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(71) Applicant *(for all designated States except US)*: **AGENCY FOR SCIENCE, TECHNOLOGY AND RESEARCH** [SG/SG]; 1 Fusionopolis Way, #20-10, Connexis, Singapore 138632 (SG).

(72) Inventor; and

(75) Inventor/Applicant *(for US only)*: **LIU, Wei** [SG/SG]; c/o Singapore Institute of Manufacturing Technology, 71 Nayang Drive, Singapore 638075 (SG).

(74) Agent: **FOO, Moo Kwang**; Axis Intellectual Capital Pte Ltd, 21 Science Park Road, #03-01 The Aquarius, Science Park II, Singapore 117628 (SG).

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(54) **Title**: SYSTEM, APPARATUS, AND METHOD FOR ORIENTATION INDEPENDENT RFID TAG DETECTION

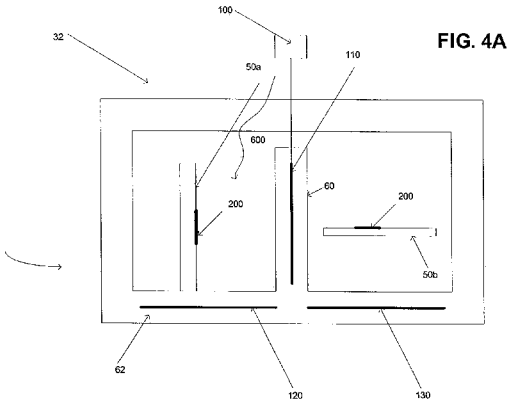


FIG. 4A

(57) **Abstract**: A system for facilitating communication between an RFID reader and an RFID tag in a manner that is independent or substantially independent of RFID tag orientation within a spatial detection volume includes a primary antenna and at least one secondary antenna spatially disposed relative to each other such that electromagnetic coupling between the antennas occurs by way of mutual inductance. The primary and secondary antennas can be loop antennas that are disposed perpendicular to each other. The RFID reader drives the primary antenna by way of electrical coupling to a feed point. Each secondary antenna can lack a direct electrical coupling or connection to the RFID reader. The primary antenna generates a primary radiation pattern. Each secondary antenna generates a secondary radiation pattern as a result of inductive coupling to the primary radiation pattern's magnetic field. The relative spatial arrangement of the primary and secondary antennas results in the generation of an augmented radiation pattern that defines an augmented detection volume. The augmented radiation pattern provides sufficient magnetic field intensity and directional variation to enable reliable coupling to an RFID tag antenna in a manner that is independent of RFID tag antenna spatial orientation.

WO 2011/037540 A1

SYSTEM, APPARATUS, AND METHOD FOR ORIENTATION INDEPENDENT RFID TAG DETECTION

Technical Field

The present disclosure relates to a radio frequency identification (RFID) system that communicates with an RFID tag by way of multiple antennas in order to increase a likelihood of successful communication with the RFID tag regardless of RFID tag orientation. More particularly, aspects of the present disclosure relate to an RFID system, apparatus, and method in which inductively coupled antennas generate an augmented radiation pattern that facilitates or enables successful RFID tag communication substantially independent or regardless of RFID tag orientation.

Background

Radio-frequency identification (RFID) is the use of an object (commonly referred to as an RFID tag) applied to or incorporated into a product, animal, or person for the purpose of identification and tracking using radio waves. Main components of an RFID system include an RFID reader, scanner, or transceiver that is coupled to an antenna or antenna assembly and an RFID tag.

The RFID tag includes an Integrated Circuit (IC) for storing and processing information, modulating and demodulating a radio frequency signal and an antenna for receiving and transmitting the radio signal. The RFID reader is a device that is used to interrogate/read an RFID tag and it can be coupled to an antenna that emits radio waves. Some tags can be read from several meters away and beyond the line of sight of the reader. Communication between the RFID tag and the RFID reader is made through radio waves activated by the RFID reader to read the RFID tags that are within a detection range of the RFID reader.

Conventionally, the RFID reader and RFID tag can function at any desired frequency, but they commonly operate at an assigned frequency of 13.56 MHz. Due to its operational capabilities, the electromagnetic energy available for communication limits the typical communication range to only a few feet. The most

basic and common antenna adopted in RFID systems is a single turn loop antenna tuned to resonance and impedance matched to a fifty ohm cable. In the near field of the antenna, energy is primarily transferred by the magnetic field and the efficiency of the antenna coupling is measured by analyzing the magnetic field in the near field.

