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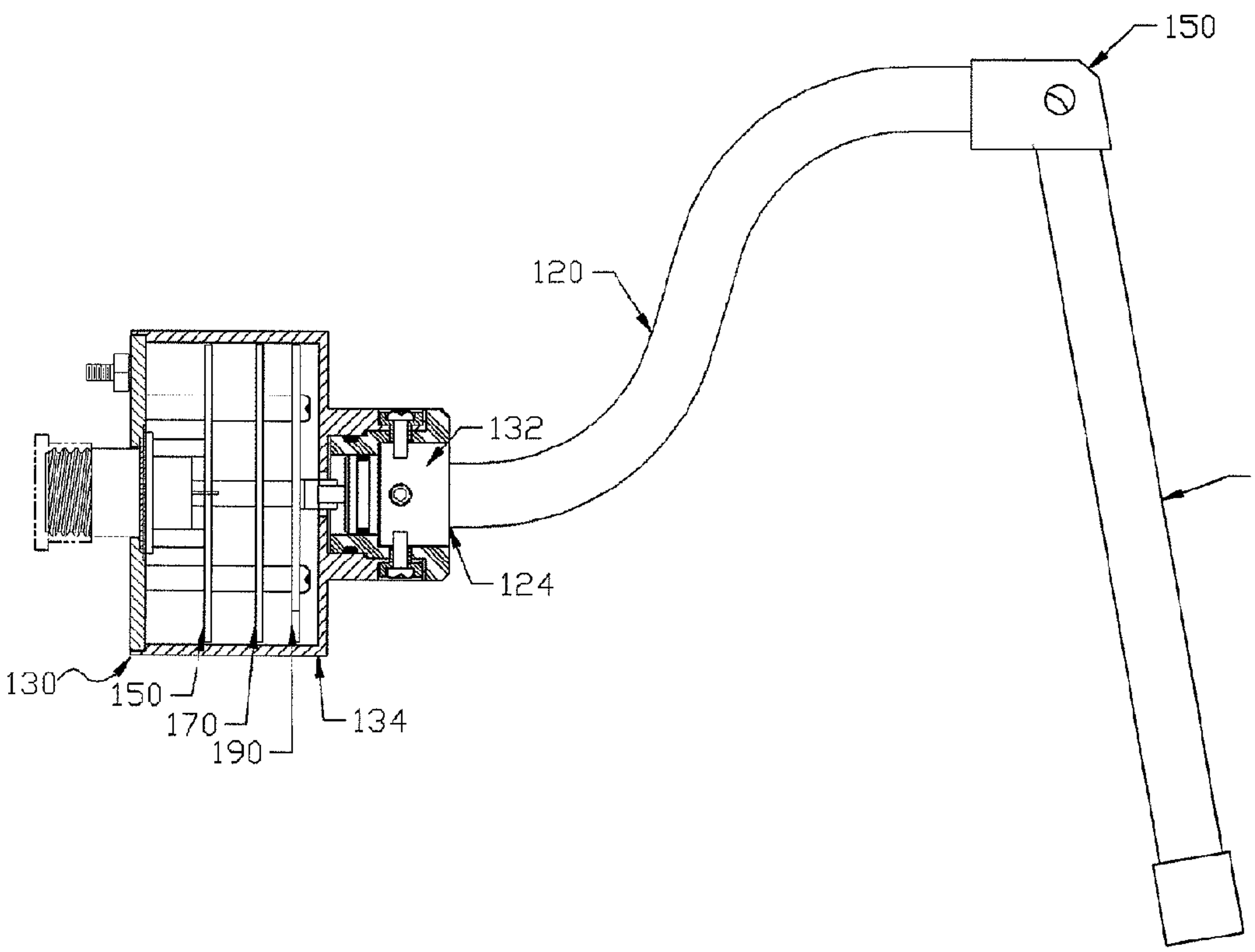
(54) Titre : SYSTEME ET PROCEDE DE MESURE PRECISE DU NIVEAU DE FLUIDE DANS UNE CUVE
(54) Title: SYSTEM AND METHOD FOR ACCURATELY MEASURING FLUID LEVEL IN A VESSEL



(57) Abrégé/Abstract:
A system and method for accurately measuring fluid level in a vessel is provided. Generally, the system contains an elongated portion being a coaxial tube having a hollow center, an arm being coaxial in shape, and a sensor containing a transmitter capable of creating and transmitting an excitation electromagnetic pulse for traversing the elongated portion and the arm, and a receiver for receiving reflected pulses, wherein a proximate end of the elongated portion joins a distal end of the arm in a manner to create a waveguide for an electromagnetic pulse provided by the sensor.

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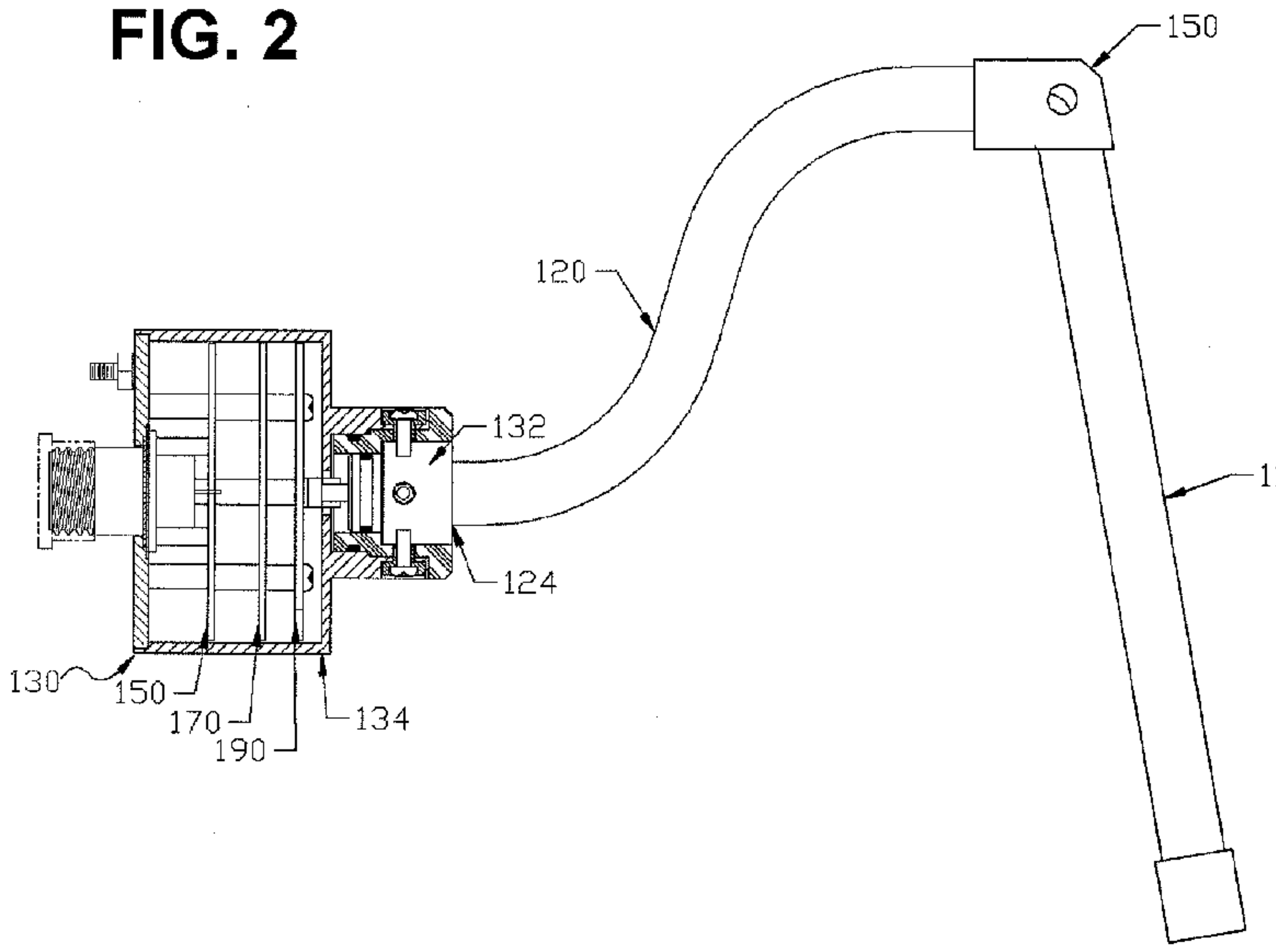
FIG. 2



(57) Abstract: A system and method for accurately measuring fluid level in a vessel is provided. Generally, the system contains an elongated portion being a coaxial tube having a hollow center, an arm being coaxial in shape, and a sensor containing a transmitter capable of creating and transmitting an excitation electromagnetic pulse for traversing the elongated portion and the arm, and a receiver for receiving reflected pulses, wherein a proximate end of the elongated portion joins a distal end of the arm in a manner to create a waveguide for an electromagnetic pulse provided by the sensor.

