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(54) **SYSTEM FOR RFID-ENABLED  
INFORMATION COLLECTION**

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(71) Applicant: **The United States of America as  
represented by the Administrator of  
the National Aeronautics and Space  
Administration**, Washington, DC (US)

(72) Inventors: **Patrick W. Fink**, Missouri City, TX  
(US); **Gregory Y. Lin**, Houston, TX  
(US); **Timothy F. Kennedy**, Houston,  
TX (US); **Phong H. Ngo**, Friendswood,  
TX (US)

(73) Assignee: **The United States of America as  
represented by the Administrator of  
the National Aeronautics and Space  
Administration**, Washington, DC (US)

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*Primary Examiner* — Santiago Garcia

(74) *Attorney, Agent, or Firm* — Kurt G. Hammerle

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12, 2015.

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**H04Q 5/22** (2006.01)  
**G06K 7/10** (2006.01)

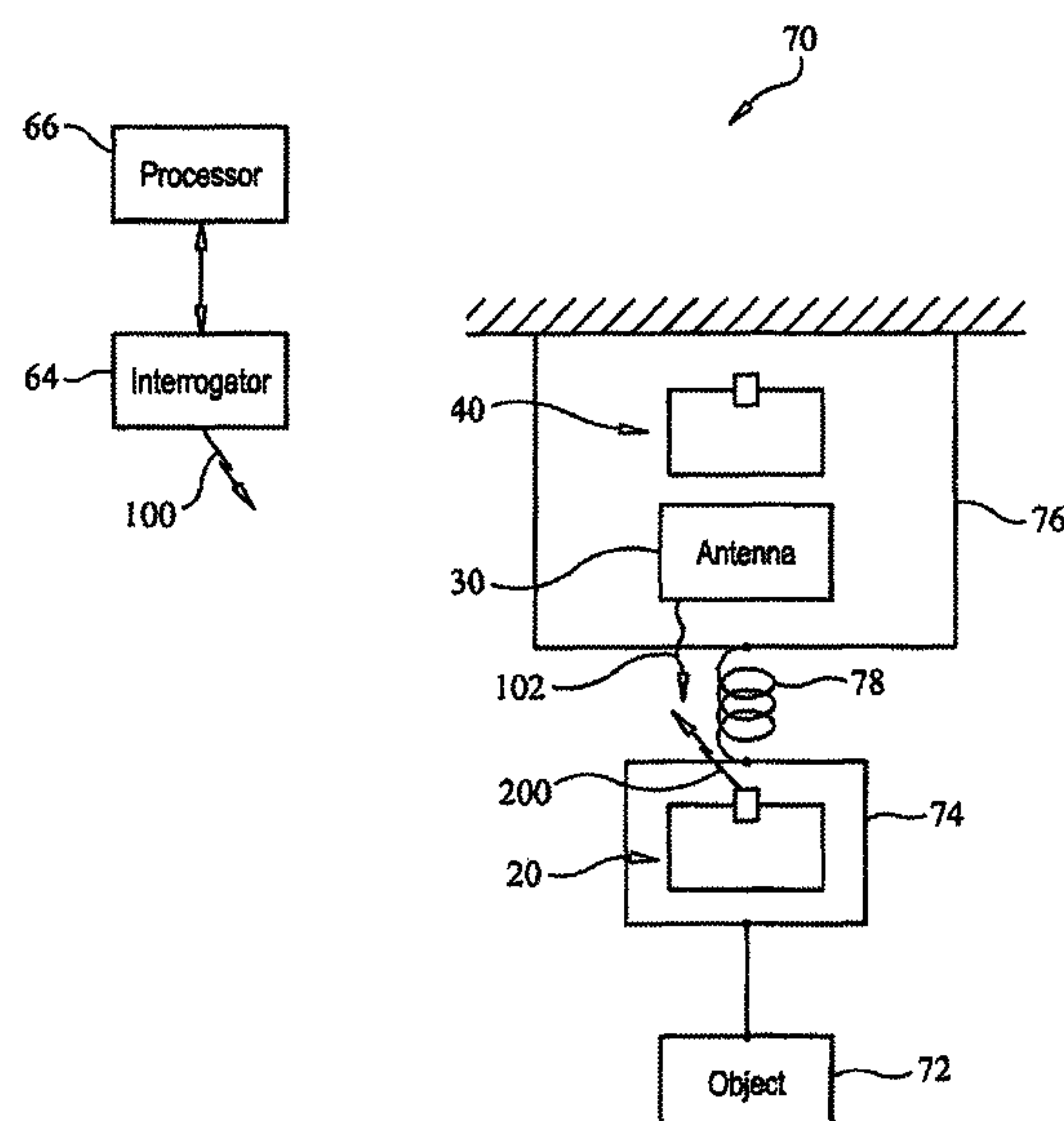
(52) **U.S. Cl.**  
CPC ..... **G06K 7/10316** (2013.01)

(58) **Field of Classification Search**  
CPC ..... G06K 7/10316  
USPC ..... 340/903  
See application file for complete search history.

(57) **ABSTRACT**

A sensor and system provide for radio frequency identification (RFID)-enabled information collection. The sensor includes a ring-shaped element and an antenna. The ring-shaped element includes a conductive ring and an RFID integrated circuit. The antenna is spaced apart from the ring-shaped element and defines an electrically-conductive path commensurate in size and shape to at least a portion of the conductive ring. The system may include an interrogator for energizing the ring-shaped element and receiving a data transmission from the RFID integrated circuit that has been energized for further processing by a processor.

**18 Claims, 7 Drawing Sheets**



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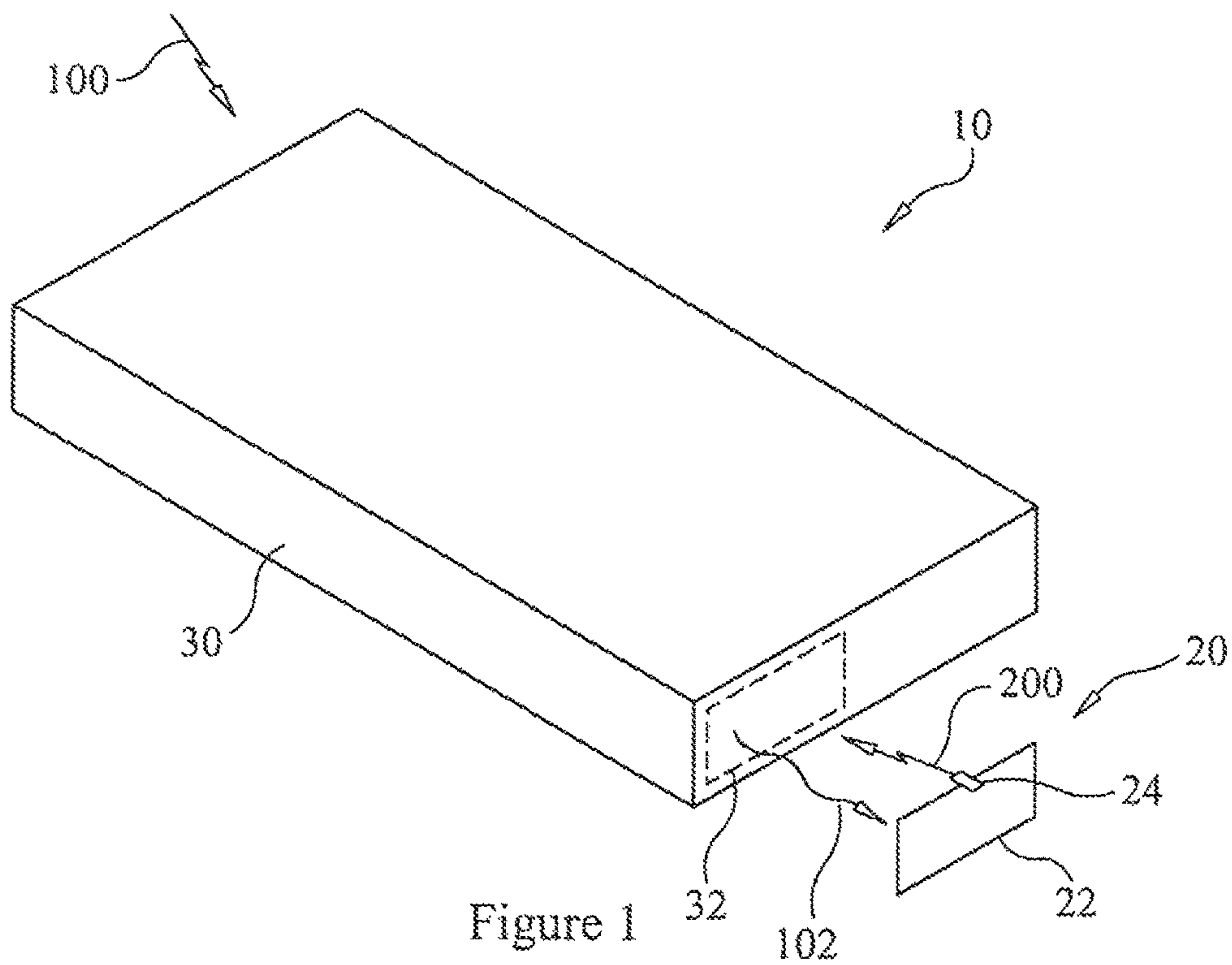


