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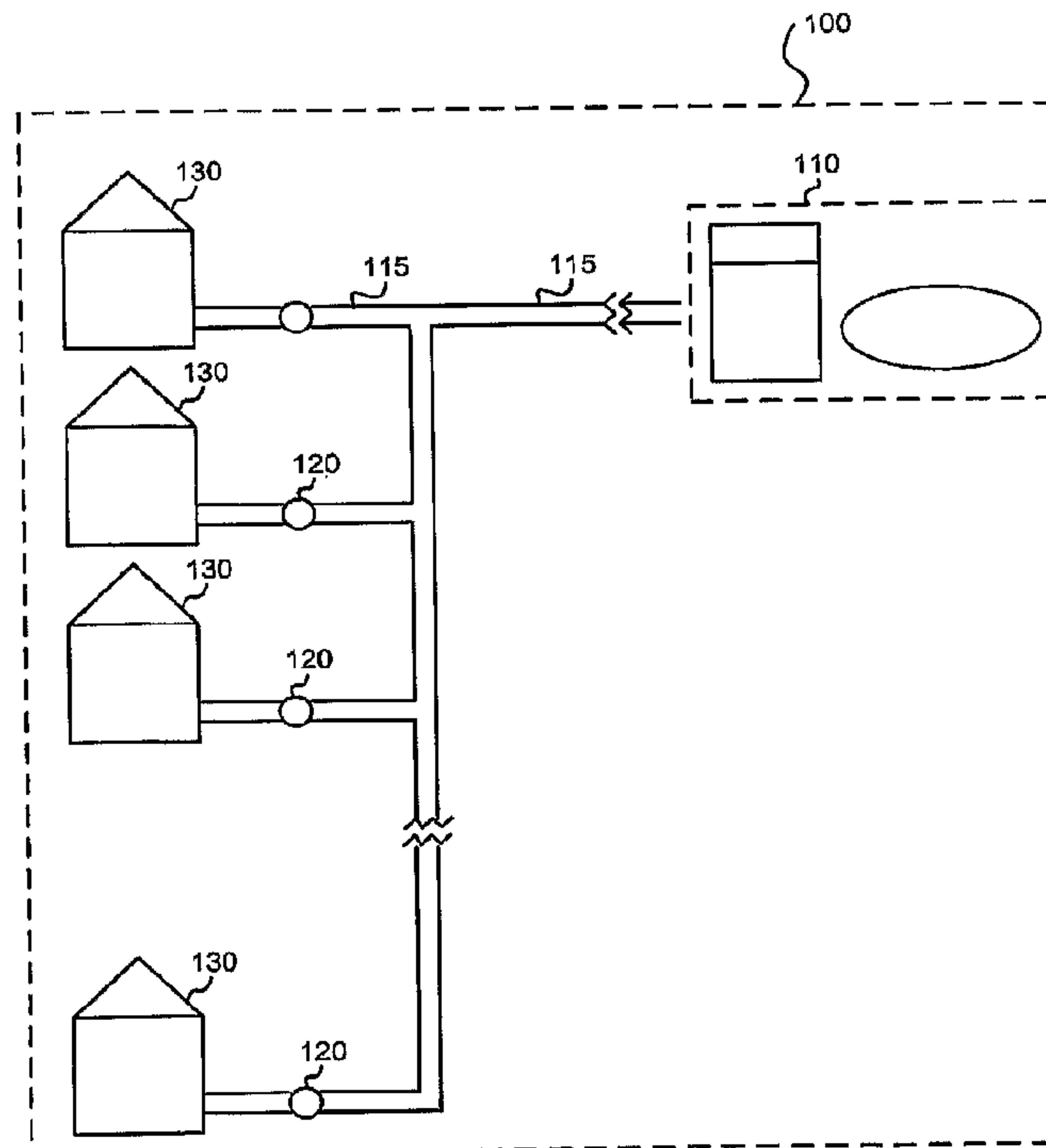
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A remote water meter monitoring system is provided. A mesh network-type transceiver unit is coupled to a water meter housing having a water counting mechanism inside to transmit water consumption information as well as other sensor information, such as backflow detection, water pressure, and water metrics (e.g., residual chlorine and temperature) to a central server system via a bridge device and a corresponding mesh network. Mechanical energy from the water flowing through the water meter housing is converted to electrical energy via an energy conversion unit. An electrically powered shut off valve is remote addressable via the transceiver unit.

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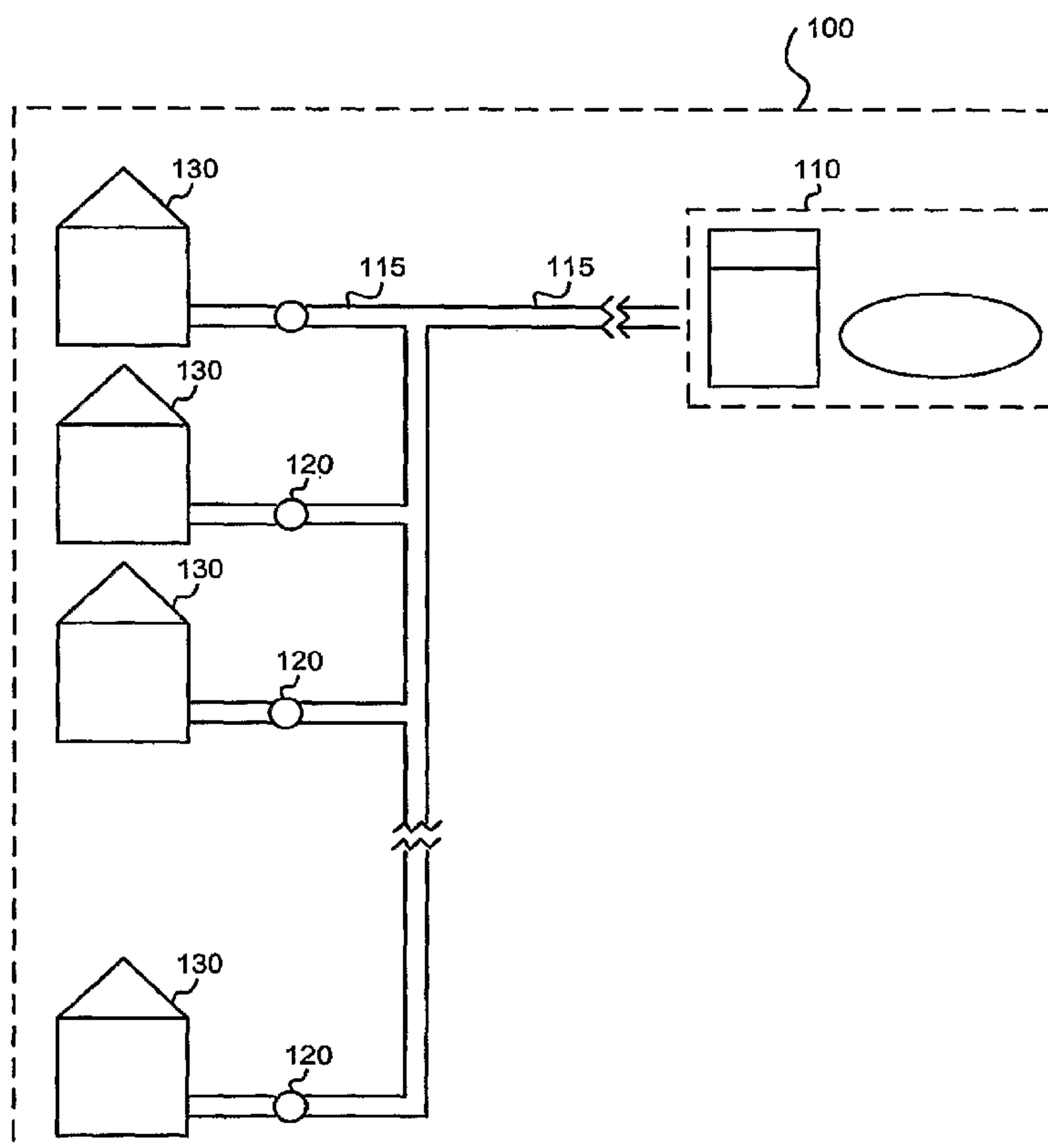
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(57) Abstract: A remote water meter monitoring system is provided. A mesh network-type transceiver unit is coupled to a water meter housing having a water counting mechanism inside to transmit water consumption information as well as other sensor information, such as backflow detection, water pressure, and water metrics (e.g., residual chlorine and temperature) to a central server system via a bridge device and a corresponding mesh network. Mechanical energy from the water flowing through the water meter housing is converted to electrical energy via an energy conversion unit. An electrically powered shut off valve is remote addressable via the transceiver unit.

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SYSTEMS AND METHODS FOR REMOTE UTILITY METERING AND METER MONITORING

[0001]

FIELD OF THE INVENTION

[0002] The present invention relates generally to automated utility meter reading and more specifically to network-based automated meter reading (AMR) system using wireless sensor network technology.

BACKGROUND OF THE INVENTION

[0003] Municipal or private water deliver systems usually deliver water from a central location through a distribution network to water customers on a cost per unit of volume basis, most often cost per gallon or cost per liter. In these systems, a water meter is typically placed between a common water supply pipe and a customer property to measure the amount of water flowing from the supply pipe to the customer. In order to bill the customer for water usage, it is necessary to periodically read the meter to determine the amount of usage over a fixed period of time. This process is referred to in the industry as metering or meter reading.

[0004] Historically, metering has been a labor intensive process, and due to the manual steps required, one that is prone to error. Some improvements have been made by utilizing

automated meter reading (AMR) techniques to capture and transmit meter reading information electronically, such as to a technician with a receiving device near the meter or to another remote location. However, these automated systems still suffer from various shortcomings including limited battery life, limited transmission range, and lack of remote addressability, among others.

SUMMARY OF THE INVENTION

[0005] In view of the aforementioned shortcomings of conventional meter reading systems, at least one embodiment of the invention provides a remote water meter monitoring system. The remote water meter monitoring system according to this embodiment comprises a water meter body coupling a water supply source to a water customer, a flow sensor contained within the water meter body that is configured to measure a bidirectional flow rate of water through the water meter, a power supply system including at least one battery, at least one capacitor, at least one rectifier circuit, and a power generator, wherein the power generator is powered by a flow of water through the water meter body, a controller communicatively coupled to the water meter body and power supply system, and at least one antenna connected to the controller.

[0006]

In this embodiment, the controller is a microcontroller within a wireless mote, the controller is coupled to the flow meter and configured to calculate water consumption based on signals received from the flow meter; and the controller is configured to perform steps comprising:

- awaking from a sleep state;
- checking battery charge levels and adjusting a charging cycle in response to available power;
- preparing a data packet for transmitting water consumption data to a collector;
- listening for a routing beacon from a collector;
- transmitting the prepared data packet;
- resetting a timer; and
- returning to a sleep state.