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SYSTEM AND METHOD FOR ACCURATELY MEASURING FLUID LEVEL IN A VESSEL

FIELD OF THE INVENTION

The present invention is generally related to fluid sensors, and more particularly is related to a fluid level sensor capable of compensating for multiple circumstances to provide an accurate fluid level reading.

BACKGROUND OF THE INVENTION

In many different fields there is a need to know a current level of fluid within a vessel. One method used to determine a current level of fluid within a vessel is the use of time domain reflectometry (TDR). As is known by those having ordinary skill in the art, TDR analysis includes the use of propagation of a step or pulse of energy having a sharp edge, also referred to as an interrogation, or excitation, signal, down a waveguide and into a system, and the subsequent observation of the energy reflected by the system. With the analyzing of the magnitude, duration, and shape of the reflected waveform, the nature of impedance variation in the transmission system can be determined.

Unfortunately, maintaining an accurate measurement of fluid level is difficult. As previously mentioned, in a TDR system an interrogation signal is transmitted down a transmission line. A transmission line passing through different media will have regions of different dielectric. As a result, the reflected waveform will contain discontinuities at times that represent dielectric changes along the transmission line. In addition, traditional TDR systems continuously sweep the entire transmission line for a time span that corresponds to when a reflection of an originating signal is received, where the originating signal traveled from one end of the transmission line to the other. This process is repeated each time a new level indication is needed, which is a processing burden resulting in a costly system requiring excess power usage.

Currently there is a need for an accurate, reliable, and safe method of measuring the amount of fluid in a container. An example of such a fluid may include, for example, a fuel tank containing volatile fluids. Thus, a heretofore unaddressed need exists in the industry to address the aforementioned deficiencies and inadequacies.

SUMMARY OF THE INVENTION

Embodiments of the present invention provide a system and method for accurately measuring fluid level in a vessel. Briefly described, in architecture, one embodiment of the system, among others, can be implemented as follows. The system contains an elongated portion being a coaxial tube having a hollow center, an arm being coaxial in shape, and a sensor containing a transmitter capable of creating and transmitting an excitation electromagnetic pulse for traversing the elongated portion and the arm, and a receiver for receiving reflected pulses, wherein a proximate end of the elongated portion joins a distal end of the arm in a manner to create a waveguide for an electromagnetic pulse provided by the sensor.

The present system and method also provides a method of accurately measuring fluid level in a vessel via use of an apparatus with a transmission line and a sensor, wherein the sensor comprises a transmitter capable of creating and transmitting an excitation electromagnetic pulse for traversing the transmission line, and an aliasing sampling receiver for converting high speed reflected waveforms into a slower speed "equal time" waveform for processing by use of a method comprising the steps of: scanning a length of the transmission line that is placed partially or fully in fluid to see where the fluid resides along the transmission line, also referred to as the current fluid level; tracking the fluid level by identifying fluid level detection points within the slower speed "equal time" waveform output by a scan window of the aliasing sampling receiver; and adjusting the aliasing sampling receiver scan window to track on the detection points within the equal time representation of the pulse reflection, where the detection points in the reflection waveform represent position in the pulse reflection waveform representing a fluid level.

Other systems, methods, features, and advantages of the present invention will be or become apparent to one with skill in the art upon examination of the following drawings and detailed description. It is intended that all such additional systems, methods, features, and advantages be included within this description, be within the scope of the present invention, and be protected by the accompanying claims.

BRIEF DESCRIPTION OF THE DRAWINGS

Many aspects of the invention can be better understood with reference to the following drawings. The components in the drawings are not necessarily to scale, emphasis instead being placed upon clearly illustrating the principles of the present invention. Moreover, in the drawings, like reference numerals designate corresponding parts throughout the several views.

FIG. 1 is a schematic diagram illustrating the probe in accordance with a first exemplary embodiment of the invention

FIG. 2 is a cross-sectional view of the probe of FIG. 1.

FIG. 3 is a sectional view of the probe where each portion of the probe is shown as separated prior to assembly.

FIG. 4 is a schematic diagram further illustrating functionality and logic defined by the digital PCB of the probe.

FIG. 5 is a schematic diagram further illustrating functionality and logic defined by the analog PCB of the probe.

FIG. 6 is a schematic diagram illustrating an example of the elongated portion of the probe of FIG. 1 for purposes of determining the dielectric constants of fluids, where temperature of the fluid is known.

FIG. 7 is a flowchart illustrating a method used by the probe to scan and lock on a fluid level, in accordance with the first exemplary embodiment of the invention.

FIG. 8 is a schematic diagram illustrating an example of a low pass filter.

DETAILED DESCRIPTION

The present invention is a fluid level detection probe capable of accurately determining fluid levels in a vessel or container. For exemplary purposes, the present probe is described as a fuel level probe being capable of being positioned within a fuel tank. In such an example, the fuel level probe may be used to provide accurate measurement of gas or oil levels within a tank. It should be noted, however, that the type of fluid and the type of vessel is not intended to be limited by the present description.

FIG. 1 is a schematic diagram illustrating the probe 100 in accordance with a first exemplary embodiment of the invention. As is shown by FIG. 1, the probe 100 contains an elongated portion 110, a shaped arm 120, and a sensor 130. The elongated portion 110 is a coaxial tube having a hollow center. The elongated portion 110 is shaped and lengthened to allow for positioning within a fuel tank, wherein a distal end 112 of the elongated portion 110 extends toward a bottom of the fuel tank, in which the elongated portion 110 may be positioned. Having the elongated portion 110 hollow allows fluid to enter the elongated portion 110, via the distal end 112, into the hollow portion to enable fluid level determination, as is explained in detail below.

A proximate end 114 of the elongated portion 110 joins a distal end 122 of the arm 120. The connection between the elongated portion 110 and the arm 120 is provided in a manner so as to allow the combination of the arm 120 and the elongated portion 110 to create a waveguide for an electromagnetic pulse provided by the sensor 130. In addition, the combination of the elongated portion 110 and the arm 120 is coaxial in shape. While FIG. 1 illustrates a connector 150 joining the elongated portion 110 and the arm 120, in accordance with an alternative embodiment of the invention, the probe 100 may instead be fabricated to have the elongated portion 110 and the arm 120 as one piece.

The elongated portion 110 and an outer shell of the shaped arm 120 are made of a conductive material having a known impedance, such as, for example, but not limited to, aluminum. It should be noted that other metals may be used as well. The arm 120 is filled with a dielectric such as, but not limited to, Teflon. The Teflon fill is a solid dielectric. Use of a Teflon fill, in accordance with the present invention, serves at least two purposes. First, the Teflon fill provides impedance matching, as is described in more detail below, and second, the

Teflon provides a means to prevent fluid ingression to a non-gauging portion of the probe 100, thereby eliminating unwanted reflections due to multiple fluid levels inside of the probe 100.

In accordance with the present invention, an electromagnetic excitation signal, also referred to herein as an interrogation signal, is sent by the sensor 130 into a transmission line, wherein the transmission line includes the combination of the arm 120, the elongated portion 110, and beyond the distal end 112 of the elongated portion 110. The transmission line has three sections. A first section of the transmission line is from an excitation source, such as the sensor 130, to a top of the probe 100, also referred to as the distal end 122 of the arm 120 (also referred to as the beginning of the gauge-able area). A second section of the transmission line is from the top of the probe 100 (the distal end 122 of the arm 120) to a bottom of the probe 100, also referred to as the distal end 112 of the elongated portion 110. The second section of the transmission line is also referred to as the gauge-able area. A third section of the transmission line is from the bottom of the probe 100 to the end of a transmission that runs past the end, or distal portion 112, of the gauge-able area. The third section of the transmission line, optionally, is placed here to allow for impedance matching to the media being measured, as is described in additional detail below.

It should be noted that having the probe 100 as coaxial in shape and partially filled with Teflon, or similar material, provides multiple advantages, such as, but not limited to, allowing for a constant impedance up to the gauging area and delimiting the gauging area. In addition, this allows the probe 100 to be mounted horizontally below a fluid level, without multiple reflections from the fluid. Further, this configuration provides wet-to-dry side isolation. Still further, the configuration also provides mechanical means of attaching the elongated portion 110 to the sensor 130, thereby providing a more solid structure.

In accordance with the first exemplary embodiment of the invention, the arm 120 of the probe 100 is shaped like an "S." It should be noted that the shape of the arm may be different from the shape described herein. This presently disclosed shape is beneficial due to the contour of the arm 120 allowing the probe 100 to rest on a lip of an entrance to a fuel tank, such as on the wing of an airplane, while the elongated portion 110 of the probe 100 extends within the fuel tank and the sensor 130 remains outside of the fuel tank. It should be noted, however, that the arm 120 may be provided in other shapes so as to accommodate location of a fuel tank for which the probe 100 is used. It should also be noted that the curved shape of the arm 120 allows for side mounting of the probe 100 within a tank. Alternatively, the arm 120 may be a wire, or the probe 100 may not even include an arm 120, but instead, have a direct connection from the sensor 130 to the elongated portion 110.

