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(54) Benævnelse: **Cross-communication between electronic circuits and electrical devices in well tools**

(56) Fremdragne publikationer:
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# DESCRIPTION

**[0001]** This disclosure relates generally to equipment utilized and operations performed in conjunction with a subterranean well and, in one example described below, more particularly provides for increased reliability through redundancy in well tools.

**[0002]** Subterranean wells are hostile environments for electrical components. Failure of an electrical component can cost many hours and much expense to remedy. Therefore, it will be appreciated that improvements are continually needed in the art of utilizing electrical components in well tools.

**[0003]** US 2007/007001 A1 discloses a well instrumentation system, comprising: a power and data supply; and a plurality of functional units attached to the power and data supply, US 7,000,693 B2 discloses an apparatus controlling the operation of a hydrocarbon producing well. US 2005/121188 A1 discloses an apparatus for controlling a fluid production well, the disclosure of US 2005/121188 A1 being considered to correspond to the preamble of Claims 1, 4 and 9 below.

**[0004]** According to a first aspect of the present invention, there is provided a well tool, comprising: at least first and second electrical devices; and at least first and second electronic circuits configured to control operation of the respective first and second electrical devices, the first and second electronic circuits including at least respective first and second isolation circuits, wherein each of the first and second isolation circuits is configured to isolate a corresponding one of the first and second electronic circuits from a respective one of the first and second electrical devices, and each of the first and second isolation circuits is also configured to connect the corresponding one of the first and second electronic circuits to an opposite one of the first and second electrical devices, characterized in that the well tool is configured such that the isolation and connection take place in response to a predetermined condition that comprises current draw by one of the first and second electrical devices being greater than a predetermined threshold.

**[0005]** According to a second aspect of the present invention, there is provided a method of operating a well tool in a subterranean well, the method comprising providing first and second electronic circuits for operation of respective first and second electrical devices of the well tool, and disconnecting the first electronic circuit from the first electrical device in the well, characterised in that, in response to a predetermined condition comprising current draw by one of the first and second electrical devices being greater than a predetermined threshold: the disconnecting is performed; connecting of the second electronic circuit to the first electrical device in the well is performed; and isolating of the first electronic circuit from the second electrical device is performed.

**[0006]** According to a third aspect of the present invention, there is provided a method of operating a well tool in a subterranean well, the method comprising providing first and second

electronic circuits for operation of respective first and second electrical devices of the well tool, and disconnecting the first electronic circuit from the first electrical device in the well, characterised in that, in response to a predetermined condition comprising current draw by one of the first and second electrical devices being greater than a predetermined threshold: the disconnecting is performed; connecting of the first electronic circuit to the second electrical device in the well is performed; and isolating of the first electronic circuit from the second electrical device is performed.

**[0007]** For a more complete understanding of the present disclosure, reference is now made, by way of example only, to the following description and drawings of embodiments of the invention and of a background example, and in which:-

FIG. 1 is a representative partially cross-sectional view of a well system and associated method according to an embodiment of the invention;

FIG. 2 is a representative schematic view of an actuator section of a well tool according to an embodiment of the invention;

FIG. 3 is a representative schematic view of a circuit diagram for redundantly operating multiple electrical devices via a single downhole electronic control circuit according to an embodiment of the invention; and

FIG. 4 is a representative schematic view of another example of the actuator section according to an embodiment of the invention.

**[0008]** Representatively illustrated in FIG. 1 is a system 10 for use with a well, and an associated method, which system and method can embody principles of this disclosure. However, it should be clearly understood that the system 10 and method are merely one example of an application of the principles of this disclosure in practice, and a wide variety of other examples are possible. Therefore, the scope of this disclosure is not limited at all to the details of the system 10 and method described herein and/or depicted in the drawings.

**[0009]** In the FIG. 1 example, a well tool 12 is connected in a tubular string 14 positioned in a wellbore 16. In the depicted example, the well tool 12 is of the type known to those skilled in the art as a safety valve 18 with a remotely controlled actuator section 20 for actuating the valve to its open and closed configurations, in which flow through the tubular string 14 is respectively permitted and prevented.

**[0010]** However, the scope of this disclosure is not limited to use only with safety valves. Other types of well tools can also benefit from the principles described herein.

**[0011]** As depicted in FIG. 1, the safety valve 18 includes an opening prong 22, which is displaced downward to pivot a flapper 24 to its open position, in which flow is permitted longitudinally through the safety valve. The opening prong 22 can be displaced upward to allow

the flapper 24 to pivot to its closed position, in which at least upward flow is prevented through the safety valve.