In this embodiment:

- the water meter can further comprise at least one water quality sensor;
- the controller can be configured to send periodic water usage information wirelessly to the water customer;
- the system can be remotely addressable via a communications network with a network content browser;
- the controller can be configured to communicate, to a collector using a multihop mesh network protocol, the calculated water consumption in a data packet;
- the controller can be configured to control the power supply system;
- the at least one capacitor can be a super capacitor and the controller can be further configured to use the super capacitor as a primary power source and the battery as a secondary power source thereby minimizing battery recharging cycles;

- the controller can be further configured to perform steps comprising:
receiving water consumption reports from another controller;
adding the received water consumption reports to a data packet including the calculated water consumption for the coupled flow meter; and
communicating the data packet to a collector;
- the controller can be further configured to include in the data packet a time stamp indicating a time when the water consumption was calculated;
- the water meter body can further comprise a shut off valve;
- the shut off valve may be remotely activated by a wireless signal received by the system;
- the flow sensor can be adapted to detect reverse water flow and to cause the shut off valve to trigger when reverse water flow exceeds a predetermined volume;
- the controller and antenna can be configured to transmit and receive information from and send information to the system;
- the controller and antenna can be configured to send water usage information wirelessly to a bridge device;
- sending water usage information can comprise sending information either directly or through one or more other water meter monitoring systems;
- the system can be configured to receive at least one command from the wireless bridge device;
- at least one command can be a command selected from the group consisting of a meter reading transmission request, a status request, and a water shutoff request;

Another embodiment according to the invention provides a wireless remote water meter monitoring network comprising:

- at least one central data processing system;

- at least one bridge device communicatively coupled to the at least one central data processing system; and

- a plurality of network nodes, each network node configured to perform two-way communication with the at least one bridge device, either directly or through one or more other network nodes,

wherein each network node comprises:

- a water meter housing coupling a water customer with a water supply line;

- a flow measurement device in the water meter housing for measuring a volume of water flowing through the meter;

- a power supply circuit including at least one power storage device, at least one capacitive device and a power converter, wherein the power converter is powered by water flow through the meter; and

- a communication circuit comprising a mesh-type controller and an antenna, wherein the communication circuit is coupled to the flow measurement device and the power supply circuit and is adapted to perform two-way communication; and

- wherein the mesh-type controller includes a microcontroller;

- wherein the microcontroller is coupled to the flow meter and configured to calculate water consumption based on signals received from the flow meter; and

wherein the microcontroller is configured to perform steps comprising:

- awaking from the sleep state;
- checking battery charge levels and adjusting a charging cycle in response to available power;
- preparing a data packet for transmitting water consumption data to a collector;
- listening for a routing beacon from a collector;
- transmitting the prepared data packet;
- resetting a timer; and
- returning to a sleep state.

In this embodiment:

- the water meter can further comprise a shut off valve operable to prevent water from flowing from the supply to the customer and configured for remote shut off via the communication circuit;
- the antenna of the communication circuit can be physically coupled to a conductive meter pit cover;
- the mesh-type controller can be configured to communicate, to a collector using a multihop mesh network protocol, the calculated water consumption in a data packet;
- the at least one bridge device can be configured to communicate to the at least one central data processing system via a WiFi wireless data network coupled to an Internet;
- the microcontroller can be configured to control the power supply system;
- the at least one capacitor can be a super capacitor and the microcontroller can be further configured to use the super capacitor as a primary power source and the battery as a secondary power source thereby minimizing battery recharging cycles;

- the microcontroller can be further configured to perform steps comprising:
 - receiving water consumption reports from another controller;
 - adding the received water consumption reports to a data packet including the calculated water consumption for the coupled flow meter; and
 - communicating the data packet to a collector; and
- the microcontroller can be further configured to include in the data packet a time stamp indicating a time when the water consumption was calculated.

Another embodiment according to the invention provides a water meter comprising:

a wireless mote element including a microcontroller and a wireless network transceiver;

a flow measurement element including

a nutating disk which displaces a volume of water with each rotation,

a drive shaft coupled to the nutating disk,

an output magnet coupled to the drive shaft; and

a rotation sensor configured to sense rotations of the output magnet and send signals to the microcontroller;

an energy harvesting element including a generator magnetically coupled to the output magnet; and

an energy storage element coupled to the generator and to the microcontroller, the energy storage element including:

a rectifier circuit;

a super capacitor coupled to the rectifier circuit and to the microcontroller;

a battery coupled to the microcontroller; and

a charging circuit coupled to the super capacitor, the battery and the microcontroller, wherein the microcontroller is configured to perform steps comprising: calculating water consumption data based on signals received from the rotation sensor; generating a data packet for transmission including the calculated water consumption data;

transmitting the generated data packet to a collector via the transceiver using a multihop mesh networking protocol; and

controlling the energy storage element by selecting one of the super capacitor or the battery for receiving power; and

wherein the microcontroller is configured with software instructions to perform further steps comprising:

awaking from a sleep state;

checking battery charge levels and adjusting a charging cycle in response to available power;

preparing a data packet for transmitting water consumption data to a collector;

listening for a routing beacon from the collector; transmitting the prepared data packet;

resetting a timer; and

returning to a sleep state.

In this embodiment:

- the microcontroller can be configured with software instructions to perform further steps comprising:

receiving data packets from another water meter, the received data packets including water consumption data and an identifier for the other water meter; and

adding the received water consumption data to the generated data packet for transmission prior to transmitting the data packet to the collector.
- the microcontroller can be configured with software instructions to perform further steps comprising including in the data packet a time stamp indicating a time when the water consumption was calculated.

[0007] Still a further embodiment according to the invention provides a circuit for a wireless water meter monitoring system. The circuit according to this embodiment comprises a mechanical energy harnessing sub-circuit for converting water flow mechanical energy into electrical energy comprising a pair of magnetically coupled rotors driven by water flow and having a plurality of magnets affixed thereto that rotate around a set of coils, thereby inducing a current in the coils, an energy storage and delivery sub-circuit comprising at least one rectifier circuit electrically coupled to the coils, at least one capacitor charged by the at least one rectifier circuit, at least one battery, and a switch for permitting the at least one battery to be charged by the at least one capacitor and for selecting either the at least one capacitor or the at least one battery to supply continuous power to the circuit and to manage charging of the at least one battery, a water flow counting sub-circuit comprising a plurality of flux change detectors that detect flux changes caused by a magnet rotating about a shaft driven by a flow sensor of a water flow chamber, a communication sub-circuit electrically coupled to the energy storage and delivery sub-circuit and the water flow counting sub-circuit

comprising a mesh-type transceiver and an antenna for enabling two-way communication between the wireless water meter monitoring system and other systems, and a sensor sub-circuit electrically coupled to the energy storage and delivery sub-circuit and the communication sub-circuit for recording sensor data and comprising at least one sensor device.

[0008] These and other embodiments and advantages of the present invention will become apparent from the following detailed description, taken in conjunction with the accompanying drawings, illustrating by way of example the principles of the invention.

BRIEF DESCRIPTION OF THE DRAWINGS

[0009] Figure 1 is an illustration of a typical water utility distribution network beginning with a water utility supply and terminating in a plurality of water consumers.

[0010] Figure 2 is a network diagram of a remote water meter monitoring system according to various embodiments of the invention.

[0011] Figure 3 is a illustration of a water meter pit including a remote water meter monitoring system according to various embodiments of the invention.

[0012] Figure 4 is a block circuit diagram of electrical components of a remote water meter monitoring system according to various embodiments of the invention.

[0013] Figure 5 is a block diagram of the power conversion circuit for a remote water meter monitoring system according to various embodiments of the invention.

[0014] Figure 6 is a flow chart of a method of converting mechanical water flow energy into electrical energy in a remote water meter monitoring system according to various embodiments of the invention.

- [0015] Figures 7A and 7B are different views of a water measurement head including a power conversion generator for a remote water meter monitoring system according to various embodiments of the invention.
- [0016] Figures 8A and 8B are different views of a water chamber and water measurement head including a water counting system for a remote water meter monitoring system according to various embodiments of the invention.
- [0017] Figure 9 is a flow chart of a method for measuring water flow with a remote water meter monitoring system according to various embodiments of the invention.
- [0018] Figure 10 is a block diagram illustrating the various logic modules utilized in the remote water meter monitoring system according to the various embodiments of the invention.
- [0019] These and other embodiments and advantages of the present invention will become apparent from the following detailed description, taken in conjunction with the accompanying drawings, illustrating by way of example the principles of the invention.

DETAILED DESCRIPTION

- [0020] The following description is intended to convey a thorough understanding of the embodiments described by providing a number of specific embodiments and details involving systems and methods for remote water meter monitoring. It should be appreciated, however, that the present invention is not limited to these specific embodiments and details, which are exemplary only. It is further understood that one possessing ordinary skill in the art, in light of known systems and methods, would

appreciate the use of the invention for its intended purposes and benefits in any number of alternative embodiments, depending upon specific design and other needs.

[0021] Referring now to Figure 1, this Figure is an illustration of a typical water utility distribution network beginning with a water utility supply and terminating in a plurality of water consumers. The network 100 begins with a water service provider 110 such as a public water utility or commercial water service provider. As is known in the art, the water service provider 110 may comprise a water reservoir and various water quality processing elements that condition the water prior to being piped to consumers. One or more water supply pipes 115 flow out of the water service provider 110 creating a water distribution network. The one or more water supply pipes 115 provide water to a plurality of water consumers 130. For ease of illustration, the water consumers 130 are illustrated as residential units. However, the water consumers may be businesses, factories, irrigations systems, or other entities that receive water from the water service provider 110.

[0022] Each water consumer 130 is coupled to the at least one water supply line 115 by a water meter 120. The water meter provides a physical interconnection between consumers 130 and the water supply line 115. The water meter 120 also measures the amount of water flowing to each consumer from the supply line 115. This data is typically used to bill the customer for their water consumption over a specified time period such as a month or quarter. The water meter 120 includes a dial, gauge, or other display that quantifies the amount of water that has passed through the meter into a number of gallons. As discussed above, in order to bill customers for their water consumption, the water utility usually sends a meter reader out to the read the number

from each water meter 120. The previous reading is subtracted from this number and the corresponding numbers of gallons consumed are billed to the customer.

- [0023] A conventional water meter usually includes a water chamber having a water input, a water output, and a water flow measuring device, such as a rotating, nutating or oscillating disk, or other flow meter, that drives the gauge on the top surface of the meter. The meter chamber is usually made of a non-corrosive metal such as copper or bronze. Also, the pipe connecting the meter chamber usually includes a manual shut off valve that can be manually engaged to prevent water from flowing from the supply pipe 115 to the consumer 130 through the meter 120, to facilitate the repair or replacement of the water meter or other elements within the customer premises.
- [0024] Figure 2 is a network diagram of a remote water meter monitoring system according to various embodiments of the invention. The network 200 shown in Figure 2 is similar to that of Figure 1 in that a water service provider 110 is coupled to a plurality of water consumers via a water supply pipe 115. However, in the network 200 of Figure 2, each water consumer is represented by a wireless communication based network node 230. For purposes of this disclosure and claims the network node 230 comprises with physical water meter housing as well as the power, control and communications circuitry. Water enters each of the consumer premises from the supply line 115 via the a water meter housing of each node 230. Each node 230 also comprises a wireless ad hoc network transceiver unit that is operable to wirelessly transmit water meter reading information to a bridge device 210, which, in turn, passes the information to one or more server computer systems associated with the water service provider 110. In various embodiments this information may be accessible over a wide area network,

such as the Internet, by anyone having appropriate access credentials with a network browser, such as an Internet web browser.

[0025] The bridge device 210 may communicate with the one or more server computer systems (not shown) via a land line, a wireless cellular connection, a wireless 802.11x connection, WiFi, (including municipal WiFi and WiMAX), fiber optic connection, a cable connection, a twisted-pair copper phone line, a satellite connection, other known or previously unknown communications medium, or combinations of any of these.. The specific communications medium between the bridge device 210 and the one or more server computers is not critical to the various embodiments of the invention.

[0026] With continued reference to Figure 2, each node 230 acts as both a sensor and a data router. Each node may transmit a signal directly to the bridge device 210, or pass the information through one or more other network nodes 230. This feature of self-forming, self-healing ad hoc networks is known in the art and particularly advantageous to the various embodiments of the invention because the physical environment of the network 200 may change due to the presence of cars, trucks and other temporary obstructions within the network 200, affecting the propagation of radio frequency (RF) signals between nodes or between a node and the bridge device 210.

