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(54) **SENSING SYSTEM FOR MEASURING SOIL PROPERTIES IN REAL TIME**

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(58) **Field of Classification Search**
CPC G01N 27/22; G01N 33/24; G01N 33/246; G01N 2033/243; G01N 2033/245; G01R 27/26; G01S 19/13; A01C 21/007; A01C 5/046; A01B 47/00; A01B 79/005
See application file for complete search history.

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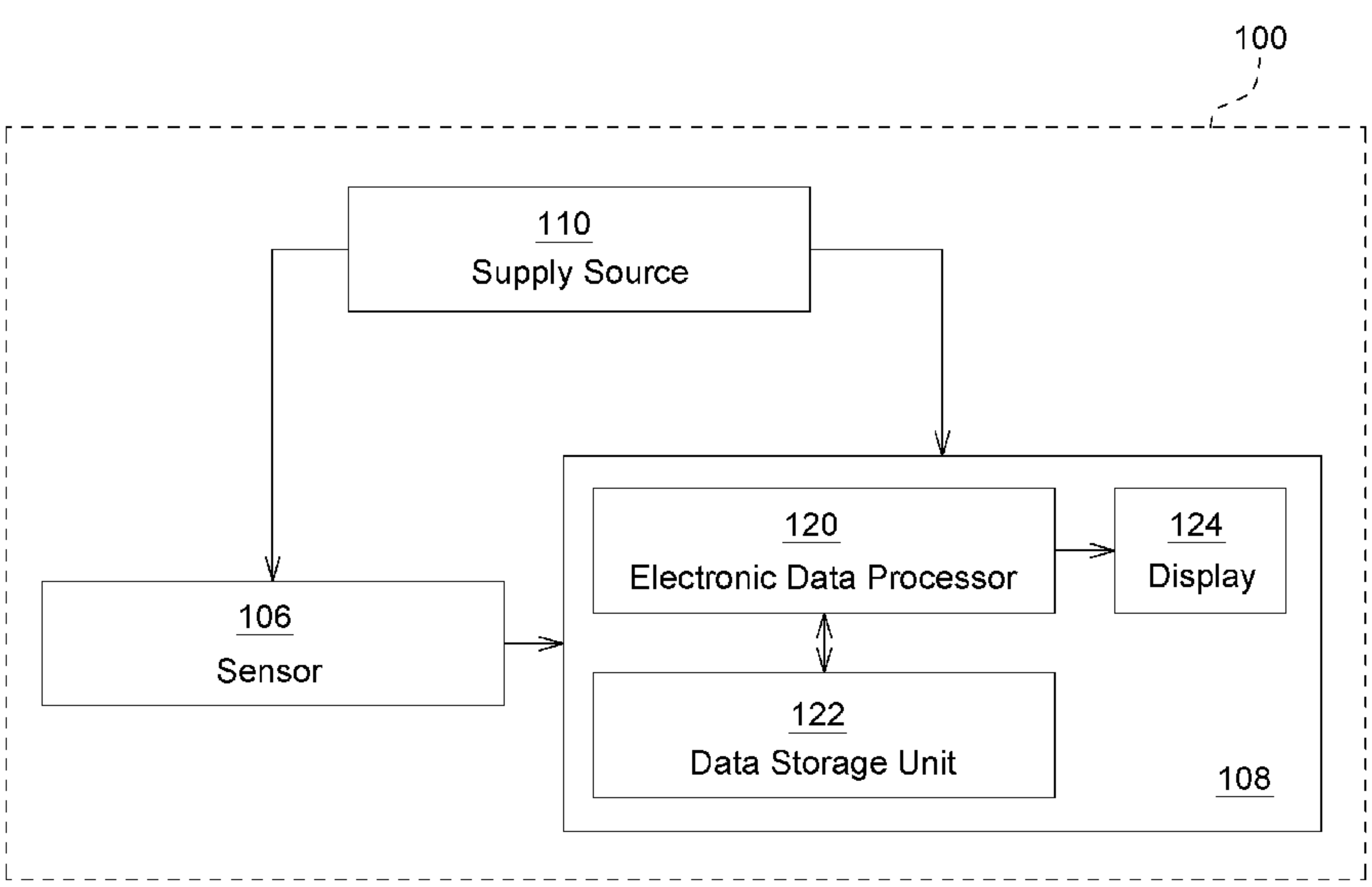
(57) **ABSTRACT**

A sensing system for obtaining a gradient of soil properties in real-time as a function of soil depth is disclosed herein. The sensing system includes a support structure coupled to an agricultural implement and which is rotatable about a rotational axis relative to a frame of the agricultural implement. A sensor is arranged on a surface of the support structure and configured to generate an output signal indicative of the measured soil property based on a sensed a capacitance change corresponding to a change in a dielectric property of a measured soil sample with which the sensor interacts. A measuring unit is coupled to the at least one sensor and processes the output signal generated by the at least one sensor to generate a gradient profile of the soil properties in real-time as a function of one or more depths for display on a user interface.

13 Claims, 6 Drawing Sheets



(51) **Int. Cl.**

G01S 19/13	(2010.01)
A01C 21/00	(2006.01)
A01B 47/00	(2006.01)
A01B 79/00	(2006.01)
A01C 5/06	(2006.01)