The sensor 130 is connected to a proximate portion 124 of the arm 120. A better illustration of the sensor 130 is provided by FIG. 2 and FIG. 3, where FIG. 2 is a cross-sectional view of the probe 100 and FIG. 3 is a sectional view of the probe 100 where each portion of the probe 100 is shown as separated, prior to assembly. In accordance with the present embodiment, the sensor 130 is connected to the proximate portion 124 of the arm 120 by a collar 132. The collar 132 connects to both the proximate portion 124 of the arm 120 and to a housing 134 of the sensor 130. As is shown by FIG. 3, the collar 132 may be connected to the arm 120 by a male/female connection having a first collar O-ring 138 there between so as to provide an air-tight seal between the collar 132 and the arm 120, to prevent fluid immigration from inside of the tank. Of course, other connection types between the collar 132 and the arm 120 may be used instead.

The collar 132 is connected to the housing 134, thereby completing connection between the housing 134 and the arm 120. Connection between the collar 132 and the housing 134 may be provided via numerous methods, such as, but not limited to, use of a series of collar screws 142 and a second collar O-ring 144.

While the shape of the housing 134 is not instrumental, the housing 134 does provide a cover for numerous objects. As is shown by FIG. 2 and FIG. 3, a series of printed circuit boards (PCBs) are located within the housing 134. Specifically, a first PCB 150, a second PCB 170, and a third PCB 190 are located within the housing 134. The first PCB 150 is a power supply PCB. The first PCB 150 contains a power source, thereby providing power to the probe 100. Electrical components on the first PCB 150 are designed to prevent high-energy signals from propagation to the fluid.

The second PCB 170 is a digital PCB having digital logic thereon, such as, but not limited to, a processor, such as, but not limited to, a digital signal processor (DSP) 172. Functionality performed by the DSP 172 and other digital logic therein is described in detail below with reference to FIG. 4 and other figures. It should be noted that the present description refers to use of a DSP, but it should be noted that this is for exemplary purposes only, and that any processor may be supplemented.

The third PCB 190 is an analog PCB having transmitter and receiver analog circuitry for allowing the probe 100 to transmit and receive signals. Functionality performed by the analog circuitry is described in detail below with reference to FIG. 5.

The first PCB 150, second PCB 170, and third PCB 190 are provided in a stacked arrangement with a series of stacking screws 146 maintaining the PCBs 150, 170, 190 in position within the housing 134. A cover 160 is also provided for sealing contents of the sensor 130 within the housing 134. It should be noted that a sensor connector 162 is partially located within the sensor housing 134. The sensor connector 162 provides an interface for connecting of the probe 100 to an aircraft interface.

In accordance with an alternative embodiment of the invention, the power supply circuitry, transmitting and receiving logic, and digital logic may all be located on the same PCB, or on more or less than three PCBs.

As mentioned above, FIG. 4 is a schematic diagram further illustrating functionality and logic defined by the digital PCB 170. In addition, FIG. 5 is a schematic diagram further illustrating functionality and logic defined by the analog PCB 190. The following is a description of the sensor 130 specific to the second PCB 170 and the third PCB 190.

FIG. 5 shows an example of basic implementation of the analog transmit and receive channels. A digital signal processor (DSP) 172, as shown by FIG. 4, is provided to scan, track, and analyze associated data. A clock signal from the DSP 172 (FIG. 4) is supplied to input A (FIG. 5) and used to initiate a transmit pulse and to synchronize the receiver to the transmit pulse on the analog PCB 190. This signal activates the transmitter 192 to send an excitation pulse down the arm 120. The pulse travels down the elongated portion 110 all the way to the distal end of the elongated portion 112. The resulting reflection from the distal end 112 travels back and is captured by the receiver 194. This signal is filtered and buffered by a low frequency buffer 195 and sent to the DSP 172 to be converted to a digital signal and to be analyzed through output D.

The same clock signal that is used to initiate the transmit pulse is also provided to the receiver 194. At the receiver 194, the clock signal is phase shifted (delayed) by a phase shifter 196 by an amount commanded by the DSP 172 (FIG. 4) on input B. The receiver pulse is therefore delayed by the DSP 172 (FIG. 4) and performs a spatial scan of the elongated portion 110 length.

The actual amount of delay between the transmitter pulse and the receiver pulse is detected by a delay detector 198 and sent back as DC voltage to the DSP 172 via output C. This enables the DSP 172 to close the loop allowing the DSP 172 to have total control over the scanning function. Thus, specific discontinuities can be scanned or tracked at will.

The transmitter 192 function is performed by elements transistor Q1, resistor R48, capacitor C5, and resistor R7. Here, transistor Q1 acts as a switch to couple the energy stored in capacitor C5 onto the transmission line. Resistor R7 serves to decouple the transmitter 192 from the receiver 194. The receiver 194 function is performed by elements receiver R36, diode D2, capacitor C6, resistor R8, capacitor C7, transistor Q2, and resistor R55. Resistor R55 and resistor R8 provide a charging path for capacitor C6. Transistor Q2 serves as a switch to couple the energy stored in capacitor C6 onto resistor R8 thus turning on diode D2 via capacitor C7. Capacitor C7 in turn charges to and stores the voltage present at the transmission line, also referred to as sampling the transmission line.

FIG. 4 shows the digital PCB 170. The DSP 172 sends a clock signal to activate transmitter 192 and receiver 194 through output A. The amount of delay is controlled by the DSP 172 via a digital to analog converter (DAC) 180 signal sent through output B to the analog PCB 190.

The amount of delay between receiver 194 and transmitter 192 pulses is sensed by analog to digital converter ADC1 (175) via a voltage into input C and converted into a digital value to be read by the DSP 172. The DSP 172 uses this signal to determine delay between the transmitter 192 and the receiver 194 and adjusts delay control output for closed loop tracking purposes.

Another analog signal fed back to the DSP 172 contains the reflection waveform from the elongated portion 110 of the probe (input D). This signal is fed into analog to digital converter ADC2 (174). From the converter, the signal is fed digitally into the DSP 172 for analysis.

Automatic gain adjustment of Sampling Receiver

It should be noted that, due to different environmental factors, the signal amplitude from the receiver 194 may be adversely affected. This may lead to level detection inaccuracies. In accordance with an alternative embodiment of the invention, these effects are compensated for by increasing amplitude of the excitation pulse proportionally with the transmitter 192 output. Specifically, the output signal at D (FIG. 5), obtained during sampling of a known value, is fed into a low pass filter 193, an example of which is illustrated by FIG. 8. Preferably, the low pass filter 193 is located separate from the receiver 194 and transmitter 192, but still within the sensor 130. The resulting DC value is added to a pre-fixed bias, amplified, and added (or subtracted) to –Vee in FIG. 5. By varying -Vee, we can vary the amplitude of the transmit pulse, hence compensating for the decrease (increase) of the signal at D due to the diode variation.

Segmented dielectric used to match the impedance of a TDR level-measuring probe

As has been mentioned above, the arm 120 of the probe 100 is filled with a dielectric having known impedance. Having the arm 120 of the probe 100 filled with a dielectric having a known impedance prevents the fluid that is being measured from entering into the arm 120 of the probe 100. In the alternative, if the fluid were allowed to enter into the arm 120 of the probe, there would be discontinuities in the excitation signal transmitted from the sensor 130, to the arm 120, to the elongated portion 110 of the probe 100. Specifically, each time that the fluid is encountered by the excitation signal a discontinuity in the signal occurs. Therefore, it is beneficial to minimize discontinuity by ensuring that no fluid enters the arm 120 of the probe 100. In accordance with the present invention, minimizing discontinuity is performed by, for example, filling the arm 120 with a dielectric having a known impedance. In accordance with a preferred embodiment of the invention, the impedance of the dielectric is similar to an impedance of air or an impedance of the fluid for which a level is being determined.

In accordance with the present probe 100 an excitation signal first travels from the sensor 130 to the top of the gauge-able section of the probe 100. If the impedance of the first transmission line section, namely, the arm 120 of the probe 100, is matched to that of a first media, such as the impedance of air, then there will not be an unwanted discontinuity between the first probe section and the second probe section, namely the elongated portion 110.

A discontinuity at a boundary between media, such as between the air and the fluid for which a level is being determined, will cause a desired reflection of the excitation signal for processing by the sensor 130. By design, as mentioned above, this reflection will not create any undesired extra reflections at the impedance matched top and bottom of the probe 100. Part of the excitation signal travels further in the second media, namely, the fluid for which a level is being determined, to the distal end 112 of the elongated portion 110, which is in the fluid.

Impedance of the third section of the transmission line is adjusted to match the value of the impedance of the second media, namely the impedance of the fluid. In summary, the impedance at the top of the probe 100 is matched to air, while the impedance at the bottom of the probe 100 is matched to the impedance of the fluid for which a level is being determined. It should be noted that the impedance matching may be performed by the sensor 130, by geometry of the probe 100, or by dielectric material adjustment. The excitation signal travels into the third section of the transmission line without any discontinuity to blur the level detection.

