

(51) International Patent Classification:
H05G 1/34 (2006.01)(21) International Application Number:
PCT/US2015/041408(22) International Filing Date:
21 July 2015 (21.07.2015)

(25) Filing Language: English

(26) Publication Language: English

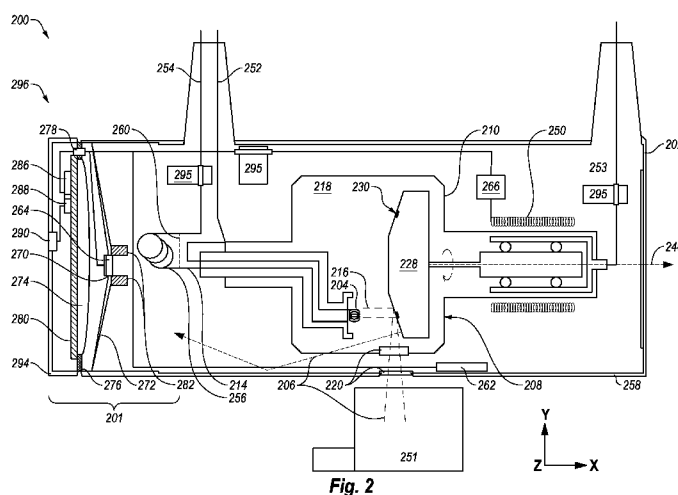
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RICHMOND, Michelle; c/o Varian Medical Systems, Inc., 3100 Hansen Way, Palo Alto, CA 94304 (US).(74) Agents: **ATZET, Ian, A.** et al.; Maschoff Brennan, 1389 Center Drive, Suite 300, Park City, UT 84098 (US).(81) Designated States (*unless otherwise indicated, for every kind of national protection available*): AE, AG, AL, AM,

AO, AT, AU, AZ, BA, BB, BG, BH, BN, BR, BW, BY, BZ, CA, CH, CL, CN, CO, CR, CU, CZ, DE, DK, DM, DO, DZ, EC, EE, EG, ES, FI, GB, GD, GE, GH, GM, GT, HN, HR, HU, ID, IL, IN, IR, IS, JP, KE, KG, KN, KP, KR, KZ, LA, LC, LK, LR, LS, LU, LY, MA, MD, ME, MG, MK, MN, MW, MX, MY, MZ, NA, NG, NI, NO, NZ, OM, PA, PE, PG, PH, PL, PT, QA, RO, RS, RU, RW, SA, SC, SD, SE, SG, SK, SL, SM, ST, SV, SY, TH, TJ, TM, TN, TR, TT, TZ, UA, UG, US, UZ, VC, VN, ZA, ZM, ZW.

(84) Designated States (*unless otherwise indicated, for every kind of regional protection available*): ARIPO (BW, GH, GM, KE, LR, LS, MW, MZ, NA, RW, SD, SL, ST, SZ, TZ, UG, ZM, ZW), Eurasian (AM, AZ, BY, KG, KZ, RU, TJ, TM), European (AL, AT, BE, BG, CH, CY, CZ, DE, DK, EE, ES, FI, FR, GB, GR, HR, HU, IE, IS, IT, LT, LU, LV, MC, MK, MT, NL, NO, PL, PT, RO, RS, SE, SI, SK, SM, TR), OAPI (BF, BJ, CF, CG, CI, CM, GA, GN, GQ, GW, KM, ML, MR, NE, SN, TD, TG).**Published:**

— with international search report (Art. 21(3))

(54) Title: OPERATIONAL STATE DETERMINATION FOR X-RAY TUBES

**Fig. 2**(57) **Abstract:** An example embodiment includes an x-ray assembly. The x-ray assembly includes an x-ray tube (208), a filament (204), and a sensor (262, 264). The x-ray tube defines an evacuated envelope (210). The filament is positioned within the evacuated envelope. The filament includes a standby operational state in which the filament is not emitting electrons (216), an exposure operational state in which the filament is emitting electrons, and a preheat operational state during which the filament transitions from the standby operational state to the exposure operational state. The sensor may be a photosensor (242) or a magnetic sensor (264) and is configured to measure a characteristic of the filament that is indicative of an operational state of the filament.

OPERATIONAL STATE DETERMINATION FOR X-RAY TUBES

FIELD

The embodiments described herein relate to x-ray tubes and cathode tubes. In particular,
5 some embodiments described herein relate to systems and methods for determining
operational states of filaments and other components in x-ray tubes and cathode ray tubes.

BACKGROUND

X-ray tubes are used in a variety of industrial and medical applications. For example, x-
10 ray tubes are employed in medical diagnostic examination, therapeutic radiology,
semiconductor fabrication, and material analysis. Regardless of the application, most x-
ray tubes operate in a similar fashion. X-rays, which are high frequency electromagnetic
radiation, are produced in x-ray tubes by applying an electrical current to a cathode,
which includes a filament, to cause electrons to be emitted from the cathode by
15 thermionic emission. The electrons accelerate towards and then impinge upon an anode.
When the electrons impinge upon the anode, the electrons can collide with the anode to
produce x-rays.

The subject matter claimed herein is not limited to embodiments that solve any
disadvantages or that operate only in environments such as those described above. Rather,
20 this background is only provided to illustrate one exemplary technology area where some
embodiments described herein may be practiced.

SUMMARY OF SOME EXAMPLE EMBODIMENTS

This summary is provided to introduce a selection of concepts in a simplified form that
25 are further described below. This summary is not intended to identify key features of the
claimed subject matter, nor is it intended to be used as an aid in determining the scope of
the claimed subject matter.

An example embodiment includes x-ray assembly. The x-ray assembly includes an x-ray
tube, a filament, and a sensor. The x-ray tube defines an evacuated envelope. The
30 filament is positioned within the evacuated envelope. The filament includes a standby
operational state in which the filament is not emitting electrons, an exposure operational
state in which the filament is emitting electrons, and a preheat operational state during
which the filament transitions from the standby operational state to the exposure

operational state. The sensor is configured to measure a characteristic of the filament that is indicative of an operational state of the filament.

Another example embodiment includes an x-ray tube operational state measurement system. The system includes a filament electrical circuit, a coil, a magnetic sensor, an analysis circuit, and a communication unit. The filament electrical circuit supplies electrical current to a filament of an x-ray tube. The coil is included in the filament electrical circuit. The coil is electrically coupled, in series, in a return side of the filament electrical circuit. The magnetic sensor is configured to measure a magnetic field induced in the coil. The analysis circuit is electrically coupled to the magnetic sensor. The analysis circuit is configured to receive a measured magnetic field from the magnetic sensor and to determine the operational state of the filament based on the measured magnetic field. The communication unit is electrically coupled to the analysis circuit and configured to transmit a signal that is representative of the operational state of the filament.

An example embodiment includes a method of determination of an operational state of a filament in an x-ray assembly. The method includes inducing a magnetic field in a coil. The coil is included in a filament electrical circuit of the filament. The method includes generating a signal that is representative of the magnetic field induced in the coil. The method includes determining an operational state of the filament based on the signal.

Additional features and advantages of the invention will be set forth in the description which follows, and in part will be obvious from the description, or may be learned by the practice of the invention. The features and advantages of the invention may be realized and obtained by means of the instruments and combinations particularly pointed out in the appended claims. These and other features of the present invention will become more fully apparent from the following description and appended claims, or may be learned by the practice of the invention as set forth hereinafter.

BRIEF DESCRIPTION OF THE DRAWINGS

A more particular description of the invention will be rendered by reference to specific embodiments thereof which are illustrated in the appended drawings. It is appreciated that these drawings depict only example embodiments of the invention and are therefore not to be considered limiting of its scope. These example embodiments will be described and explained with additional specificity and detail through the use of the accompanying drawings in which:

Figure 1 illustrates a plot depicting current changes of an example filament and current changes in an example stator;

Figure 2 illustrates a block diagram of an example x-ray system;

Figure 3 illustrates disassembled portions of an example x-ray assembly;

5 Figure 4A illustrates a first view of an example sensor assembly;

Figure 4B illustrates a second view of the sensor assembly of Figure 4A;

Figure 5 illustrates a diaphragm assembly;

Figure 6 illustrates the diaphragm assembly as it is being positioned in an example coverplate;

10 Figure 7 illustrates the diaphragm assembly of Figure 5 assembled with the coverplate;

Figure 8 illustrates a block diagram of an example analysis circuit that may be implemented in the x-ray system of Figure 2;

Figure 9 illustrates an example instrument amplifier that may be implemented in the analysis circuit of Figure 8;

15 Figure 10 illustrates an example converter that may be implemented in the analysis circuit of Figure 8;

Figure 11 illustrates an example comparator that may be implemented in the analysis circuit of Figure 8;

20 Figure 12 illustrates an example communication unit that may be implemented in the analysis circuit of Figure 8; and

Figure 13 is a block diagram of a method of determination of an operational state of a filament in an x-ray assembly.

DESCRIPTION OF SOME EXAMPLE EMBODIMENTS

25 Hot cathode tubes such as x-ray tubes function by heating a filament within a vacuum. When the filament is hot enough, the filament produces free electrons that are then accelerated through space by an electric field. The electric field is created by a voltage difference between the filament (cathode) and a target (an anode). A tube current is a measure of these fast moving free electrons. When the electrons strike the target, x-rays
30 are produced.

It may be beneficial to know and monitor operational states of cathode tubes and x-ray tubes (collectively, tube or tubes). For example, x-ray related equipment such as imaging panels may be placed in a low-power state when not actively receiving x-rays. If the operational state of an x-ray tube is known, then the operational state information may be

communicated to the related equipment. In response, the related equipment may transition to a fully operational (high-power) state from the low-power state or vice versa. Additionally, the operational state information may be used to quantify use of components of the tubes, which may help track performance over the lives of the components, diagnose failure of the components, track maintenance, and the like.

However, in current tubes, operational states are surmised by knowledge of what a user has requested (e.g., a request for x-rays) or by a presence or absence of x-rays. The operational state information of the tube is not directly sensed or reported. Accordingly, some embodiments described herein include an x-ray assembly that is configured to directly measure characteristics that are indicative of an operational state of the x-ray tube and components included therein. In particular, some embodiments of the x-ray assembly are configured to directly measure an operational state of a filament implemented in the x-ray assembly. The operational state of the filament is measured because an operational state of the filament is directly related to the operational state of the x-ray tube.

These and other embodiments of the x-ray assembly include an x-ray tube that defines an evacuated envelope. The filament is positioned within the evacuated envelope. The filament includes a standby operational state in which the filament is not emitting electrons, an exposure operational state in which the filament is emitting electrons, and a preheat operational state during which the filament transitions from the standby operational state to the exposure operational state. The x-ray tube includes a sensor that is configured to measure a characteristic of the filament that is indicative of an operational state of the filament. The sensor can include a magnetic sensor and/or a photodetector.

In embodiments in which the sensor includes a magnetic sensor, the x-ray assembly further includes a coil that is included in a filament electrical circuit. The magnetic sensor is positioned relative to the coil to measure a magnetic field induced in the coil as a filament current is supplied through the coil. The magnetic sensor communicates a signal indicative of the magnetic field to an analysis circuit, which is configured to determine the operational state of the filament based on the signal.

In embodiments in which the sensor includes a photodetector, the x-ray assembly includes an evacuated envelope that is transparent (e.g., glass) or includes a transparent portion (e.g., a quartz window). The photodetector measures radiance of the filament. A signal representing the radiance can be communicated to the analysis circuit. Because radiance is related to the temperature of the filament, the analysis circuit can determine an operational state of the filament based on the signal. Operational state information may be

communicated from the x-ray assembly (e.g., to a wireless imaging panel) or stored therein at least temporarily.

Reference will now be made to figures wherein like structures will be provided with like reference designations. It is understood that the drawings are diagrammatic and schematic representations of exemplary embodiments, and are not necessarily limiting to
5 embodiments described herein nor are they necessarily drawn to scale.

Generally, the x-rays are not produced constantly in a tube. Instead, the filament is cycled between a standby operational state and an exposure operational state. For example, Figure 1 illustrates a plot 100 depicting current changes of an example filament and
10 current changes in an example stator as the filament is cycled between a standby operational state 110 and the exposure operational state 112. In the standby operational state 110, the filament does not emit electrons. In the exposure operational state 112, the filament emits electrons. Additionally, in the standby operational state 110, a temperature of the filament is much less than the temperature of the filament in the exposure
15 operational state 112. For example, a standby temperature of the filament in the standby operational state 110 may be between about 800° Celsius (C) and about 1500° C. An exposure temperature of the filament in the exposure operational state 112 may be between about 2000° C and about 2600° C.

Referring to Figure 1, a standby current, denoted at 102 in Figure 1, may be maintained in
20 the filament between times in which x-rays are produced (e.g., during the standby operational state 110). Particular standby currents 102 may vary between tubes. An example preheat current may be about two amperes (Amps). A purpose of the standby current 102 includes a reduction in stress on the filament as the filament cycles between the standby operational state 110 and the exposure operational state 112.

When x-rays are requested, tubes increase current in the filament from the standby current
25 102 to a preheat current, denoted at 104 in Figure 1. The specific preheat current 104 may vary between tubes, but is generally greater than the standby current 102. An example preheat current may be about five Amps. A preheat operational state 114 occurs while the preheat current 104 is applied to the filament to transition the filament from a standby
30 temperature to an exposure temperature. A preheat operational state 114 may occur in between about 0.5 and about 2 seconds in some instances.