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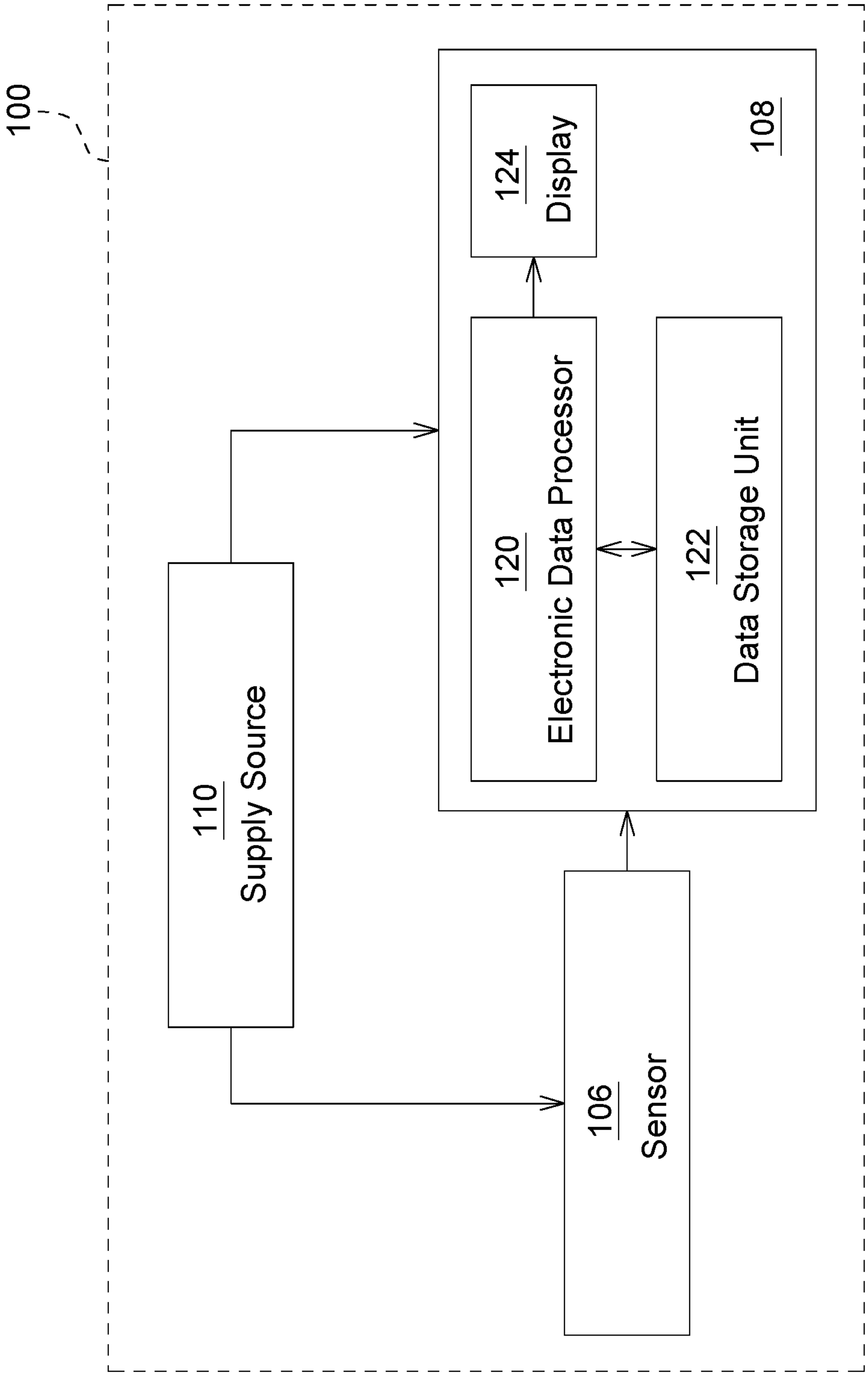

100
124
Display
108
120
Electronic Data Processor
122
Data Storage Unit
110
Supply Source
106
Sensor

