

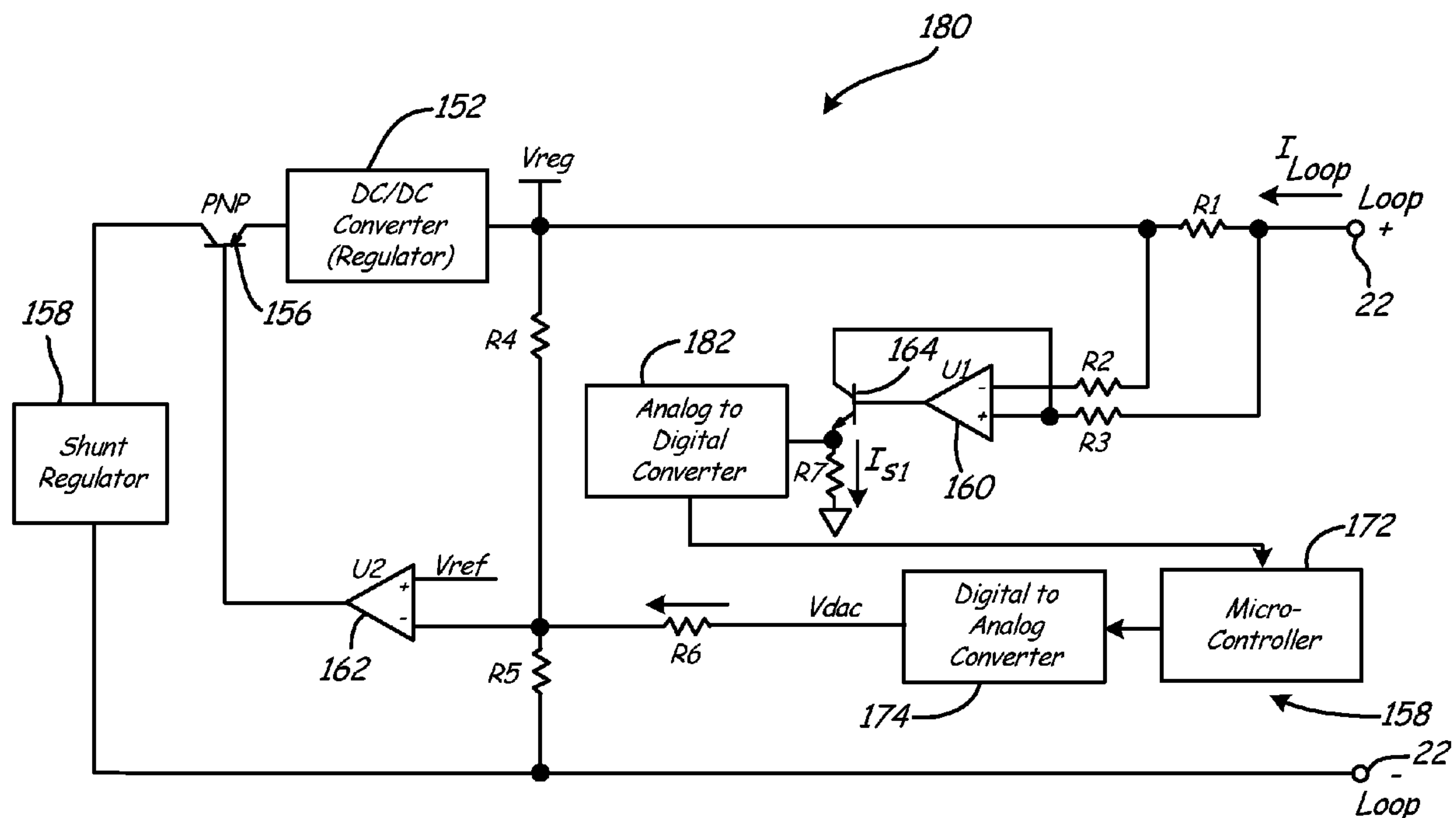


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(54) Title: RF ADAPTER FOR FIELD DEVICE WITH VARIABLE VOLTAGE DROP



(57) Abrégé/Abstract:

A wireless adapter for use in a two-wire process control loop (22) includes wireless communication circuitry and first and second terminals configured to couple in series with the two-wire process control loop (22). A regulator (152) having a regulated input is coupled to the first terminal and an output. A shunt (154) is coupled to the output of the regulator (152) and is configured to provide power to the wireless communication circuitry. A feedback circuit (158) is configured to control current flowing from the regulator (152) to the shunt (154) as a function of a loop current flowing through the two-wire process control loop (22).

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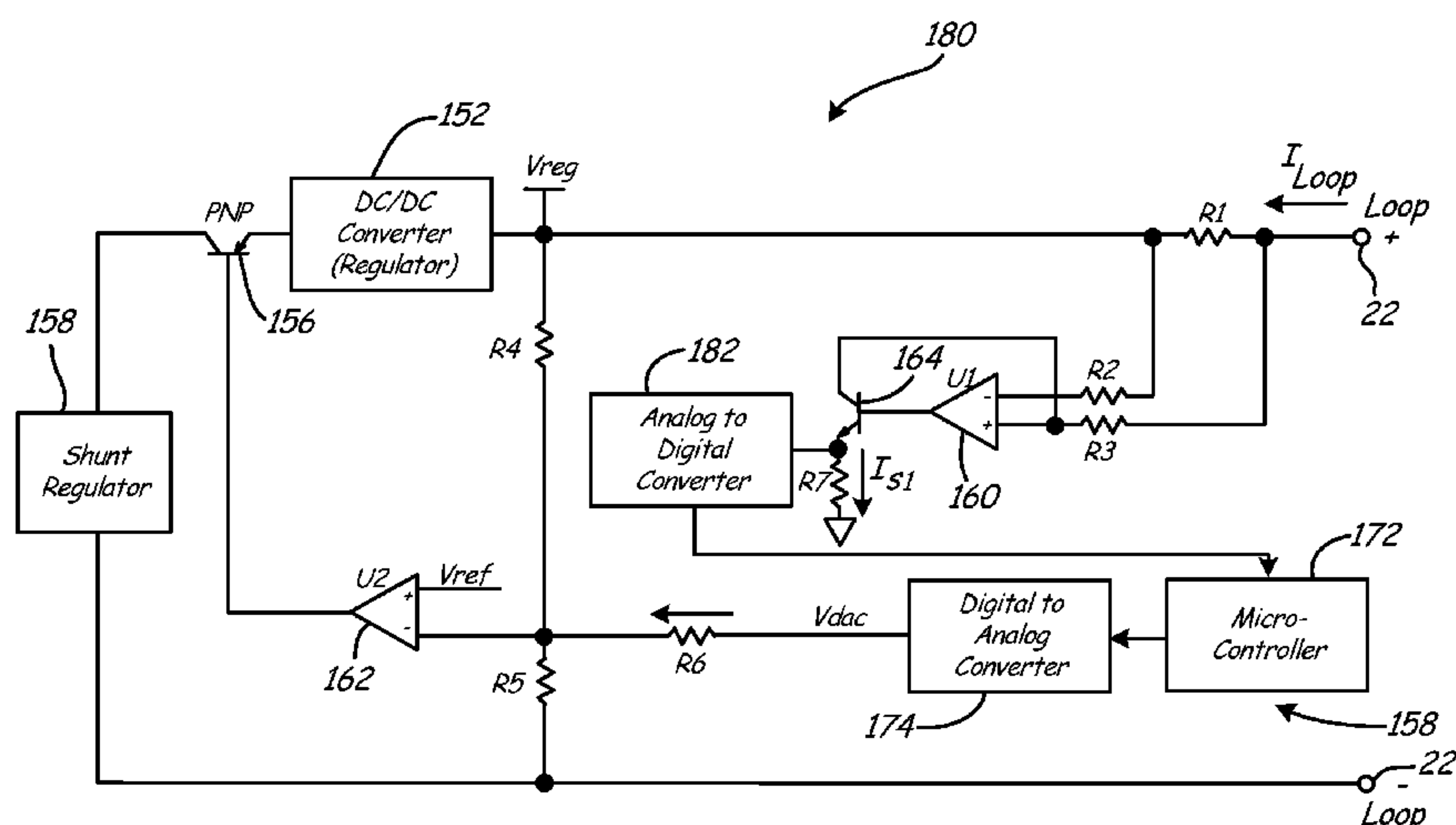


FIG. 6

(57) Abstract: A wireless adapter for use in a two-wire process control loop (22) includes wireless communication circuitry and first and second terminals configured to couple in series with the two-wire process control loop (22). A regulator (152) having a regulated input is coupled to the first terminal and an output. A shunt (154) is coupled to the output of the regulator (152) and is configured to provide power to the wireless communication circuitry. A feedback circuit (158) is configured to control current flowing from the regulator (152) to the shunt (154) as a function of a loop current flowing through the two-wire process control loop (22).

RF ADAPTER FOR FIELD DEVICE WITH VARIABLE VOLTAGE DROP

BACKGROUND OF THE INVENTION

5 The present invention relates to industrial process control or monitoring systems. More specifically, the present invention relates to field devices in such systems which are capable of Radio Frequency (RF) communication.

 In industrial settings, control systems are used to monitor and control inventories of industrial and chemical processes, and the like. Typically, the
10 control system performs these functions using field devices distributed at key locations in the industrial process and coupled to the control circuitry in the control room by a process control loop. The term "field device" refers to any device that performs a function in a distributed control or process monitoring system, including all devices currently known, or yet to be known, used in the
15 measurement, control and monitoring of industrial processes.