Ideally, the magnetic field from the RFID reader and the RFID tag must be high in strength and the range of it must be sufficiently extended to ensure that the magnetic field from the RFID reader and the RFID tag can couple to each other so as to establish a communication path between the reader and the tag.

Both the reader and tag have separate antennas for magnetic field coupling. Each antenna has its respective magnetic field and antenna radiation pattern which is sensitive to polarization. The orientation of the antenna radiation patterns between the reader and the tag affects the amount of coupling, and this impacts the quality of the communication path.

For example, if the antenna radiation pattern of the tag is not oriented with the antenna radiation pattern of the reader in a manner that achieves optimal coupling, the reader may not be sensitive enough to be able to retrieve the required information from the tag. Several research efforts have been directed to increase the sensitivity of the reader and improving the quality of communication between the reader and the tag.

U.S. Pat. No. 6,166,706 (Gallagher) teaches two distal loop antennas with a third overlapping coupled loop used to produce a rotating magnetic field. U.S. Pat. No. 5,103,235 (Clemens) teaches a figure eight type of antenna with paired leads that are mutually coupled. The objectives described are to reduce the effects of interference and false alarms and to produce a flatter amplitude response and more linear phase response versus frequency.

U.S. Pat. No. 5,963,173 (Lian) teaches adjacent double loop antennas in a figure eight configuration that is operated in phase or out of phase. Two frequencies are used to produce a field that excites a nonlinear magnetic tag. A compensating tuned

loop is used to reduce detuning effects which occur when switching between the two phases. Lian teaches the use of two generators driving respective loops.

U.S. Pat. No. 5,602,556 (Bowers) teaches the use of various antenna loop configurations to produce a desired field, and a larger passive unturned loop surrounding that antenna to effectively cancel far field response as a far field cancelling antenna. The cancelling antenna uses separate antennas for transmit and receive without impedance compensation of the coupled loops.

One drawback of these prior art readers and tags is the generation of insufficient field strength over a spatial area and a desired range from the reader to read a tag from a distal position.

Another problem is tag polarization sensitivity. The prior art readers and tags may not read reliably due to insufficient field strength and poor coupling as a result of undesirable antenna radiation pattern orientation. In some cases, the tag may be stationary. However, in more common applications, the tag moves through the magnetic field of the reader, such as in an RFID system configured to detect items moving along a conveyor belt. In these situations, different antenna radiation pattern orientations may prohibit the tag from being read as the tag moves through different parts of the magnetic field generated by the reader.

Furthermore, the teachings revealed in the prior art relate to systems that require unnecessarily complex circuitry, leading to increased system cost.

It is therefore desirable to provide a solution to address at least one of the foregoing problems associated with conventional RFID communication.

Summary

In accordance with an aspect of the disclosure, there is disclosed a system having an operating frequency for communicating information. The system includes an RFID reader assembly having a signal processing unit having an output configured to provide a drive signal, a first loop antenna having a first length of wire that defines a

first planar region and a second loop antenna having a second length of wire that defines a second planar region. The first loop antenna has a feed point to receive the drive signal to provide an electrical signal to the first loop antenna thereby generating a first radiation pattern that includes a first magnetic field. The second planar region is disposed substantially perpendicular to the first planar region. The second loop antenna exposed to the first magnetic field to thereby generate a second radiation pattern by way of inductive coupling. The second radiation pattern includes a second magnetic field. Furthermore, the first radiation pattern and the second radiation pattern combine to form a first augmented radiation pattern coupleable to the RFID tag antenna in a manner that is at least substantially independent of RFID tag antenna orientation.

The system can further include a third loop antenna having a third length of wire that defines a third planar region. The third planar region is disposed substantially perpendicular to the first planar region. The second planar region and the third planar region are disposed on opposite sides of the first planar region and the third loop antenna is exposed to the first magnetic field to thereby generate a third radiation pattern by way of inductive coupling. The third radiation pattern includes a third magnetic field. The first radiation pattern and the third radiation pattern can combine to form a second augmented radiation pattern coupleable to the RFID tag antenna in a manner that is at least substantially independent of RFID tag antenna orientation.

In various embodiments, the second and third loop antennas each lack a feed point coupleable to the signal processing unit.