[0027] It should be appreciated that each network node 230 may, up load information to the bridge 210 as well as receive information and/or instructions from the bridge 210. That is, a network node 230 may repeat a signal destined for the bridge device 210 or one that is destined for another node 230. Techniques and algorithms for optimizing ad hoc or mesh networks are well known in the art. The various embodiments of the

invention do not depend on any particular type or brand of ad hoc or mesh network hardware.

- [0028] As will be discussed in greater detail herein, in the network 200, each network node 230 may upload information according to a predetermined schedule, such as, for example, once every hour. Also, an upload signal may be sent on demand, from the bridge device 210 to each of the network nodes 230 causing them to perform a specified task or to upload information to the bridge device 210.
- [0029] It should be appreciated that this information may include current water meter reading information as well as other information associated with the node, such as, for example, current state, power information, temperature information, water pressure information, backflow indication, and/or any other sensor-based information from one or more electronic sensors in communication with the network node 230, as will be discussed in greater detail herein.
- [0030] Referring now to Figure 3, this Figure is an illustration of a water meter pit including a remote water meter monitoring system according to various embodiments of the invention. In a conventional system, a water pit typically includes a water meter, that is comprised of a water chamber and a water measurement head that is equipped with a gauge or other meter on the top and a manually shut off valve coupling the water supply line to the customer premises. In the system depicted in Figure 3, the conventional water measurement head has been replaced with a new water measurement head, 265, according to the various embodiments of the invention. The water meter 250 may include a water chamber 260 through which water flow passes from the water supply 115 to the consumer water system 215, and a water

measurement head 265 that attaches to the water chamber 260. The measurement head 265 may also include a water counting module 270 having a flow meter, a power conversion module 280 and a control module 300. The control module 300 may also include a wireline connection 315 to an antenna 320 coupled to the meter pit cover 245. In various embodiments, the meter pit cover 245 may comprise a metal plate with a through-hole near the center allowing the antenna 320 to contact the wire 315. The antenna 320 may be encased in resin or plastic, or other material, in order to prevent breakage when the meter pit cover 245 is stepped on or driven over with a bicycle, car, or other vehicle. The fact that the meter pit cover 245 is a relatively massive, conductive object, it serves as an ideal ground plane for the antenna thereby increasing the range and performance of the wireless network according to the various embodiments of the invention. This is particularly advantageous for retrofitting the system according to the various embodiments of the invention to existing water supply networks. The only required modification to the meter pit cover 245 is making a through-hole and attaching the antenna 320.

[0031] In various embodiments, a separate manual shut-off valve 116 may be placed or left in the meter pit 240 to permit manual shut off of the water supply using conventional techniques. Alternatively, and/or in combination therewith, an electronically controllable shut off valve may be incorporated into the water chamber 260, or attached pipe, 215, thereby permitting remote water shut off, as will be discussed in greater detail herein. This electronically controllable shut off valve may comprise a spring loaded valve. In various embodiments, this valve may be manually tensioned into an open position with an external switch or valve control. A solenoid may be used

to release the shut off valve based on a remote command received by the control module 300 of the meter system 250. This may require the water service provider to send a technician or other person out to the customer premises to return the shut off valve to the pre-tensioned, open position, such as, for example, after the consumer's water service account has been made current.

[0032] In the water meter, 250, according to Figure 3, water flowing through the water chamber 260 may be counted by the water counting module 270 using a nutating valve assembly or other water volume measuring device that passes a known volume of water with each complete rotation, as is discussed in greater detail in the context of Figures 8 and 9. It should be appreciated that the various embodiments of the invention are not reliant on the particular type of water volume measuring device that is utilized. Several such mechanical devices are known in the art.

[0033] Also, in the water meter 250, mechanical energy of the pressurized water passing through the water chamber 260, may be harnessed by the power conversion module 280 to provide electrical power for all the meter system components in the measurement head 265, as is discussed in greater detail in the context of Figures 4-6.

[0034] Referring now to Figure 4, this Figure is a block circuit diagram of electrical components of a remote water meter monitoring system according to various embodiments of the invention. The electrical components include a power conversion module 280. The power conversion module 280 includes a mechanical energy converter 287 located in the water chamber 260. The energy converter 287 may include an impellor, nutating disk, blade assembly or other surface area device rotating about a drive shaft to which torque is imparted by the flow of water. This rotating

shaft may be used to energize one or more components in a power converter and supply module 290. The power converter and supply 290 may include one or more capacitors, one or more batteries, and control logic and/or switches for supplying system power to various components of the remote water meter monitoring system according to the various embodiments of the invention.

[0035] The power converter and supply 290 may output power to a power bus 295. The power bus 295 may supply power to the control module 300 as well as one or more sensors 289-1, 289-2. The power bus 295 may also supply power to a solenoid or other actuator of an electronic shut off valve 325.

[0036] The control module 300 may include a transmitter and receiver (transceiver) 305, a microprocessor 310 and one or more memory structures (not shown) storing a control program executed by the control module 300 as well as historical data from the water counting module 270 and sensors 289-1, 289-2, ..., 289-N. The sensors 289-1, 289-2, ..., 289-N, may comprise water pressure sensors, temperature sensors, water quality sensors, or other sensors. Alternatively, or in combination, the sensors 289-1, 289-2, ..., 289-N may be incorporated into a single sensor module, such as a board or chip-based sensor lab that performs a variety of diagnostic tests on the water. The sensor information may be communicated periodically or in real time to the control module 300 via communication bus 335, such as universal asynchronous receiver/transmitter (UART), serial peripheral interface (SPI) bus, inter-integrated circuit (I²C), 1-Wire or USB. Also, the control module 300 may poll the one or more sensors 289-1, 289-2, ..., 289-N periodically or on demand to obtain information corresponding to water conditions, current or past. The water counting module 270 may be electrically

coupled to the power bus 295 and communicatively coupled to the control module 300 via the data bus 335.

[0037] Referring now to Figure 5, this Figure is a block diagram of a power conversion circuit of a power conversion module for a remote water meter monitoring system according to various embodiments of the invention. As discussed briefly in the context of Figure 4, the power conversion circuit may include an energy converter 287 driven by an mechanical energy of water flow. The energy converter 287 may convert the mechanical energy of the rotating shaft into electrical energy as discussed in greater detail in the context of Figures 6 and 7. After conversion by rectifier 288, the electrical energy generated by the energy converter 287 may charge a capacitor 292 of the power converter and storage module 290, which may in turn charge a battery 294. A switch 296 may select either the capacitor 292 or the battery 294 to supply output power, such as to the power supply bus 295 shown in Figure 4. In various embodiments, the switch 296 may include decision logic for selecting either the capacitor 292 or the battery 294 based on a current state of either or both devices, or in accordance with a predetermine power management scheme stored in a memory device of the switch 296 or another memory structure external to the switch 296. In various embodiments, by placing the capacitor 292 between the energy converter 287 and the battery 294, the number of charge cycles of the battery 294 may be significantly reduced over direct charging techniques, thereby increasing the effective life of the system. Also, the switch 296 may help to insure that the battery 294 is charged by the capacitor 292 only after the battery 294 has been fully discharged to avoid battery memory problems and increase the usable life of the battery 294.

[0038] Figure 6 is a flow chart of a method of converting mechanical water flow energy into electrical energy in a remote water meter monitoring system according to various embodiments of the invention. The method begins in block 400 and proceeds to block 405 where water flowing through the meter's water chamber rotates a turbine, impeller, blade and shaft assembly, or other mechanism that rotates with the flow of water, or causes a nutating disk assembly or other volume measuring assembly to be actuated. The mechanical energy created in block 405, in the form of the shaft rotation, is used to drive a drive magnet, in block 410. In block 415, the rotation of the drive magnet creates a time varying magnetic flux density that drives a registration magnet, which, in various embodiments, may be located above the portion of the meter assembly through which water is flowing. In block 420, the rotation of the registration magnet may drive the generator, either directly, such as via a drive shaft, or indirectly, through a mechanical gear assembly. In various embodiments, this may comprise spinning a pair of magnetically coupled rotors around a set of coils as discussed in the context of Figures 7A and 7B. The time changing magnetic flux caused by the rotation of the magnetically coupled rotors induces a time varying current in the coils generating an electrical current. In block 425, the current created in block 420 is output to a charge storage circuit. In various embodiments, this may comprise communicating the current to the input of a rectifier circuit that converts alternating current (AC) to direct current (DC) that can be used to create a stored charge in the capacitor. This stored charge can be used to provide line power to the remote meter monitoring system. This stored charge can also be used to charge the battery of the power conversion module.

[0039] Figures 7A and 7B are different views of a water meter, including a power conversion generator for a remote water meter monitoring system according to various embodiments of the invention. Figure 7A shows a cut-away view of the water meter system 250, including the energy converter 287. Water enters the water chamber 260 in the direction indicated by the arrow 115A. The force of this water contacts the energy converter 287, which, in this example, includes a nutating disk assembly. It should be appreciated that another water volume measuring device may be utilized to measure the flow rate. In the exemplary embodiment depicted in Figure 7A, the nutating disk's motion drives a drive magnet 281 via a drive shaft 281A in the water chamber 260. In addition to providing a magnetic flux change detectable by the water counting module 270, the drive magnet 281 drives a registration magnet 282, located in the measurement head 265, via magnetic conduction. The registration magnet 282 rotates about an axis 282A, which also controls the rotation of the rotor elements 283 of the power conversion module 280. The power conversion module 280, also referred to herein as an generator, may comprise a pair of magnetically coupled rotors 283 that face each other having magnetic plates 284 affixed thereto, the rotation of which is driven by the registration magnet, either directly, or via a mechanical gear assembly.

[0040] In various embodiments, such as is shown in the context of Figure 7B, each rotor 283 may have a number of magnets, or magnetic plates 284 affixed thereto. For illustration purposes only, eight magnets are shown in Figure 7B. However, it should be appreciated that more or fewer magnets maybe used with the various embodiments of the invention. Also, a magnetic disk with one or more magnetic pole pairs may be utilized instead of the rotor 283 shown in Figure 7B, without departing from the spirit

or scope of the invention. In fact, the various embodiments of the invention are not tied to any particular rotor design. In the example of Figures 7A and 7B, the magnets 284 are coupled to one another with North-South poles facing each on the respective upper and lower rotors 283. Between the rotors 283 is a set of fixed conductive coils 285. In various embodiments a number of multi-turn coils may be suspended between the magnetically coupled rotors. Also, the coils 285 may be oriented so that when the rotors 283 rotate, the direction of the magnetic field passes through the center axis of each coil, thereby inducing a maximum current in each coil 285. However, it should be appreciated that other orientations may be utilized as well. Furthermore, the number of coils that may be utilized is not critical to the various embodiments of the invention.

[0041] With continued reference to Figure 7A, as the water flow drives the rotation device, this in turn rotates the drive shaft 281A. Rotation of the drive shaft causes the drive magnet 281 to rotate, either directly, or indirectly, through a gear assembly. Rotation of the drive magnet 281, in turn, may cause a registration magnet 282 to rotate via magnetic conduction. The registration magnet may rotate about its own shaft 282A. Rotation of the shaft 282A may cause a pair of magnetically coupled rotors 283 to rotate, thereby inducing a current in a series of coils 285 suspended between the facing rotors 283. This current may have a generally sinusoidal magnitude over time due to the changing pattern of magnetic flux density over the rotors' 283 rotation. The outputs of the coils 285 are supplied to the input of the power conversion and supply module 290. For example, the output of the coils 285 may be rectified and used to charge a capacitor such as the capacitor 292 in Figure 5.