At an end of the preheat operational state 114, a high voltage is applied between the filament (e.g., the cathode) and the target (e.g., the anode). As the high voltage is applied, an electron beam is thermionically emitted from the filament, which impinges upon the

target. Collisions of the electrons with the target produce x-rays that may exit the x-ray tube and may be implemented.

Figure 1 also depicts an example stator current, which is represented by a dashed line. The stator current can be applied to a stator concurrently with a transition from the standby operational state 110 to the preheat operational state 114. During the preheat
5 operational state 114 or prior to the exposure operational state 112, the stator current may be high, which may be referred to as a boost. The high stator current may correlate to high rotational speed of an anode. During the exposure operational state 112, the stator current may fall compared to the stator current during the preheat operational state 114.
10 Following the exposure operational state 112, the stator current may be negative, which may break rotation of the anode.

In Figure 1, the filament current and the stator current have a substantially constant amplitude. In some circumstances, the filament current and the stator current may include some small variations or ripples. For instance, when the preheat current 104 is applied to
15 the filament some current ripples can occur.

Figure 2 illustrate a block diagram of an example x-ray system 200. The x-ray system 200 includes an x-ray assembly 202 and a wireless image panel 251. In general, the x-ray assembly 202 generates x-rays 206. A portion of the x-rays 206 exit the x-ray assembly 202 to produce an image on the wireless image panel 251. The wireless image panel 251
20 may transition from a low-power state to a high-power state based on an operational state of the x-ray assembly 202. For example, in response to the x-ray assembly 202 not generating the x-rays 206 or between times in which the x-ray assembly 202 is generating the x-rays 206, the wireless image panel 251 may transition to a low-power state to conserve power. In response to the x-ray assembly 202 generating x-rays 206, the
25 wireless image panel 251 may transition to a high-power state in which the wireless image panel 251 is configured to receive the x-rays 206 and produce an image using the x-rays 206.

The present disclosure is not limited to the x-ray system 200 that includes an x-ray assembly 202 and the wireless image panel 251. In some embodiments, the x-ray system
30 200 may include the x-ray assembly 202 with one or more other pieces of equipment and/or omit the wireless image panel 251. In these and other embodiments, the operational state information of the x-ray assembly 202 may be stored or used by the one or more other pieces of equipment.

The x-ray assembly 202 is generally defined by a tube housing 258. The tube housing 258 at least partially surrounds an x-ray tube 208. The tube housing 258 further at least partially defines a cooling fluid volume 253. For example, cooling fluid volume 253 may be defined between the x-ray tube 208 and the tube housing 258. The cooling fluid
5 volume 253 may be filled with oil to which heat generated during generation of the x-rays 206 is transferred.

The x-ray tube 208 includes an evacuated envelope 210. The evacuated envelope 210 is at least a portion of an outer structure of the x-ray tube 208. The evacuated envelope 210 defines an evacuated volume 218. One or more of components (described herein) of x-ray
10 tube 208 are positioned within the evacuated volume 218 defined by the evacuated envelope 210.

The x-ray tube 208 may include a filament electrical circuit 214. The filament electrical circuit 214 is configured to supply electrical current into the evacuated envelope 210 and to the filament 204. In some embodiments, the filament electrical circuit 214 may include
15 a supply side 252 and a return side 254. The supply side 252 generally includes from a source (not shown) to the filament 204 and the return side 254 includes from the filament 204 back to the source. In these and other embodiments, the return side 254 may include a coil 256 coupled in series (e.g., as opposed to in parallel). When current is supplied to the filament 204, a magnetic field is induced in the coil 256. In other embodiments, the coil
20 256 is omitted. In Figure 2, an alternative line 260 is included that may be included in embodiments in which the coil 256 is omitted.

The filament 204 is configured to receive the electrical current transferred from the filament electrical circuit 214. The filament 204 emits electrons 216 by thermionic emission based at least partially on the electrical current supplied to the filament 204. The
25 electrons 216 are emitted into the evacuated volume 218 towards a rotating anode 228.

During operation of the x-ray tube 208, the rotating anode 228, and the filament 204 are connected in an electrical circuit that includes the filament electrical circuit 214. The electrical circuit allows the application of a high voltage potential between the rotating anode 228 and the filament 204, which causes the electrons 216 to propagate through the
30 evacuated volume 218 towards the target surface 230.

Rotation of the rotating anode 228 is controlled by a stator 250. The stator 250 may be supplied electrical current based on an operational state of the x-ray tube 208 as generally described with reference to Figure 2.

The rotating anode 228 is positioned within the evacuated volume 218. The rotating anode 228 may rotate about an axis 240 that is substantially parallel to the x-axis in an arbitrarily defined coordinate system of Figure 2. The rotating anode 228 is spaced apart from and positioned opposite the filament 204. The electrons 216 emitted from the filament 204 impinge upon a target surface 230 of the rotating anode 228. The target surface 230 is oriented with respect to one or more windows 220 such that a portion of the x-rays 206 generated from such impingement are directed towards the windows 220. A portion of the x-rays 206 then exits the x-ray tube 208 and the x-ray assembly 202 via the windows 220.

The x-rays 206 that exit the x-ray assembly 202 may be directed towards the wireless image panel 251 or another related system such as a digital detector or photographic film. The x-rays 206 that exit the x-ray assembly 202 may be used to generate an image or perform some other function.

The wireless image panel 251 may include a low-power state in which the wireless image panel 251 operates at a reduced power state. The wireless image panel 251 may also include a high-power state in which the wireless image panel 251 is configured to receive the portion of x-rays 206 produced by the x-ray tube 208. The x-ray assembly 202 is not constantly producing x-rays 206. Between such x-ray 206 productions, the wireless image panel 251 may transition to the low-power state to conserve battery power, for instance.

The wireless image panel 251 may receive a signal indicative of the operational state of the x-ray tube 208. In response, the wireless image panel 251 may transition from the low-power state to the high-power state or vice versa.

In the embodiment of Figure 2, the x-ray assembly 202 is configured to enable direct measurement of one or more characteristics of the x-ray tube 208 that are indicative of an operational state of the x-ray tube 208. The direct measurement may be performed by a sensor. In Figure 2, three sensors 262, 264, and 266 are included in the x-ray assembly 202. The sensors 262, 264, and 266 may be configured to measure a characteristic of the x-ray tube 208 indicative of the operational state of the x-ray tube 208 as described herein.

The embodiment depicted in Figure 2 includes three x-ray tube operational state measurement systems (measurement systems). In some embodiments, the x-ray assembly 202 may include a subset of the measurement systems. In a first measurement system 201, a current of the filament 204 is measured. By measuring the current of the filament

204, an operational state of the filament 204 may be determined, which may directly correlate to an operational state of the x-ray tube 208.

In a second measurement system, a radiance of the filament 204 may be measured. The radiance of the filament 204 may be related to a power of the filament 204, and accordingly may indicate an operational state of the filament 204 and x-ray tube 208. Embodiments in which the radiance of the filament 204 is measured may be limited to those in which an evacuated envelope 210 and/or a tube housing 258 that surrounds the x-ray tube 208 is substantially transparent or includes a window through which the radiance may be measured.

In a third measurement system, a current of the stator 250 may be measured. The current of the stator 250 may be indicative of the operational state of the x-ray tube 208. The current of the stator 250 may not directly correlate to an operational state of the x-ray tube 208. For example, with reference to Figures 1 and 2, in some circumstances, current is applied to the stator 250 concurrently with a transition from the standby operational state 110 to the preheat operational state 114. During the preheat operational state 114 or prior to the exposure operational state 112, rotation of an anode 228 may be high, which may correlate to high stator current. This rotation of the anode 228 may however be variable. Accordingly, while the stator current may be generally indicative of an operational state of the x-ray tube 208, the relationship between the stator current and the operational state may not be direct. Each of the measurement systems are discussed below.

The first measurement system 201 measures the filament current of the filament 204. As discussed above, the filament 204 may include a standby operational state in which the filament 204 is not emitting electrons, an exposure operational state in which the filament 204 is emitting electrons, and a preheat operational state during which the filament 204 transitions from the standby operational state to the exposure operational state. The filament current is related to the operational state of the filament 204.

To measure the filament current, the first measurement system 201 may include a magnetic sensor 264. The magnetic sensor is positioned relative to the coil 256 that is included in the filament electrical circuit 214. The magnetic sensor 264 is configured to measure the magnetic field induced in the coil 256. The magnetic sensor 264 may include a magnetoresistive bridge, for instance.

The first measurement system 201 may also include a sensor housing shield 272. The sensor housing shield 272 may be configured to shield the x-rays 206 from radiating from

the x-ray assembly 202. For example, the sensor housing shield 272 may be comprised of lead that may shield the x-rays 206.

The sensor housing shield 272 may define a sensor opening 270. The sensor opening 270 is configured to receive the magnetic sensor 264. The sensor opening 270 may be an opening through which the x-rays 206 may escape. Accordingly, the first measurement system 201 may also include a sensor shield 282. The sensor shield 282 extends from a surface of the sensor housing shield 272 and surrounds the sensor opening 270. The sensor shield 282 also shields x-rays 206 from radiating through the sensor opening 270 and eventually from the x-ray assembly 202.

The material of the sensor shield 282 may be configured to shield the x-rays 206 and to not interfere with the magnetic field induced in the coil 256 and/or measured by the magnetic sensor 264. In some embodiments, the sensor shield 282 may be comprised of an x-ray shielding material such as Tungsten. The Tungsten may be embedded in an epoxy or a plastic, for instance. The Tungsten is nonferrous and accordingly may not produce reverse eddies because of the induced magnetic field.

The magnetic sensor 264 may be electrically coupled to an analysis circuit 286. The analysis circuit 286 is configured to receive a signal representative of the measured characteristic from the magnetic sensor 264. The analysis circuit 286 determines the operational state of the filament 204 based on the signal. The analysis circuit 286 may then communicate a signal representative of the operational state to a communication unit 288 and/or an external connector 290.

The communication unit 288 may be configured to transmit an operational signal from the x-ray assembly 202 that is indicative of the operational state of the filament 204. For example, the communication unit 288 may transmit the operational signal to the wireless image panel 251. The communication unit 288 can include a wireless transmitter.

In some embodiments, the first measurement system 201 may determine the operational state of the filament 204 and communicate the signal to the wireless image panel 251 within about 50 milliseconds (ms) of application of a preheat current to the filament 204. Accordingly, the wireless image panel 251 may have sufficient time to transition to a high-power state to receive the x-rays 206 generated by the x-ray assembly 202.

In some embodiments, the first measurement system 201 may be retrofit onto one or more existing tubes. For example, one or more of the components of the first measurement system 201 (e.g., 256, 286, 294, 272, 270, 282, 274, etc.) may be fit onto an end 296 of an existing tube. The first measurement system 201 may be configured such that little or no

modifications are involved in the retrofit. For example, the first measurement system 201 may be configured such that an existing tube implementing the first measurement system does not have to recertify for medical or federal compliance.

5 The second measurement system may include a photodetector 262. The photodetector 262 may be positioned within the cooling fluid volume 253. Additionally or alternatively, the photodetector 262 may be positioned external to the tube housing 258. The photodetector 262 is configured to measure the radiance of the filament 204. A signal representative of the radiance may be communicated to the analysis circuit 286. The analysis circuit 286 may determine an operational state of the filament 204 based on the radiance. For
10 example, the radiance may be proportional to a filament temperature to the fourth power. The analysis circuit 286 may then communicate a signal representative of the operational state to a communication unit 288 and/or an external connector 290. The communication unit 288 may communicate the signal to the wireless image panel 251.

The third measurement system may include a current meter 266. The current meter 266 in
15 Figure 2 is depicted in the cooling fluid volume 253. In other embodiments, the current meter 266 may be included in the analysis circuit 286. The current meter 266 is configured to generate data representative of the stator current. The data is then communicated to the analysis circuit 286. The analysis circuit 286 may then communicate an operational signal representative of the operational state to a communication unit 288
20 and/or an external connector 290. The communication unit 288 may communicate the operational signal to the wireless image panel 251.

The analysis circuit 286 may be positioned on a circuit board 280. The circuit board 280 may be mounted to a diaphragm securing ring 276. The diaphragm securing ring 276 may be mounted to an oil diaphragm 274. The oil diaphragm 274 may be configured to seal
25 the cooling fluid volume 253. The diaphragm securing ring 276 may include a feedthrough 278. A wiring harness that couples the magnetic sensor 264, the photodetector 262, or the current meter 266 to an external connector 290 may pass through the feedthrough 278.

The x-ray assembly 202 may include a coverplate 294. The coverplate 294 may be
30 configured to be secured to an end 296 of the tube housing 258. The coverplate 294 may be configured to have positioned therein the analysis circuit 286, the circuit board 280, the diaphragm securing ring 276, the oil diaphragm 274, the sensor housing shield 272, other components, portions thereof, or combinations thereof. The tube housing 258 may define a coverplate opening that is configured to receive the coverplate 294. In some

embodiments, when the coverplate 294 is positioned in the coverplate opening (as depicted in Figure 2), the diaphragm securing ring 276 may seal against the tube housing 258.