Figure 1

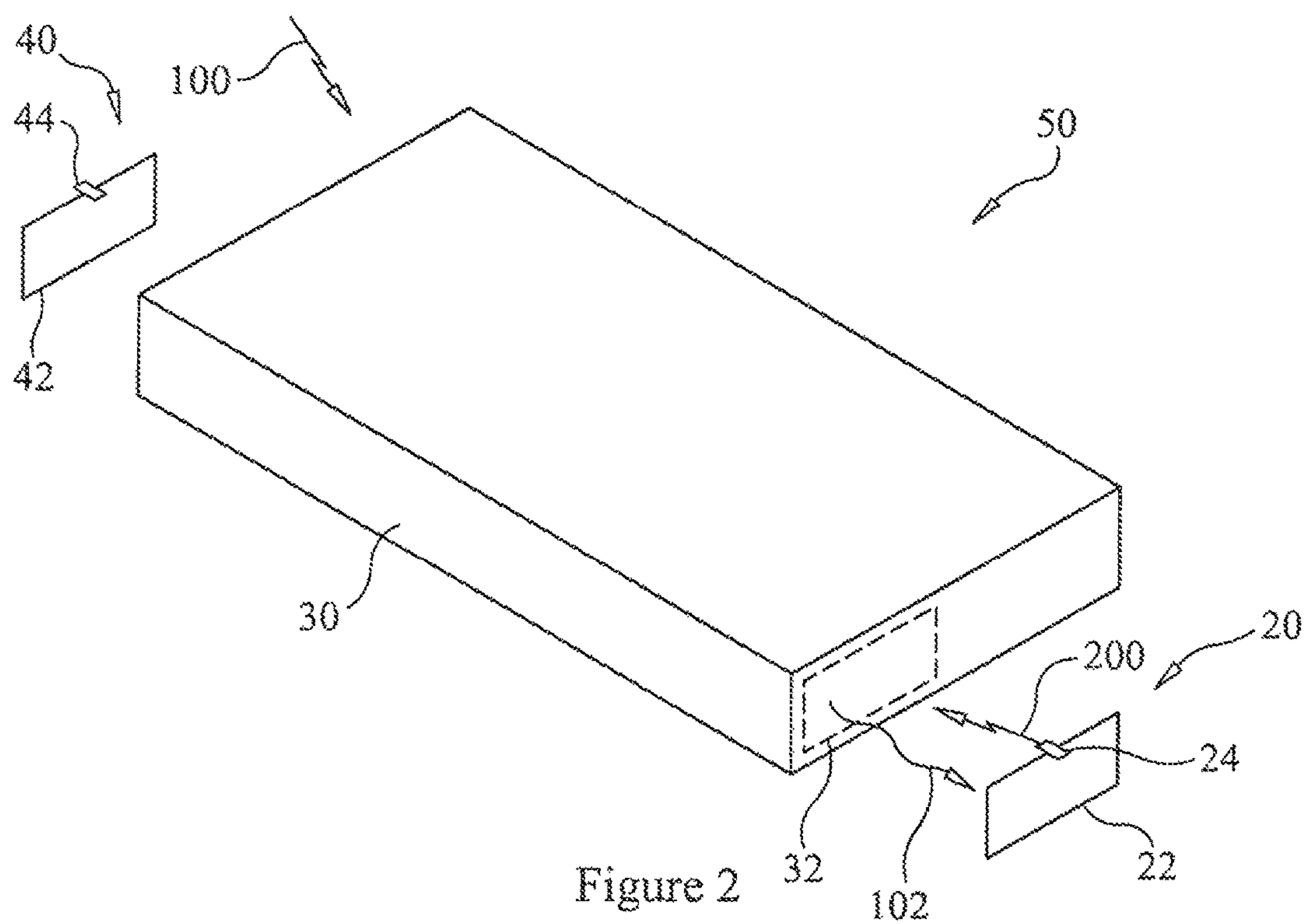
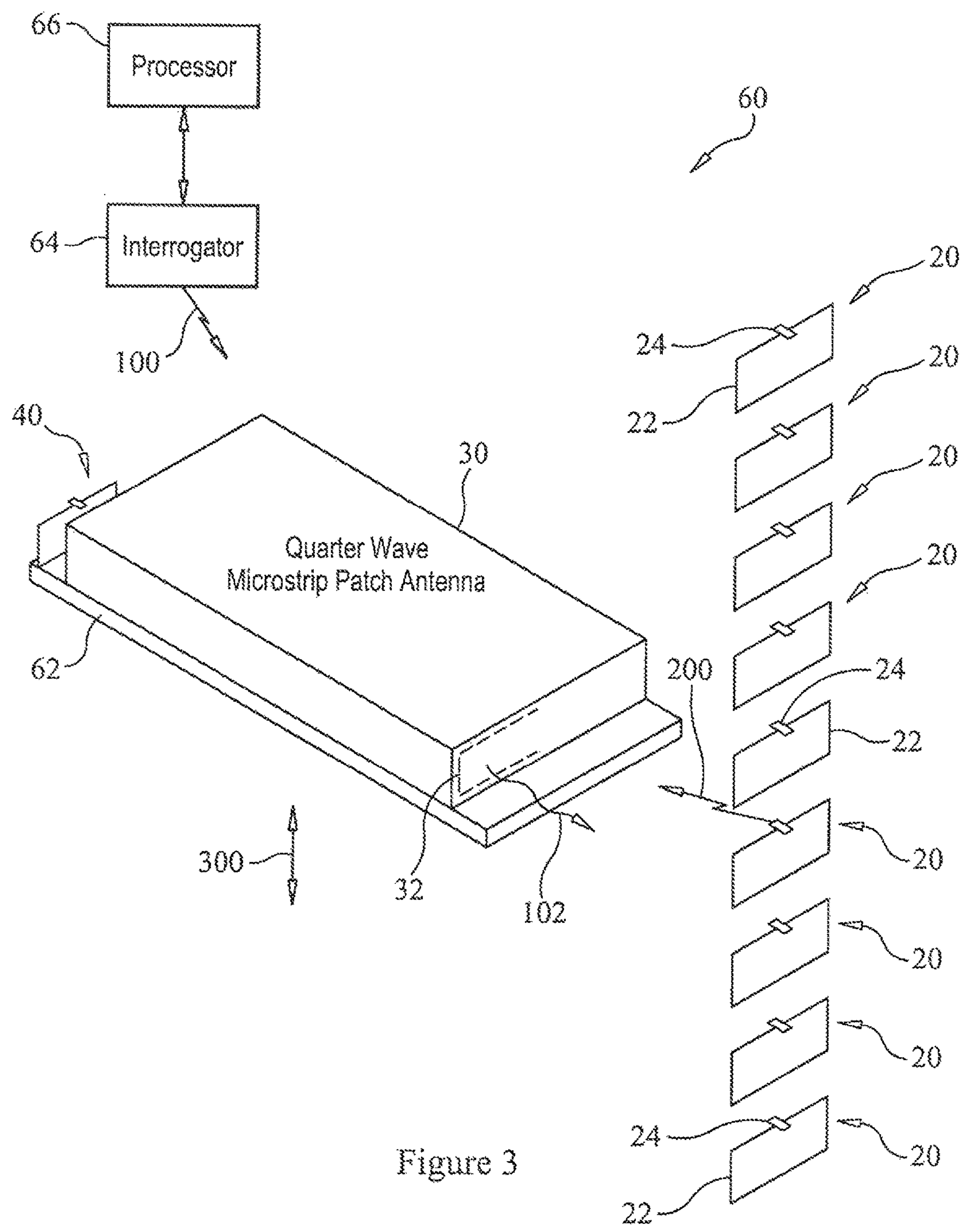