 Some field devices include a transducer. A transducer is understood to mean either a device that generates an output signal based on a physical input or that generates a physical output based on an input signal. Typically, a transducer transforms an input into an output having a different form. Types of transducers
20 include various analytical equipment, pressure sensors, thermistors, thermocouples, strain gauges, flow transmitters, positioners, actuators, solenoids, indicator lights, and others.

 Typically, each field device also includes communication circuitry that is used for communicating with a process control room, or other circuitry, over a
25 process control loop. In some installations, the process control loop is also used to deliver a regulated current and/or voltage to the field device for powering the field device. The process control loop also carries data, either in an analog or digital format.

 Traditionally, analog field devices have been connected to the control
30 room by two-wire process control current loops, with each device connected to

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the control room by a single two-wire control loop. Typically, a voltage differential is maintained between the two-wires within a range of voltages from 12-45 volts for analog mode and 9-50 volts for digital mode. Some analog field devices transmit a signal to the control room by modulating the current running
5 through the current loop to a current proportional to the sensed process variable. Other analog field devices can perform an action under the control of the control room by controlling the magnitude of the current through the loop. In addition to, or in the alternative, the process control loop can carry digital signals used for communication with field devices.

10 In some installations, wireless technologies have begun to be used to communicate with field devices. For example, completely wireless installations are used in which the field device uses a battery, solar cell, or other technique to obtain power without any sort of wired connection. However, the majority of field devices are hardwired to a process control room and do not use wireless
15 communication techniques. Further, in many field installations, "intrinsic safety" standards must be implemented which limit the amount of stored energy which can be discharged into the environment.

In some configurations, an RF adapter can be connected in series with the process control loop. In such a configuration, the voltage drop across
20 terminals of the adapter may affect operation of the process control loop. Further, the amount of this voltage drop affects the maximum power available to the adapter for use in operation of circuitry of the adapter.

SUMMARY OF THE INVENTION

A wireless adapter for use in a two-wire process control loop includes
25 wireless communication circuitry and first and second terminals configured to couple in series with the two-wire process control loop. A regulator having a regulator input is coupled to the first terminal and an output. Shunt circuitry is coupled to the output of the regulator and is configured to provide power to the wireless communication circuitry. A feedback circuit is configured to control

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current flowing from the regulator to the shunt circuitry as a function of a loop current flowing through the two-wire process control loop.

According to an aspect of the present invention there is provided a wireless
5 adapter for use in a two-wire process control loop configured to couple to a process field device in an industrial process control system coupled to the two-wire process control loop and provide wireless communication to the process field device, the wireless adapter comprising:

- wireless communication circuitry;
- 10 first and second loop terminals configured to couple in series with the two-wire process control loop and a process variable transmitter, the first and second loop terminals carrying a loop current therebetween, the loop current powering the wireless adapter and carrying information;
- a switching regulator having a switching regulator input coupled to the first loop
15 terminal and an output;
- a shunt circuitry coupled to the output of the switching regulator and configured to provide power to the wireless communication circuitry; and
- a feedback circuit configured to control current flowing from the switching
20 regulator to the shunt circuitry as a function of the loop current flowing through the two-wire process control loop as measured through at least one of the first and second loop terminals, wherein the feedback circuit is configured to control a voltage drop across the first and second loop terminals.

According to another aspect of the present invention there is provided a method of providing wireless communication to a process field device coupled to a two-wire
25 process control loop using a wireless adapter, the method comprising:

- coupling first and second loop terminals of the wireless adapter to the two-wire process control loop and in series with a process variable transmitter, the first and second loop terminals carrying a loop current therebetween, the loop current powering the wireless adapter and carrying information;
- 30 generating a regulated output with a regulator in the wireless adapter coupled to the first loop terminal;
- providing power to wireless communication circuitry in the wireless adapter using shunt circuitry which is coupled to the regulated output of the regulator and thereby providing power to the wireless communication circuitry;
- 35 communicating wirelessly using the wireless communication circuitry; and

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adjusting current flowing from the regulator to the shunt circuitry as a function of the loop current flowing through the two-wire process control loop as measured through at least one of the first and second loop terminals and thereby controlling a voltage drop across the first and second loop terminals.

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BRIEF DESCRIPTION OF THE DRAWINGS

Figure 1 is a simplified diagram showing an industrial process control or monitoring system which includes field devices having wireless adapters.

Figure 2 is a cross-sectional view of a field device of Figure 1 including a wireless adapter.

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Figure 3 is a wiring diagram showing a field device and wireless adapter coupled to a two-wire process control loop.

Figure 4 shows an example configuration of a variable voltage drop circuit for coupling to a two-wire process control loop.

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Figure 5 shows another example embodiment of a variable voltage drop circuit including a microcontroller.

Figure 6 is another example configuration of a variable drop circuit including a microcontroller having a feedback.

Figure 7 is a simplified circuit diagram of a variable voltage drop circuit having another example configuration.

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Figure 8 is a schematic diagram of a variable voltage drop circuit including a switch for switching between a variable and a fixed voltage drop mode.

Figure 9 is a simplified block diagram showing components of a wireless adapter having a variable voltage drop circuit.

DETAILED DESCRIPTION OF ILLUSTRATIVE EMBODIMENTS

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The present invention provides a wireless adapter for use with a field device in an industrial process control or monitoring system. The wireless adapter couples to the field device and provides the field device with wireless communication abilities. The adapter also couples to a two-wire process control loop which is used to a local location such as a

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process control room or the like. The adapter has a power supply arrangement which allows the voltage drop across terminals of the adapter to vary.

Figure 1 is a simplified block diagram of a process control and monitoring system 10. In Figure 1, field device 12 is shown coupled to process piping 14 which carries a process fluid 16. In this example, the field device 12 is illustrated as being a process variable transmitter. For example, a process variable transmitter may measure a process variable of process piping 14 such as pressure, flow rate, temperature, etc. Other types of field devices include control devices which are used to control operation of industrial process 10. However, the present invention is not limited to such a device. Field device 12 is typically located at a remote location, for example in a field of an industrial process plant and couples to a local location, such as a control room 20 through a two-wire process control loop 22. Control room 20 includes a load resistance 20A and a power source 20B. The two-wire process control loop 22 can operate in accordance with any appropriate standard or technique. A typical communications standard includes 4-20 mA process control loops in which a process variable is represented by a current level flowing through the process control loop. Another example includes digital communication techniques which may be modulated onto the analog current level of the two-wire loop, for example HART® communication standard. Other purely digital techniques are also employed including FieldBus based protocols. Typically, the field device 12 is powered using power received over the process control loop 22.

In Figure 1, a wireless adapter 30 is shown coupled to the field device 12. Wireless adapter 30 can be used for wireless communications, illustrated by arrows 32 and 34 with other devices. For example, the adapter 30 can communicate with a handheld communicator 40 or another field device 42 which includes a wireless adapter 44. Field device 42 is shown coupled to process piping 46.

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The wireless adapter 30 can communicate to other devices or components as desired. The communication can be in accordance with any appropriate protocols. One example protocol includes the formation of a mesh network in which data is passed between wireless devices in order to expand and improve the reliability of the communication system

Figure 2 shows a simplified cross-sectional view of field device 12 and wireless adapter 30 coupled to two-wire process control loop 22. In the example of a process variable transmitter, field device 12 includes a process variable sensor 50 which is connected to measurement circuitry 52 configured to measure a process variable. Transmitter circuitry 54 is configured to receive the process variable and communicate the process variable onto the two-wire process control loop 22 using known techniques. The transmitter 12 couples to the two-wire process control loop through connection block 106. The wireless adapter 30 also couples to connection block 106 and is mounted to the housing of transmitter 12, for example, through threaded connections 122 and 109. For example, the coupling is through an NPT conduit coupling 109. A similar conduit connection 109 is also used to couple to conduit 111 which carries the two-wire process control loop 22 therethrough. The chassis of the wireless adapter 30 couples to an electrical ground connector 110 of transmitter 12 through wire 108. The transmitter 12 includes a two-wire process control connection block 102 which couples to connection 112 from the wireless adapter 30. A housing 120 of the wireless adapter 30 carries an antenna 126 which couples to circuitry of the wireless adapter 30. An RF transparent end cap 124 can be sealably coupled to the housing 120 to allow transmission of RF signals therethrough. In the arrangements shown in Figure 2, five electrical connections are provided to the RF adapter which include four loop connections along with an electrical ground connection.

Figure 3 shows a simplified block diagram 150 which illustrates the electrical connections between the control room 20, the field device 12 and the

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wireless adapter 30. As illustrated in Figure 3, the wireless adapter 30 is coupled in series with the process control loop 22 through the Loop+ (also identified herein as L+) and Loop- (also identified herein as L-) connections and the field device 12 is also coupled in series with its plus power and minus power connections. HART® communication connection is used by the adapter 30 to communicate on the process control loop 22.

During operation, the adapter 30 operates using current from the 4-20 mA current flowing through the process control loop 22. As current flows through adapter 30, a small voltage drop occurs across its L+ and L- terminal connections. Preferably, the amount of that voltage drop is kept sufficiently small to ensure that there is enough voltage remaining in the process control loop 22 to provide power to the field device 12. For example, the voltage that the adapter drops may be on the order of 1.0 volts. The current in the process control loop may be as low as 3.5 mA under some conditions, and as high as 25 mA under other conditions. Therefore, in such a configuration, the power available to the adapter 30 may vary from 3.5 mA to 25 mA assuming a fixed 1.0 volt drop. Thus, the circuitry of the adapter 30 receives more operating power when the loop is operating at higher current levels.