In some embodiments, the x-ray assembly 202 may include an internal power generation system 295. The internal power generation system 295 may include a ring-type transformer. The internal power generation system 295 may generate power for the analysis circuit 286 and/or other components of the x-ray assembly 202. The internal power generation system 295 may be positioned such that a portion of the filament electrical circuit 214 passes through the internal power generation system 295. Additionally or alternatively, the internal power generation system 295 may be positioned such that a stator current supply passes through the internal power generation system 295. Modifications, additions, or omissions may be made to the x-ray system 200 without departing from the scope of the present disclosure. Specifically, the present disclosure may apply to an x-ray tube including a stationary anode. In these embodiments, the stator 250 is omitted and accordingly the third measurement system. Additionally, the x-ray tube 208 of Figure 2 may include multiple filaments 204; the filament current of both may be directly measured. Additionally, in some embodiments, the x-ray assembly 202 may include a manual trigger that may actuate the x-ray assembly 202. Furthermore, the separation of various components in the embodiments described herein is not meant to indicate that the separation occurs in all embodiments. It may be understood with the benefit of this disclosure that the described components may be integrated together in a single component or separated into multiple components.

Figure 3 illustrates disassembled portions of the x-ray assembly 202. One or more of components depicted in Figure 3 may be included in an embodiment of the x-ray assembly 202 including a magnetic sensor 264. The portions of the x-ray assembly 202 include a sensor assembly 400, a diaphragm assembly 500, and the coverplate 294.

The sensor assembly 400 may include a coil holder 304. The coil holder 304 may be configured to support the sensor housing shield 272 and a coil (e.g., the coil 256). The sensor assembly 400 includes the magnetic sensor 264 received in the sensor opening 270. A sensor electrical connector 306 may be electrically coupled to the magnetic sensor 264.

Referring to Figures 2 and 3, a first shield surface 320 faces away from the x-ray tube 208. The first shield surface 320 may be curved to receive the oil diaphragm 274 of the diaphragm assembly 500 when the diaphragm assembly 500 is assembled with the sensor

housing shield 272. The sensor electrical connector 306 may connect to an intermediate electrical connector 310. The intermediate electrical connector 310 may pass through the feedthrough 278 of the diaphragm securing ring 276. The intermediate electrical connector 310 connects to components (e.g., the analysis circuit 286) mounted to the circuit board 280. A terminal connector 308 may be connected to one or more of the components on the circuit board 280. When assembled, the oil diaphragm 274 and the circuit board 280 may be positioned within a cavity 312 defined by the coverplate 294. Additionally, the terminal connector 308 connects to a coverplate connector 302.

Figures 4A and 4B illustrate the sensor assembly 400. The sensor assembly 400 is depicted in a perspective view in Figure 4A and a side view in Figure 4B. As visible in Figure 4A, the coil holder 304 may be configured to receive the coil 256. Additionally, the coil holder 304 is coupled to the sensor housing shield 272. Accordingly, when positioned in the coil holder 304, the magnetic sensor 264 can measure an induced magnetic field in the coil 256.

In Figure 4B, a second shield surface 402 of the sensor housing shield 272 is visible. The second shield surface 402 may be configured to substantially block x-rays produced in an x-ray tube. The coil holder 304 may be mechanically coupled to the sensor housing shield 272 at the second shield surface 402. The sensor shield 282 may also be mounted to the second shield surface 402. The sensor shield 282 may substantially surround the sensor opening 270. The sensor shield 282 may be configured to not substantially interrupt the magnetic field induced in the coil 256 (of Figure 4A) and to block x-rays. The sensor shield 282 may be composed of a plastic that is substantially filled with Tungsten powder. The plastic filled with the Tungsten approximates the x-ray attenuation of lead, but does not significantly attenuate magnetic fields.

Figure 5 depicts another view of the diaphragm assembly 500. Figure 5 depicts a surface 502 of the circuit board 280 on which the analysis circuit 286 is mounted. The intermediate electrical connector 310 is depicted passing through the feedthrough 278 of the diaphragm securing ring 276. The intermediate electrical connector 310 is connected to the analysis circuit 286.

Figure 6 illustrates the diaphragm assembly 500 as it is being positioned in the coverplate 294. In particular, the surface 502 on which the analysis circuit 286 is mounted faces the cavity 312. When assembled, the analysis circuit 286 and the circuit board 280 are substantially positioned within the cavity 312. Additionally, the coverplate connector 302 is coupled to the external connector 290. The orientation of the oil diaphragm 274 enables

the analysis circuit 286 and other components mounted to the circuit board 280 to be positioned in a volume that is substantially free of compression by the possible expansion of the oil diaphragm 274.

Figure 7 illustrates the diaphragm assembly 500 assembled with the coverplate 294 as it is electrically coupled to the sensor electrical connector 306. In Figure 7, circuit board is not visible as it is positioned within the cavity. A portion of the diaphragm securing ring 276 extends past the coverplate 294. The portion of the diaphragm may include a seal 702 that is configured to seal against a tube housing such as the tube housing 258 of Figure 2.

The magnetic sensor 264 is coupled to the sensor electrical connector 306. Additionally, the sensor electrical connector 306 is coupled to the intermediate electrical connector 310 which passes through the feedthrough 278. Generally, the diaphragm assembly 500 is positioned within the coverplate 294 as depicted in Figure 6 prior to the electrical connection depicted in Figure 7. Accordingly, the magnetic sensor 264 is electrically connected to the analysis circuit (286 in Figure 6).

With combined reference to Figures 2 and 7, to assemble the x-ray assembly 202, the coil holder 304 may be positioned in the x-ray assembly 202. The coil holder 304 may be positioned within the cooling fluid volume 253 and between the x-ray tube 208 and the coverplate 294. The sensor housing shield 272 is positioned between the coil holder 304 and the coverplate 294. The coil 256 may be positioned within the coil holder 304, which is electrically coupled to the filament electrical circuit 214. The sensor housing shield 272 is mechanically coupled to the coil holder 304. The coverplate 294 may then be placed over the end 296 of the tube housing 258. The seal 702 may seal against an internal surface of the tube housing 258.

Figure 8 illustrates a block diagram of an example analysis circuit 286 that may be implemented in the x-ray system 200 of Figure 2. The analysis circuit 286 of Figure 8 is depicted implemented in the x-ray system 200. In general, a source 812 of the x-ray assembly 202 supplies a filament current to the filament 204. The filament current may then be supplied to the coil 256 that is connected in series in the return side of the filament electrical circuit 214. The filament current may induce a magnetic field 802 in the coil 256.

The magnetic sensor 264 may generate a signal that is representative of the magnetic field 802 of the coil 256. The magnetic sensor 264 may then communicate the signal to the analysis circuit 286.

The analysis circuit 286 may be configured to determine the operational state of the filament 204 based on the signal received from the magnetic sensor 264. The analysis circuit 286 may include an instrument amplifier 804, a root mean square (RMS)-to-direct current (DC) converter (converter) 806, and open collector comparator op amps (comparator) 808.

The instrument amplifier 804 may be configured to filter, amplify, and/or clean the signal communicated from the magnetic sensor 264. The instrument amplifier 804 may amplify portions of the signal communicated from the magnetic sensor 264, mitigate noise, or perform another signal amplification process.

An example of the instrument amplifier 804 is depicted in Figure 9. The instrument amplifier 804 may include one or more of the components illustrated in Figure 9 in the configuration depicted therein. The instrument amplifier 804 however is not limited to the embodiment depicted in Figure 9. In some embodiments, the instrument amplifier 804 may include one or more additional or alternative components.

Referring back to Figure 8, the instrument amplifier 804 may output a filtered signal to the converter 806. The filtered signal output by the instrument amplifier 804 may include an alternating current (AC) signal. The converter 806 is configured to convert the filtered signal to a direct current (DC) signal.

An example of the converter 806 is depicted in Figure 10. In the embodiment of the converter 806, the filtered signal is input as an RMS signal and output as a DC signal derived therefrom. The converter 806 may include one or more of the components illustrated in Figure 10 in the configuration depicted therein. The converter 806 however is not limited to the embodiment depicted in Figure 10. In some embodiments, the converter 806 may include one or more additional or alternative components.

Referring back to Figure 8, the DC signal output by the converter 806 is communicated to the comparator 808. The comparator 808 may be configured to compare a voltage of the DC signal to a comparator signal. Based on the comparison between the voltage of the DC signal and the comparator signal, the comparator 808 outputs an output signal. Moreover, based on the output signal and thus on the comparison between the voltage of the DC signal and the comparator signal, the analysis circuit 286 can determine an operational state of the filament 204.

The output signal may include a binary-type signal such as a transistor-transistor logic (TTL) signal. For example, if the voltage of the DC signal is greater than a voltage of the comparator signal, then the comparator 808 may output a particular voltage (e.g., 5

Volts). If the voltage of the DC signal is less than a voltage of the comparator signal, then the comparator 808 may output a ground signal (e.g., 0 Volts).

The determined operational state of the filament 204 may be based on the output of the comparator. For example, the determined operational state of the filament 204 may be a standby operational state in response to the voltage of the DC signal being less than a voltage of the comparator signal. Additionally, the determined operational state of the filament 204 may be an exposure operational state in response to the DC signal being greater than the voltage of the comparator signal.

An example of the comparator 808 is depicted in Figure 11. Figure 11 also includes an example converter 806. The comparator 808 may include one or more of the components illustrated in Figure 11 in the configuration depicted therein. The comparator 808 however is not limited to the embodiment depicted in Figure 11. In some embodiments, the comparator 808 may include one or more additional or alternative components.

Referring back to Figure 8, the comparator 808 may communicate the output signal that is representative of the operational state of the filament 204 to the communication unit 288. The communication unit 288 may communicate a signal 810 representative of the operational state to the wireless image panel 251. In response, the wireless image panel 251 may transition from a low-power state to a high-power state or vice versa. The signal 810 may be a wireless signal as discussed elsewhere herein.

In some embodiments, the communication unit 288 may include a port for direct physical connection to a communication network or to another communication channel. For example, the communication unit 288 may include a universal serial bus (USB), standard definition (SD), CAT-5, or similar port for wired communication. In some embodiments, the communication unit 288 includes a wireless transceiver for exchanging data via communication channels using one or more wireless communication methods, including IEEE 802.11, IEEE 802.16, BLUETOOTH®, or another suitable wireless communication method.

An example of the communication unit 288 is provided in Figure 12. The communication unit 288 may include one or more of the components illustrated in Figure 12 in the configuration depicted therein. The communication unit 288 however is not limited to the embodiment depicted in Figure 12. In some embodiments, the communication unit 288 may include one or more additional or alternative components.

The x-ray assembly 202 may further include a processor 814 and memory 816 that may be coupled to the analysis circuit 286 and/or the communication unit 288. The processor

814 may include an arithmetic logic unit (ALU), a microprocessor, a general-purpose controller, or some other processor or processor array to perform one or more operations described herein. The processor 814 generally processes data signals. The processor 814 may include various computing architectures including a complex instruction set computer (CISC) architecture, a reduced instruction set computer (RISC) architecture, or
5 an architecture implementing a combination of instruction sets.

The memory 816 may be configured to store instructions and/or data that may be executed by the processor 814. The instructions and/or data may include code for performing the techniques or methods described herein. The memory 816 may include
10 Dynamic Random Access Memory (DRAM), Static RAM (SRAM), flash memory, or any other applicable type of memory. In some embodiments, the memory 816 also includes a non-volatile memory or similar permanent storage device and media including a hard disk drive, a floppy disk drive, a CD-ROM device, a DVD-ROM device, a DVD-RAM device, a DVD-RW device, a flash memory device, or some other mass storage device for storing
15 information on a more permanent basis.

In some embodiments, the analysis circuit 286 omits the instrument amplifier 804. Additionally, the analysis circuit 286 may include one or more additional filters. Additionally, the analysis circuit 286 may be configured to receive a signal from a stator that is representative of a stator current and/or a signal from a photodetector that is
20 representative of a radiance of the filament. For example, in Figure 8, light 820 emitted by the filament 204 may be measured by the photodetector (in Figure 8, PD) 262. The photodetector 262 may communicate a signal representative of a radiance of the light 820 to the analysis circuit 286. The analysis circuit 286 can determine an operational state of the filament 204 based on the signal.

Figure 13 is a block diagram of a method 1300 of determination of an operational state of a filament in an x-ray tube assembly. In some embodiments, the method 1300 may be performed by the x-ray assembly 202 described with reference to Figure 2, or some component(s) thereof. In some embodiments, the x-ray assembly 202 or another computing device may include or may be communicatively coupled to a non-transitory
30 computer-readable medium (e.g., the memory 816 of Fig. 8) having stored thereon programming code or instructions that are executable by a processor (such as the processor 814 of Fig. 8) to cause a computing device and/or the x-ray assembly 202 to perform one or more portions of the method 1300. Additionally or alternatively, the x-ray assembly 202 may include the processor 814 described above that is configured to

execute computer instructions to cause performance of the one or more portions of the method 1300. Although illustrated as discrete blocks, various blocks may be divided into additional blocks, combined into fewer blocks, or eliminated, depending on the desired implementation.

5 The method 1300 may begin at block 1302, in which a magnetic field may be induced in a coil. The coil is included in a filament electrical circuit of the filament. In some embodiments, the coil may be electrically coupled in series in a return side of the filament electrical circuit. At block 1304, shielding a portion of x-rays generated in the x-ray assembly. In some embodiments, a sensor housing shield and a sensor shield may be used
10 to shield the portion of the x-rays. The sensor housing shield may be configured to secure the magnetic sensor and a sensor shield that is attached to the sensor housing shield. The sensor shield may be comprised of plastic filled with Tungsten and may surround a sensor opening configured to receive the magnetic sensor.