Therefore, in design of the probe 100, it is desirable to have similar dielectric of the material used to fill the arm 120, the air, and the fluid. The similarities of the dielectrics results in less discontinuities in the excitation signal being transmitted from the sensor 130, through the arm 120 of the probe 100, into the elongated portion 110 of the probe 100, and into the fluid for which a level is being determined.

Temperature measurement of fluid using time of flight

The physical characteristics and functionality of the present probe 100 allow for the probe 100 to provide temperature measurement of fluid. This process is described in detail herein and performed by the DSP 172. Specifically, in processes where fluid level measurement is monitored, it is often desirable to know the fluid temperature as well. Knowing the fluid temperature may prove useful for process control or adjustments to fluid level readings itself to compensate for volume of fluid changed due to temperature. The present probe 100 alleviates the prior need for utilizing a separate, independent temperature sensor, and instead, integrates the properties of a temperature measurement sensor with the level measurement properties of the probe 100, resulting in a probe with less wiring and less intrusion into the process, and therefore, better reliability.

By knowing the dielectric constants of the fluids (e.g., air and gas) in various temperatures, the temperature of the fluid being measured can be deduced by measuring the actual dielectric constant of the fluid and comparing the measured actual dielectric constant to a chart having known dielectric constant values. As an example, consider, for example, a hydrocarbon fluid. The propagation velocity of the signal in the fluid having a dielectric constant ε_1 at certain temperature is shown by equation 1.

$$V = \frac{C}{\sqrt{\varepsilon_1}} \qquad \text{(Eq. 1)}$$

In equation 1, C is speed of light.

As the fluid temperature changes, its dielectric also changes to ε_2.

The relationship between the propagation velocities may be represented by equation 2.

$$\frac{V_1}{V_2} = \sqrt{\frac{\varepsilon_2}{\varepsilon_1}} \qquad \text{(Eq. 2)}$$

In equation 2, ε_1 is the dielectric constant at, for example, 25°C and ε_2 is the dielectric constant at unknown temperature T. Equation 2 may be rewritten as equation 3 below.

$$\varepsilon_2 = \varepsilon_1 \left(\frac{V_1}{V_2}\right)^2 \qquad \text{(Eq. 3)}$$

Knowing ε_1 and V_1, and by using a lookup table of ε values in various temperatures for this particular fluid, we find out the actual temperature T of the fluid. Alternatively, as shown by equation 4, if we know the real length of the fluid column L, and the perceived length L' (time of flight measured from fluid surface to bottom of tank), we can calculate the dielectric constant of the fluid at the current temperature (whatever it is) ε_T:

$$\varepsilon_T = \left(\frac{L'}{L}\right)^2 \qquad \text{(Eq. 4)}$$

By looking up ε_T and ε in a lookup table (ε is dielectric constant of this fluid at 25°C) we can tell the temperature of the fluid.

It should be noted that alternative embodiments of the invention may be provided for measuring in situ temperature to compensate for dielectric changes due to temperature. As an example, in accordance with a second exemplary embodiment of the invention, a thermistor may be placed in the gauging portion of the probe 100 in direct contact with the fluid being measured. The main characteristic of a thermistor is the ability of the thermistor to change impedance according to the temperature to which it is exposed. The sensor 130 of the probe 100 then detects the thermistor impedance change and correlates the impedance change to a fluid temperature.

Alternatively, in accordance with a third exemplary embodiment of the invention, the thermistor may also be located within the gauging portion, however, circuitry for sensing thermistor impedance may need to be connected to the probe 100.

Fluid Level Determination Via Pulse Time of Flight Thru fluid

A pulse transmitted out into a transmission line will be partially or fully reflected back to the transmit port whenever the characteristic impedance of the transmission line changes. The characteristic impedance of a transmission line will change with the dielectric. Different transmission line geometries (coax, parallel wire, etc.) will have different relationships for characteristic impedance changes in different dielectrics. For a given transmission line geometry the dielectric changes in the transmission line will cause predictable changes in characteristic impedance.

A level measuring system, the probe 100, is designed to have a transmission line that passes thru different dielectrics. The transmission line will then have a very large impedance change at its end (open or short circuit). This very large impedance change in the transmission line will cause a very strong reflection at its end.

A level measuring system could have a pulse travel in a transmission line that is placed in a medium of known dielectric. Part of the distance the pulse will travel will be in air (air dielectric) another part of the distance is traveled in a medium (medium dielectric). Using Equation 1 a velocity of propagation for each medium can be determined. We know the total distance traveled (length of transmission line). By analyzing the reflected waveform the travel time from the beginning of the transmission line, thru both dielectrics, to the large impedance mismatch at the end of the transmission line can be measured. The distance traveled in the medium can be derived by use of equation 5 hereafter, which assumes that velocity in air is C.

$$|H| = [D - C(T)] / [1 - \mathrm{sqrt}(\varepsilon_m)] \qquad \text{(Eq. 5)}$$

In equation 4:

D = total distance of transmission thru both air and medium. This is the length or height, of the medium;

C = speed of light;

ε_m = dielectric of medium;

T = total time for a pulse or signal to travel thru both the air dielectric transmission line part and the medium dielectric part of the transmission line to the end of said transmission line;

H = height of medium = the distance traveled in only medium dielectric part of the transmission line; and

sqrt = square root.

Finding dielectric constant in TDR where the temperature is known

FIG. 6 is a schematic diagram illustrating an example of the elongated portion 110 of the probe 100 for purposes of determining the dielectric constants of fluids, where temperature of the fluid is known. Length L, which is length of the elongated portion 110, is known, while length L1, which is length of the elongated portion 110 having air therein, and length L2 which is length of the elongated portion 110 having fluid therein, are measured by time of reflections, also referred to herein as time of flight.

In accordance with the present invention, the probe 100 may also be used to determine dielectric constants of fluids, where the temperature of the fluid is known. This process is described in detail herein and performed by the DSP 172. If the temperature of the fluid is known, the dielectric constant of the fluid can be deduced by measuring the perceived length of the coaxial tube (elongated portion 110) immersed in the fluid. Since the real length of the tube, or elongated portion 110, is known, the dielectric constant of the fluid can be calculated at this temperature from the ratio of the perceived length and real length of the fluid columns (L2 in FIG. 6). Equation 4 may be referred to for further explanation.

By using a lookup table of temperature and dielectric constant ε_t for this particular fluid, dielectric constant ε in 25 °C can be determined. In addition, theoretical dielectric constant $\mathcal{E}$ can be compared to actual dielectric constant $\mathcal{E}_T$ above to detect possible contamination in the fluid if the two are not the same.

Find and lock level

In accordance with the first exemplary embodiment of the invention, in order to provide fast fluid level scanning with reduced sensor processing time, the probe 100 is capable of tracking fluid level. Specifically, in the present fluid level measuring probe 100 very high speed reflecting waveforms need to be analyzed to determine positional changes in dielectric material caused by changes in fluid level. FIG. 7 is a flowchart 300 illustrating a method used by the probe 100 to scan and lock on a fluid level, in accordance with the first exemplary embodiment of the invention.

It should be noted that any process descriptions or blocks in flow charts should be understood as representing modules, segments, portions of code, or steps that include one or more instructions for implementing specific logical functions in the process, and alternative implementations are included within the scope of the present invention in which functions may be executed out of order from that shown or discussed, including substantially concurrently or in reverse order, depending on the functionality involved, as would be understood by those reasonably skilled in the art of the present invention.

Instead of continuously scanning the entire length of the elongated portion 110 for the level detection, as shown by block 302, the present probe 100 scans the entire length of the elongated portion 110 once via use of the excitation signal, to see where the fluid resides in the elongated portion 110 of the probe 100, also referred to as the current fluid level. One method of analyzing high-speed waveforms, such as the interrogation (excitation) signal provided by the sensor 130, is to use an aliasing sampling system to create a slower "equal time" waveform. The probe 100 can preserve the shape of the original very fast periodic waveform and render the waveform at a much slower rate. Sweeping a very narrow sampling point along a repeating waveform does this. Each time the high-speed waveform is repeated, a single narrow sample of the waveform is taken by the sensor 130. At regular intervals, the sampling window is delayed in time to sample the next fragment of the high-speed waveform. After many waveforms, the samples are combined by the sensor 130 into a slower representation of the original high-speed waveform which is suitable for processing by the DSP 172.

By analyzing the equal-time waveform, the reflection of interest can be located. The reflection of interest represents the current fluid level on the elongated portion (110) of probe 100. As shown by block 304, once the position of the current fluid level is determined, the fluid level is tracked by creating an equal-time representation of the high-speed waveform only in the vicinity of where the reflection of interest was located on previous cycles. As shown by block 306, periodically, the scan window timing is adjusted to keep the reflection of interest within the scan window.

Scanning only where the fluid level can be expected and tracking the level greatly cuts required sensor processing time. Having a decreased sensor processing time allows a much faster system response rate for determining fluid level. This also results in a less costly system and less power consumption.

