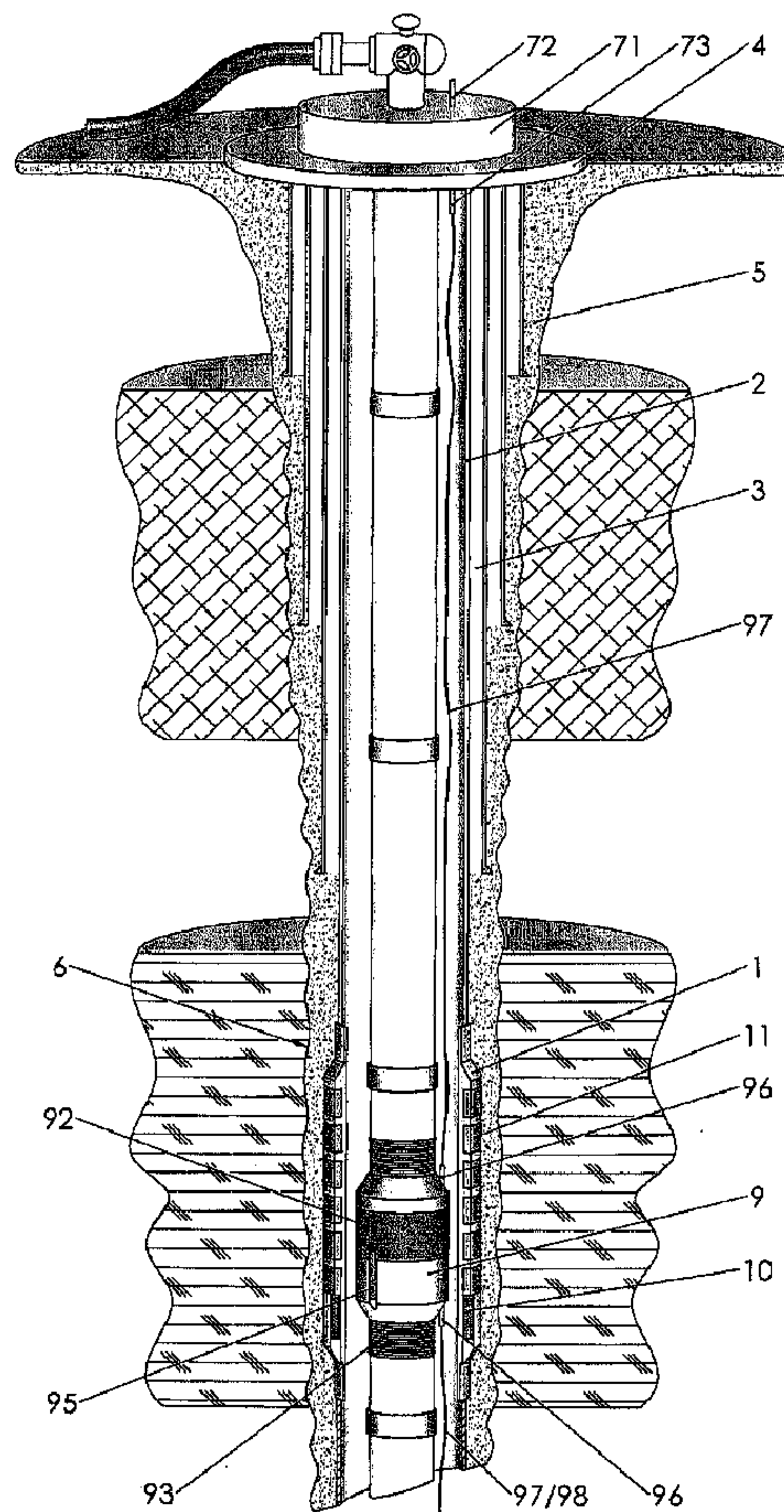




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(54) **Titre : PROCÉDE ET APPAREIL POUR LES MESURES DE FORAGE SUR SITE**
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(57) **Abrégé/Abstract:**

An apparatus and method to monitor parameters outside the wellbore casing (2) of the well comprising a Wireless Sensor Unit (WSU) (1) located outside a section of a non-magnetic casing of the well, said WSU including a sensor device (10) to measure



(57) Abrégé(suite)/Abstract(continued):

parameters of the surroundings. The apparatus further includes an internal Sensor Energiser Unit (SEU) (9) inside the wellbore casing used for power and communication with the WSU. The SEU and the WSU are arranged to be at the same elevation and they communicate data using electromagnetic modulation techniques.

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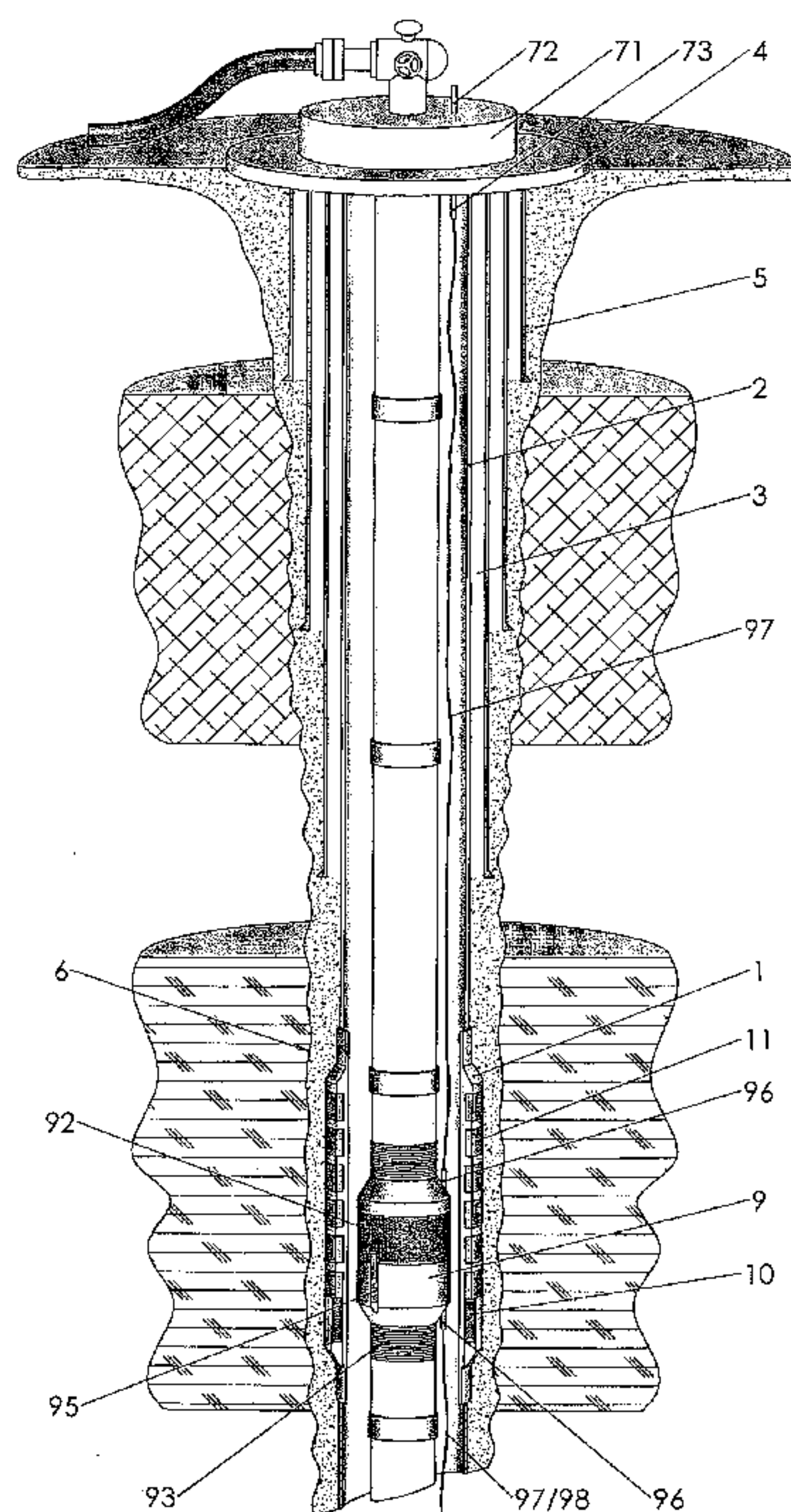
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[Continued on next page]

(54) Title: METHOD AND APPARATUS FOR IN-SITU WELLBORE MEASUREMENTS

FIGURE 1



(57) Abstract: An apparatus and method to monitor parameters outside the wellbore casing (2) of the well comprising a Wireless Sensor Unit (WSU) (1) located outside a section of a non-magnetic casing of the well, said WSU including a sensor device (10) to measure parameters of the surroundings. The apparatus further includes an internal Sensor Energiser Unit (SEU) (9) inside the wellbore casing used for power and communication with the WSU. The SEU and the WSU are arranged to be at the same elevation and they communicate data using electromagnetic modulation techniques.