At block 1306, a signal may be generated. The signal may be representative of the
15 magnetic field induced in the coil. In some embodiments, the signal may originate at a magnetic sensor that is configured to measure the magnetic field. An example of the magnetic sensor may include a magnetoresistive bridge.

At block 1308, power may be generated for an analysis circuit. The power may be generated using a ring-type transformer that may use as an energy source a portion of the
20 filament electrical circuit. Additionally, in some embodiments, the analysis circuit includes a converter and a comparison circuit. At block 1310, the signal may be converted to a direct current (DC) signal. At block 1312, a voltage of the DC signal may be compared to comparator signal.

At block 1314, an operational state of the filament may be determined based on the
25 signal. The determined operational state of the filament may be a standby operational state in response to the voltage of the DC signal being less than a voltage of the comparator signal. The determined operational state of the filament may be an exposure operational state in response to the DC signal being greater than the voltage of the comparator signal.

30 At block 1316, an operational state signal may be wirelessly communicated from the x-ray assembly to a wireless image panel. The operational state signal is configured to transition the wireless image panel from a low-power state in which the wireless image panel operates at a reduced power state and a high-power state in which the wireless

image panel is configured to receive at least a portion of x-rays produced by the x-ray tube.

One skilled in the art will appreciate that, for this and other procedures and methods disclosed herein, the functions performed in the processes and methods may be implemented in differing order. Furthermore, the outlined steps and operations are only
5 provided as examples, and some of the steps and operations may be optional, combined into fewer steps and operations, or expanded into additional steps and operations without detracting from the disclosed embodiments.

The embodiments described herein may include the use of a special-purpose or general-
10 purpose computer including various computer hardware or software modules, as discussed in greater detail below.

Embodiments described herein may be implemented using computer-readable media for carrying or having computer-executable instructions or data structures stored thereon. Such computer-readable media may be any available media that may be accessed by a
15 general-purpose or special-purpose computer. By way of example, and not limitation, such computer-readable media may include tangible or non-transitory computer-readable storage media including RAM, ROM, EEPROM, CD-ROM or other optical disk storage, magnetic disk storage or other magnetic storage devices, or any other non-transitory storage medium which may be used to carry or store desired program code in the form of
20 computer-executable instructions or data structures and which may be accessed by a general-purpose or special-purpose computer. Combinations of the above may also be included within the scope of computer-readable media.

Computer-executable instructions comprise, for example, instructions and data, which cause a general-purpose computer, special-purpose computer, or special-purpose
25 processing device to perform a certain function or group of functions. Although the subject matter has been described in language specific to structural features and/or methodological acts, it is to be understood that the subject matter defined in the appended claims is not necessarily limited to the specific features or acts described above. Rather, the specific features and acts described above are disclosed as example forms of
30 implementing the claims.

As used herein, the terms “module,” “component,” and/or “engine” may refer to software objects or routines that execute on the computing system. The different components, modules, engines, and services described herein may be implemented as objects or processes that execute on the computing system (e.g., as separate threads). While the

system and methods described herein are preferably implemented in software, implementations in hardware or a combination of software and hardware are also possible and contemplated. In this description, a “computing entity” may be any computing system as previously defined herein, or any module or combination of modules running on a
5 computing system.

All examples and conditional language recited herein are intended for pedagogical objects to aid the reader in understanding the invention and the concepts contributed by the inventor to furthering the art, and are to be construed as being without limitation to such specifically recited examples and conditions. Although embodiments of the present
10 invention have been described in detail, it should be understood that the various changes, substitutions, and alterations could be made hereto without departing from the spirit and scope of the invention.

CLAIMS

What is claimed is:

1. An x-ray assembly comprising:
an x-ray tube that defines an evacuated envelope;
5 a filament positioned within the evacuated envelope, the filament including a standby operational state in which the filament is not emitting electrons, an exposure operational state in which the filament is emitting electrons, and a preheat operational state during which the filament transitions from the standby operational state to the exposure operational state; and
10 a sensor configured to measure a characteristic of the filament that is indicative of an operational state of the filament.
2. The x-ray assembly of claim 1, further comprising:
an analysis circuit that is electrically coupled to the sensor, wherein the
15 analysis circuit is configured to receive a measured characteristic from the sensor and to determine the operational state of the filament based on the measured characteristic; and
a communication unit that is electrically coupled to the analysis circuit and configured to transmit a signal from the x-ray assembly that is indicative of the operational state of the filament.
20
3. The x-ray assembly of claim 2, wherein the evacuated envelope is substantially transparent and the sensor includes a photodetector.
4. The x-ray assembly of claim 2, further comprising:
25 a filament electrical circuit that supplies electrical current to the filament; and
a coil that is included in the filament electrical circuit,
wherein the coil is electrically coupled in series in a return side of the filament electrical circuit, and
wherein the sensor includes a magnetic sensor configured to measure a
30 magnetic field induced in the coil.
5. The x-ray assembly of claim 4, wherein:
the magnetic sensor includes a magnetoresistive bridge; and

the analysis circuit includes a root mean square (RMS)-to-direct current (DC) converter that receives a signal representative of the magnetic field measured by the magnetic sensor, and an open collector comparator that receives DC voltages output from the RMS-to-DC converter.

5

6. The x-ray assembly of claim 4, further comprising:

a coverplate;

a rotating anode positioned within the evacuated envelope to receive at least a portion of electrons emitted by the filament when the filament is in the exposure operational state;

10

a stator that is configured to induce rotation of the rotating anode;

a tube housing that at least partially surrounds the x-ray tube and at least partially defines a cooling fluid volume defined between the x-ray tube and the tube housing, wherein the tube housing defines a coverplate opening;

15

a coil holder positioned between the x-ray tube and the coverplate;

a sensor housing shield that is positioned between the coil holder and the coverplate, wherein the sensor housing shield is configured to secure the magnetic sensor and is comprised of a shielding material that reduces x-rays produced in the x-ray tube from escaping through the coverplate opening;

20

an oil diaphragm;

a diaphragm securing ring defining a feedthrough; and

a circuit board mounted to the diaphragm securing ring, wherein the circuit board includes the analysis circuit,

wherein the coverplate is configured to be secured to an end of the tube housing defining the coverplate opening.

25

7. The x-ray assembly of claim 6, further comprising a sensor shield that is attached to the sensor housing shield, wherein the sensor shield is comprised of a plastic filled with Tungsten and surrounds a sensor opening configured to receive the magnetic sensor.

30

8. The x-ray assembly of claim 6, further comprising:

an external connector positioned on the coverplate; and

a wiring harness that couples the magnetic sensor to the external connector, wherein the wiring harness extends from the magnetic sensor to the external connector and passes through the feedthrough.

5 9. An x-ray system comprising:

a wireless image panel including a low-power state in which the wireless image panel operates at a reduced power state and a high-power state in which the wireless image panel is configured to receive at least a portion of x-rays produced by the x-ray tube; and

10 the x-ray assembly of claim 2, wherein the communication unit includes a wireless transmitter that communicates an operational signal that is representative of the operational state of the filament to the wireless image panel.

10. The x-ray assembly of claim 1, further comprising an internal power
15 generation system that is configured to generate power for an analysis circuit.

11. The x-ray assembly of claim 10, wherein the internal power generation system includes a ring-type transformer, through which a portion of a filament electrical circuit is positioned.

20

12. An x-ray tube operational state measurement system, the system comprising:
a filament electrical circuit that supplies electrical current to a filament of an x-ray tube;

a coil that is included in the filament electrical circuit, wherein the coil is
25 electrically coupled, in series, in a return side of the filament electrical circuit;

a magnetic sensor configured to measure a magnetic field induced in the coil;

an analysis circuit that is electrically coupled to the magnetic sensor, wherein
the analysis circuit is configured to receive a measured magnetic field from the magnetic sensor and to determine the operational state of the filament based on the measured
30 magnetic field; and

a communication unit that is electrically coupled to the analysis circuit and configured to transmit a signal that is representative of the operational state of the filament.

13. The system of claim 12, wherein the analysis circuit includes:
a root mean square (RMS)-to-direct current (DC) converter that receives a
signal representative of the magnetic field measured by the magnetic sensor, and
an open collector comparator that receives DC voltages output from the RMS-
5 to-DC converter.
14. The system of claim 13, further comprising:
a coil holder into which the coil is positioned;
a sensor housing shield defining a sensor opening that is configured to receive
10 the magnetic sensor; and
a sensor shield that extends from a surface of the sensor housing shield and
surrounds the sensor opening, wherein the sensor shield is comprised of an x-ray
shielding material.
15. The system of claim 14, further comprising:
an oil diaphragm;
a coverplate configured to be secured to an end of a tube housing;
a diaphragm securing ring configured to be mounted to the oil diaphragm,
wherein the diaphragm securing ring defines a feedthrough; and
20 a circuit board mounted to the diaphragm securing ring, wherein the circuit
board includes the analysis circuit.
16. A method of determining an operational state of a filament in an x-ray
assembly, the method comprising:
25 inducing a magnetic field in a coil, wherein the coil is included in a filament
electrical circuit of the filament;
generating a signal that is representative of the magnetic field induced in the
coil; and
based on the signal, determining an operational state of the filament.
- 30 17. The method of claim 16, further comprising:
converting the signal to a direct current (DC) signal; and
comparing a voltage of the DC signal to a comparator signal,

wherein the determined operational state of the filament is a standby operational state in response to the voltage of the DC signal being less than a voltage of the comparator signal and to be an exposure operational state in response to the DC signal being greater than the voltage of the comparator signal.

5

18. The method of claim 16, further comprising wirelessly communicating an operational state signal from the x-ray assembly to a wireless image panel, wherein the operational state signal is configured to transition the wireless image panel from a low-power state in which the wireless image panel operates at a reduced power state and a
10 high-power state in which the wireless image panel is configured to receive at least a portion of x-rays produced by an x-ray tube.

19. The method of claim 16, further comprising:
shielding a portion of x-rays generated in an x-ray tube using a sensor housing
15 shield configured to secure a magnetic sensor and a sensor shield that is attached to the sensor housing shield; and
generating power for an analysis circuit using a ring-type transformer.

20. The method of claim 19, wherein:
20 the magnetic sensor includes a magnetoresistive bridge;
the coil is electrically coupled in series in a return side of the filament electrical circuit; and
the sensor shield is comprised of a plastic that is filled with Tungsten and surrounds a sensor opening configured to receive the magnetic sensor.