Figure 2



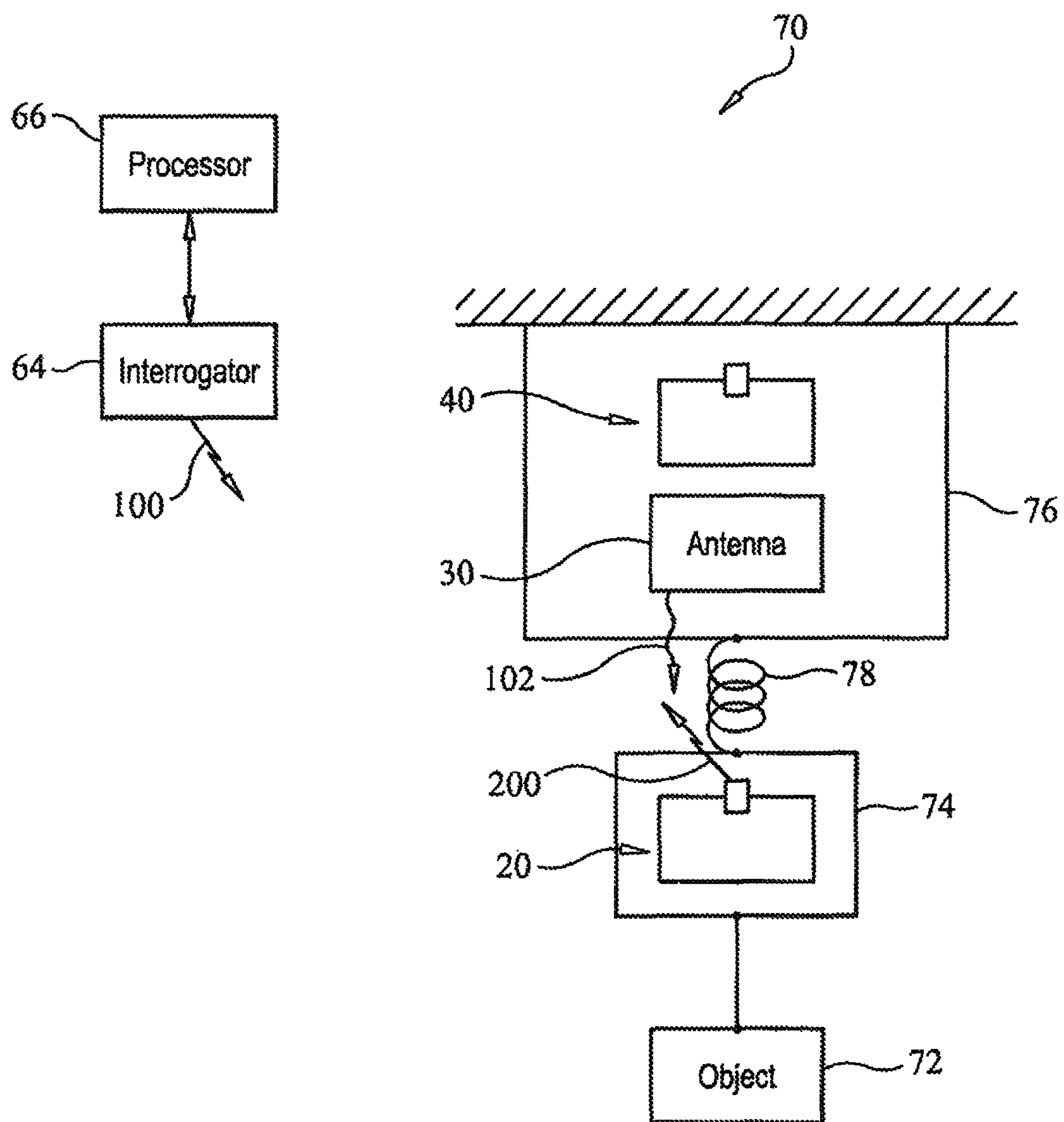


Figure 4



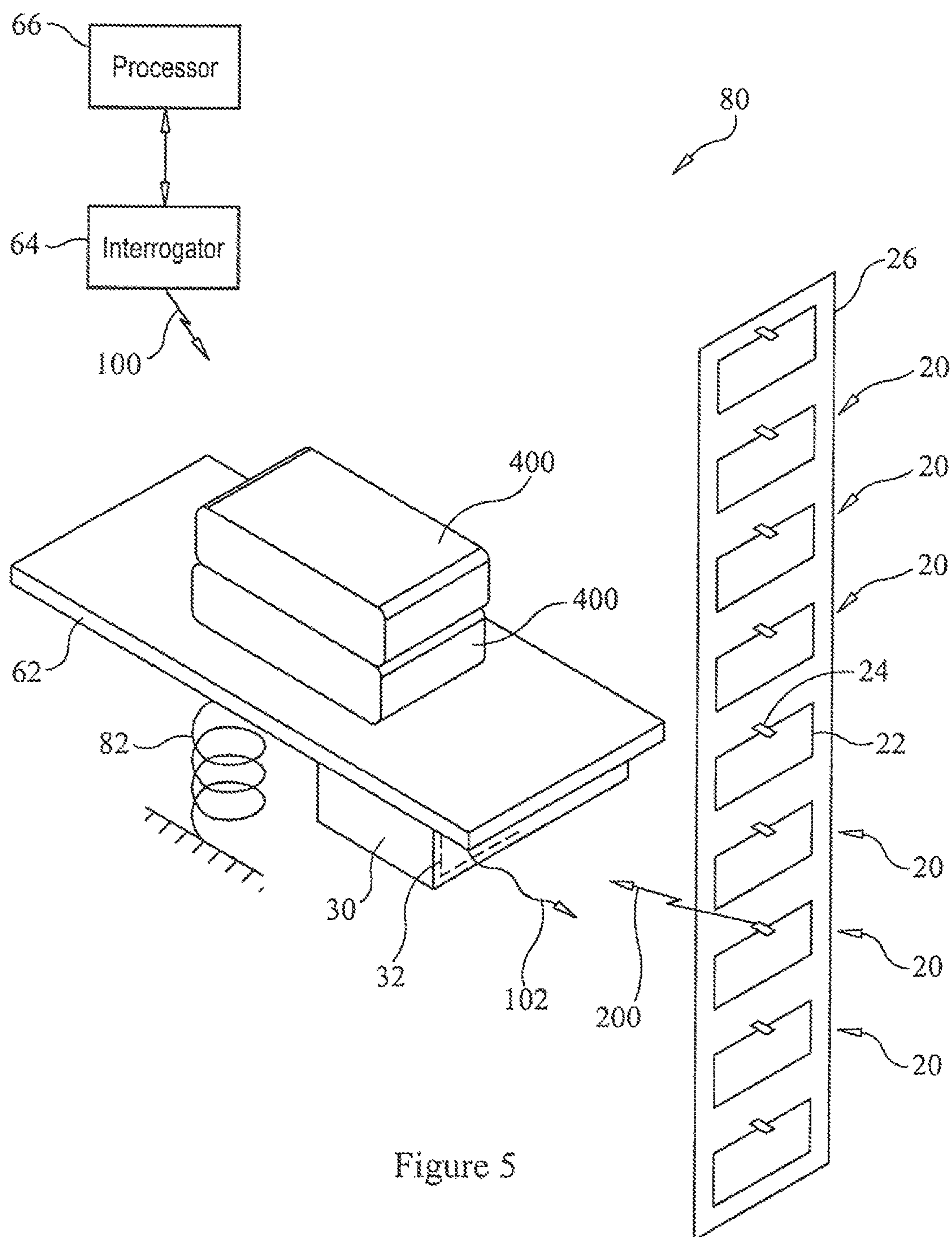
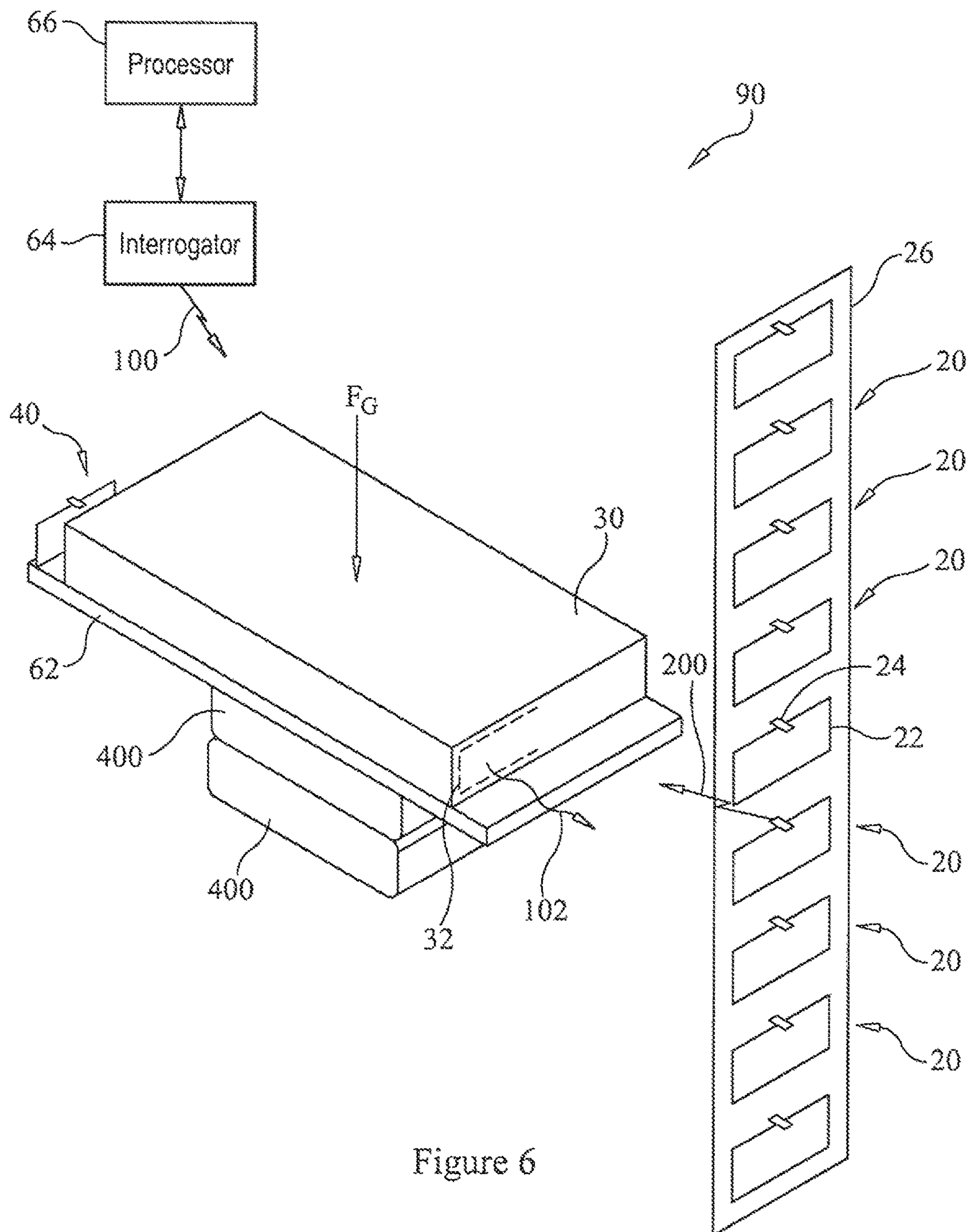