**[0012]** The opening prong 22 is displaced by redundant actuators 26a,b of the actuator section 20. Although two actuators 26a,b are depicted in FIG. 1, any number of actuators may be used, as desired.

**[0013]** The actuators 26a,b have redundancy, in that either of them may be used to actuate the safety valve 18 by displacing the opening prong 22. A particular actuator 26a,b is redundant, in that it can be used to displace the opening prong 22 in the event that another actuator is not available, whether or not the particular actuator was previously used for displacing the opening prong.

**[0014]** In the FIG. 1 example, the actuator section 20 is controlled via lines 28 extending to a remote location (such as, the earth's surface, a subsea location, etc.). In other examples, the actuator section 20 could be controlled via wireless telemetry, or it could be controlled locally. The scope of this disclosure is not limited to any particular well tool control location or means.

**[0015]** Referring additionally now to FIG. 2, an example of the actuator section 20 is representatively illustrated, apart from the remainder of the well tool 12. In this example, it may be seen that each of the actuators 26a,b includes an electronic circuit 30a,b for controlling operation of a respective electrical device 32a,b.

**[0016]** The electrical devices 32a,b comprise motors in this example, with each motor having an associated motor winding 34a,b. However, in other examples the electrical devices 32a,b could be other types of electrical devices, such as, electrical brakes, clutches, valves, etc.

**[0017]** In normal operation, electronic circuit 30a is used to control operation of the device 32a, and electronic circuit 30b is used to control operation of device 32b. However, the electronic circuit 30a can be used to operate the device 34b, and the electronic circuit 30b can be used to operate the device 32a.

**[0018]** Referring additionally now to FIG. 3, the electronic circuit 30a is representatively illustrated in schematic form. In this view, it may be seen that the electronic circuit 30a includes a driver circuit 36 and an isolation circuit 38. The other electronic circuit 30b is similarly configured.

**[0019]** The isolation circuit 38 isolates the motor windings 34a,b (and any other common actuator windings) from the driver circuit 36 if the driver circuit fails. In addition, the isolation circuit 38 isolates the driver circuit 36 from a failed motor winding 34a,b.

**[0020]** The isolation circuit 38 is triggered by excessive current draw by the respective device 32a,b. The isolation circuit 38 isolates the output of an electronic circuit 30a,b from its respective electrical device 32a,b.

**[0021]** The electronic circuits 30a,b, thus, have multiple outputs and the isolation circuits 38 that allow the electronic circuits 30a,b to switch electrical power from one output to another, as needed. This switching is not necessarily permanent. The switching can be software or hardware driven. Preferably, the switching of the outputs may also be initiated by a command from a remote location, and in response the downhole electronic circuits 30a,b performing the actual switching.

**[0022]** For example, if the electronic circuit 30b fails (e.g., the driver circuit 36 thereof fails), but the electrical device 32b can still be used to actuate the well tool 12, the isolation circuit 38 of the electronic circuit 30b disconnects the driver circuit 36 of the electronic circuit 30b from the device 32b, and the isolation circuit of the electronic circuit 30a connects the driver circuit of the electronic circuit 30a to the device 32b, so that the electronic circuit 30a can be used to operate the device 32b. Such a change is performed automatically in response to the failure of the electronic circuit 30b.

**[0023]** Similarly, if the electronic circuit 30a fails (e.g., the driver circuit 36 thereof fails), but the electrical device 32a can still be used to actuate the well tool 12, the isolation circuit 38 of the electronic circuit 30a disconnects the driver circuit 36 of the electronic circuit 30a from the device 32a, and the isolation circuit of the electronic circuit 30b connects the driver circuit of the electronic circuit 30b to the device 32a, so that the electronic circuit 30b can be used to operate the device 32a. Such a change is performed automatically in response to the failure of the electronic circuit 30a.

**[0024]** Thus, if either of the electronic circuits 30a,b fails, the electrical device 32a,b formerly operated by the failed electronic circuit is instead operated by the still operational one of the electronic circuits. The failed one of the electronic circuits 30a,b is effectively isolated from its respective electrical device 32a,b in this situation.

**[0025]** In some situations, only a portion of an electronic circuit 30a,b may fail that prevents the respective one of the actuators 26a,b from being operated. For example, a motor driver circuit, a clutch driver circuit, etc., may fail, without resulting in an increase in current draw by the respective actuator 26a,b.

**[0026]** In those situations, in a background example, a voltage greater than a normal operating voltage could be transmitted via a respective line 28a,b from the surface. This would trigger an isolation circuit 38 that is driven by a voltage. Upon triggering the isolation circuit 38 with the overvoltage, the electronic circuit 30a and actuator 26a would disconnect.