FIG. 1

FIG. 2A

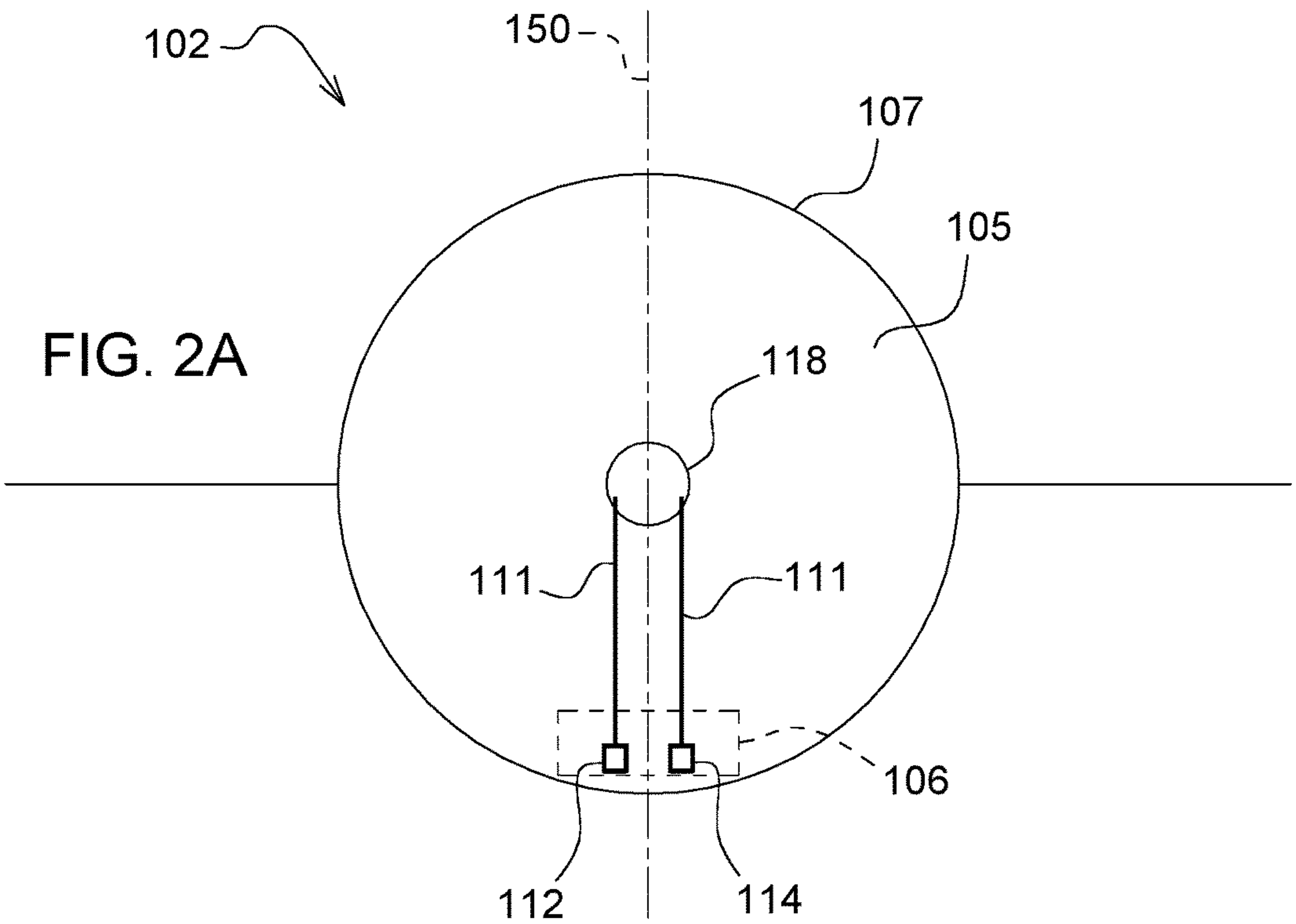
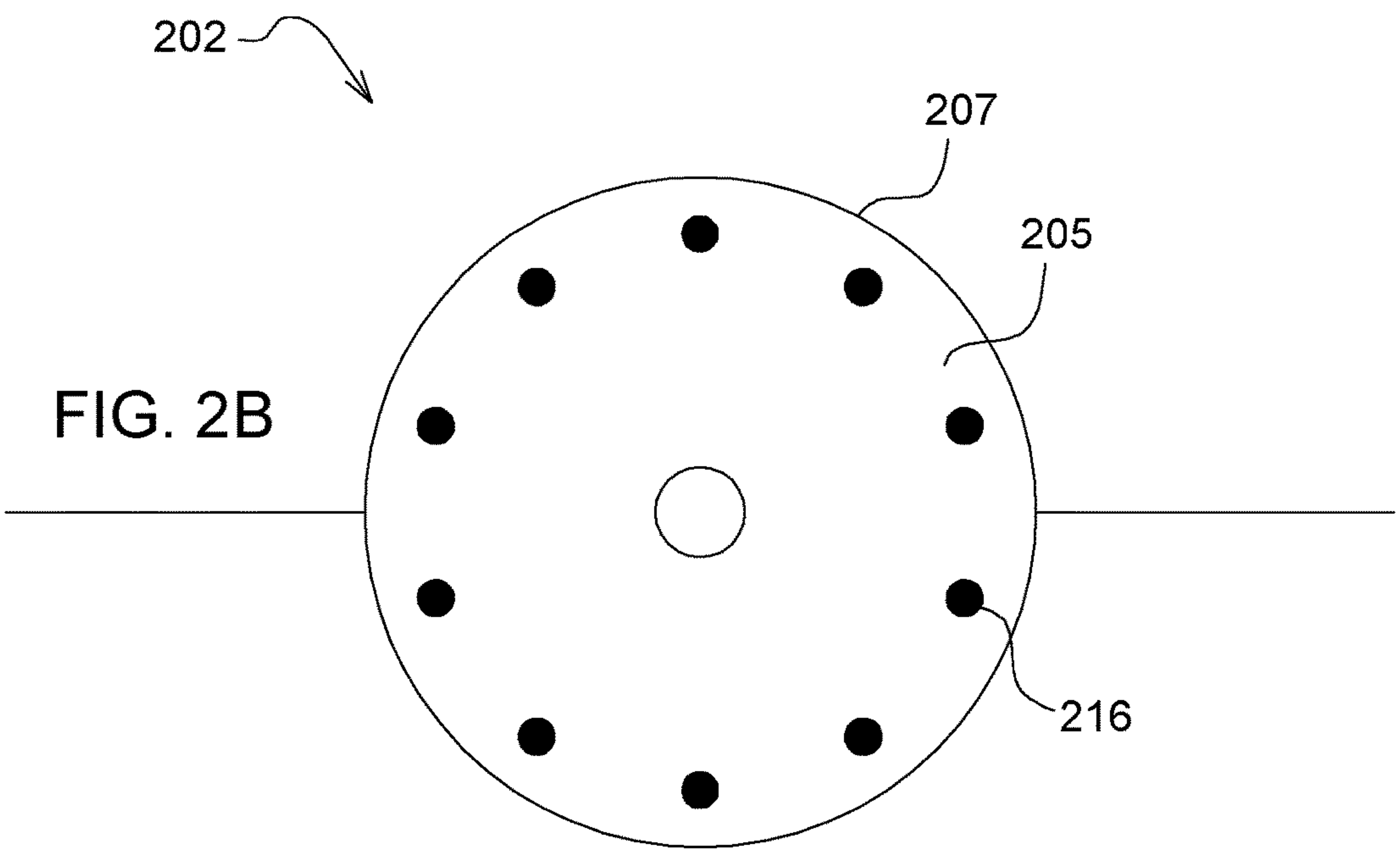


