

ACTIVATION MODE CONTROL OF OILFIELD TOOLS

CROSS-REFERENCE TO RELATED APPLICATION

5 The present application is a continuation-in-part of U.S. Application No. 14/786,755, filed October 23, 2015, which is a U.S. National Stage Application of International Application No. PCT/US2014/038217 filed May 15, 2014, all of which are incorporated herein by reference in their entirety for all purposes.

BACKGROUND

10 The present disclosure relates generally to drilling operations and, more particularly, to determining control and actuation of downhole tools.

 Completion is the general process of bringing a well into production after drilling into a subterranean formation having a hydrocarbon reservoir. A single well may be completed multiple times, creating multiple “zones” for fluids to communicate between the
15 reservoir and the wellbore.

 When completing a given zone, the zone may need to be isolated from other zones. For example, when a zone is to be hydraulically fractured, the zone may need to be isolated from uncompleted zones to prevent their premature fracturing and from previously completed zones to prevent fluid losses into the formation.

20 Zones are generally isolated by downhole tools. Downhole tools may include cement or packers for sealing zones, sliding sleeves operable to permit flow to and from specific zones, control valves for controlling and directing flow, and various other tools for performing other functions. To permit individual zones to be selectively isolated, the downhole tools may be operable between different positions or modes of operation.

25 Some downhole tools are operated in part by onboard electronics that require electrical power. Due to complications with providing electrical power via downhole cabling, some downhole tools may use batteries as a power source. However, because of the need for the downhole tool to operate for extended periods of time below the earth’s surface, the weight and size requirements associated with adding additional batteries,
30 generally harsh downhole conditions, and various other factors, the useful operating life of

battery-operated downhole tools may be a concern. As a result, a reliable means for extending the useful lifetime of battery-operated downhole tools is desirable.

FIGURES

Some specific exemplary embodiments of the disclosure may be understood
5 by referring, in part, to the following description and the accompanying drawings.

FIG. 1 is a schematic of a well system following a multiple-zone completion operation.

FIG. 2 is a block diagram depicting an embodiment of onboard electronics, actuators and other electronic components of a downhole tool.

10 FIGS. 3A, 3B, 3C and 3D are a series of graphs representing different embodiments of magnetic signals.

FIG. 4 is a schematic view of an embodiment of a magnetic source tool.

FIG. 5 is a schematic view of another embodiment of a magnetic source tool.

15 FIGS. 6A, 6B and 6C are schematic views of an embodiment using magnetic balls for signaling the downhole tool.

FIG. 7 is a flowchart of transitions from sleep to active modes triggered by detection of certain signals.

FIG. 8 is a graph illustrating an example mode transition when certain signals are detected.

20 FIG. 9 is a flowchart of transitions from sleep to twilight to active modes triggered by detection of certain signals.

FIG. 10 is a graph illustrating an example mode transition when certain signals are detected.

While embodiments of this disclosure have been depicted and described and
25 are defined by reference to exemplary embodiments of the disclosure, such references do not imply a limitation on the disclosure, and no such limitation is to be inferred. The subject matter disclosed is capable of considerable modification, alteration, and equivalents in form and function, as will occur to those skilled in the pertinent art and having the benefit of this disclosure. The depicted and described embodiments of this disclosure are examples
30 only, and not exhaustive of the scope of the disclosure.

DETAILED DESCRIPTION

The present disclosure relates generally to drilling operations and, more particularly, to determining control and actuation of downhole tools.

FIG. 1 is a schematic of a well system following a multiple-zone completion operation. A wellbore extends from a surface and through subsurface formations. The wellbore has a substantially vertical section 104 and a substantially horizontal section 106, the vertical section 104 and horizontal section 106 being connected by a bend 108. The horizontal section 106 extends through a hydrocarbon bearing formation. One or more casing strings 110 are inserted and cemented into the vertical section 104 to prevent formation fluids from entering the wellbore.

The well system depicted in FIG. 1 is generally known as an open hole well because the casing strings 110 do not extend through the bend 108 and horizontal section 106 of the wellbore. As a result, the bend 108 and horizontal section 106 of the wellbore are "open" to the formation. In another embodiment, the well system may be a closed hole type in which one or more casing strings are inserted in the bend 108 and the horizontal section 106 and cemented in place.

