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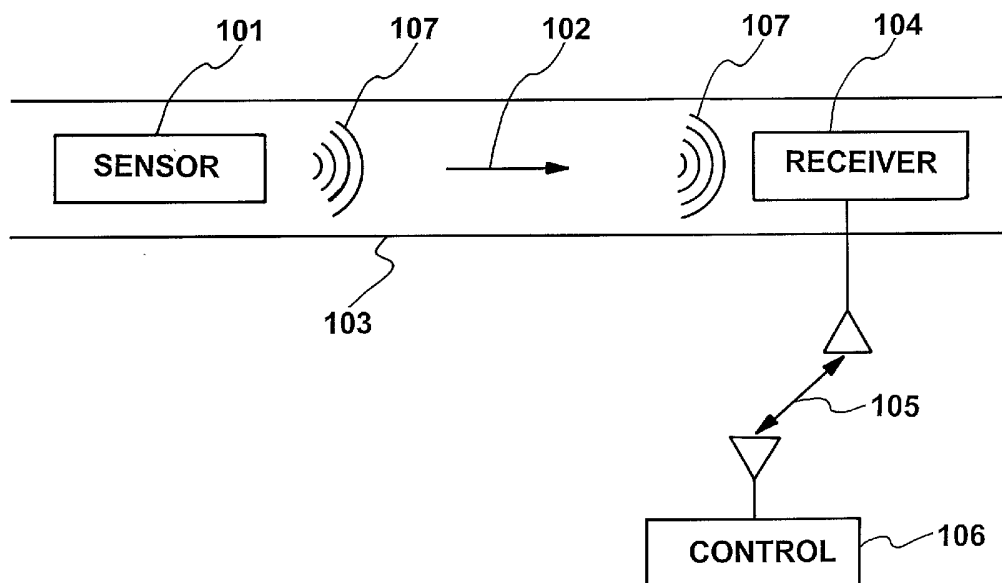
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(54) Title: SYSTEM FOR COMMUNICATION IN PIPELINES



(57) Abstract: A system for sensing and communicating in a pipeline that contains a fluid. An acoustic signal containing information about a property of the fluid is produced in the pipeline. The signal is transmitted through the pipeline. The signal is received with the information and used by a control.



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SYSTEM FOR COMMUNICATION IN PIPELINES

[0001] The United States Government has rights in this invention pursuant to Contract No. W-7405-ENG-48 between the United States Department of Energy and the University of California for the operation of Lawrence Livermore National Laboratory.

BACKGROUND

Field of Endeavor

[0002] The present invention relates to communication systems, and more particularly to a system for communication in pipelines.

State of Technology

[0003] A news release on November 26, 2001, Water Supplies Need Better Protection by Richard G. Luthy, Copyright © 2003 National Academy of Sciences, provides the following state of technology information, "The United States' water supply systems are among the greatest engineering accomplishments of the past century. Large investments by local, state, and federal government agencies led to many improvements in the supply, treatment, and distribution of water. The payoff has been great strides in improving public health. Protecting water sources and installing treatment plants virtually eliminated the most deadly waterborne diseases such as typhoid and cholera. Today, we enjoy the safest drinking water in the world. But since the terrorist acts on September 11, questions have arisen about the vulnerability of our water systems to deliberate attacks. In addition, many components are aging and need replacement. Thus, in the context of today's war on terrorism, both the infrastructure and protection of water systems must be considered in a new light. Safeguarding water supplies from sabotage will require engineering analysis and problem-solving, scientific advances, and evaluation of institutional arrangements

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and water policies. Top priority should be given to protecting physical water storage and transmission structures that serve large populations. Many dams, aqueducts, and pumping stations that capture and convey water over long distances are especially vulnerable to physical damage and would be difficult to replace."

[0004] U.S. Patent No. 6,082,193 for a pipeline-monitoring array, issued July 4, 2000, provides the following state of technology information, "a cable is deployed in the pipeline, with at least one acoustic sensor attached. The acoustic sensor is selected to detect acoustic emissions in the fluid in which it is put. The acoustic emissions are those generated by an acoustic event in a pipeline such as emissions produced by a wire break or a high-pressure leak. In a preferred embodiment, the sensor is a hydrophone."

[0005] Acoustic sensors have been proposed for water supply system monitoring. Savic, U.S. Patent No. 5,416,724, uses passive (listening) acoustic transducers to monitor the sound generated within a pipe or pipe network filled with flowing fluid and distinguishes between acoustic signals originating from leaks and signals from ambient acoustic noise. His related patent U.S. Patent No. 5,623,421 selectively identifies specific spectral lines from generally expected spectra. Sound generated by a leak is introduced into a digital processing and pattern recognition device to detect the presence of leaks.

[0006] In U.S. Patent No. 6,389,881, Yang, et al., describe the use of sophisticated signal processing techniques, such as pattern match filtering, to identify failure in fluid filled pipes. In their application, they use the signal processing to deconvolve the signal of interest, i.e., the sounds related to pipe failure, from the ambient 'noise' resulting from the fluid flow in the pipe. The technique uses an array of passive, 'listening' acoustic

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transducers to monitor the fluid for sounds relating to pipe failure. The frequency range associated with these events is very low, approximately 0.01 Hz to 10 Hz.

[0007] U.S. Patent Application No. 2002/0189362 by Vladimir Havlena for communication for water distribution networks, published December 19, 2002, provides the following state of technology information, "Control of processes is a broad general concern for every industry, particularly where fluids such as water are distributed in a network of pipes, vessels, containers and tanks. Often it is necessary to know conditions at various remote locations in a process in order to control the overall operation effectiveness and efficiency of production. One particular industry that requires significant control and which presently does not have adequate abilities for this goal is the water distribution networks that bring potable water from water supply sources and water treatment plants providing these water supply sources. It is well recognized that interruption of fluid flow in systems such as water supply systems needs to be minimized to identify and repair any interruption, such as by a pipe rupture or puncture, or by blockage of the line of flow."

SUMMARY

[0008] Features and advantages of the present invention will become apparent from the following description. Applicants are providing this description, which includes drawings and examples of specific embodiments, to give a broad representation of the invention. Various changes and modifications within the spirit and scope of the invention will become apparent to those skilled in the art from this description and by practice of the invention. The scope of the invention is not intended to be limited to the particular forms disclosed and the invention covers all

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modifications, equivalents, and alternatives falling within the spirit and scope of the invention as defined by the claims.

[0009] The present invention provides a system for sensing and communicating in a pipeline. A sensor obtains information about the fluid in the pipeline. The information relates to at least one property of the fluid comprising a biological property or a chemical property or a temperature property or a density property or a thermal conductivity property or an electrical resistivity property or a sound property or a speed property or a viscosity property or an optical property of the fluid. An acoustic signal containing information is produced in the pipeline. The signal is transmitted through the pipeline. The signal is received with the information and used to perform a desired operation.

[0010] In one embodiment, a sensor is connected to the pipeline that senses properties of the fluid and produces a signal in the pipeline. A receiver is connected to the pipeline for receiving the signal. A central control unit communicates with the receiver and the sensor communicates with the central control unit through the receiver. In one embodiment, an ultrasonic signal is produced in the pipeline. In one embodiment, the acoustic signal is produced by an acoustic signal generator. In another embodiment, the acoustic signal is produced by a pinger. In one embodiment, the acoustic signal is produced by a digital pulse generator. In one embodiment, the acoustic signal is produced by a binary pulse generator. In one embodiment, the acoustic signal is produced by an acoustic signal generator that is an octal pulse generator. In one embodiment, the acoustic signal is produced by an acoustic signal generator that is amplitude modulated. In one embodiment, the acoustic signal is produced by an acoustic signal generator that is frequency modulated. In

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one embodiment, the numerical value of information is related to the time between said pulses.

[0011] In one embodiment, the sensor is a pair of electrodes. In another embodiment, the sensor contains a reference electrode. In another embodiment, the sensor contains a Pt, Au, Ag, Ni, Co, Cu, Ti, or other transition metal electrode. In another embodiment, the sensor contains an oxidation/reduction potential (ORP) measuring electrode. In another embodiment, the sensor contains an oxidation/reduction potential (ORP) measuring electrode and the ORP is cleaned by imposition of a cathodic or anodic current to remove biofouling or mineral deposits. In one embodiment, a cathodic current removes mineral deposits. In another embodiment, an anodic current removes mineral deposits.

[0012] One embodiment includes a central control unit and the sensor communicates with the central control unit for quality assurance and process control feedback. In one embodiment, power is supplied to the receiver by an internal battery, fuel cell, hydraulic electric generator, or thermoelectric generator. In another embodiment, power is supplied to the sensor by an internal battery, fuel cell, hydraulic electric generator, or thermoelectric generator.

[0013] In one embodiment, the sensor is introduced into the pipe by a robot. In another embodiment, the sensor is introduced into the pipe by a robot and fixed to the inside of the pipe by a mechanical fastener installed by the robot. In another embodiment, the sensor is introduced into the pipe by a robot and fixed to the inside of the pipe by an adhesive material installed by the robot. In another embodiment, the sensor is introduced into the pipe through a threaded hole in the pipe. In another embodiment, the sensor is introduced into the pipe through a fire hydrant. In another

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embodiment, the sensor is introduced into the pipe through a fire hydrant with a tether comprised of a flattened tape of metal, a steel cable, or a polymer cable.

[0014] The invention is susceptible to modifications and alternative forms. Specific embodiments are shown by way of example. It is to be understood that the invention is not limited to the particular forms disclosed. The invention covers all modifications, equivalents, and alternatives falling within the spirit and scope of the invention as defined by the claims.

BRIEF DESCRIPTION OF THE DRAWINGS

[0015] The accompanying drawings, which are incorporated into and constitute a part of the specification, illustrate specific embodiments of the invention and, together with the general description of the invention given above, and the detailed description of the specific embodiments, serve to explain the principles of the invention.

FIG. 1 illustrates an embodiment of a system constructed in accordance with the present invention.

FIG. 2 illustrates additional details of the communication system.

FIG. 3 illustrates an embodiment an embodiment of a system for introducing a warning unit such as sensor or a receiver into the pipe through a fire hydrant.

FIG. 4 illustrates a system that provides early warning of contamination of a water distribution system.

FIG. 5 illustrates another embodiment of a system constructed in accordance with the present invention.

FIG. 6 illustrates another embodiment of a system for introducing a warning unit such as sensor or a receiver into a pipeline.

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FIG. 7 illustrates an embodiment of a service connection system constructed in accordance with the present invention.

FIG. 8 illustrates an embodiment of a service connection system that is illustrated in connection with a water distribution early warning system for warning of contamination.

FIG. 9 illustrates another embodiment of a system constructed in accordance with the present invention.

FIG. 10 illustrates another embodiment of a communication system.

FIG. 11 show additional details of the communication system.

DETAILED DESCRIPTION OF THE INVENTION

[0016] Referring now to the drawings, to the following detailed description, and to incorporated materials, detailed information about the invention is provided including the description of specific embodiments. The detailed description serves to explain the principles of the invention. The invention is susceptible to modifications and alternative forms. The invention is not limited to the particular forms disclosed. The invention covers all modifications, equivalents, and alternatives falling within the spirit and scope of the invention as defined by the claims.

[0017] Referring now to FIG. 1, an embodiment of a system constructed in accordance with the present invention is illustrated. The system is designated generally by the reference numeral 100. The system 100 provides communication using a sensor 101, a receiver 104, and a control 106 in any pipe network 103 that contains a fluid 102. The fluid 102 can be water, oil, gas, an aqueous solution, or a chemical mixture. Examples of pipe networks that the system 100 can be used with include oil and gas collection and distribution pipelines, chemical processing units, and cooling water systems. Examples of the sensors used by the system 100 include sensors

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that obtain information about a property of the fluid 102. The property can be a biological property or a chemical property or a temperature property or a density property or a thermal conductivity property or an electrical resistivity property or a sound property or a speed property or a viscosity property or an optical property.

[0018] The system 100 also utilizes installation methods such as insertion through a fire hydrant, use of a conventional hot-tap saddle with an interlock valve on an exposed pipe, and use of the Bernoulli effect to draw liquid to a sensor outside the pipe.