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METHOD AND APPARATUS FOR
IN-SITU WELLBORE MEASUREMENTS

5 This invention relates to a method and apparatus for in-situ wellbore
measurements for the monitoring and control of oil and gas production,
injection and observation wells. More particularly, this invention relates to a
method and apparatus to monitor wellbore and formation parameters in-situ.
Operating means may be wirelessly installed behind the wellbore casing or
production barrier, without the need for a cable or cord to power, and without
10 compromising the pressure integrity of the well or well design in any way.

The present invention leads to better interpretation of process or formation
parameters, as the sensors are placed closer to or in direct contact with the
investigation zone of interest. The apparatus involved enables parameters to be
15 measured simultaneously inside and outside of the wellbore casing. The sensor
closeness to formation and the overall performance of the data acquisition
enable the operator to better distinguish whether a change in physical
parameter measured is caused by change of the physical parameter itself or is
caused by process or environmental fluctuations.

20

The invention also includes a telemetry for the communication from surface to
downhole as well as a combined "power harvesting" and telemetry device for
communicating with the wireless sensor unit that is located behind the well
casing or barrier. The surface-to-downhole power and telemetry link enables
25 numerous sensor units to be attached and operated on the same downhole

cable. This network configuration enables in-situ monitor of wellbore parameters of different zones in one and the same wellbore.

5 The management of oil and gas as well as storage type reservoirs constitutes an on-going concern of the petroleum industry. Those concerns are mainly due to the enormous monetary expenses involved in manufacturing and running any type of petroleum well as well as the risks associated with workovers and recompletions. Herein, a petroleum type well is defined as any type well being drilled and equipped for the purpose of producing or storage of hydrocarbon
10 fractures from or to subsurface formations. Further, petroleum type wells are categorized as any of or combination, storage, observation, producing or injection type wells.

15 Modern reservoir management systems more and more look into the advancement of including measurements from outside of the wellbore casing. Measurements close as well as far from the wellbore are being considered. Thus the prospect and purpose of formation parameter monitoring has become more complex than was previously the case. As with the industry in general, the motivation is to fully understand the physical properties and geometry of
20 the reservoir as this in the long-term contributes to extending the lifetime of the well as well as production yields.

25 There are numerous formation parameters that may be of interest when having sensor technology available for looking into the formation side of the casing as in the present invention. Thus, the sensor measurement technology proposed applies to any type formation measurements such as, for example, resistivity,

multi-axes seismic, radiation, pressure, temperature, chemical means, to mention a few. For the purpose of this invention we have chosen a specific measurement application in order to display the features and functionality of the present invention. Thus, the process example for the continuing discussion is the art to correctly predict pore-pressure of a formation outside the wellbore casing at the same time as the well produces. The application requires the sensor to be cemented in place behind the casing as close to the formation as possible.

10 Generally, all control and access of the petroleum well is provided through a wellhead. The present invention has applications to any petroleum type wells, for example, wells located on land, on a platform or at the seabed. However, for simplicity and to facilitate uniform understanding of the present invention it is described herein particularly as it relates to a generic type petroleum well and its wellhead.

There are numerous prior art patents related to the measurement of parameters outside the well casing annuli. One system that is close is described in US6,513,596B2. The system described is illustrative in nature and show a well data monitoring system with sensors placed inside the outer annuli of a well casing program. The system is a non-intrusive approach to measure pressure and other parameters within a plurality of annuli space and preserves the pressure containing integrity of the well. The system shows sensors placed inside the annuli that communicate with an interrogation system located externally or internally of the wellhead housing. It confirms that the sensors will require power and communication to perform that operation and lists generally alternative sources to power and methods of communication without solving the actual challenges of how to implement it in a real world application.

This method is not believed to have been installed in any petroleum well or field.

Another related approach is described by EP 1 662 673 A1. The method described by this is magnetic saturation of the well casing or conduit to make a “window” for operating locally an AC magnetic field to excite a sensor located outside a casing. The principle described is not considered realistic due to a relatively high power consumption required to magnetically saturate the well casing. Further, the method would require uniform current flux within the material to be saturated which in turn would require optimum contact (evenly distributed contact resistance over the exposed area) performance of the electrodes implied. Due to combination of exposed electrodes and high currents, such system would rapidly degrade due to galvanic reactions (oxidation/corrosion) inside the pressure containment system of a well. Thus, the method is considered non-applicable for a prescribed permanent wellbore measurement application due to exposed electrodes and high current density required to magnetically saturate the wellbore casing permanently. Further, it is not illustrated nor believed this method and apparatus may work in a multi-sensor configuration to provide a common infrastructure to enable placement of in-situ wellbore sensors at different zones of investigation like the present invention.

An aspect of the present invention is to provide method and apparatus to obtain in-situ wellbore measurements. In certain applications it is required to place sensors behind the well casing close to the formation. To achieve this, the need to establish a wireless link for power and communication across the wellbore casing or barrier is required. Traditionally, sensors have not been placed behind the casing due to the need of a traditional cable to provide power and

communication. However, the introduction of a cable and a penetration in the casing of a well does not contribute pressure integrity of the barrier and is a non-optimal installation. Thus, only special applications involving a cemented section of a liner or equivalent have been accomplished, providing sensors on the outside of the production casing.

Furthermore, and adding to the complexity, some applications of new production methods make use of the traditional annuli space (annulus-A) as live elements of their process system. Consequently, new regulatory requirements arise and a need to move the traditional production casing barrier and well integrity outwards follows. The present invention discloses a non-intrusive method that preserves the pressure integrity of the well at the same time as it allows sensors to be placed behind the wellbore casing. Another important feature of the method and apparatus of this invention is that it allows a cluster of sensor systems (SEU) to be mounted and operated on the same electrical cable downhole. Thus, a multi-sensor configuration in borehole measurement is achievable.

A second aspect of the invention is that the system is able to correct for transient offsets induced by environmental or process load changes. Typically load changes are caused by fluctuations in the process or environment temperature. This is the case of a pressure sensing device that conveys a constant volume of hydraulic fluid, such as in a pore pressure measurement application. As the temperature of a producing well changes or fluctuates, the fluid of the system and the pressure inside the containment system of a pressure sensor will expand or contract resulting in an offset reading. The change is not critical, but simply adds to misinterpretation and erroneous monitoring of pressure, over the transient period. The smaller the containment system, the

larger the deviation is. To overcome this, a real-time acquisition of process and environment data in combination with the in-situ measurements constitutes an important advance over prior art in that the present invention can help management to anticipate and react to potential problems as they appear and even before they occur. In addition, the remote sensor package can be dressed with numerous and different evaluation sensors that may be important to evaluate or filter the status and or integrity of a wellbore measurement parameter.

10 In accordance with one aspect of the present invention is a Wireless Sensor Unit (WSU). The WSU is a non-intrusive in-situ measurement system provided for monitoring one or more wellbore parameters behind the casing close to the formation. A feature of the WSU is that it contains a Sensor Package (SP) that for the purpose of illustrating this invention consists of a sensor package to permanently monitor pressure and temperature without compromising any of the pressure integrity barriers of the well casing annuli in any way. The SP is specific for the application and consists of a set of highly accurate quartz pressure and temperature sensor crystals and produces outputs of pressure and temperature as well as temperature gradients (i.e., change). In turn, the SP is connected to an Electromagnetic Transceiver (ET) which includes circuitry for two-way communication and power harvesting. Both the SP and the ET is attached or integrated to the outer perimeter of a Non-Magnetic Casing Section (NMCS) which is part of the well casing program (barrier).

25 Another aspect of the present invention is a Sensor Energizer Unit (SEU) and is typically part of or attached to the well completion tubing. The SEU is adapted to host the Wireless Sensor Unit. The SEU consists of three main elements. The first and main element of the SEU is an Electromagnetic Armature (EA),

second; an Adjustable Mandrel (AM), and third; a Cable Adaptor (CA). The EA provides as a combination power source and communications link for the WSU. The principle transmission of the EA is by low frequency induction or electromagnetic (EM) means, which is picked up and converted to electric energy by the WSU. To ensure optimum efficiency vice versa the WSU, the EA is attached to the AM, which enhances the facility or "fine tune" to optimize the efficiency to host the WSU by vertical adjustment means. Attached to the EA is also a Cable Adaptor (CA) connecting the control cable from outside of the well. The control cable is attached to the completion tubing by traditional cable clamps and exits the well thru the wellhead, all according to prior art means. Typically, the control cable is a single-conductor Tubing Electric Cable (TEC) type, providing power to the SEU as well as and communication between the mentioned and the monitoring facilities (i.e., outside the well).

For practical reasons the EA may be attached to an Adjustable Mandrel (AM) that provides freedom of vertical adjustment/positioning of the EA in respect to the WSU. The freedom of vertical adjustment after being attached to the process tubing enables the operators involved to position it in the exact position adjacent to the WSU in the well without introducing "space-out" complexity, involving the completion or process tubing inside the well. Thus, the purpose of the AM is two-fold, first; to provide a holder, carrier and/or protector for the EA, secondly; to allow vertical adjustment so the two main embodiments of the invention (i.e., the WSU and the SEU) are correctly arranged in relation to one another.

Depending on the type and conditions to provide a particular wellbore measurement, the SEU may also include a Sensor Package (SP) equal to or

different that of the WSU to enhance more complex data acquisition to interpret wellbore measurements.