The embodiment in FIG. 1 includes a top production packer 112 disposed in the vertical section 104 of the wellbore that seals against the innermost casing string. Production tubing 114 extends from the production packer 112, along the bend 108 and extends along the horizontal section 106 of the wellbore. Disposed along the production tubing 114 are various downhole tools including packers 116A-E and sleeves 118A-F. The packers 116A-E engage the inner surface of the horizontal section 106, dividing the horizontal section 106 into a series of production zones 120 A-F.

Each of the sleeves 118A-F is generally operable between an open position and a closed position such that in the open position, the sleeves 118 A-F allow communication of fluid between the production tubing 114 and the production zones 120A-F.

During production, fluid communication is generally from the formation, through the open sleeves, and into the production tubing. The packers 116 A-F and the top production packer 112 seal the wellbore such that any fluid that enters the wellbore below

the production packer 112 is directed through the sleeves 118 A-F, the production tubing 114, and the top production packer 112 and into the vertical section 104 of the wellbore.

Communication of fluid may also be from the production tubing 114, through the sleeves 118 A-F and into the formation, as is the case during hydraulic fracturing. Hydraulic fracturing is a method of stimulating production of a well and generally involves pumping specialized fracturing fluids down the well and into the formation. As fluid pressure is increased, the fracturing fluid creates cracks and fractures in the formation and causes them to propagate through the formation. As a result, the fracturing creates additional communication paths between the wellbore and the formation.

In wells having multiple zones, such as the well depicted in FIG. 1, it is often necessary to fracture each zone individually. To fracture only one zone at a time, the zone is isolated from other zones and fracturing fluid is prevented from entering the other zones. Isolating the zone being fractured may require actuating one or more downhole tools between different configurations, positions, or modes. For example, isolating the zone may require a sliding sleeve tool to move between a closed configuration and an open configuration, a packer may need to engage or disengage the wellbore, or a control valve may need to change its configuration to redirect the fracturing fluid.

In general, a downhole tool may include onboard electronics and one or more actuators to facilitate operation of the downhole tool. FIG. 2 is a block diagram depicting a configuration of onboard electronics, actuators and other electronic components of a downhole tool. The onboard electronics 202 may include a controller 204 for storing and executing instructions. In general, the controller 204 includes a processor 206 for executing instructions and a memory 208 for storing instructions to be executed by the processor 206 and may further include one or more input/output (I/O) modules 209 for communication between the controller 204 and other electronic components of the downhole tool.

In one embodiment, the controller 204 communicates with an actuator 210 to operate the downhole tool between configurations, positions, or modes. In one embodiment, the actuator 210 convert electrical energy from a power source 212 to move one or more downhole tool components. For example, one actuator may be a linear actuator that retracts or extends a pin for permitting or restricting movement of a downhole tool component. In

certain embodiments, a second actuator may rotate a valve body to redirect a fluid flow through the downhole tool. In certain embodiments, the actuator may engage a sliding sleeve of the downhole tool and be structured and arranged to open the sliding sleeve. In certain embodiments, the actuator may shift a baffle disposed on the downhole tool from a first baffle position (for example, where the baffle is not in position to catch a wellbore projectile, such as a ball or a dart) to a second baffle position (for example, where the baffle is positioned to catch such a wellbore projectile).

The onboard electronics 202 and the actuator 210 may be connected to a power source 212. In one embodiment, the power source 212 may be a battery integrated with the downhole tool or integrated with another downhole tool electrically connected to the downhole tool. The power source 212 may also be a downhole generator incorporated into the downhole tool or as part of other downhole equipment.

The downhole tool may include at least one sensor 216 for detecting a physical property and converting the property into an electrical signal. The sensor 216 communicates the electrical signal to the onboard electronics 202. After receiving the electrical signal, the controller 204 may execute instructions based on the electrical signal. One or more of the instructions executed by the controller 204 may include sending signals to the actuator 210, causing the actuators to actuate.

For purposes of this disclosure, the one or more sensors 216 may comprise a temperature sensor, a pressure sensor, a flow rate sensor, an accelerometer, a strain sensor, an audio sensor, a magnetic sensor, or any combination thereof. The sensor may be operable to detect changes a series of changes that occur over time or may be operable to detect simultaneous changes. For example, the sensor may detect a decrease in temperature and an increase in acoustic noise as fluid is pumped into the wellbore. In another example, the sensor may detect a decrease in temperature as the fluid is pumped into the wellbore and subsequently detect a magnetic field introduced by a permanent magnet placed in the fluid stream. In some embodiments, the magnetic sensor may be a Hall Effect sensor, Giant Magnetoresistive Sensor, or similar sensor that detects magnetic field strength. In other embodiments, the magnetic sensor may be a magnetometer or similar sensor that detects magnetic field direction and strength.