[0042] Referring now to Figures 8A and 8B, these Figures are different views of a water chamber and water measurement head including a water counting system for a remote water meter monitoring system according to various embodiments of the invention. The water counting module 270 is comprised of a water counting mechanism. The water counting mechanism is configured to quantify motion of a volumetric element to a specified volume of water. This in turn can be used to determine water consumption through the meter. One example of such a volumetric element is a nutating disk based system, such as that depicted in Figure 8A. It should be appreciated that other mechanical volume meters may be used without departing from the spirit or scope of the invention. In the example of Figure 8A, water entering the water chamber 260 passes through a disk chamber 271. A nutating disk 272 wobbles about a ball and cradle type joint 273 having a center axis 274. The movement of the center axis 274 causes a shaft 281A to drive a magnet 281. Thus, each rotation of the magnet 281 may be correlated mathematically to the passage of a discrete and known volume of water. A plurality of magnetic flux detectors 277A, 277B, 277C, such as a Hall effect sensors or other sensors, attached to the cover 278 may be used to “count” the number of rotations of the drive magnet 281. Using a known conversion parameter, these counts may be used to determine flow rate and therefore water consumption.

[0043] In the exemplary system shown in Figure 8, three sensors 277A, 277B, and 277C are used. In various embodiments, a first sensor 277A may be used to selectively wake up a controller in the control module 300 from a sleep or low power state. For example, the CPU of the control module may default to a sleep state to reduce power consumption. When the first sensor 277A senses a magnetic flux change caused by

rotation of the drive magnet 281, it may send a signal to wake up the processor of the control module via an interrupt pin on the CPU, causing the CPU to prepare to begin recording water consumption.

[0044] The second sensor 277B may be used to count the number of rotations of the magnet that occur. A parameter may be stored in advance in the controller or elsewhere correlating the number of rotations per gallon of water flow. Thus, in various embodiments, each count by the sensor 277B sends a signal to the control module. Every N of these signals may cause the microprocessor to increment a water usage variable stored in memory to reflect the increased water consumption.

[0045] In various embodiments, a third sensor 277C may be incorporated to permit the system to detect a backflow condition, that is, water flowing into the supply pipe from a customer premises. This may be indicative of incorrectly connected plumbing lines within the premises, an attempt to introduce contaminants into the water supply, or even a break in the water supply line. By positioning the third sensor 277C within a predetermined number of radians with respect to the second sensor 277B, such as, for example, between $\pi/4$ and $\pi/2$ radians, it may be possible to determine the direction of water flow through the chamber 271. This may be done by comparing the measured north-south pole transitions from the second sensor 277B and the third sensor 277C for a given time period. The pattern will be different in the case of reverse motion of the magnet causing the control module to determine that back flow is occurring. The control module may increment a different counter to record backflow. Also, backflow in excess of a predetermined amount may cause a shut off valve to be automatically

engaged and/or a signal to be sent to the bridge device notifying the water supplier of the existence of the backflow condition.

- [0046] It should be appreciated that the particular type of water counting mechanism is not critical to the various embodiments of the invention. Various different sensor types may be used in conjunction with mechanical flow control devices such as a nutating disk to count the volume of water flowing through the water chamber 260, with a general goal of reducing and minimizing current drawn by the sensors.
- [0047] Referring now to Figure 9, this Figure is a flow chart of a method for measuring water flow with a remote water meter monitoring system according to various embodiments of the invention. The method begins in block 500 and proceeds to block 505 where water flows into the water flow chamber of the water meter. Generally, such flows are driven by a release of water in a customer premises such as by turning on a faucet.
- [0048] In block 510, the water flowing into the water flow chamber must pass through a rotating, nutating, or oscillating disk or other flow measuring mechanism, or flow meter, causing a shaft to rotate in accordance with a cycle of the disk. As discussed above in the context of Figure 8A, in one nutation cycle a known volume of water has flowed through the water meter. Next, in block 515, the rotation of the nutation disk, or other flow sensor causes a drive shaft to turn which in turn causes a drive magnet to rotate due to mechanical coupling of the flow sensor to the drive magnet.
- [0049] The rotation of the drive magnet generates a time changing magnetic field, that is, a change in flux density over time. In block 520, a sensor, such as a Hall effect sensor, or other flux change sensor, detects this changing flux density caused by the drive magnet's rotation. In various embodiments a non-magnetic material will be used for

the water chamber to enable the flux change to be detected through the sealed water chamber. In block 525, the sensor sends a wake-up signal to a control module to “wake up” and begin recording water flow. In block 530, another sensor counts the magnetic pole changes caused by the rotating magnet and sends a count signal to the control module. In block 535, based on a look-up value corresponding to the parameters of the meter, the control module calculates a flow rate based on the number of nutation cycles. In block 540, a water usage variable is incremented for each unit of flow, such as, for example, for each gallon.

[0050] Referring now to Figure 10, this Figure is a block diagram illustrating the various logic modules utilized in the remote water meter monitoring system according to the various embodiments of the invention. The system 600 comprises various modules which may provide functionality for facilitating rewards-based investments over a communication network.

[0051] In the example of Figure 10, a control module 610, a communication module 620, a water flow module 630, a sensor module 640 and a memory module 650 are shown. It should be appreciated that each module 610, 620, 630, 640, and 650 may be configured as a software application executing on computer hardware, an application specific integrated circuit (ASIC), a combination of hardware and software, combinations of these, or other suitable configuration. In commercially available mesh network nodes, single package solutions are available that includes a programmable microprocessor and a radio transceiver based on one or more communications protocols, such as, but not limited to, for example, the IEEE 802.15.4 standard for wireless personal area networks (WPANs). It should also be appreciated that one or

more of modules 610, 620, 630, 640, and 650 may be combined or broken into multiple additional modules. Furthermore, modules different than the exemplary ones depicted in Figure 10 may be used with the various embodiments of the invention.

- [0052] The control module 610 may comprise an embedded microprocessor, DSP, or other processor, or even a real-time kernel of an embedded operating system. The control module 610 may be programmed with an instruction set tailored to the specific application of remote water meter monitoring. For example, the control module 610 may be programmed with a set of instructions that can be received remotely, as well as a set of manufacturer/integrator defined parameters, including a schedule of operator, e.g., uploading data every hour. The control module may also include a system clock.
- [0053] The communication module 620 may comprise a two-way radio (transceiver) configured to communicate using one or more wireless communications protocols. The communication protocol may also store mesh network selection algorithms for determining an optimal network path. This type of information is typically programmed by the manufacturer of the transceiver. The communication module 620 may permit two-way communication from the system 600 to/from a bridge device, either directly, or through one or more other such systems.
- [0054] The counting module 630 may receive count signals from one or more sensors or detectors indicative of a water flow through the water flow chamber. The counting module 630 may convert these count signals, based on a stored value correlating the count signals to a particular volume of water, into a flow rate. This flow rate may then be used to increment a running total of water consumption in a particular billing unit, such as in gallons. The counting module 630 may store and increment this value in the

memory module 640. The memory module may consist of a relatively small amount of non-volatile memory that is used to store water consumption information as well as information from other sensors and components.

[0055] The sensor module 650 may receive information from one or more transducers or other sensors that are capable of sending electrical signals corresponding to physical phenomena. The sensor module 650 may include a standard or non-standard data bus connected to sensor bus adapted to interface with one or more sensors. For example, a pressure sensor may sense ambient water pressure in the pressure chamber and convert this information to an electrical signal that is received by the sensor module 650. The sensor module 650 may poll the sensors to provide information periodically. Alternatively, the sensors may send the information to the sensor module 650 periodically. The sensor module 650 may store this sensor information in the memory module 640 so that it can be uploaded by the control module 610 via the communication module 620 in accordance with an upload schedule or on demand. The sensor module 650 may communicate with individual sensors, such as sensors for pressure, temperature, water quality, etc. Alternatively, the sensor module 650 may communicate with an integrated sensor, such as a lab-on-a-chip or lab-on-a-board that is capable of performing a plurality of different water quality tests in real or near real time.

[0056] The various embodiments disclosed herein may provide a remote water meter monitoring system that reduces costs and increases accuracy of water meter reading. Also, various embodiments may provide access to water meter information remotely via network-based interface such as any computing device executing a network

browser such as an Internet web browser. Further, various embodiments may provide additional services such as remote water shut off, event-based messaging, back flow detection, and water quality monitoring. For example, the control module may be programmed to upload a message when more than a pre-determined amount of water has flowed through the meter, indicating a potential leak situation. This may cause a message to be sent to the water customer based on previously specified contact information. Additionally, the customer may be able to access his/her own account via a server system maintained by the water service provider in order to remotely monitor past and current water usage conditions at the customer's premises. Also, various embodiments may harness mechanical energy from water flowing through the meter to generate power. This power generation may eliminate the need for redundant power systems or line power. Furthermore, by using the capacitor as the primary power source and managing the charging cycles of the system batteries, may extend the life of the system, eliminate the need for battery replacement, and provide additional power for the other sensors discussed herein.

[0057] The embodiments of the present inventions are not to be limited in scope by the specific embodiments described herein. For example, although many of the embodiments disclosed herein have been described in the context of systems and methods for performing remote water meter monitoring, other embodiments, in addition to those described herein, will be apparent to those of ordinary skill in the art from the foregoing description and accompanying drawings. Thus, such modifications are intended to fall within the scope of the following appended claims. Further, although some of the embodiments of the present invention have been described herein

in the context of a particular implementation in a particular environment for a particular purpose, those of ordinary skill in the art will recognize that its usefulness is not limited thereto and that the embodiments of the present inventions can be beneficially implemented in any number of environments for any number of purposes.

Many modifications to the embodiments described above can be made.

Accordingly, the claims set forth below should be purposively construed. Also, while the foregoing description includes many details and specificities, it is to be understood that these have been included for purposes of explanation only, and are not to be interpreted as limitations of the present invention.

CLAIMS

1. A remote water meter monitoring system comprising:
 - a water meter body coupling a water supply source to a water customer;
 - a flow meter contained within the water meter body that is configured to measure a bidirectional flow rate of water through the water meter;
 - a power supply system including at least one battery, at least one capacitor, at least one rectifier circuit, and a power generator, wherein the power generator is powered by a flow of water through the water meter body;
 - a controller communicatively coupled to the water meter body and power supply system; and
 - at least one antenna connected to the controller; and

wherein the controller is a microcontroller within a wireless mote;

wherein the controller is coupled to the flow meter and configured to calculate water consumption based on signals received from the flow meter; and

wherein the controller is configured to perform steps comprising:

 - awaking from a sleep state;
 - checking battery charge levels and adjusting a charging cycle in response to available power;
 - preparing a data packet for transmitting water consumption data to a collector;
 - listening for a routing beacon from a collector;
 - transmitting the prepared data packet;
 - resetting a timer; and
 - returning to a sleep state.

2. The system according to claim 1, wherein the water meter further comprises at least one water quality sensor.
3. The system according to claim 1, wherein the controller is configured to send periodic water usage information wirelessly to the water customer.
4. The system according to claim 1, wherein the system is remotely addressable via a communications network with a network content browser.
5. The remote water meter monitoring system of claim 1, wherein the controller is configured to communicate, to a collector using a multihop mesh network protocol, the calculated water consumption in a data packet.
6. The remote water meter monitoring system of claim 1, wherein the controller is configured to control the power supply system.
7. The remote water meter monitoring system of claim 6, wherein the at least one capacitor is a super capacitor and the controller is further configured to use the super capacitor as a primary power source and the battery as a secondary power source thereby minimizing battery recharging cycles.
8. The remote water meter monitoring system of claim 1, wherein the controller is further configured to perform steps comprising:

receiving water consumption reports from another controller;

adding the received water consumption reports to a data packet including the calculated water consumption for the coupled flow meter; and

communicating the data packet to a collector.
9. The remote water meter monitoring system of claim 8, wherein the controller is further configured to include in the data packet a time stamp indicating a time when the water consumption was calculated.
10. The system according to claim 1, wherein the water meter body further comprises a shut off valve.
11. The system according to claim 10, wherein the shut off valve may be remotely activated by a wireless signal received by the system.