FIG. 2B



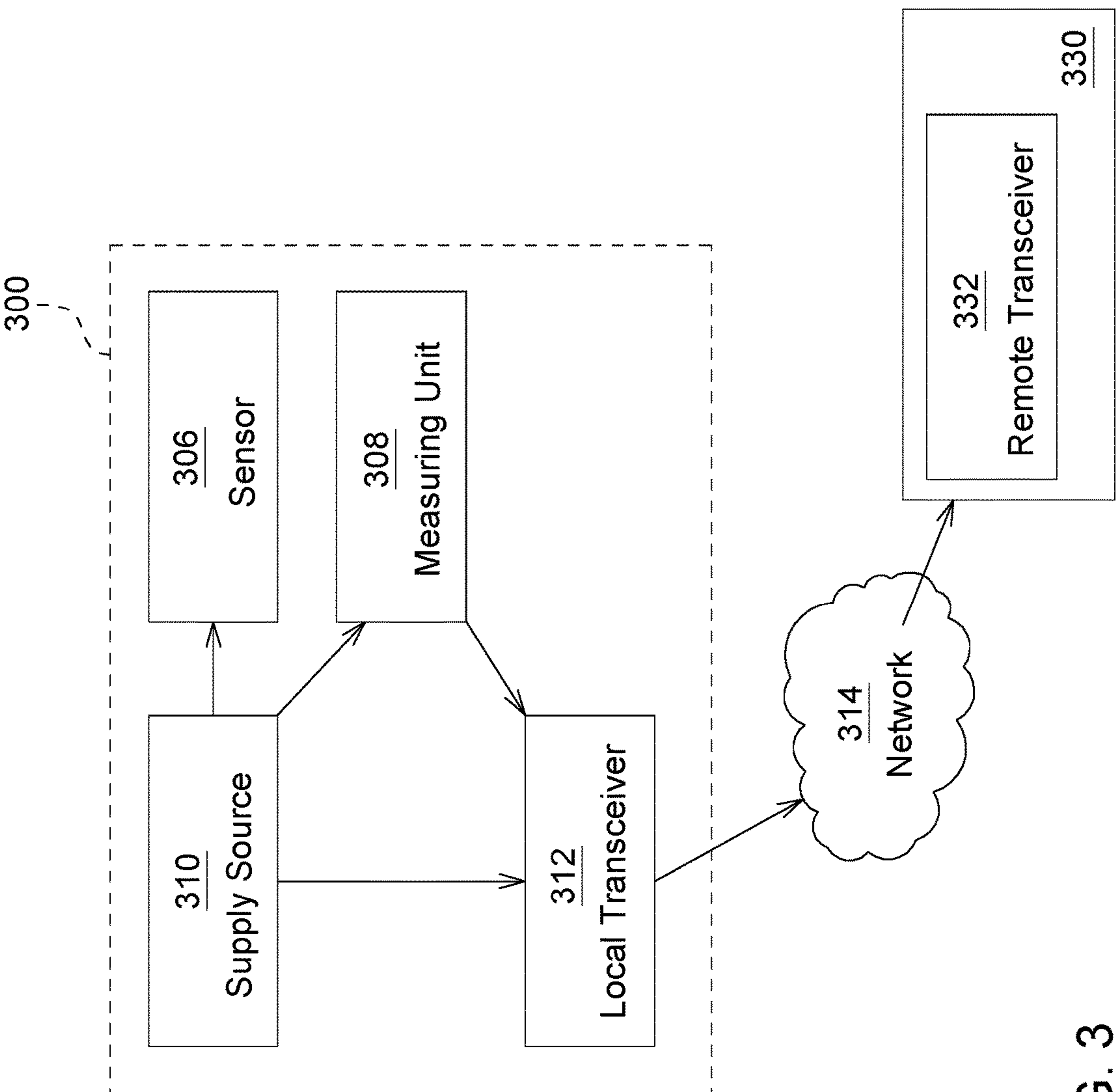

300
306
Sensor
308
Measuring Unit
310
Supply Source
312
Local Transceiver
314
Network
330
332
Remote Transceiver