The first augmented radiation pattern defines a first augmented detection volume that includes magnetic field components that are perpendicular to the first planar region and magnetic field components that are perpendicular to the second planar region.

The second augmented radiation pattern defines a second augmented detection volume that includes magnetic field components that are perpendicular to the first planar region and magnetic field components that are perpendicular to the third planar region.

In another aspect of this disclosure, a system having an operating frequency for communicating information is disclosed. The system comprises an RFID reader system comprising a signal processing unit having an output configured to provide a drive signal and a plurality of loop antenna systems driven by the drive signal. Each loop antenna system comprises a first loop antenna having a first length of wire that defines a first planar region and a second loop antenna having a second length of wire that defines a second planar region. Each first loop antenna has a feed point to receive the drive signal to provide an electrical signal to the first loop antenna thereby generating a first radiation pattern that includes a first magnetic field. The second planar region is disposed substantially perpendicular to the first planar region. The second loop antenna is exposed to the first magnetic field to thereby generate a second radiation pattern by way of inductive coupling. The second radiation pattern includes a second magnetic field. Furthermore, the first radiation pattern and the second radiation pattern combine to form a first augmented radiation pattern coupleable to the RFID tag antenna in a manner that is at least substantially independent of RFID tag antenna orientation.

The system further includes an article storage structure that carries the plurality of loop antenna systems in one of an adjacent or vertically stacked manner.

In a further aspect of this disclosure, an RFID communication system includes a first antenna having a feed point coupleable to a drive signal, the first antenna configured to generate a first radiation pattern in response to the drive signal, the first radiation pattern including a first magnetic field having a maximum magnitude along a first axis. The system also includes a second antenna configured to generate a second radiation pattern by way of inductive coupling to the first radiation pattern, the second radiation pattern including a second magnetic field having a maximum magnitude along a second axis. Additionally, the system further includes a set of support members configured to spatially dispose the first antenna and the second antenna relative to each other such that the first axis is substantially perpendicular to the second axis. The second antenna is offset away from the first axis toward a periphery of the first antenna in a direction parallel to the second axis, and the first radiation pattern and the second radiation patterns are combinable to generate an augmented radiation pattern within a detection volume in which the augmented

radiation pattern includes magnetic field components of sufficient magnitude and directional variation to enable reliable coupling to an RFID tag antenna in a manner that is independent or essentially independent of RFID tag antenna orientation within the detection volume.

In accordance with another aspect of this disclosure, there is disclosed a process or method of detecting an RFID tag carrying an antenna within a detection volume in a manner that is substantially independent of RFID tag orientation. The process includes generating a first radiation pattern by way of a first loop antenna having a feed point and a length of wire that defines a first planar region. The first radiation pattern includes a first magnetic field. Additionally, the process includes exposing a second loop antenna to the first magnetic field, the second loop antenna having a second length of wire that defines a second planar region disposed substantially perpendicular to the first planar region. The process also includes generating a second radiation pattern with the second loop antenna by way of inductive coupling to the first magnetic field. The second radiation pattern includes a second magnetic field. The first radiation pattern and the second radiation pattern combine to form a first augmented radiation pattern coupleable to the RFID tag antenna in a manner that is at least substantially independent of RFID tag orientation.

The process can further include exposing a third loop antenna to the first magnetic field and generating a third radiation pattern with the third loop antenna by way of inductive coupling. The third loop antenna includes a third length of wire that defines a third planar region disposed substantially perpendicular to the first planar region. The third radiation pattern includes a third magnetic field. The first radiation pattern and the third radiation pattern can combine to form a second augmented radiation pattern coupleable to the RFID tag antenna in a manner that is at least substantially independent of RFID tag orientation.

In accordance with a further aspect of this disclosure, a process or method of manufacturing an RFID reader assembly is disclosed. The process includes providing a first loop antenna having a first length of wire that defines a first planar region. The first loop antenna has a feed point and is carried by a first housing member. The process further includes providing a second loop antenna having a second length of

wire that defines a second planar region. The second loop antenna is carried by a second housing member such that the second planar region is substantially perpendicular to the first planar region and the second loop antenna is inductively coupleable to the first loop antenna.