According to one aspect of the present invention, there is provided apparatus to
5 provide monitoring of parameters outside the wellbore casing of a well, said
apparatus comprising: a Wireless Sensor Unit (WSU), placed outside a section
of a non-magnetic casing, said WSU including a sensor device to measure
parameters of its surroundings, in which the WSU may be installed or
positioned at any elevation of the wellbore and wherein the WSU is powered
10 by Power Harvesting where the frequency of the induction signal is in the
range of 10-1000 Hz for deep penetration through the non-magnetic casing; an
internal Sensor Energizer Unit (SEU) placed inside the wellbore casing, said
SEU being used for power and communication with the WSU, and wherein the
SEU is attached to the well tubing or completion program by tubing having a
15 thread that allows adjustment of its elevation, and wherein SEU converts the dc
power supplied on a cable from surface to an alternating electromagnetic field
that provides a source of power for the WSU outside the casing; wherein the
SEU and WSU use an electromagnetic modulation technique to provide
communication of data between the two components; and wherein the SEU and
20 the WSU are arranged to be at exactly the same elevation.

The WSU may be mounted near the wellhead or it may be mounted distally
from the wellhead, far down in the formation. There may be two or more
sensors in the WSU and these may all or part be placed on the outside of the
25 wellbore casing without compromising the pressure integrity of the well.

The sensors measure one or more parameters of the surroundings and they may
be branched off from the WSU and connected to a common electrical wire

harness attached to the outside of the casing. The wiring harness is either a single or multi-conductor type downhole cable (TEC).

5 The sensor or sensors of the WSU may be of a permanent type which may be cemented in place directly facing the formation or which may be open hole and directly facing the formation. Alternatively, the WSU and its sensor configuration may be part of a wellbore pressure containment system in the annulus and facing an outer wellbore casing or cemented in place facing an outer wellbore casing.

10

The apparatus may further comprise one or more power harvesting coils spaced out over a given section of the non magnetic casing. The coils or a band of the non-magnetic casing may provide the required completion or space-out tolerance for system when landing the well tubing or tubing-hanger in the wellhead or tree.

15

The WSU may additionally include or be connected to a secondary energy source which may be a battery or a downhole generator, for example.

20 The SEU may further include one or more sensors to measure parameters inside the wellbore casing or tubing to which it is attached and these sensors may be an integral part of the SEU, or they may be branched-off from the SEU and connected to a common electrical wiring harness, or the sensor system may be a combination of integral sensor and sensors branched-off. When present,

25 the wire harness may be a single or multi-conductor type downhole cable (TEC).

The sensors of the present invention may measure parameters relating to the well process, its structural components, or formation parameters.

5 Examples of well process properties which may be measured include: pressure, temperature, flow quantity, flow velocity, flow direction, turbidity, composition, oil level, oil-water interface level, density, salinity, displacements, vibrations, pH, resistivity, radioactivity, sand content, thermal conductivity, as well as other chemical and physical properties.

10

Examples of structural components of the wellbore which may be measured include: shock, vibrations, inclinations, magnetic properties, electrical properties, tool-face or other type of tool orientation, as well as stress and strain properties

15

Examples of formation or open hole properties outside the wellbore casing which may be measured include: pressure, temperature, radioactivity, resistivity, density, pH, salinity, electro- magnetic and/or electrical fields, sound, sound velocity, thermal conductivity, as well as other chemical and physical properties.

20

The apparatus may further include means to induce a response from the surroundings, which means may be selected from: a magnetic field source, an electric field source, sound waves, pressure, temperature, shear-force waves,

other final element or actuator part of downhole process control, final element or actuator used towards formation to assist any of above listed measurements.

5 The apparatus may also additionally further comprise one or more of: noise cancelling of parameter offsets due to offset created by the well process or environment; prediction and correction of measurements due to thermal and pressure gradients within the system.

10 The invention also extends to a method of monitoring parameters outside the wellbore casing of a well, said method comprising: installing a Wireless Sensor Unit (WSU), including a sensor device to measure parameters of its surroundings, at a location outside a section of a non-magnetic casing, in which the WSU may be installed or positioned at any elevation of the wellbore; installing an internal Sensor Energizer Unit (SEU) inside the wellbore casing, 15 said SEU being used for power and communication with the WSU, and wherein the SEU is attached to the well tubing or completion program by tubing having a thread that allows adjustment of its elevation; arranging the SEU and the WSU to be at exactly the same elevation; powering the WSU by Power Harvesting where the frequency of the induction signal is in the range of 20 10-1000 Hz for deep penetration through the non-magnetic casing; converting the dc power supplied on a cable from surface to an alternating electromagnetic field that provides a source of power for the WSU outside the casing; and using an electromagnetic modulation technique to provide communication of data between the WSU and the SEU.

Optional and preferred features of the apparatus as discussed above apply equally to the method of the present invention and will be discussed further in the specific description below.

5 These and other features and advantages of the present invention will be appreciated and understood by those skilled in the art from the detailed description and drawings. Referring now to drawings, wherein like elements are numbered alike in the several Figures:

10 Figure 1 is a diagrammatic view depicting the Method and Apparatus of the present invention for use in In-situ Wellbore Measurements;

Figure 2 shows an enlarged diagrammatic view of one aspect of Figure 1, depicting the Wireless Sensor Unit (WSU).

Figure 3 shows an enlarged diagrammatic view of another aspect of Figure 1, depicting the Sensor Energizer Unit (SEU);

15 Figure 4 shows a simplified electrical block diagram of the Pressure Management System in accordance with the present invention;

Figure 5 is a diagrammatic view similar to Figure 1, but showing the use of multiple sensors on either side of the wellbore casing;

20 Figure 6 is a block diagram showing a sensor network running from a single node;

Figure 7 is a diagrammatic view similar to Figure 1, showing the use of multiple sensors on a single down hole cable; and

Figure 8 is a block diagram showing the sensor network of Figure 7.

This invention relates to in-situ wellbore measurements. The object is to place one or more sensors in and around a wellbore in order to measure a physical parameter or property of a formation. The most common or frequent parameters to monitor are one or both of pressure and temperature at a target elevation within a reservoir or formation. In particular a Wireless Sensor Unit (WSU) 1 in the present invention is made part of the casing program of the main production barrier 2 of the well. The Casing Section 20 (see figure 2) of the WSU 1 is made in a non-magnetic material and hosts a Sensor Package 10 and a plurality of Electromagnetic Transceivers 11a-f. For the purpose of this invention the Sensor Package is configured to measure and monitor the annular space outside the main barrier of the well producing system as shown in figure 1.

Referring to Figure 1 this space 3 is also often referred to as Annulus-B and the WSU 1 is typically positioned close to the and underneath the wellhead structure or housing 4. The wellhead structure is shown here in context, with reference numerals depicting the earth through which the well has been bored, where 6 depicts the wellbore. The WSU 1 is wirelessly powered by Sensor Energize Unit (SEU) 9 by electromagnetic means, also referred to as "power harvesting" (referred to as reference numeral 100 in Figure 4) by those who are skilled in the art of electrical engineering. The WSU 1 is provided with supervisory circuits, that enables two-way communications with the SEU 9. In turn, the communication is by electromagnetic means.

Figure 2 shows the main elements of one component of the present invention in greater detail, which together defines the configuration of the Wireless Sensor Unit (WSU) 1. The WSU 1 consists of a Sensor Package (SP) 10, an Electromagnetic Transceiver (ET) 11a-f, and a Non-Magnetic Casing Section

(NMCS) 20. A more detailed connection and function diagram of the WSU 1 is illustrated on the right hand side of the dotted line of Figure 4.

5 Referring to Figure 3, a second component of the present invention is the Sensor Energizer Unit (SEU) 9. The SEU 9 is typically mounted to a Mandrel 91 and attached to a section of the production tubing 94. For the present illustration production tubing 94 is provided with an external thread 93 although this could equally be an internal thread. The thread 93 allows the elevation of the SEU 9 to be adjusted so that the elevation of the SEU 9 in the well corresponds exactly with the elevation of the WSU 1. This will ensure proper communications as well as providing optimum efficiency of the power harvesting (reference 100 in Figure 4).

15 Power supply and communications for the SEU 9 are provided through the Tubular Electric Cable (TEC) 97 which is attached to the process tubing 7 and feedthrough 72 and 73, typically exiting at the tubing hanger 71 (see figure 1). The SEU 9 may also host a Sensor Package 95, which in principle is the same as Sensor Package 10 of the WSU 1 but be configured to read parameters of the inner annuli 8. Typically, the inner annulus 8 is often referred to as Annulus-A by those skilled in the art, otherwise this is below the production packer of the well.

25 Referring to Figures 3 and 4, power to the SEU 9 is provided from the well site mounted Downhole Interface Unit (DIU) 101 through cable conduit (TEC) 97. The TEC 97 also hosts the communication in and out of the well between the DIU 101 and the SEU 9. Typically the communication is by means of a superimposed signal onto the power as the TEC 97 is a single-conductor cable.

TEC 97 is terminated at the SEU 9 at the Cable Adaptor 96. Power is routed internally through the mandrel 91 and connected to the Electromagnetic Armature (EA) 92. A detailed description of the internal electronic functions and routing is given in Figure 4, on the left hand side of the dotted line.