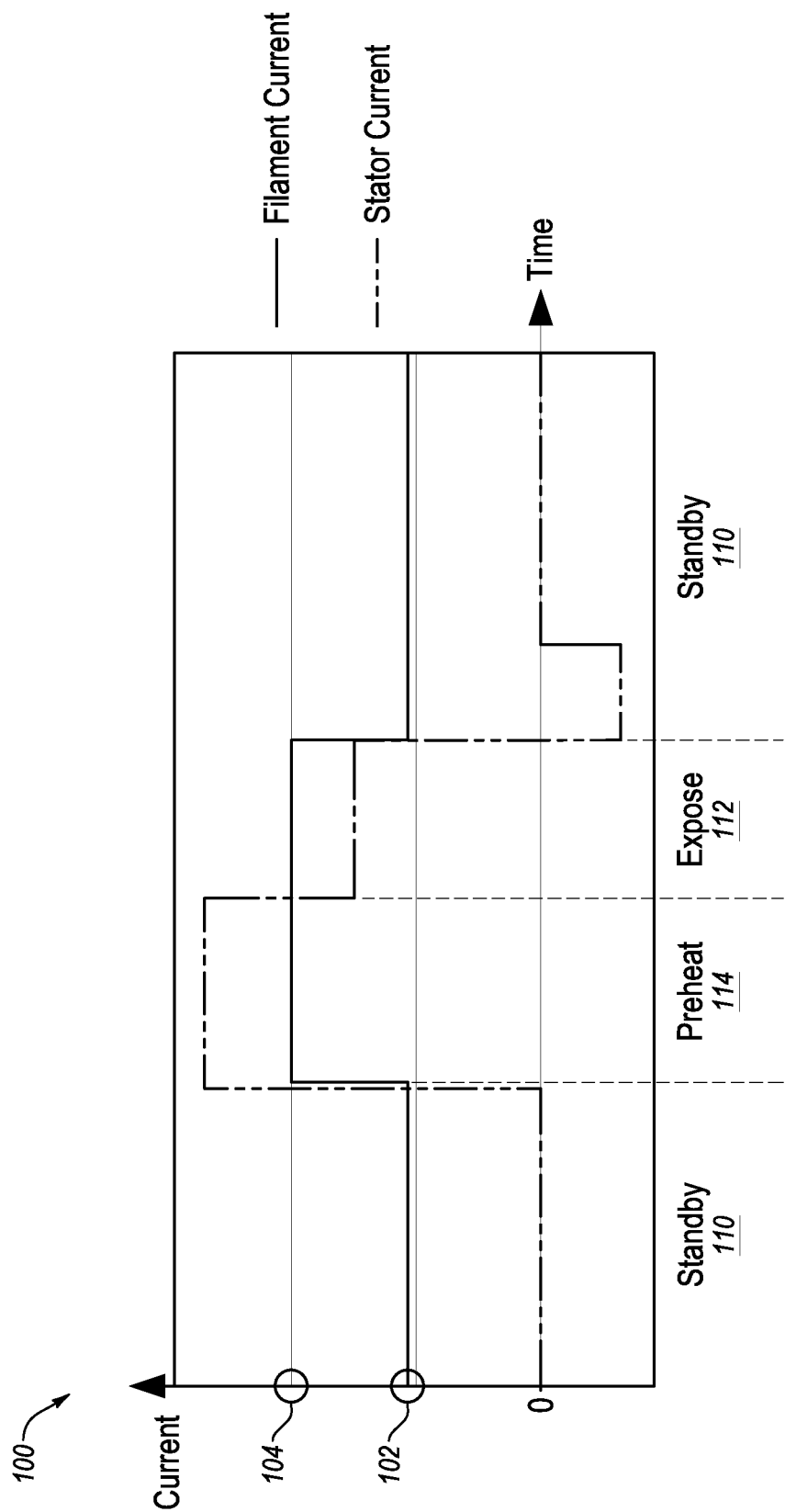
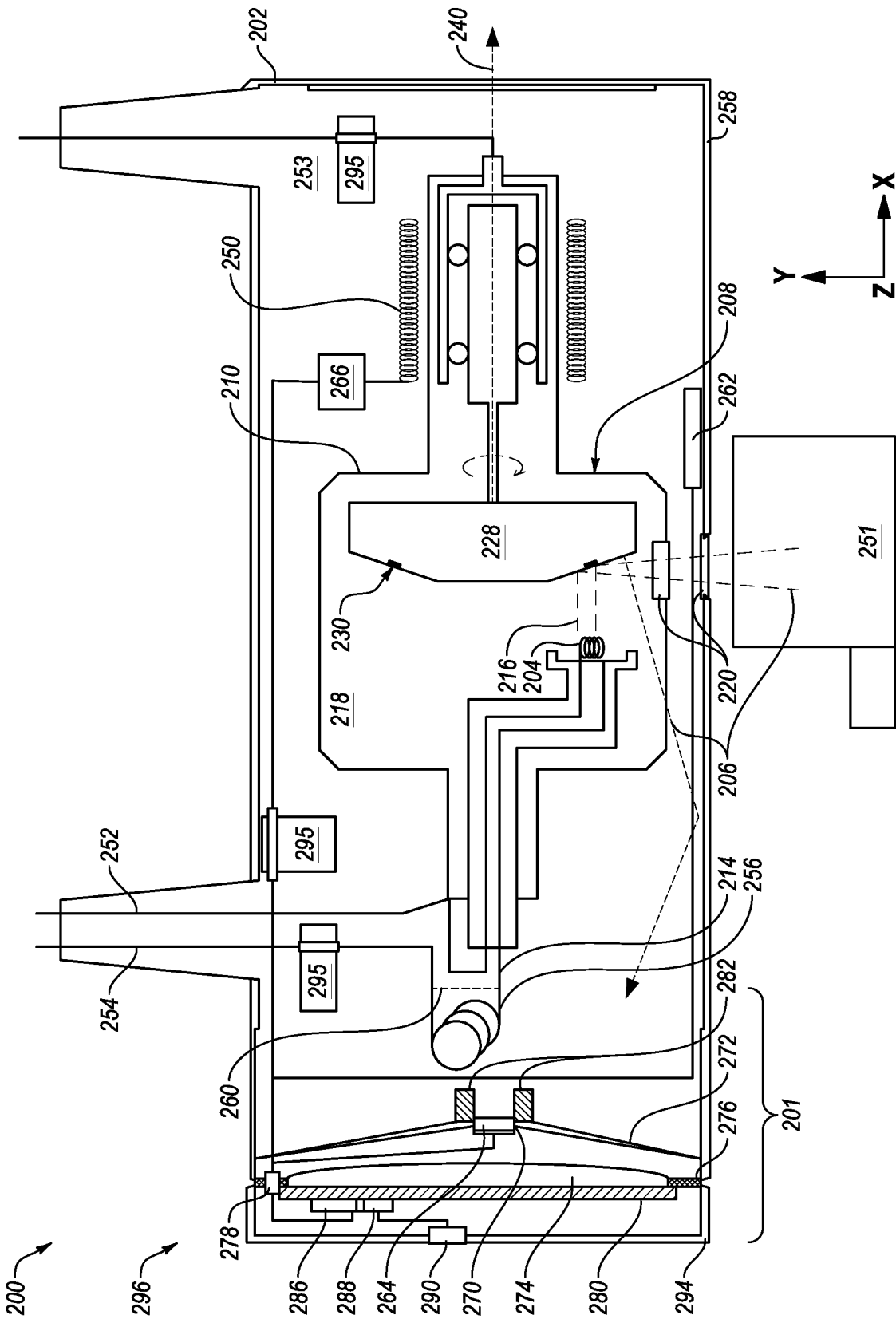