FIG. 3

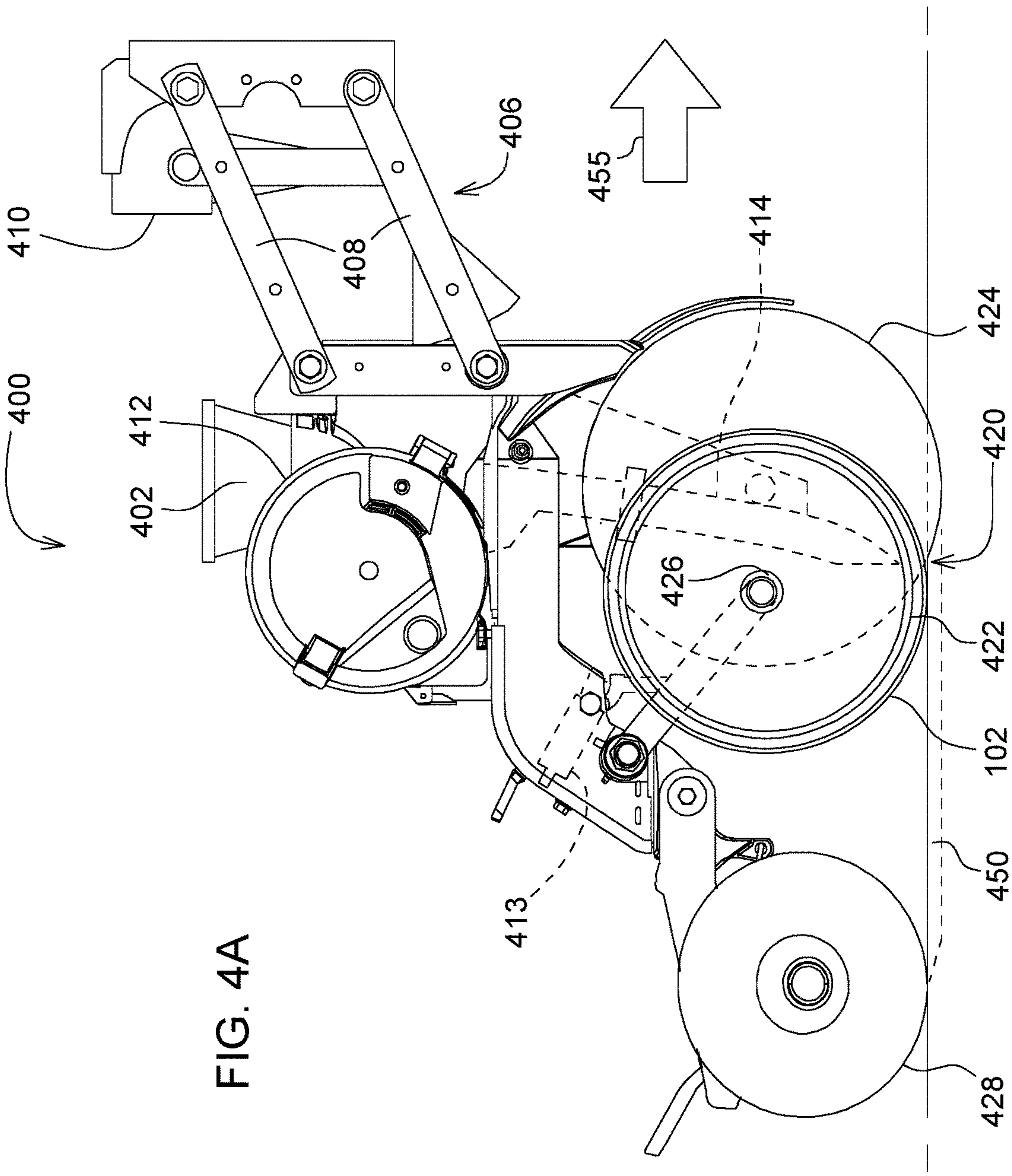


FIG. 4A

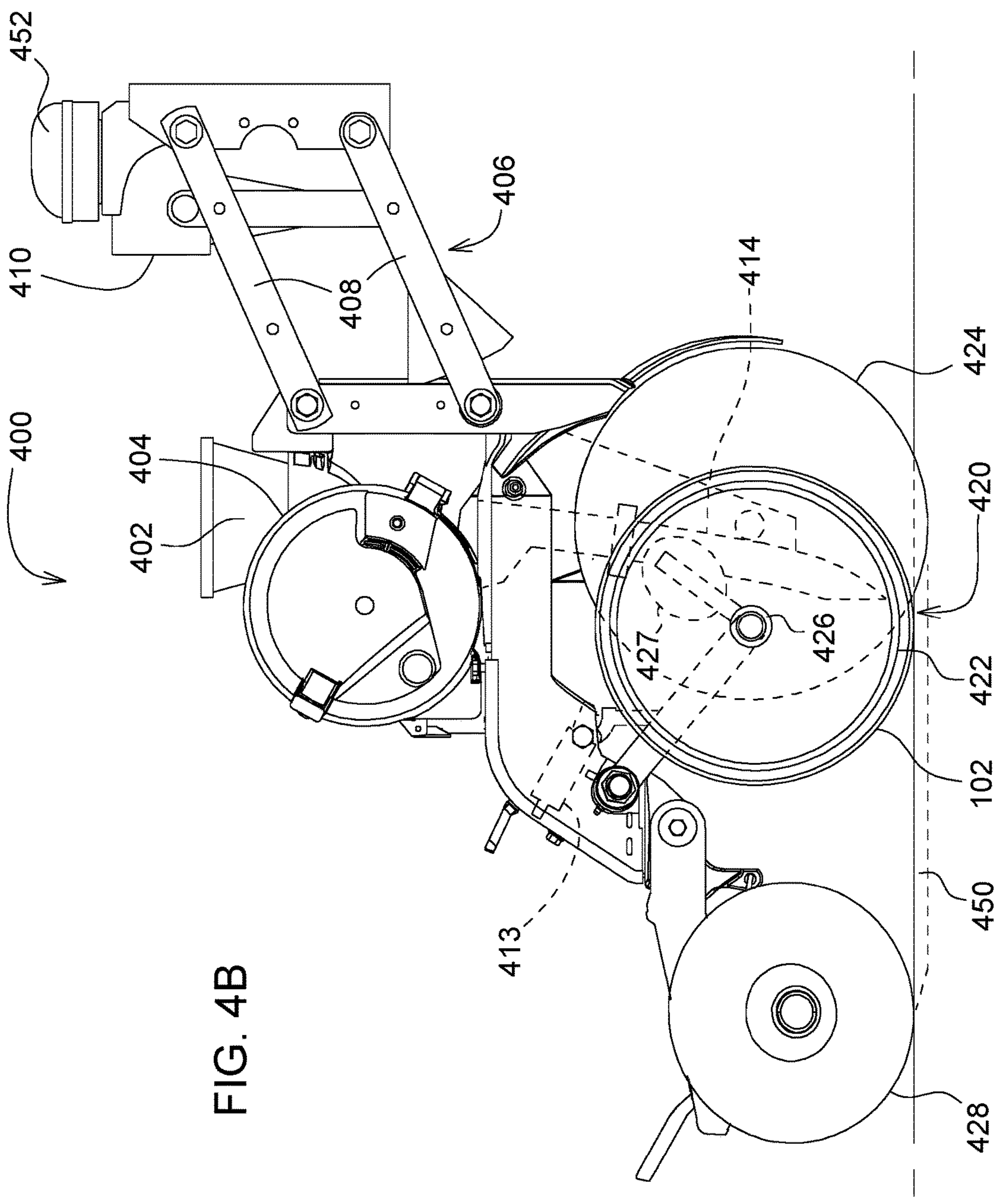

400
402
404
406
408
410
413
414
420
422
424
426
427
428
450
452
102

FIG. 4B

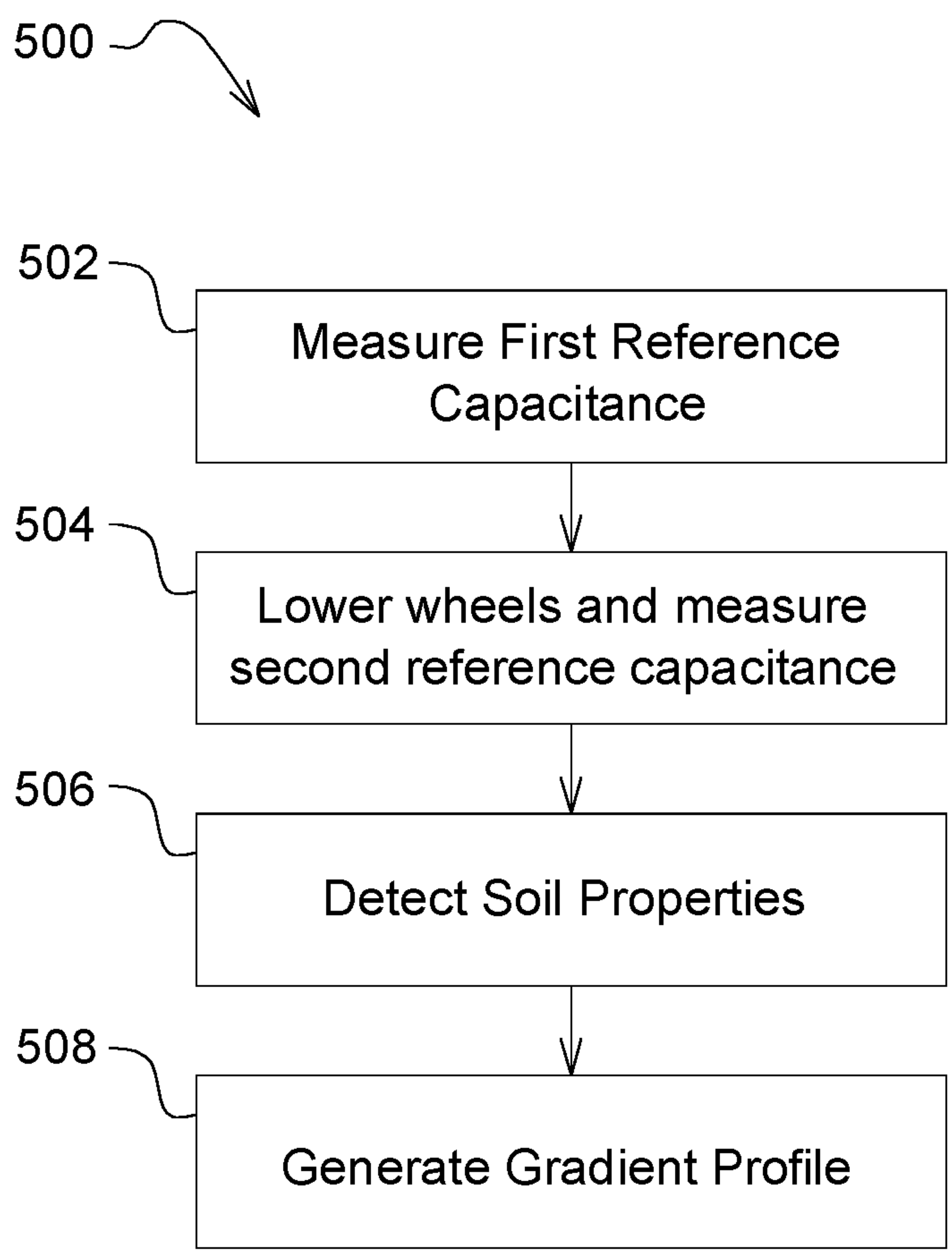

500
502
Measure First Reference Capacitance
504
Lower wheels and measure second reference capacitance
506
Detect Soil Properties
508
Generate Gradient Profile

FIG. 5

SENSING SYSTEM FOR MEASURING SOIL PROPERTIES IN REAL TIME

TECHNICAL FIELD

The present disclosure generally relates to a sensing system that utilizes real-time data measurements to obtain gradient profiles of soil properties.

BACKGROUND

In farming applications, it is often desirable to know certain properties of the soil in real-time as the farmer is performing a task such as planting or tilling. Such properties may include moisture, compaction, temperature, and trench depth; each of which can be of extreme importance in ensuring optimal yields. For example, inadequate moisture or temperature conditions may adversely affect crop production, thereby leading to decreased yields.

Drawbacks to some prior art approaches, however, include increased costs or decreased sensor resolution. As such, there is a need in the art for a sensor system that provides increased resolution at lower costs.

SUMMARY

In accordance with one embodiment, a sensing system for obtaining a gradient of soil properties in real-time as a function of soil depth is provided. The sensing system includes a support structure that is coupled to an agricultural implement and is rotatable about a rotational axis relative to a frame of the agricultural implement. The support structure is adapted for ground engagement and a sensor is arranged on a surface of the support structure. The sensor is configured to sense a change in capacitance corresponding to a change in dielectric property of a measured soil sample with which the sensor interacts, and is configured to generate an output signal indicative of the measured soil property. A measuring unit is coupled to the at least one sensor and configured to process the output signal generated by the at least one sensor and generate a gradient profile of the soil properties in real-time as a function of one or more depths for display on a user interface.

BRIEF DESCRIPTION OF THE DRAWINGS

FIG. **1** is a block diagram of a sensor system according to an embodiment;

FIG. **2**A is a front view of a sensor incorporated in the sensor system of FIG. **1** according to an embodiment;

FIG. **2**B is a front view of a sensor incorporated in the sensor system of FIG. **1** according to an embodiment;

FIG. **3** is a block diagram of a sensor system according to an embodiment

FIG. **4**A is a side view of a planter unit in which the sensor system of FIG. **1** is incorporated according to an embodiment;

FIG. **4**B is a side view of a planter unit in which the sensor system of FIG. **1** is incorporated according to an embodiment;

FIG. **5** is a flow diagram of a method for obtaining a gradient of soil properties utilizing the sensing system of FIG. **1**.

Like reference numerals are used to indicate like elements throughout the several figures.

DETAILED DESCRIPTION

For purposes of clarity, the present disclosure will be described as being implemented in a planter unit. It should