5

Also, if required a Sensor Package (SP) 95 may be adapted to provide more data for the evaluation of the pressure integrity of the annuli of interest. SP 95 the same as the SP 10 of the WSU but may alternatively be any kind of sensor capable of providing data to enhance safety and risk assessment of a particular well.

10

For example, the sensor 95 could measure one or more of the following properties: pressure, temperature, flow quantity, flow velocity, flow direction, turbidity, composition, oil level, oil-water interface level, density, salinity, radioactivity, displacement, vibrations, pH, resistivity, sand content, thermal conductivity, as well as other chemical and physical properties.

15

As mentioned, EA 92 and SP 95, may be attached to mandrel 91. The mandrel 91 serves as both a holder for and protection of the mentioned elements and allows for adjustment to match the vertical position or elevation of WSU 1. The adjustment range of the present invention is typically in the range 0-50cm, for example 10-40cm or 25-35cm but may be more or less depending on the requirement to provide freedom of proper space-out for the installation. Both the Mandrel 91 and the process tubing 94 may be manufactured in a magnetic material.

20

25

16

Referring to Figure 4, this is a simplified electronic block diagram of the present invention and is provided for those skilled in the art in order to visualize the inherent architecture as well as operation of the system. As may be seen from the block diagram one or more SEU 9 units may be attached to the control cable 97.

In this figure, this is illustrated using additional TEC 98, leading to additional SEU units shown by 28. In a multi-unit system (i.e., two or more SEU 9 units), each SEU is connected in a parallel configuration onto the cable 97. Due to relatively high power consumption, the nature of the system is also that only one SEU unit is active at a time.

The active status of a SEU is addressed during the initial start-up and through a command issued by the DIU 101 at the well site. At power-up the DIU actively addresses one of the SEU units 9 on the line and makes it the active node of the system. To change to another SEU, the DIU simply powers-down the line to reset or resume. At the next power-up another SEU may be addressed. Using this mode of operation, power is directed to one SEU at the time and the system is capable of hosting many SEU units on the line without gross voltage drop on the cable due to heavy loads.

Power harvesting 100 is achieved by correct vertical alignment of the SEU 9 in relation to the WSU 1. As mentioned above, this adjustment is provided by the adjustable mandrel 91. A second requirement and feature of this invention is the use of the non-magnetic casing section (NMCS) 20 which makes the lower frequency (50–1000 Hz) electromagnetic field induced by the Electromagnetic Armature (EA) 92 deep penetrating and thus visible to the Electromagnetic

Transceiver (ET) 11 of the WSU 1. The efficiency of the power transfer is poor due to non-ideal conditions of the induction coupling, however tests show that a ratio in the range of 20:1 is achievable and is sufficient to operate a low-power sensor package as described in the present invention.

5

Referring again to figure 4 in detail, the SEU 9 consists of a Power Supply 21 that provide a regulated dc for the electronic functions of the unit. The SEU is supervised by the internal Controller 25. Upon a wake-up call, the Controller makes the address interpretation and when addressed it turns on the internal
10 Modulating Chopper Oscillator 27. The MCO converts electrical energy into an alternating magnetic field through the Electromagnetic Armature 92. The induced field has a frequency that enables electromagnetic waves to propagate deeply into the surrounding structures, and thereafter be picked up by the Electromagnetic Transceiver (ET) 11 a-f of the WSU 1. The MCO also assists
15 in modulating data 22 in between the SEU and the WSU.

The SEU also has a Modem 23. The main purpose of the Modem is to read and transmit data 22 from/to the power line 97. However, data 22 in and out of the SEU is buffered and interpreted by the internal Controller 25. The Crystal
20 Sensors (for example, for detecting pressure 29 and temperature 30) of the described device, are driven by the respective Oscillators 26 and each sensor crystal provides a frequency output as function of its measurand. The sensor frequency is measured by the Signal Processor 24 and is continuously feed to an input buffer of the Controller 25.

25

For the WSU 1, the internal electronic functions are equivalent to these for the SEU 9 with the exception of the Rectifying Bridge 31. The Rectifying Bridge

converts the alternating current induced by the local electromagnetic field into a dc voltage/current that internally powers the WSU 1. The prescribed electromagnetic principle used is referred to as Power Harvesting 100 by persons skilled in the art. For the purpose of this invention, the WSU 1 is provided with highly accurate pressure 29 and temperature 30 sensors. In principle, the WSU 1 may include a Sensor Package that may hold any kind of sensors to measure a plurality of measurement parameters outside the wellbore casing or barrier.

Figures 1 to 4 have generally shown a system including either a single sensor within the SEU or two sensors, one within the SEU and the other in the WSU.

Figure 5 shows the system described by Figure 1 expanded to include more sensors on either side of the wellbore casing. Similar reference numerals are used for similar features as in Figures 1 to 4. On the inside, branched-off from the SEU are sensors 95a, 95b and 95c, for example, and on the outside, branched-off from the WSU are further sensors 10a, 10b and 10c, for example.

Figure 6 is the corresponding schematic block diagram showing the multiple sensors networked to operate from a single-node and illustrates the cascading of sensors on both sides of wellbore casing. Referring to Figure 6, the sensors are depicted measuring open hole properties, for example, pressure 29, temperature 30, resistivity 32, and the oil/water interface level 33.

Figure 7 shows the system described by Figure 1 expanded to include multiple nodes by means of two or more sets of SEU and WSU installed. Similar

reference numerals are used for similar features as in Figures 1 to 4. On the inside, and operated on the same cable 97, are shown two SEUs 9 which have associated WSUs 1 at the same elevation externally of the wellbore. In the figure, both WSUs 1 are facing the formation, but it would be possible to have both facing inwards or have one facing inwards and one facing the formation.

Figure 8 is the corresponding schematic block diagram showing the multiple sensors on the multiple WSUs, associated with the multiple SEUs all operated off the one cable 97. Referring to Figure 8, the sensors are depicted measuring open hole properties, for example, pressure 29 and temperature 30.

CLAIMS:

1. Apparatus to provide monitoring of parameters outside the wellbore casing of a well, said apparatus comprising:

a Wireless Sensor Unit ("WSU"), placed outside a section of a non-magnetic casing, said WSU including a sensor device to measure parameters of its surroundings, wherein the WSU may be installed or positioned at any elevation of a wellbore and wherein the WSU is powered by Power Harvesting where the frequency of an induction signal is in the range of 10-1000 Hz for deep penetration through the non-magnetic casing;

an internal Sensor Energizer Unit ("SEU") for placement inside the wellbore casing, said SEU being used to provide power and communication with the WSU, and wherein the SEU is attached to the well production tubing on a process tubing segment having a thread that allows adjustment of said SEU's elevation, and wherein the SEU converts DC power supplied by a cable from the surface to an alternating electromagnetic field that provides a source of power for the WSU outside the wellbore casing;

wherein the SEU and WSU use an electromagnetic modulation technique to provide communication of data between the two components; and

wherein the SEU and the WSU are arranged to be at exactly the same elevation.

2. Apparatus as claimed in claim 1, wherein the WSU is arranged and configured for mounting near a wellhead.

3. Apparatus as claimed in claim 1, wherein the WSU is arranged and configured for mounting distally from a wellhead, far down in a formation.

4. Apparatus as claimed in claim 1, wherein the WSU and its sensor device is cemented in place in the wellbore directly facing the formation.

5. Apparatus as claimed in claim 1, wherein the WSU and its sensor device is open hole and directly faces a formation.

6. Apparatus as claimed in claim 1, wherein the WSU and its sensor device are part of a wellbore pressure containment system in an annulus located between the wellbore casing and an outer wellbore casing.
7. Apparatus as claimed in claim 1, further comprising means to induce a response from the surroundings, which means are selected from the group consisting of:
a magnetic field source, an electric field source, sound waves, pressure, temperature, shear-force waves, another final element or actuator part of downhole process control, and a final element or actuator used towards formation to assist any of the previously listed measurements.
8. Apparatus as claimed in claim 1, further comprising one or more of:
apparatus for performing one or more of: noise cancelling of parameter offsets due to offset created by the well process or environment; and prediction and correction of measurements due to thermal and pressure gradients within the system.
9. Apparatus as claimed in claim 1, wherein the WSU further comprises one or more power harvesting coils spaced out over a given section of the non-magnetic casing.
10. Apparatus as claimed in claim 9, wherein the power harvesting coils or a band of the non-magnetic casing provides the required completion or space-out tolerance when landing the well production tubing or a tubing-hanger in a wellhead or tree.
11. Apparatus as claimed in claim 1, wherein the WSU comprises or is connected to a secondary energy source.
12. Apparatus as claimed in claim 11, wherein the secondary energy source is selected from the group consisting of a battery and a downhole generator.

13. Apparatus as claimed in claim 1, wherein the SEU further comprises one or more sensors to measure parameters inside the wellbore casing or the well production tubing to which they are attached.

14. Apparatus as claimed in claim 13, wherein the sensors are either or both an integral part of the SEU, or branched-off from the SEU and connected to a common electrical wiring harness.