Intrinsically safe coaxial TDR with low RF transmission/susceptibility for aircraft applications

Using a metallic coaxial tube (the combination of the arm 120 and the elongated portion 110) offers a unique advantage of low radio frequency emissions for the TDR device. This is extremely important for air borne application where the aircraft instrumentation is extremely sensitive to radiated noise. It also makes radio frequency reception by the TDR (susceptibility) less likely.

It has an added benefit in case of flammable fluids immersion. An electrical spark can ignite the fluid in which the transmission line is immersed. By shrouding the inner conductor of the elongated arm 110 by an outer metallic tube, we prevent a spark between the inner conductor and the tank in which the fluid is held. By electrically connecting the outer tube to the tank, we prevent an electric potential difference between the tank and the elongated tube (110), thus, reducing the possibility of a spark.

The amount of energy delivered into the measured fuel is limited by capacitor C5 (FIG. 5). The capacitor prevents a direct current from flowing into the fuel. The only energy delivered is in a form of a pulse. This pulse has a limited energy dictated by the capacitance of C5. By keeping the capacitance low, we keep the amount of energy entering the fluid below a critical amount needed for ignition.

Another safety feature is the addition of voltage surge suppressors to the power supply that powers the probe 100 and communications inputs to the probe 100. These limit the amount of energy that can reach the fuel in case of a short circuit or over voltage transient.

It should be emphasized that the above-described embodiments of the present invention are merely possible examples of implementations, merely set forth for a clear understanding of the principles of the invention. Many variations and modifications may be made to the above-described embodiments of the invention without departing substantially from the spirit and principles of the invention. All such modifications and variations are intended to be included herein within the scope of this disclosure and the present invention and protected by the following claims.

What is claimed is:

1. A method of accurately measuring fluid level in a vessel via use of an apparatus with a transmission line and a sensor, wherein the sensor comprises a transmitter capable of creating and transmitting an excitation electromagnetic pulse for traversing the transmission line, and an aliasing sampling receiver for converting high speed reflected waveforms into a slower speed "equal time" waveform for processing by use of a method comprising the steps of:

scanning a length of the transmission line that is placed partially or fully in fluid to see where the fluid resides along the transmission line, also referred to as the current fluid level;

tracking the fluid level by identifying fluid level detection points within the slower speed "equal time" waveform output by a scan window of the aliasing sampling receiver; and

adjusting the aliasing sampling receiver scan window to track on the detection points within the equal time representation of the pulse reflection,

where the detection points in the reflection waveform represent position in the pulse reflection waveform representing a fluid level.

2. The method of claim 1, wherein the method of accurately measuring fluid level is instead used to detect an additional point of interest on the slower speed time waveform.