[0019] In one embodiment of the system 100, the sensor 101 utilizes a pair of electrodes. In another embodiment of the system 100, the sensor 101 utilizes a reference electrode. In another embodiment of the system 100, the sensor 101 utilizes a Pt, Au, Ag, Ni, Co, Cu, Ti, or other transition metal electrode. In another embodiment of the system 100, the sensor 101 utilizes an oxidation/reduction potential (ORP) measuring electrode. In another embodiment of the system 100, the sensor 101 utilizes an oxidation/reduction potential (ORP) measuring electrode and the ORP is cleaned by imposition of a cathodic or anodic current to remove biofouling or mineral deposits. In one embodiment a cathodic current removes mineral deposits. In another embodiment an anodic current removes mineral deposits.

[0020] The system 100 utilizes sensor 101 that is exposed to fluid 102 in the pipe 103. The sensor 101 communicates with receiver 104. The receiver 104 communicates by communication system 105 to control 106. The control 105 can take appropriate action in response to the information obtained by the sensor 101. The control can be connected to various locations along the

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pipeline 103 by the connection 107. The control can also be connected to an alarm 108 by connection 107.

[0021] A system of communication for water distribution networks is shown in U.S. Patent Application No. 2002/0189362 published December 19, 2002 and International Patent Application No. WO 02/103303 published December 27, 2002. Both patent applications are owned by Honeywell International Inc. and were invented by Vladimar Havlena. The disclosures of U.S. Patent Application No. 2002/0189362 and International Patent Application No. WO 02/103303 are incorporated herein by this reference.

[0022] The systems described in U.S. Patent Application No. 2002/0189362 is the following, "A pressure sensor 13 measures the pressure at a specific location 15, and generates a signal in response to that pressure to an acoustic transmitter 17. Transmitter 17 then transmits an acoustic signal along pipe 11 to an acoustic receiver 19, which in turn converts the sound wave into information about the remote pressure 21 that is used by the master pressure controller 25 to define the setpoint for the slave controller that controls the pressure-reducing valve 23. Internally, the pressure controller receives the measured, compares with setpoint for the remote pressure, and defines the outlet pressure for the pressure-reducing valve 23 to reduce the difference between the measured pressure and its set point. The slave controller compares the measured outlet pressure at the pressure reduce valve 23 outlet with the set point and open/close the valve to follow this set point. For reliable communication between sensor 13 and valve 23, only plane sound waves are propagated in pipe 11. A transverse wave is excited for a wavelength less than 1.7 times the diameter. Therefore, for a typical pipeline diameter D between 0.08 and 0.3 meters, the maximum frequency

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is 11 to 3 kHz.” The system described in International Patent Application No. WO 02/103303 is identical.

[0023] In the system 100, the communication system 105 provides a wired or wireless connection to control 106. The receiver 104 includes a wireless transmission unit 105. The control 106 includes a wired or wireless receiver 105B. In one embodiment the wireless transmission unit 105 and the wireless receiver 105B are radio units. In another embodiment the wireless transmission unit 105 and the wireless receiver 105B are cell phone units. The control is connected to the pipeline 303 by connection 107. The control 106 can take appropriate action in response to the information obtained by the sensor 101 and transferred to the control 106 via wireless transmission unit 105.

[0024] In one embodiment of the system 100 that provides communication using a network of sensors 101 to a control to any pipe network that distributes a fluid the sensor, 101 is a sensor that produces an ultrasonic signal in the fluid 102 in the pipe 103. In another embodiment the sensor 101 is acoustic signal generator that produces an acoustic signal in the fluid 102 in the pipe 103. In another embodiment the sensor 101 is a pinger that produces an acoustic signal in the fluid 102 in the pipe 103. In another embodiment the sensor 101 is a digital pulse generator that produces a digital pulse signal in the fluid 102 in the pipe 103. In another embodiment the sensor 101 is a binary pulse generator that produces a binary pulse signal in the fluid 102 in the pipe 103. In another embodiment the sensor 101 is an octal pulse generator that produces an octal pulse signal in the fluid 102 in the pipe 103. In another embodiment the sensor 101 is an acoustic signal generator that is amplitude modulated. In another embodiment the sensor 101 is an acoustic signal generator that is frequency modulated. In

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one embodiment the sensor 101 produces acoustic pulses and numerical value of information transmitted is related to the time between the acoustic pulses. In one embodiment the fluid is circulated from the pipe 103 by a tube protruding into the fluid utilizing the Bernoulli effect.

[0025] In one embodiment, the sensor 101 senses physical properties of the fluid. In another embodiment, the sensor 101 senses temperature or density or thermal conductivity or electrical resistivity or sound speed or sound absorption or viscosity or magnetic susceptibility or magnetic moment relaxation of the fluid. In another embodiment, the sensor 101 senses turbidity or opacity or light absorption or light rotation or light scattering or absorption on a surface. In another embodiment, the sensor 101 senses chemical properties of the fluid. In another embodiment, the sensor 101 senses specific ion concentration or specific molecular composition of the fluid.

[0026] In another embodiment, the sensor 101 senses biological, biochemical or chemical contaminants in the fluid. In another embodiment, the sensor 101 senses biochemicals or sporulated bacteria or viral organisms or microbial organisms in the fluid. In another embodiment, the sensor 101 senses elemental chlorine or oxidative oxy-halogen compounds or ozone or oxygen or peroxydisulfate or strong reducing agents or hyposulfite or thiosulfate or sulfide or H₂S or cyanide or selenium or lead sensor or mercury or arsenic or nerve agents or blistering or Lewisite or G-agents or phosgene or gas or actinides or radioactive isotopes or radioactive iodine or radioactive cesium or radioactive strontium sensor or thorium or radioactive cobalt or radioactive thorium in the fluid.

[0027] The central control unit 106 is connected to the receiver 104 by a radio control system 105 and the sensor 110 communicates with the central

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control unit for quality assurance and process control feedback. Power is supplied to the receiver 104 by an internal battery, fuel cell, hydraulic electric generator, or thermoelectric generator. Power is supplied to the sensor 101 by an internal battery, fuel cell, hydraulic electric generator, or thermoelectric generator.

[0028] Referring now to FIG. 2, additional details of the communication system 100 are illustrated. The communication system 100 uses acoustic signal bursts 107 in the fluid 102. The communication system 100 can be used in any pipe network that distributes a fluid. Examples of pipe networks that the system 100 can be used in include oil and gas collection and distribution pipelines, chemical processing units, and cooling water systems. The system 100 transmits a signal 107 through the fluid 102 in the pipe 103.

[0029] The sensor 101 obtains information about a property of the fluid 102. The property can be a biological property or a chemical property or a temperature property or a density property or a thermal conductivity property or a resistivity property or a sound property or a speed property or a viscosity property or a turbidity property or opacity property or light absorption property or light rotation property or light scattering property or magnetic property or adsorption on a surface property. The sensor 101 in various embodiments senses biochemicals or sporulated bacteria or viral organisms or microbial organisms in the fluid. In another embodiment, the sensor 101 senses elemental chlorine or oxidative oxy-halogen compounds or ozone or oxygen or peroxydisulfate or strong reducing agents or hyposulfite or thiosulfate or sulfide or H_2S or cyanide or selenium or lead sensor or mercury or arsenic or nerve agents or blistering or Lewisite or G-agents or phosgene or gas or actinides or radioactive isotopes or radioactive

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iodine or radioactive cesium or radioactive strontium sensor or thorium or radioactive cobalt or radioactive thorium in the fluid.

[0030] The sensor 101 transmits the signal 107 into the fluid 102 in the pipe 103 where it is available for the receiver 104. The signal 107 in one embodiment is an ultrasound signal above 20,000 hertz. The signal 107 is recovered by receiver and transmitted to the control 106.

[0031] The sensor 101 and the receiver 104 can be installed in existing pipes using systems of the present invention. The systems can be used in installing water quality monitoring sensors into buried water pipes. The systems can also be used to install a service connection for any purpose. The systems can be used to install connections in any buried fluid distribution system with minimal excavation.

[0032] The central control unit 106 is connected to the receiver 104 by a radio control system 105 and the sensor 110 communicates with the central control unit for quality assurance and process control feedback. Each system is wireless and autonomous, being powered by a primary battery, micro fuel cell, or a secondary battery trickle charged by a thermoelectric device, solar cell, or a water-powered generator. Power is supplied to the receiver 104 by an internal battery or fuel cell. Power is supplied to the sensor 101 by an internal battery or fuel cell.

[0033] Referring now to FIG. 3, an embodiment of a system for introducing a warning unit such as sensor 301 or a receiver 304 into the pipe 303 through a fire hydrant 307 is illustrated. The system is designated generally by the reference numeral 300. The system 300 provides an inexpensive method of installing a warning unit such as water monitoring sensors, transmitters, or receivers into a water distribution network.

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[0034] The system 300 uses existing water distribution networks and enables a warning unit such as sensor/transmitter 310 or receiver 304 to be installed into a buried pipe 303 without excavation. The system 300 can be used in installing water quality monitoring sensors and receiver into buried water pipes. The system 300 can also be used as a service connection for any purpose. The system 300 can be used to install connections in any buried fluid distribution system without excavation.

[0035] The system 300 utilizes sensor 301 that is exposed to fluid 302 in a pipe 303. The sensor 301 communicates with receiver 304. The receiver 304 communicates by communication system 305 to control 306. The control 306 can take appropriate action in response to the information obtained by the sensor 301.

[0036] The fire hydrants 307 are connected to the pipe 303 through standard connections 309. The sensor 301 and receiver 304 are introduced into the pipe 303 through the fire hydrants 307 and connections 309 with a tether 308. The tether 308 can be a flattened tape of metal, a steel cable, a polymer cable or other type of tether. Power is provided to the sensor 301 and receiver by internal batteries or fuel cells.

[0037] The system 300 can be used as a service connection for any purpose. The system 300 can be used for installing sensors and receiver into buried water pipes. In one embodiment the sensor 301 and receiver 304 are introduced into a pipeline network by a robot and fixed to the inside of the pipe 303 by a mechanical fastener installed by the robot. In another embodiment the sensor 301 and receiver 304 are introduced into the pipeline network by a robot and fixed to the inside of the pipe 303 by an adhesive material installed by the robot. In another embodiment the sensor 301 and receiver 304 are emplaced into a threaded hole in the water pipe.

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[0038] Referring now to FIG. 4, another embodiment of a system constructed in accordance with the present invention is illustrated. The system is designated generally by the reference numeral 400. The system 400 provides early warning of contamination of water distribution systems. The contamination can be unauthorized contamination or accidental contamination. A system for the detection of contaminants of a fluid in a water distribution system by one of the Applicants, John F. Cooper, is shown in U.S. Patent Application Serial No. 10/797,986, filed March 11, 2004, titled, "Detection of Contamination of Municipal Water Distribution Systems," and published as U.S. Patent Application No. _____ on _____, which is incorporated herein by this reference.

[0039] The system 400 includes an array of autonomous sensors/communicators 401 that are exposed to the water flow 402, from a water source 408, in pipes 403, comprising the treated (e.g., chlorinated, filtered) water municipal distribution system. The array of autonomous sensors 401 detects the loss of chlorination shield upon introduction of non-specific biological or chemical reducing agents 404 into the water 402. Each sensor communicates by emitting acoustic signal burst 409, using the pipes 403 as wave-guides or channels. The preexisting Supervisory Control and Data Acquisition Systems (SCADAS) 405 receive the signal 409 and communicate by radio 406 to water management 407 where appropriate action can be taken.

[0040] The sensors 401 communicate by emitting acoustic signal bursts 409, using the pipes 403 as wave-guides or channels. The Supervisory Control and Data Acquisition Systems (SCADAS) 405 receives the signal 409 and communicates by radio 406 to water management 407. The system 400 can be installed in existing pipes through standard procedures. In one

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embodiment only micrometer-thick layers of platinum are required. The sensor array 401 senses a drop in the oxidation potential of the water when a reducible chemical or biological substance is introduced and tends to neutralize or fully neutralizes the chlorination and communicates such a drop in potential by generating and transmitting an acoustic signal through the water 402 using the water-filled pipes 403 as wave guides and the water as the acoustic medium. The signal (e.g., a 32 bit binary code) is transmitted to pre-existing monitoring sites or Supervisory Control and Data Acquisition systems commonly called "SCADA's" (SCADA's) that are linked to water management or other process control. Each system is wireless and autonomous, being powered by a primary battery, micro fuel cell, or a secondary battery trickle charged by a thermoelectric device, solar cell, or a water-powered generator. The system 400 detects gross biological or chemical contamination, or defeat of the chlorination shield using a reducing agent (e.g., glucose, ascorbate, thiosulfate, hyposulfite, or ferrocyanide, and many other common reducing agents) preliminary to the introduction of biological or chemical agent that might be destroyed by the ca. 1 ppm ambient chlorine or chlorine-equivalent concentration.