Fig. 1



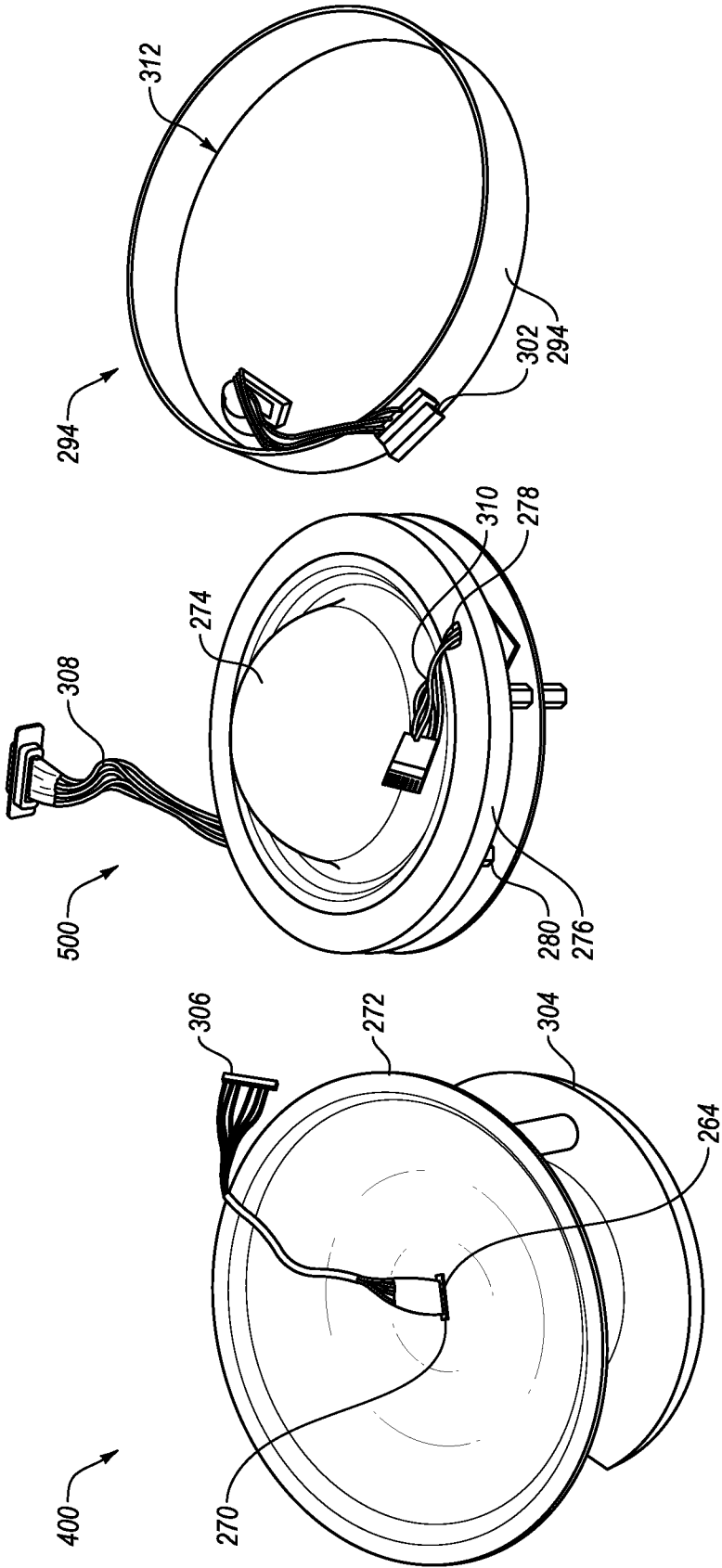


Fig. 3

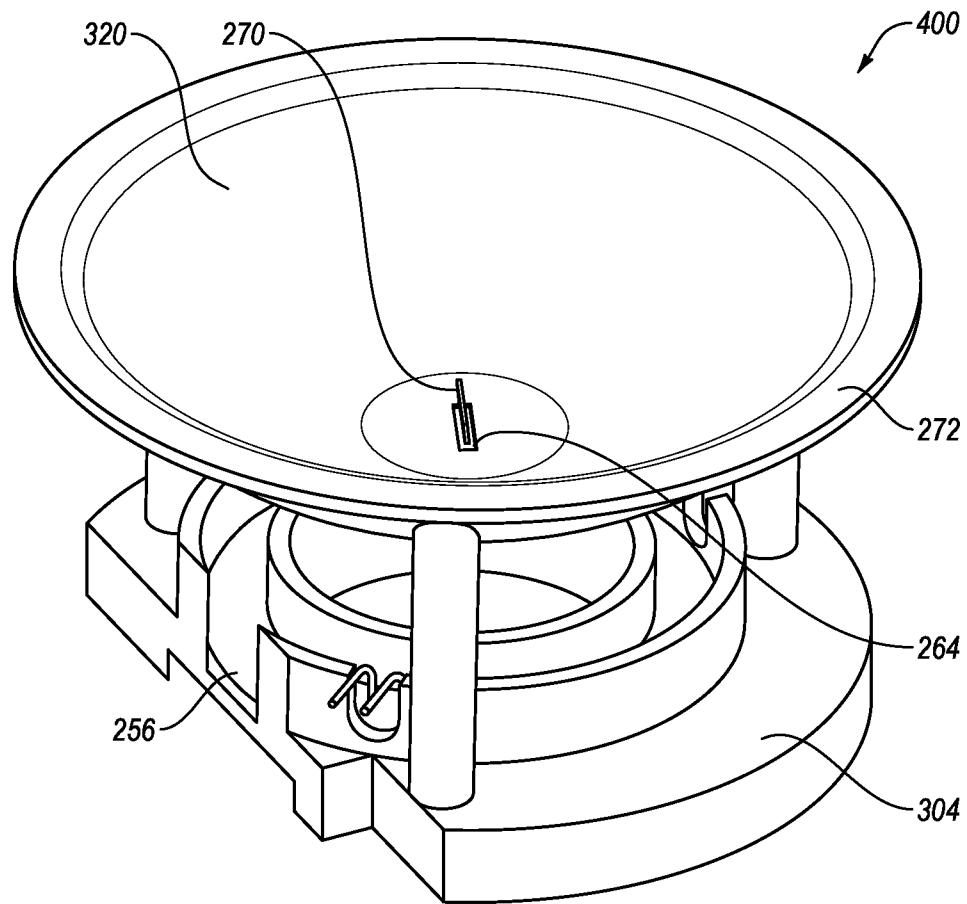


Fig. 4A

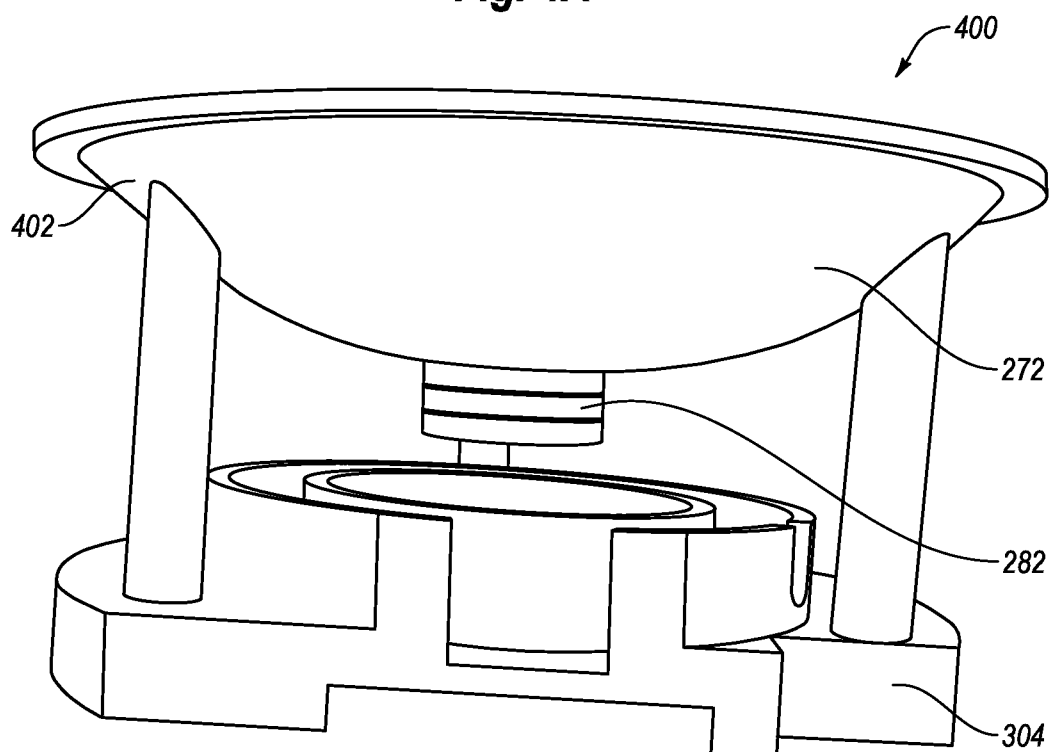


Fig. 4B

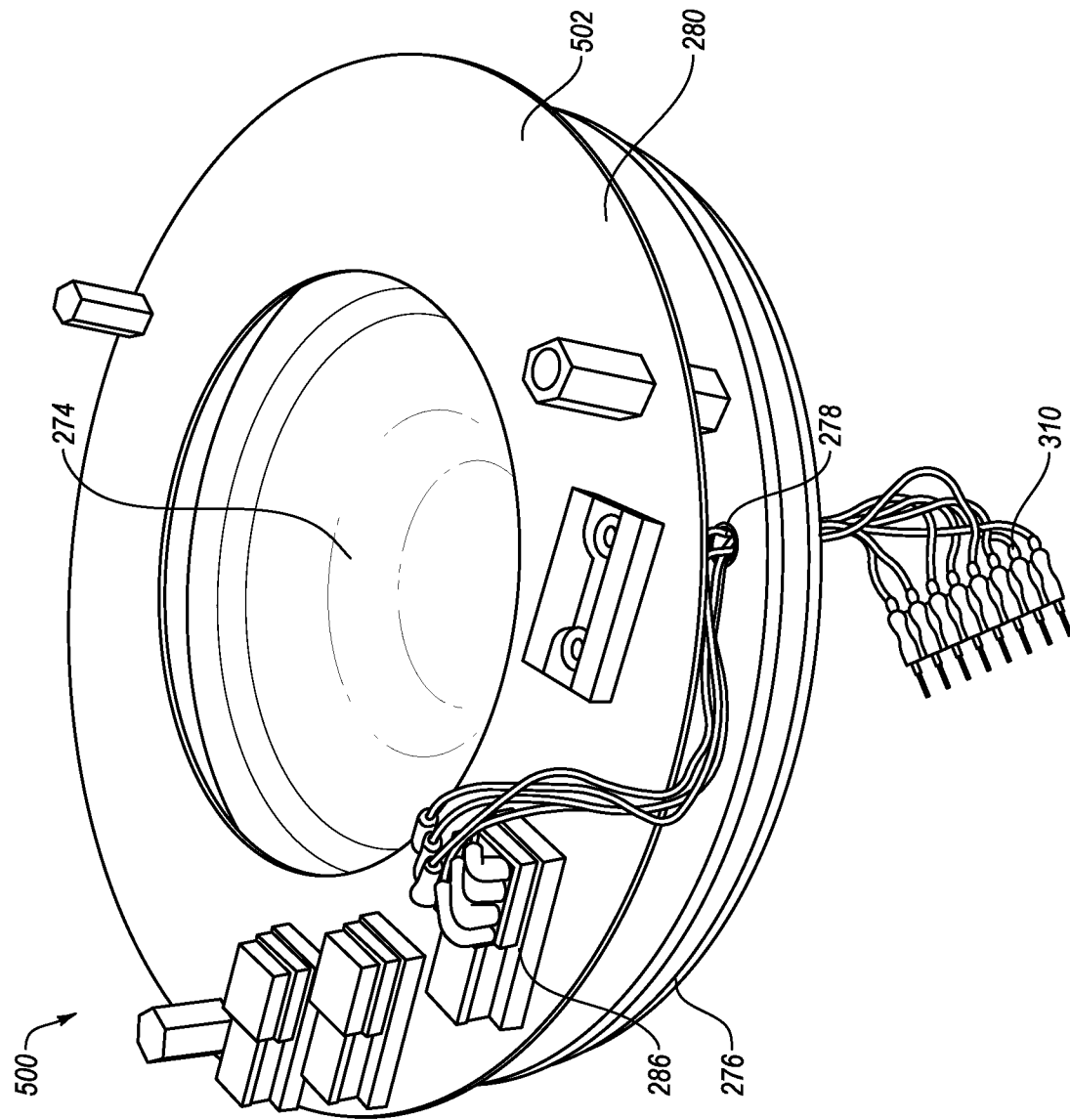
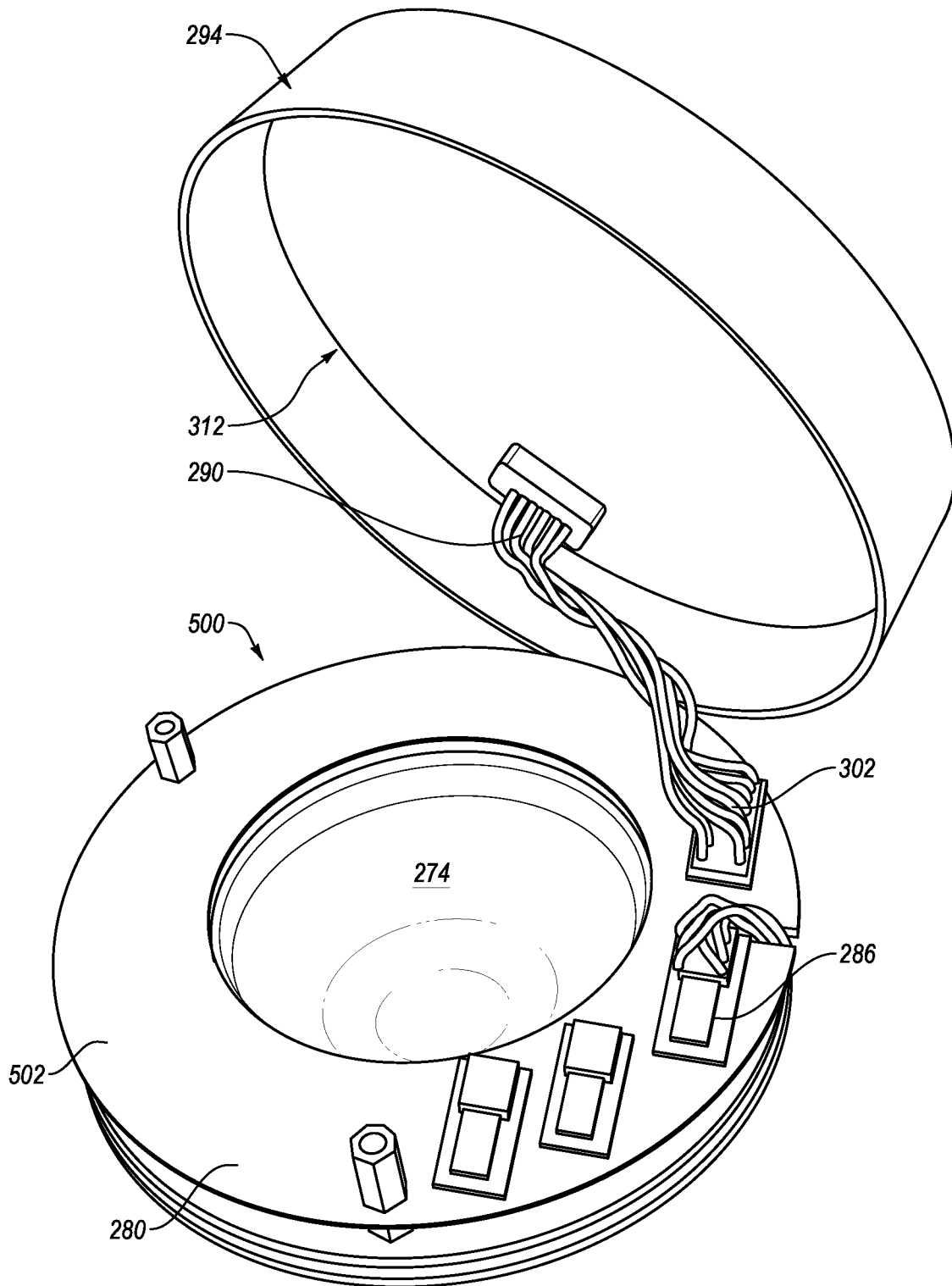
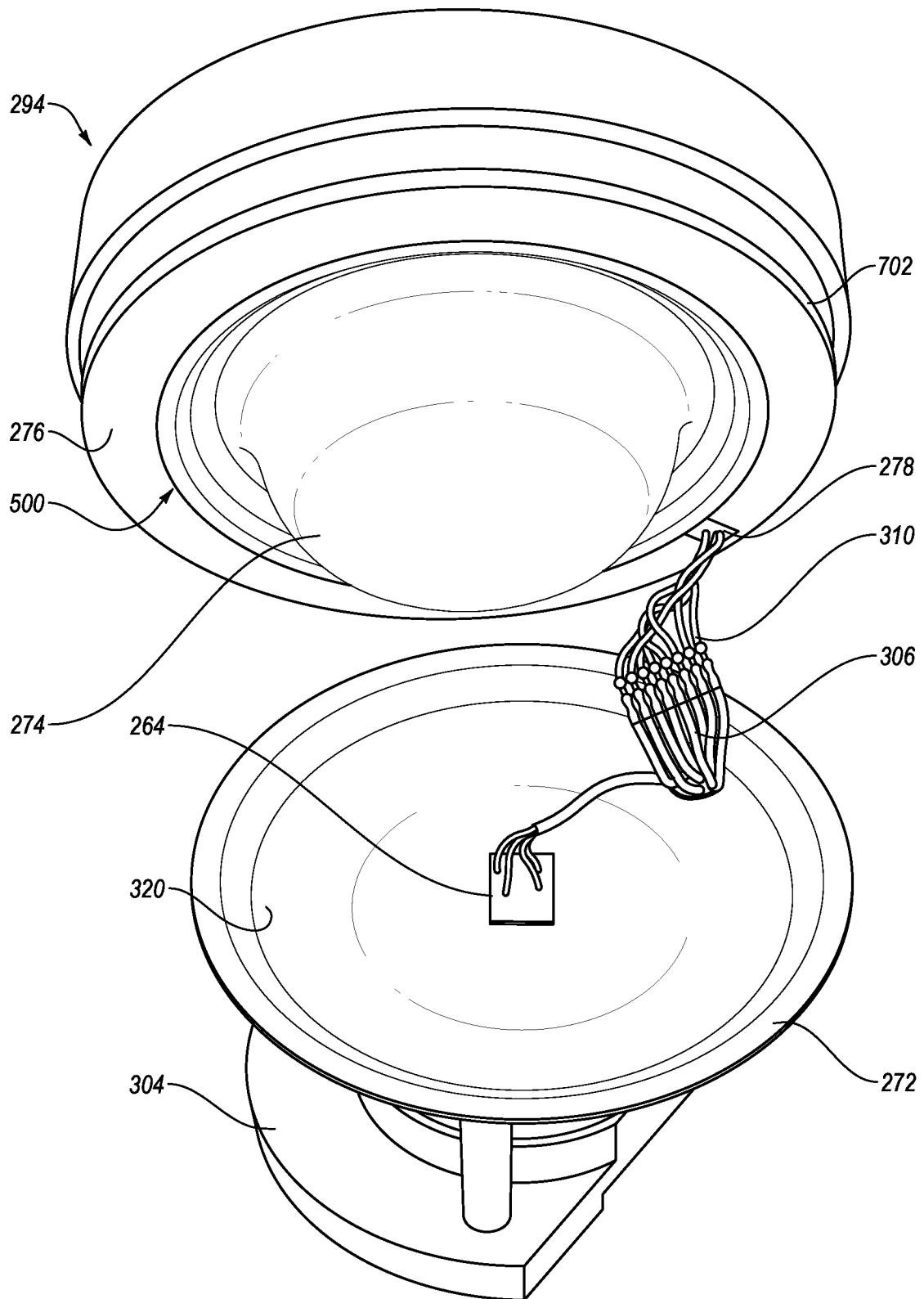