The sensor 216 converts detected signals into electrical signals that reflect characteristics of the detected signals. As a result, different signals may be used to generate electrical signals. Because the onboard electronics 202 execute instructions based on electrical signals from the sensor 216, different signals may be used to cause the controller to execute different instructions and to perform different functions of the downhole tool. For example, in one embodiment, one magnetic signal may cause the controller 204 to execute an instruction issuing a command to an actuator to move in a first direction, while a second magnetic signal may cause the controller 204 to issue a command to the actuator to move in a second direction. In another embodiment, a first signal may cause the onboard electronics to enter into a “sleep” mode in which the onboard electronics are placed in a lower power mode to conserve battery life, where the tool is inoperable to perform downhole functions, and a second signal may “awaken” the onboard electronics to enable the tool to perform downhole functions.

FIGS. 3A-D are graphs depicting magnetic fields over time for illustrating different magnetic signals. The magnetic signals in FIGS. 3A-D are merely illustrative and do not limit the appropriate types of magnetic signals.

A magnetic signal is any magnetic field or change in a magnetic field that is converted to an electrical signal by the downhole tool sensor, the electrical signal causing the controller to execute one or more instructions. Magnetic signals are differentiated by detectable characteristics of the magnetic signal. A detectable characteristic may be any characteristic of a magnetic signal that may be detected by the magnetic sensor, captured in the electrical signal generated by the magnetic sensor, and recognized by the onboard electronics 202.

FIG. 3A is a graph illustrating magnetic signals in which the detectable characteristic is based on a series of magnetic pulses. For magnetic signals based on pulses, the onboard electronics may be configured to execute instructions in response to different quantities or to different patterns of magnetic pulses. For example, in certain embodiments the onboard electronics may respond to a total quantity of pulses, a specific number of pulses within a period of time, a delay between pulses, a specific pattern of pulses and delays, or any similar signal. Several possible magnetic signals may be represented by the

pulses depicted in FIG. 3A. For example, magnetic signals in FIG. 3A may include a total of five pulses, three quick pulses in quick succession, or a delay, followed by three quick pulses.

5 In certain embodiments, the magnetic signals may be generated with a magnet having a steady and/or constant strength, where the magnetic signals may be pulses created by changing the distance between the magnet and the sensor. For example, in certain embodiments, the magnet may be encapsulated within a ball to form a magnetic ball, where the magnetic ball may be moved past the sensor to create a magnetic pulse. In such
10 embodiments, a specific number of pulses may be generated by dropping a corresponding number of magnetic balls past the sensor.

FIG. 3B is a graph illustrating magnetic signals in which the detectable characteristic is the frequency. For magnetic signals based on frequency, the onboard electronics may be configured to execute instructions in response to a specific frequency of a magnetic field, a specific change in frequency of a magnetic field, a pattern of frequencies
15 of a magnetic field, or any similar measureable characteristic of the frequency of a magnetic field. Several magnetic signals may be represented by the sinusoidal magnetic field depicted in FIG. 3B. For example, one signal may be the higher frequency sinusoid in the middle of the graph.

FIG. 3C is a graph illustrating magnetic signals in which the detectable
20 characteristic is the field strength. For magnetic signals based on field strength, the onboard electronics may be configured to execute instructions in response to a magnetic field being above a threshold strength, being within a range of strengths, undergoing a change in strength, or any pattern of field strengths or changes in field strength.

In certain embodiments, the magnetic signal may comprise a magnetostatic
25 magnetic field, which has magnet field lines that travel in a closed path. In such a magnetostatic magnetic field, the magnetic field may emanate from the north pole of the magnet and form a closed path to the south pole of the magnet.

In certain embodiments, the magnetic signal may comprise an
30 electromagnetic field (or electromagnetic radiation), which has a time-varying field that may radiate outwards. Such a electromagnetic magnetic field may propagate through space.