Figure 5



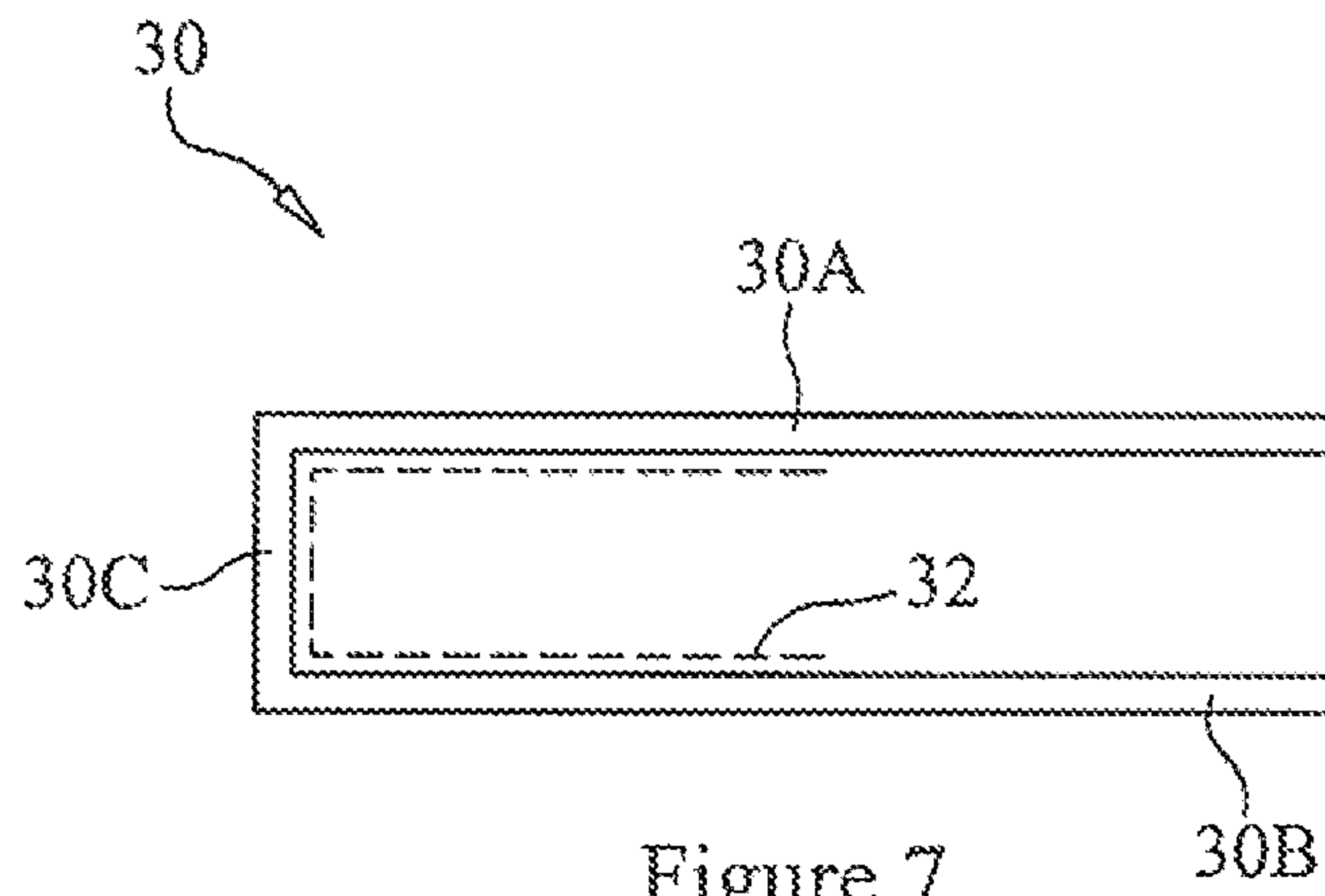


Figure 7

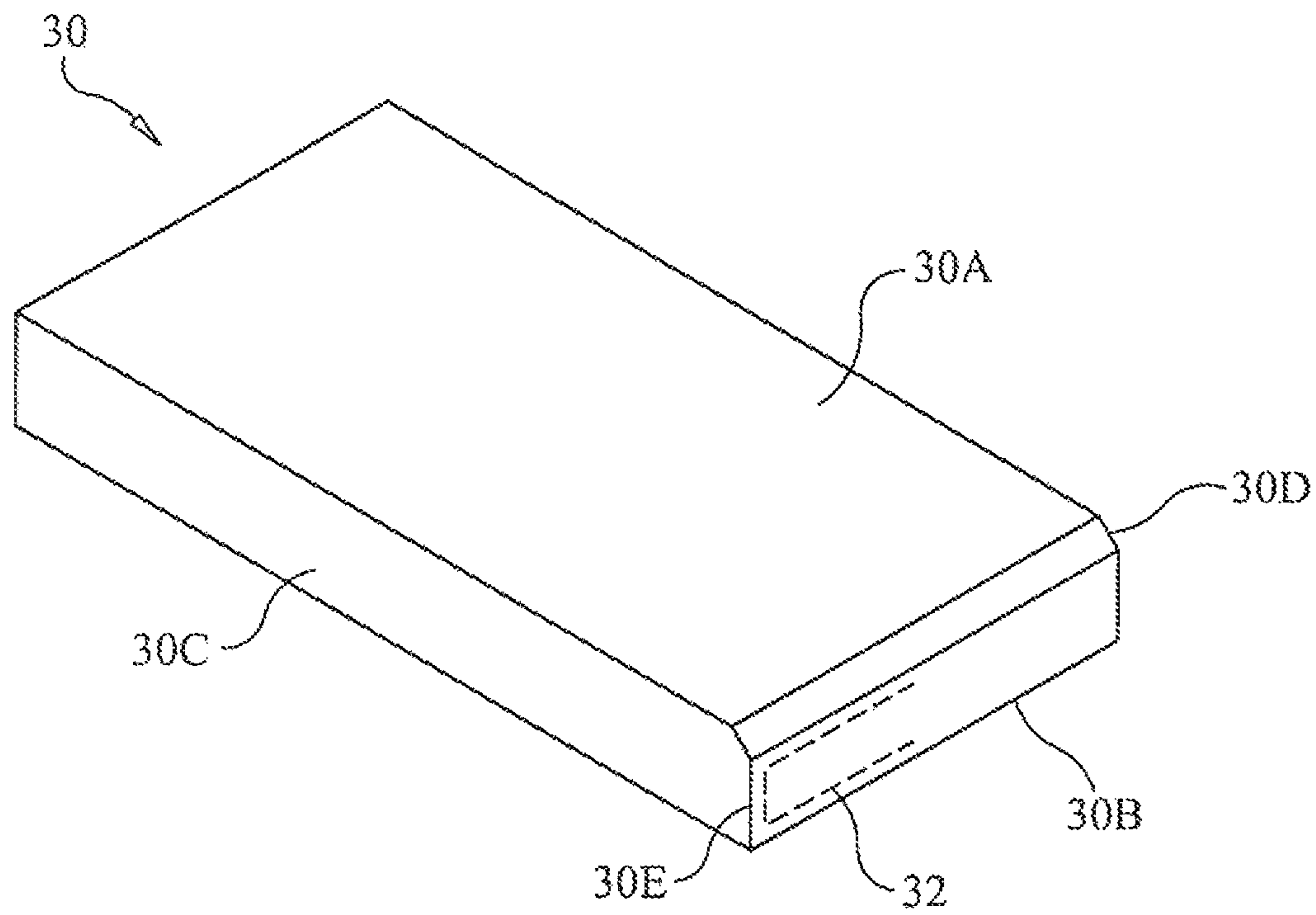


Figure 8



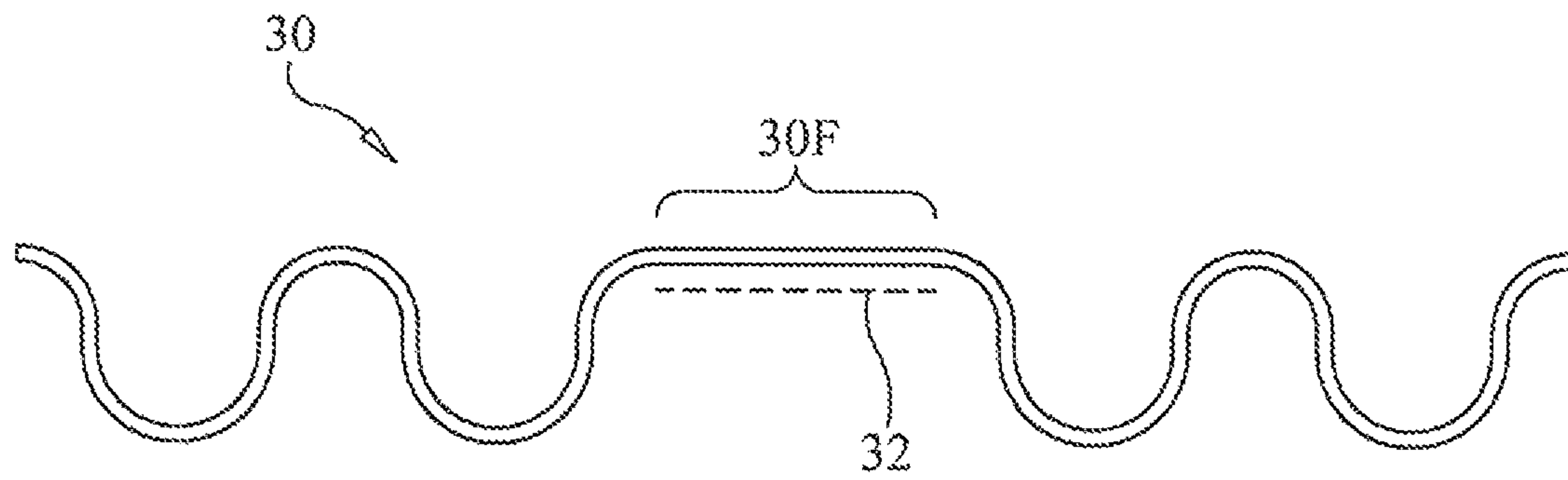


Figure 9

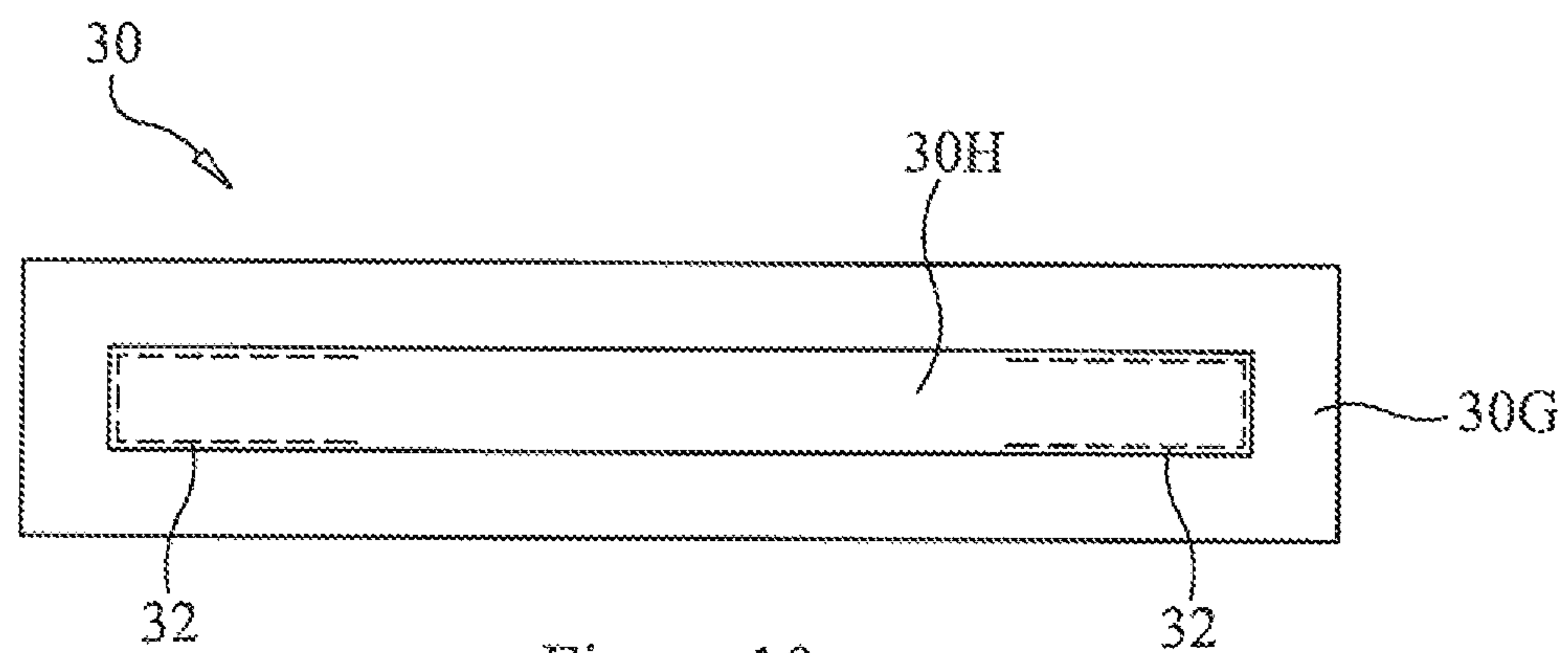


Figure 10

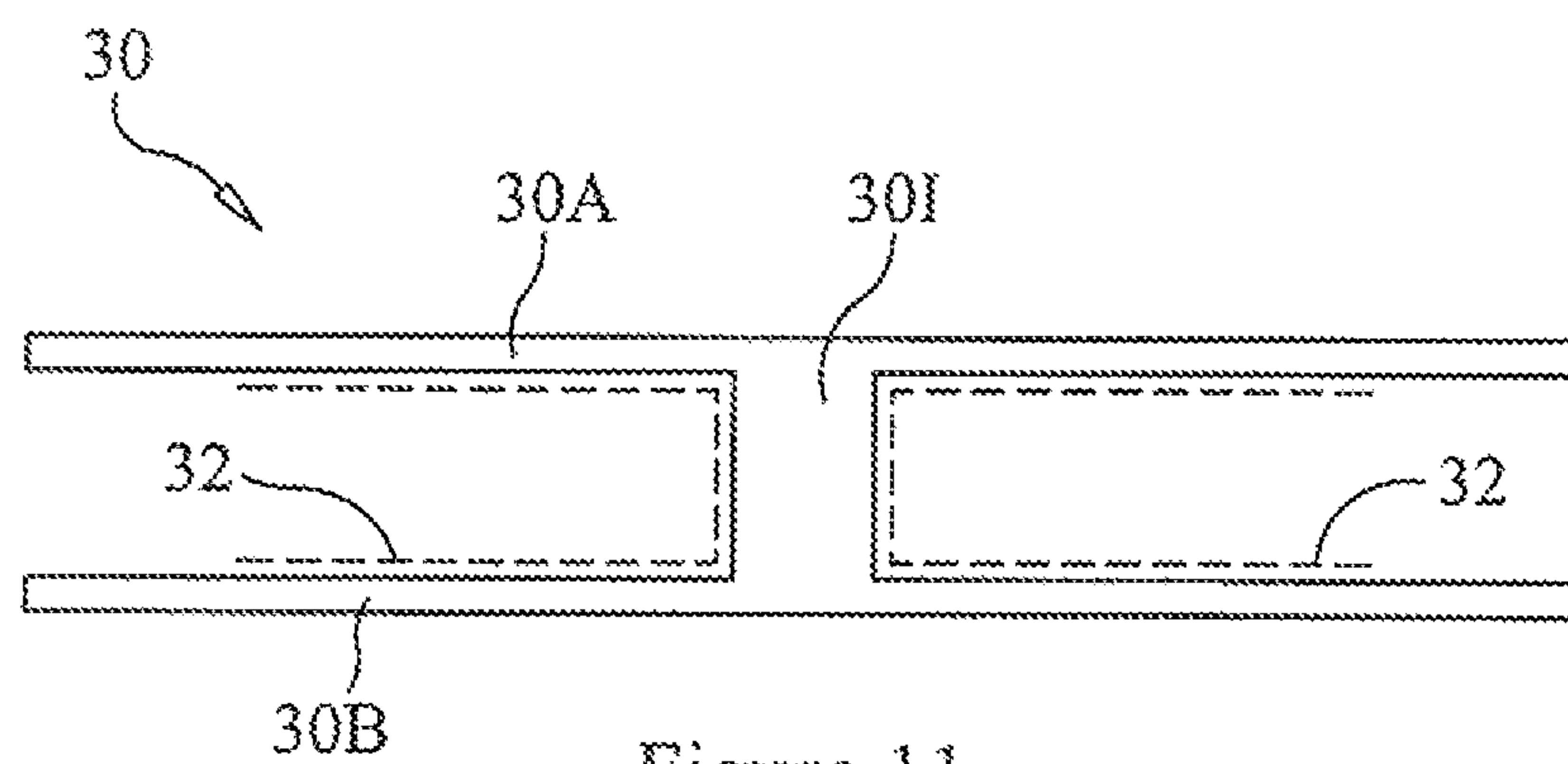


Figure 11

## SYSTEM FOR RFID-ENABLED INFORMATION COLLECTION

### CROSS-REFERENCE TO RELATED PATENT APPLICATION(S)

This patent application claims the benefit of and priority to U.S. Provisional Patent Application Ser. No. 62/102,352, filed Jan. 12, 2015, the contents of which are hereby incorporated by reference in their entirety.

This patent application is related to U.S. Pat. Nos. 8,933,789 and 9,031,689, the contents of which are hereby incorporated by reference in their entirety.

### ORIGIN OF THE INVENTION

The invention described herein was made by employees of the United States Government and may be manufactured and used by or for the Government of the United States of America for governmental purposes without the payment of any royalties thereon or therefor.

### FIELD OF THE INVENTION

The present invention relates generally to radio frequency identification (RFID) sensor systems, and more particularly to a system for RFID-enabled information collection that can include position information.

### BRIEF SUMMARY OF THE INVENTION

The present invention is a system for radio frequency identification (RFID)-enabled information collection. In one embodiment, a plurality of ring-shaped elements are arrayed linearly in a spaced apart fashion in a plane. Each ring-shaped element includes an electrically-conductive ring and an RFID integrated circuit electrically coupled to the electrically-conductive ring. An antenna is coupled to a movable support for movement therewith. The antenna defines an electrically-conductive path commensurate in size and shape to at least a portion of the electrically-conductive ring. An interrogator transmits a signal to the antenna wherein electric current is generated along its electrically-conductive path and electromagnetic energy emanates from the antenna. At least one of the ring-shaped elements and the RFID integrated circuit associated therewith is energized by the electromagnetic energy. Each RFID integrated circuit so-energized generates a data transmission for receipt by the interrogator. A processor coupled to the interrogator derives information related to position of the movable support using the data transmission.