15. Apparatus as claimed in claim 14, wherein the wire harness is a single-conductor or a multi-conductor type downhole Tubular Electric Cable ("TEC").

16. Apparatus as claimed in claim 13, wherein the sensors measure parameters relating to the well process, its structural components, or formation parameters.

17. Apparatus as claimed in claim 16, wherein the sensors measure one or more of the following well process properties:

pressure, temperature, flow quantity, flow velocity, flow direction, turbidity, composition, oil level, oil-water interface level, density, salinity, displacements, vibrations, pH, resistivity, radioactivity, sand content, thermal conductivity, as well as other chemical and physical properties.

18. Apparatus as claimed in claim 16, wherein the sensors measure one or more of the following structural components of the wellbore:

shock, vibrations, inclinations, magnetic properties, electrical properties, tool-face or other type of tool orientation, as well as stress and strain properties.

19. Apparatus as claimed in claim 1, wherein there are two or more sensors in the sensor device of the WSU.

20. Apparatus as claimed in claim 19, wherein the sensors measure one or more of the following formation or open hole properties outside the wellbore casing:

pressure, temperature, radioactivity, resistivity, density, pH, salinity, electro-magnetic and/or electrical fields, sound, sound velocity, thermal conductivity, as well as other chemical and physical properties.

21. Apparatus as claimed in claim 19, wherein all of the sensors of the WSU are arranged and configured for placement on the outside of the wellbore casing without compromising the pressure integrity of the well.

22. Apparatus as claimed in claim 19, wherein the sensors measure one or more parameters of their surroundings.

23. Apparatus as claimed in claim 19, wherein the sensors of the WSU are of a permanent type.

24. Apparatus as claimed in claim 23, wherein the WSU and its sensor device are cemented in place facing an outer wellbore casing.

25. Apparatus as claimed in claim 4, wherein the sensors are branched off from the WSU and connected to a common electrical wire harness attached to the outside of the wellbore casing.

26. Apparatus as claimed in claim 25, wherein the wiring harness is either a single-conductor or multi-conductor type downhole Tubular Electric Cable ("TEC").

27. A method of monitoring parameters outside the wellbore casing of a well, said method comprising:

installing a Wireless Sensor Unit ("WSU"), including a sensor device to measure parameters of its surroundings, at a location on the outside of a section of a non-magnetic casing, in which the WSU may be installed or positioned at any elevation of a wellbore;

installing an internal Sensor Energizer Unit ("SEU") inside the wellbore casing, said SEU being used for power and communication with the WSU, and wherein the SEU is attached to the well production tubing on a process tubing having a thread that allows adjustment of said SEU's elevation;

arranging the SEU and the WSU to be at exactly the same elevation;

powering the WSU where the frequency of an induction signal is in the range of 10-1000 Hz for deep penetration through the non-magnetic casing;

converting DC power supplied by a cable from surface to an alternating electromagnetic field that provides a source of power for the WSU outside the wellbore casing; and

using an electromagnetic modulation technique to provide communication of data between the WSU and the SEU.

28. A method as claimed in claim 27, wherein the WSU is mounted near a wellhead.

29. A method as claimed in claim 27, wherein the WSU is mounted distally from a wellhead, far down in a formation.

30. A method as claimed in claim 27, further comprising the step of:

inducing a response from the surroundings, which inducement are by any means suitable for inducing any one or more of: a magnetic field, an electric field, sound waves, pressure, temperature, shear-force waves, another final element or actuator part of downhole process control, and a final element or actuator used towards formation to assist any of the previously listed measurements.

31. A method as claimed in claim 27, further comprising one or more of the following steps:

noise cancellation of parameter offsets due to offset created by the well process or environment; and

prediction and correction of measurements due to thermal and pressure gradients within the system.

32. A method as claimed in claim 27, wherein the WSU further comprises one or more power harvesting coils spaced out over a given section of the non-magnetic casing.

33. A method as claimed in claim 32, wherein the power harvesting coils or a band of the non-magnetic casing provides the required completion or space-out tolerance when landing the well production tubing or a tubing-hanger in a wellhead or tree.

34. A method as claimed in claim 27, wherein the WSU comprises or is connected to a secondary energy source.

35. A method as claimed in claim 34, wherein the secondary energy source is selected from the group consisting of a battery and a downhole generator.

36. A method as claimed in claim 27, wherein the SEU further comprises one or more sensors to measure parameters inside the wellbore casing or the well production tubing to which they are attached.

37. A method as claimed in claim 36, wherein the sensors are either or both an integral part of the SEU, or branched-off from the SEU and connected to a common electrical wiring harness.

38. A method as claimed in claim 37, wherein the wire harness is a single-conductor or a multi-conductor type downhole Tubular Electric Cable ("TEC").

39. A method as claimed in claim 36, wherein the sensors measure parameters relating to the well process, its structural components, or formation parameters.

40. A method as claimed in claim 39, wherein the sensors measure one or more of the following well process properties:

pressure, temperature, flow quantity, flow velocity, flow direction, turbidity, composition, oil level, oil-water interface level, density, salinity, displacements, vibrations, pH, resistivity, radioactivity, sand content, thermal conductivity, as well as other chemical and physical properties.

41. A method as claimed in claim 39, wherein the sensors measure one or more of the following structural components of the wellbore:

shock, vibrations, inclinations, magnetic properties, electrical properties, tool-face or other type of tool orientation, as well as stress and strain properties.

42. A method as claimed in claim 27, wherein there are two or more sensors in the sensor device of the WSU.

43. A method as claimed in claim 42, wherein the sensors measure one or more of the following formation or open hole properties outside the wellbore casing:

pressure, temperature, radioactivity, resistivity, density, pH, salinity, electro-magnetic and/or electrical fields, sound, sound velocity, thermal conductivity, as well as other chemical and physical properties.

44. A method as claimed in claim 42, wherein all of the sensors in the sensor device of the WSU are placed on the outside of the wellbore casing without compromising the pressure integrity of the well.

45. A method as claimed in claim 42, wherein the sensors measure one or more parameters of their surroundings.

46. A method as claimed in claim 42, wherein the sensors are branched off from the WSU and connected to a common electrical wire harness attached to the outside of the wellbore casing.

47. A method as claimed in claim 43, wherein the wiring harness is either a single-conductor or multi-conductor type downhole Tubular Electric Cable ("TEC").

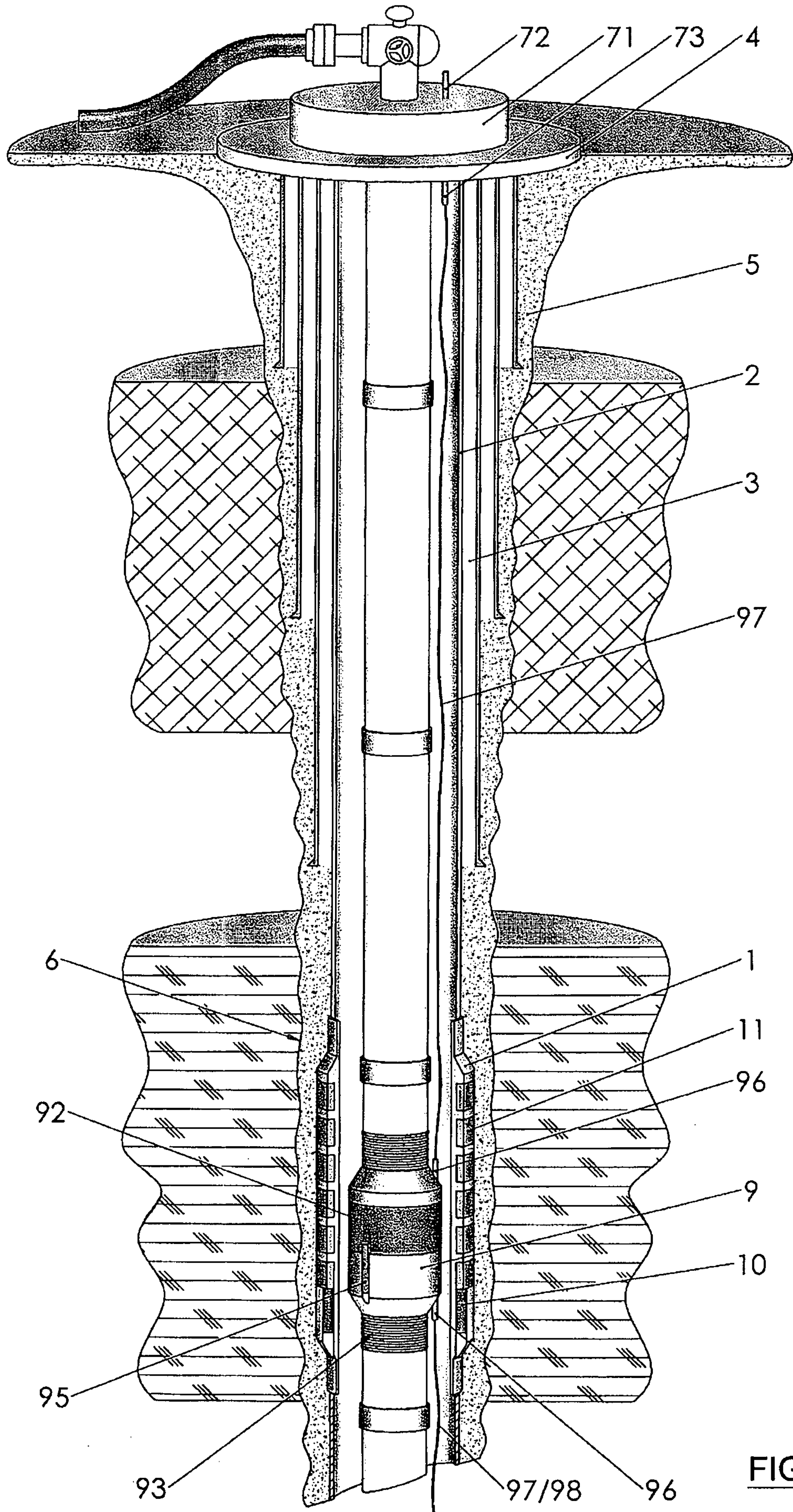
48. A method as claimed in claim 42, wherein the sensors of the WSU are of a permanent type.