FIG. 3D is a graph that illustrating magnetic signals in which the detectable characteristic is the duration or dwell time of a magnetic field. For magnetic signals based on dwell time, the onboard electronics may be configured to execute instructions in response to a magnetic field being present for a particular period of time, being absent for a particular period of time, or any pattern of being present and absent.

For downhole tools configured to respond to two or more magnetic signals, the two or more magnetic signals may or may not be of the same types of signal. For example, in one embodiment, a first magnetic signal may be based on frequency, while a second magnetic signal may be based on a series of magnetic pulses. In another embodiment, a first magnetic signal may be based on a first frequency, while a second magnetic signal may be based on a second, different frequency.

The onboard electronics may also take into account an order in which the magnetic signals are received by the onboard electronics. For example, the onboard electronics may respond to a magnetic signal based on magnetic field but only after first detecting another magnetic signal based on a series of magnetic pulses.

At least one magnetic source may be used to generate the magnetic signals. The magnetic source may include at least one magnet. The magnet may be a permanent magnet or an electromagnet.

FIG. 4 is a schematic view of a magnetic source tool in accordance with one embodiment. The magnetic source tool 400 includes multiple permanent magnets 402A-C disposed on a central body 404. As depicted in FIG. 4, the magnetic source tool 400 may be lowered into a wellbore by a wireline 406 or similar line such as a coiled cable. The magnetic source tool may be lowered into the wellbore under the force of gravity or may be pumped down the wellbore. FIG. 4 also includes a downhole tool 408 with a sensor 410 for detecting magnetic signals generated by the magnetic source tool 400.

Different magnetic signals with different detectable characteristics may be achieved by altering the quantity, positioning, and strength of the permanent magnets 402A-C, or by changing the manner in which the magnetic source tool 400 is inserted into the wellbore. For example, one magnetic signal consisting of a series of three pulses may be generated by moving the magnetic source tool 400 past the sensor 410, each pulse being

generated as each of the permanent magnets 402A-C passes the sensor 410. The magnetic source tool 400 may also be used to generate a second magnetic signal based on dwell time by positioning the magnetic source tool 400 such that one of the permanent magnets 402A-C is maintained in close proximity to the sensor 410.

5 FIG. 5 is a schematic view of another embodiment in which the magnetic source tool includes an electromagnet 502. FIG. 5 also includes a downhole tool 508 having a sensor 510 for detecting magnetic signals generated by the electromagnet 502. The electromagnet 502 is supplied with power by a power source via an electrical line 504. In an alternate embodiment, the magnetic source tool may include an onboard power source such
10 as a battery. The power source is connected to the electromagnet such that when the power source is activated, current flows to the electromagnet and the electromagnet generates a magnetic field. A wireline 506 may be attached to the electromagnet 502. The electrical line 504 and the wireline 506 may be separate lines, as depicted, or may be integrated into a single cable.

15 The electromagnet 502 generates a magnetic field when it receives electrical power from the power supply. By varying the power supplied by the power source, the electromagnet may produce various magnetic fields and various magnetic signals. For example, the frequency or waveform of the power supplied to the electromagnet may be changed to create different magnetic fields and magnetic signals with changes in frequency
20 or waveform corresponding to those of the power supplied. To modify the power supplied by the power source, power electronics may be incorporated directly into the power source or otherwise included in a broader power system.

 In another embodiment, the magnetic source may comprise one or more magnetic wellbore projectiles, for example, a magnetic ball. The one or more magnetic
25 balls may be any. The one or more magnetic wellbore projectiles are designed such that they may be dropped into or shot into the wellbore by a ball launcher. The downhole tool sensors detect the magnetic fields of the one or more magnetic wellbore projectiles as the one or more magnetic wellbore projectiles move through the wellbore and past the downhole tool. Among other things, the quantity of magnetic projectiles, frequency at
30 which the one or more magnetic wellbore projectiles are introduced, and the magnetic

strength of the one or more magnetic wellbore projectiles may be varied to produce different magnetic signals.

FIG. 6A depicts a portion of a horizontal wellbore having production tubing on which a series of downhole tools are disposed. The downhole tools include four packers
5 604A-D and three sliding sleeve tools 606 A-C.