be noted, however, that the present disclosure may also be employed in a variety of planting and/or soil preparation applications to include, but not limited to, tillage, seeding, and others. Referring to FIGS. **1**-**2**B, a sensing system **100** for determining soil properties in real time is shown according to an embodiment. In embodiments, the sensing system **100** can comprise at least one sensor **106** disposed on a support structure **102** (in FIG. **2**A) and operatively coupled to a measuring unit **108**. The support structure **102** can be adapted for coupling to an agricultural implement (e.g., planter unit **400** in FIG. **4**A) and arranged such that it rotationally engages with or penetrates the surrounding soil as the implement is moved throughout a field. In some embodiments, the support structure **102** can comprise a disc or another wheel-like structure (refer, e.g., to FIG. **2**A) that comprises at least one aperture **118** formed therein for receiving an axle shaft **426** or bearing of the agricultural implement. In some embodiments, the support structure **102** may be coaxially aligned with the at least one opener disc **422** (see FIG. **4**A and FIG. **4**B) along the rotational axis **424** of the axle **426**. In other embodiments, the support structure **102** may include an opener disc such as opener disc **422** with the sensor **106** being arranged on an outer surface of the opener disc. In still other embodiments, the support structure **102** can be rotationally or fixedly coupled to a second axle (not shown) and arranged following the opener disc **422**.

The at least one sensor **106** can be arranged proximate an outer periphery **107** (in FIG. **2**A) of the support structure **102** on a sensing surface **105** to provide the sensor **106** with increased soil interaction as measurements are taken. In some embodiments, the sensor **106** can be configured as a capacitive sensor that is responsive to capacitance changes related to changes in the dielectric properties of the surrounding soil as the sensor **106** interacts with the soil. For example, the sensor **106** can comprise a first conductive element **112** spaced apart from a second conductive element **114** by a predetermined distance such that each is arranged generally offset from a center axis **150** of the support structure **102** so as to form a capacitor. The first and second conductive elements **112**, **114** can comprise a metallic material such as gold, nickel, aluminum, copper, alloys, combinations thereof, or any other suitable electrical current carrying materials. A supply source **110**, which may include, for example, a harvested energy source or an AC or DC power source, is electrically coupled to sensor **106** via leads **111**. The supply source **110** transmits a supply signal (e.g., an alternating or pulsed electrical signal) to at least one of the first or second conductive elements to generate an electric field proximate the conductive elements **112**, **114**, which can be influenced by the dielectric property of the soil. For example, the dielectric property of the soil may change depending upon the depth from the surface of the soil or the geographic location from which the sensor measurement of the sensor **106** is taken. For example, as the sensor **106** interacts with soil, soil samples having uniform or variable dielectric properties will pass through the spaced region of the first and second conductive element **112**, **114** thereby distorting the electric field and resulting in a change in the capacitance. This resulting change in capacitance is measured by the measuring unit **108**.