12. The system according to claim 10, wherein the flow sensor is adapted to detect reverse water flow and to cause the shut off valve to trigger when reverse water flow exceeds a predetermined volume.
13. The system according to claim 1, wherein the controller and antenna are configured to transmit and receive information from and send information to the system.
14. The system according to claim 13, wherein the controller and antenna are configured to send water usage information wirelessly to a bridge device.
15. The system according to claim 14, wherein sending water usage information comprises sending information either directly or through one or more other water meter monitoring systems.
16. The system according to claim 14, wherein the system is configured to receive at least one command from the wireless bridge device.
17. The system according to claim 16, wherein the at least one command is a command selected from the group consisting of a meter reading transmission request, a status request, and a water shutoff request.
18. A wireless remote water meter monitoring network comprising:
 - at least one central data processing system;
 - at least one bridge device communicatively coupled to the at least one central data processing system; and
 - a plurality of network nodes, each network node configured to perform two-way communication with the at least one bridge device, either directly or through one or more other network nodes,wherein each network node comprises:
 - a water meter housing coupling a water customer with a water supply line;
 - a flow measurement device in the water meter housing for measuring a volume of water flowing through the meter;

a power supply circuit including at least one power storage device, at least one capacitive device and a power converter, wherein the power converter is powered by water flow through the meter; and

a communication circuit comprising a mesh-type controller and an antenna, wherein the communication circuit is coupled to the flow measurement device and the power supply circuit and is adapted to perform two-way communication; and

wherein the mesh-type controller includes a microcontroller;

wherein the microcontroller is coupled to the flow meter and configured to calculate water consumption based on signals received from the flow meter; and

wherein the microcontroller is configured to perform steps comprising:

awaking from the sleep state;

checking battery charge levels and adjusting a charging cycle in response to available power;

preparing a data packet for transmitting water consumption data to a collector;

listening for a routing beacon from a collector;

transmitting the prepared data packet;

resetting a timer; and

returning to a sleep state.

19. The network according to claim 18, wherein the water meter further comprises a shut off valve operable to prevent water from flowing from the supply to the customer and configured for remote shut off via the communication circuit.
20. The network according to claim 18, wherein the antenna of the communication circuit is physically coupled to a conductive meter pit cover.

21. The wireless remote water meter monitoring network of claim 18, wherein the mesh-type controller is configured to communicate, to a collector using a multihop mesh network protocol, the calculated water consumption in a data packet.
22. The wireless remote water meter monitoring network of claim 18, wherein the at least one bridge device is configured to communicate to the at least one central data processing system via a WiFi wireless data network coupled to an Internet.
23. The wireless remote water meter monitoring network of claim 18, wherein the microcontroller is configured to control the power supply system.
24. The wireless remote water meter monitoring network of claim 23, wherein the at least one capacitor is a super capacitor and the microcontroller is further configured to use the super capacitor as a primary power source and the battery as a secondary power source thereby minimizing battery recharging cycles.
25. The wireless remote water meter monitoring network of claim 18, wherein the microcontroller is further configured to perform steps comprising:

receiving water consumption reports from another controller;

adding the received water consumption reports to a data packet including the calculated water consumption for the coupled flow meter; and

communicating the data packet to a collector.
26. The wireless remote water meter monitoring network of claim 25, wherein the microcontroller is further configured to include in the data packet a time stamp indicating a time when the water consumption was calculated.

27. A water meter, comprising:

a wireless mote element including a microcontroller and a wireless network transceiver;

a flow measurement element including

a nutating disk which displaces a volume of water with each rotation,

a drive shaft coupled to the nutating disk,

an output magnet coupled to the drive shaft; and

a rotation sensor configured to sense rotations of the output magnet and send signals to the microcontroller;

an energy harvesting element including a generator magnetically coupled to the output magnet; and

an energy storage element coupled to the generator and to the microcontroller, the energy storage element including:

a rectifier circuit;

a super capacitor coupled to the rectifier circuit and to the microcontroller;

a battery coupled to the microcontroller; and

a charging circuit coupled to the super capacitor, the battery and the microcontroller, wherein the microcontroller is configured to perform steps comprising: calculating water consumption data based on signals received from the rotation sensor; generating a data packet for transmission including the calculated water consumption data;

transmitting the generated data packet to a collector via the transceiver using a multihop mesh networking protocol; and

controlling the energy storage element by selecting one of the super capacitor or the battery for receiving power; and

wherein the microcontroller is configured with software instructions to perform further steps comprising:

awaking from a sleep state;

checking battery charge levels and adjusting a charging cycle in response to available power;

preparing a data packet for transmitting water consumption data to a collector;

listening for a routing beacon from the collector; transmitting the prepared data packet;

resetting a timer; and

returning to a sleep state.

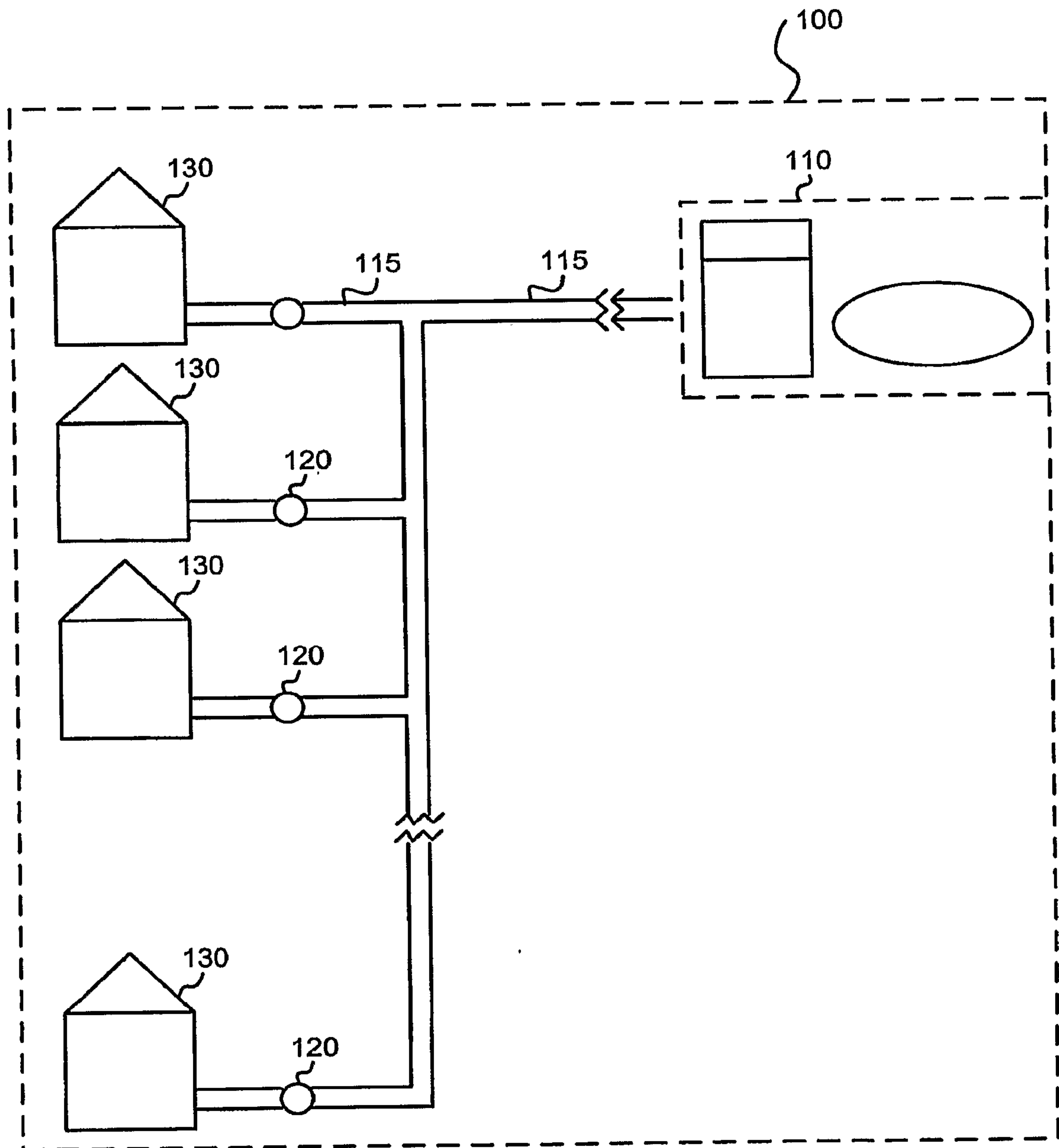
28. The water meter of claim 27, wherein the microcontroller is configured with software instructions to perform further steps comprising:

receiving data packets from another water meter, the received data packets including water consumption data and an identifier for the other water meter; and

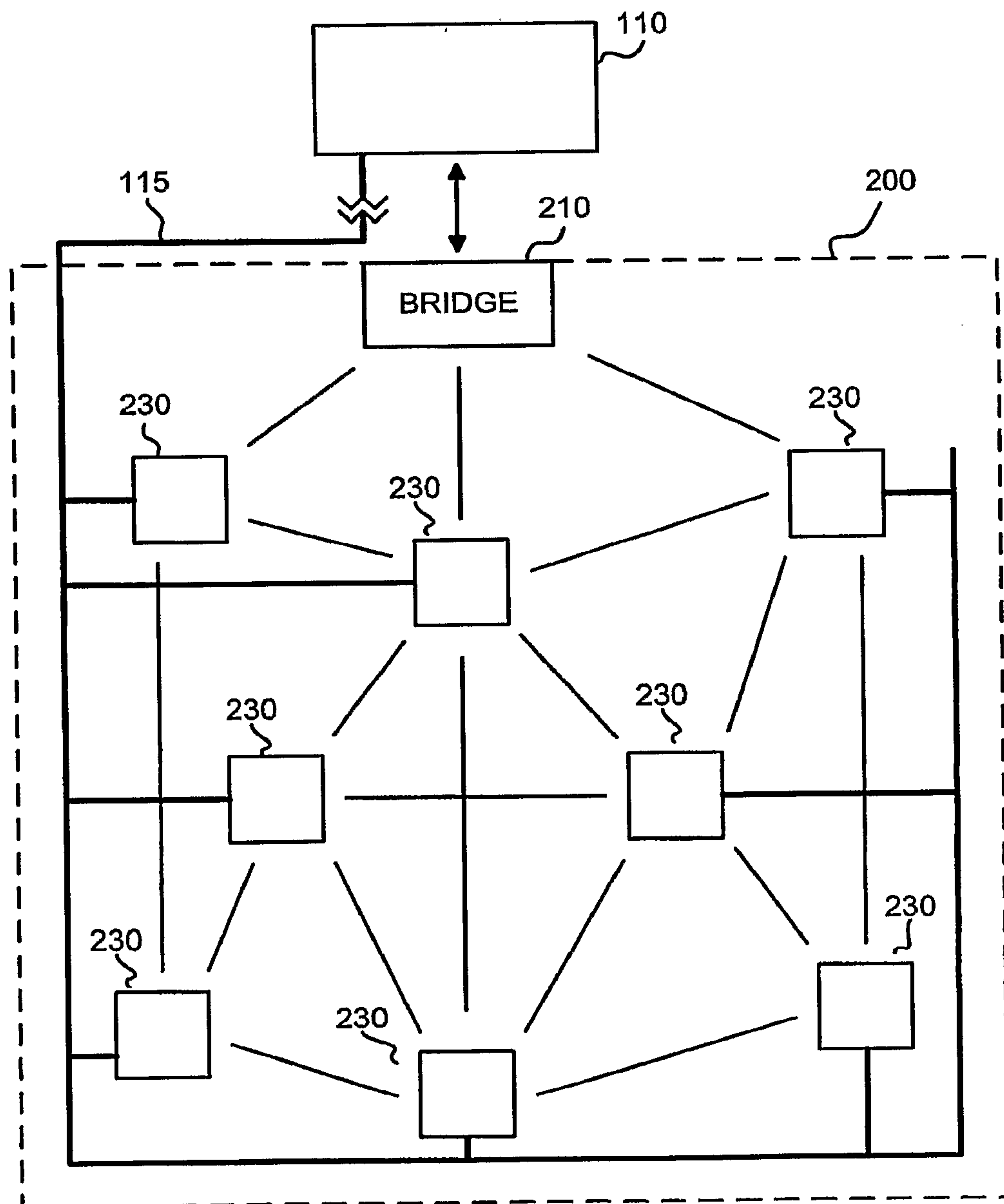
adding the received water consumption data to the generated data packet for transmission prior to transmitting the data packet to the collector.