[0041] In addition to the oxidation potential and pH sensing, the system 400 has applicability and use for: elemental chlorine, chloramines, oxidative oxy-halogen compounds, ozone, oxygen, peroxydisulfate, peroxymonosulfate; strong reducing agents including hyposulfite, thiosulfate, ferrocyanide, sulfide, H_2S ; and specific ions and solid/liquid dispersions of cyanide, selenium, lead, mercury and arsenic containing compounds; specific nerve and blistering agents including but not necessarily limited to VX, Lewisite, G-agents, phosgene, and mustard gases; and radiological sources including actinides and radioactive isotopes of

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iodine, cesium, strontium, thorium and cobalt. The sensors 401 may include specific sensors for biological materials, biochemicals or live, dead or sporulated bacteriological, viral or microbial organisms. The sensors 401 are emplaced on autonomous sensor/communicator platforms consisting of sensors, energy storage, microprocessor units, and acoustic signal generators. The energy storage unit is comprised of batteries, primary or secondary, in combination with power generation devices based on thermoelectric generators, hydraulic generators, fuel cells, solar, or wind converters. The system 400 can also be used in non-water based applications wherein the combination of sensor and communicator may be applied to oils, molten salts, gases, and liquid metals, or other media capable of sustaining acoustic signals within a conduit or pipe.

[0042] Referring now to FIG. 5, another embodiment of a system constructed in accordance with the present invention is illustrated. This embodiment is designated generally by the reference numeral 500. The system 500 provides communicate using a network of sensors 501 to a control to any pipe network that distributes a fluid. The fluid can be water, oil, gas, an aqueous solution, or a chemical mixture.

[0043] The system 500 utilizes a sensor 501 that is exposed to a fluid 502 in a pipe 503. The sensor 501 communicates with receiver 504. The receiver 504 communicates by communication system 505 to control 506. The control 505 can take appropriate action in response to the information obtained by the sensor 501.

[0044] The communication system 505 provides a signal to control 506. The control is connected to the pipeline 303 by connection 507. The control 506 can take appropriate action in response to the information obtained by the sensor 501 and transferred to the control 506 through a connection 505.

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[0045] In one embodiment, the sensor 501 senses physical properties of the fluid. In another embodiment, the sensor 501 senses temperature or density or thermal conductivity or electrical resistivity or sound speed or viscosity or optical absorbance or scattering of the fluid. In another embodiment, the sensor 501 senses chemical properties of the fluid. In another embodiment, the sensor 501 senses specific ion concentration or specific molecular composition of the fluid. In another embodiment, the sensor 501 senses biological, biochemical or chemical contaminants in the fluid. In another embodiment, the sensor 501 senses biochemicals or sporulated bacteria or viral organisms or microbial organisms in the fluid. In another embodiment, the sensor 501 senses elemental chlorine or oxidative oxy-halogen compounds or ozone or oxygen or peroxydisulfate or strong reducing agents or hyposulfite or thiosulfate or sulfide or H₂S or cyanide or selenium or lead sensor or mercury or arsenic or nerve agents or blistering or VX or Lewisite or G-agents or phosgene or gas or actinides or radioactive isotopes or radioactive iodine or radioactive cesium or radioactive strontium sensor or thorium or radioactive cobalt or radioactive thorium in the fluid.

[0046] The central control unit 506 is connected to the receiver 504 by connection 505 and the sensor 510 communicates with the central control unit for quality assurance and process control feedback. Power is supplied to the receiver 504 by an internal battery, fuel cell, hydraulic electric generator, or thermoelectric generator. Power is supplied to the sensor 501 by an internal battery, fuel cell, hydraulic electric generator, or thermoelectric generator.

[0047] Referring now to FIG. 6, an embodiment of another system for introducing a warning unit 609 such as a sensor 609' or a receiver 609'' into a pipeline 603 buried below the surface 607 using an installation robot 608 is

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illustrated. The system is designated generally by the reference numeral 600. The system 600 provides an inexpensive method of installing a warning unit such as water monitoring sensors, transmitters, and/or receivers into a water distribution network.

[0048] The system 600 uses existing water distribution networks and enables a warning unit 609 such as a sensor/transmitter or receiver to be installed into a buried pipeline 603 without excavation. The system 600 can be used in installing water quality monitoring sensors and receiver into water pipes buried below the surface 607. The system 600 can also be used as a service connection for any purpose. The system 600 can be used to install connections in any buried fluid distribution system without excavation.

[0049] The system 600 installs sensor 609' and receiver 609'' using the robot 608 that is introduced into the pipeline 603 through an existing standard connection 601. The sensor 609' and receiver 609'' are installed so that they are exposed to the fluid 602 in the pipeline 603. The sensor 609' communicates with receiver 609'' through acoustic transmission. The receiver 609'' communicates by communication system 605 to control 606. The control 606 can take appropriate action in response to the information obtained by the sensor 609'. For example, the control 606 can sound alarm 604 upon receiving an alarm signal. Power can be provided to the sensor 609', receiver 609'', communication system 605, control 606, and/or alarm 604 by internal batteries or fuel cells or other source.

[0050] The installation robot 608 is introduced to the pipeline 603 through any standard connection 601. The sensor 609' and receiver 609'' are introduced into the pipe 603 through the connections 601 with the installation robot 608. Robot system for installation of devices into pipelines

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are known and available. For example, systems are described in the following patents:

[0051] United States Patent No. 6,688,337 for an apparatus and method for the robotic repairing of an underground pipe junction with a flexible patch mechanism, issued February 10, 2004 to Robert M. Ward, shows a method of using a robot mechanism 100, support cage 116 and patch 118 to perform a patching operation. The first step requires identifying the lateral service line 126 requiring a patch 118 after the installation of a liner in the main pipeline 104. Identification may be done visually by an operator or remotely using a video camera or other sensing device. Once the lateral service line 126 is identified, access is provided to the lateral service line 126 by drilling a hole through the liner with the use of a remotely controlled drill attached to a robotic apparatus, which is pulled through the main pipeline 104. If the lateral line 126 overextends into the main pipeline 104, the excess can be trimmed with a robotic grinder or the like, and U.S. Patent No. 6,678,954 for methods to set a hollow device into and to retrieve said hollow device from a flow pipe, issued January 20, 2004 to Alcino Resende De Almedia shows method of setting a hollow device into an undersea flow pipe having a flow of fluids flowing in it, the method comprising: inserting at least one stop means into a position where said hollow device is to operate; first inserting said hollow device ahead of a driving means into an end of said flow pipe located upstream of a point where said hollow device should operate; allowing said driving means to be urged by said flow flowing in said flow pipe, thereby displacing said hollow device along said flow pipe; allowing said at least one stop means to halt the displacement of said hollow device, thereby setting said hollow device into its operating position; and allowing

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said driving means to pass through a passage into said hollow device, urged by a pressure exerted by said flow.

[0052] The disclosures of U.S. Patent No. 6,678,954 and U.S. Patent No. 6,678,954 are incorporated herein by this reference.

[0053] The system 600 can be used as a service connection for any purpose. The system 600 can be used for installing sensors and receivers into buried water pipes. The sensor 609' and receiver 609'' are introduced into a pipeline network by the robot 601 and fixed to the inside of the pipe 603 by a mechanical fastener installed by the robot 601.

[0054] Referring now to FIG. 7, an embodiment of a service connection system constructed in accordance with the present invention is illustrated. The system is designated generally by the reference numeral 700. The system 700 provides an inexpensive method of installing a warning unit such as water monitoring sensors, transmitters, or receivers into a water distribution network.

[0055] A hole 701 substantially smaller than a person can fit into is drilled from the ground surface 702 above a pipe 703 to the upper surface 704 of the pipe 703. A drilling collar/pipe reinforcement fitting 705 is affixed to the pipe 703 with a waterproof glue. A combination shutoff valve/clamp 706 is screwed into the collar 705. A hole 707 is drilled into the pipe 703 through a valve 708. The drill is removed and the valve 708 closed. Clamps 712 are engaged by screwing the combination valve/clamp first in and then out to provide a positive lock of the fixture to the pipe. The compression fitting 706 is then tightened by turning collar 709 to provide a watertight seal.

[0056] A sensor/transmitter 710 is positioned in the passage above the valve 708. The valve 708 is opened and the sensor/transmitter 710 is moved into place inside the pipe 703. A compression seal 711 locks the

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sensor/transmitter 710 in place in the pipe 703 and provides a watertight seal.

[0057] The system 700 provides a fitting 706 that enables a warning unit such as sensor/transmitter 710 to be installed into a buried pipe 703 without extensive excavation. The system 700 can be used in installing water quality monitoring sensors into buried water pipes. The system 700 can also be used to install a service connection for any purpose. The system 700 can be used to install connections in any buried fluid distribution system with minimal excavation.

[0058] Referring now to FIG. 2, an embodiment of service connection system is illustrated in connection with a water distribution early warning system for warning of contamination. The contamination can be unauthorized contamination or accidental contamination. This embodiment is designated generally by the reference numeral 200.

[0059] Water flows from a water source 208 through pipes 203. By way of example, the water source 208 can be a treated (e.g., chlorinated, filtered) water municipal distribution system. A news release on November 26, 2001, Water Supplies Need Better Protection by Richard G. Luthy, Copyright © 2003 National Academy of Sciences, provides a warning that, "since the terrorist acts on September 11, questions have arisen about the vulnerability of our water systems to deliberate attacks. In addition, many components are aging and need replacement. Thus, in the context of today's war on terrorism, both the infrastructure and protection of water systems must be considered in a new light. Safeguarding water supplies from sabotage will require engineering analysis and problem-solving, scientific advances, and evaluation of institutional arrangements and water policies. Top priority should be given to protecting physical water storage and transmission

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structures that serve large populations. Many dams, aqueducts, and pumping stations that capture and convey water over long distances are especially vulnerable to physical damage and would be difficult to replace.”

[0060] The system 800 includes an array of autonomous sensors/communicators 801 that are exposed to water flow 810 that flows through the pipes 804 from the water source 808. The array of autonomous sensors/communicators 801 detects, for example, the loss of chlorination shield upon any introduction of non-specific biological or chemical reducing agents 802 into the water 810. Any compact sensor to detect any water property can be used. Each sensor communicates by emitting acoustic signal burst 809, using the pipes 803 as wave-guides or channels. The preexisting Supervisory Control and Data Acquisition Systems (SCADAS) 805 receive the signal 809 and communicate by radio 806 to water management 807 where appropriate action can be taken.

[0061] The sensors/communicators 801 communicate by emitting acoustic signal bursts 809, using the pipes 804 as wave-guides or channels. The Supervisory Control and Data Acquisition Systems (SCADAS) 805 receive the signal 809 and communicate by radio 806 to water management 807. Systems for providing communication through fluid filled pipes are known, for example, various systems are shown in U.S. Patent Application No. 2002/0189362 published December 19, 2002 and International Patent Application No. WO 02/103303 published December 27, 2002. Both patent applications are owned by Honeywell International Inc. and were invented by Vladimar Havlena. The disclosures of U.S. Patent Application No. 2002/0189362 published December 19, 2002 and International Patent Application No. WO 02/103303 published December 27, 2002 are incorporated herein by this reference.