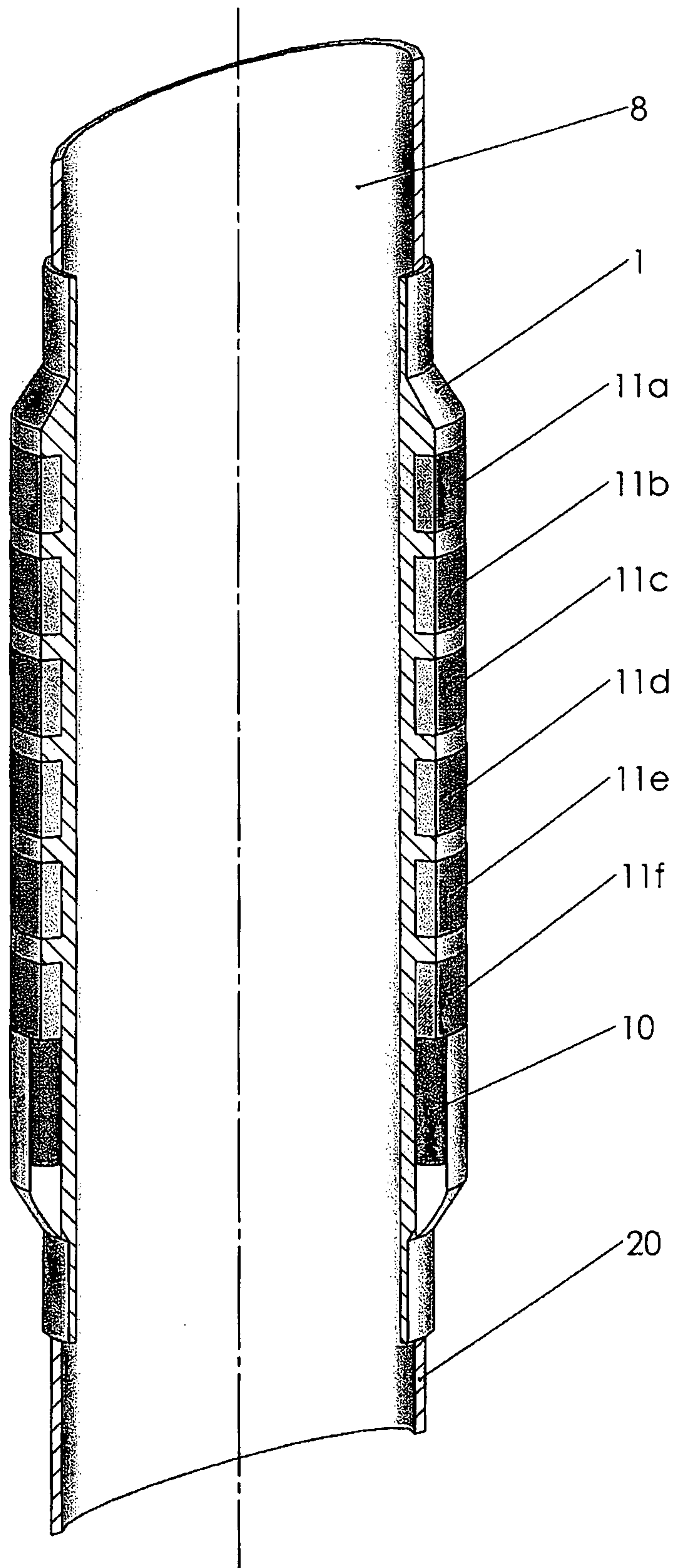
49. A method as claimed in claim 48, wherein the WSU and its sensor configuration is cemented in place directly facing the formation.

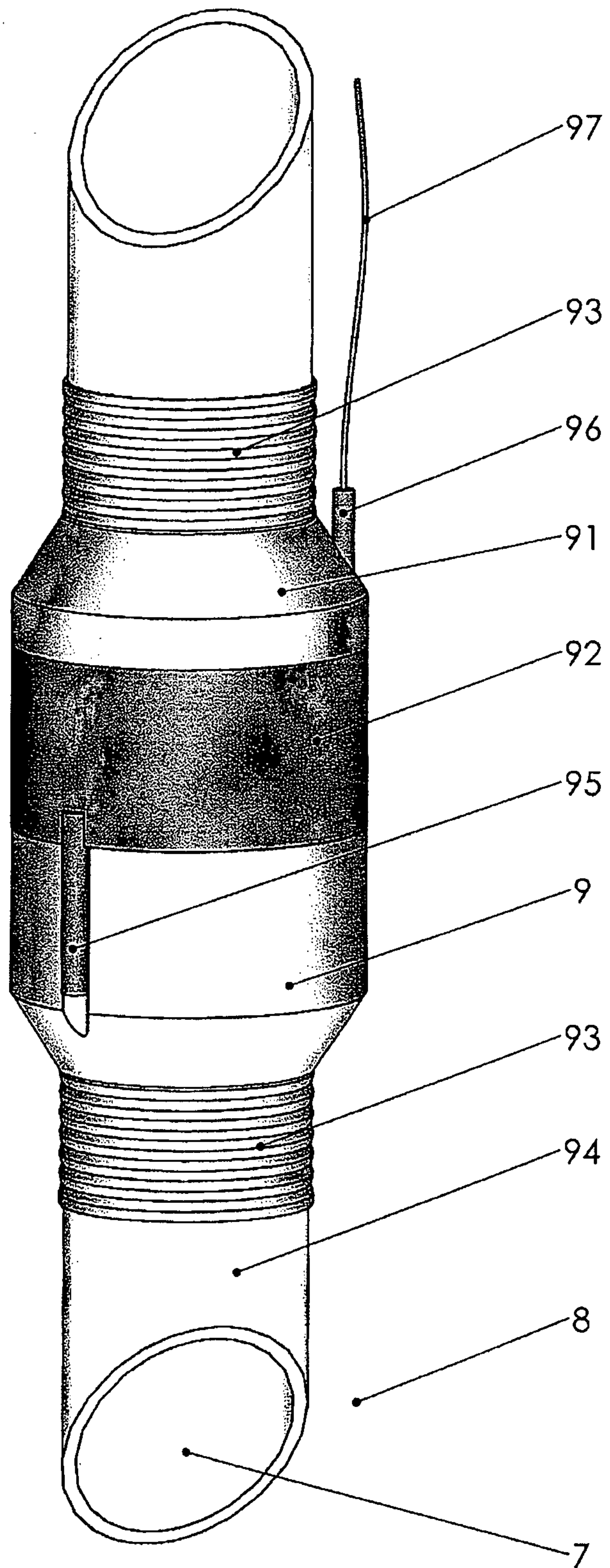
50. A method as claimed in claim 48, wherein the WSU and its sensor device is open hole and directly faces a formation.

51. A method as claimed in claim 48, wherein the WSU and its sensor device are part of a wellbore pressure containment system in an annulus located between the wellbore casing and an outer wellbore casing.

52. A method as claimed in claim 48, wherein the WSU and its sensor device are cemented in place facing an outer wellbore casing.

