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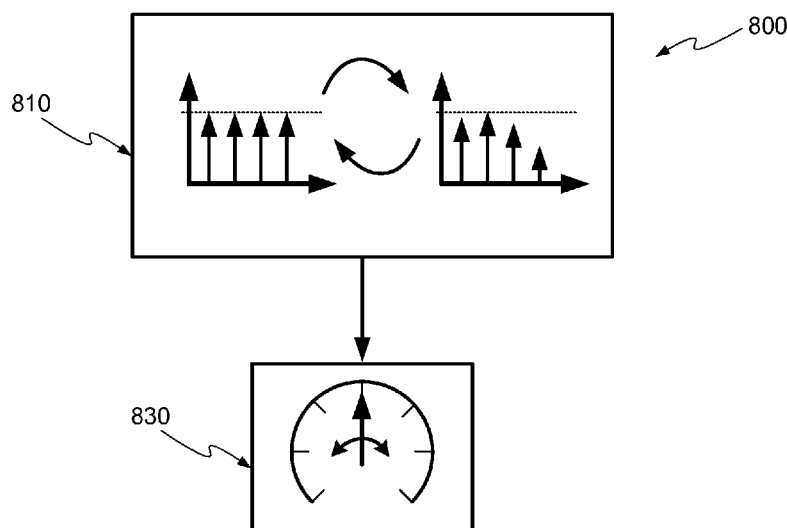


Fig. 8a

(57) **Abstract:** Disclosed is a method (800) for downhole data communication in a downhole communications system. The method is performed by a communication equipment configured to be arranged to transmit and receive signals via an associated wireline at a bitrate. The method comprises the steps of, determining (810), at one or more frequencies, one or more characteristics of the wireline associated with each of the one or more frequencies, and adjusting (830) the bitrate based on the determined one or more characteristics. Also, a downhole data communications system, comprising at least one communication equipment configured to perform the method is presented. Further to this, a communication equipment (210) configured to be arranged to perform the method is disclosed.



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DOWNHOLE WIRELINE COMMUNICATION

Description

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The present invention relates to a downhole wireline communication system in general and in particular to a high reliability downhole wireline communication system for high speed communication with downhole equipment, sensors and devices.

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Downhole operations normally require tools to be inserted in the downhole environment, which tools are typically controlled from the surface.

In order to control downhole tools, a wired control interface is used, i.e. wireline communication. This interface is used for sending and receiving control commands and also for receiving sensor data which keeps track of the changing conditions downhole. The distance from an uphole command centre to a downhole tool can be measured in kilometres which means that an extremely long wire needs to be used for the interface. These extreme lengths of cabling introduce parasitic elements distorting the communication.

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The ever-changing environment downhole makes it essential to have full control of the downhole tool. The communication between the uphole command centre and the downhole tool has to be reliable and bit-errors and lost data packets must be kept at a minimum.

25

Further to this, new sensors are emerging on the market, and these sensors are much more bandwidth demanding than older devices. The downhole tool may be equipped with high resolution thermal imaging, and high bitrates will be necessary in order to transfer these images or streams of images to the uphole command centre.

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It is evident that there is a need for a high reliability, high speed communications method for downhole tools.

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In US2014091943, a system providing data communication between a downhole tool and an uphole command centre is disclosed. The system introduces a coding algorithm that is used in conjunction with automatic signal gain control at the receiver end which is specific to each cable equalisation algorithm. This enables
5 increased bitrates compared to legacy system but there is still a need for increased reliability with high bitrates.

From the above, it is understood that there is room for improvements.

10 An object of the present invention is to provide a new type of method for downhole data communication which is improved over prior art, and which eliminates or at least mitigates some of the drawbacks discussed above. More specifically, an object of the invention is to provide a wireline data communication system that is capable of optimising data transfer and of automatically adjusting the bitrate. These objects
15 are achieved by the technique set forth in the appended independent claims with preferred embodiments defined in the dependent claims related thereto.

In a first aspect, a method for downhole data communication in a downhole communication system performed by a communication equipment configured to be
20 arranged to transmit and receive signals via an associated wireline at a bitrate is presented. The method comprises the steps of determining, at one or more frequencies, one or more characteristics of the wireline associated with each of the one or more frequencies, and adjusting the bitrate based on the determined one or more characteristics. One advantage of this method is that it allows for the
25 bitrate to be adjusted to the characteristics of the wireline and consequently adapt the performance of the communication system to a desired level of speed and reliability.

In one embodiment, the method further comprises the step of estimating, from the
30 one or more characteristics, a wireline frequency response function associated with each of the one or more frequencies. The step of adjusting the bitrate is further based on the estimated wireline frequency response function. By estimating a wireline frequency response function, it is possible to more accurately adjust the bitrate, and the system design will require less design margin further increasing
35 reliability and speed in combination with the potential to reduce cost.

In a further embodiment of the method comprising the step of estimating, the step of adjusting comprises comparing the estimated wireline frequency response function with a first threshold and a second threshold. If the estimated wireline frequency response function is above the first threshold, the bitrate is increased, and if it is below the second threshold, the bitrate is decreased. One benefit of having these limits is that the bitrate may be controlled in any number of steps. Comparing the estimated wireline frequency response function with the first and/or second threshold may be made in various ways. In one embodiment, the frequency response function is a series of values, each value being associated with a specific frequency. Hence, the comparison may be made independently for each value, in common for a number of values (e.g. a mean value), or for all values together.

In yet another embodiment of the method comprising the step of estimating, the step of adjusting comprises comparing each of the values of the estimated wireline frequency response function with a third threshold. For each value below the third threshold, the frequencies being associated with such values are barred from use. This has the advantage that it is possible to avoid using bad frequencies that may reduce the system performance.

In one embodiment, the one or more characteristics of the wireline comprise a loss of characteristic. This has at least the benefit of allowing the adjustment of the bitrate as a function of the loss of the wireline.

One embodiment of the method comprises the step of determining transmitting and/or receiving at least one single tone characterisation signal. In doing this, it is possible to dynamically evaluate the characteristics of the wireline.

In a further embodiment with the single tone characterisation signal, more than one single tone characterisation signal is sent, each single tone characterisation signal having different frequencies and/or amplitudes. Using more than one single tone characterisation signal enables the characterisation of the wireline across a number of different frequencies and/or amplitudes.

The method is in one embodiment presented with the step of determining comprising receiving one or more single tone characterisation signal(s). In this embodiment, the step of estimating comprises comparing the one or more received single tone characterisation signals to a reference characterisation signal. Using

more than one single tone characterisation signal enables the characterisation of the wireline across a number of different frequencies and/or amplitudes and the comparison to a reference enables evaluation of wireline effect on the single tone characterisation signal.

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In an additional embodiment, the one or more single tone characterisation signals are more than one single tone characterisation signal. The single tone characterisation signal is spaced in frequency between 1Hz and 10Mhz, preferably between 10Hz and 1MHz. One benefit of characterising the wireline across a bandwidth is that higher bitrates may be used, since frequency response across the bandwidth is estimated.

10

One embodiment presents the method as comprising, after the step of estimating, a step of shaping the signal. The step of shaping comprises calculating and applying one or more shaping parameters. One benefit of shaping the signal is that a received shaped signal will have substantially the same behaviour as the signal sent before it was shaped for the shaped parameters.

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Further, in one embodiment, the method is initiated by the detection of a characterisation trigger. One benefit is that this enables the restarting and rerunning of the process responsively to the characterisation trigger.

20

In another embodiment with the characterisation trigger, the characterisation trigger comprises the detection of start-up of the wireline transceiver. One benefit of this embodiment is that it ensures a characterised wireline and desired bitrate at each start up.

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In one embodiment with the characterisation trigger, the characterisation trigger comprises detecting a change in one or more environmental parameters. This is beneficial since it allows automatic rerunning of the method on changes in environmental parameters.

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In a further embodiment with the environmental parameters, the one or more environmental parameters comprise(s) any or all of temperature, acidic concentration, air pressure, humidity and cable changes. This enables adaptive and automatic adjustment of the bitrate as the environmental conditions change.

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In one aspect, a downhole data communication system is presented comprising at least one communication equipment configured to perform the method according to any embodiment of the method.