3. The method of claim 2, wherein the additional point of interest is an end portion of the transmission line.

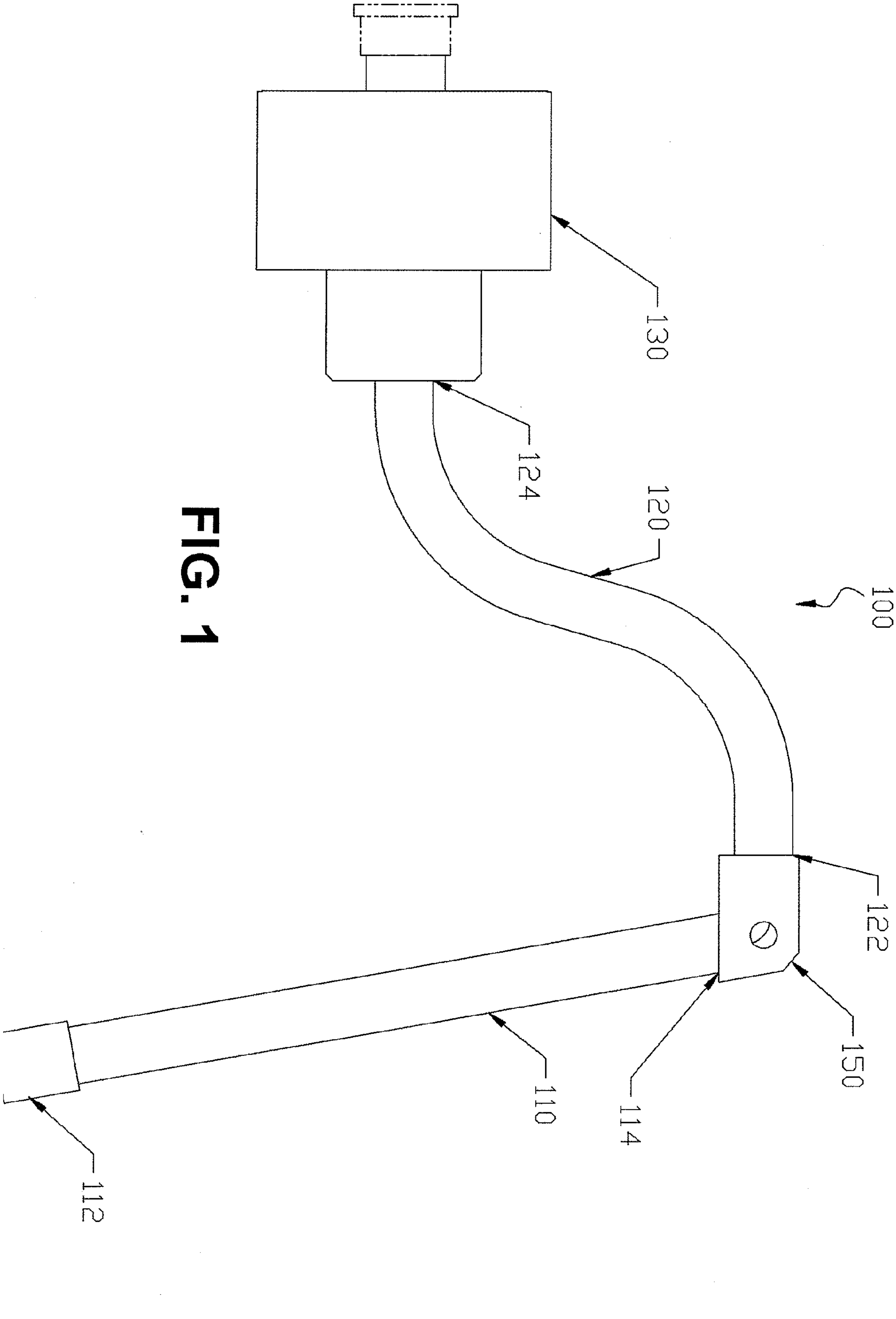


FIG. 1