As depicted, the measuring unit **108**, which is also powered by supply source **110** or a suitable direct current source, can be configured to receive and process data signals outputted by the sensor **106** related to the various soil properties (e.g., soil moisture, density, temperature, ion mobility, pH levels, depth, etc.) based upon the measured capacitance or other measured soil property. In some embodiments, the measuring unit **108** can comprise a portable communications and/or computing device mounted inside a cab of an operator's vehicle (e.g., a tractor) to which the implement is attached. In other embodiments, the measuring unit **108** may be located remotely at a remote data processing facility as will be discussed with reference to FIG. **3**. The measuring unit **108** may include an electronic data processor **120**, a data storage unit **122** coupled to the processor **120**, and a display **124** for displaying data processed by processor **120**. Processor **120** may include a microprocessor, a microcontroller, a digital signal processor, a programmable logic controller, or other suitable computing devices capable of processing sensor data in real time. For example, the processor **120** may determine a dielectric property of the soil based on the measured capacitance and generate a gradient profile of the soil properties for one or more corresponding soil depths below a surface of the soil for display on display **124** (e.g., as a map of soil property versus position in a field) to allow an operator to view such information in real time. In other embodiments, the processed sensor data may be stored in memory **122**, which may include, but is not limited to, random access memory (RAM), read only memory (ROM), optical data storage, dynamic data storage, and/or combinations thereof. For example, in some embodiments, the processor **120** may retrieve data stored in memory **122** to allow an operator to use such data for diagnostic, calibration or historical purposes.

With respect to FIGS. **1**-**2**B, it will be appreciated by those skilled in the art that FIGS. **1**-**2**B are not drawn to scale and are for illustrative purposes only. Notably, the size, dimensions, structural layout, and quantity of the various components can and will vary in other embodiments. For example, in some embodiments, the support structure, such as support structure **202**, can comprise a plurality of protruding elements **216** arranged to equidistantly extend around the sensing surface **205** of the support structure **202** proximate the outer periphery **207** to facilitate preparation of the soil as the implement is moved throughout a field as illustrated in FIG. **2**B. In other embodiments, sensing system **100** may comprise a plurality of sensors **106** axially aligned along the center axis **150** or arranged on each of the protruding elements **216** or at least two rows of sensors **106** concentrically arranged on support structure **102** about its rotational axis or central aperture **118**. In still other embodiments, sensing system **100** may further comprise one or more secondary sensors, such as temperature sensors to allow simultaneous monitoring of temperature and other related soil properties.

Referring now to FIG. **3**, a sensing system **300** is shown, which is substantially similar to sensing system **100** discussed with reference to FIG. **1**. In embodiments, sensing system **300** may comprise a supply source **310** electrically coupled to a sensor **306**, measuring unit **308**, and a local transceiver **312**. The local transceiver **312** may be configured to transmit and receive data transmissions to and from one or more remote transceivers **332** wirelessly over network **314**, which may include the Internet. For example, as illustrated, the local transceiver **312** can transmit sensor data from measuring unit **308** to a remote processing unit **330** having a remote transceiver **332**. The transceivers **312**, **332** may be compatible with IEEE 802.11 and/or Bluetooth protocols and access to network **314** may be provided, for example, via a local area network (LAN), wide area network (WAN), wireless area network (WLAN), or suitable communication network. In some embodiments, the remote processing unit **330** can perform the functions described above with respect to the measuring unit **108**. In other embodiments, the remote processing unit **330** may be configured to perform additional processing or data analysis, which may be made available to a secondary user or operator.

In FIG. **4**, a planter unit **400** in which sensor **106** is incorporated is shown according to an embodiment. The planter unit **400** can comprise a hopper **402** arranged in a generally upright position that is mounted to a frame **404**. A parallel arm arrangement **406** comprising linkages **408** and an actuation device **410** can be mounted to frame **404** in a cantilever-like configuration such that it extends outwardly and away from frame **404**. In some embodiments, actuation device **410** can be coupled to at least one of linkages **408** and can include mechanical, pneumatic, hydraulic, or other suitable actuators to apply lift and/or downforce to planter unit **400**. A metering unit **412** having a generally circular configuration can be arranged beneath hopper **402** and can be configured to distribute seeds received from hopper **402** into a seed tube **414**. The seed tube **414** directs the seeds received from the metering unit **412** to a soil opening **450** formed in the ground by an opener assembly **420**.

The opener assembly **420** can comprise at least one opener disc **422** that is arranged to create the soil opening **450** for receiving seeds or other materials at a predetermined depth upon engagement with the soil. In some embodiments, support structure **102**, as discussed with reference to FIG. **1**, may be coaxially aligned with the at least one opener disc **422** along the rotational axis **424** of the axle **426**. At least two gauge wheels **424** are mounted proximate opener assembly **420** such that the soil penetration depth of the opener disc **422** and support structure **102** are regulated by gauge wheels **424**. For example, as previously discussed, actuation device **410** operates to apply a downforce to planter unit **400**, which in turn applies applicable downforces to each of the ground engaging devices (i.e., gauge wheels **424**, opener disc **422**, and support structure **102**) mounted to planter unit **400**. Once the devices are lowered, a gauge wheel adjustment mechanism **413** enables the vertical position of the gauge wheels **424** to be adjusted relative to the opener disc **422** and support structure **102**, which establishes the depth to which the opener disc **422** and support structure **102** are inserted into the soil (i.e., the depth of the soil opening **450**). A closing wheel assembly **428** can be arranged following the opener assembly **420**, support structure **102**, and gauge wheels **424** and is operable to close the soil opening **450** formed by opener assembly **420**. In other embodiments, referring now to FIG. **4**B, planter unit **400** may further comprise a location-determining receiver **452**, such as a satellite navigation receiver, that is mounted to the planter unit **400** and configured to provide field location data. For example, the location-determining receiver **452** can be used to determine the field location where each soil measurement is taken such that a 2-dimensional or 3-dimensional plot of the field location and corresponding soil property may be generated. In still other embodiments, planter unit **400** may also comprise a scraper unit **427** mechanically coupled to the axle shaft **426** that is configured to remove excess dirt or other residual buildup from support structure **102** and conductive elements **112**, **114**. For example, in muddy soil conditions, mud or other similar materials may stick to the support structure **102** and interfere with the sensing accuracy of sensor **106**. Therefore, to prevent such interference, scraper unit **427** will operate to clear excess material from support structure **102** and conductive elements **112**, **114** as they are rotated above the ground.