**[0027]** In some situations, portions of an electronic circuit 30a,b may be functioning, but the respective device 32a,b cannot be operated. In those situations, and others, a command could be sent from the surface to activate the associated isolation circuit 38, thereby isolating the electronic circuit 30a,b, in total or in part.

**[0028]** The isolation circuit 38 can comprise, in some examples, a switch type circuit for selectively connecting and disconnecting the driver circuit 36 and/or other portions of the associated electronic circuit 30a,b to its respective electrical device 32a,b. The isolation circuit 38 can be similar to a normally closed transistor(s), which is open when activated.

**[0029]** Referring additionally now to FIG. 4, another example of the actuator section 20 is representatively illustrated. In this example, each of the devices 32a,b includes multiple windings 34a,b. Each electronic circuit 30a,b is used to control electrical power delivery to the respective windings 34a,b in both of the devices 32a,b.

**[0030]** In the event of a failure of either electronic circuit 30a,b, an isolation circuit 38 is activated, and power to the failed electronic circuit 30a,b is disconnected. If power to the failed circuit 30a,b is not turned off, the respective device 32a,b could have residual magnetism from current in the circuit 30a,b which may prevent the device from operating properly.

**[0031]** It may now be fully appreciated that significant advancements are provided to the art by the above disclosure. In examples described above, multiple well tool actuators 26a,b can be operated redundantly, even though an electronic circuit 30a,b or an electrical device 32a,b thereof fails.

**[0032]** A well tool 12 is provided to the art by the above disclosure. In one example, the well tool 12 includes at least first and second electrical devices 32a,b, at least first and second electronic circuits 30a,b which control operation of the respective first and second electrical devices 32a,b, the first and second electronic circuits 30a,b including at least respective first and second isolation circuits 38, wherein each of the first and second isolation circuits 38 isolates a corresponding one of the first and second electronic circuits 30a,b from a respective one of the first and second electrical devices 32a,b in response to a predetermined condition.

**[0033]** Each of the first and second isolation circuits 38 connect the corresponding one of the first and second electronic circuits 30a,b to an opposite one of the first and second electrical devices 32a,b in response to the predetermined condition.

**[0034]** The predetermined condition comprises current draw by the respective one of the first and second electrical devices 32a,b being greater than a predetermined threshold. The predetermined condition may also comprise, in addition to the current draw exceeding a predetermined threshold, voltage across the respective one of the first and second electrical devices 32a,b greater than a predetermined threshold, a predetermined signal transmitted from a remote location (for example, via the lines 28), and/or a failure of the respective one of the first and second electrical devices 32a,b.

**[0035]** The first and second electrical devices 32a,b may comprise motor windings. The first and second electrical devices 32a,b may actuate the well tool 12 positioned in a subterranean well.

**[0036]** A method of operating a well tool 12 in a subterranean well is also described above. In one example, the method comprises: providing first and second electronic circuits 30a,b for operation of respective first and second electrical devices 32a,b of the well tool 12; disconnecting the first electronic circuit 30a from the first electrical device 32a in the well; and connecting the second electronic circuit 30b to the first electrical device 32a in the well.

**[0037]** The method includes isolating the first electronic circuit 30a from the second electrical device 32b.

**[0038]** The method includes operating the second electrical device 32b with the second electronic circuit 30b.

**[0039]** The method includes operating the first and second electrical devices 32a,b with the second electronic circuit 30b.

**[0040]** The disconnecting step is performed in response to a predetermined condition of current draw by the respective one of the first and second electrical devices being greater than a predetermined threshold.

**[0041]** Each of the first and second electrical devices 32a,b may comprise multiple motor windings 34a,b.

**[0042]** Another method of operating a well tool 12 in a subterranean well comprises: providing first and second electronic circuits 30a,b for operation of respective first and second electrical devices 32a,b of the well tool 12; disconnecting the first electronic circuit 30a from the first electrical device 32a in the well; and connecting the first electronic circuit 30a to the second electrical device 32b in the well.

**[0043]** The method can include, prior to the connecting the first electronic circuit 30a to the second electrical device 32b: operating the second electrical device 32b with the second electronic circuit 30b and then disconnecting the second electronic circuit 30b from the second electrical device 32b in the well.

**[0044]** The step of connecting the first electronic circuit 30a to the second electrical device 32b includes connecting the first electronic circuit 30a to a first one of multiple motor windings 34a,b of the second electrical device 32b. The method also includes operating the second electrical device 32b with the second electronic circuit 30b connected to a second one of the multiple motor windings 34a,b.