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[0062] The system 800 can detect gross biological or chemical contamination, or agent that would defeat the chlorination shield using a reducing agent (e.g., glucose, ascorbate, thiosulfate, hyposulfite, or ferrocyanide, and many other common reducing agents) preliminary to the introduction of biological or chemical agent that might be destroyed by the ca. 2 ppm ambient chlorine or chlorine-equivalent concentration. In addition to the oxidation potential and pH sensing, the system 800 has applicability and use for: elemental chlorine, chloramines, oxidative oxy-halogen compounds, ozone, oxygen, peroxydisulfate, peroxymonosulfate; strong reducing agents including hyposulfite, thiosulfate, ferrocyanide, sulfide, H_2S ; and specific ions and solid/liquid dispersions of cyanide, selenium, lead, mercury and arsenic containing compounds; specific nerve and blistering agents including but not necessarily limited to VX, Lewisite, G-agents, phosgene, and mustard gases; and radiological sources including actinides and radioactive isotopes of iodine, cesium, strontium, thorium and cobalt. The sensors/communicators 801 may include specific sensors for biological materials, biochemicals or live, dead or sporulated bacteriological, viral or microbial organisms.

[0063] The system 800 provides an inexpensive distributed sensor network that can help assure the water quality in water distribution systems. The system 800 can be installed in existing pipes. The sensors/communicators 801 are installed by digging a hole substantially smaller than a person can fit into from the ground surface above the pipes 804 to the upper surface of the pipes 804. A drilling collar/pipe reinforcement fitting is affixed to the pipe 804 with a waterproof glue, and a combination shutoff valve/clamp is screwed into the collar. A hole is drilled into the pipe 804 through the open valve, the drill removed, and the shutoff valve closed. Clamps are engaged

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by screwing the combination valve/clamp first in and then out. A compression fitting 11 is then tightened to provide a watertight seal. The system 800 provides an inexpensive method of installing water monitoring sensors/communicators, transmitters, and receivers into a water distribution network.

[0064] The system 800 use in installing water quality monitoring sensors into buried water pipes. The system 800 can be used to install a service connection for any purpose. The system 800 can be used to install connections in any buried fluid distribution system with minimal excavation.

[0065] The system 800 is low in cost. The signal (e.g., a 32 bit binary code) is transmitted to pre-existing monitoring sites or Supervisory Control and Data Acquisition systems 805 that are linked to water management 807. Each system is wireless and autonomous, being powered by a primary battery, micro fuel cell, or a secondary battery trickle charged by a thermoelectric device, solar cell, or a water-powered generator.

[0066] Referring now to FIG. 9, this embodiment of the communication system constructed in accordance with the present invention is illustrated. The system is designated generally by the reference numeral 900. A flowing fluid 902 passes from a fluid source 901 through the pipes 903 of a pipe network or pipeline system. An external source 911 supplies a data signal to be transmitted. A data encoder 909 encodes the data for transmission by the acoustic transmitter 907. The transmitter 907 is comprised of an acoustic transducer in the 3-100 kHz range 904 and associated electronics for pulse or waveform generation 906. This frequency range allows the use of well-developed technology for the acoustic hardware. The soundwaves in this frequency range can propagate long distances in water 902 and are above

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most of the noise sources in the pipeline 904. The hardware for these frequencies is relatively inexpensive, and allows for a good compromise between power and size. The transducer 904 is located in the pipeline and exposed to the flowing fluid 902. The transducer 904 sends an acoustic signal 921 which propagates through the water 902 in the pipe 903. The acoustic signal 921 is received by receiver 916, which is composed of a receiving transducer 913, and associated amplifiers and filters 915. The signal received by receiver 916 is digitized electronically 918, and then processed at 920 for extraction of the initial data 912. At the end of the process, the original data 912 are recovered and transmitted on for the intended application.

[0067] Noise/interference sources in the pipeline 903 are addressed at the receiver 916 in order to minimize transmitter cost and complexity. The pipeline 903 constitutes a potentially noisy environment, and significant signal distortion can be introduced by sources including (but not limited to): external noise, multi-path echoes, inter-modal interference, and pipe geometry including bends, "T's," junctions, size/material changes, and joints. It is possible to address some or all of these issues by increasing the capability of the transmitter 907, however when an array of transmitters is desired, as in Figure 2 below, the large number of transmitter units makes this undesirable. Applicants utilize relatively simple transmitters and develop signal processing techniques to deconvolve the coded information at the receiver 905 (i.e., "dumb" transmitters and smart receivers).

[0068] In one embodiment, the system constitutes a signal encoder, an acoustic transmitter in the frequency range of 3-100 kHz, a narrow-band acoustic receiver tuned to the transmitter, a means to digitize the received acoustic signal, and a computer-based apparatus for applying advanced

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signal processing techniques to deconvolve the received data from the distortion induced by the effects of the pipe boundaries, junctions, corners, etc.

[0069] In another embodiment, the system constitutes a signal encoder, acoustic transmitter in the frequency range of 3-100 kHz, a broad-band acoustic receiver, a means to digitize the received acoustic signal, and a computer-based apparatus for applying advanced signal processing techniques to deconvolve the received data from the distortion induced by the effects of the pipe boundaries, junctions, corners, etc. In one embodiment, the broad-band receiver is a hydrophone.

[0070] In another embodiment, the system constitutes an array of identical acoustic transmitters in the frequency range of 3-100 kHz, a narrow-band acoustic receiver tuned to the transmitters, a means to digitize the received acoustic signal, and a computer-based apparatus for applying advanced signal processing techniques to deconvolve the received data from the position-dependant transfer function of the pipe or pipe network. The receiver distinguishes the source transmitters from one another by an identification code transmitted as part of the data.

[0071] Referring now to FIG. 10, this embodiment is schematically shown whereby a pipe network 1001 has several sources of fluid 1005 and one drain 1006, although the configuration and number of the sources and drains are not important. The figure shows an array of identical transmitters 1002 transmitting acoustic signals in the 3-100 kHz range 1004 through the pipe network 1001 to a single centralized receiver 1003. The receiver 1003 passes converts the received acoustic signals to electrical signals, and passes them to a digitizer 1008 and then to a signal processing

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unit 1007. The receiver 1003 is a narrow-band receiver tuned to the frequency of the transmitters.

[0072] In another embodiment, the system constitutes an array of identical acoustic transmitters in the frequency range of 3-100 kHz, a narrow-band acoustic receiver tuned to the transmitters, a means to digitize the received acoustic signal, and a computer-based apparatus for applying advanced signal processing techniques to deconvolve the received data from the distortion induced by the effects of the pipe boundaries, junctions, corners, etc. (the position-dependant transfer function of the pipe). The position-dependant transfer function will be a unique function for each transmitter dependent upon the transmitter location. The receiver distinguishes the source transmitters from one another by deconvolving the transfer function from the portion of the received signal corresponding to a known pilot signal transmitted as part of the data.

[0073] Referring now to FIG. 11, one transmitter – receiver pair is shown schematically for this embodiment. The embodiment is designated generally by the reference numeral 1100. A transmitter 1101 located in the pipeline 1104 communicates with the receiver 1105 by emitting acoustic signal bursts 1106 using the pipeline 1104 as a wave-guide or channel. The acoustic information signal 1106 is transmitted by transmitter 1101 through the pipeline 1104 to the receiver 1105, where it is available for a time reversal processor 1106 and code extractor 1107. The transmitter 1101 includes pilot generator 1108 and code generator 1109. The receiver 1106 utilizes sophisticated signal processing algorithms including model (physics)-based, time reversal, or other techniques to deconvolve the encoded signal from the distortion caused by the pipeline. The implementation of these techniques to the acoustic communication system 1100 essentially consists of sending a

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known pilot signal 1108 from the transmitter 1101 to the receiver 1105 prior to the transmission of the data. The signal processing algorithms are used to deconvolve the known pilot signal 1108 and the unknown "transfer function" of the propagation medium (the pipeline between the transmitter and receiver). Once the effect of the pipeline on the known pilot signal is quantified, the appropriate signal processing can be applied to the distorted data signal to recover the data which might not otherwise be intelligible.

Additional details of a communication system that can be used for the communication system 1100 are shown in U.S. Patent Application 2003/0138053 by James V. Candy, James and Alan W. Meyer, published July 24, 2003 and titled, "Time Reversal Communication System." The disclosure of U. S. Patent Application 2003/0138053 by James V. Candy, James and Alan W. Meyer, published July 24, 2003 and titled, "Time Reversal Communication System" is incorporated herein by the reference.

[0074] In another embodiment, the system constitutes an array of different frequency acoustic transmitters in the frequency range of 3-100 kHz, a broad-band acoustic receiver, a means to digitize the received acoustic signal, and a computer-based apparatus for applying advanced signal processing techniques to deconvolve the received data from the position-dependant transfer function of the pipe or pipe network. The receiver distinguishes the source transmitters from one another by the frequency content of the transmitted data, or by an identification code transmitted as part of the data, or by the deconvolving the transfer function of a known pilot signal transmitted as part of the data in the acoustic signal.

[0075] In another embodiment, the system constitutes an array of acoustic transmitters with different frequencies in the range of 3-100 kHz, a broad-band acoustic receiver, various frequency filters tuned to the different

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frequency transmitters, a means to digitize the received acoustic signal, and a computer-based apparatus for applying advanced signal processing techniques to deconvolve the received data from the position-dependant transfer function of the pipe or pipe network. The receiver distinguishes the source transmitters from one another by the frequency content of the transmitted data, or by an identification code transmitted as part of the data, or by the deconvolving the transfer function of a known pilot signal transmitted as part of the data in the acoustic signal.

[0076] In various other embodiments the computer-based apparatus used for signal processing utilizes Green's function analysis, and/or matched filter techniques, and/or time reversal techniques, and/or other unspecified digital signal processing techniques to deconvolve the received data from the position-dependant transfer function of the pipe or pipe network.

[0077] One embodiment of the present invention provides a system for acoustic communication in a fluid filled pipe, or network of pipes, or in a fluid bounded on 2 or more sides (for example, shallow water) with a dimension on the order of or larger than the acoustic wavelength. The communication could be used to relay data from remote sensors regarding analysis of the fluid, of the pipe or pipes, or for other purposes. Numerous embodiments of the invention can be proposed to accommodate various different applications and environments.

[0078] One embodiment of the present invention comprises the steps of encoding information into an acoustic signal in the frequency range of 3-100 kHz, introducing the acoustic signal into the fluid contained within the pipe or pipeline or network of pipes, transmitting the signal through the pipe or pipeline or network of pipes, receiving the signal, converting the acoustic signal to an analog electric signal, digitizing the electric signal, and

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deconvolving the information from the received, digitized signal by applying suitable signal processing including, but not limited to, Green's function analysis, matched filter techniques, and/or time reversal techniques. The invention may use a known pilot signal to enable deconvolution of the position-dependant transfer function of the pipe or pipe or pipeline or pipe network.

[0079] While the invention may be susceptible to various modifications and alternative forms, specific embodiments have been shown by way of example in the drawings and have been described in detail herein.

However, it should be understood that the invention is not intended to be limited to the particular forms disclosed. Rather, the invention is to cover all modifications, equivalents, and alternatives falling within the spirit and scope of the invention as defined by the following appended claims.

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THE INVENTION CLAIMED IS

1. An apparatus for sensing and communicating in a pipeline containing a fluid, comprising:
 - a sensor connected to the pipeline that senses at least one property of the fluid and produces in the pipeline a signal related to said property, said property comprising a biological property or a chemical property or a temperature property or a density property or a thermal conductivity property or a heat capacity property or an electrical resistivity property or a sound property or a speed property or a viscosity property or an optical property or a magnetic property or an absorbance-on-a-surface property,
 - a receiver connected to the pipeline for receiving said signal related to said property,
 - a control connected to said pipeline, said control producing an output function, and
 - a system for transmission of said signal related to said property from said receiver to said control.
2. The apparatus for sensing and communicating in a pipeline of claim 1 including wherein said sensor is a sensor for sensing elemental chlorine or oxidative oxy-halogen compounds or ozone or oxygen or peroxydisulfate or strong reducing agents or hyposulfite or thiosulfate or sulfide or H₂S or cyanide or selenium or lead sensor or mercury or arsenic or nerve agents or blistering or Lewisite or G-agents or phosgene or gas or actinides or radioactive isotopes or radioactive iodine or radioactive cesium or radioactive strontium sensor or thorium or radioactive cobalt or radioactive thorium in the fluid.

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3. The apparatus for sensing and communicating in a pipeline containing a fluid of claim 1 wherein said biological property is sporulated bacteria or viral organisms or microbial organisms or biochemicals.

4. The apparatus for communication in a pipeline containing a fluid of claim 1 wherein said sensor is introduced into the pipe by a robot.