In another embodiment described herein, a plurality of identical ring-shaped elements are arrayed linearly in a spaced apart fashion in a plane. Each ring-shaped element defines a series circuit to include an electrically-conductive rectangular ring and an RFID integrated circuit. An antenna is coupled to a movable support for movement therewith. The antenna defines an electrically-conductive path commensurate in size and shape to at least a portion of the rectangular ring. The path is parallel to the plane containing the ring-shaped elements. An interrogator transmits a signal to the antenna wherein electric current is generated along its path and electromagnetic energy emanates from the antenna. At least one of the ring-shaped elements and the RFID integrated circuit associated therewith is energized by the electromagnetic energy. Each RFID integrated circuit so-energized generates a data transmission for receipt by the

interrogator. A processor coupled to the interrogator derives information related to position of the movable support using the data transmission.

Another embodiment described herein is a sensor system for radio frequency identification (RFID)-enabled information collection. A ring-shaped element includes an electrically-conductive ring and an RFID integrated circuit electrically coupled to the electrically-conductive ring. An antenna spaced apart from the ring-shaped element defines an electrically-conductive path commensurate in size and shape to at least a portion of the electrically-conductive ring.

Yet another embodiment described herein is a sensor system for radio frequency identification (RFID)-enabled information collection. A ring-shaped element lying in a plane defines a series circuit to include an electrically-conductive rectangular ring and an RFID integrated circuit. An antenna spaced apart from the ring-shaped element defines an electrically-conductive path commensurate in size and shape to at least a portion of the rectangular ring. The path is parallel to the plane containing the ring-shaped element.

These and other embodiments of the present invention will be further understood and appreciated by those skilled in the art by reference to the following specification, claims, and appended drawings.

### BRIEF DESCRIPTION OF THE SEVERAL VIEWS OF THE DRAWING(S)

FIG. 1 is a schematic view of a sensor system for radio frequency identification (RFID)-enabled information collection in accordance with an embodiment of the present invention;

FIG. 2 is a schematic view of a sensor system for RFID-enabled information collection in accordance with another embodiment of the present invention;

FIG. 3 is a schematic view of a system for RFID-enabled information collection in accordance with an embodiment of the present invention;

FIG. 4 is a schematic view of a system for RFID-enabled information collection in accordance with another embodiment of the present invention;

FIG. 5 is a schematic view of a pusher-type product dispenser system including RFID-enabled inventory monitoring in accordance with an embodiment of the present invention;