29. The water meter of claim 28, wherein the microcontroller is configured with software instructions to perform further steps comprising including in the data packet a time stamp indicating a time when the water consumption was calculated.

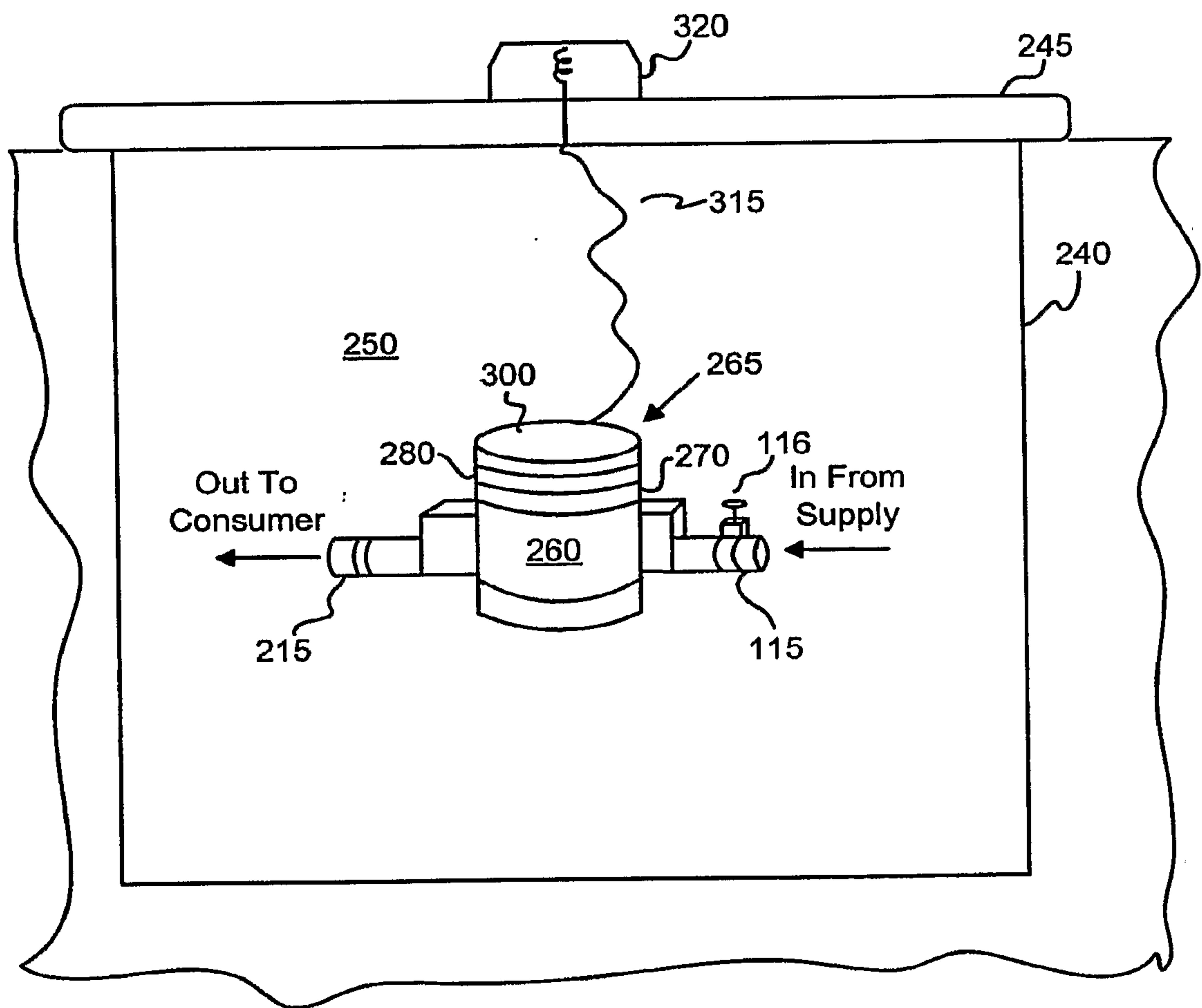
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FIGURE 1

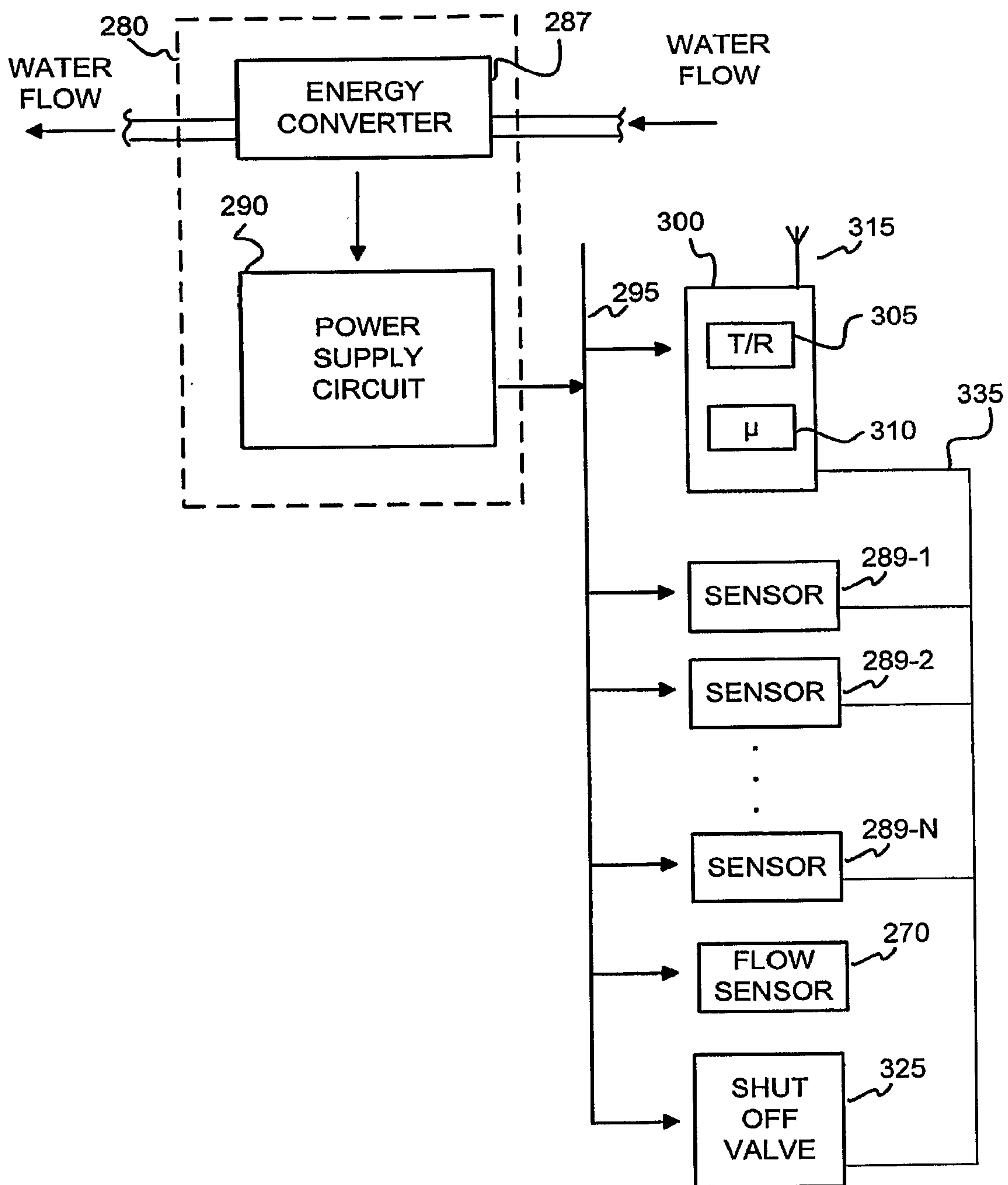
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FIGURE 2

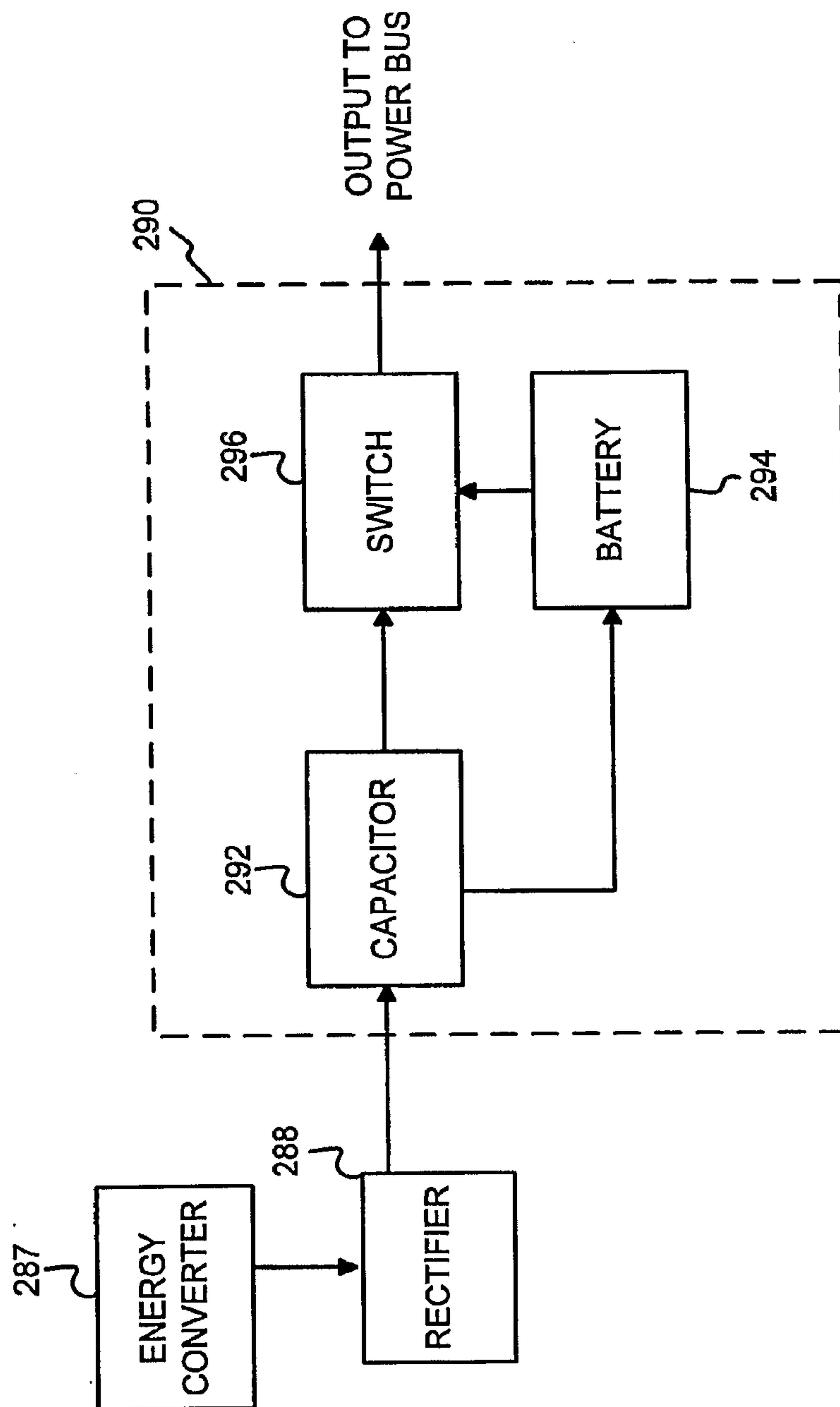
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FIGURE 3