In another aspect of this disclosure, an RFID communication process or method includes providing a first antenna configured to generate a first radiation pattern including a first magnetic field having a maximum magnitude along a first axis. Additionally, the process includes providing a second antenna configured to generate a second radiation pattern including a second magnetic field having a maximum magnitude along a second axis and positioning the first and second antennas relative to each other such that the first axis is substantially perpendicular to the second axis and the second antenna is offset away from the first axis toward a periphery of the first antenna in a direction parallel to the second axis. The process also includes driving the first antenna to generate the first radiation pattern. Further, the process includes inductively coupling the second antenna to the first radiation pattern to generate the second radiation pattern; and generating an augmented radiation pattern within a detection volume, the augmented radiation pattern corresponding to a combination of the first radiation pattern and the second radiation pattern, the augmented radiation pattern including magnetic field components having sufficient magnitude and directional variation to enable reliable coupling to an RFID tag antenna essentially independent of RFID tag antenna orientation within the detection volume.

Brief Description of the Drawings

FIG. 1A is a block diagram showing a set of main elements of a representative orientation independent RFID communication assembly according to an embodiment of the disclosure.

FIG. 1B is a schematic illustration of an orientation independent RFID communication system in accordance with an embodiment of the disclosure.

FIG. 1C is a schematic side view of the RFID communication system of FIG. 1B.

FIGs. 2A and 2B are schematic illustrations of an RFID communication system according to another embodiment of the disclosure.

FIG. 3 is a circuit diagram of an impedance matching circuit in accordance with an embodiment of the disclosure.

FIG. 4A is a schematic illustration of a manner in which an object such as a first book and a second book that each carry an RFID tag can be detected by an embodiment of the present disclosure in a manner that is independent of RFID tag orientation.

FIG. 4B is a schematic illustration of an orientation independent RFID based article storage system according to an embodiment of the disclosure.

FIG. 5 is a flow diagram of a process for detecting an RFID tag in a manner that is substantially independent of RFID tag orientation in accordance with an embodiment of the disclosure.

FIG. 6 is a flow diagram of a process for manufacturing portions of an RFID communication assembly and/or an RFID communication system according to an embodiment of the present disclosure.

FIG. 7 is a graph illustrating a manner in which a gap between a primary antenna and a secondary antenna affects a maximum distance away from the primary antenna at which an RFID tag can be successfully or reliably detected for a representative implementation of an RFID communication system according to an embodiment the disclosure.

Detailed Description

Embodiments of the present disclosure relate to systems, apparatus, devices, and processes that facilitate or enable communication between an RFID reader, scanner, or transceiver and an RFID tag in a manner that is independent or substantially independent of RFID tag orientation within a spatial detection volume. More particularly, embodiments of the present disclosure relate to an RFID communication

system in which a primary antenna and at least one secondary antenna are spatially disposed, positioned, arranged, oriented, or aligned relative to each other such that electromagnetic coupling between antennas occurs by way of mutual inductance when the RFID reader drives the primary antenna.

The primary antenna generates a primary radiation pattern as a result of being driven by the RFID reader, and each secondary antenna generates a secondary radiation pattern as a result of inductive coupling to the primary radiation pattern's magnetic field. In various embodiments, the primary antenna is directly driven by the RFID reader, for instance, as a result of electrical coupling to the RFID reader by way of a feed point, and each secondary antenna is indirectly driven by way of inductive coupling to the primary antenna. That is, each secondary antenna lacks a direct electrical coupling or connection to the RFID reader.

The primary antenna radiation pattern and one or more secondary antenna radiation patterns combine to form an augmented or composite radiation pattern that defines an augmented or composite detection volume. The relative spatial arrangement of the primary and secondary antenna(s) results in the generation of an augmented radiation pattern that includes magnetic field components having sufficient intensity and directional variation to enable reliable coupling to an RFID tag antenna within the augmented detection volume in a manner that is independent or essentially independent of the spatial orientation of the RFID tag antenna.

Each secondary antenna is physically or spatially separated, isolated, or segregated from the primary antenna. More specifically, each secondary antenna is disposed relative to the primary antenna such that the major or highest intensity magnetic field component(s) of each secondary radiation pattern are orthogonal, essentially orthogonal, or substantially orthogonal to the major or highest intensity magnetic field component(s) of the primary radiation pattern. In addition, each secondary antenna is disposed or offset away from an axis that can be defined along a direction of the primary radiation pattern's highest intensity magnetic field component(s), i.e., an axis that corresponds to or is aligned with the primary antenna's highest intensity magnetic field. As a result, the augmented radiation pattern can efficiently and/or reliably couple to an RFID tag antenna that is oriented a) orthogonal to the primary

antenna's highest intensity magnetic field component(s); as well as b) parallel to the primary antenna's highest intensity magnetic field component(s), thereby facilitating or enabling orientation independent RFID tag communication.

