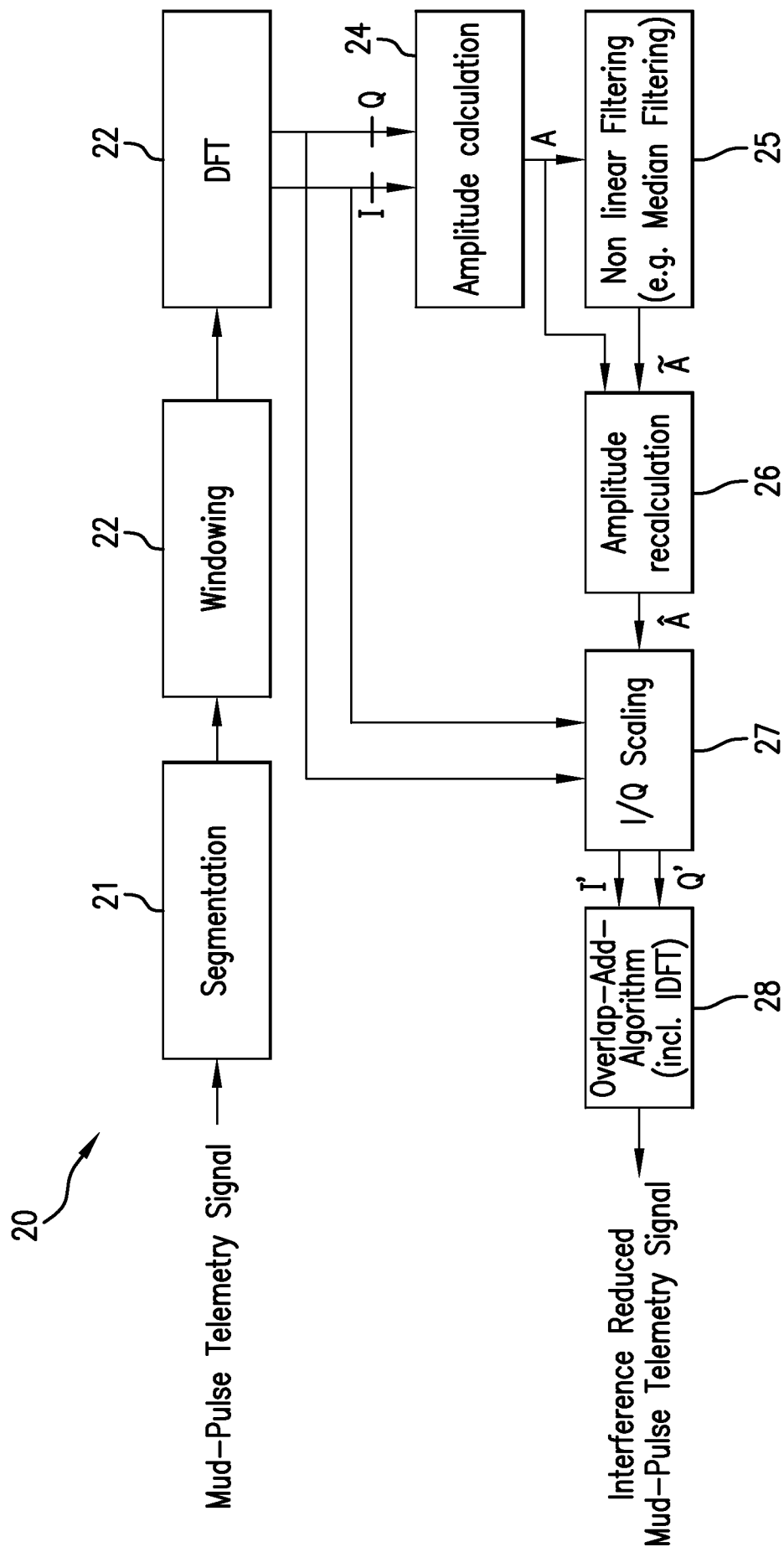


FIG.2

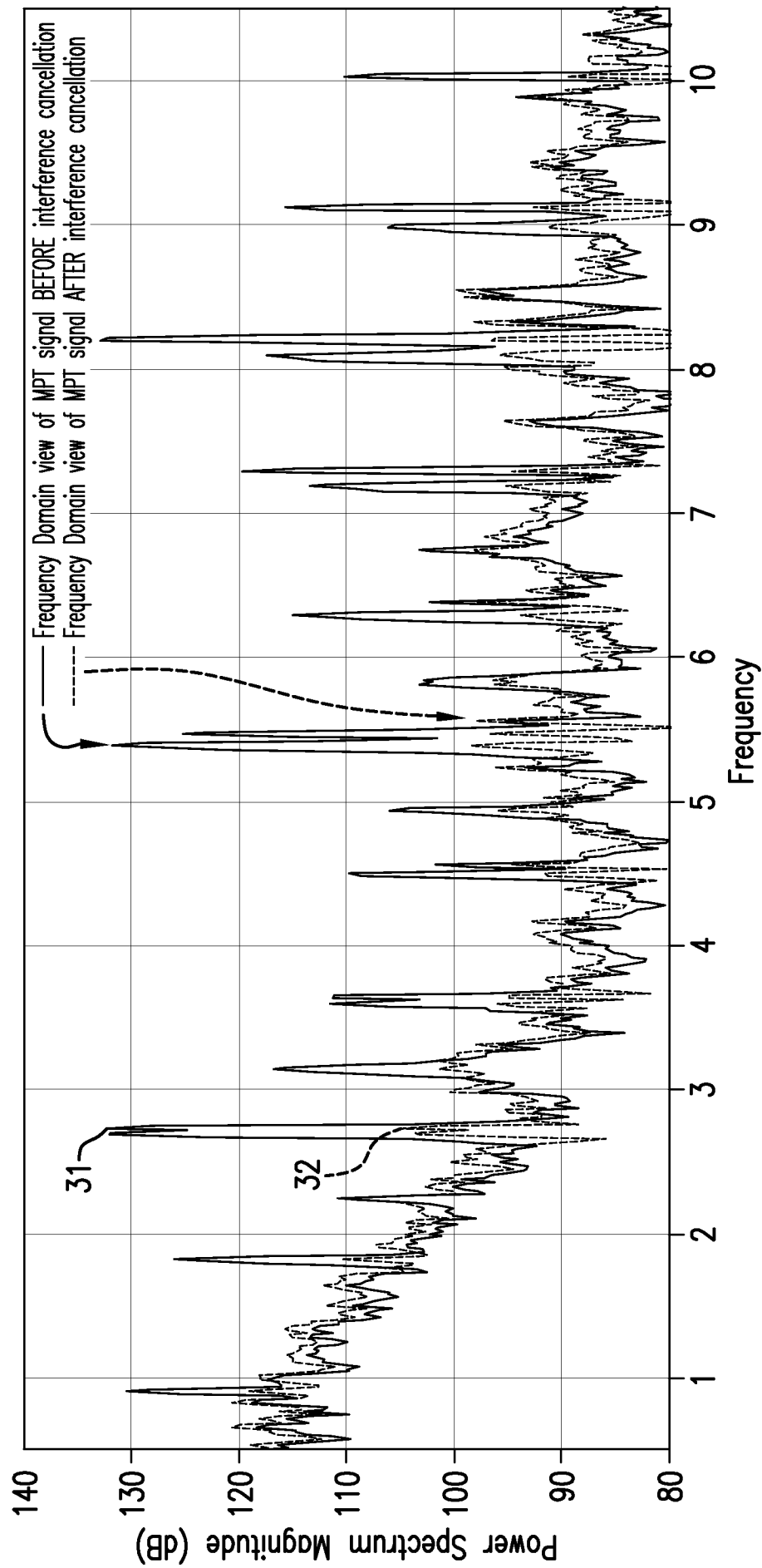


FIG.3

A. CLASSIFICATION OF SUBJECT MATTER***E21B 47/18(2006.01)i, E21B 21/08(2006.01)i, E21B 47/12(2006.01)i***

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)