FIG. 6 is a schematic view of a gravity-type product dispenser system including RFID-enabled inventory monitoring in accordance with still another embodiment of the present invention;

FIG. 7 is a side view of a quarter wave microstrip patch antenna that can be used in an embodiment of the present invention;

FIG. 8 is a perspective view of a modified quarter wave microstrip patch antenna that can be used in an embodiment of the present invention;

FIG. 9 is a side view of a meandering half wave dipole antenna that can be used in an embodiment of the present invention;

FIG. 10 is a side view of a slot antenna that can be used in an embodiment of the present invention; and

FIG. 11 is an end view of a planar inverted-F antenna that can be used in an embodiment of the present invention.

### DETAILED DESCRIPTION OF THE INVENTION

Referring now to the drawings, and more particularly to FIG. 1, a sensor system for radio frequency identification



(RFID)-enabled information collection is shown and is referenced generally by numeral **10**. Sensor system **10** can be used in a variety of sensing modalities including, but not limited to, sensing the distance between two objects, the state of proximity between two objects (e.g., whether a drawer of an enclosure is open or closed, whether an item has been removed from an enclosure, etc.) strain, weight, pressure, mass, and orientation. Sensor system **10** can also be the basic sensing element of an information collection system. For example and as will be described further below, sensor system **10** can be the base sensing element for a position indicating system or an inventory monitoring system working in conjunction with product dispensers.

Sensor system **10** includes a ring-shaped element **20** and an antenna **30** spaced apart from ring-shaped element **20**. The spacing between element **20** and antenna **30** can be fixed or variable depending on the goals of the particular sensing application. Ring-shaped element **20** includes an electrically-conductive ring **22** (e.g., wire, conductive trace, etc.) and an RFID integrated circuit **24** electrically coupled or connected with ring **22**. In general, RFID integrated circuit **24** is an RFID element that can be energized by electromagnetic energy and generate a transmission indicative of data (e.g., unique identity data) once energized, as may be known by those having ordinary skill in the art and the benefit of this detailed description. In the illustrated example, ring-shaped element **20** is a series electrical circuit that includes ring **22** and RFID integrated circuit **24**. Further, ring **22** is rectangular and lies in a plane. For example, ring-shaped element **20** could be fabricated on a planar substrate (not shown) such as a printed circuit board or other substrate without departing from the scope of the present invention.