**[0045]** The disconnecting step is performed in response to a predetermined condition. The predetermined condition comprises current draw by the first electrical device 32a being greater than a predetermined threshold.

**[0046]** Although various examples have been described above, with each example having

certain features, it should be understood that it is not necessary for a particular feature of one example to be used exclusively with that example. Instead, any of the features described above and/or depicted in the drawings can be combined with any of the examples, in addition to or in substitution for any of the other features of those examples. One example's features are not mutually exclusive to another example's features. Instead, the scope of this disclosure encompasses any combination of any of the features.

**[0047]** Although each example described above includes a certain combination of features, it should be understood that it is not necessary for all features of an example to be used. Instead, any of the features described above can be used, without any other particular feature or features also being used.

**[0048]** It should be understood that the various embodiments described herein may be utilized in various orientations, such as inclined, inverted, horizontal, vertical, etc., and in various configurations, without departing from the principles of this disclosure. The embodiments are described merely as examples of useful applications of the principles of the disclosure, which is not limited to any specific details of these embodiments.

**[0049]** In the above description of the representative examples, directional terms (such as "above," "below," "upper," "lower," etc.) are used for convenience in referring to the accompanying drawings. However, it should be clearly understood that the scope of this disclosure is not limited to any particular directions described herein.

**[0050]** The terms "including," "includes," "comprising," "comprises," and similar terms are used in a non-limiting sense in this specification. For example, if a system, method, apparatus, device, etc., is described as "including" a certain feature or element, the system, method, apparatus, device, etc., can include that feature or element, and can also include other features or elements. Similarly, the term "comprises" is considered to mean "comprises, but is not limited to."

**[0051]** Of course, a person skilled in the art would, upon a careful consideration of the above description of representative embodiments of the disclosure, readily appreciate that many modifications, additions, substitutions, deletions, and other changes may be made to the specific embodiments, and such changes are contemplated by the principles of this disclosure. For example, structures disclosed as being separately formed can, in other examples, be integrally formed and *vice versa.* Accordingly, the foregoing detailed description is to be clearly understood as being given by way of illustration and example only, the invention being solely defined by the appended claims.

# REFERENCES CITED IN THE DESCRIPTION

This list of references cited by the applicant is for the reader's convenience only. It does not

form part of the European patent document. Even though great care has been taken in compiling the references, errors or omissions cannot be excluded and the EPO disclaims all liability in this regard.

**Patent documents cited in the description**


- US2007007001A1 [0003]
- US7000693B2 [0003]
- US2005121188A1 [0003] [0003]

Title: Kryds-kommunikation mellem elektroniske kredsløb og elektriske indretninger i brøndværktøjer

Krav:

1. Brøndværktøj (12) omfattende: mindst første og anden elektrisk indretninger (32a,b); og mindst første og anden elektronisk kredsløb (30a,b), der er konfigurerede til at styre betjeningen af de respektive første og anden elektriske enheder, de første og anden elektroniske kredsløb indbefatter mindst respektive første og anden isoleringskredsløb (38),
hvori hvert af de første og anden isoleringskredsløb er konfigureret til at isolere et tilsvarende et af de første og anden elektroniske kredsløb fra en af de respektive første og anden elektriske indretninger, og hvert af de første og anden isoleringskredsløb også er konfigureret til at forbinde det tilsvarende ene af de første og anden elektroniske kredsløb til en modsat en af de første og anden elektriske indretninger, **kendetegnet ved at** brøndværktøjet er konfigureret således, at isoleringen og forbindelsen finder sted som reaktion på en forudbestemt tilstand, der omfatter at strømtræk af en af de første og anden elektriske indretninger er større end en forudbestemt tærskelværdi.

2. Brøndværktøj ifølge krav 1, hvori de første og anden elektriske indretninger omfatter motorviklinger (34a,b).

3. Brøndværktøj ifølge krav 1 eller krav 2, hvori de første og anden elektriske indretninger er konfigurerede til at aktivere brøndværktøjet, der er placeret i en underjordisk brønd.

4. Fremgangsmåde til betjening af et brøndværktøj (12) i en underjordisk brønd, fremgangsmåden omfatter at tilvejebringe første og anden elektroniske kredsløb (30a,b) til betjening af brøndværktøjets respektive første og anden elektriske indretninger (32a,b), og at frakoble det første elektroniske kredsløb fra den første elektriske indretning i brønden,
**kendetegnet ved at**, som reaktion på en forudbestemt tilstand, der omfatter at strømtræk af en af de første og anden elektriske indretninger er større end en forudbestemt tærskelværdi:
at udføre frakoblingen;
at udføre tilslutning af det anden elektroniske kredsløb til den første elektriske indretning i brønden; og

at udføre isolering af det første elektroniske kredsløb fra den anden elektriske indretning.