**FIGURE 1**

FIGURE 2

FIGURE 3

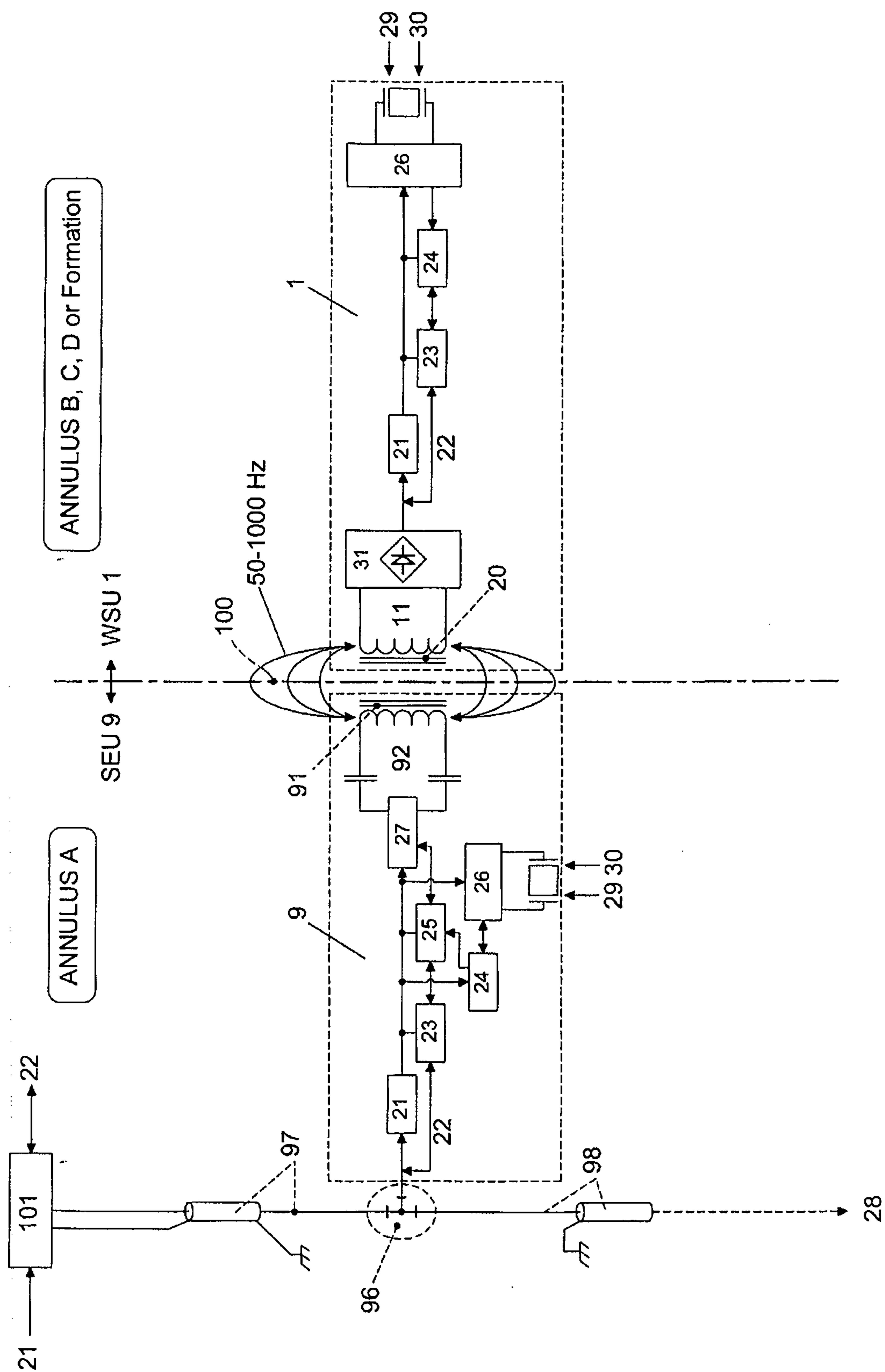
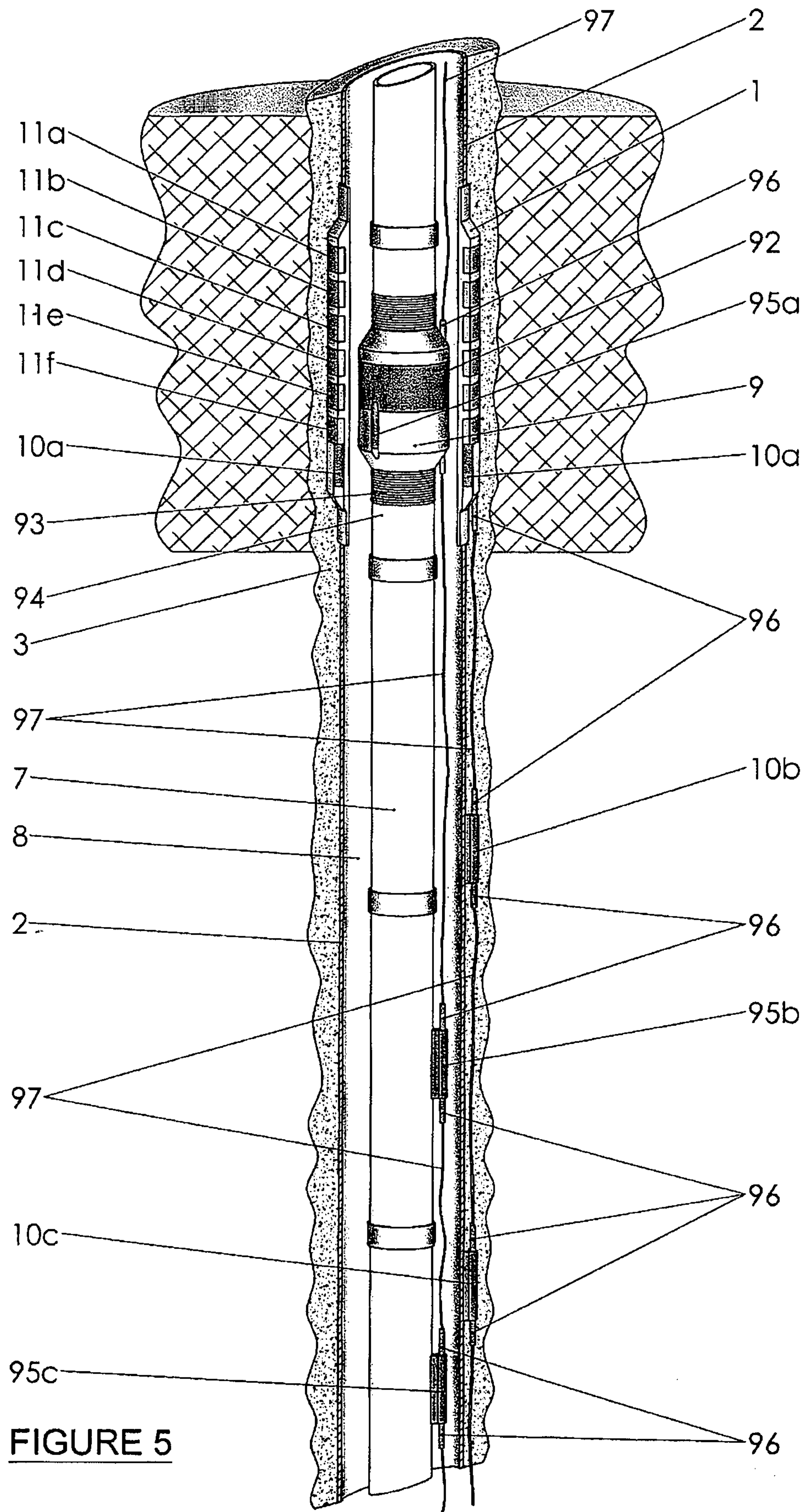