5. The apparatus for communication in a pipeline containing a fluid of claim 1 wherein said sensor is introduced into the pipe by a robot and fixed to the inside of the pipe by a mechanical fastener installed by said robot.

6. The apparatus for communication in a pipeline containing a fluid of claim 1 wherein said sensor is introduced into the pipe by a robot and fixed to the inside of the pipe by an adhesive material installed by said robot.

7. The apparatus for communication in a pipeline containing a fluid of claim 1 wherein said sensor is introduced into the pipe through a threaded hole in the pipe.

8. The apparatus for communication in a pipeline containing a fluid of claim 1 wherein said sensor is introduced into the pipe through a fire hydrant.

9. The apparatus for communication in a pipeline containing a fluid of claim 1 wherein said sensor is introduced into the pipe through a fire hydrant with a tether comprised of a flattened tape of metal, a steel cable, or a polymer cable.

10. The apparatus for communication in a pipeline containing a fluid of claim 1 including apparatus for installing warning unit in a buried pipe, comprising a collar, means for affixing said collar to the pipe, and a valve operatively connected to said collar, said valve having a passage

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communicating with said collar for allowing the warning unit to be moved into place in the buried pipe.

11. The apparatus for communication in a pipeline containing a fluid of claim 1 wherein said receiver connected to the pipeline for receiving said signal related to said property and said system for transmission of said signal related to said property comprises an encoding and transmitting system connected to the pipe or pipeline, or network of pipes that transmits a signal in the frequency range of 3-100 kHz into the pipe or pipeline, or network of pipes containing a fluid, and a receiver and processor system connected to the pipe or pipeline, or network of pipes containing a fluid that receives said signal and uses said signal for a desired application.

12. The apparatus of claim 11 wherein said encoding and transmitting system includes a digital electronic or computer-based apparatus used to encode information onto an electric signal suitable for conversion to an acoustic signal by an acoustic transmitter frequency range of 3-100 kHz.

13. The apparatus of claim 11 wherein said encoding and transmitting system includes an acoustic transmitter in the frequency range of 3-100 kHz immersed in the fluid.

14. The apparatus of claim 11 wherein said encoding and transmitting system includes an acoustic transmitter in the frequency range of 3-100 kHz immersed in a portion of the fluid and wherein the portion of fluid is part of the pipe or pipeline, or network of pipes.

15. The apparatus of claim 11 wherein said encoding and transmitting system includes an acoustic transmitter in the frequency range of 3-100 kHz immersed in a portion of the fluid and wherein the portion of fluid is not part of the pipe or pipeline, or network of pipes.

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16. The apparatus of claim 11 wherein said receiver and processor system includes an apparatus for electronically digitizing said signal.

17. The apparatus of claim 11 wherein said receiver and processor system includes a digital electronic or computer-based apparatus used for signal processing.

18. The apparatus of claim 11 wherein said receiver and processor system includes a digital electronic or computer-based apparatus used for signal processing using Green's function analysis.

19. The apparatus of claim 11 wherein said receiver and processor system includes a digital electronic or computer-based apparatus used for signal processing using matched filter techniques.

20. The apparatus of claim 11 wherein said receiver and processor system includes a digital electronic or computer-based apparatus used for signal processing using time reversal techniques.

21. The apparatus of claim 11 wherein said receiver and processor system includes a broad-band receiver in the frequency range of 3-100 kHz.

22. The apparatus of claim 11 wherein said receiver and processor system includes a narrow-band receiver in the frequency range of 3-100 kHz.

23. A method of sensing and communicating in a pipeline containing fluid, comprising the steps of:

sensing information about at least one property of the fluid, said at least one property comprising a biological property or a chemical property or a temperature property or a density property or a thermal conductivity property or a heat capacity property or an electrical resistivity property or a sound property or a speed property or a viscosity property or an optical property or a magnetic property,

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producing an acoustic signal in the pipeline containing said information,

transmitting said information through the pipeline,

receiving said information from the pipeline,

taking action based upon said information.

24. The method of sensing and communicating in a pipeline of claim 23 wherein said step of producing an acoustic signal produces an ultrasonic signal in the pipeline.

25. The method of sensing and communicating in a pipeline of claim 23 wherein said step of sensing information produces acoustic pulses and numerical value of information transmitted and said acoustic pulses and numerical value of information is related to the time between said acoustic pulses.

26. The method of sensing and communicating in a pipeline of claim 23 including the step of sensing chemical properties of the fluid.

27. The method of sensing and communicating in a pipeline of claim 23 including the step of sensing biochemicals or sporulated bacteria or viral organisms or microbial organisms in the fluid.

28. The method of sensing and communicating in a pipeline of claim 23 including the step of sensing elemental chlorine or oxidative oxy-halogen compounds or ozone or oxygen or peroxydisulfate or strong reducing agents or hyposulfite or thiosulfate or sulfide or H₂S or cyanide or selenium or lead sensor or mercury or arsenic or nerve agents or blistering or Lewisite or G-agents or phosgene or gas or actinides or radioactive isotopes or radioactive iodine or radioactive cesium or radioactive strontium sensor or thorium or radioactive cobalt or radioactive thorium in the fluid.

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29. The method of sensing and communicating in a pipeline of claim 23 wherein said surface absorption property is measured by changes in resistance of a polymer or changes in a surface acoustic wave or changes in an evanescent light wave property or bending of a cantilever or changes in a cantilever vibrational property or changes in an optical reflection property.

30. The method of sensing and communicating in a pipeline of claim 23 including the step of introduced a sensor into the pipe through a fire hydrant.

31. The method of sensing and communicating in a pipeline of claim 23 including the step of introduced a sensor into the pipe through a fire hydrant with a tether comprised of a flattened tape of metal, a steel cable, or a polymer cable.

32. The method of sensing and communicating in a pipeline of claim 23 including the steps of:

- digging a hole in the ground to the pipe,
- affixing a collar to the pipe,
- attaching a valve with an internal passage to said collar,
- drilling a hole in the pipe, and

installing a warning unit in the pipe by moving the warning unit through said internal passage, said collar, and said hole in the pipe.