- 5 In yet another aspect, a communication equipment configured to be arranged to perform the method according to any embodiments of the method is presented.

The invention and its many advantages will be described in more detail below with reference to the accompanying schematic drawings, which for the purpose of
10 illustration show some non-limiting embodiments and in which:

Embodiments of the invention will be described in the following; references being made to the appended diagrammatical drawings which illustrate non-limiting examples of how the inventive concept can be reduced into practice.

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Fig. 1a shows a partly cross-sectional view of a downhole system having a downhole tool,

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Fig. 1b is a schematic view of a downhole system including uphole/surface equipment,

Fig. 2 is a schematic view of a downhole communication system according to an embodiment,

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Fig. 3 is a schematic view of a communication equipment of a downhole communication system according to an embodiment,

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Figs. 4a-c are diagrams showing signals before and after being subjected to a transfer function according to different embodiments,

Fig. 5 is a diagram showing a data signal and a corresponding distorted signal, according to an embodiment,

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Figs. 6a-b are diagrams showing single tone characterisation signals according to some embodiments,

Figs. 7a-d are diagrams showing how a gain curve can be used with a data signal, and

Fig. 8a-b are schematic views of a method according to some embodiments.

5

Hereinafter, certain embodiments will be described more fully with reference to the accompanying drawings. The invention may, however, be embodied in many different forms and should not be construed as limited to the embodiments set forth herein; rather, these embodiments are provided by way of example so that
10 this disclosure will be thorough and complete, and will fully convey the scope of the invention, such as it is defined in the appended claims, to those skilled in the art.

The word symbol is used to describe any communications symbol comprising one
15 or more bits. In e.g. a system using BPSK or 2-GFSK modulation, one symbol would equal one bit. In for instance a system using QPSK, one symbol equals two bits and so on. This means that symbol and bit may be used interchangeably with associated terms such as symbol-rate and bitrate.

20 Fig. 1 shows a downhole system 100 comprising a downhole tool 110 being inserted into a well tubular structure 120. The well tubular structure 120 is arranged for producing hydrocarbon-containing fluid from a reservoir 130. The downhole system 100 comprises one or more sensors 140 that may be placed both outside the well tubular structure 120 or be comprised in the downhole tool 110. The downhole tool
25 110 is attached to a wireline 150 that comprises cables for communication, power cables, fastening cables etc.

The downhole tool 110 is provided with a wireline communication equipment 210 to form part of a downhole communications system 200, as will be explained in the
30 following description.

Fig. 1b reveals, schematically (and not to scale), a downhole operation system for operating the downhole tool 110. The wireline 150 is attached to the downhole tool 110 and runs to a lowering means 170 located on a rig or vessel 160. The wireline
35 150 is arranged so that it enables communication and control between a surface data acquisition system 180 and the downhole tool 110. Typically, the wireline 150

will be provided from a spool and will unspool as the downhole tool 110 is lowered into the well tubular structure 120 and re-spooled as it is raised.

In Fig. 2, a downhole communication system 200 is shown. The downhole communication system 200 comprises at least one wireline communication equipment 210 in communication over a wireline 150. For clarification, normal use would entail at least two wireline communication equipment 210, one comprised in or at the downhole tool 110, and the other comprised in e.g. the surface data acquisition system 180. However, in a start-up and during characterisation phases, the system 200 may run with only one wireline communication equipment 210, this will be further elaborated in the following sections. The wireline 150 is not ideal and will consequently distort a data signal $f(t)$ sent over the wireline 150. Distortion may occur e.g. due to parasitic inductance and/or capacitance of the individual cables comprised in the wireline 150. Distortion may further occur due to capacitive or inductive loading between the individual cables comprised in the wireline 150. This will be explained in more detail further on. As explained with reference to Fig. 1b, the wireline 150 is typically provided on a spool making it equivalent of a large coil. This means that the inductive effects, i.e. high frequency loss, will be most significant when the cable is spooled. This is considered the worst case, from an inductance standpoint, since the wireline 150 only gets better as it is unspooled.

Looking at Fig. 3, a schematic view of one example of a wireline communication equipment 210 for downhole wireline communication is shown. The wireline communication equipment 210 comprises a wireline transceiver 320 and a controller 310. The wireline communication equipment 210 is connected to the at least one part of the wireline 150. The controller 310 is adapted to be arranged to control the transceiver 320 so that the wireline communication equipment 210 may send and receive data packets across the wireline 150. The skilled person is well aware that the schematic view presented in Fig. 3 does not fully convey a working wireline communication equipment 210. Details such as power supply, memory, various interfaces etc. are left uncommented as they are well known in the art.

As mentioned earlier, the wireline 150 is not ideal but will affect the data signals $f(t)$ transmitted through the wireline 150. This effect can be described with a wireline transfer function $h(t)$ that describes how the wireline affects the data signal $f(t)$.

The left-hand side of Fig. 4a shows an example of a data signal $f(t)$ transmitted by the wireline communication equipment 210. The signal $f(t)$ is subjected to the transfer function $h(t)$, i.e. transmitted through the wireline 150, and a distorted signal $h(f(t))$ is received by another wireline communication equipment 210. In the example shown in Fig. 4a, the distortion, i.e. the transfer function $h(t)$ of the wireline 150, is manifested as low pass filtering and attenuation. A similar example is given in Fig. 4b wherein the distorted signal $h(f(t))$ is manifested with an oscillating amplitude indicative of a LC load in the wireline 150. In Fig. 4c, another example of a distorted signal $h(f(t))$ is shown, visualising a rise time T_R , a fall time T_F and a time per symbol T_S . From Fig 4c, it can be seen that if the rise time T_R or the fall time T_F becomes a significant part of the time per symbol T_S , the amplitude of the distorted signal $h(f(t))$ will drop rapidly to a point where it will not be possible to decode the distorted signal $h(f(t))$. The possibility to decode the distorted signal is also dependent on noise in the system, typically Additive White Gaussian Noise, AWGN. This, among other factors, causes the ability to decode a distorted signal to be a random function, and the term Bit Error Rate, BER, is used to signal the possibility that a bit is incorrectly decoded. The BER is a function of noise and Energy per Symbol E_S . As can be seen in Fig. 4c, as the amplitude of the distorted signal $h(f(t))$ drops due to increased distortion, the energy of the received bit will decrease thus increasing the BER. In Fig 4c, the energy of the distorted signal $h(f(t))$ is integrated function $h(f(t))$ over the time per symbol T_S , i.e. the area of the distorted signal $h(f(t))$.

The example given with reference to Fig. 4c is just one example used to simplify the understanding of how distortion affects the BER. The example was given with a distortion, i.e. transfer function of the wireline 150, with a low pass characteristic, but other types of distortion will have similar effect on BER. After inventive and insightful thinking by the inventors, it was concluded that increasing the time per symbol T_S as a function of the distortion would greatly improve the reliability of the downhole communications system 200. This is equivalent with decreasing the bitrate since the symbol-rate is the inverse of the time per symbol T_S .

In Fig. 5, the data signal $f(t)$ is shown in the same diagram as the distorted signal $h(f(t))$. From the data given in Fig. 5, it would be possible to generate a compensation as the difference between the data signal $f(t)$ and the known received distorted signal $h(f(t))$. However, doing these compensations in the time domain is very costly in terms of processing power and a better approach is to do

compensation in the frequency domain. Also, using a chirp function or even a step function, as illustrated by the data signal $f(t)$ in Fig. 5, would require rather heavy computational resources and a more cost effective and robust, although slightly more time consuming, method is to send single tone characterisation signals 610.

5

The single tone characterisation signal 610 is a signal of only one frequency. Fig 6a depicts a single tone characterisation signal 610 transmitted at a first reference frequency f_0 with a transmit power P_{Tx} . The wireline transfer function $h(t)$ can be Fourier transformed into a wireline frequency response function $H(f)$. When the characterisation signal 610 is subjected to the frequency response function $H(f)$ of the wireline 150, it will change the amplitude, which means that the attenuation of the wireline 150 at the first frequency f_0 may be described according to Eqn. 1.