Antenna **30** is any of a variety of antennas that, when in receipt of a signal for which it is tuned, supports electric current along an electrically-conductive path whose shape and size are commensurate with some or all of the shape/size of ring **22**. For example, in the illustrated embodiment, the electrically-conductive path should be a rectangular or some portion thereof whose size/shape mirrors that of ring **22** or some portion thereof. The electrically-conductive path is defined along some or all of the dashed-line rectangle referenced by numeral **32**. Suitable choices for antenna **30** include, but are not limited to, microstrip patch antennas (e.g., quarter wave, half wave, etc.), slot antennas, dipole antennas, and planar inverted-F antennas (PIFA). In general, when antenna **30** receives a signal **100** (from an RFID interrogator not shown in FIG. 1) for which antenna **30** is tuned, electric current travels along some or all of path **32** and antenna **30** emanates electromagnetic energy as indicated by wavy-lined arrow **102**. Electromagnetic energy **102** couples to ring-shaped element **20** thereby energizing the operation of RFID integrated circuit **24**. Once energized, RFID integrated circuit **24** generates a transmission back to the RFID interrogator (not shown in FIG. 1 but shown generally in FIG. 3) through antenna **30** via an RF signal **200**. Generally speaking, the transmission from an energized RFID integrated circuit **24** contains "data" where such data can include one or more of stored identity data associated with RFID integrated circuit **24**, sensed-condition data, inherent-condition data provided by the magnitude and/or phase associated with signal **200**, etc. Coupling of electromagnetic energy **102** to ring-shaped element **20** is generally stronger when path **32** lies in a plane that is parallel to the plane containing ring-shaped element **20** and when path **32** aligns with the ring-shaped element. More generally, power transfer of energy **102** to ring-shaped element **20** is opti-

mized when ring **22** enables a conjugate impedance match with the impedance of RFID integrated circuit **24**. The prescribed positioning of the ring along the antenna's current path facilitates this conjugate impedance match. Attainment of the conjugate impedance match may require elongation of the ring, broadening it, meandering it, or aligning it with certain portions of path **32** known to support stronger or weaker currents. Thus, it is to be understood that the ring may not be fully parallel to the path of the current on the antenna in order to achieve the optimal match.

Referring now to FIG. 2, another sensor system **50** includes the elements of sensor system **10** and further includes a reference ring-shaped element **40** positioned/configured to be in a fixed relationship to antenna **30**. Element **40** includes an electrically-conductive ring **42** and an RFID integrated circuit **44** such that element **40** matches the configuration, size, and shape of ring-shaped element **20**. Ring-shaped element **40** provides for calibration of sensor system **50** as well as providing a reference output (when energized) that can be used when evaluating the data associated with signal **200** transmitted by ring-shaped element **20**. For example, the strength/magnitude and phase of the signal received from ring-shaped element **20** can be compared to the strength/magnitude and phase of the signal received from the fixed position of reference ring-shaped element **40** in order to estimate the position and orientation of ring-shaped element **20**.

As mentioned above, the exemplary sensor system **10** or sensor system **50** can serve as the building block of an information collection system such as a position indicating system or an inventory monitoring system. Several examples of such systems will be described below with the aid of FIGS. 3-6. In each embodiment, data is transmitted from one or more ring-shaped elements in the same fashion as described above.

Referring first to the embodiment illustrated in FIG. 3, a position indicating system **60** includes a plurality of ring-shaped elements **20** that are arranged linearly and spaced-apart from one another in a plane. In one embodiment, all of the plurality of ring-shaped elements **20** are identical to one another in size and/or shape. In another example, all of ring-shaped elements **20** can be affixed to common planar substrate (not shown) such that all elements **20** lie in a common plane. Each of ring-shaped elements **20** includes an electrically-conductive ring **22** and an RFID integrated circuit **24** as described above. Each RFID integrated circuit **24** has a unique identity associated therewith where the unique identity is transmitted therefrom when circuit **24** is energized. Antenna **30** is mounted on a movable support **62** where such movement is indicated by two-headed arrow **300** such that movement **300** results in corresponding movement of antenna **30**. A reference ring-shaped element **40** can also be mounted on movable support **62** and used to facilitate calibration and/or provide reference data.

In the illustrated embodiment, antenna **30** is a shorted quarter wave microstrip patch antenna configured and oriented such that a current path **32** is sized/shaped to match a portion of each ring **22** and lie in a plane that is parallel to the plane containing ring-shaped elements **20**. For example, in terms of a shorted quarter wave microstrip patch antenna, path **32** is defined at either end of the antenna that includes conductive edges of the top and bottom faces of the antenna and the edge of the conductive face of the antenna used to short the top and bottom faces as will be explained further below. System **60** also includes an interrogator **64** and a processor **66** located remotely with respect to movable support **62** and antenna **30**. Interrogator **64** transmits signal



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100 that is received by antenna 30. As a result and as described above, electric current along path 32 causes electromagnetic energy 102 to emanate from antenna 30. Electromagnetic energy 102 coupled to one or more of ring-shaped elements 20 causes the energized ones thereof to transmit data via signal 200 that, in turn, is coupled to interrogator 64 through antenna 30. The one or more received signals 200 are received by interrogator 64 and processed by processor 66. The one of ring-shaped elements 20 that is closest to antenna 30 will yield the strongest signal 200. Because each of RFID integrated circuits 24 has a unique identity transmitted in its signal 200, the strongest signal 200 is indicative of the position of antenna 30 relative to the array of ring-shaped elements 20.

FIG. 4 illustrates another system embodiment of the present invention that is referenced generally by numeral 70. System 70 is a means for measuring the mass of an object 72 attached to or hanging from a movable support 74 on which a single ring-shaped element 20 is mounted. Support 74 is suspended from a fixed body 76 via a spring 78 or other elastic element. Mounted on fixed body 76 is antenna 30 and reference ring-shaped element 40. System 70 also includes interrogator 64 and processor 66. Ring-shaped element 20, antenna 30, reference ring-shaped element 40, interrogator 64, and processor 66 function as described previously herein. In operation, interrogator 64 receives a received signal strength indication (i.e., RSSI) from each of ring-shaped element 20 and reference ring-shaped element 40. The difference between the two RSSI readings can be used to estimate the mass of object 72 since the object's mass changes the distance between ring-shaped element 20 and antenna 30, while the distance between reference ring-shaped element 40 and antenna remains fixed at all times.

FIGS. 5 and 6 illustrate inventory monitoring systems constructed using the principles described herein. Referring first to FIG. 5, a pusher-type product dispenser has the above-described RFID-enabled information collection system incorporated therewith where the combination is referenced generally by numeral 80. For clarity of illustration, only those elements of a pusher-type product dispenser used by the present invention are illustrated. Identical reference numerals are used for those elements previously-described herein. In system 80, movable support 62 is the pusher plate of a pusher-type product dispenser. Support 62 is acted upon on one side thereof by an elastic force provided by, for example, a spring 82 (e.g., coil spring, elastic band, or any other elastic element/system that can perform the functions of a spring). Support 62 is acted upon on the other side thereof by the opposing force (e.g., the weight) of a stack of one or more products 400. Each time one of products 400 is removed, which as shown in the vertical arrangement of FIG. 5 would be a product 400 near the top of the stack, support 62 is pushed under the force of spring 82 so that the next one of products 400 is readily accessible. Such pusher-type dispensers can be arranged vertically as shown in FIG. 5, horizontally, or at any angle without departing from the scope of the present invention. The linear array of ring-shaped elements 20 are positioned on a support substrate 26 adjacent to the line or route of travel associated with support 62. Antenna 30 is mounted on support 62 as previously described herein. A reference ring-shaped element (not shown) such as reference ring-shaped element 40 described herein can also be mounted on support 62 in a fixed relationship to antenna 30. Interrogator 64 and processor 66 operate as described above to determine the position of support 62/antenna 30 that is indicative of the number of products 400 remaining at any given time. Interrogator 64

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and processor 66 can be fixed in their positions or contained, for example, in a hand-held or robotic device.

The structure of system 80 illustrated in FIG. 5 can also be used to implement a scale system in which gravity acting upon the mass of one or more items 400 causes a force to compress spring 82 to bring about movement of support 62 and antenna 30. Interrogator 64 and processor 66 can be configured to estimate the mass or weight of the one or more items 400 based on the received identification numbers, signal strength, and signal phase from one or more ring-shaped elements 20. System 80 can also be representative of a dispenser in which the number of items remaining can be inferred from the mass.