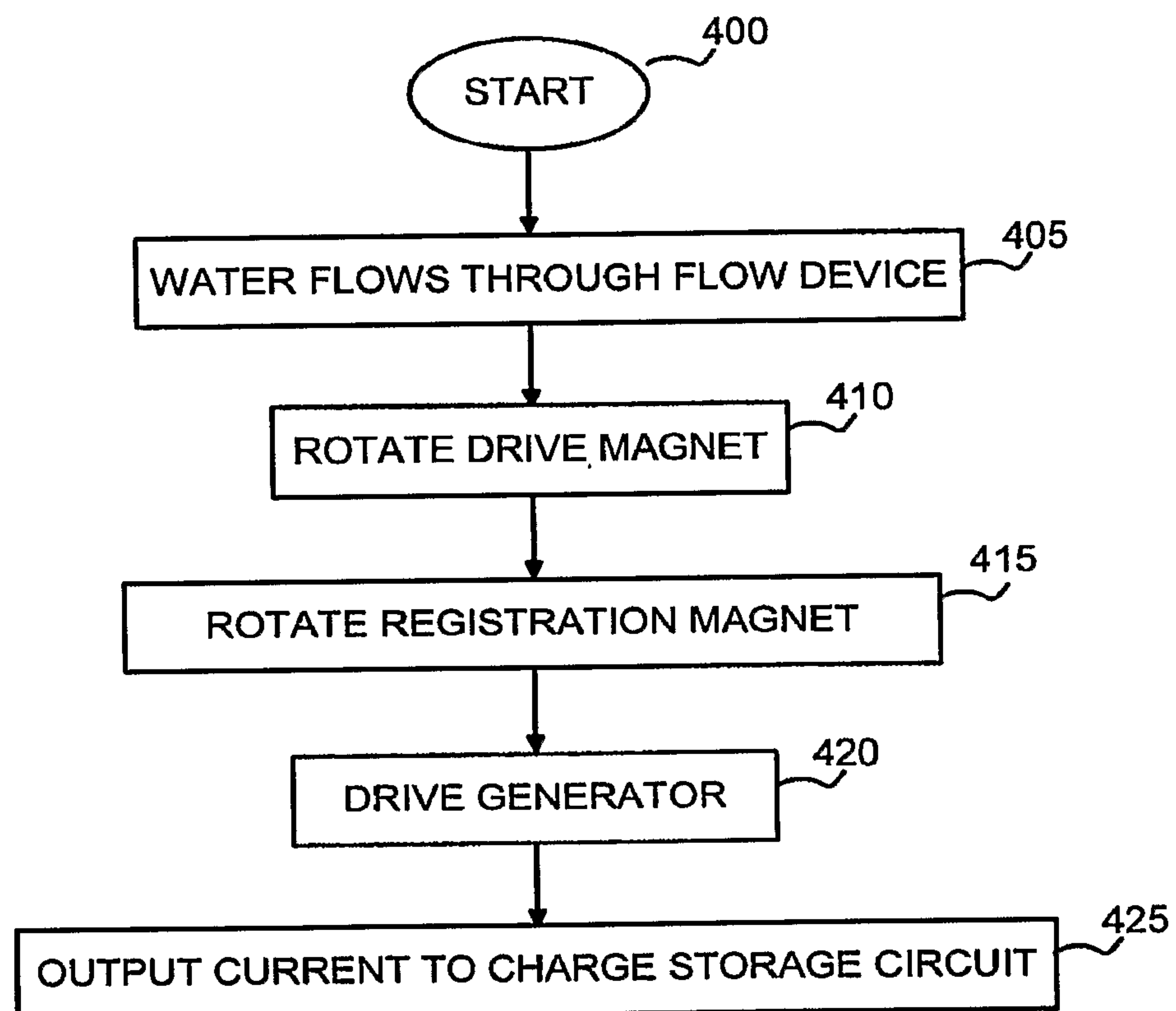
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FIGURE 4

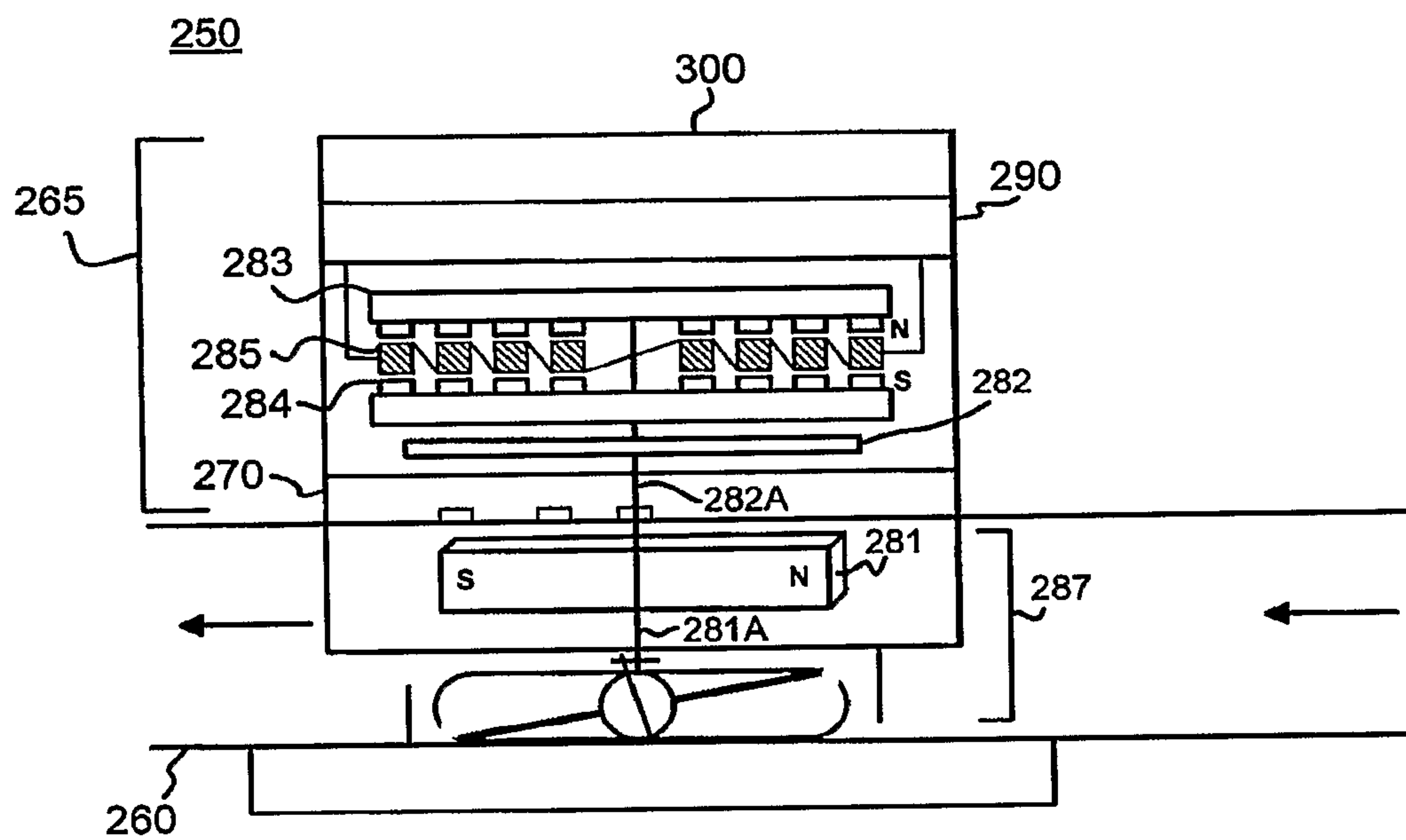
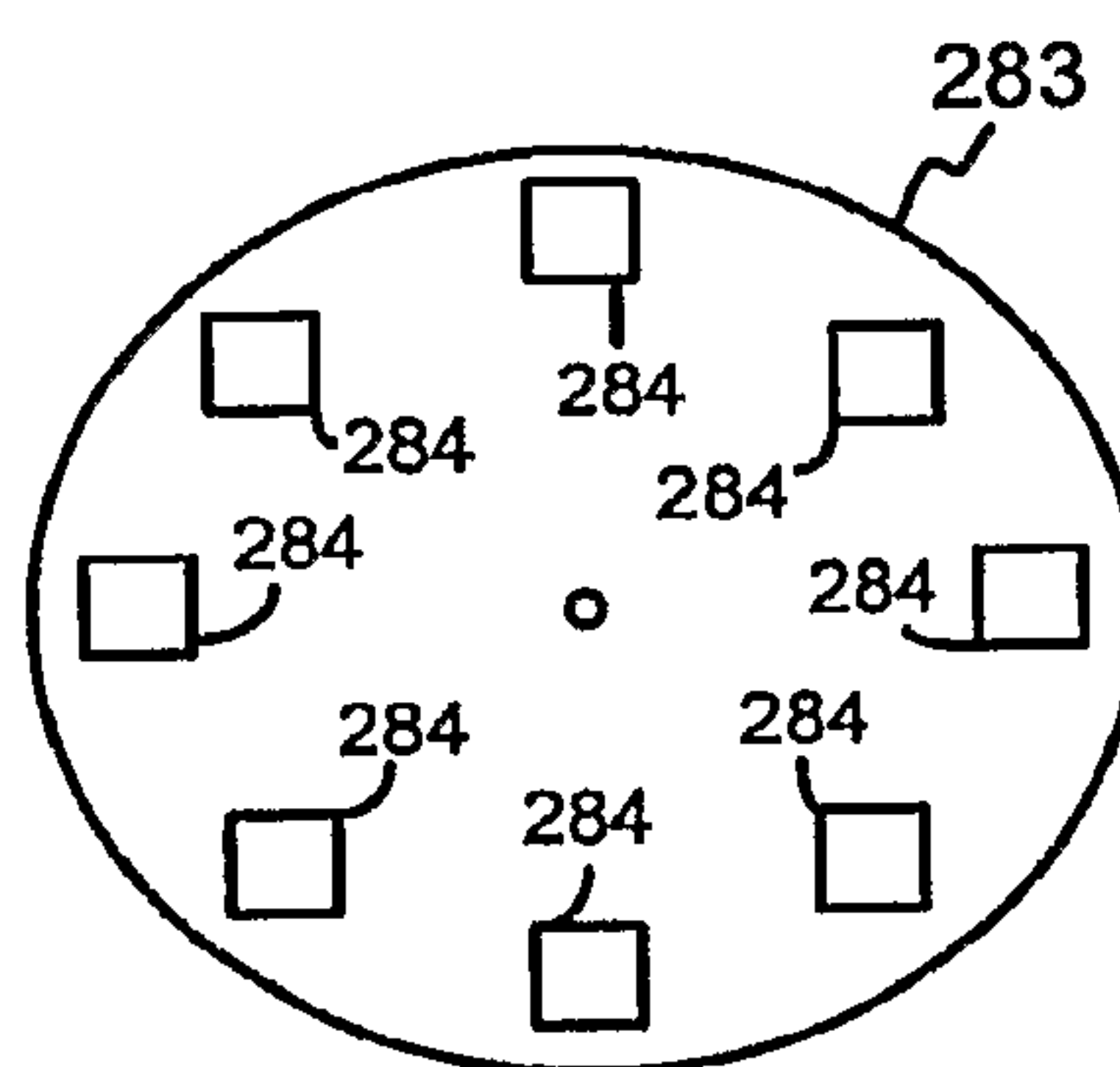
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FIGURE 5