10

$$A_0 = H(F(f_0)) - P_{Tx} \quad \text{Eqn. 1}$$

15

The same scenario applies if several characterisation signals are used as depicted in Fig. 6b. In Fig 6b, single tone characterisation signals 610 are transmitted at the frequencies f_0 to f_{n-1} . The frequency response may be different at each of the frequencies as shown on the right side of Fig. 6b, where the single tone characterisation signals 610 are shown after being subjected to the wireline 150 frequency response function $H(f)$. The attenuation A_j at each of the transmitted frequencies f_0 to f_{n-1} may be calculated according to Eqn. 2.

20

$$\{A_j\}_{j=0}^{n-1} = H(F(f_j)) - P_{Tx} \quad \text{Eqn. 2}$$

25

By characterising the wireline 150 by single tone characterisation signals 610 and calculating the corresponding attenuation A_j , it is possible to compensate for the attenuation of the wireline 150. In practice, this may be achieved by increasing the amplitude of the signal to be transmitted with the corresponding attenuation value A_j .

30

Looking to Fig. 7a to 7d, an example of how a gain curve, associated with the wireline frequency response function $H(f)$ shown in Fig. 6b, can be used will be explained. From Fig. 6b and using Eqn. 2, the attenuation A_j at each of the single tone characterisation signals 610 can be calculated. Starting with n single tone characterisation signals 610 of the same transmit amplitude P_{Tx} , a gain function $G(f)$ can be estimated. Such a gain function $G(f)$ is shown in Fig. 7b. This gain

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function can be implemented as a digital filter and the filter can be applied to the single tone characterisation signals 610 in Fig. 7a. This will result in the signal of Fig. 7c. Passing the single tone characterisation signals 610 to the frequency response function $H(f)$ that was the basis for the gain function $G(f)$ will result in a substantially level response at a power of P_{Rx} , as shown in Fig. 7d. Note that the gain in Fig. 7b is marked with a peak at 0dB, this is of course just an example to simplify the explanation. The gain may be any number, positive or negative and the skilled person will know how to dimension the gain to optimise transmitter linearity and minimise noise.

10

The transmission loss L_T of a wireline may be characterised as the transmitted power P_{Tx} minus the received power P_{Rx} . The transmission loss L_T may, as has been explained together with the single tone characterisation signals 610, be used frequency dependent. The wireline transceivers 320 used in the downhole communications system 200 typically have a limited dynamic range. The dynamic range is characterised by the minimum received power $P_{Rx:min}$ necessary to, with sufficiently low BER, receive, demodulate and decode data; this is called the sensitivity. Analogously, the transmit part of the transceiver has a maximum output power $P_{Tx:max}$ at which it, with e.g. sufficient linearity and spectral efficiency, transmits data. There are corresponding limits in maximum received power $P_{Rx:max}$ and minimum transmitted power $P_{Tx:min}$ and their impact can be clearly derived from the reasoning of the other levels. The specified power may be different depending on which modulation and modulation speed is used. For instance, the minimum received power $P_{Rx:min}$ necessary for successful decoding is lower for e.g. GFSK than for 16QAM. As has been explained in previous sections, a lower symbol-rate will increase the energy per symbol E_s and reduce the minimum received power $P_{Rx:min}$. The maximum dynamic range of the downhole communication system 200 is calculated as $P_{Tx:max} - P_{Rx:min}$.

The transmitting wireline transceiver 320 of the downhole communication system 200 is naturally aware of which modulation and bitrate (and consequently symbol-rate) to use. Further to this, the dynamic range of the system is known and from this, the maximum allowable compensation or shaping of the transmitted signal can be estimated. If the frequency response function $H(f)$ requires a compensation outside of the dynamic range of the downhole communication system, the bitrate may be decreased, and/or the modulation changed.

With reference to Fig. 8a and Fig. 8b, a method 800 performed by a wireline communication equipment 210 in a downhole communication system 200 will be explained. The method comprises the steps of determining 810 the characteristics of a wireline 150. Based on these characteristics, a wireline frequency response function $H(f)$ is estimated and this, and/or the characteristics of the wireline 150, is used to adjust 830 the bitrate such that the highest speed is achieved with required reliability.

The step of determining 810 may be done in many different ways and the following section will give an overview of how the step may be performed. The order in which things are done, and which device is configured to do what may be varied and the skilled person understands that such modifications of the description are well within the scope of the disclosure.

In one embodiment of the method 800, the step of determining 810 comprises transmitting at least one single tone characterisation signal 610 with a transmit power P_{Tx} configured so that it is possible for a receiving wireline communication equipment 210 to estimate e.g. the attenuation of the wireline 150 and/or other wireline 150 characteristics from the received single tone characterisation signal 610.

It should be noted that the receiving and the transmitting wireline communication equipment 210 may be one and the same. This may be done by having the wireline 150 comprise different signals paths for transmitting data and receiving data and connect these paths together in one end of the wireline 150 and connect the other end to the wireline communication equipment 210. By having the transceiver 320 of the wireline communication equipment 210 simultaneously transmitting and receiving the single tone characterisation signal 610, it is possible to determine characteristics of the wireline 150 with one single wireline communication equipment 210. These characteristics may comprise e.g. loss and phase shift of the wireline 150. The phase shift may be determined by comparing the phase of the received single tone characterisation signal 610 with the transmitted single tone characterisation signal 610. The loss is, as described earlier, achieved by comparing amplitudes of received and transmitted single tone characterisation signal 610. It goes without saying that the characterisation using a single wireline communication equipment 210 will result in double the phase shift and loss since the wireline 150 is characterised both in transmit and receive at the same time and

consequently this needs to be compensated. It should be pointed out that phase shift along a wireline 150 may occur both directly as a function of the electrical length of the wireline, i.e. the length as a factor of the wavelength λ at the frequency of the single tone characterisation signal, and also due to parasitic effects and resonances occurring along the wireline 150. If the wireline 150, in the single wireline communication equipment 210, is arranged so that the total phase shift of the signal round trip is more than 360° it will not be possible to differentiate e.g. 380° phase shift from 20° phase shift which would result in different phase shift characteristics of 190° and 10° respectively, i.e. a possibly erroneous phase shift of 180° . This phase shift error is not relevant for most types of communication, but there are modulations where it is important to have all signals in phase e.g. adjacent subcarriers in OFDM where, if high bandwidth channels are used, there may be phase shifts on certain channels that need to be accurately determined. This potential problem may be solved by transmitting the single tone characterisation signal 610 at low frequencies stepping the frequency of the single tone characterisation signal 610 while keeping track of the accumulation of the phase shift to determine when a full 360° occurs and compensate accordingly. A similar solution is presented below when dual wireline communication equipment 210 is used to determine the wireline characteristics.

If characterisation is done with a pair of wireline communication equipment 210, the receiving wireline communication equipment 210 will know the reference power used to transmit the single tone characterisation signal 610 and will thus be able to determine the loss characteristics of the wireline 150 at the frequency of the single tone characterisation signal 610. The phase shift may be determined in a number of ways. One way to determine the relative frequency shift across a frequency range is to sweep the frequency of the single tone characterisation signal 610 at a defined pace and measure the frequency and phase of the received signal. Any difference in phase, once the pace of the frequency sweep has been compensated for, is due to phase shift in the wireline 150. In a dual path wireline 150, i.e. a wireline 150 comprising separate transmit and receive paths, the determining of wireline 150 characteristics may be done simultaneously in both transmit and receive. If a wireline with a single path is used, it may be possible to only characterise the communication in one direction and share the wireline 150 characteristics with the other wireline communication equipment 210. It may also, in any scenario, be possible to only have one wireline communication equipment 210 knowing the wireline 150 characteristics; this may be the case if, e.g. data in

one direction is comparably slow and neither speed nor reliability is a factor in that direction.

- 5 Sending a series of single tone characterisation signals 610 on different frequencies will make it possible to determine the characteristics of the wireline on multiple frequencies. If a multi-carrier communications protocol, such as e.g. OFDM or any FDM system for that matter, is used it may be beneficial to characterise the wireline on the frequencies of all, or at least a subset of the carriers to be used.
- 10 In another embodiment of the method 800 in Fig. 8a and Fig. 8b, the step of determining 810 comprises sending at least two single tone characterisation signals 610 at at least two different frequencies. In a further embodiment, the downhole communication system is a channelised system comprising at least two carriers at at least two different frequencies, and the step of determining 810 comprises
- 15 sending a single tone characterisation signal 610 on at least two of the at least two different frequencies.