Fig. 5

**Fig. 6**

**Fig. 7**

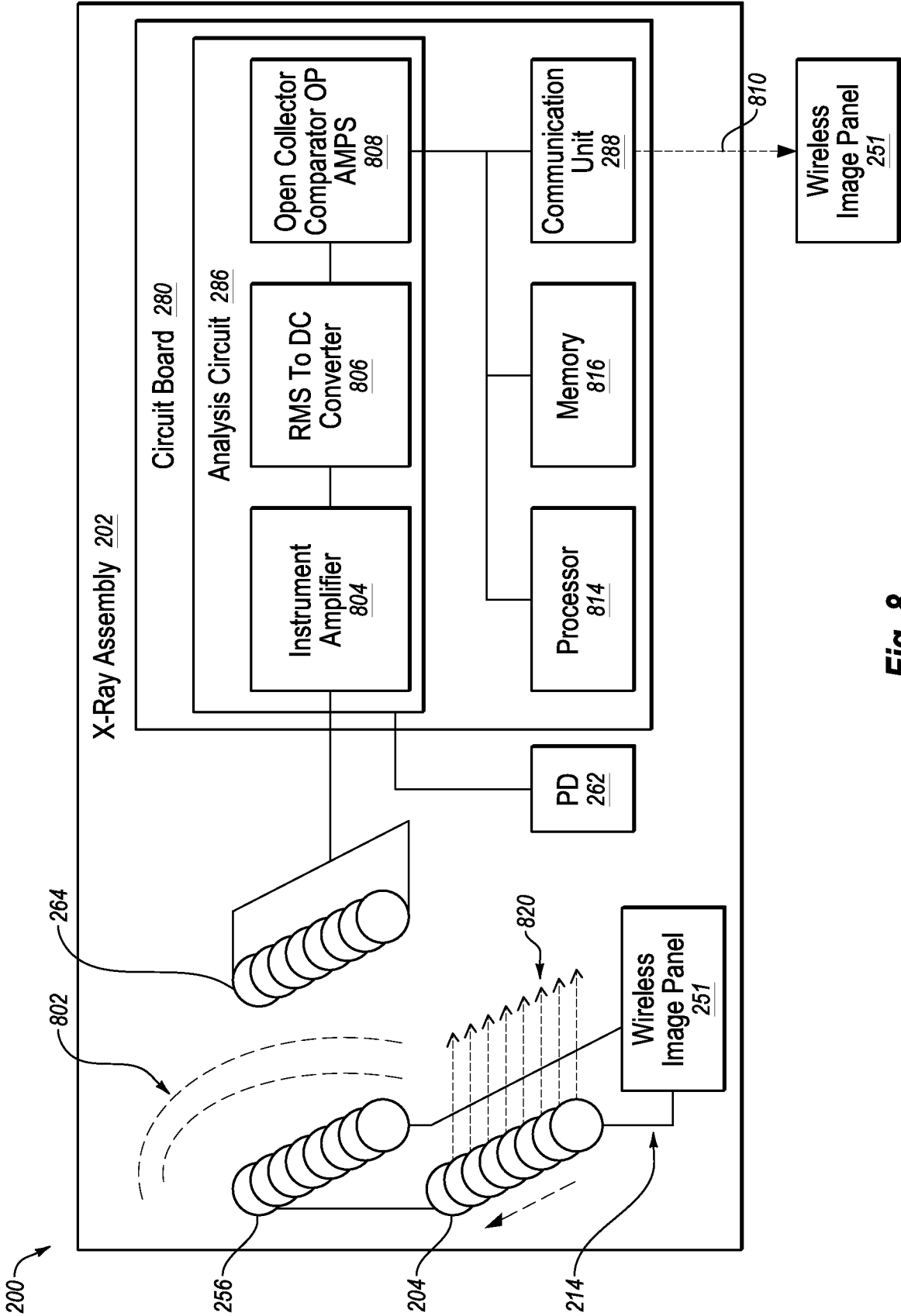


Fig. 8

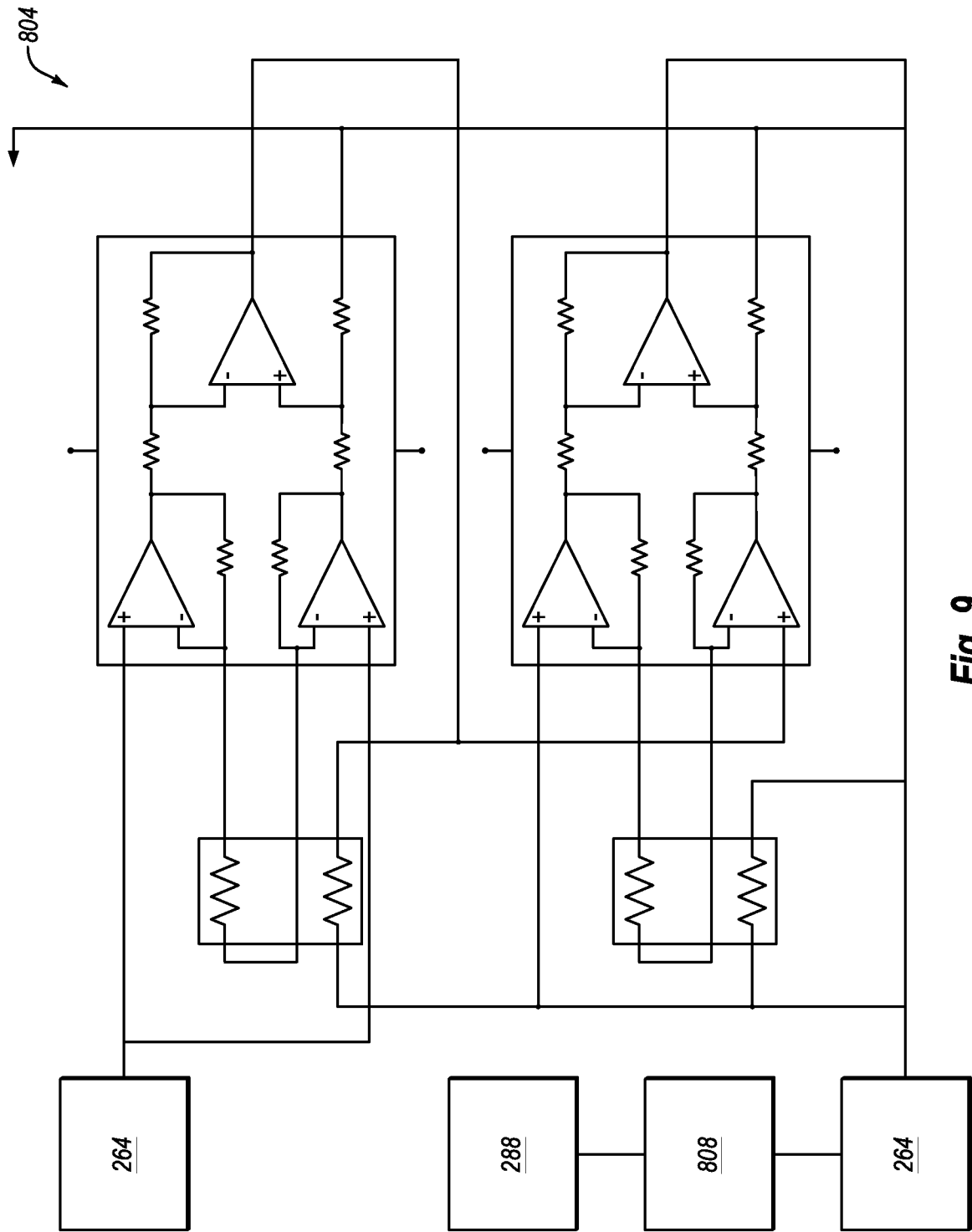


Fig. 9

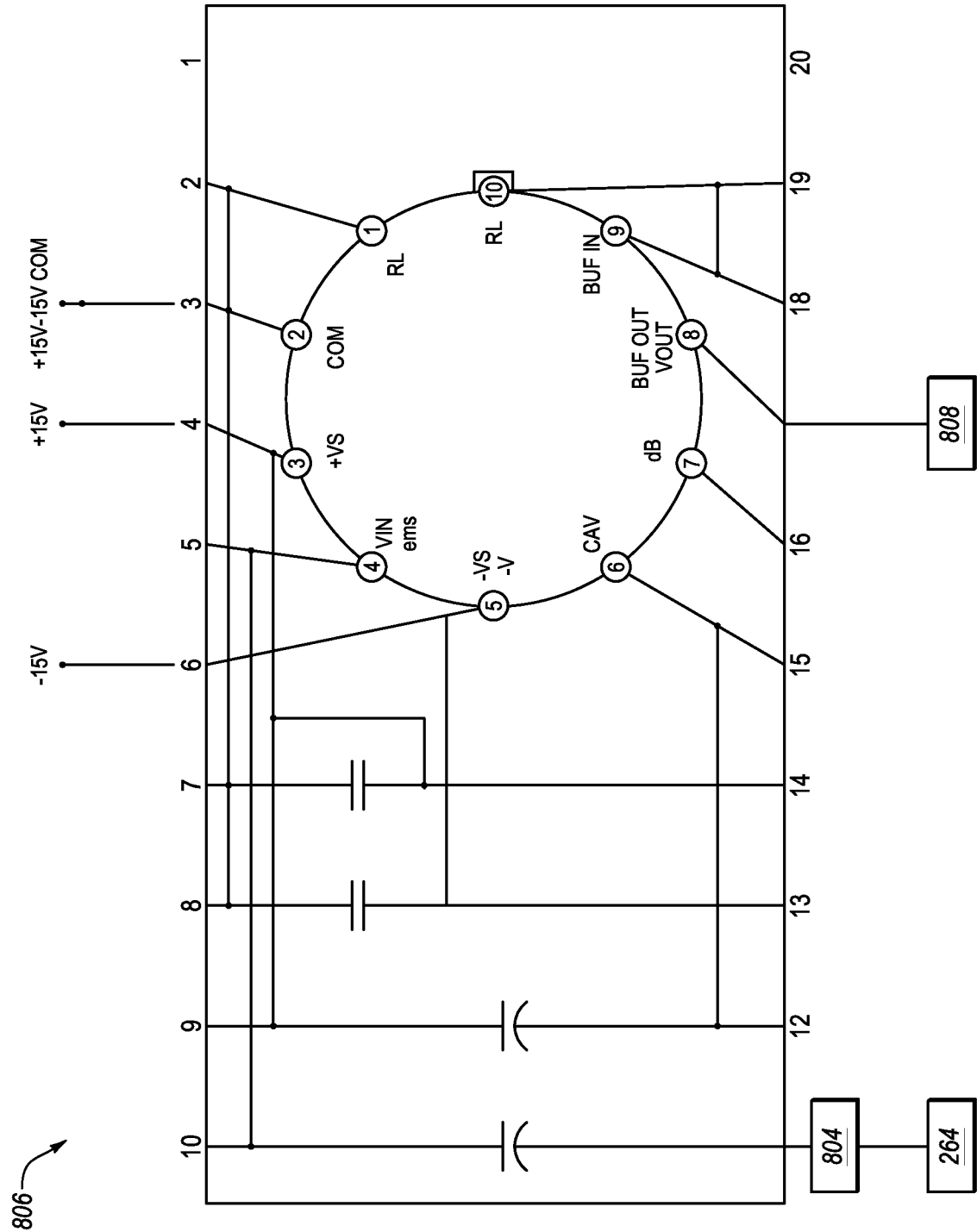
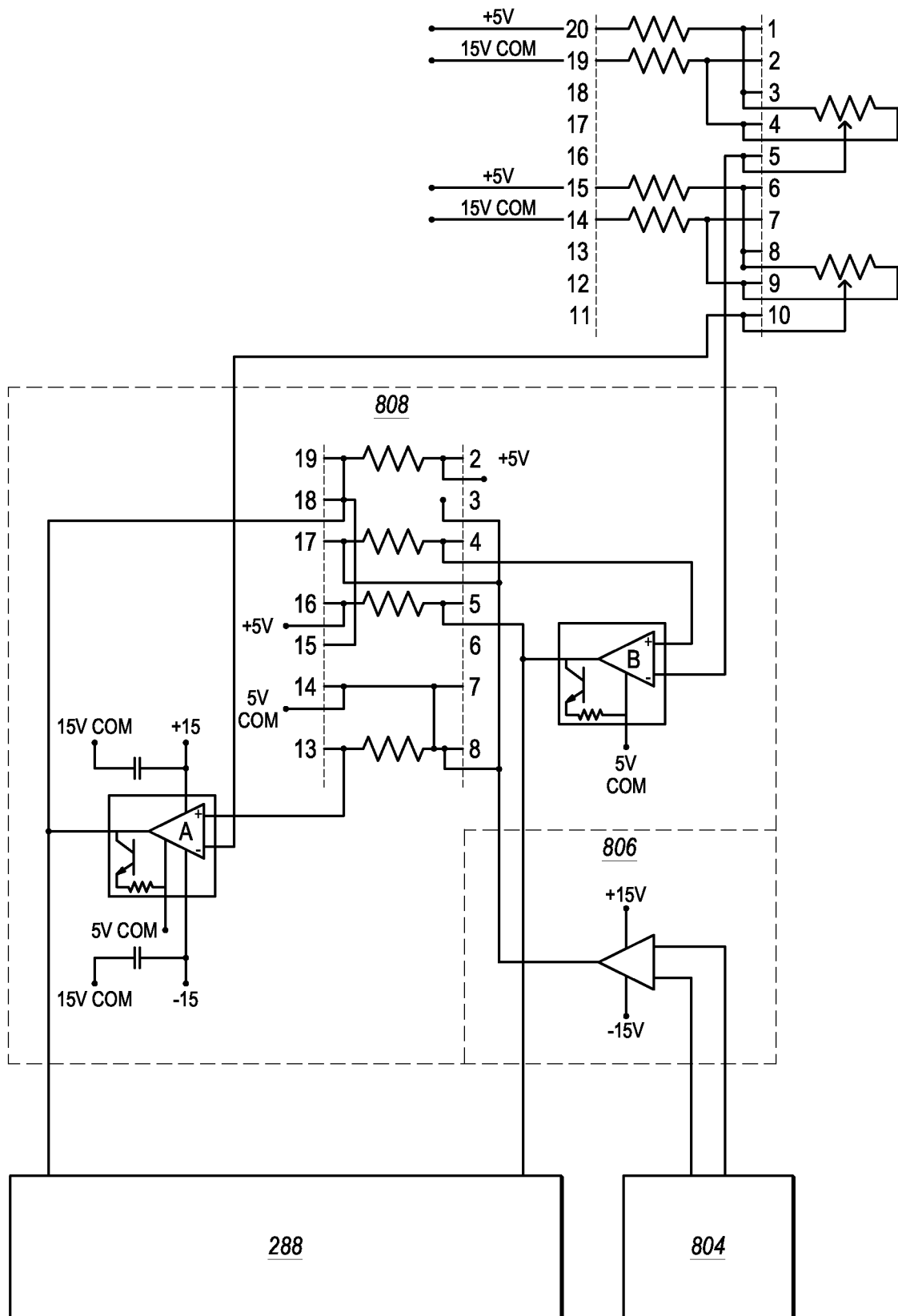