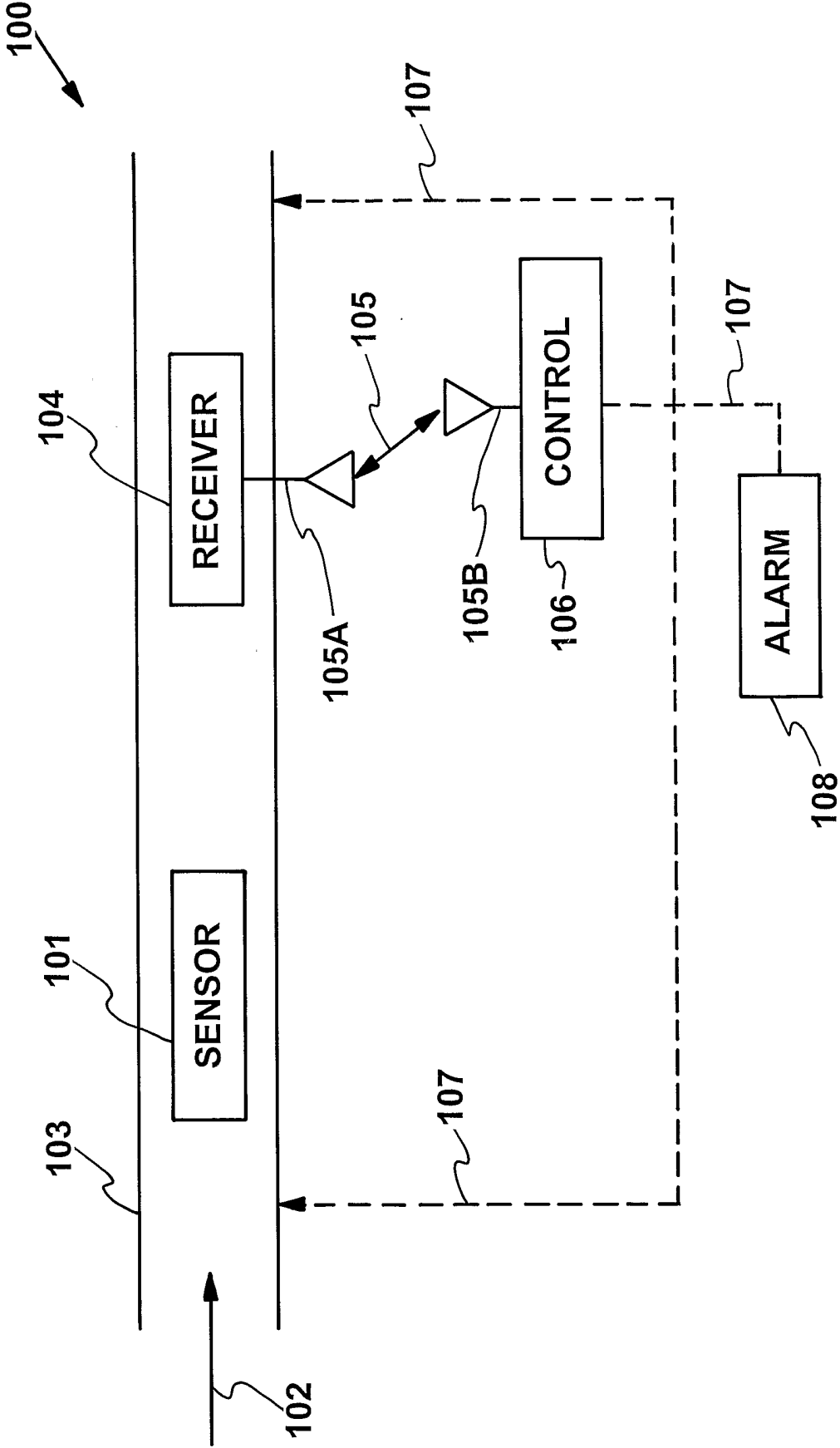


FIG. 1

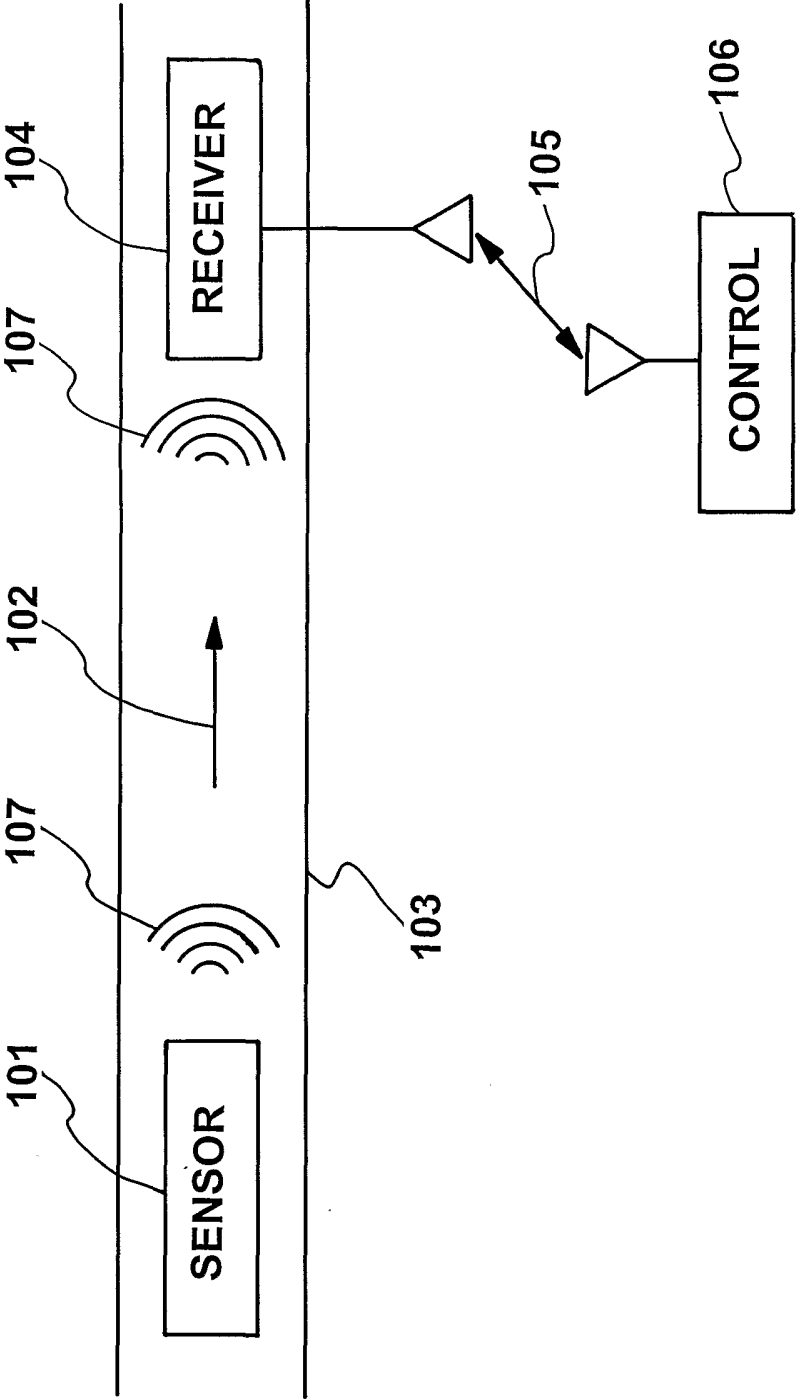


FIG. 2

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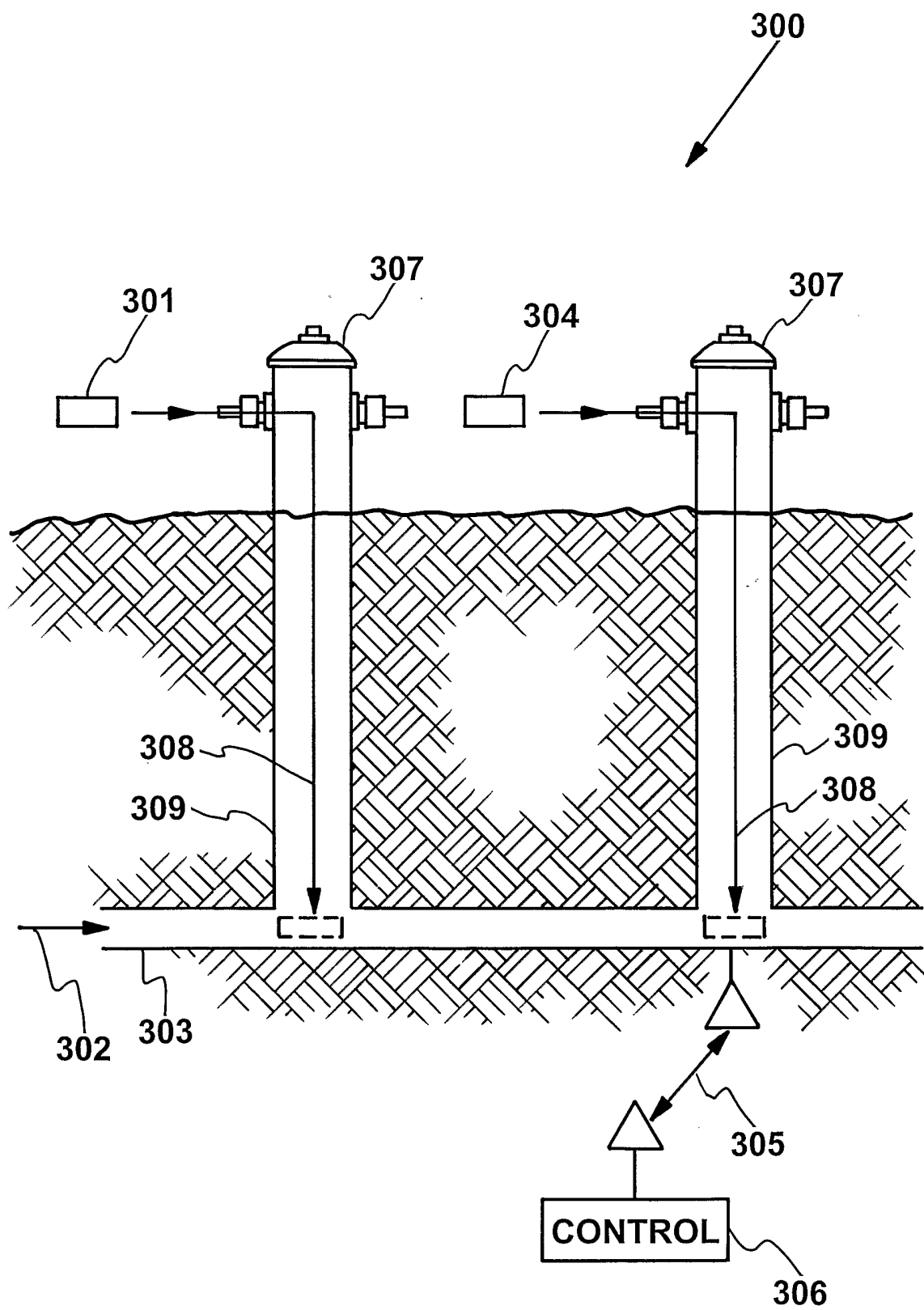


FIG. 3

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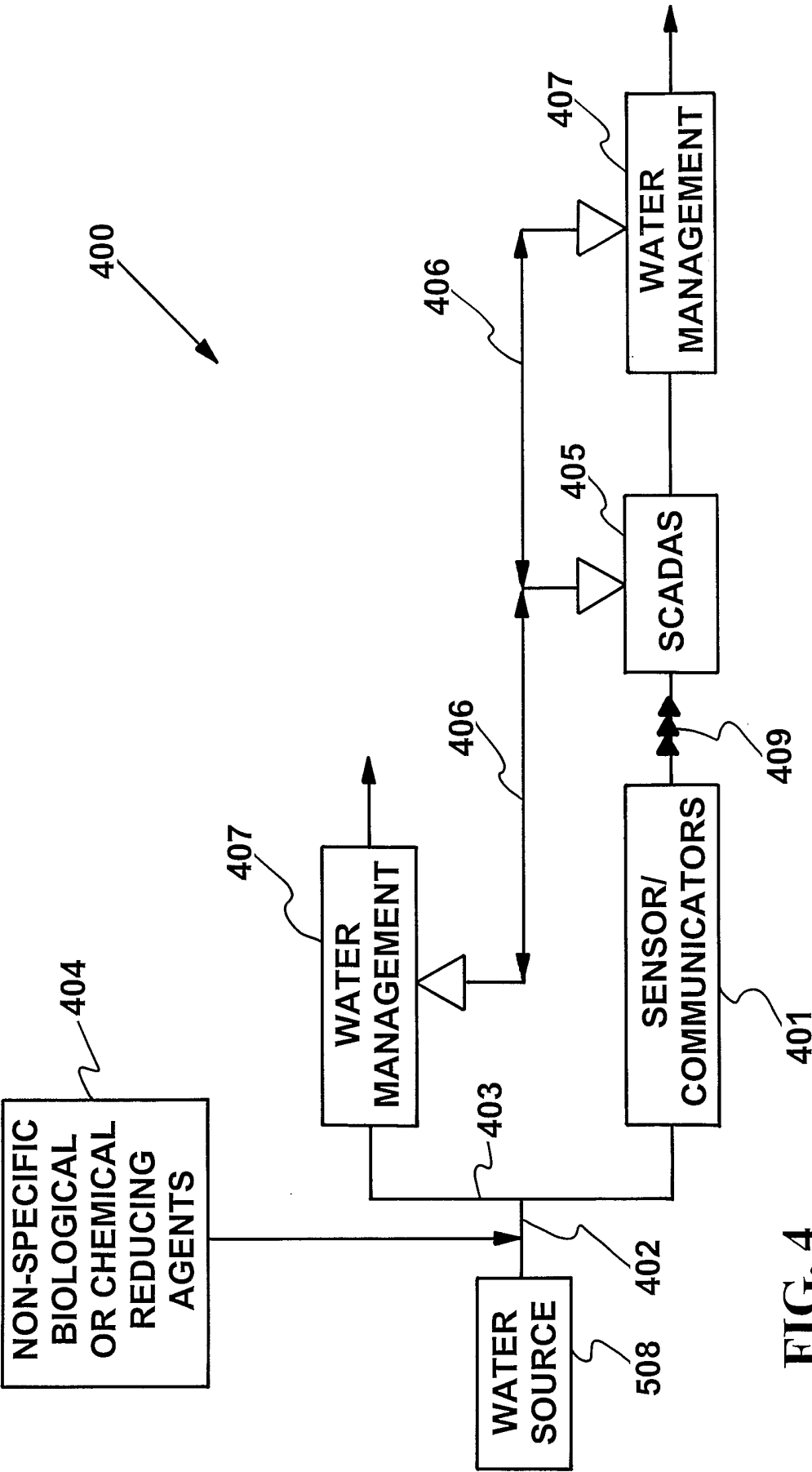