In Figure 3, the load resistor 20A is illustrated. Load resistor 20A is used by the process control system to sense the current I_{Loop} flowing through the process control loop 22. For example, a process control system can convert a measured voltage across the load resistance to a value which is indicative of the process variable being sensed by a process variable transmitter. This variable may be related, for example, to process pressure, temperature, level, flow, or some other measured parameter. Typically, the load resistance has a value of 250 ohms. When the process control loop is carrying 4 mA, the voltage across this resistor is 1.0 volts. Similarly, when the process control loop is operating at 20 mA, the voltage drop across the resistor is 5 volts. If the voltage drop of the process variable transmitter is relatively constant as the current in the loop

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varies, there is more voltage available for the circuitry of adapter 30 when the control loop is operating at 4 mA than when the control loop is operating at 20 mA. The present invention provides a technique for varying the voltage drop across the adapter whereby a greater voltage drop is available to the adapter (and more power is available to the adapter) when the current flowing through the process control loop is at a low value. Similarly, less voltage drop is provided across the adapter when the loop is operating at a higher current level. In this way, the minimum power that the adapter 30 may obtain is raised and therefore the performance in the circuitry can be improved, for example, to increase wireless communication power.

Figure 4 is a simplified schematic diagram of variable voltage drop circuitry 150 in accordance with one example embodiment. Variable voltage drop 150 includes a DC to DC switching converter or switching regulator 152 which is coupled to a shunt regulator 154 through a transistor 156. The input of regulator 152 couples to the process control loop 22 through a resistor R_1 . The input to regulator 152 is at a voltage level V_{reg} . The base of transistor 156 is coupled to feedback circuitry 158 which comprises OpAmps 160 and 162, transistor 164 and resistors R_2 , R_3 , R_4 and R_5 .

The circuitry shown in Figure 4 senses the loop current using resistor R_1 and varies the regulated voltage at the terminals L+ and L-. OpAmp 160 operates as a current sensing amplifier and creates a voltage drop across R_3 that is equal to the voltage drop across R_1 by varying the current I_s . The relationship between I_s and the loop current is as follows:

$$I_{Loop} * R_1 = I_s * R_3 \quad \text{Eq. 1}$$

$$I_s = I_{Loop} * (R_1 / R_3) \quad \text{Eq. 2}$$

Thus, the current I_s is proportional to the loop current based upon the ratio established by R_1 and R_3 . Example values for R_1 and R_3 may be 1 ohm and 5000

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ohms, respectively. In such a configuration, I_s is equal to the loop current divided by 5000.

OpAmp 162 operates to regulate the voltage drop across L+ and L- terminals of the adapter by varying the current to the shunt regulator 154 by maintaining the voltage on its inverting input equal to the voltage on its non-inverting input. In Figure 4, the non-inverting input is coupled to a reference voltage V_{ref} , V_{reg} is the value of the voltage across the loop terminals. The reference voltage V_{ref} can be established using any appropriate technique, for example, using a band gap voltage reference. The inverting input of OpAmp 162 operates as a summing node into which current I_s flows. As the voltage across R_5 is fixed, the current through R_5 is also fixed. Therefore, as I_s varies with the loop current, the current flowing through R_4 varies in an equal but opposite manner. As I_s increases with the loop current, the current through R_4 decreases and therefore V_{reg} , the voltage across the L+ and the L- decreases. This causes a lower voltage drop across the terminals as the current in the process control loop increases. For example, the value of V_{reg} when the loop is operating at 4 mA and 20 mA can be adjusted by changing the values of R_1 , R_3 , R_4 and R_5 . If R_1 is one ohm, R_3 is 5000 ohms, R_4 is 309 kohms, R_5 is 39.1 kohms, and $V_{ref}=0.25$ volts, then V_{reg} will be 1.98 volts when the loop is operating at 4 mA and 0.99 volts when the loop is operating at 20 mA.

One feature of the configuration shown in Figure 4 is that the circuitry has a very fast response time. For example, the loop current may change from 4 to 20 mA in a relatively short period of time. It is important that if a change occurs, the voltage drop will change as quickly as possible. This is because at 20 mA loop currents, the load resistor 20A “consumes” more of the loop voltage. To ensure that the process device, such as a process variable transmitter, always has sufficient voltage for operation, the voltage drop across the adapter 30 must change rapidly in response to changes in the loop current.

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Figure 5 shows another example embodiment of variable voltage drop circuitry 170 in which the voltage drop is controlled by a microprocessor 172. Microprocessor 172 provides a digital value to digital to analog converter 174 which connects to the inverting terminal of OpAmp 162 through a resistor R_6 . In this configuration, the feedback circuitry 158 can operate in an open loop configuration such that the current I_S into the summing node of OpAmp 162 can be varied as desired. Thus, the voltage drop across the L+ and L- terminals can be varied as desired. For example, V_{reg} can be set during manufacture and modified during operation depending upon the voltage available to the adapter circuitry in a particular process control loop 22. However, one drawback to such a configuration is that the voltage available for the adapter 30 must be predetermined by either the manufacturer or operator. Further, this configuration does not take advantage of the fact that more voltage will be available to the adapter 30 when the loop current is low than when the loop current is high.

Figure 6 shows another example configuration in which the micro controller 172 receives a digital representation of the current I_{Loop} flowing through the process control loop 22. Note that similar elements have retained their numbering. In Figure 6, an analog to digital converter 182 is arranged to sense a voltage drop across a resistor R_7 which is proportional to the current I_{S1} . This value is digitized and provided to microcontroller 172. As discussed above, microcontroller 172 can then control the voltage across the L+ and L- terminals by controlling the digital to analog converter 174. One advantage of such configuration is that the microcontroller 172 is able to receive information related to the loop current and this information can be communicated, for example using HART® communication, to an operator over the process control loop 22 or through the wireless interface. However, the additional analog to digital and digital to analog converters, as well as the decreased speed of the system, provide disadvantages.

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In the above circuitry configurations there are situations which may cause the circuitry to reset. For example, if the circuitry is set such that V_{reg} is approximately 2.25 volts when the loop current is operating at 3.5 mA, and decreases to approximately 1.0 volts when the loop current increases to 25 mA.

5 A failure in the loop may cause the loop current to increase beyond 25 mA. If this happens, the voltage V_{reg} will continue to increase and approach the value of V_{ref} which is coupled to OpAmp 162. If the DC to DC switching regulator 152 requires a voltage input which is greater than V_{ref} for operation, the output from the DC to DC converter will decrease and potentially cause the microprocessor

10 or wireless communication circuitry in the adapter 30 to reset. If the wireless communication circuitry resets, the adapter 30 will disconnect from the wireless communication network and require a rejoining process once the circuitry is stable. During such an occurrence, it is not possible to communicate wirelessly with the device. If a mesh network is employed, the network may need to

15 reconfigure itself. Further, the OpAmp 160 must be able to function with its input terminals operating near the upper power supply voltage. For example, the supply voltage may be approximately 2.35 volts. It may be desired that the voltage across the L+ and L- terminals may be as high as 2.5 volts. In such a situation, the input terminals of OpAmp 160 may exceed the positive power

20 supply voltage.

Figure 7 is a schematic diagram of variable voltage drop circuitry 190 which is configured such that the circuitry does not cause the loop terminal voltage to drop below the operating range of the switching regulator 152 and does not require that the current sensing OpAmp be operated near its positive

25 power supply voltage. In Figure 7, similar elements have retained their numbering. However, note that in Figure 7, R_3 has a new location at the output of OpAmp 160. Further, R_1 is connected in series with the negative loop terminal. In this configuration, OpAmp 160 creates an output voltage that is proportional to the current flowing through R_1 . The varying voltage of this

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output causes a varying current through resistor R_3 , which in turn causes an equally varying current through resistor R_4 . This varying current through R_4 causes V_{reg} to also change. The relationship between loop current and V_{reg} is as follows:

5

$$I_{Loop} * R_1 = I_b * R_b \quad \text{Eq. 3}$$

$$I_{Loop} = I_b * R_b / R_1 \quad \text{Eq. 4}$$

$$V_{out} = I_b * R_f + I_b * R_b + I_{Loop} * R_f \quad \text{Eq. 5}$$

10 Now, substituting Equation 4 into Equation 5:

$$V_{out} = I_{Loop} * (R_1 / R_b) * (R_f + R_b) + I_{Loop} * R_f \quad \text{Eq. 6}$$

$$I_S = (V_{out} - V_{ref}) / R_3 \quad \text{Eq. 7}$$

15

$$V_{reg} = (I_S + I_5) * R_4 + V_{ref} \quad \text{Eq. 8}$$

Equation 6 above shows that the output of OpAmp 160 (V_{out}) is directly proportional to the current flowing through the adapter, I_{Loop} . As I_{Loop} increases, I_S increases due to V_{out} increasing as shown in the relationships set forth in Equation 7. As I_S increases, the current flowing through R_4 must decrease as the current flowing through R_5 is constant because V_{ref} is constant. As the current flowing R_4 decreases, the voltage across R_4 decreases and therefore V_{reg} decreases. Thus, the equations illustrate that as the loop current increases the

20 voltage across the adapter loop terminals (V_{reg}) decreases.