On the topic of determining phase and amplitude characteristics of the wireline, it should be mentioned that in the scenario with a pair of wireline communication,

20 the characteristics will not only comprise the wireline 150 but also the associated path of the wireline transceiver 320 used when determining the wireline 150 characteristics. This means that amplitude shifts, and phase shifts associated with the transmit and receive paths of the wireline transceiver 320 may also be characterised with regards to phase and amplitude. With this knowledge, it may

25 be considered to use different power levels as well as different frequencies for the single tone characterisation signals 610. Such a configuration with different power levels will enable further shaping of the transmitted signal so that non-linearities of the signal chain are compensated for.

- 30 In one embodiment of the method 800, the step of determining 810 comprises determining one or more wireline characterisation parameters. In a further embodiment, the step of determining 810 further comprises sending at least two single tone characterisation signals 610 with at least two different power levels.
- 35 The method 800 may be initiated for several reasons and depending on arrangement and configuration a characterisation trigger of the method may be different. In, for instance, one embodiment, the method 800 is initiated at the

installation of a wireline 150 to a downhole tool 110, e.g. when presence of a wireline is detected by the wireline communication equipment 210. Depending on e.g. if there is a connection between the receive path and the transmit path in a wireline comprising separate paths for transmitting and receiving, the determining step 810 associated with one single wireline communication equipment 210 may be initiated. If not, the determining step 810 associated with dual wireline communication equipment 210 may be attempted by a first wireline communication equipment 210 detecting the presence of the wireline, if no suitable acknowledgement is received from a second wireline communication equipment 210, it is likely that only the first wireline communication equipment 210 is connected and the determining step 810 has to wait until the second wireline communication equipment 210 is connected. Once the second wireline communication equipment 210 detects the presence of the wireline 150, it may attempt the determining step 810 and the first wireline communication equipment 210 will acknowledge in a suitable manner.

In another embodiment, which may very well be additional to any other embodiment, the determining step 810 is initiated at the start-up of the wireline communication equipment 210.

Additionally, in another embodiment, the determining step 810 is initiated upon detection of a change in one or more environmental parameters. These environmental parameters may be any measurable parameter e.g. acidic concentration, air pressure, humidity, temperature etc. It may be that many of these parameters are not directly correlated to the frequency response $H(f)$ of the wireline 150, but they may very well affect the performance of the wireline transceiver 320. Take temperature as an example, where a temperature shift of 20° has little or no effect on passive cabling but may greatly impact e.g. the linearity and noise of the wireline transceiver 320.

In a further embodiment, the determining step 810 may be initiated by the detection of an increase in bit error rate of the received signal and/or a decrease of the signal strength of the received signal.

In yet another embodiment, the determining step 810 may be started at configurable time intervals and/or manually by control commands communicated to the wireline communication equipment 210.

With reference to Fig. 8b, having determined the wireline characteristics the wireline transfer function $H(f)$ may be estimated 820. The wireline characteristics may comprise one or more attenuations A_j and/or one or more phase shifts each associated with one or more frequencies and/or transmit amplitude P_{Tx} . The wireline transfer function $H(f)$ may, in any embodiment, be one single, or a series of discrete characteristics rather than a continuous function. From the estimated wireline transfer function $H(f)$, an inverse transfer function $H^{-1}(f)$ may be estimated simply by e.g. changing positive wireline 150 characteristic values to negative values and/or calculating the inverse wireline 150 characteristic factors. Note that the estimated wireline characteristics may be separate for both e.g. different frequencies and power levels but also for e.g. different environmental conditions, further detailed below. Each of the different series or value of characteristic of the wireline 150 may be stored and accessed as the appropriate situation arises. For instance, if wireline characteristics are estimated for a number of environmental situations, a change in environmental conditions may not have to trigger a restart of the method 800 but could simply result in the applicable wireline characterisation being retrieved from storage.

In one embodiment of the method 800 in Fig. 8b, the estimate step 820 comprises estimating one or more wireline 150 attenuation values. In another embodiment, estimating 820 comprises estimating one or more wireline 150 phase shift values and in yet another embodiment, the step of estimating 820 comprises estimating both phase shift and attenuation values of the wireline 150. In a further embodiment, the step of estimating is done for different power levels of the single tone characterisation signal 610.

In Fig. 8a and Fig. 8b, the step of adjusting 830 comprises changing, if necessary, the bitrate/symbol-rate of transmissions. The wireline characteristics are known from the step of determining 820 and these are used to find a suitable bitrate. If the wireline characteristics comprise loss characteristics, the loss may be used together with the known system factors such as the sensitivity and maximum transmit power of the wireline transceiver 320 at different modulation parameters, e.g. type, speed etc. If the loss characteristics is higher than the link budget allows, i.e. the sensitivity subtracted from the maximum transmit power, the bitrate may be reduced. At the reduced bitrate, the receiver will have a lower sensitivity (lower sensitivity means more sensitive, i.e. better) and the link budget may hold with

the determined loss characteristics. It may be that there is head room in the link budget, and in that case the bitrate may be increased without significant loss in reliability. If the bitrate is at a maximum speed and the link budget still has significant head room, the transmit power of the wireline transceiver 320 may be reduced. It may be that each of the supported bitrates and modulations has a first threshold for the estimated wireline transfer function $H(f)$ so that if the estimated wireline transfer function is above the first threshold, the bitrate may be increased. Further to this, each of the supported bitrates and modulations may have a second threshold for the estimated wireline transfer function $H(f)$ so that if the estimated wireline transfer function is below the second threshold, the bitrate may be decreased.

In FDM systems, or any system utilising carriers on different frequencies, where wireline characterisation has revealed one or more carriers and/or channels to be too poor to use, these carriers may be omitted or barred from communication. The decision to remove a frequency may be based on a third threshold that is below or the same as the second threshold as introduced above. It may be that there are transmissions of different bitrates at different channels depending on the estimated wireline transfer function $H(f)$, i.e. all channels do not necessarily have to have the same bitrate and/or modulation. Alternatively, if flat bitrate across the frequency band is desired, the carrier exhibiting the worst bitrate may be used to set the bitrate for all carriers or, the worst channel may be removed (omitted or barred) as mentioned above, and the bitrate of the other carriers may be raised.

The discussion above regarding limits and their relation to change of bitrate is of exemplary nature. There may be any number of limits, thresholds or intervals with or without hysteresis relating to the estimated wireline frequency response function ($H(f)$). Each interval may be associated with a particular bitrate and/or modulation. There may be different sets of limits or intervals associated e.g. with different environmental conditions or power levels. All mentioned limits, thresholds and intervals may be configurable limits, thresholds or intervals. It is of course possible to make each limit, threshold or interval individually configurable, i.e. one threshold may be configurable, and another threshold may be fixed.

In one embodiment of the method 800 in Fig. 8a and Fig. 8b, the adjusting step comprises comparing the estimated wireline frequency response function ($H(f)$) to a first limit and a second limit and if the estimated wireline frequency

response function ($H(f)$) is above the first limit, increasing the bitrate and if it is below the second limit, decreasing the bitrate. In further embodiments, if any value of the estimated wireline frequency response function ($H(f)$) generates a response below a third limit, the frequencies being associated with such values are barred from use.

The inverse transfer function $H^{-1}(f)$ may be used as a shaping function, and the corresponding discrete values may be used as shaping parameters. An optional shaping step 840 may be comprised in the method 800 of Fig. 8b. The shaping step 840 is performed after the step of estimating 820 and may be done either before or after the step of adjusting 830. An example using amplitude shaping will be used to explain this step, and the skilled reader understands that a similar approach can be used when applying phase pre-distortion. The estimated wireline frequency response function ($H(f)$) comprises, in this example, losses at frequencies. In order to have, from a power perspective, a substantially flat transmission across all relevant frequencies used in the downhole communication system 200, the frequency resulting in the highest loss from the estimated wireline frequency response function ($H(f)$) is identified. This frequency will be the baseline, the 0dB, and the losses at the other frequencies are relative to this frequency. These losses will all be below the baseline since the baseline was the maximum. The relative losses calculated are used to attenuate all the channels prior to transmission thus enabling a, power wise, substantially flat transmission across all frequencies. Shaping is very beneficial on e.g. communication systems using sub-carriers where one burst comprises several sub-carriers. In many of these applications, there is a limit as to how much the power is allowed to vary across the burst. In a similar manner, shaping may be used within the same channel to have a linear power response all the way to saturation. This is beneficial in systems with an amplitude component in the modulation.