5. Fremgangsmåde ifølge krav 4, yderligere omfattende betjening af den anden elektriske indretning med det anden elektroniske kredsløb.

6. Fremgangsmåde ifølge krav 4 eller krav 5, yderligere omfattende betjening af de første og anden elektriske indretninger med det anden elektroniske kredsløb.

7. Fremgangsmåde ifølge ethvert af kravene 4 til 6, hvori de første og anden elektriske indretninger omfatter motorviklinger (34a,b).

8. Fremgangsmåde ifølge krav 7, hvori hver af de første og anden elektriske indretninger omfatter flere motorviklinger.

9. Fremgangsmåde til betjening af et brøndværktøj (12) i en underjordisk brønd, fremgangsmåden omfatter at tilvejebringe første og anden elektroniske kredsløb (30a,b) til betjening af brøndværktøjets respektive første og anden elektriske indretninger (32a,b), og at frakoble det første elektroniske kredsløb fra den første elektriske indretning i brønden,

**kendetegnet ved at**, som reaktion på en forudbestemt tilstand, der omfatter at strømtræk af en af de første og anden elektriske indretninger er større end en forudbestemt tærskelværdi:

at udføre frakoblingen;

at udføre tilslutning af det første elektroniske kredsløb til den anden elektriske indretning i brønden; og

at udføre isolering af det første elektroniske kredsløb fra den anden elektriske indretning.

10. Fremgangsmåde ifølge krav 9, yderligere omfattende, før tilslutningen af det første elektroniske kredsløb til den anden elektriske indretning: at betjene den anden elektriske indretning med det anden elektroniske kredsløb og derefter at frakoble det anden elektroniske kredsløb fra den anden elektriske indretning i brønden.

11. Fremgangsmåde ifølge krav 9 eller krav 10, hvori tilslutning af det første elektroniske kredsløb til den anden elektriske indretning yderligere omfatter at forbinde det første elektroniske kredsløb til en første en af flere motorviklinger (34a,b) i den anden elektriske indretning.

12. Fremgangsmåde ifølge ethvert af kravene 9 til 11, der yderligere omfatter betjening af den anden elektriske indretning med det anden elektroniske kredsløb, der er forbundet til en anden en af de flere motorviklinger.

13. Fremgangsmåde ifølge krav 9 eller krav 10, hvori de første og anden elektriske indretninger omfatter motorviklinger.

14. Fremgangsmåde ifølge krav 13, hvori hver af de første og anden elektriske indretninger omfatter flere motorviklinger.