25

The circuitry of Figure 7 overcomes the first drawback discussed above as the input terminals of OpAmp 160 operate slightly below the negative power supply of voltage of the device. One example OpAmp is the LMP2231 available from National Semiconductor which is capable of operating with its input

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terminal voltages below the negative power supply voltage. The device can also operate using a relatively low power supply voltage and supply current. The device has a low input offset voltage as well as low input offset voltage drift due to ambient temperature changes.

5 If the resistor values of the circuitry shown in Figure 7 are selected correctly, the second shortcoming discussed above can be overcome. As the output V_{out} of OpAmp 160 saturates at or near the positive power supply voltage, the resistors values may be selected such that when the loop current reaches 25 mA, the output V_{out} can no longer increase. If the output of OpAmp
10 160 does not increase further, the value of V_{reg} will similarly decrease no further. Therefore, these circuits can be arranged such that V_{reg} reaches a minimum value when I_{Loop} reaches 25 mA which will not be exceeded. If I_{Loop} increases beyond 25 mA, V_{reg} will maintain this minimum voltage and thus the DC to DC converter 152 will always have sufficient voltage for operation. This
15 will ensure that the microprocessor and wireless communication circuitry of the adapter 30 will continue operating even if the loop current has an abnormally high value.

Further, similar to some of the circuits discussed above, the circuit 190 shown in Figure 7 has a relatively fast response time. One additional advantage
20 of the configuration shown in Figure 7 is that the circuitry may be easily modified to provide a fixed voltage drop. Figure 8 shows an example variable or fixed voltage drop circuit 192. Circuit 192 is similar to circuit 190 shown in Figure 7 except that a switch 194 is included in the path of current I_s . When switch 194 is opened, I_s becomes zero and the voltage across R4 no longer
25 changes such that V_{reg} no longer changes. Thus, the circuit of Figure 8 is switchable between a variable voltage drop circuit and a fixed voltage drop circuit. One example switch which may be employed is the ADG842 available from Analog Devices. This switch is normally closed so that the circuit operates normally in the variable voltage drop mode. The switch may be controlled by

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the microcontroller in the adapter and changed upon receiving the appropriate wired or wireless command.

Suitable values for the components shown in Figure 8 are as follows:

5 Table 1

R_f = resistance of fuse (~2 ohms)
R_1 = 5 ohms
R_b = 12.1 kohms
R_F = 232 kohms
R_3 = 332 Kohms
R_4 = 187 Kohms
R_5 = 35.7 kohms
160 = LMP2231 (National Semiconductor)
162 = TC1035 (Microchip Technology Inc.)
V_{ref} = 0.34 volts
DC/DC converter = TPS61070 (Texas Instruments)

Figure 9 is a schematic diagram of circuitry of adapter 30 shown in block diagram format including variable loop voltage drop circuitry 190. Adapter 30 includes a microprocessor 200 having an internal memory which is configured to control operation of the device and communicate using, for example, the HART® communication protocol over the process control loop 22 using a HART® modem 202. A radio communication module 204 is provided for wireless communications using an antenna 206. The microprocessor 200 is powered by an LDO (Low Dropout Regulator) 210 which is coupled to the output from DC to DC converter 152. A reset circuit 212 is provided to reset microprocessor 200 should the voltage drop below a desired operating point. In this configuration, the shunt regulator 154 is illustrated as a number of

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components. A capacitor 214 is shown having a value of 10,000 μ F which is used to store power for use in operating radio module 204. A voltage clamp/current shunt 216 is provided to set the maximum voltage across capacitor 214. A DC to DC switching regulator 218 is used to provide a regulated three volt output to LDO 220 which provides power to the radio module 204. A reset circuit 222 is provided to reset the radio module 204 if the voltage drops below a desired threshold. A level shift circuit 226 is provided for coupling communication signals between the radio module 204 and the microprocessor 200. HART® modem 202 receives HART® communication signals from the HART® connection using HART® receive circuit 230 and transmits HART® communication signals using HART® transmit circuit 232. These circuits are coupled to the HART® terminal through a capacitor 234. In Figure 9, a variable voltage network 240 is provided and couples between the + Loop terminal and the output of OpAmp 160. The variable voltage network 240 comprises resistors R_3 , R_4 and R_5 shown in Figure 7. (Note that in this simplified illustration resistors R_b , R_f and R_F are not shown).

The present invention provides a field device and/or adapter configured to couple to a process control loop which further includes a wireless communication module for one way or bi-directional wireless communication. The wireless communication module can transmit and/or receive an RF signal from a remote device or location. The module can be directly powered with power received from the two-wire process control loop, or can be powered with power received from the process control loop and stored for subsequent use. The module can be a removable module in which the module need only couple to those field devices in which wireless communication is desired. The module can be configured as an adapter to retrofit an existing transmitter.

The above configuration provides an adapter which enables wireless communication with a process variable transmitter. The circuitry can be configured to operate from power which is already available to the process

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variable transmitter. Increased efficiency can be obtained by placing the energy storage element as a shunt element in a loop shunt regulator. A "step up" regulator can be provided which is part of the feedback circuit for the shunt regulator control. This configuration increases efficiency while reducing the number of components required. The voltage drop across the device can be varied as desired.

The term "field device" as used herein can be any device which is used in a process control monitoring system and does not necessarily require placement in the "field." The device can be located anywhere in the process control system including in a control room or control circuitry. The terminals used to connect to the process control loop refer to any electrical connection and may not comprise physical or discrete terminals. Any appropriate radio frequency communication circuitry can be used as desired as can any appropriate communication protocol, frequency or communication technique. The power supply circuitry is configured as desired and is not limited to the configurations set forth herein. In some embodiments, the field device includes an address which can be included in any RF transmissions such that the device can be identified. Similarly, such an address can be used to determine if a received signal is intended for that particular device. However, in other embodiments, no address is utilized and data is simply transmitted from the wireless communication circuitry without any addressing information. In such a configuration, if receipt of data is desired, any received data may not include addressing information. In some embodiments, this may be acceptable. In others, other addressing techniques or identification techniques can be used such as assigning a particular frequency or communication protocol to a particular device, assigning a particular time slot or period to a particular device or other techniques. Any appropriate communication protocol and/or networking technique can be employed including token-based techniques in which a token is

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handed off between devices to thereby allow transmission or reception for the particular device.

Although the present invention has been described with reference to preferred embodiments, workers skilled in the art will recognize that changes may be made in form and detail without departing from the scope of the invention. As used herein, Radio Frequency (RF) can comprise electromagnetic transmissions of any frequency and is not limited to a particular group of frequencies, range of frequencies or any other limitation. Any communication protocol can be used, as desired, including IEEE 802.11b, 802.15.4, or other protocols, including proprietary protocols as well as standardized protocols such as the wireless HART® communication protocol. In the discussion above, the wireless adapter provides a digital signal communication connection for coupling to the two-wire process control loop and, in some embodiments, communicating in accordance with the HART® communication protocol. The adapter can be configured to mount externally to a process control transmitter, for example, through a threaded coupling to NPT fittings in the transmitter housing. In the above discussion, when a capacitor which is not a super capacitor is employed, for example on the order of 10,000 μ F is used to store energy, the intrinsic safety circuitry of the present invention operates to limit the maximum available energy which is entering the circuitry of the adapter. This is because in accordance with intrinsic safety standard, the voltage across a given capacitance must be kept below a level that could result in the capacitance creating a spark if an instantaneous short circuit occurred. Thus, in the above discussion, by limiting the maximum circuit voltage which can be received by circuitry in the adapter, the size of the capacitance can be increased. As used herein, "shunt regulator" is not limited to the particular configurations shown and may comprise any type of circuitry in the adapter in which current is ultimately (and substantially) shunted back to the two-wire process control loop. More generally, this can comprise shunt circuitry which is used to power

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wireless communication circuitry. Current flowing through the shunt circuitry is returned (shunted) to the two-wire process control loop. Although the present invention has been described with reference to preferred embodiments, workers skilled in the art will recognize that changes may be made in form and detail without departing from the scope
5 of the invention.

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The embodiments of the invention in which an exclusive property or privilege is claimed are defined as follows:

1. A wireless adapter for use in a two-wire process control loop configured to couple to a process field device in an industrial process control system coupled to the two-wire process control loop and provide wireless communication to the process field device, the wireless adapter comprising:

wireless communication circuitry;

first and second loop terminals configured to couple in series with the two-wire process control loop and a process variable transmitter, the first and second loop terminals carrying a loop current therebetween, the loop current powering the wireless adapter and carrying information;

a switching regulator having a switching regulator input coupled to the first loop terminal and an output;

a shunt circuitry coupled to the output of the switching regulator and configured to provide power to the wireless communication circuitry; and

a feedback circuit configured to control current flowing from the switching regulator to the shunt circuitry as a function of the loop current flowing through the two-wire process control loop as measured through at least one of the first and second loop terminals, wherein the feedback circuit is configured to control a voltage drop across the first and second loop terminals.

2. The wireless adapter of claim 1 wherein the shunt circuitry includes a voltage regulator.

3. The wireless adapter of claim 2 wherein the voltage regulator comprises a DC to DC converter.

4. The wireless adapter of any one of claims 1 to 3 wherein the shunt circuitry includes a capacitor configured to receive charge from the two-wire process control loop and provide power to the wireless communication circuitry.