FIGS. 6B and 6C each provide an illustrative views of sliding sleeve tool 606A, where FIG. 6B depicts the sliding sleeve tool in a closed position. FIG. 6C depicts the sliding sleeve tool in an open position. Because the sliding sleeve tools 606A-C are substantially the same, the description of the structure and operation of sliding sleeve tool
10 606A, below, generally applies to the other sliding sleeve tools 606B-C.

As depicted in FIG. 6B, the sliding sleeve tool includes an actuator 614 and onboard electronics 608, which further include a sensor 609. The sliding sleeve tool may comprise a sleeve 622, which may further comprise a baffle 615 disposed on the sleeve 622. In certain embodiments, the baffle 615 may be a ball seat.

The sleeve 622 may be in a closed position (shown in FIG. 6B) in which the
15 sleeve 622 may prevent fluid flow through a communication port 620. The sleeve 622 may be configured to move or collapse into an open position (shown in FIG. 6C). In certain embodiments, fluid contained within a chamber 616 may prevent the sleeve 622 from moving into the open position. In certain embodiments, the actuator 614 may open a port
20 (not shown) allowing fluid to move from within the chamber 616, thereby allowing the sleeve 622 to move from the closed position to the open position.

The sliding sleeve tool includes a series of communication ports 620 around its circumference. With the sleeve 622 in the open position, fluid may flow through the communication ports 620, which may connect, for example, an inner flow path of tubing
25 and a formation. In certain embodiments, the sleeve 622 may be moved from the closed position to the open position by a wellbore projectile such as a ball 624. If the sleeve 622 is in the open position, the ball 624 simply passes through the sliding sleeve tool and further down the wellbore. When the sleeve 622 is closed, the ball 624 may engage the baffle 615. For example, in certain embodiments, when the sleeve 622 is in the closed position, the
30 baffle 615 may prevent the ball 624 from moving further downhole.

In certain embodiments, when the ball 624 engages the baffle 615, the ball 624 may prevent the fluid flow through the sliding sleeve tool. For example, in certain embodiments, the ball 624 and baffle 615 may form a seal. In such embodiments, the fluid may apply a force (such as through hydraulic pressure) to the ball 624, which in turn may apply a force on the baffle 615 and sleeve 622. The fluid may apply a force to the sleeve 622 via the ball 624 and the baffle 615 sufficient to move the sleeve 622 into the open position.

In one embodiment, the balls may be magnetic balls that comprise magnetic components and have a magnetic field. As the magnetic balls pass through the sliding sleeve tools, the sensor 609 detects the magnetic field of the passing magnetic ball as a magnetic pulse and transmits a corresponding electronic signal to the onboard electronics 608. Each sliding sleeve tool is configured to collapse its respective baffle after a certain number of balls have passed, that is, after the onboard electronics receive a certain number of electronic signals from the sensor 609 generated by the sensor 609 in response to passing magnetic balls.

For example, referring back to FIG. 6A, the furthest downhole sleeve 606C may begin with its baffle in a collapsed position to catch the first magnetic ball and open the sleeve with that first magnetic ball. As the first magnetic ball passes through sliding sleeve tools 606A and 606B, the onboard electronics of sliding sleeve tools 606A and 606B register a first magnetic pulse.

The onboard electronics of sliding sleeve tool 606B may be configured to collapse the baffle of sliding sleeve tool 606B when the onboard electronics register a single magnetic pulse via the sensor 609. As a result, after detecting the first magnetic pulse generated by the first magnetic ball, the baffle of the sliding sleeve tool 606B would collapse, permitting the sliding sleeve tool 606B to catch and be opened by a second magnetic ball introduced into the wellbore. As the second magnetic ball passes through sliding sleeve tool 606A, the onboard electronics of sliding sleeve tool 606A would register a second magnetic pulse.

The onboard electronics of sliding sleeve tool 606A may be configured to collapse the baffle of sliding sleeve tool 606A when the onboard electronics detect a

magnetic signal consisting of two magnetic pulses. As a result, after detecting the second pulse generated by the second magnetic ball, the baffle of the sliding sleeve tool 606A would collapse, permitting the sliding sleeve tool 606 A to catch and be opened by a third magnetic ball.

5 By configuring the sliding sleeve tools 606A-C as described, the sliding sleeve tools can be sequentially opened by introducing magnetic balls. This permits sequential completion of production zones adjacent to each sliding sleeve tool.