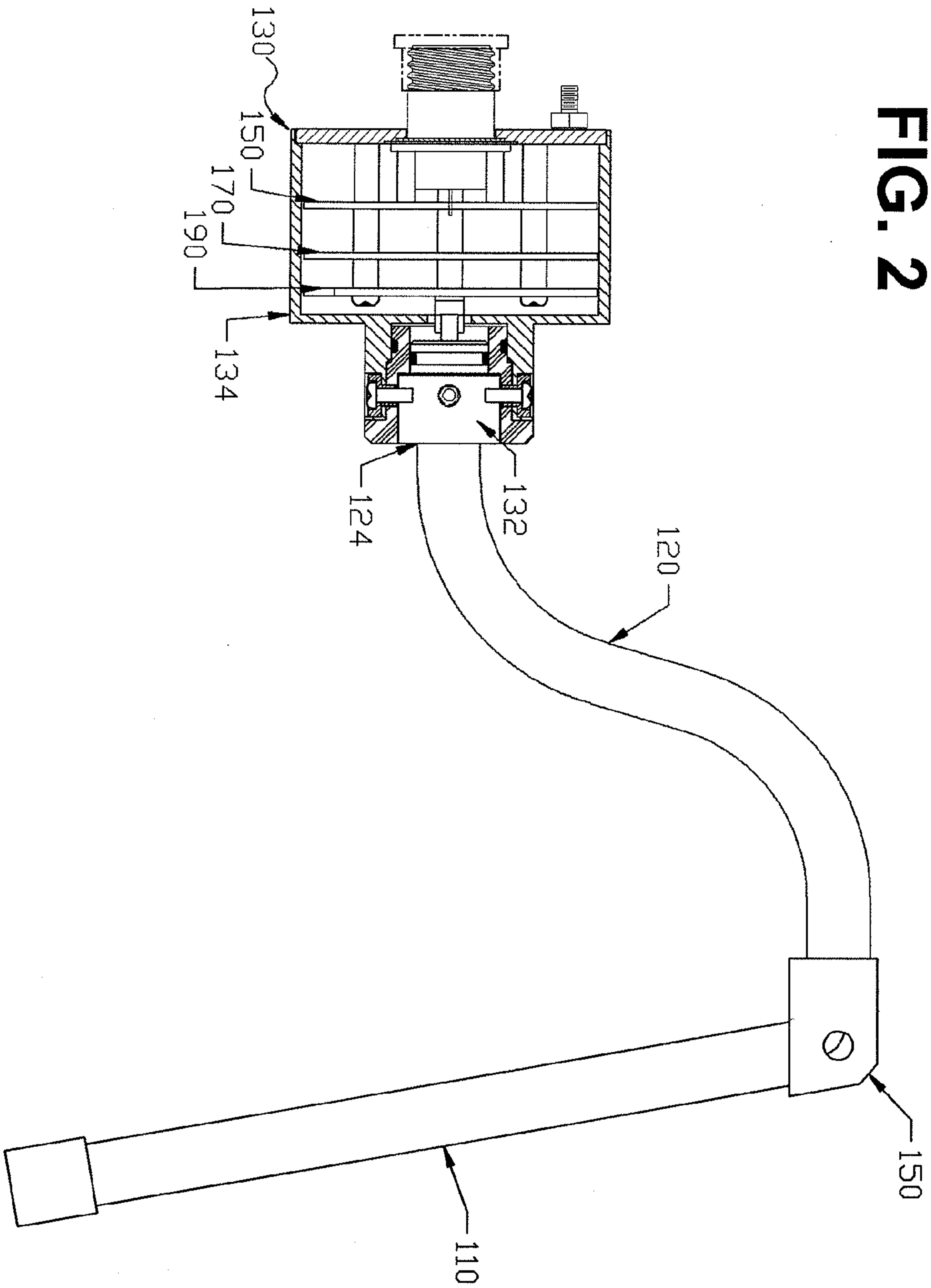


FIG. 2

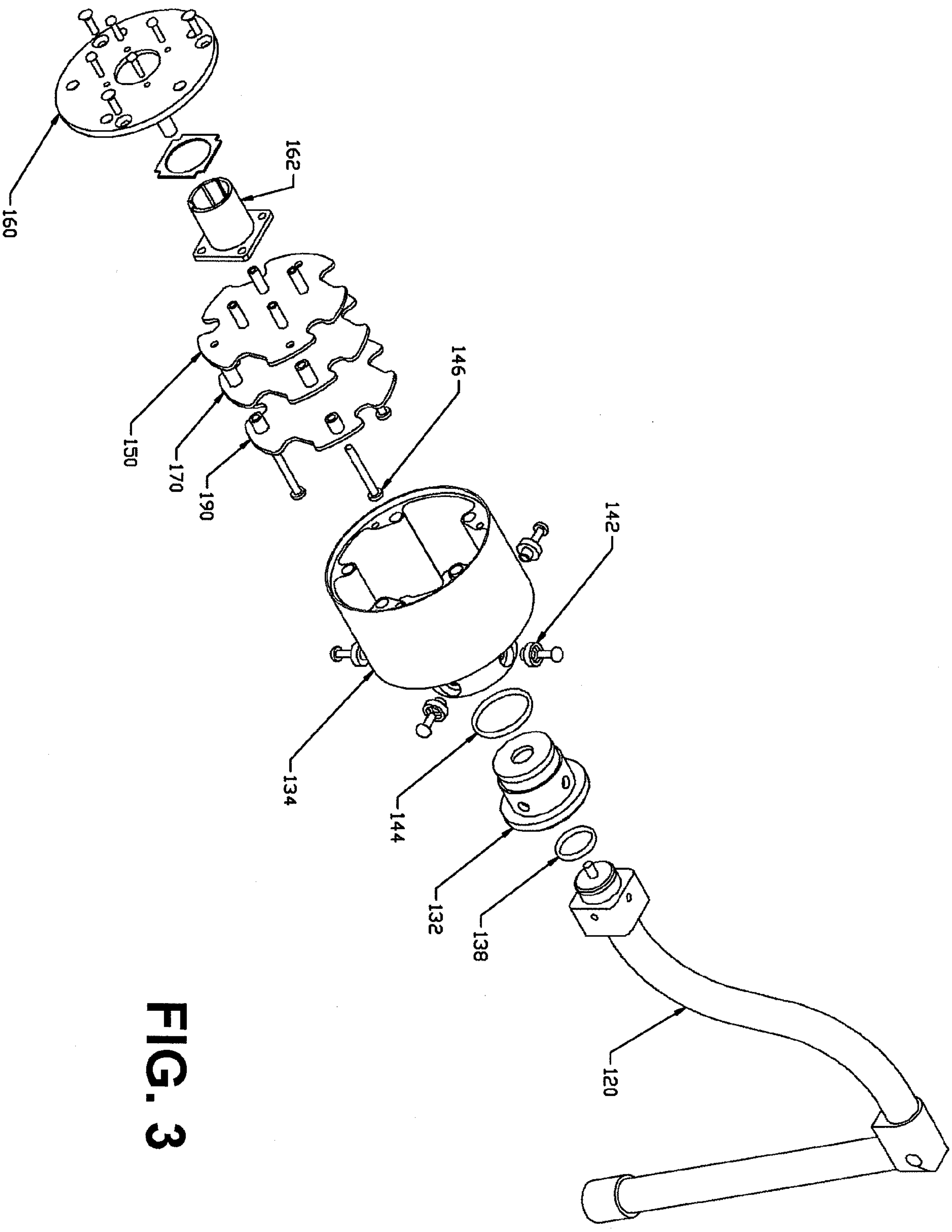


FIG. 3

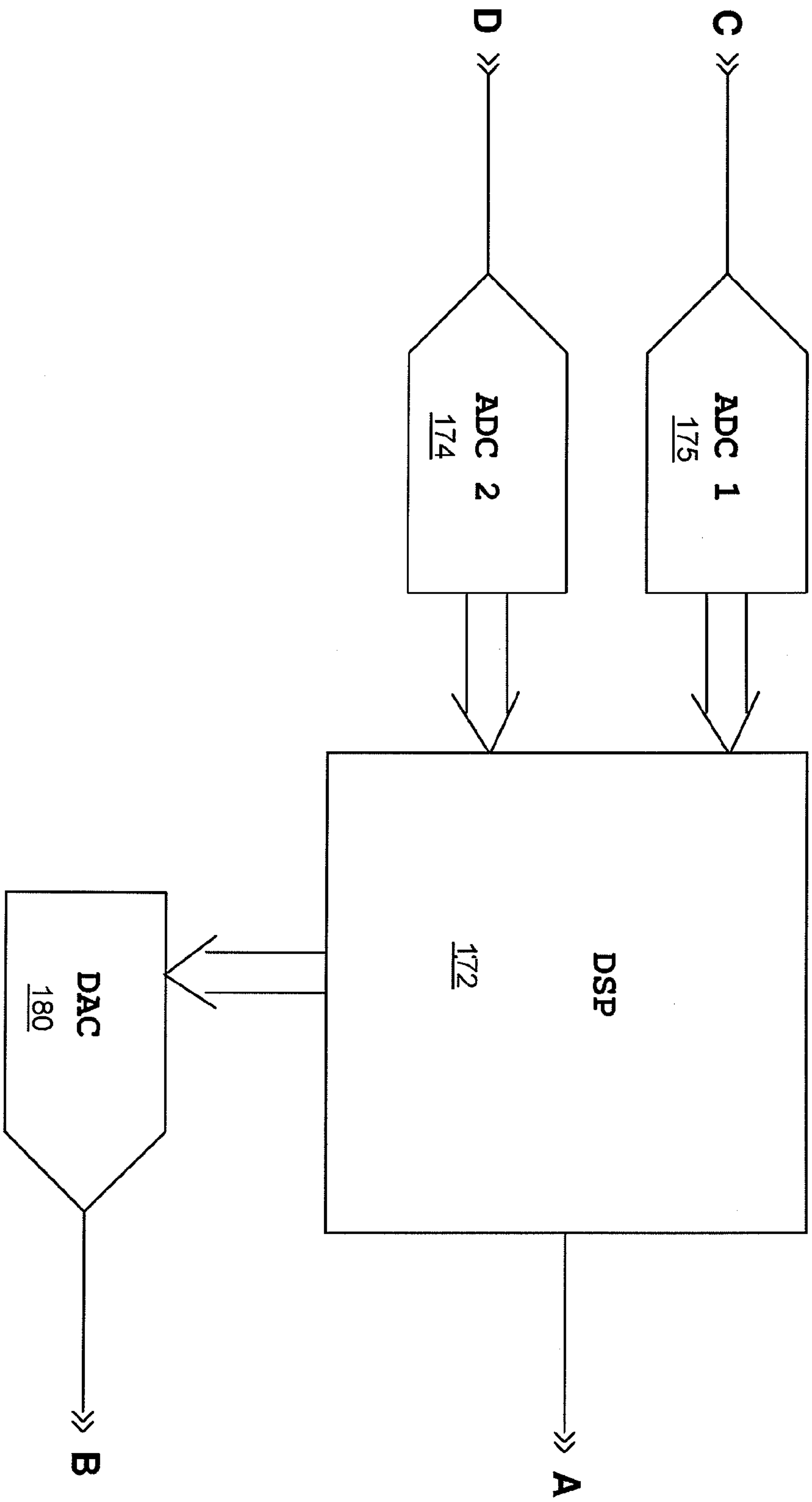
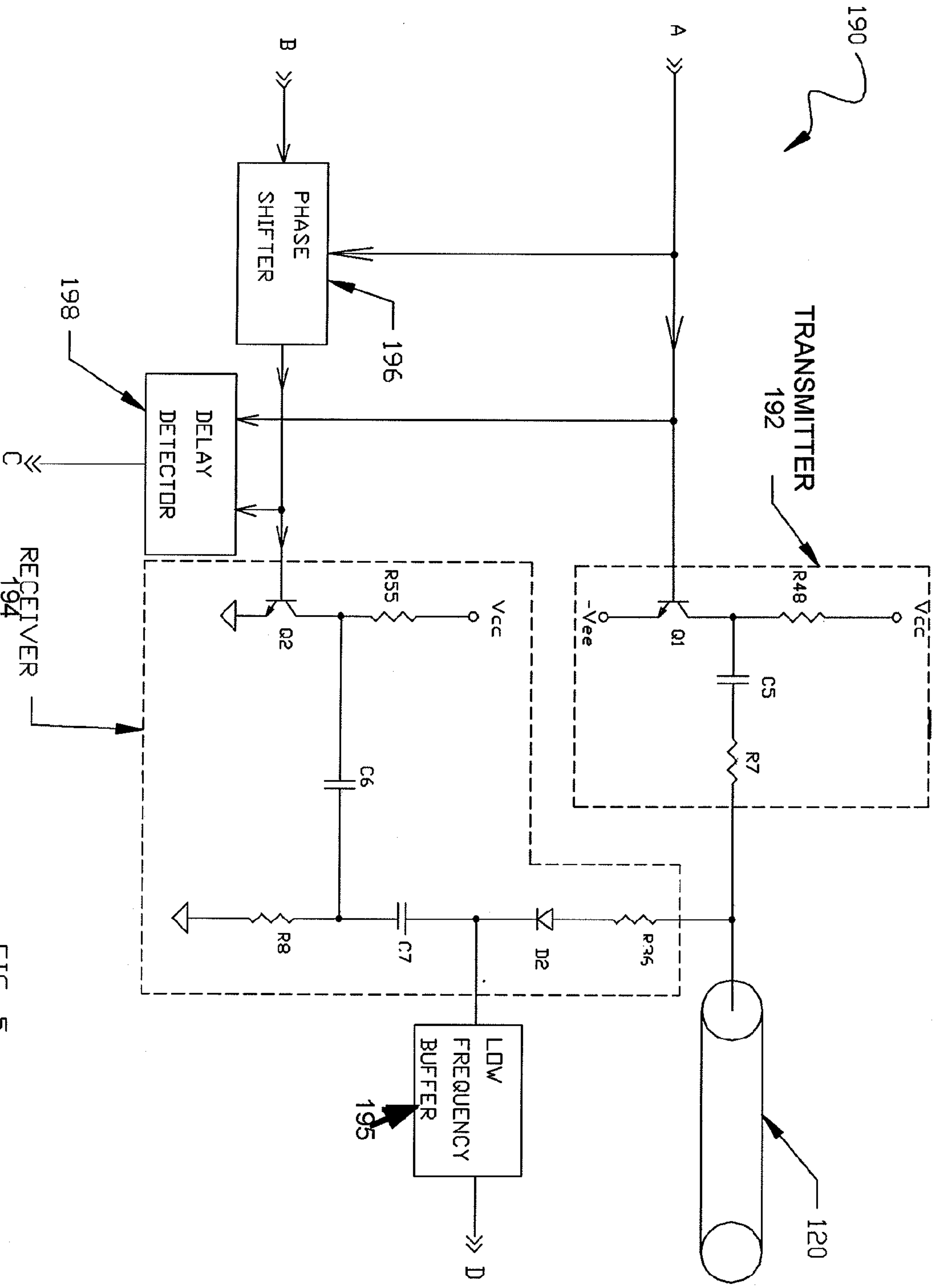