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5. The wireless adapter of claim 1 wherein the switching regulator comprises a DC to DC regulator.
6. The wireless adapter of claim 1 wherein the feedback circuitry includes an input which is used to control the voltage drop across the first and second loop terminals.
7. The wireless adapter of claim 1 wherein the feedback circuit includes a transistor which is used to couple the shunt circuitry to the switching regulator.
8. The wireless adapter of claim 7 wherein the feedback circuit controls operation of the transistor to thereby control a voltage drop across the first and second loop terminals.
9. The wireless adapter of claim 1 wherein the feedback circuitry measures a current flowing from the two-wire process control loop and through the switching regulator.
10. The wireless adapter of claim 9 wherein the feedback circuitry controls power delivered to the shunt circuitry as a function of a sensed current.
11. The wireless adapter of claim 6 wherein the input is coupled to a microcontroller.
12. The wireless adapter of claim 1 wherein one of the first and second loop terminals couples to the process field device, and wherein the wireless adapter further includes a communication terminal which couples to the process field device and is used to communicate with the process field device.
13. The wireless adapter of any one of claims 1 to 12 wherein the two-wire process control loop comprises a 4-20 mA current loop.
14. The wireless adapter of claim 1 wherein the feedback circuitry is switchable between a first mode of operation in which a voltage drop across the first and second loop terminals is variable and a second mode of operation in which a voltage drop across the first and second terminals is fixed.

15. A method of providing wireless communication to a process field device coupled to a two-wire process control loop using a wireless adapter, the method comprising:

coupling first and second loop terminals of the wireless adapter to the two-wire process control loop and in series with a process variable transmitter, the first and second loop terminals carrying a loop current therebetween, the loop current powering the wireless adapter and carrying information;

generating a regulated output with a regulator in the wireless adapter coupled to the first loop terminal;

providing power to wireless communication circuitry in the wireless adapter using shunt circuitry which is coupled to the regulated output of the regulator and thereby providing power to the wireless communication circuitry;

communicating wirelessly using the wireless communication circuitry; and

adjusting current flowing from the regulator to the shunt circuitry as a function of the loop current flowing through the two-wire process control loop as measured through at least one of the first and second loop terminals and thereby controlling a voltage drop across the first and second loop terminals.

16. The method of claim 15 wherein the regulator comprises a switching voltage regulator.

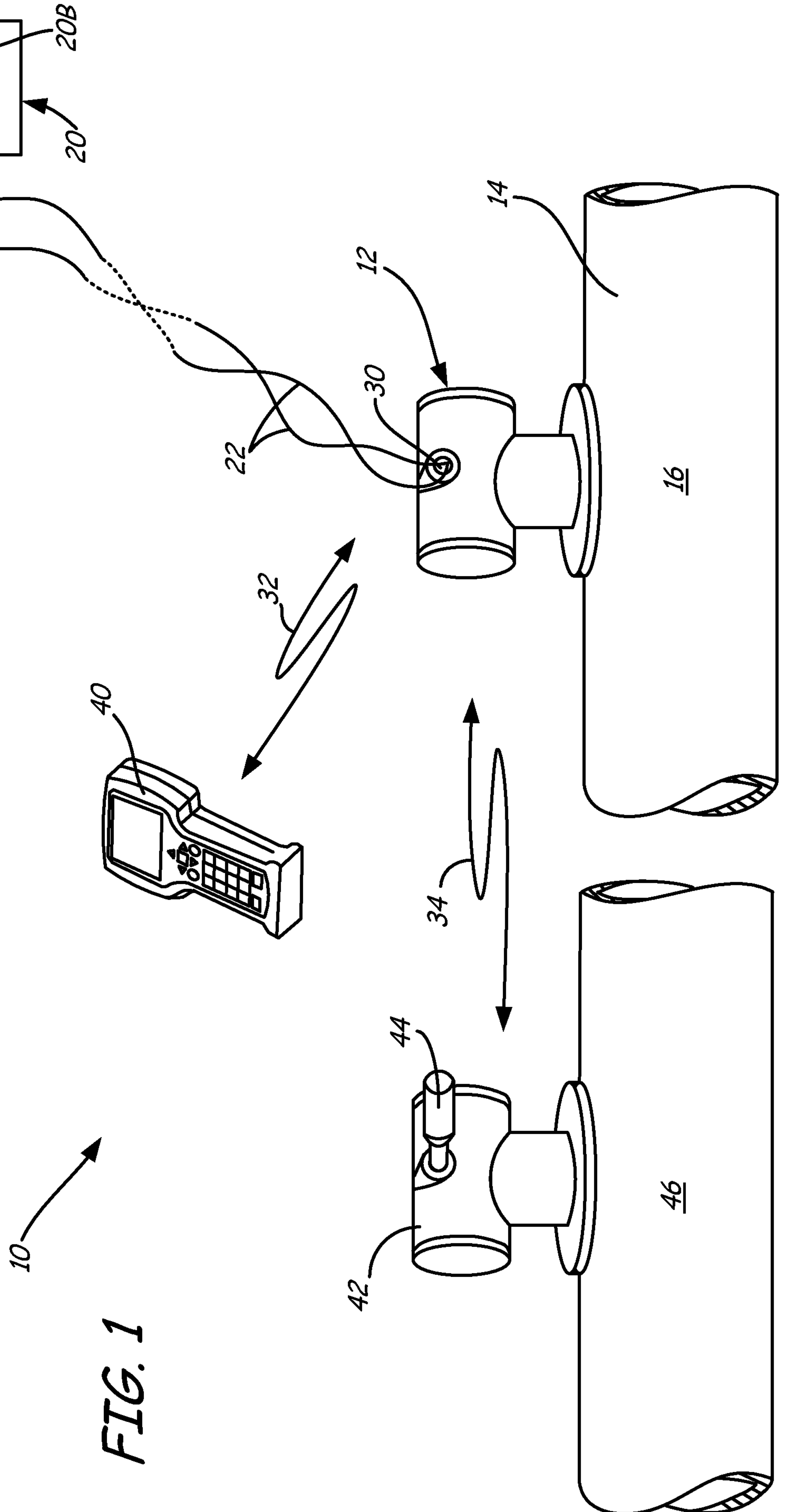
17. The method of claim 15 further including charging a capacitor with charge from the two-wire process control loop.

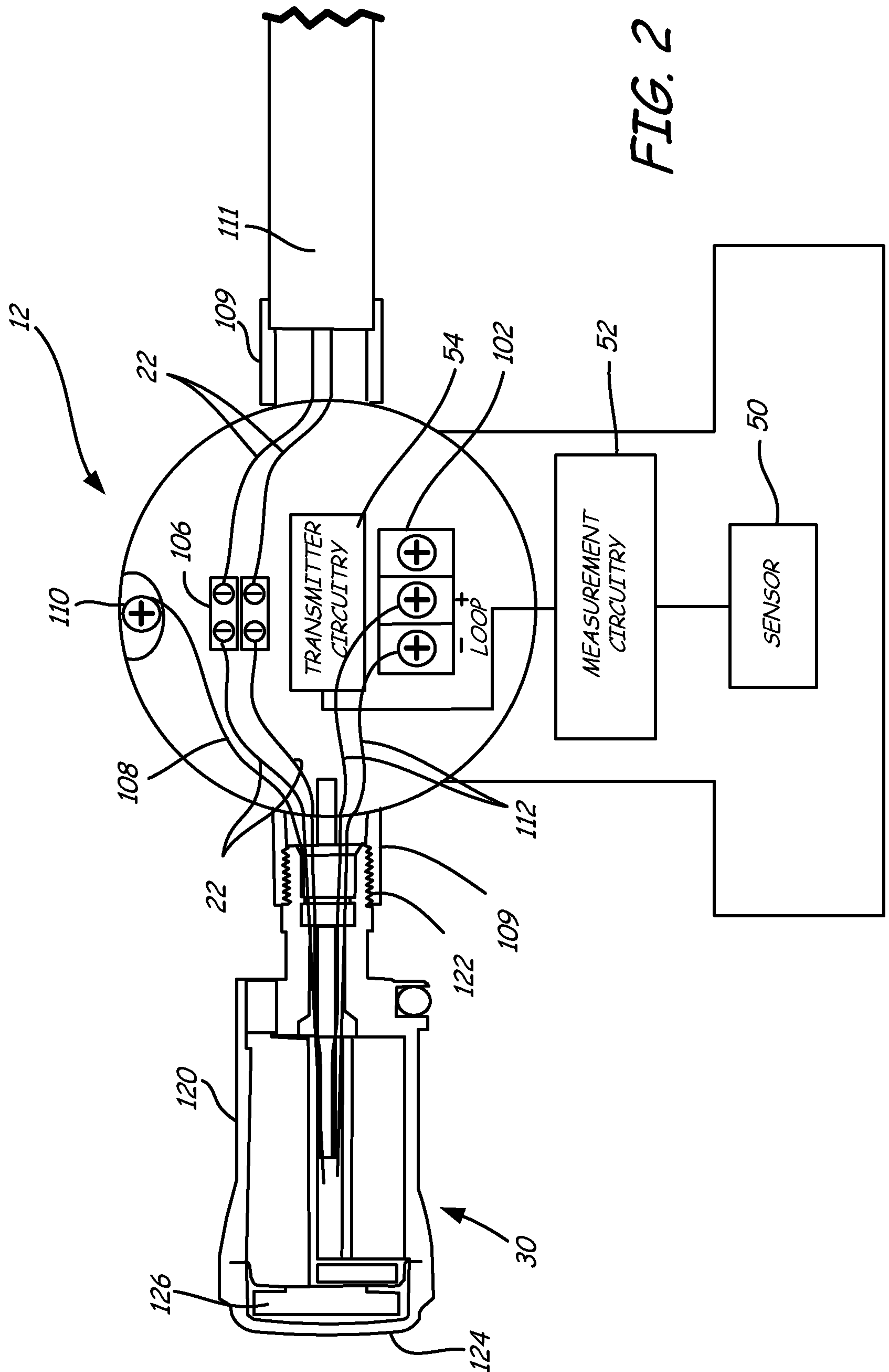
18. The method of any one of claims 15 to 17 further including measuring a current flowing from a loop terminal into the wireless adapter and responsively controlling the voltage drop across the first and second loop terminals.