Although the completion operation discussed above involved only one magnetic signal per sliding sleeve tool, problems may occur during completion that may
10 require the sliding sleeve tools to perform additional functions.

For example, if fracturing of a particular formation zone is carried out but found to be insufficient, it may be necessary to survey the zone being fractured before moving on to another zone. Some survey tools survey the formation using a high powered magnetic field. Such a field could cause the onboard electronics of the sliding sleeve tools to
15 detect false pulses and to actuate out of sequence.

Another example is when downhole equipment becomes damaged or dislodged. To retrieve broken equipment, a magnetic retrieval tool may be used to retrieve the equipment from the wellbore. Similar to the survey tool, the magnetic field of the magnetic retrieval tool may cause the sliding sleeve tools to detect false pulses and to
20 actuate out of sequence.

In accordance with one embodiment, the sliding sleeve tools overcome the above problems by being configured to actuate in multiple ways in response to multiple magnetic signals. As a result, several options exist to ensure that the sliding sleeve tools 606A, 606B and 606C are either not actuated out of sequence or can be reset if they are.

25 To prevent out of sequence actuation, the sliding sleeve tools may be configured to respond to a second magnetic signal that toggles the sliding sleeve tool into and out of a "sleep" mode. During sleep mode, all functions of the sliding sleeve tool, including counting magnetic pulses, are suspended until the second magnetic signal is used to "wake" the sliding sleeve tool. A magnetic source tool, as described earlier in this
30 disclosure, may be introduced into the wellbore and used to produce the second magnetic

signal.

An alternative to sleep mode is for the sliding sleeve tools to respond to a second magnetic signal by resetting themselves. In one embodiment, the resetting could be a mechanical resetting of the baffle. In this embodiment, the second magnetic signal could be used to cause an actuator open a relief port that relieves fluid pressure within the chamber 616 and returns the baffle its expanded position. In another embodiment, the resetting could be a resetting of the logic within the onboard electronics. Specifically, the second magnetic signal may be used to reset the count of magnetic pulses for one or more of the sliding sleeve tools. As further described herein, the tool may enter a sleep mode until a secondary sensor signal is reached, such as a temperature sensor rising above a predetermined temperature measurement.

FIG. 7 is a flowchart illustrating the tool's transitions from sleep to active modes triggered by detection of certain signals. A downhole tool, such as a sliding sleeve tool, is prepared to be inserted into the wellbore in step 702. Preparation of the tool may comprise programming the tool to respond to the desired trigger signals, testing signals to ensure the tool is functioning properly, or adding new batteries to the tool to ensure the longest possible operational lifetime for the tool. It may be desirable to place the tool into a sleep mode before it is placed in the wellbore, as shown in step 704. Placing the tool in a sleep mode may conserve battery power until it has reached the location in the wellbore where it may perform the downhole functions. Once the tool has reached its destination in the wellbore, one or more signals may be detected 706 by the tool's sensor. Certain signals 722 may trigger a transition to an active mode 708. Otherwise, the tool may remain 720 in the sleep mode 704 and await additional signals 706.

In the active mode 708, the tool is operable to perform downhole functions when certain signals are detected 710. For example, if the tool is a sliding sleeve tool, a downhole function may comprise opening or closing a sliding sleeve to divert fluid. An operator on the surface may generate a signal to trigger the tool to trigger a downhole function. By way of example and not limitation, an operator may introduce fluid into the wellbore, causing a temperature, acoustic noise, pressure, or flow rate to change or pass a threshold such that the sensor may detect the signal 710. Other signals may comprise a

magnetic field of sufficient amplitude or frequency, an electrical field of sufficient amplitude or frequency. Alternatively, a change in environmental conditions, without operator influence, may be detected by the sensor 710. For example, a decrease in fluid flow rate may occur when a reservoir is depleted or if fracturing fluid is diverted into a new reservoir. Certain signals 732 may trigger the tool to perform a downhole function 712, such as opening or closing a sliding sleeve on a sliding sleeve tool. After performing the downhole function, the tool may remain 740 in the active mode 708 so that it is prepared to receive additional signals 710. However, it may be desirable for specific signals 734 to return the tool to a sleep mode 704. As illustrated by FIG. 7, the tool may be operable to transition between sleep and active modes multiple times. If the tool is battery powered, such transitions may occur repeatedly before sufficient power is unavailable to enable downhole functions. Because the downhole function consumes battery power, judicious use of the sleep mode may enable operation of the tool for longer than if the tool remained active at all times. By way of example and not limitation, an unexpected delay in production, such as a sandout, may prompt an operator to generate a signal to trigger the downhole tool to enter the sleep mode to conserve battery life. Once production can continue, the operator may generate another signal to trigger the downhole tool to enter the active mode. In certain embodiments, the tool may begin performing operations immediately upon transitioning to the active mode, while in other embodiments, the downhole tool may require additional stimulus, such as an operator-generated signal, to prompt performance of a downhole function.