# DRAWINGS

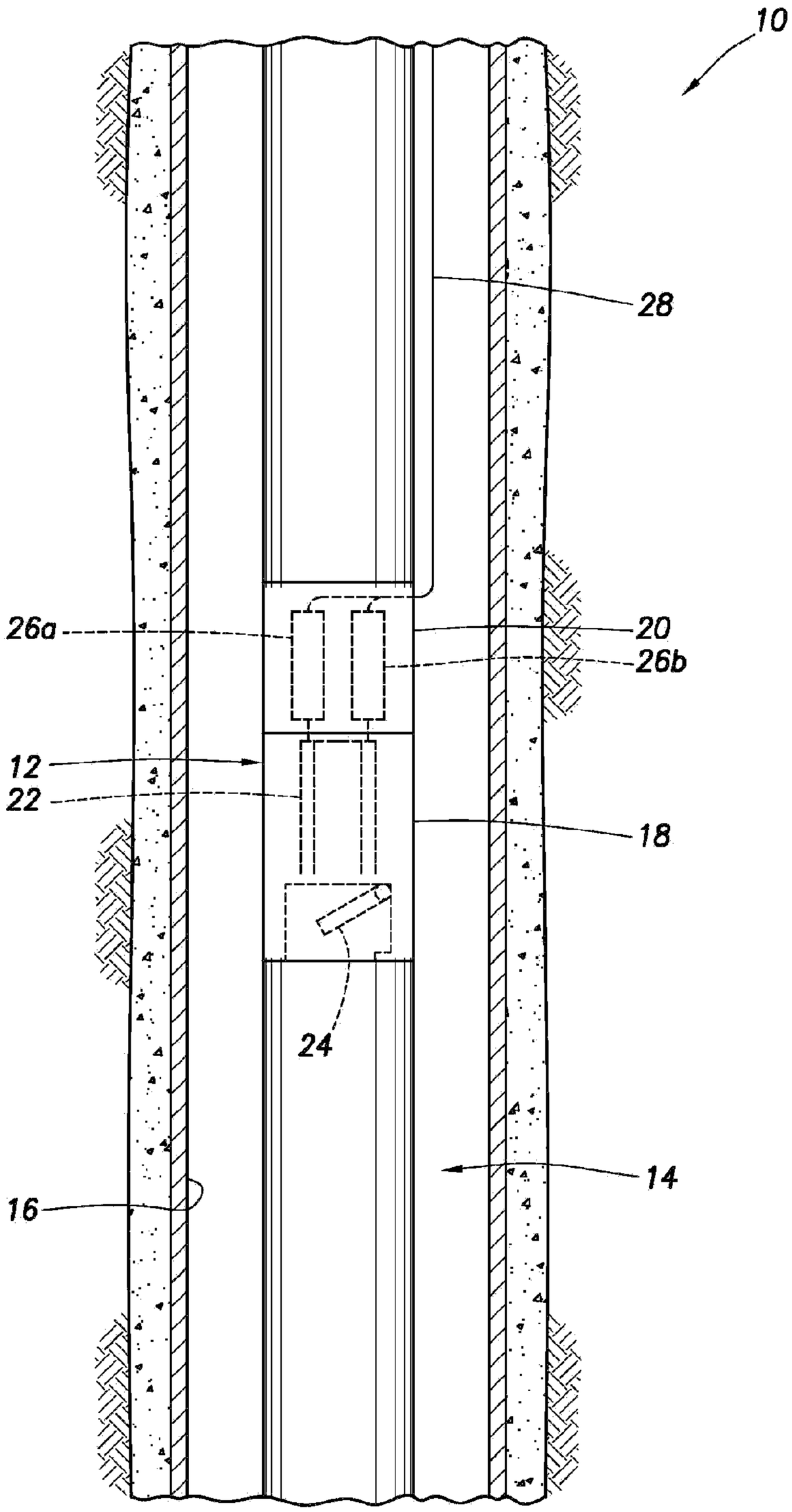


FIG. 1