19. The method of any one of claims 15 to 18 wherein one of the first and second loop terminals couples to the process field device, and wherein the method further includes coupling a communication terminal to the process field device for use in communicating with the process field device.

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20. The method of any one of claims 15 to 19 wherein the two-wire process control loop comprises a 4-20 mA current loop.
21. The method of any one of claims 15 to 20 wherein the two-wire process control loop carries digital communication in accordance with the HART® communication protocol.
22. The wireless adapter of any one of claims 1 to 14 wherein the shunt circuitry comprises a shunt regulator.
23. The method of any one of claims 15 to 21 wherein using shunt circuitry comprises using a shunt regulator.





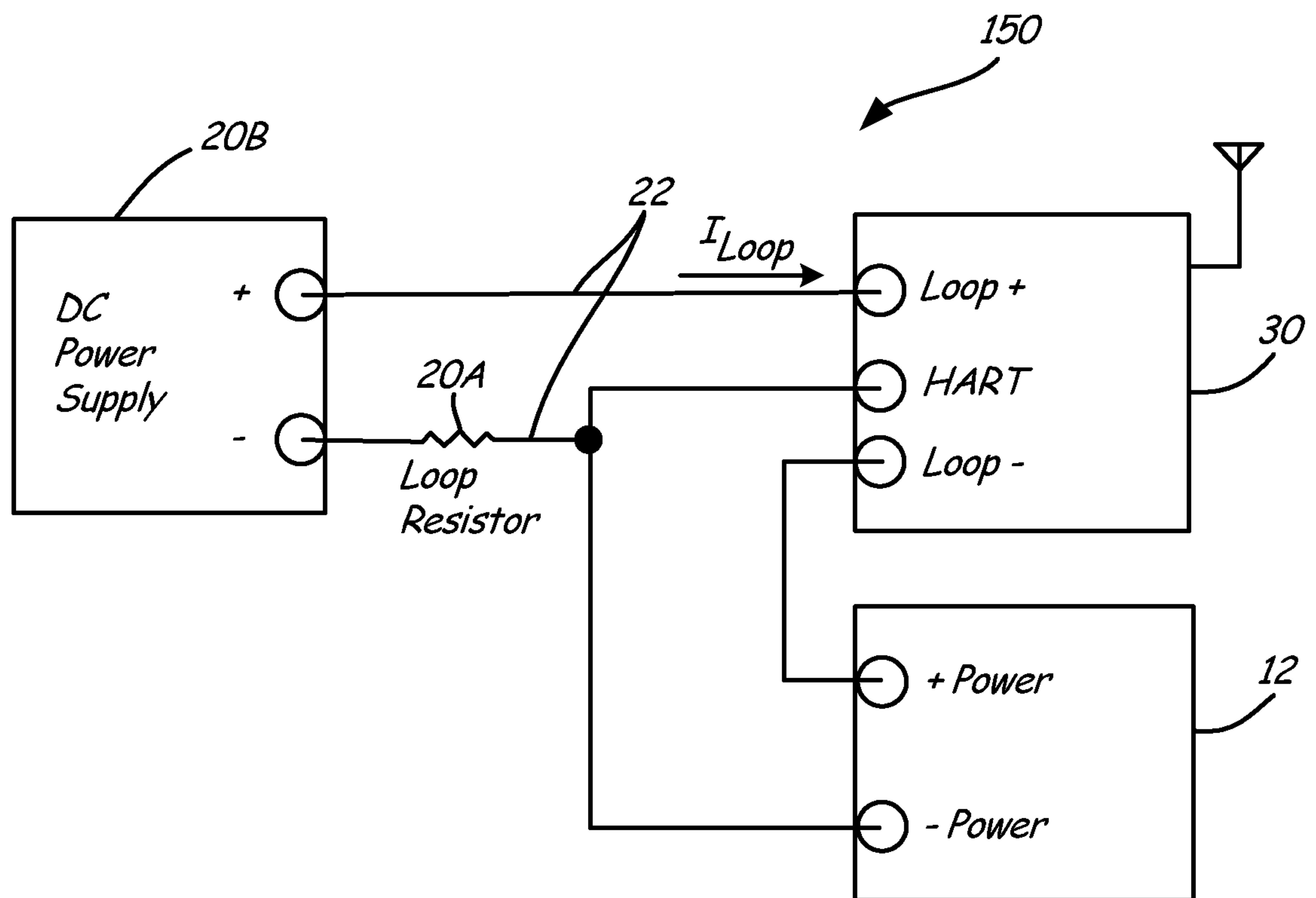
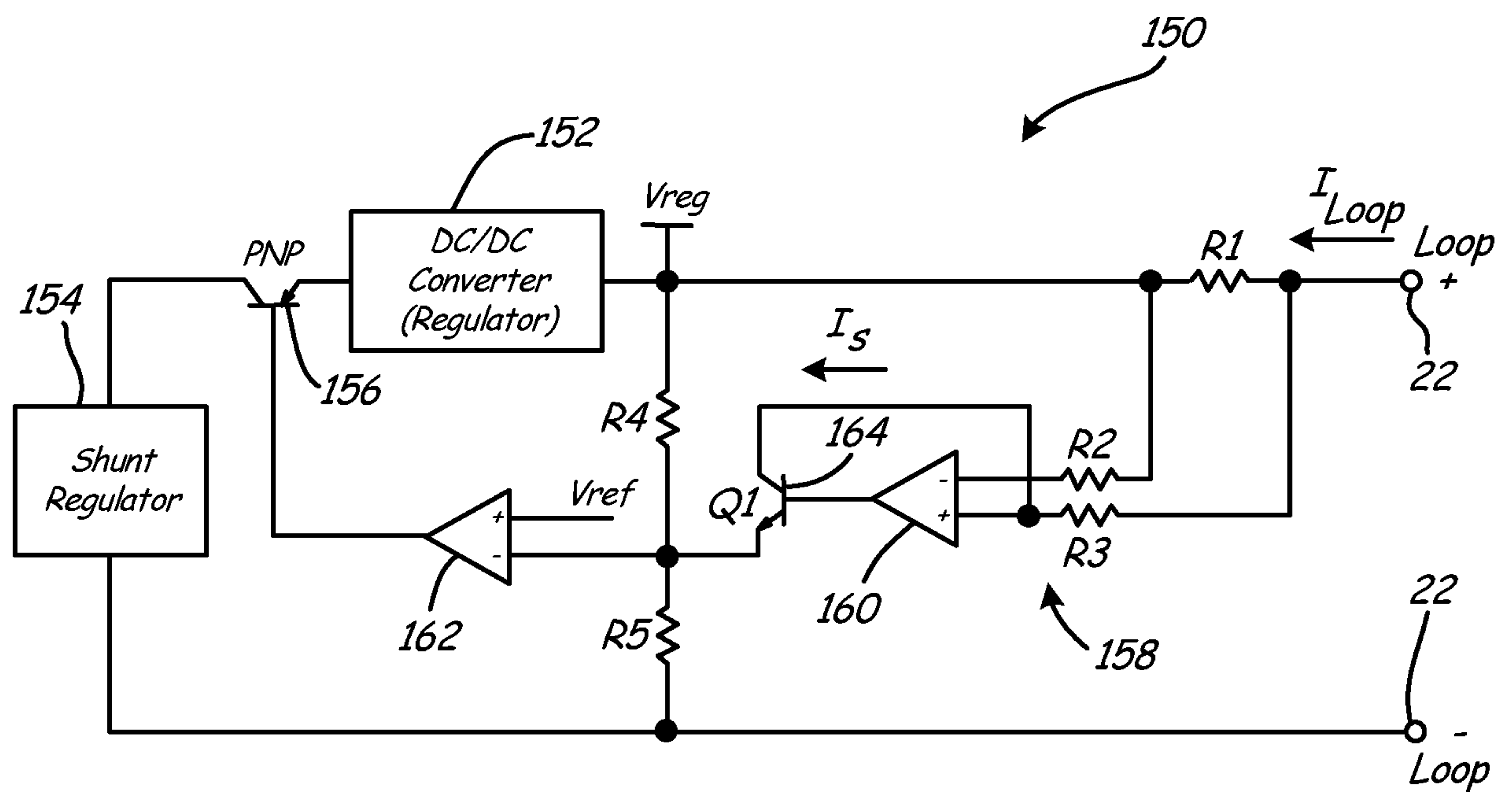