In one embodiment of the method 800 of Fig. 8b, the method comprises the step of applying shaping 840 after the step of estimating 820.

It should be mentioned that the bitrate adaptation described above may very well be used with in combination with other signalling protocols where for instance low speed control channels are utilised. These control channels may be used to e.g. communicate the start of a determining step 810, changes in environment,

characterisation data of the wireline 150, bitrates at different channels/frequencies etc.

Many of the embodiments have been described as utilising one or more single tone
5 characterisation signals 610. The skilled person understands that these signals may
be broadband signals of a certain bandwidth and that single tone does not
necessarily mean one absolute tone as noise by e.g. oscillators and phase locked
loops will increase the bandwidth of the signal. The single tone characterisation
signal 610 may be understood to mean any suitable characterisation signal, and in
10 many cases a single tone is the most cost-effective solution.

Claims

1. A method for downhole data communication in a downhole communications system (200) performed by a communication equipment (210) configured to be arranged to transmit and receive signals via an associated wireline (150) at a bitrate, the method comprising the steps of:
- determining (810), at one or more frequencies, one or more characteristics of the wireline (150) associated with each of the one or more frequencies,
- estimating (820), from the one or more characteristics, a wireline frequency response function ($H(f)$) associated with each of the one or more frequencies, and wherein the step of adjusting (830) the bitrate is further based on the estimated wireline frequency response function ($H(f)$), and
- adjusting (830) the bitrate based on the determined one or more characteristics, wherein the step of adjusting (830) comprises comparing the estimated wireline frequency response function ($H(f)$) with a first threshold and a second threshold and if the estimated wireline frequency response function is:
- above the first threshold, increase the bitrate,
- below the second threshold, decrease the bitrate, and
- wherein the step of adjusting (830) comprises comparing at least one of the values of the estimated wireline frequency response function ($H(f)$) with a third threshold and for each value below the third threshold, bar a frequency being associated with such value from use.
2. The method according to claim 1, wherein the one or more characteristics of the wireline (150) comprises a loss characteristic.
3. The method according to any of the preceding claims, wherein the step of determining (810) comprises transmitting and/or receiving at least one single tone characterisation signal (610).
4. The method according to claim 3, wherein more than one single tone characterisation signal (610) is sent, each single tone characterisation signal (610) having different frequency and/or amplitude.
5. The method according to any of the claims 1 to 4, wherein the step of determining (810) comprises receiving one or more single tone characterisation signals (610) and the step of estimating (820) comprises comparing the one or

more received single tone characterization signals (610) to a reference characterisation signal.

6. The method according to any of claims 3 to 5, wherein the one or more single
5 tone characterisation signals (610) are more than one single tone characterisation signal (610) and the single tone characterisation signal (610) spaced in frequency between 1 Hz and 10 Mhz, preferably between 10 Hz and 1 MHz.

7. The method according to any of the preceding claims, further comprising,
10 after the step of estimating (820), a step of shaping (840) the signal, wherein the step of shaping (840) comprises calculating and applying one or more shaping parameters.

8. The method according to any of the preceding claims, wherein the method
15 (800) is initiated by the detection a characterisation trigger.

9. The method according to claim 8, wherein the characterisation trigger comprises the detection of start-up of the wireline transceiver (320).

20 10. The method according to claim 8 or 9, wherein the characterisation trigger comprises detecting a change in one or more environmental parameters.

11. The method according to claim 10, wherein the one or more environmental parameters comprise(s) any or all of temperature, acidic concentration, air
25 pressure, humidity and cable changes.

12. A downhole data communications system (200), comprising at least one communication equipment (210) configured to perform the method according to any one of claims 1 to 11.

30

13. A communication equipment (210) configured to be arranged to perform the method according to any one of claims 1 to 11.