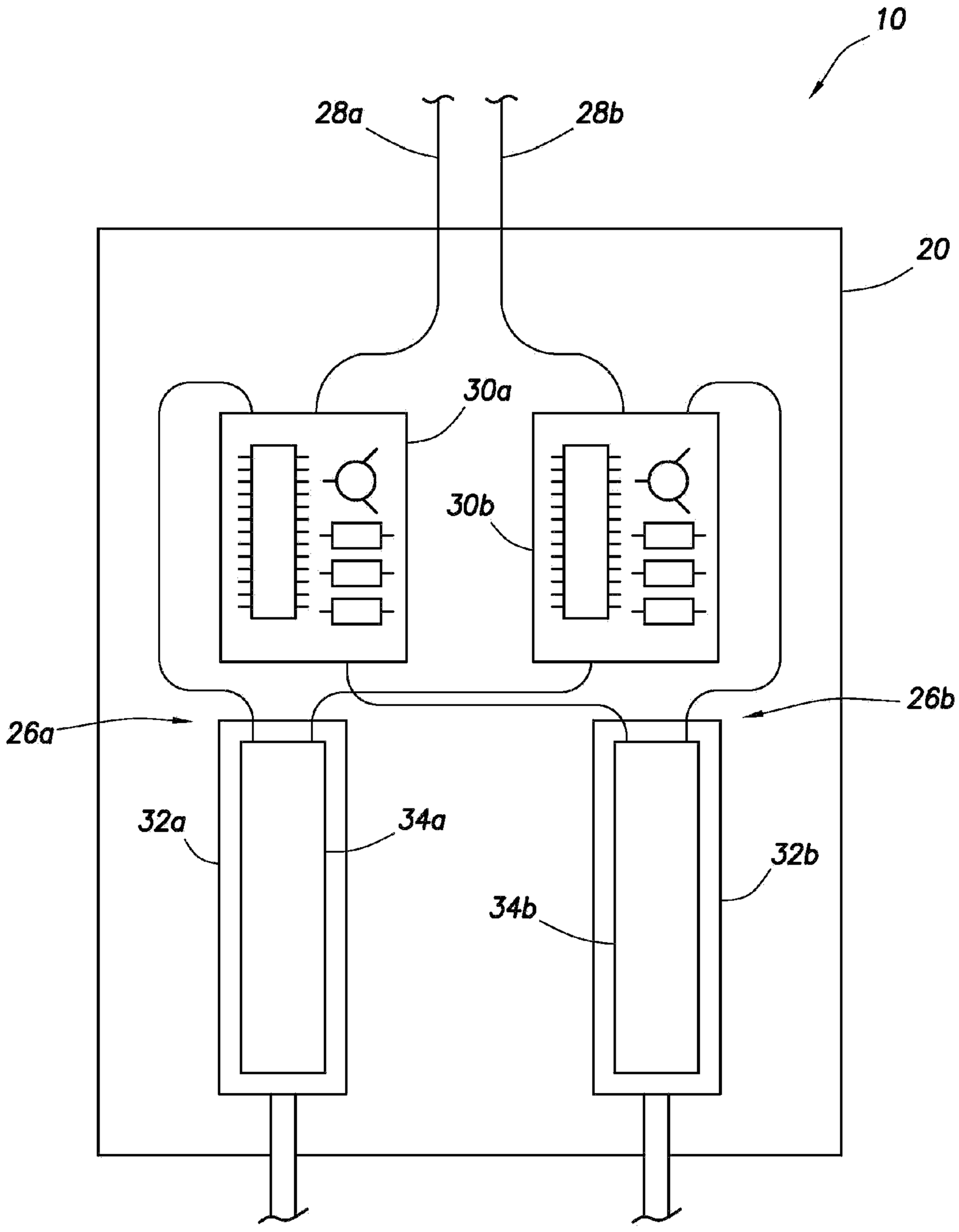


FIG.2

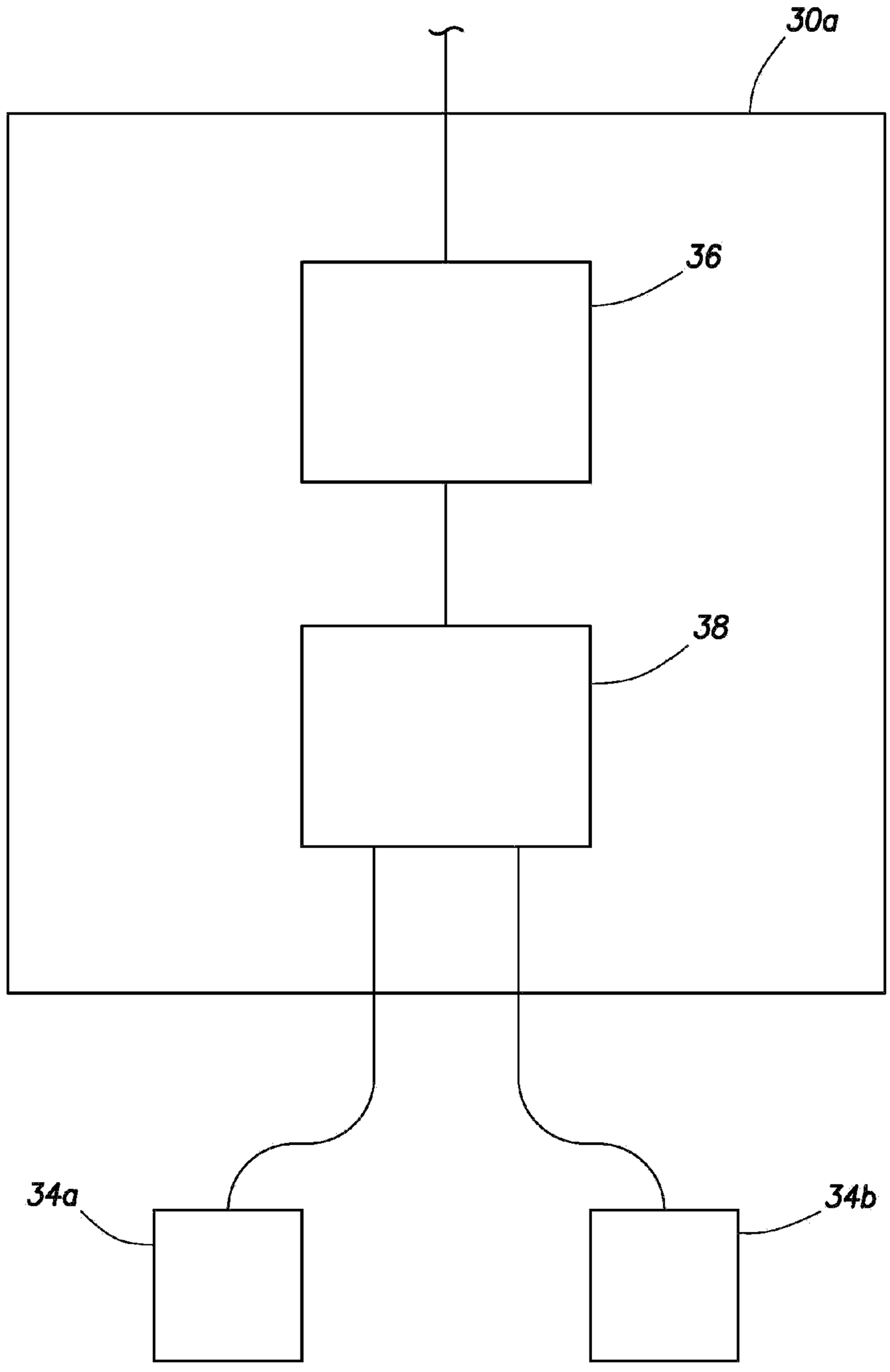