FIG. 3

**FIG. 4**

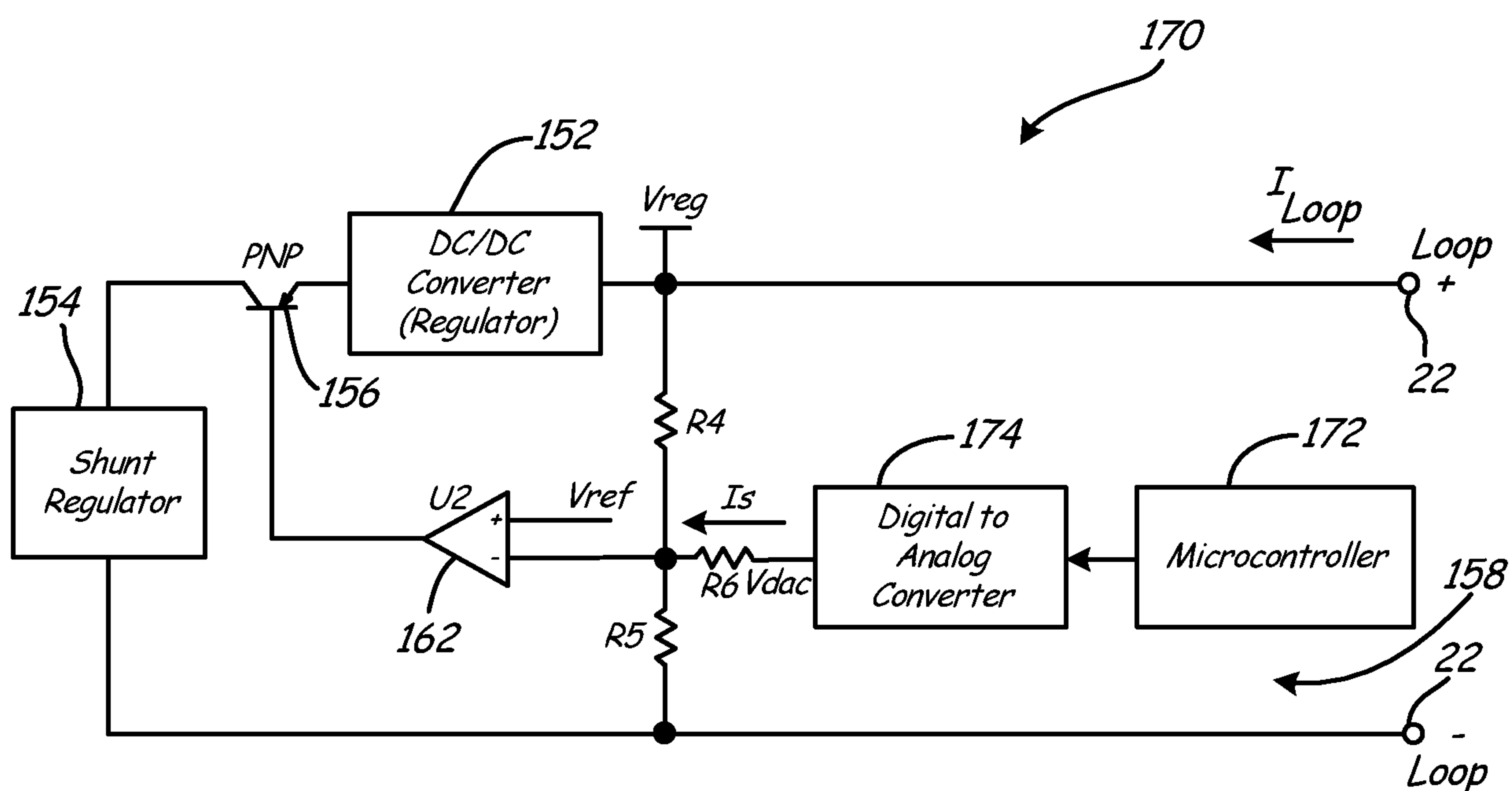


FIG. 5

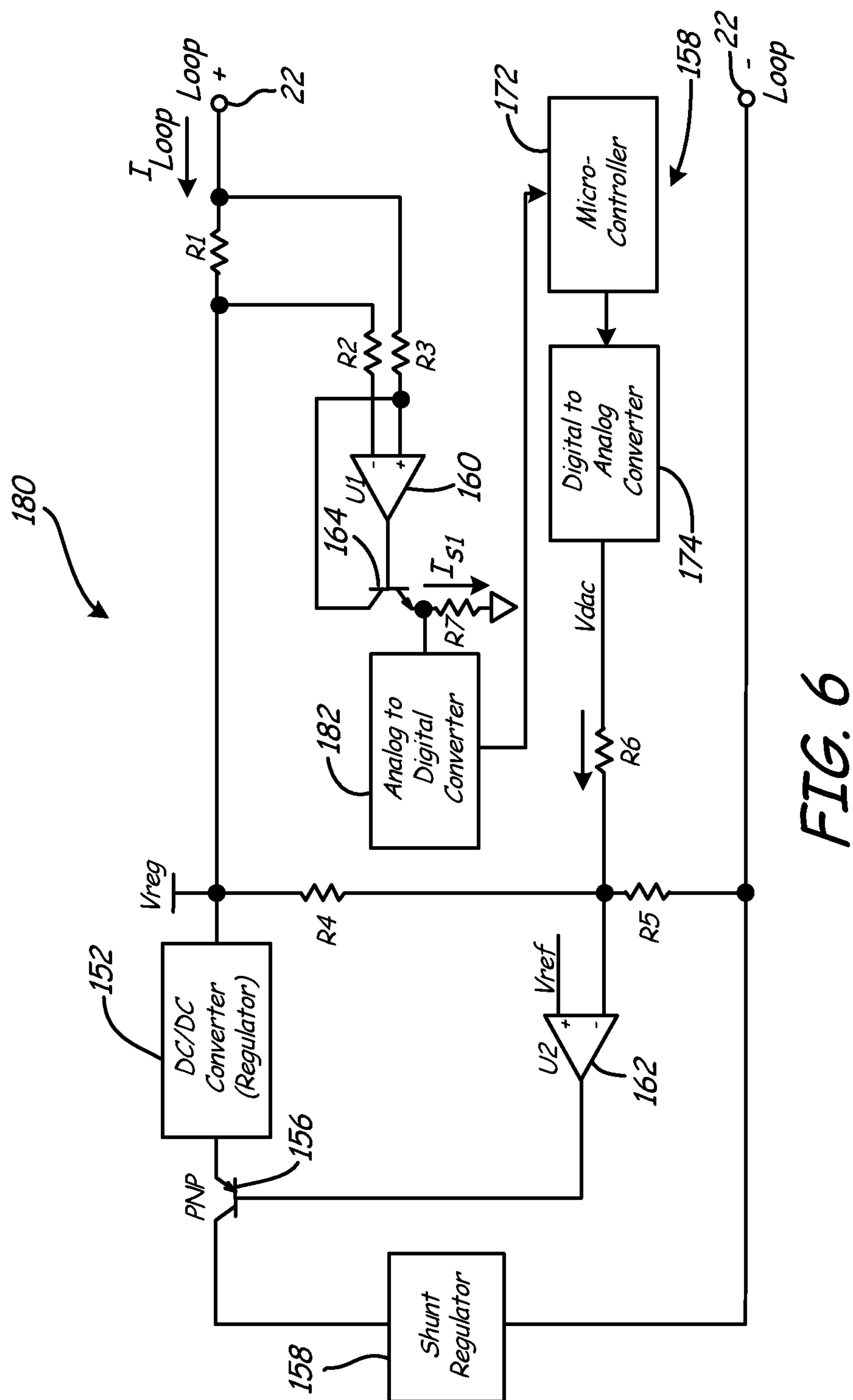


FIG. 6