FIG. 8 is a graph illustrating an example mode transition when certain signals are detected. At t_1 , a first signal 802 is detected causing the downhole tool to transition from the sleep mode and to the active mode, as shown by line 810. A second signal 804 at t_2 causes the tool to transition from the active mode and to the sleep mode. In this example, the tool is programmed to react only when the detected signal exceeds the threshold 806 as indicated by the absence of a change in the tool's mode when signal 808 fails to exceed the defined threshold 806.

In yet another embodiment, the downhole tool may have three operable modes as illustrated in FIGS. 9 and 10. FIG. 9 is a flowchart of transitions from sleep to

twilight to active modes triggered by detection of certain signals. The downhole tool is prepared for insertion into the wellbore in 902 and placed in the sleep mode 904 for reasons discussed above. When it detects a signal 906, the tool determines if satisfies certain conditions to transition 922 to twilight mode 908 or if the signal does not match a predetermined condition 920, the tool may remain in sleep mode 904.

Once the tool is in twilight mode 908, additional detected signals 910 may trigger transitions to the active mode or return to the sleep mode. If the signal 910 satisfies certain conditions 934, the tool may return to sleep mode 904. Another signal 932 may trigger the tool may transition to active mode 912. If neither condition is satisfied 930, the tool may remain in twilight mode 908. Like the sleep mode, the tool may detect additional signals in the twilight mode, but is not operable to perform downhole functions.

When the tool is operating in active mode 912, certain signals 944 may trigger a transition back to twilight mode 908. Alternatively, a different signal 942 may trigger the tool to perform a downhole function 916. The tool may perform the downhole function 916 and return 950 to the active mode 912 to await additional signals 914. If neither signal condition is satisfied 940, the tool may remain in active mode 912 to await additional signals 914.

FIG. 10 is a graph illustrating an example mode transition when certain signals are detected. FIG. 10 illustrates detected signals triggering transitions from sleep mode to twilight mode, and from twilight mode to active mode. At t_1 , a first signal A 1002 is detected causing the downhole tool to transition to a twilight mode, as illustrated by tool mode 1010. A second signal B 1006 at t_2 initiates a transition from the twilight mode to the active mode. The first and the second signals may, but need not, be of the same type and may comprise temperature, pressure, flow rate, audio, or magnetic signals, or any combination thereof. By way of illustration and not limitation, signal A may represent a rapid change in temperature, while signal B may represent a rapid change in acoustic noise. In this example, once the tool has entered the active mode, a second change in signal A 1004 does not trigger a transition out of the active mode. In other embodiments, transitions between modes may be initiated by one or more signals of one or more types. Furthermore, the tool may transition from the active mode to the twilight mode and from the twilight

mode to the sleep mode when it detects other signals.

In sleep mode, tool electronics may consume substantially lower power and/or energy as compared with a normal tool operation mode. In certain embodiments, the tool may transition to sleep mode by reducing the clock speed of tool processor(s), by
5 deactivating selective electrical components (such as sensors or processors), and/or by avoiding or disallowing power consuming processes such as writing to memory. For example, in certain embodiments, in sleep mode only a watchdog timer and an external interrupt are powered. Sleep mode may also be referred to as hibernation.

In certain embodiments, the tool may enter a twilight mode between sleep
10 mode and normal active mode (or full active mode). In twilight mode, selective power consuming modes may be deactivated while other select power consuming modes or processes are active.

Although numerous characteristics and advantages of embodiments have been set forth in the foregoing description and accompanying figures, this description is
15 illustrative only. Changes to details regarding structure and arrangement that are not specifically included in this description may nevertheless be within the full extent indicated by the claims.