In FIG. **5**, a flow diagram of a method **500** for carrying out the present disclosure is shown. At **502**, and prior to operation, a first reference capacitance may be measured while the sensor **106** is positioned above the ground and stored in memory **122**. In other embodiments, however, the first reference capacitance may be measured and stored during manufacturing. Once the measurement is taken, at **504**, an operator may input a command through a user interface of display **124** to enable adjustment of the vertical position (i.e., raising or lowering) of the gauge wheels **424**, which, in turn, adjusts the vertical position of the opener disc **422** and the support structure **102** in which sensor **106** is arranged. This establishes the penetration depth to which the opener disc **422** and support structure **102** are inserted into the soil, i.e., the depth of the soil opening **450**. Upon insertion, a second reference capacitance may be measured and stored in memory **122** while the planter unit **400** is in a rest state.

Once planter unit **400** is in operation and moving throughout a field, at **506**, a plurality of capacitance measurements are taken by sensor **106** and transmitted to measuring unit **108**. For example, as the support structure rotates throughout the soil, the plurality of capacitance measurements are taken above and beneath the soil and compared against the first and second reference capacitances to determine an overall change in capacitance of sensor **106**. For example, because the difference in the dielectric constant between air (~1), soil (~3 to ~5) and water (~80) is quite large, it would be quite evident when the sensor **106** enters (i.e., dielectric change from air to soil) and exits the soil (i.e., dielectric change from soil to air) as the support structure **102** is rotating.

Next at **508**, a gradient profile of the measured soil properties is generated. For example, measuring unit **108** processes the measured capacitances to determine corresponding soil properties (e.g., temperature, moisture content, density), which may be stored in memory **122** or plotted against the depth in a 2-dimensional curve on display **124** to generate the gradient. Notably, the displayed depth measurements, which may be determined in a number of ways, will include measurements taken from the soil's surface downward (i.e., measurements taken once the sensor enters the soil). For example, in some embodiments, sensing system **100** may further comprise an angle sensor (not shown) coupled to the axle shaft **426** that is used to determine the depth at which sensor **106** is positioned in the soil based on the angular position of support structure **102**. In such a configuration, the angle sensor may be configured to generate sinusoidal output signals (i.e., cosine and sine signals) that are used to determine the angular position of the support structure **102**. For example, measuring unit **108** can be configured to compute an arc tangent function utilizing the output signals to determine a corresponding rotation angle. In other embodiments, the rotational velocity of the support structure may be used to determine the depth. Additionally, in embodiments in which the support structure comprises the opener disc, the depth may be determined by sensing abrupt changes in impedance between the air and the soil along with the angular travel of the support structure.

Without in any way limiting the scope, interpretation, or application of the claims appearing below, a technical effect of one or more of the example embodiments disclosed herein is sensor system and method for obtaining a gradient of soil properties in real time. While the present disclosure has been illustrated and described in detail in the drawings and foregoing description, such illustration and description is not restrictive in character, it being understood that illustrative embodiment(s) have been shown and described and that all changes and modifications that come within the spirit of the present disclosure are desired to be protected. Alternative embodiments of the present disclosure may not include all of the features described yet still benefit from at least some of the advantages of such features. Those of ordinary skill in the art may devise their own implementations that incorporate one or more of the features of the present disclosure and fall within the spirit and scope of the appended claims.

What is claimed is:

1. A sensing system for obtaining a gradient of soil properties in real-time as a function of soil depth, the sensing system comprising:

a support structure adapted for ground engagement and coupling to an agricultural implement, wherein the support structure is rotatable about a rotational axis relative to a frame of the agricultural implement;

at least one sensor arranged on the support structure, wherein the at least one sensor is configured to sense changes in a capacitance corresponding to changes in a dielectric property of a measured soil sample with which the at least one sensor interacts, and wherein the at least one sensor is configured to generate an output signal indicative of the measured soil property; and

a measuring unit coupled to the at least one sensor, wherein the measuring unit is configured to process the output signal generated by the at least one sensor and generate a gradient profile of the soil properties in real-time as a function of one or more corresponding depths from a surface of the soil of a field for display on a user interface.

2. The sensing system of claim **1**, wherein the at least one sensor comprises two or more sensors arranged on the support structure.

3. The sensing system of claim **1**, wherein the at least one sensor comprises at least two conductive elements equidistantly spaced apart from one another and offset from a center axis of the support structure.

4. The sensing system of claim **3**, wherein the at least two conductive elements comprises one or more of a copper material, a gold material, a silver material, or combinations thereof.

5. The sensing system of claim **1**, further comprising a secondary sensor selected from the group consisting of a temperature sensor, an angle sensor, or combinations thereof.

6. The sensing system of claim **1**, wherein the support structure comprises a wheel structure having at least one aperture arranged therein.

7. The sensing system of claim **1**, wherein the support structure comprises at least one or more opener discs of an opener assembly.

8. The sensing system of claim **1**, wherein the support structure comprises a plurality of protruding elements arranged to extend around a sensing surface of the support structure proximate an outer periphery of the support structure so as to facilitate preparation of the measured soil sample, and wherein the at least one sensor comprises a plurality of sensors respectively arranged on each of the plurality of protruding elements.

9. The sensing system of claim **1**, wherein the at least one sensor is arranged on a bottom surface of an outer periphery of the support structure.

10. The sensing system of claim **1**, wherein the measured soil property comprises one or more of the following: soil moisture, soil density, soil temperature, ion mobility, soil pH levels.

11. The sensing system of claim **1** further including a satellite navigation receiver for determining each position of the at least one sensor and its associated respective measurements of the soil properties.

12. The sensing system of claim **11**, wherein the satellite navigation receiver is adapted to determine a vertical height of the implement or the vehicle that is associated with each position of the at least one sensor and its associated respective measurements of the soil properties.

13. A method for generating a gradient of soil properties in real-time as a function of soil depth, the method comprising:

providing at least one sensor arranged on a support structure, wherein the support structure is coupled to an agricultural implement and adapted for rotational engagement with the soil;

sensing with the at least one sensor a capacitance change indicative of a changing dielectric property of the measured soil sample as the agricultural implement is moved throughout the field; and

determining with a processor a dielectric property of the measured soil sample in real time to generate a gradient profile of the determined soil property as a function of depth.

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