FIG.3

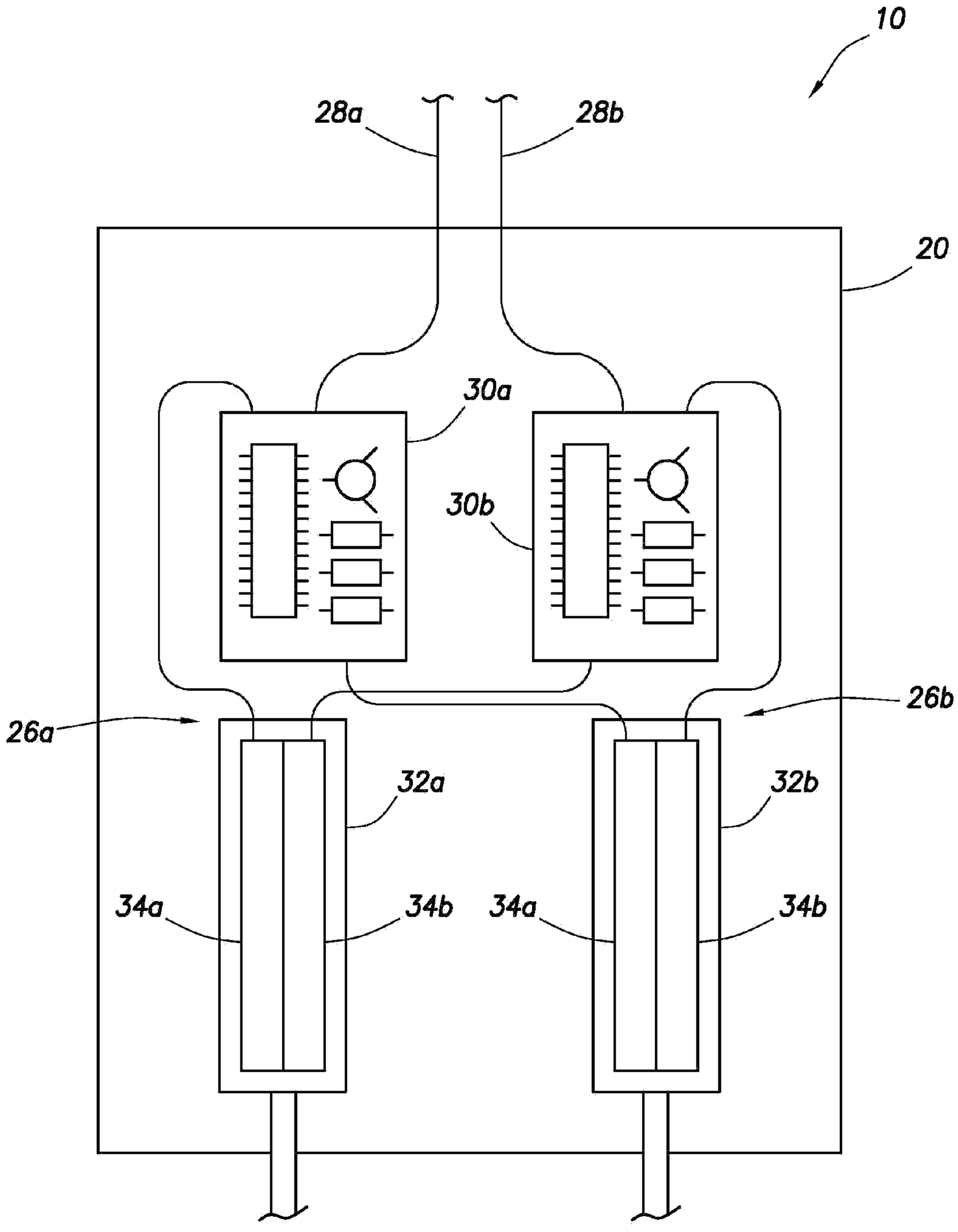


FIG.4