35

**ANY REFERENCE TO FIGURE 1 SHALL BE CONSIDERED
NON-EXISTENT**

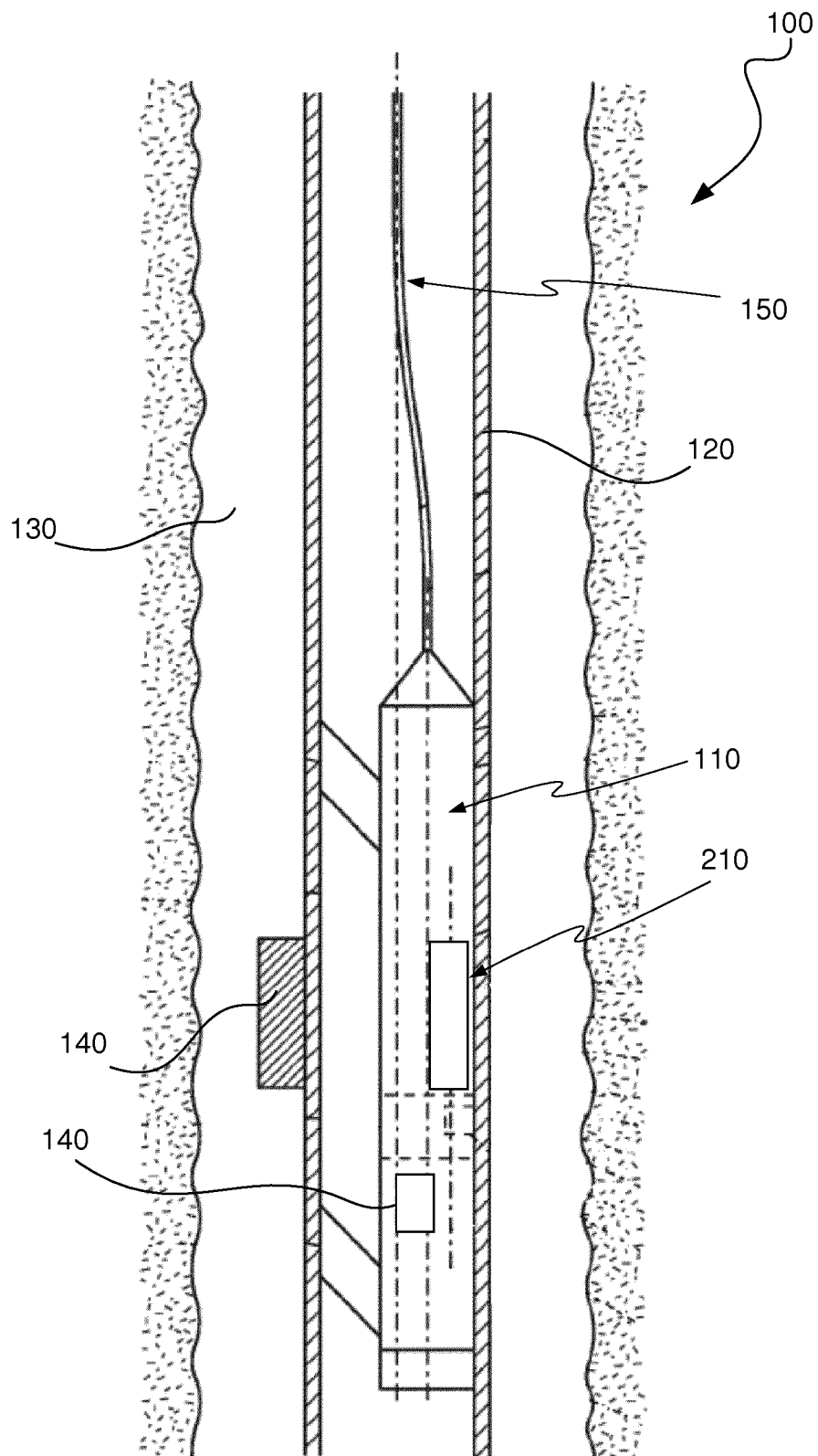


Fig. 1a

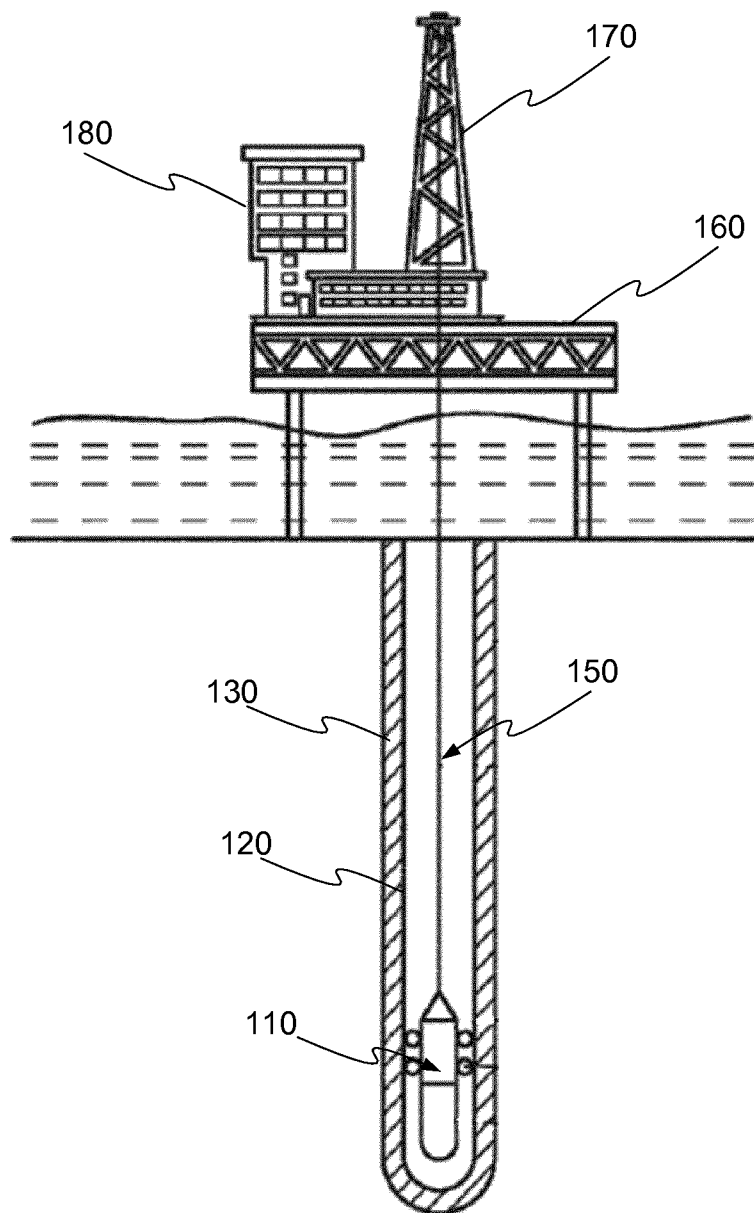


Fig. 1b

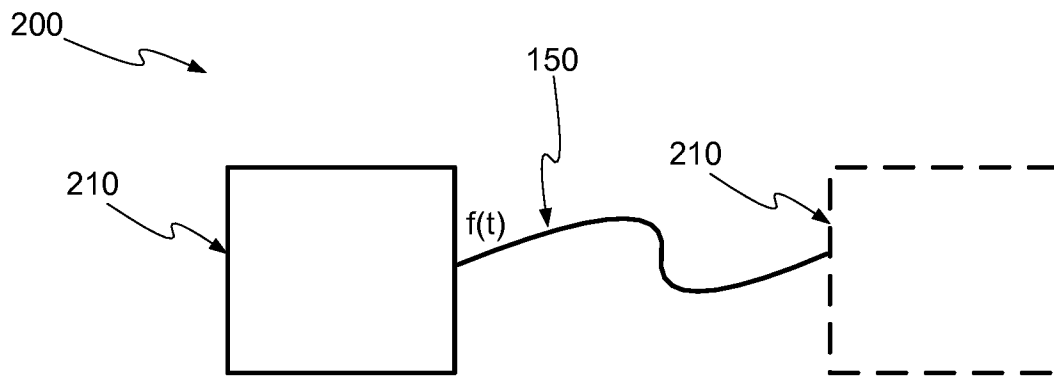


Fig. 2

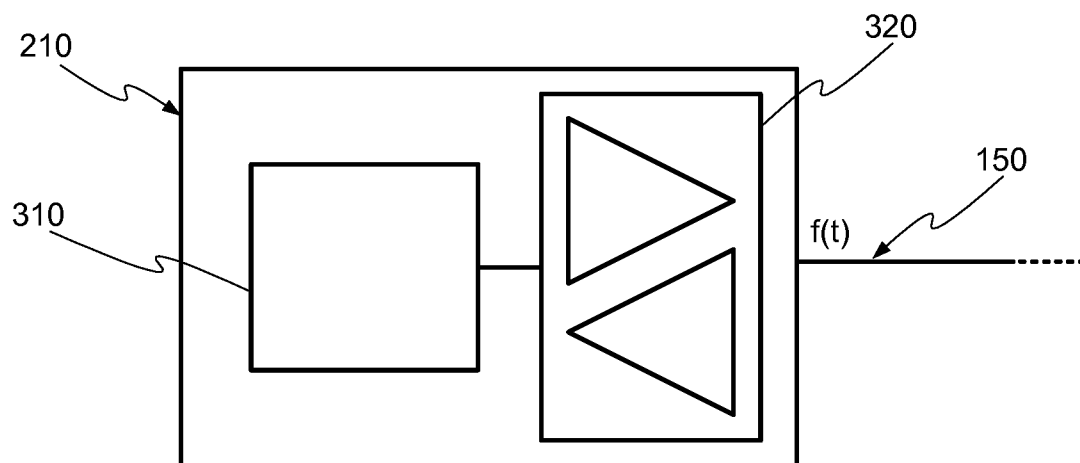


Fig. 3

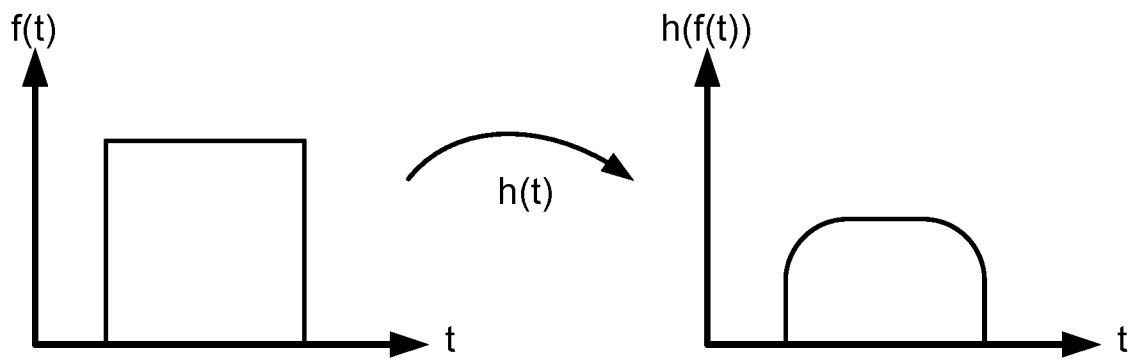


Fig. 4a

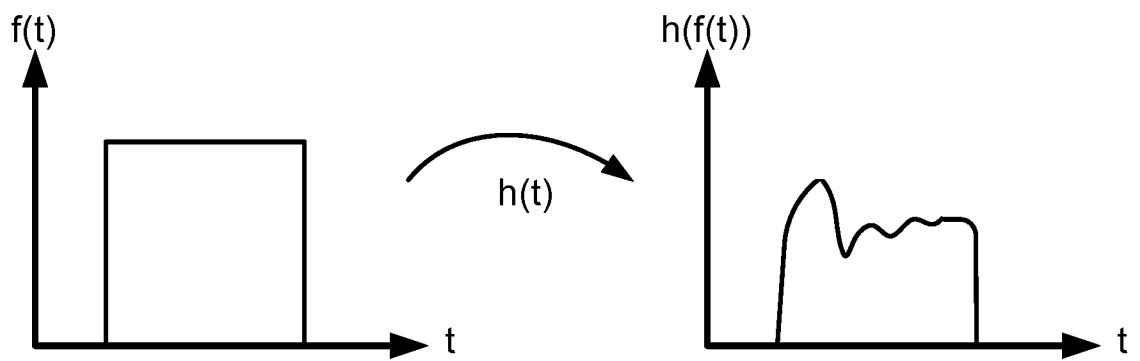


Fig. 4b

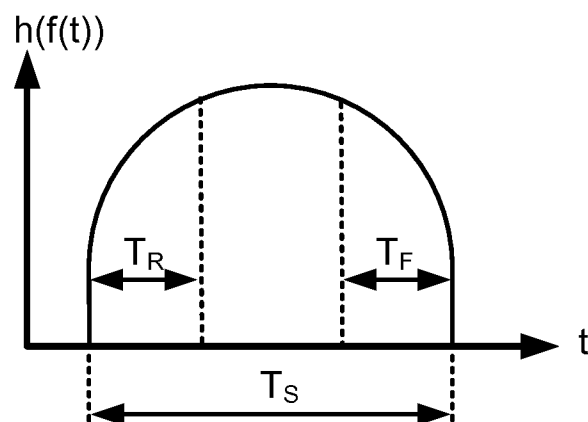


Fig. 4c

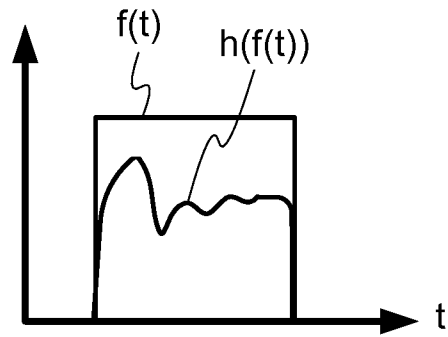


Fig. 5

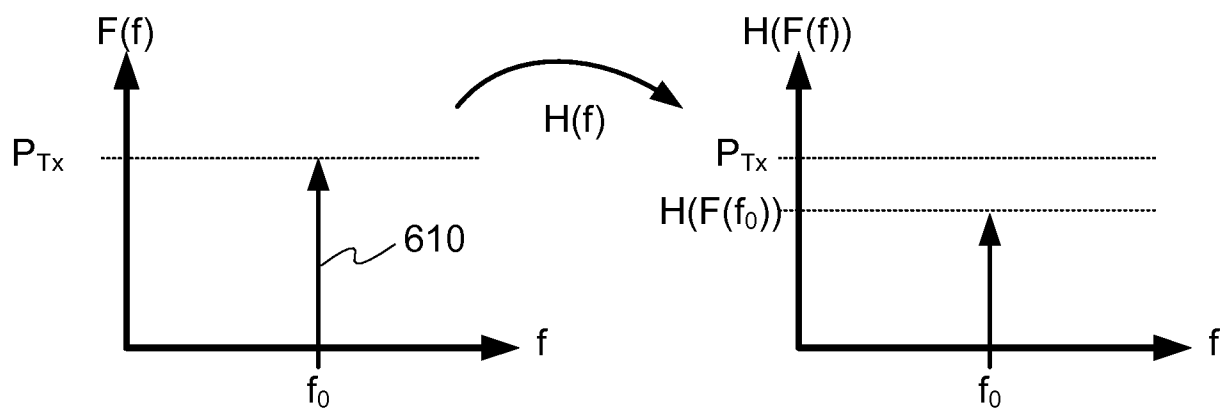


Fig. 6a

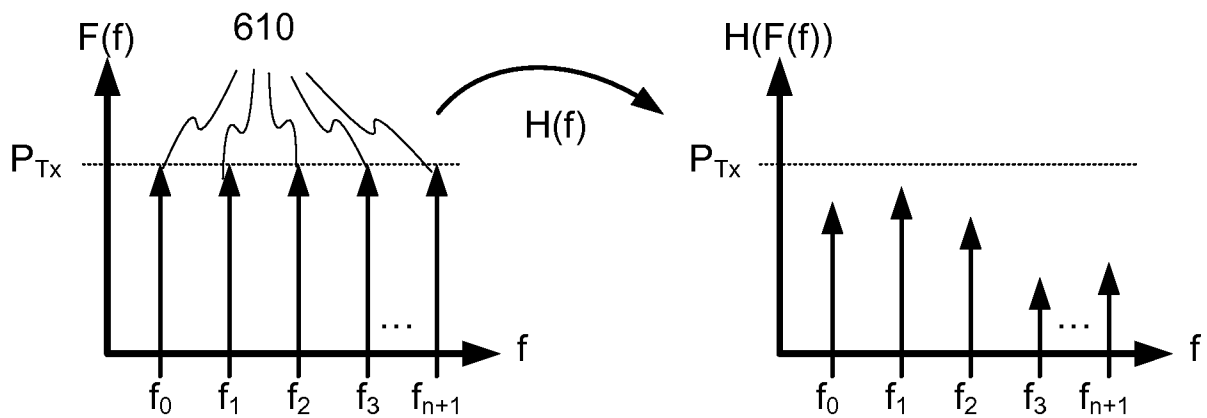


Fig. 6b

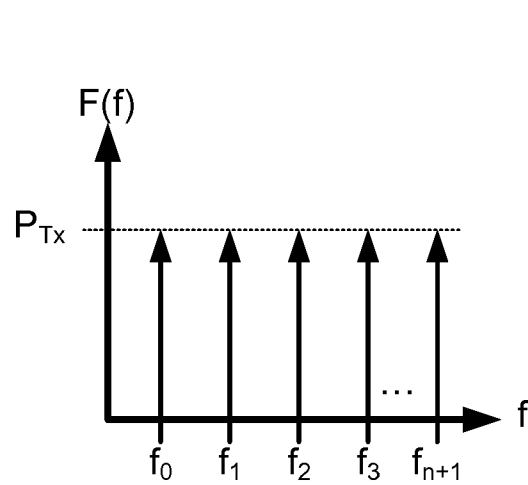


Fig. 7a

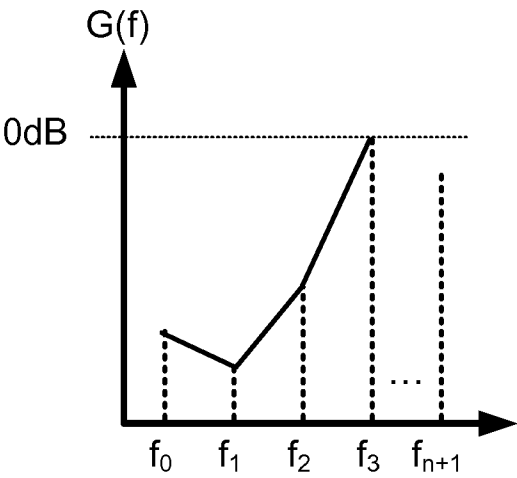


Fig. 7b

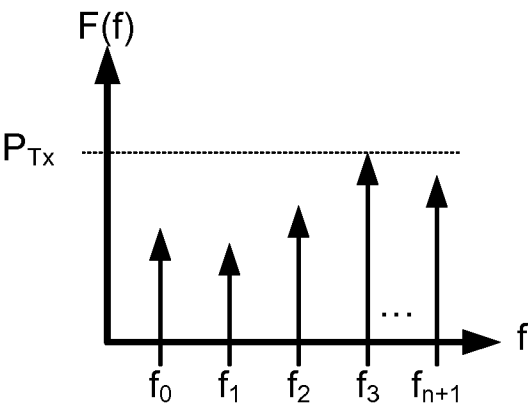


Fig. 7c

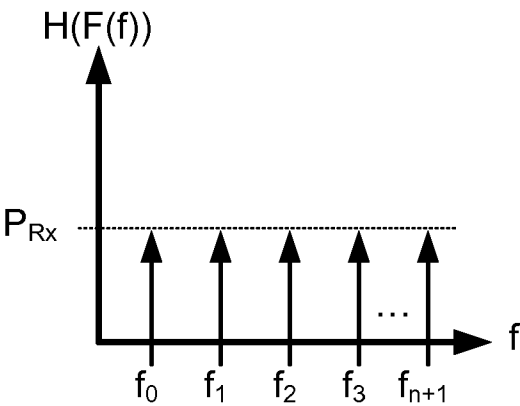


Fig. 7d

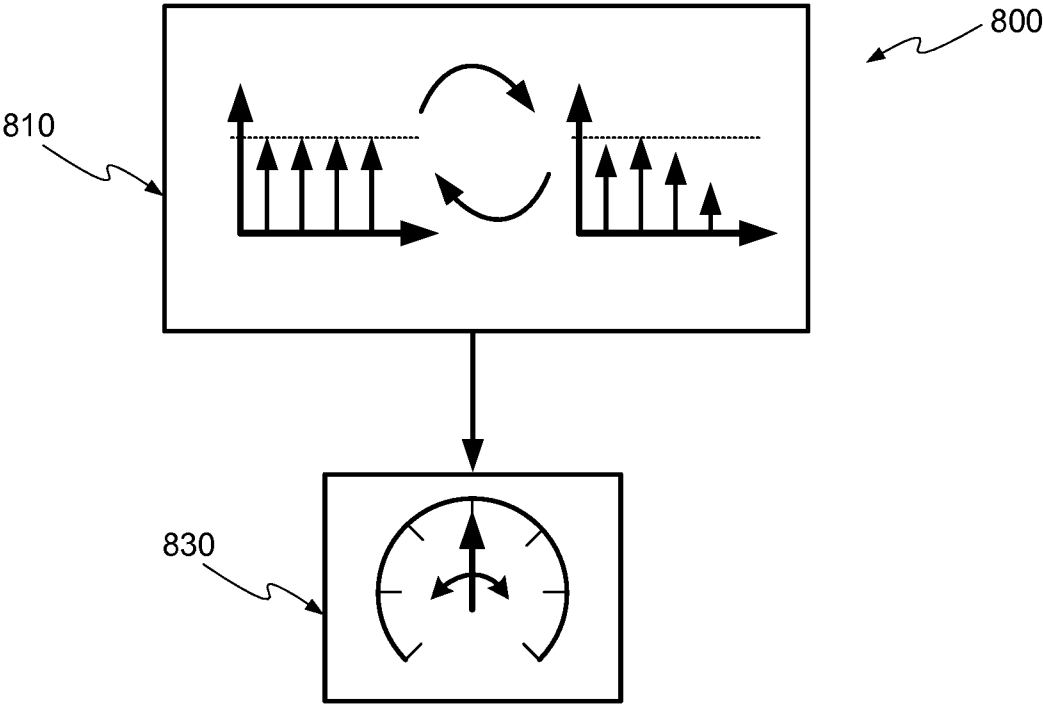


Fig. 8a