FIG. 4

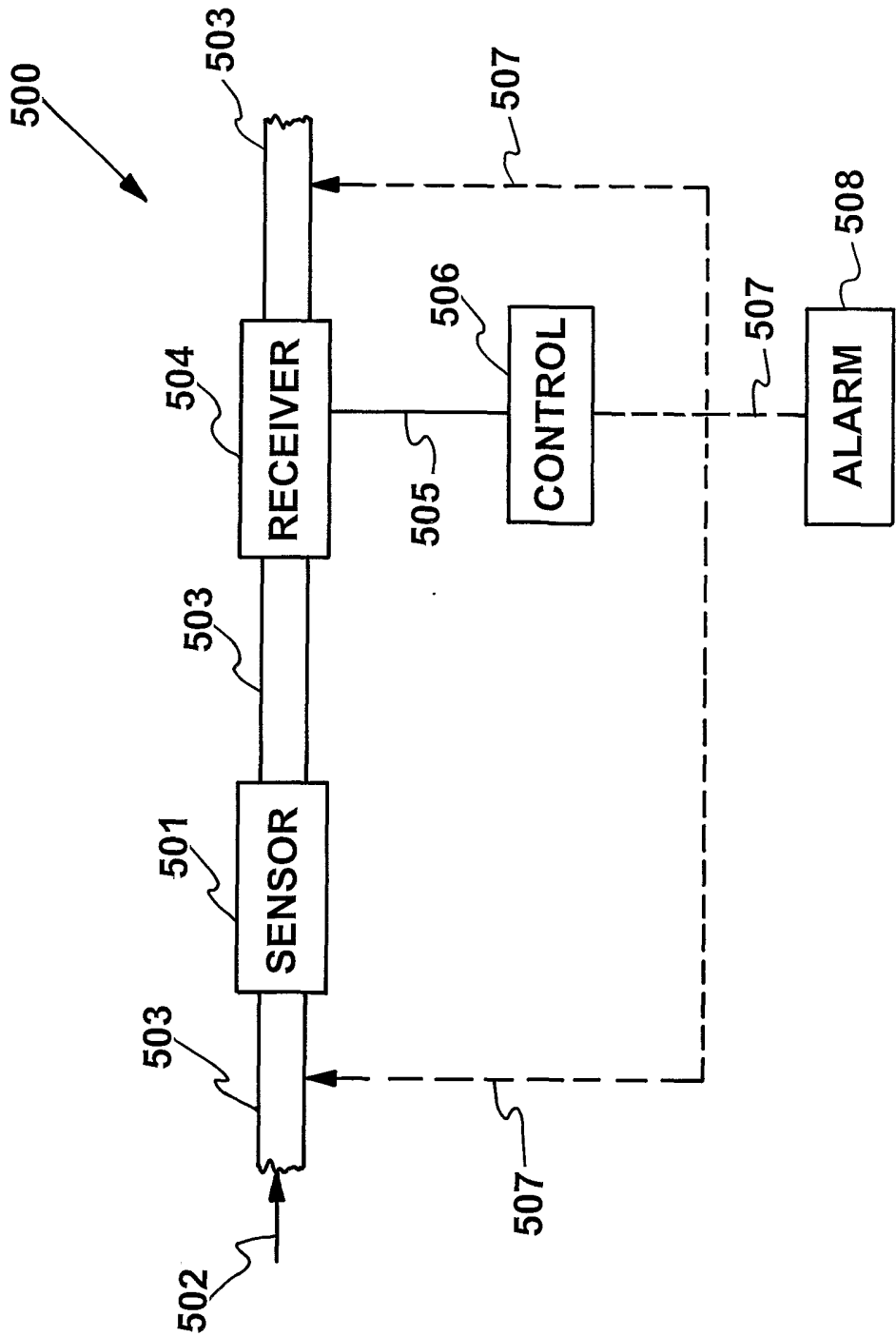


FIG. 5

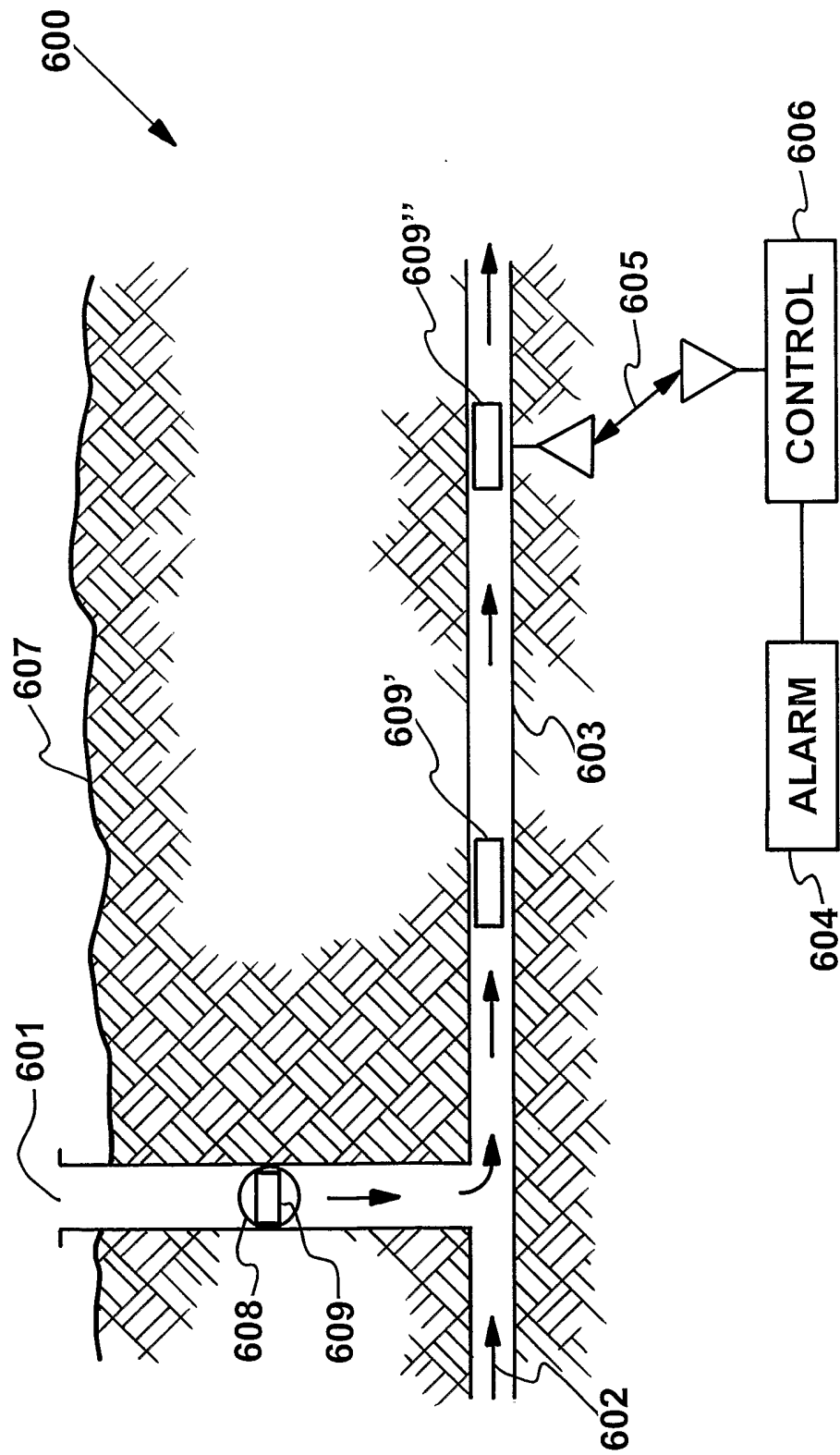


FIG. 6

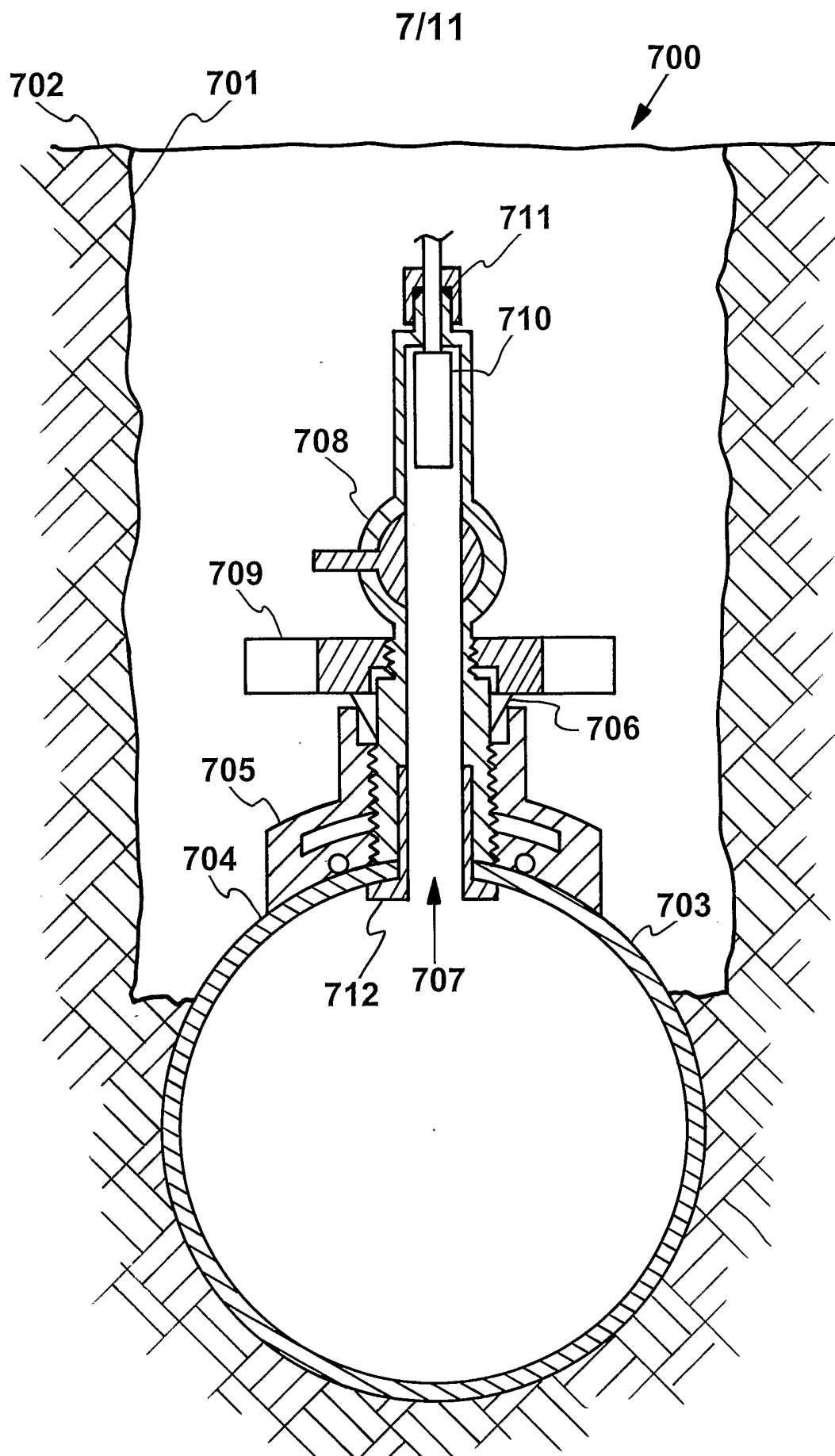


FIG. 7

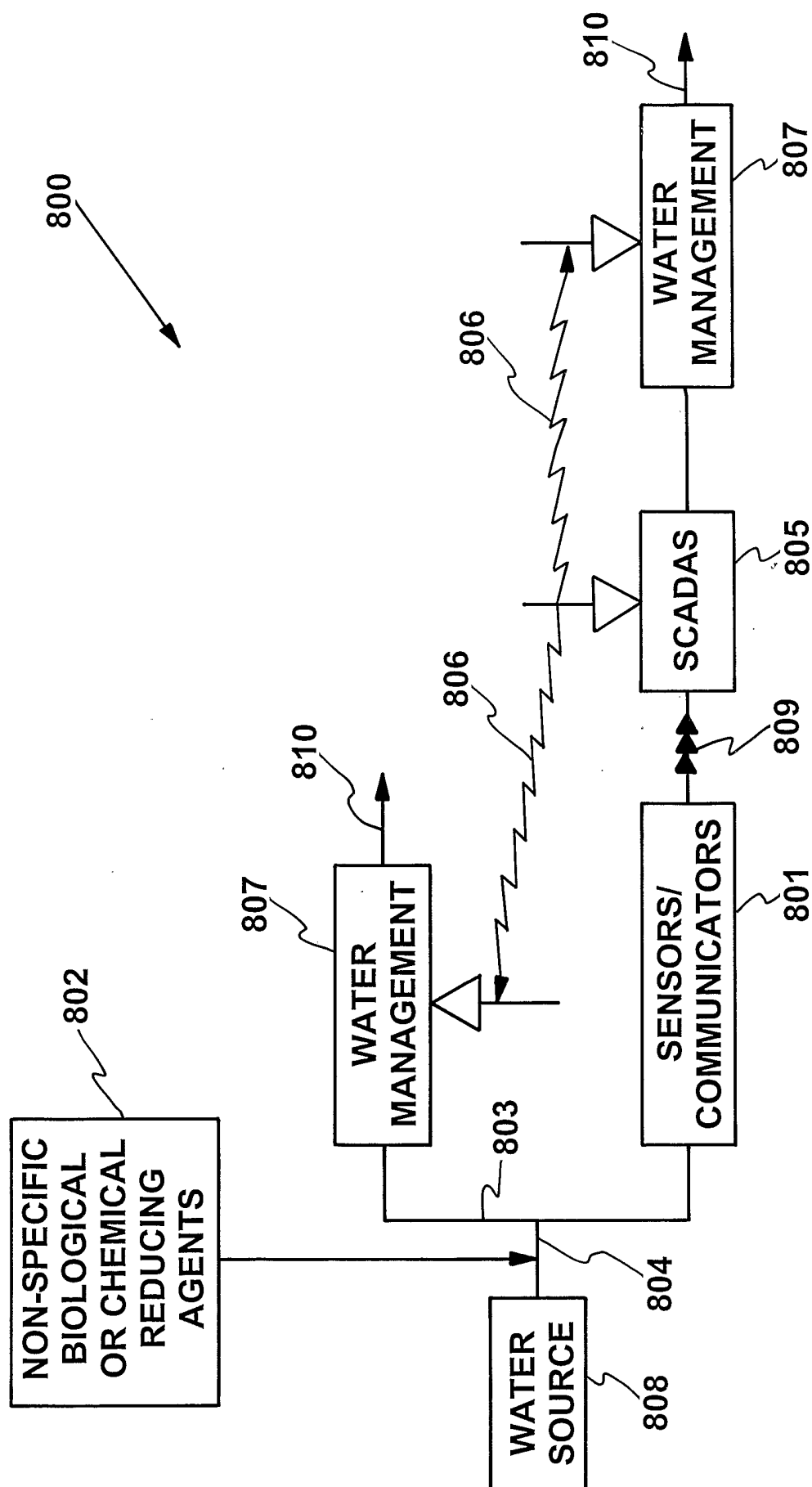


FIG. 8

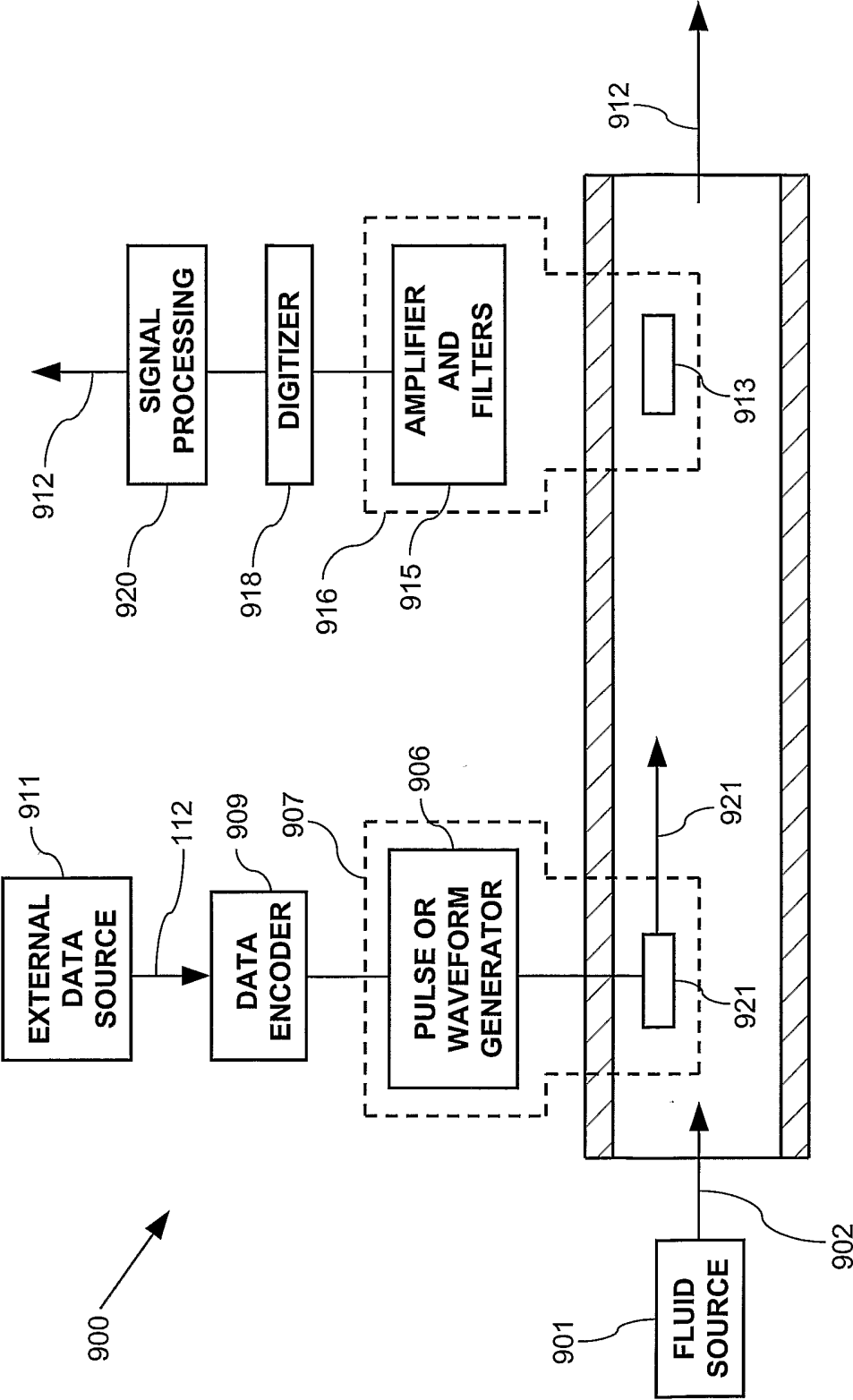


FIG. 9

10/11

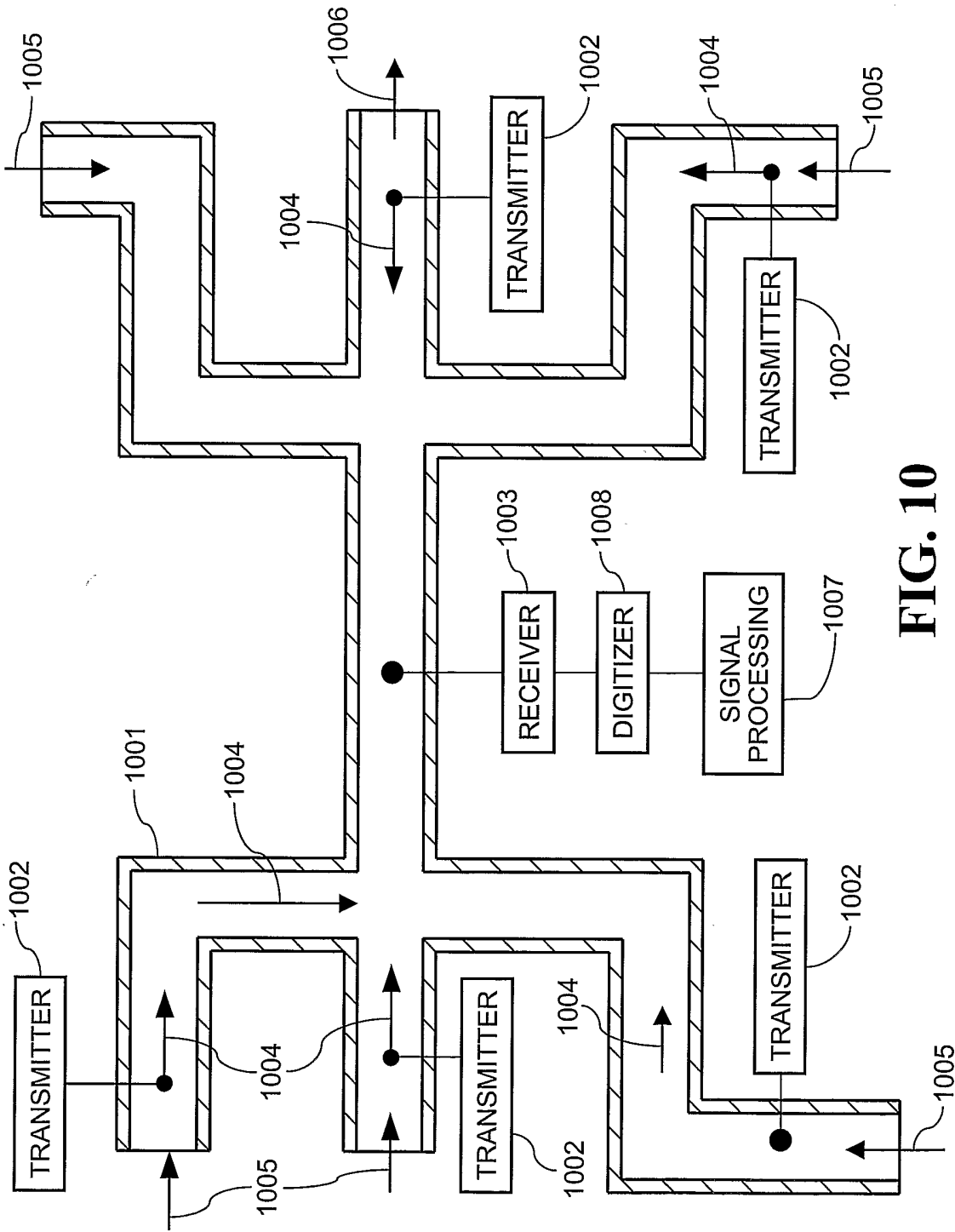


FIG. 10

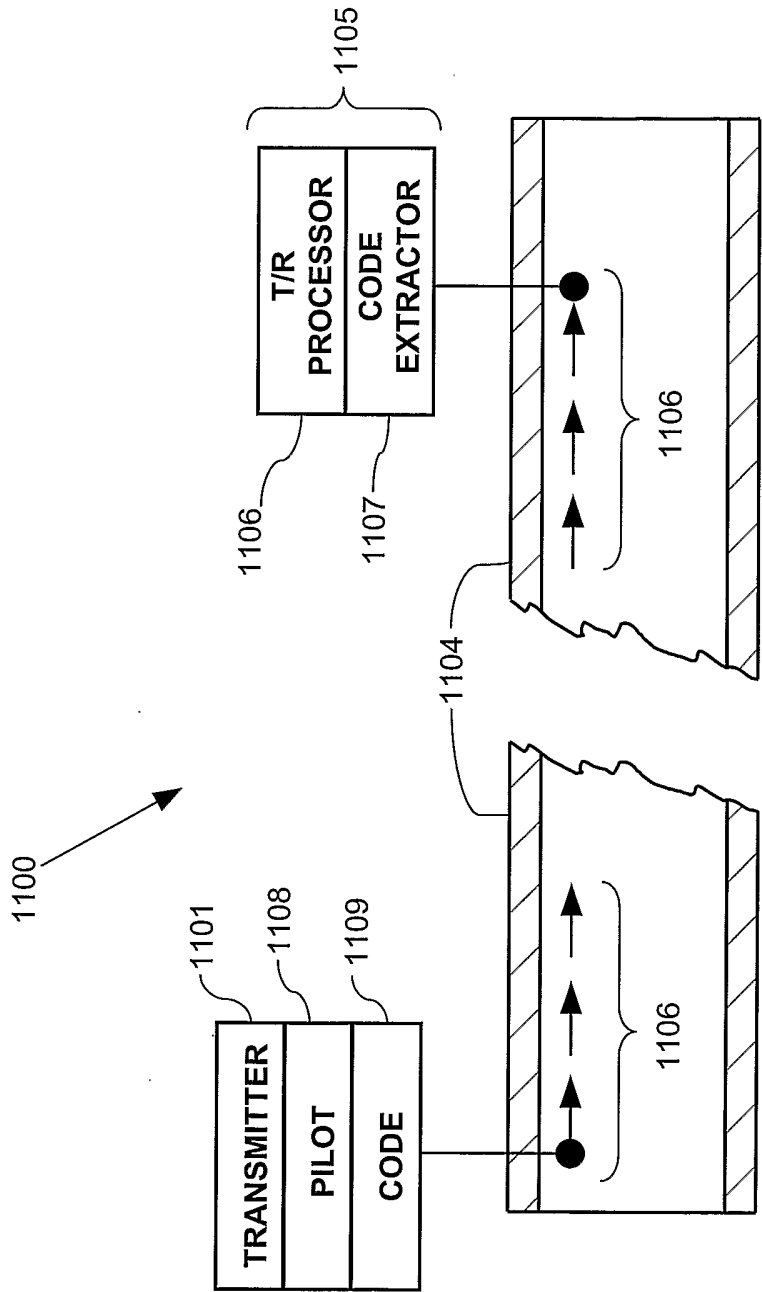


FIG. 11

INTERNATIONAL SEARCH REPORT

 International Application No
 PCT/US2004/021330

A. CLASSIFICATION OF SUBJECT MATTER

IPC 7 H04B13/00 G01F1/66 G08C23/00

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

B. FIELDS SEARCHED

Minimum documentation searched (classification system followed by classification symbols)

IPC 7 H04B G01F G08C 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 practical, search terms used)

EPO-Internal, WPI Data, PAJ

C. DOCUMENTS CONSIDERED TO BE RELEVANT

Category *	Citation of document, with indication, where appropriate, of the relevant passages	Relevant to claim No.
X	DE 40 37 600 A (STANDARD ELEKTRIK LORENZ AG) 4 June 1992 (1992-06-04)	1-10, 16-23, 25-32
Y	column 2, line 16 - column 3, line 40; figure 1	11-15,24
Y	----- US 2002/189367 A1 (KRAFT NANCY C ET AL) 19 December 2002 (2002-12-19)	11-15,24
A	page 1, paragraph 15 - page 2, paragraph 19; figure 1 -----	1-10, 16-23, 25-32

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

☒ Patent family members are listed in 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 document 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.
- *Z* document member of the same patent family

Date of the actual completion of the international search

10 December 2004

Date of mailing of the international search report

23/12/2004

Name and mailing address of the ISA

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Authorized officer

Koch, B

INTERNATIONAL SEARCH REPORT

International Application No
PCT/US2004/021330

Patent document cited in search report		Publication date	Patent family member(s)		Publication date
DE 4037600	A	04-06-1992	DE	4037600 A1	04-06-1992
US 2002189367	A1	19-12-2002	US	6460402 B1	08-10-2002
			AU	3482300 A	25-08-2000
			WO	0046583 A1	10-08-2000