E21B 47/18; H04B 3/20; E21B 47/09; E21B 21/08; H04B 110; G10L 21/00

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

Korean utility models and applications for utility models

Japanese utility models and applications for utility models

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

eKOMPASS(KIPO internal) & Keywords: interference, signal, amplitude, and filter

C. DOCUMENTS CONSIDERED TO BE RELEVANT

Category*	Citation of document, with indication, where appropriate, of the relevant passages	Relevant to claim No.
A	US 2010-0314169 A1 (JARROT, ARNAUD et al.) 16 December 2010 See paragraphs [0025],[0034], claims 1,2, and figure 1.	1-31
A	US 6847689 B1 (VUORINEN, OLLI et al.) 25 January 2005 See columns 5-8 and claims 1,7.	1-31
A	US 5742591 A (HIMAYAT, NAGEEN et al.) 21 April 1998 See abstract, column 2 lines 60-65, and claim 3.	1-31
A	US 2010-0305864 A1 (GIES, PAUL D.) 02 December 2010 See abstract and paragraphs [0005],[0015].	1-31
A	US 2002-0198706 A1 (KAO, YU-HUNG et al.) 26 December 2002 See claim 1 and figure 2.	1-31



Further documents are listed in the continuation of Box C.



See patent family annex.

* Special categories of cited documents:

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

"E" earlier application or patent but published on or after the international filing date

"L" document which may throw doubts on priority claim(s) or which is cited to establish the publication date of citation or other special reason (as specified)

"O" document referring to an oral disclosure, use, exhibition or other means

"P" document published prior to the international filing date but later than the priority date claimed

"T" later document published after the international filing date or priority date and not in conflict with the application but cited to understand the principle or theory underlying the invention

"X" document of particular relevance; the claimed invention cannot be considered novel or cannot be considered to involve an inventive step when the document is taken alone

"Y" document of particular relevance; the claimed invention cannot be considered to involve an inventive step when the document is combined with one or more other such documents, such combination being obvious to a person skilled in the art

"&" document member of the same patent family

Date of the actual completion of the international search

02 May 2013 (02.05.2013)

Date of mailing of the international search report

03 May 2013 (03.05.2013)

Name and mailing address of the ISA/KR

Korean Intellectual Property Office
189 Cheongsu-ro, Seo-gu, Daejeon Metropolitan
City, 302-701, Republic of Korea

Facsimile No. 82-42-472-7140

Authorized officer

KIM, Jin Ho

Telephone No. 82-42-481-8699



INTERNATIONAL SEARCH REPORT

Information on patent family members

International application No.

PCT/US2013/022089

Patent document cited in search report	Publication date	Patent family member(s)	Publication date
US 2010-0314169 A1	16.12.2010	EP 2278122 A2 US 8380438 B2	26.01.2011 19.02.2013
US 6847689 B1	25.01.2005	DE 60002823 D1 DE 60002823 T2 EP 1130831 A1 EP 1130831 B1 FI 107477 B1 JP 2001-186066 A	26.06.2003 08.04.2004 05.09.2001 21.05.2003 15.08.2001 06.07.2001
US 5742591 A	21.04.1998	CA 2176409 C EP 0748120 A1 EP 0748120 B1	22.08.2000 11.12.1996 12.01.2000
US 2010-0305864 A1	02.12.2010	CA 2694225 A1 WO 2009-012591 A1	29.01.2009 29.01.2009
US 2002-0198706 A1	26.12.2002	US 7103547 B2	05.09.2006