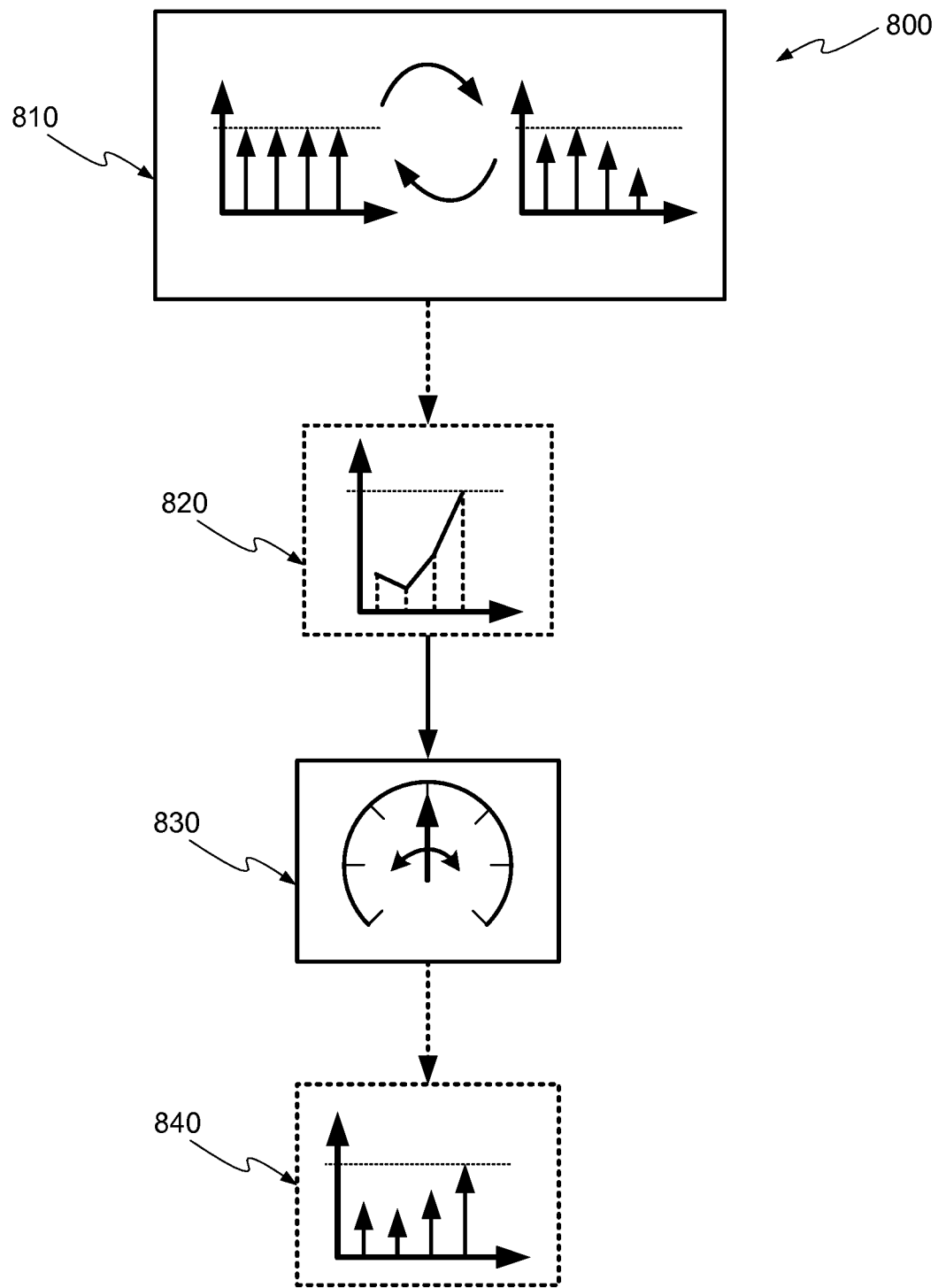


Fig. 8b

INTERNATIONAL SEARCH REPORT

International application No
PCT/EP2019/068825

A. CLASSIFICATION OF SUBJECT MATTER
INV. E21B47/12
ADD.

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

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

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

EPO-Internal, WPI Data

C. DOCUMENTS CONSIDERED TO BE RELEVANT

Category*	Citation of document, with indication, where appropriate, of the relevant passages	Relevant to claim No.
A	GB 2 408 432 A (BAKER HUGHES INC [US]) 25 May 2005 (2005-05-25) page 7, paragraph 20 - page 8, paragraph 23; figure 4 page 9, paragraph 26 - page 10, paragraph 27	1-13
A	----- WO 2018/070998 A1 (HALLIBURTON ENERGY SERVICES INC [US]) 19 April 2018 (2018-04-19) page 4, paragraph 21 - paragraph 22	1-13
A	----- WO 02/077413 A1 (HALLIBURTON ENERGY SERV INC [US]; GARDNER WALLACE R [US]; SCHULTZ ROGE) 3 October 2002 (2002-10-03) page 6, line 28 - page 7, line 5 ----- -/-	1-13



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 another 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

11 September 2019

Date of mailing of the international search report

08/10/2019

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INTERNATIONAL SEARCH REPORT

International application No

PCT/EP2019/068825

C(Continuation). DOCUMENTS CONSIDERED TO BE RELEVANT		
Category*	Citation of document, with indication, where appropriate, of the relevant passages	Relevant to claim No.
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INTERNATIONAL SEARCH REPORT

Information on patent family members

International application No

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