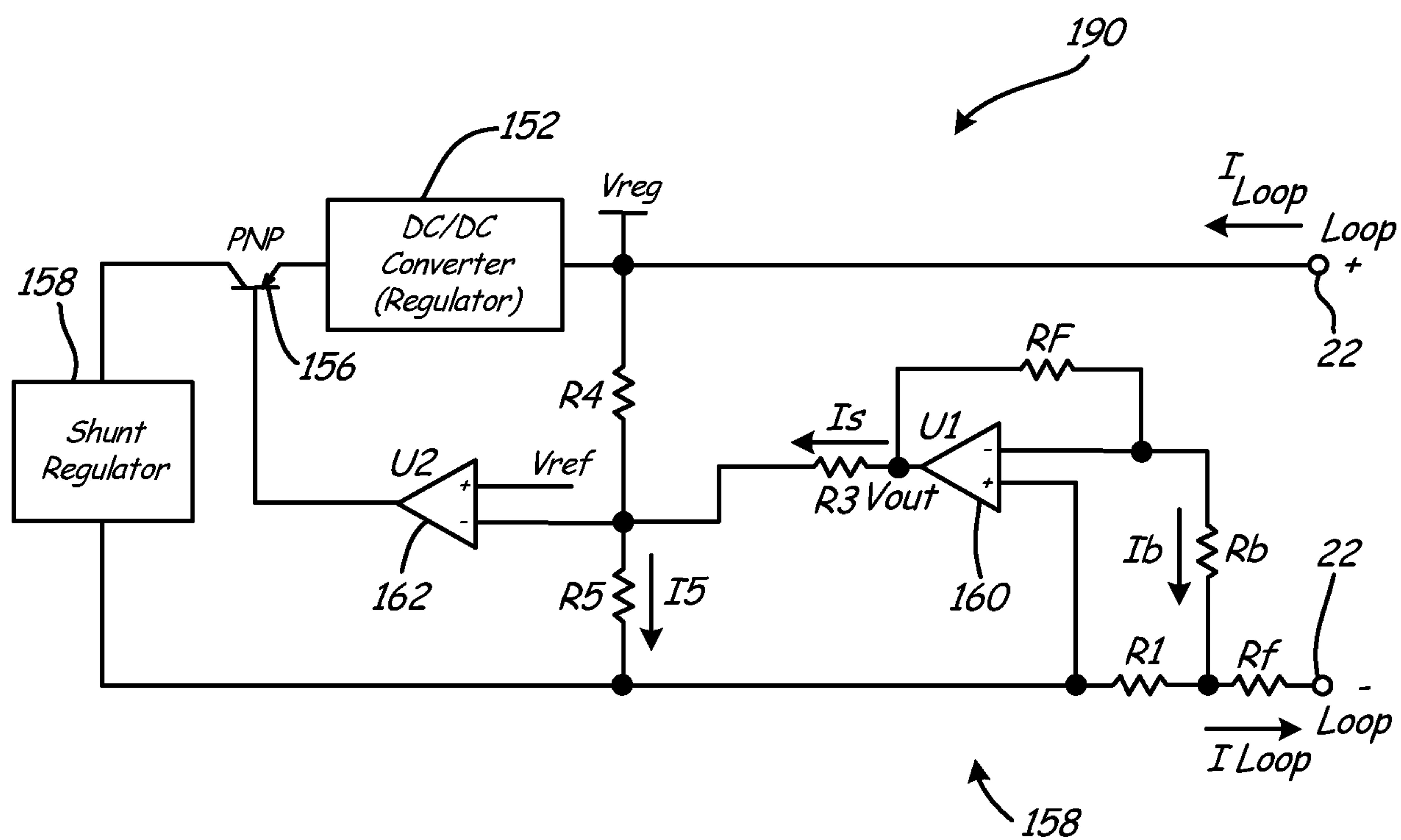


FIG. 7

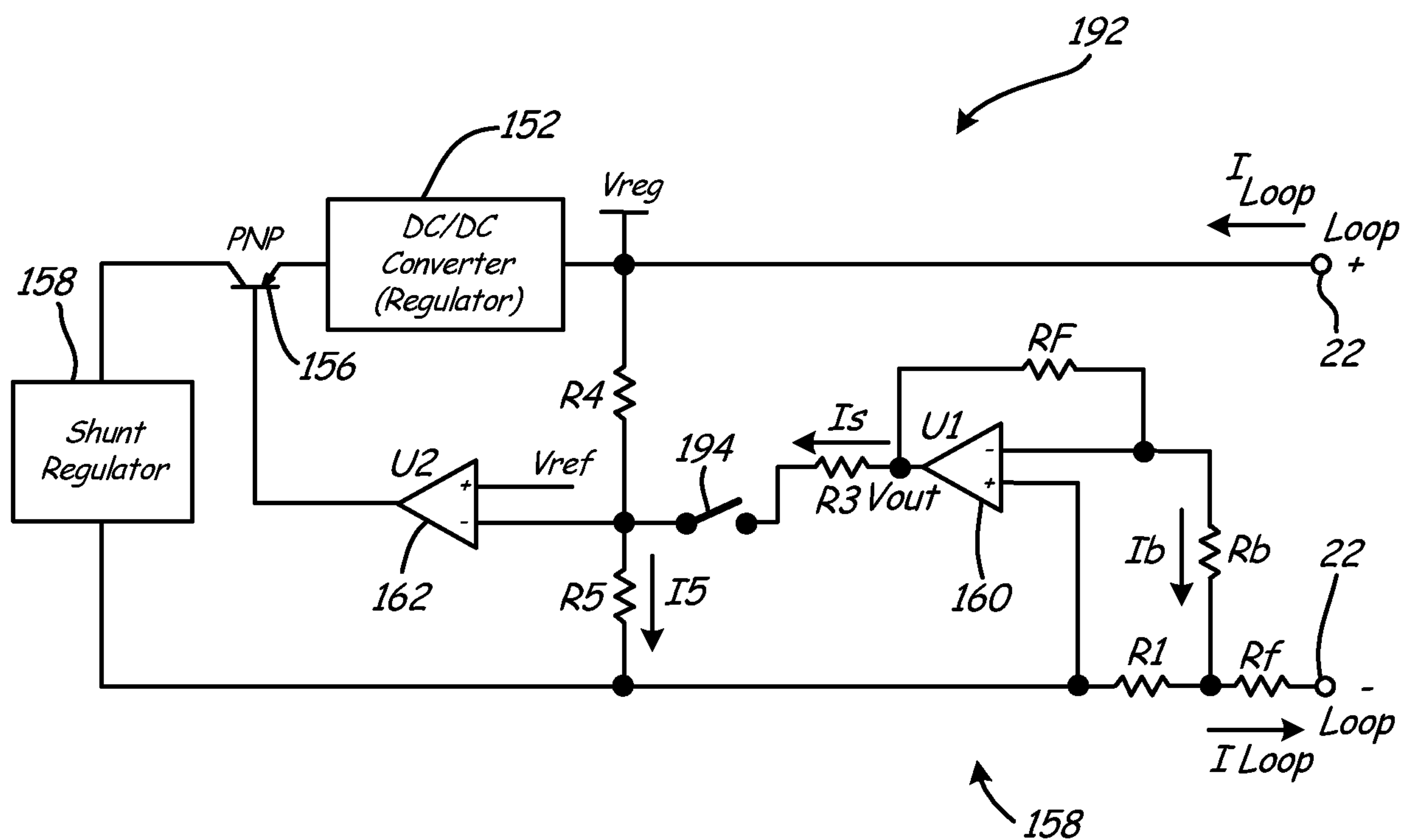


FIG. 8

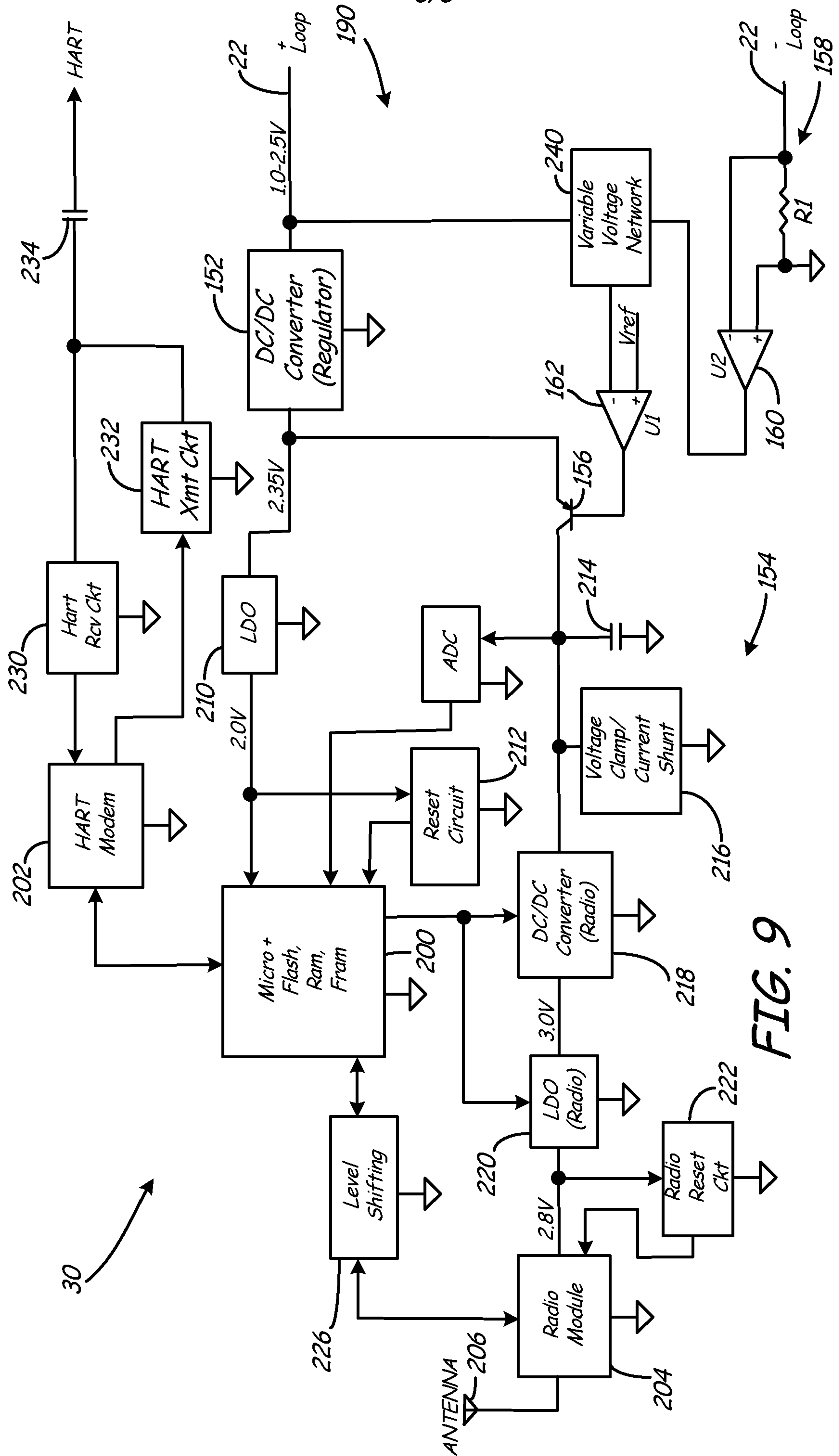


FIG. 9