FIGURE 4



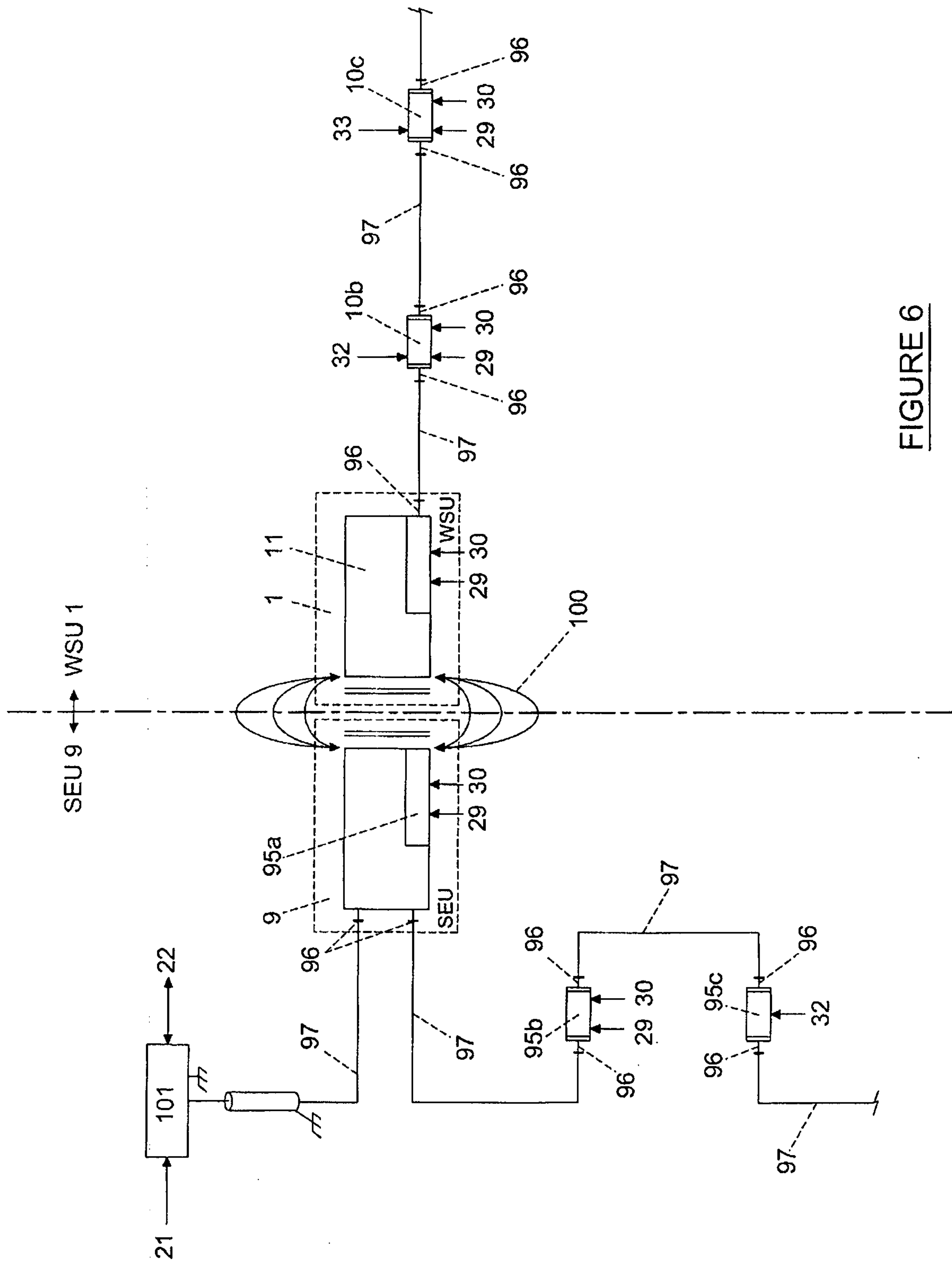


FIGURE 6

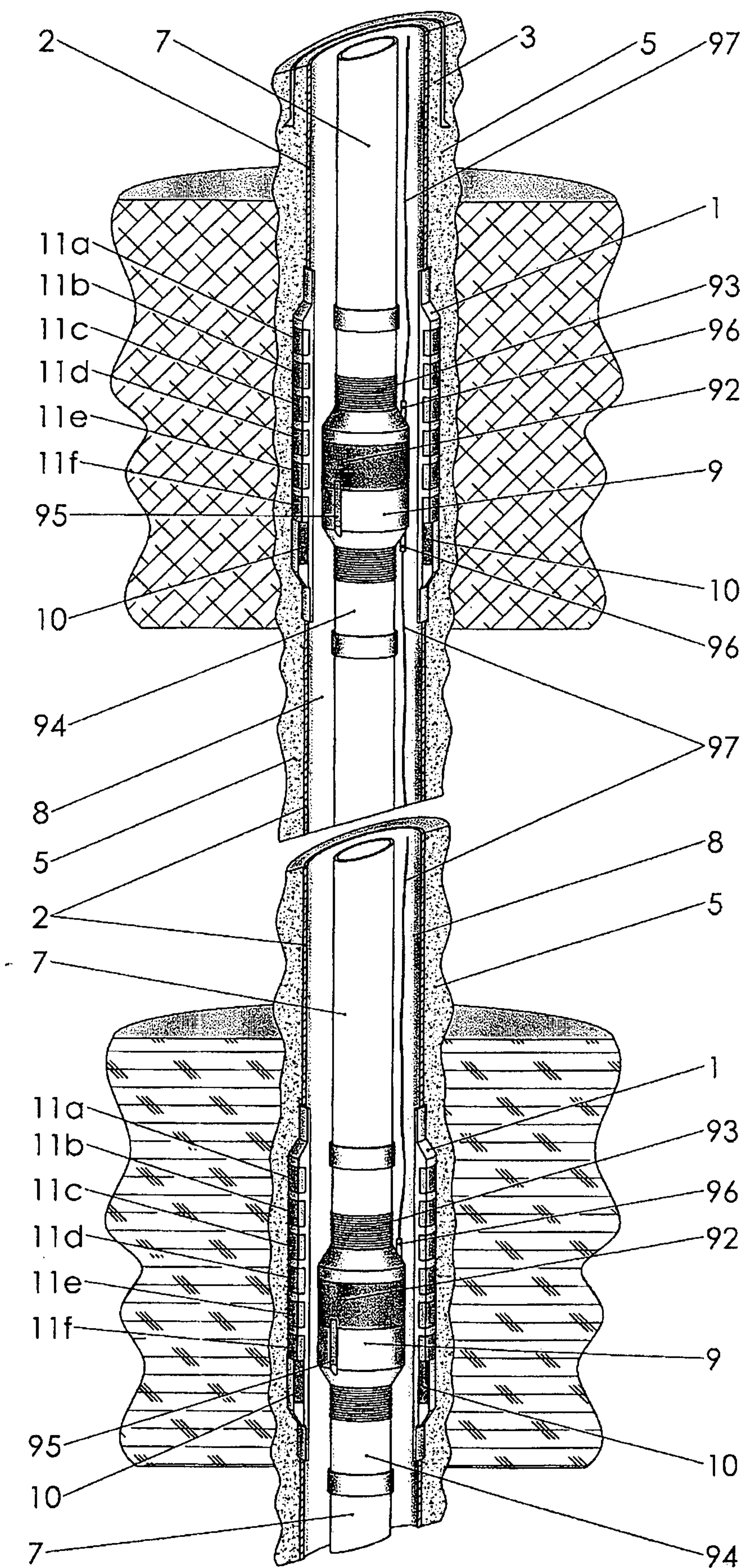


FIGURE 7

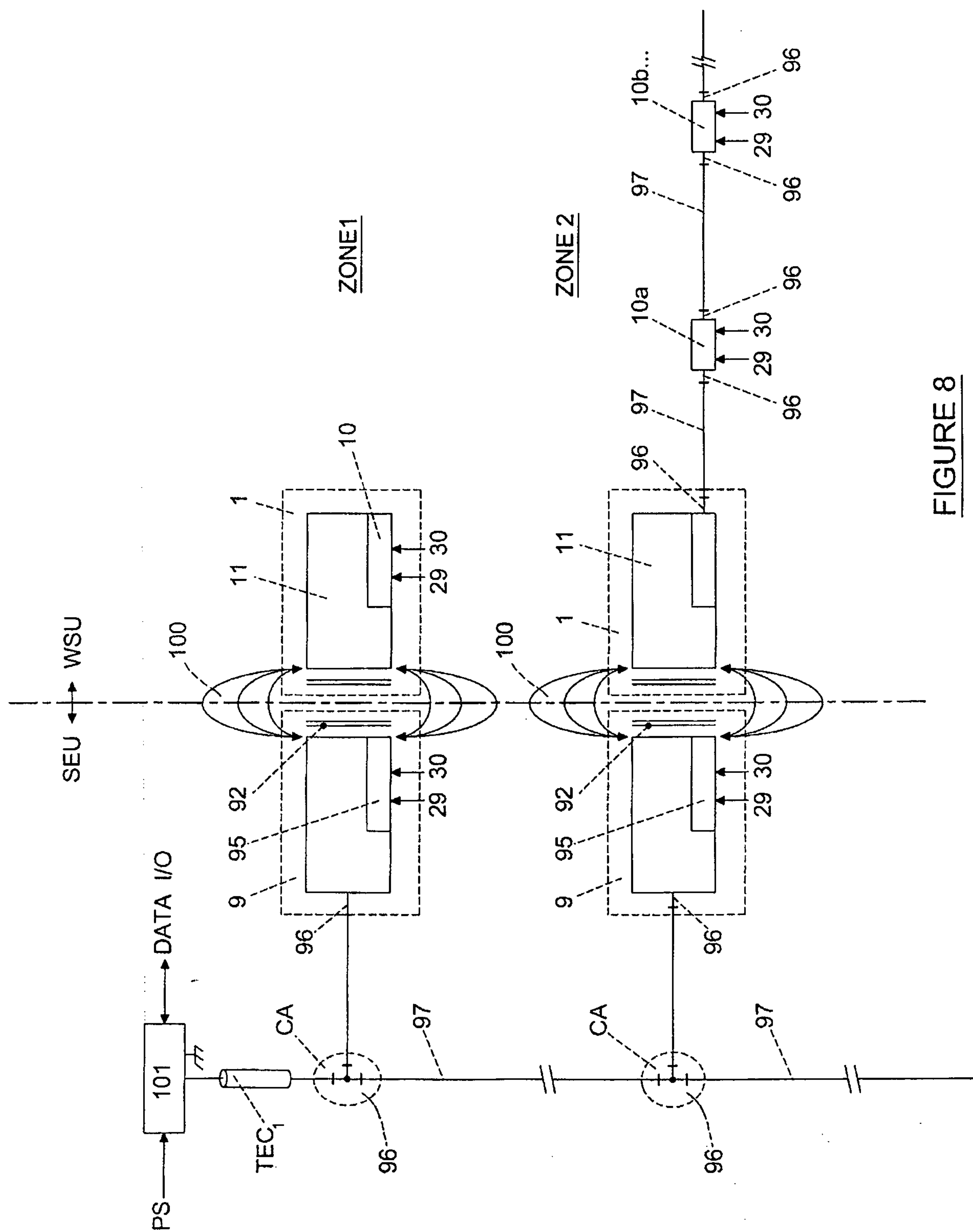


FIGURE 8