Fig. 10

**Fig. 11**

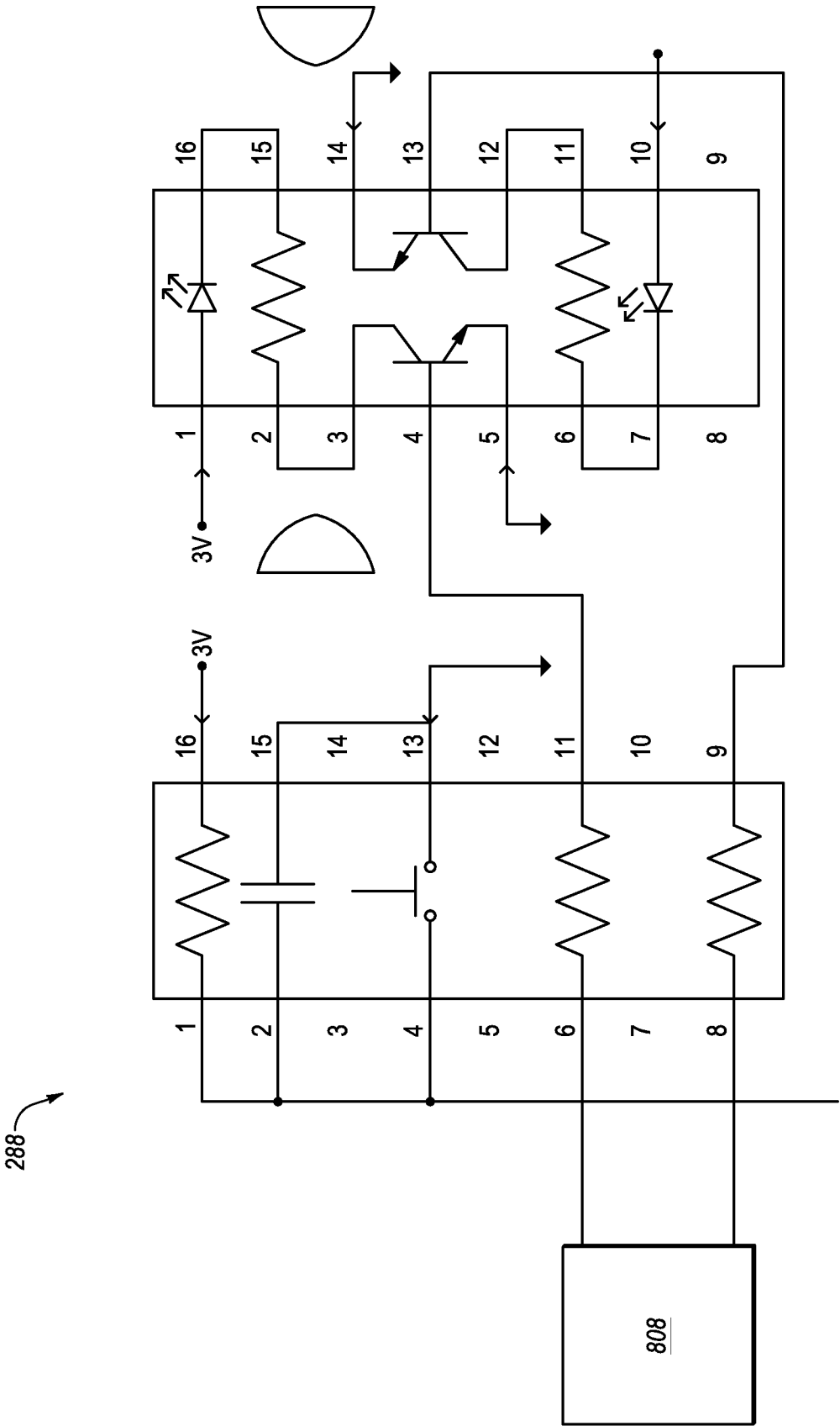
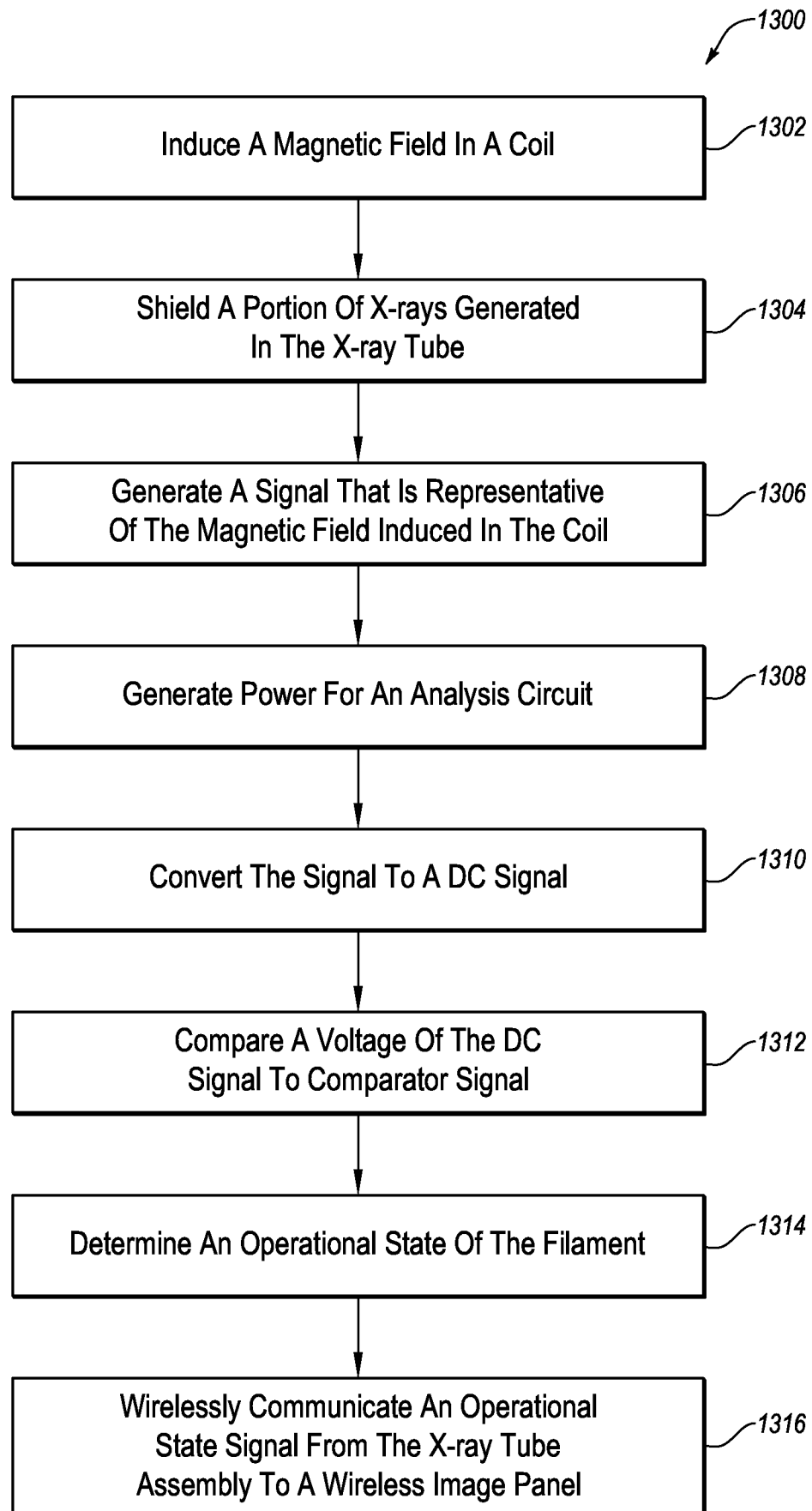


Fig. 12

**Fig. 13**

INTERNATIONAL SEARCH REPORT

International application No

PCT/US2015/041408

A. CLASSIFICATION OF SUBJECT MATTER

INV. H05G1/34

ADD.

According to International Patent Classification (IPC) or to both national classification and IPC

B. FIELDS SEARCHED

Minimum documentation searched (classification system followed by classification symbols)

H05G H01J

Documentation searched other than minimum documentation to the extent that such documents are included in the fields searched

Electronic data base consulted during the international search (name of data base and, where practicable, search terms used)

EP0-Internal

C. DOCUMENTS CONSIDERED TO BE RELEVANT

Category*	Citation of document, with indication, where appropriate, of the relevant passages	Relevant to claim No.
X	US 2012/082294 A1 (VIRSHUP GARY [US] ET AL) 5 April 2012 (2012-04-05)	1-3,9
Y	paragraphs [0026], [0028], [0047];	4,12,16,
A	figure 2	18
	-----	5,13-15,
		17,19,20
Y	US 2006/290340 A1 (SHAPIRO JONATHAN S [US]) 28 December 2006 (2006-12-28)	4,12,16,
	paragraphs [0001], [0038], [0039],	18
	[0045]	

A	US 4 918 714 A (ADAMSKI JOSEPH R [US] ET AL) 17 April 1990 (1990-04-17)	6-8
	figure 1	

☐ Further documents are listed in the continuation of Box C.

☒ See patent family annex.

* Special categories of cited documents :

"A" document defining the general state of the art which is not considered to be of particular relevance

"E" earlier application or patent but published on or after the international filing date

"L" document which may throw doubts on priority claim(s) or which is cited to establish the publication date of another citation or other special reason (as specified)

"O" document referring to an oral disclosure, use, exhibition or other means

"P" document published prior to the international filing date but later than the priority date claimed

"T" later document published after the international filing date or priority date and not in conflict with the application but cited to understand the principle or theory underlying the invention

"X" document of particular relevance; the claimed invention cannot be considered novel or cannot be considered to involve an inventive step when the document is taken alone

"Y" document of particular relevance; the claimed invention cannot be considered to involve an inventive step when the document is combined with one or more other such documents, such combination being obvious to a person skilled in the art

"&" document member of the same patent family

Date of the actual completion of the international search

6 June 2016

Date of mailing of the international search report

23/06/2016

Name and mailing address of the ISA/

European Patent Office, P.B. 5818 Patentlaan 2
NL - 2280 HV Rijswijk
Tel. (+31-70) 340-2040,
Fax: (+31-70) 340-3016

Authorized officer

Oestreich, Sebastian

INTERNATIONAL SEARCH REPORT

International application No.
PCT/US2015/041408

Box No. II Observations where certain claims were found unsearchable (Continuation of item 2 of first sheet)

This international search report has not been established in respect of certain claims under Article 17(2)(a) for the following reasons:

1. ☐ Claims Nos.:
because they relate to subject matter not required to be searched by this Authority, namely:
2. ☐ Claims Nos.:
because they relate to parts of the international application that do not comply with the prescribed requirements to such an extent that no meaningful international search can be carried out, specifically:
3. ☐ Claims Nos.:
because they are dependent claims and are not drafted in accordance with the second and third sentences of Rule 6.4(a).

Box No. III Observations where unity of invention is lacking (Continuation of item 3 of first sheet)

This International Searching Authority found multiple inventions in this international application, as follows:

see additional sheet

1. ☐ As all required additional search fees were timely paid by the applicant, this international search report covers all searchable claims.
2. ☐ As all searchable claims could be searched without effort justifying an additional fees, this Authority did not invite payment of additional fees.
3. ☐ As only some of the required additional search fees were timely paid by the applicant, this international search report covers only those claims for which fees were paid, specifically claims Nos.:
4. ☒ No required additional search fees were timely paid by the applicant. Consequently, this international search report is restricted to the invention first mentioned in the claims; it is covered by claims Nos.:

1-9, 12-20

Remark on Protest

- ☐ The additional search fees were accompanied by the applicant's protest and, where applicable, the payment of a protest fee.
- ☐ The additional search fees were accompanied by the applicant's protest but the applicable protest fee was not paid within the time limit specified in the invitation.
- ☐ No protest accompanied the payment of additional search fees.

FURTHER INFORMATION CONTINUED FROM PCT/ISA/ 210

This International Searching Authority found multiple (groups of) inventions in this international application, as follows:

1. claims: 1-9, 12-20

x-ray assembly, comprising a tube and a magnetic sensor,
measuring the magnetic field induced by a coil included in
the filament electrical circuit, to measure a characteristic
of the filament that is indicative of an operational state
of the filament.

magnetoresistive sensor

mechanical set-up of the assembly

2. claims: 10, 11

x-ray assembly, comprising a tube and a sensor to measure a
characteristic of the filament that is indicative of an
operational state of the filament and an internal power
generation system.

INTERNATIONAL SEARCH REPORT

Information on patent family members

International application No

PCT/US2015/041408

Patent document cited in search report	Publication date	Patent family member(s)	Publication date
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