FIG. 6 illustrates a gravity-type product dispenser that has the above-described RFID-enabled information collection system incorporated therewith where the combination is referenced generally by numeral 90. Once again, only those elements of a gravity-type product dispenser used by the present invention are illustrated. In system 90, movable support 62 with antenna 30 mounted thereon is positioned on top of a stack of products 400 where the next one of products 400 that is to be removed is located at the bottom of the stack. Accordingly, in terrestrial applications of system 90, the force of gravity  $F_G$  causes the movement of support 62 whenever one of products 400 is removed from the bottom of the stack or from some position within the stack. The position of support 62 is determined as has been previously described herein where such position is indicative of the number of products 400 remaining in the stack. In each of the embodiments illustrated in FIGS. 5 and 6, a reference ring-shaped element 40 can be mounted on movable support 62 (as illustrated in FIG. 6) and used to facilitate calibration and/or provide reference data as previously described herein.

As mentioned above, the present invention can use a variety of antennas for the above-described antenna 30. In general, such antennas include microstrip patch antennas, dipole antennas, slot antennas, and planar inverted-F antennas (PIFA). Several exemplary antennas are shown in FIGS. 7-11, wherein a portion 32 of an electrically-conductive path defined by the antenna is illustrated therewith. As described above, path portion 32 (or simply "path" hereinafter) is commensurate in size and shape to at least a portion of the ring-shaped element that will be used in conjunction with the antenna. In FIG. 7, a side view of a quarter wave microstrip patch antenna 30 illustrates that the antenna has spaced-apart top and bottom surface conductors 30A and 30B, respectively, shorted together along one edge thereof by a shorting back conductor 30C. Because current is strongest at the shorted end of the antenna, the antenna can be positioned such that path 32 (that is to align with a ring-shaped element 20) is at the shorted end. Note that path 32 is created at either end of the antenna thereby supporting the antenna's interrogation of a reference ring-shaped element 40 as described earlier herein. In FIG. 8, a modified quarter wave microstrip patch antenna 30 has spaced-apart top and bottom surface conductors 30A and 30B, respectively, and a shorting back conductor 30C. A chamfered face conductor 30D angles downward from top surface 30A towards bottom surface 30B to thereby define a shorter-length shorting conductor edge 30E as compared to a quarter wave microstrip patch antenna without a chamfered face conductor. Path 32 is at the shorted end as in the previous example. Chamfered face conductor 30D allows a greater spacing between surface conductors 30A and 30B for impedance matching and bandwidth purposes, while also providing for the use of a shorter conductor edge 30E for



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closer ring spacing and hence improved resolution. In FIG. 9, a meandering half wave dipole antenna 30 has a straight center portion 30F where current is stronger than at the ends of the dipole. Accordingly, this type of antenna would be positioned such that center portion 30F defines path 32 for purposes of the present invention. FIG. 10 illustrates a slot antenna 30 defined by a conductive portion 300 surrounding a non-conductive slot 30H. Currents are strongest at either end of slot 30H such that either end of slot 30H defines a path 32. Finally, FIG. 11 illustrates a PIFA 30 having spaced-apart top and bottom surface conductors 30A and 30B, respectively, and a shorting section 30I along a portion of one edge of surface conductors 30A and 30B. Currents are strongest along both sides of section 30I such that this region is included in two of path 32.

While some embodiments of the invention have been herein illustrated, shown and described, it is to be appreciated that various changes, rearrangements and modifications may be made therein, without departing from the scope of the invention as defined by the appended claims. It is intended that the specific embodiments and configurations are disclosed for practicing the invention, and should not be interpreted as limitations on the scope of the invention as defined by the appended claims and it is to be appreciated that various changes, rearrangements and modifications may be made therein, without departing from the scope of the invention as defined by the appended claims.

Although only a few exemplary embodiments of this invention have been described in detail above, those skilled in the art will readily appreciate that many modifications are possible in the exemplary embodiments without materially departing from the novel teachings and advantages of this invention. Accordingly, all such modifications are intended to be included within the scope of this invention as defined in the following claims. In the claims, means-plus-function and step-plus-function clauses are intended to cover the structures or acts described herein as performing the recited function and not only structural equivalents, but also equivalent structures. Thus, although a nail and a screw may not be structural equivalents in that a nail employs a cylindrical surface to secure wooden parts together, whereas a screw employs a helical surface, in the environment of fastening wooden parts, a nail and a screw may be equivalent structures.

What is claimed as new and desired to be secured by Letters Patent of the United States is:

1. A system for radio frequency identification (RFID)-enabled information collection, comprising:

a plurality of ring-shaped elements arrayed linearly in a spaced apart fashion in a plane, each of said ring-shaped elements including an electrically-conductive ring and an RFID integrated circuit electrically coupled to said electrically-conductive ring;

a movable support;

an antenna coupled to said movable support for movement therewith, said antenna defining an electrically-conductive path commensurate in size and shape to at least a portion of said electrically-conductive ring;

an interrogator for transmitting a signal to said antenna wherein said electric current is generated along said electrically-conductive path and electromagnetic energy emanates from said antenna, wherein at least one of said ring-shaped elements and said RFID integrated circuit associated therewith is energized by said electromagnetic energy, and wherein each said RFID integrated circuit so-energized generates a data transmission for receipt by said interrogator; and

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a processor coupled to said interrogator for deriving information related to position of said movable support using said data transmission.

2. The system of claim 1, wherein said electrically-conductive path is parallel to said plane.

3. The system of claim 1, wherein each of said ring-shaped elements is rectangular.

4. The system of claim 1, wherein said data transmission includes a unique identity for each said RFID integrated circuit.

5. The system of claim 1, wherein said antenna is selected from the group consisting of a microstrip patch antenna, a slot antenna, a dipole antenna, and a planar inverted-F antenna.

6. The system of claim 1, wherein said movable support comprises a portion of a product dispenser adapted to store products, and wherein said movable support experiences movement whenever one of the products is removed from said product dispenser.

7. The system of claim 6, further comprising an elastic element coupled to said movable support for causing said movement whenever one of the products is removed from said product dispenser.

8. The system of claim 6, wherein such movable support is configured such that gravity causes movement of said movable support whenever one of the products is removed from said product dispenser.

9. The system of claim 1, further comprising a reference ring-shaped element coupled to at least one of said antenna and said movable support for movement therewith, said reference ring-shaped element maintained in a fixed relationship with respect to said antenna, said reference ring-shaped element including an electrically-conductive reference ring and a reference RFID integrated circuit electrically coupled to said electrically-conductive reference ring, said reference ring element being positioned to be energized by said electromagnetic energy emanating from said antenna.

10. The system of claim 1, wherein said data transmission includes magnitude and phase information associated therewith.

11. A system for radio frequency identification (RFID)-enabled information collection, comprising:

a plurality of ring-shaped elements arrayed linearly in a spaced apart fashion in a plane, each of said ring-shaped elements defining a series circuit to include an electrically-conductive rectangular ring and an RFID integrated circuit;

a movable support;

an antenna coupled to said movable support for movement therewith, said antenna defining an electrically-conductive path commensurate in size and shape to at least a portion of said rectangular ring, said electrically-conductive path being parallel to said plane;

an interrogator for transmitting a signal to said antenna wherein said electric current is generated along said electrically-conductive path and electromagnetic energy emanates from said antenna, wherein at least one of said ring-shaped elements and said RFID integrated circuit associated therewith is energized by said electromagnetic energy, and wherein each said RFID integrated circuit so-energized generates a data transmission for receipt by said interrogator; and

a processor coupled to said interrogator for deriving information related to position of said movable support using said data transmission.



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12. The system of claim 11, wherein said data transmission includes a unique identity for each said RFID integrated circuit.

13. The system of claim 11, wherein said antenna is selected from the group consisting of a microstrip patch antenna, a slot antenna, a dipole antenna, and a planar inverted-F antenna.

14. The system of claim 11, wherein said movable support comprises a portion of a product dispenser adapted to store products, and wherein said movable support experiences movement whenever one of the products is removed from said product dispenser.

15. The system of claim 14, further comprising an elastic element coupled to said movable support for causing said movement whenever one of the products is removed from said product dispenser.

16. The system of claim 14, wherein such movable support is configured such that gravity causes movement of

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said movable support whenever one of the products is removed from said product dispenser.

17. The system of claim 11, further comprising a reference ring-shaped element coupled to at least one of said antenna and said movable support for movement therewith, said reference ring-shaped element maintained in a fixed relationship with respect to said antenna, said reference ring-shaped element including an electrically-conductive reference ring and a reference RFID integrated circuit electrically coupled to said electrically-conductive reference ring, said reference ring element being positioned to be energized by said electromagnetic energy emanating from said antenna.

18. The system of claim 11, wherein said data transmission includes magnitude and phase information associated therewith.

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