Therefore, the present disclosure is well adapted to attain the ends and advantages mentioned as well as those that are inherent therein. The particular
20 embodiments disclosed above are illustrative only, as the present disclosure may be modified and practiced in different but equivalent manners apparent to those skilled in the art having the benefit of the teachings herein. Furthermore, no limitations are intended to the details of construction or design herein shown, other than as described in the claims below. It is therefore evident that the particular illustrative embodiments disclosed above
25 may be altered or modified and all such variations are considered within the scope and spirit of the present disclosure. Also, the terms in the claims have their plain, ordinary meaning unless otherwise explicitly and clearly defined by the patentee. The indefinite articles “a” or “an,” as used in the claims, are defined herein to mean one or more than one of the element that it introduces.

What is claimed is:

1. A method for operating a downhole tool, comprising:
 - generating a first signal;
 - detecting the first signal using at least one sensor;
 - 5 switching the downhole tool to a first operating mode in response to detecting the first signal;
 - generating a second signal;
 - detecting the second signal using the at least one sensor; and
 - switching the downhole tool to a second operating mode in response to detecting the
 - 10 second signal.
2. The method of claim 1, wherein the first operating mode comprises an awake mode, wherein the downhole tool has an increased energy consumption in the awake mode than in the second operating mode.
3. The method of claim 1, wherein the second operating mode comprises a sleep mode,
- 15 wherein the downhole tool consumes less energy in the sleep mode than in the first operating mode.
4. The method of claim 3, wherein the downhole tool further comprises an actuator, wherein the actuator is disabled during sleep mode.
5. The method of claim 1, further comprising:
 - 20 generating a third signal;
 - detecting the third signal using the at least one sensor;
 - switching the downhole tool to a third operating mode in response to detecting the third signal;
 - wherein the first operating mode comprises a twilight mode; wherein the downhole
 - 25 tool in the twilight mode consumes energy at a lower rate than in the second operating mode and consumes energy at a higher rate than in the third operating mode.

6. The method of claim 4, wherein the downhole tool must switch from first operating mode to second operating mode, before switching from second operating mode to third operating mode.
7. The method of claim 4, wherein switching the downhole tool to the third operating
5 mode in response to detecting the third signal, further comprises switching from twilight mode to the third operating mode.
8. The method of claim 1, wherein the first signal comprises a change of a temperature, pressure, flow rate, acoustic, magnetic field, or any combination thereof.
9. The method of claim 1, wherein detecting the first signal comprises detecting a
10 change in electromagnetic field.
10. The method of claim 1, wherein detecting the first signal comprises detecting a change in temperature field.
11. A system for operating a downhole tool, comprising:
a downhole tool, comprising
15 a sensor configured to detect at the signal;
a controller connected to the sensor and an actuator; and
an actuator; wherein the actuator is configured to perform a first tool action in response to the sensor detecting the signal;
an energy source connected to at least one of the controller, the actuator, and the
20 sensor; and
at least one source for creating the signal.
12. The system of claim 1, wherein the signal comprises a predetermined change in electromagnetic field.

13. The system of claim 1, wherein the signal comprises a predetermined change in temperature.

14. The system of claim 11, wherein the actuator is configured to perform a second tool action in response to the sensor detecting a second signal.

5 15. The system of claim 14, wherein the first tool action comprises switching the downhole tool to a first operating mode, and wherein the second tool action comprises switching the downhole tool to a second operating mode.

16. The system of claim 15, wherein the first operating mode comprises a sleep mode in which the downhole tool consumes less power than in the second operating mode.

10 17. The system of claim 14, wherein the second operating mode comprises an awake mode in which the downhole tool consumes more power than in the first operating mode.

18. The system of claim 11, wherein the sensor is capable of detecting a change in temperature, pressure, fluid flow rate, acoustics, electromagnetic field, or any combination thereof.

15 19. A method for operating a downhole tool, comprising:
generating a first signal
detecting the first signal using at least one sensor;
switching the downhole tool to a twilight operating mode in response to detecting
the first signal;
20 generating a second signal;
detecting the second signal using the at least one sensor; and
switching the downhole tool to an awake operating mode in response to detecting
the second signal;
generating a third signal;
25 detecting the third signal using the at least one sensor;

switching the downhole tool to a sleep operating mode in response to detecting the third signal;

20. The method of claim 19, wherein the downhole tool performs an active tool function in active mode, and wherein the downhole tool performs a twilight tool function in twilight mode.
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