FIG. 4


190
A
B
TRANSMITTER
192
Vcc
R48
Q1
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C5
R7
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DETECTOR
198
C
RECEIVER
194
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C6
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FIG. 5

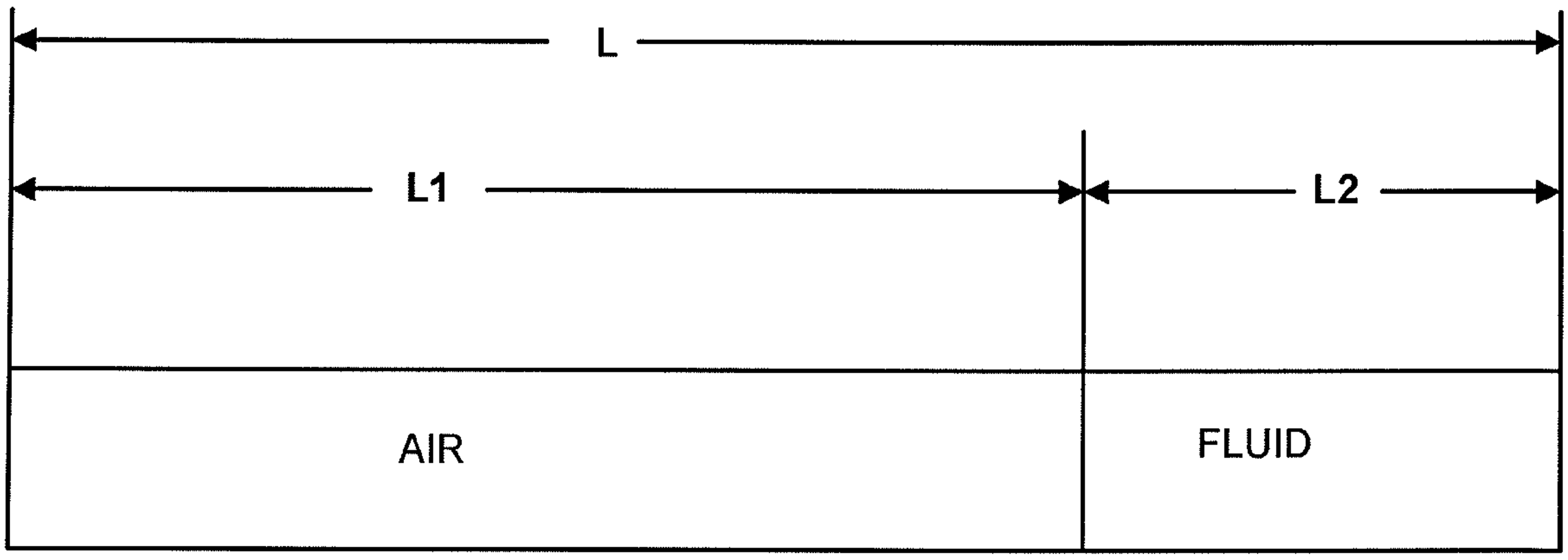


FIG. 6

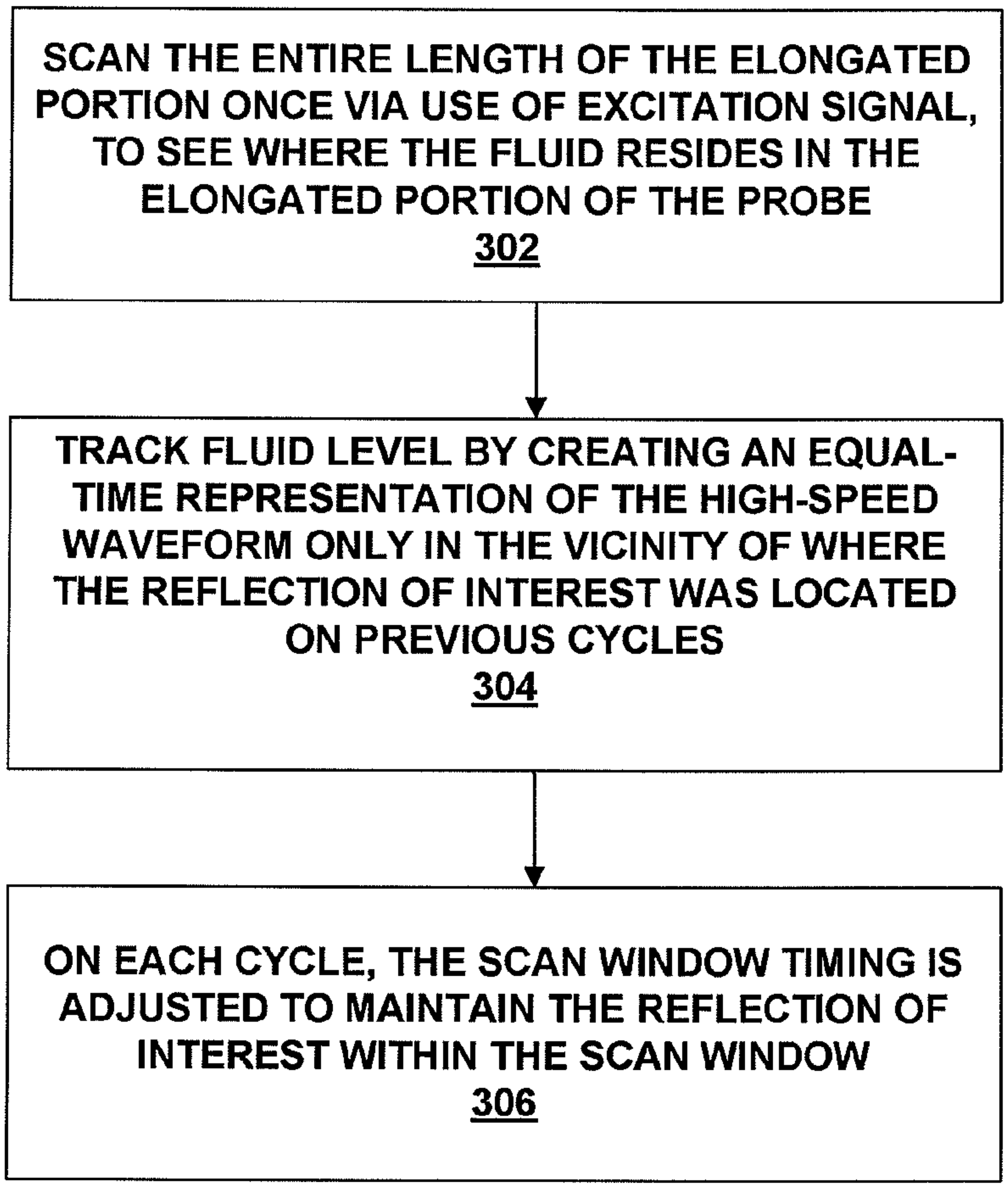

SCAN THE ENTIRE LENGTH OF THE ELONGATED PORTION ONCE VIA USE OF EXCITATION SIGNAL, TO SEE WHERE THE FLUID RESIDES IN THE ELONGATED PORTION OF THE PROBE
302
TRACK FLUID LEVEL BY CREATING AN EQUAL-TIME REPRESENTATION OF THE HIGH-SPEED WAVEFORM ONLY IN THE VICINITY OF WHERE THE REFLECTION OF INTEREST WAS LOCATED ON PREVIOUS CYCLES
304
ON EACH CYCLE, THE SCAN WINDOW TIMING IS ADJUSTED TO MAINTAIN THE REFLECTION OF INTEREST WITHIN THE SCAN WINDOW
306

FIG. 7

300

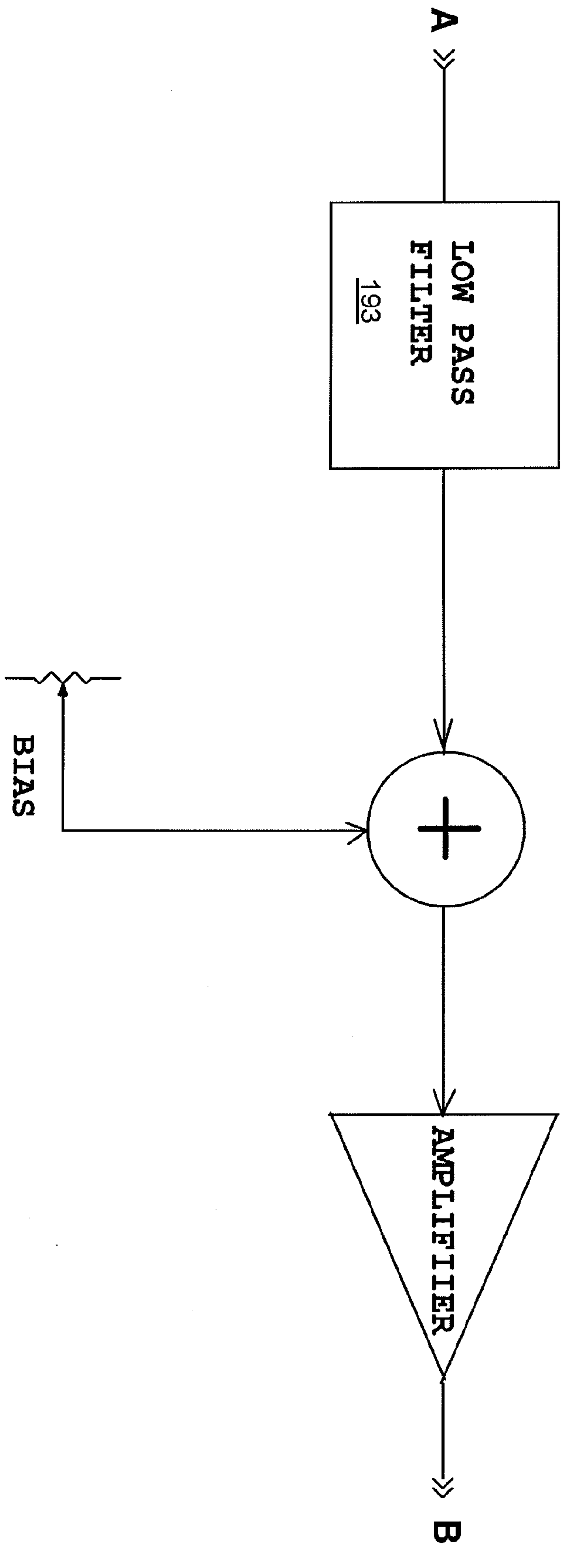
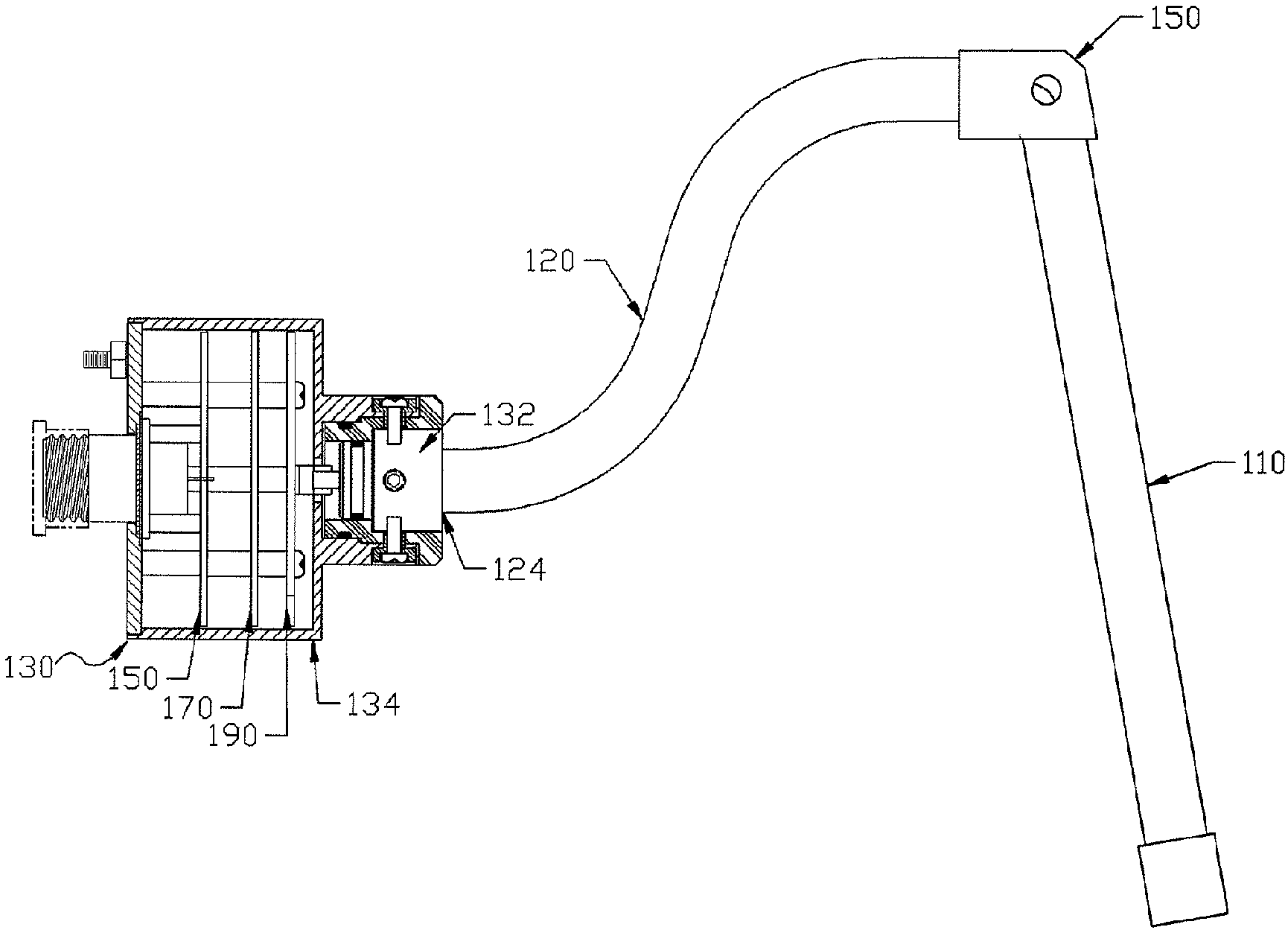


FIG. 8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