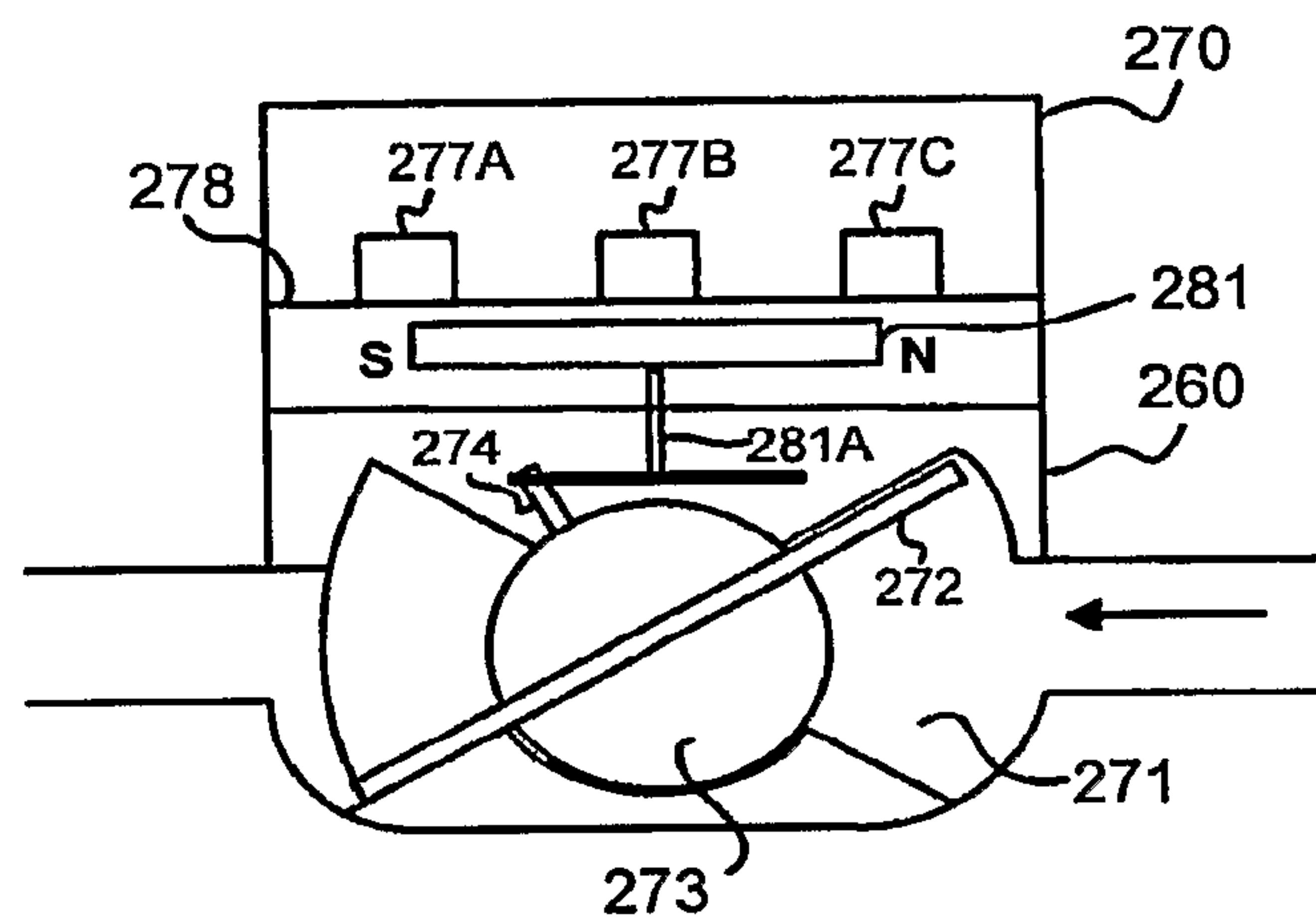
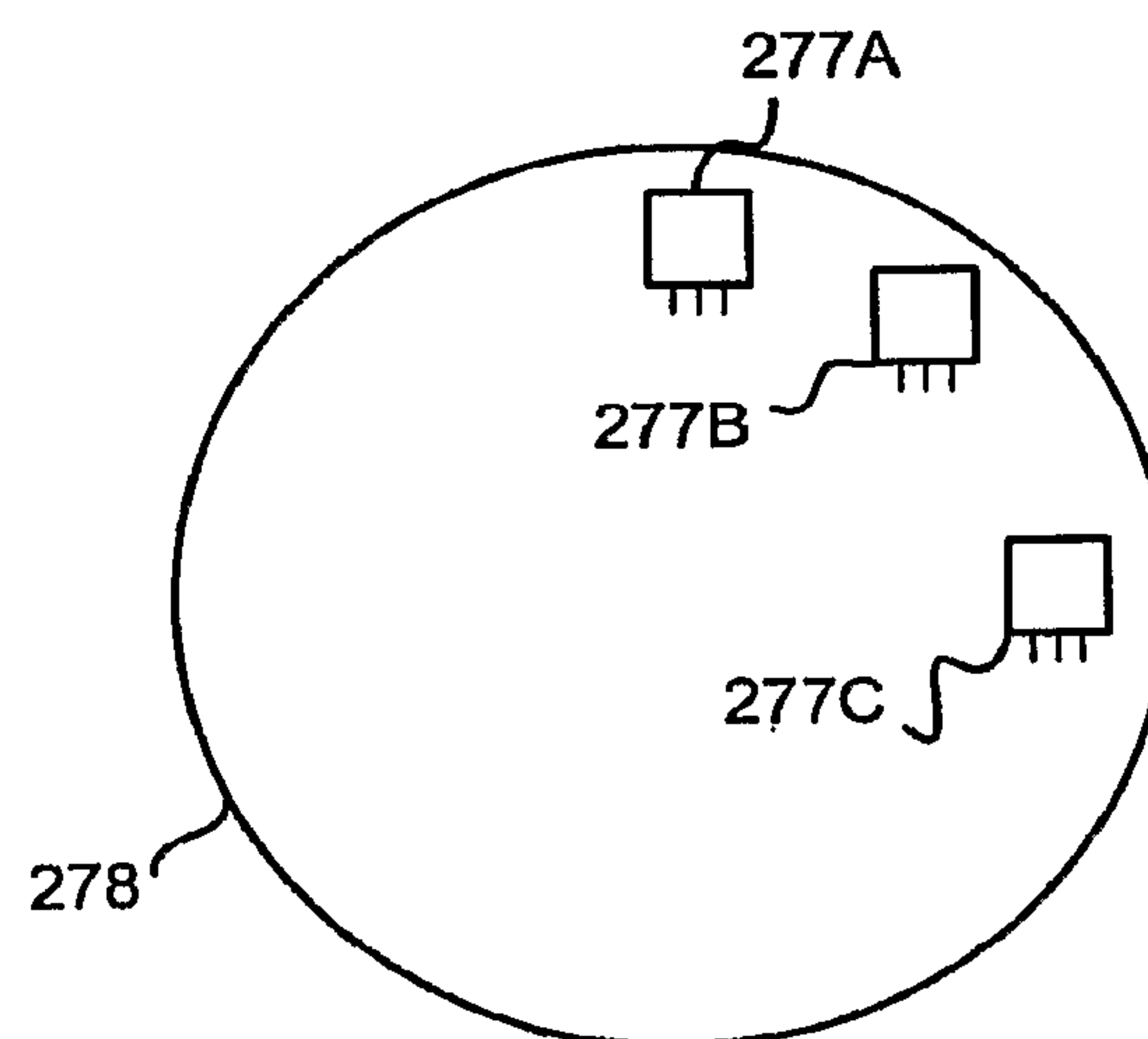
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FIGURE 6

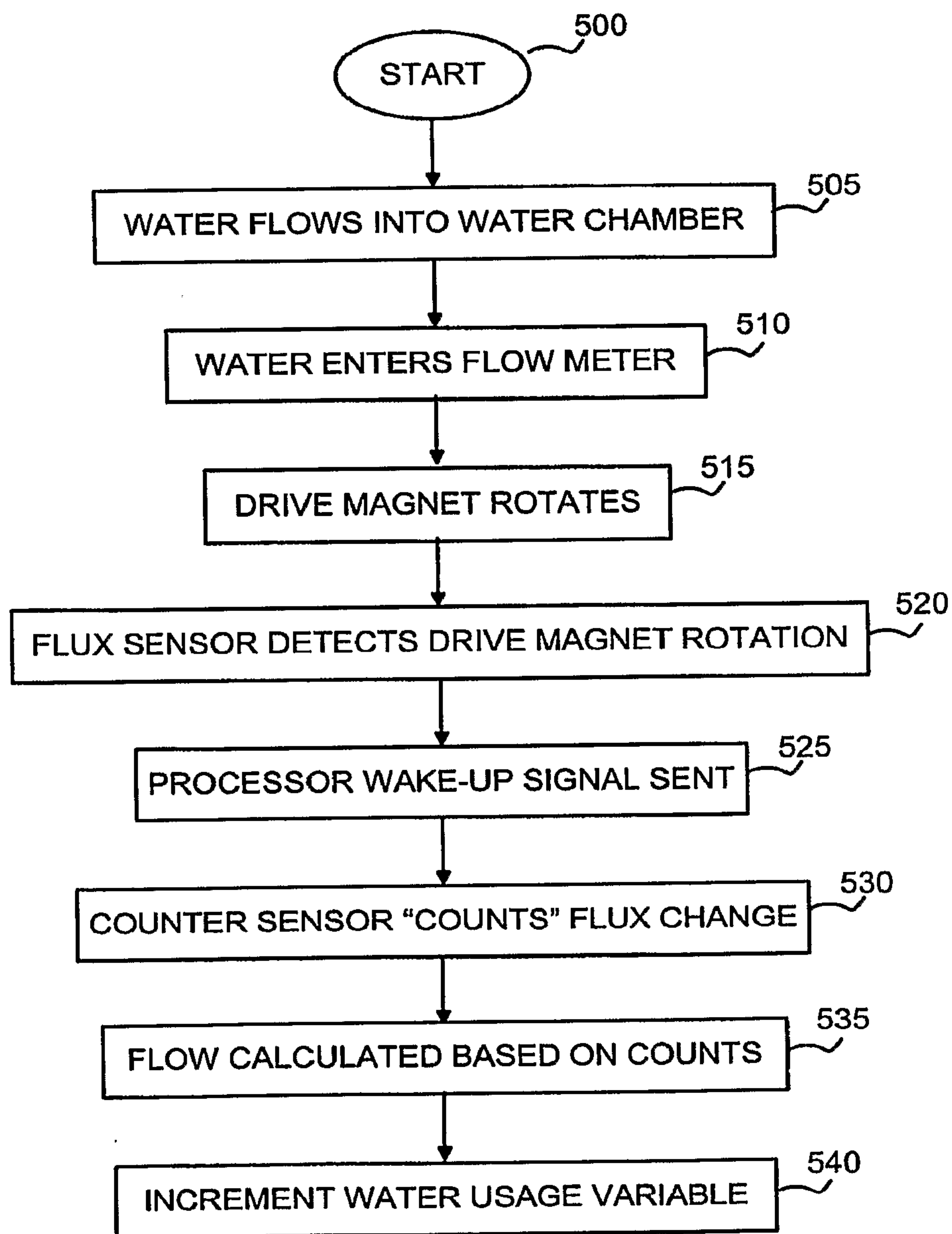
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FIGURE 7A**FIGURE 7B**

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FIGURE 8A**FIGURE 8B**

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FIGURE 9

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FIGURE 10