In multiple embodiments, the primary antenna and each secondary antenna is a loop or loop type antenna that includes a length of wire that defines a portion of a loop, plane, or planar area or region. The primary antenna and/or each secondary antenna can be a single turn loop antenna. The primary antenna and each secondary antenna are disposed relative to each other such that the planar area of the primary antenna is substantially orthogonal or perpendicular to the planar area of each secondary antenna. Each secondary antenna is disposed away from a main axis of the primary antenna's planar area (i.e., an axis that is orthogonal or perpendicular to the primary antenna's planar area), for instance, towards, proximate to, or beyond a periphery, border, or boundary of the primary antenna's planar area.

In contrast to prior approaches directed to orientation independent RFID tag communication, various embodiments of the present disclosure drive only a single antenna (i.e., the primary antenna), and avoid a need for multiple RFID readers. Additionally, the primary antenna and/or secondary antenna(s) can be loop antennas having a single loop or turn of wire. As a result, embodiments of the disclosure exhibit a substantially simplified system design and significantly reduced system cost compared to prior approaches directed to orientation independent RFID tag communication.

Representative embodiments of the disclosure for addressing one or more of the foregoing problems associated with conventional approaches for orientation independent RFID tag communication are described hereafter with reference to FIGs. 1A to 7. In the description that follows, like or analogous reference numerals indicate like or analogous elements. Additionally, the recitation of a given reference numeral shown in a particular FIG. can indicate the simultaneous consideration of another FIG. in which such reference numeral is also shown.

For purpose of clarity, the description herein is directed to RFID communication systems having an operating frequency of approximately 10 – 15 MHz, e.g.,

approximately 13.56 MHz. However, this does not preclude various embodiments of the present disclosure from systems or applications that utilize or require similar operating capabilities at or within one or more other operating frequencies, such as one or more known or standard RF communication frequency bands (e.g., approximately 125 kHz, 840 – 845 MHz, 869 MHz, 912 – 928 MHz, 955 MHz, 2.45 GHz, or 5.8 GHz). Embodiments of the present disclosure encompass RFID communication systems having a different operating frequency or frequency range, or which operate within a plurality of frequency bands.

FIG. 1A is a block diagram showing a set of main elements of a representative orientation independent RFID communication apparatus or assembly 10 according to an embodiment of the disclosure. In an embodiment, the RFID communication assembly 10 includes an RFID reader, scanner, transceiver, or signal processing unit 100, a first loop antenna 110, and a second loop antenna 120. In some embodiments, the RFID communication assembly 10 can include one or more additional loop antennas, such that the system includes three or more loop antennas, as further detailed below.

The RFID reader 100 is electrically coupled to the first loop antenna 110, for instance by way of an electrical input or feed point. The RFID reader 100 can provide or supply a drive signal to the first loop antenna 110, thereby generating an electrical current in the first loop antenna 110 in a manner understood by one of ordinary skill in the art. The second loop antenna 120 lacks, omits, or excludes a direct electrical coupling to the RFID reader 100, and is physically separated or isolated from the first loop antenna, as more particularly described below. That is, the second loop antenna 120 need not be electrically and/or physically coupled or connected to the RFID reader. The first loop antenna 110 can thus function as a primary antenna, and the second loop antenna 120 can thus function as a secondary antenna that can be electromagnetically coupled to the first loop antenna 110 by way of magnetic induction.

The first and second loop antennas 110, 120 can respectively include a first length of wire 112 and a second length of wire 122. Each of the first and second lengths of wire 112, 122 includes a low loss material and/or a low resistance material such as at

least one of copper, gold and silver. Depending upon embodiment details, the first and/or second lengths of wire 112, 122 can be configured in accordance with various types of shapes or patterns, for instance, a circle, an oval, a triangle, a square, or a figure of eight.

The first length of wire 112 defines at least a portion of a first loop or planar region 114, and the second length of wire 122 defines at least a portion of a second loop or planar region 124. In multiple embodiments, the first and second planar regions 114, 124 define or have equal or approximately equal areas. In other embodiments, the first planar region 114 has a different physical area than the second planar region 124.

As indicated above, the first and second loop antennas 110, 120 are spatially disposed, positioned, oriented, or arranged relative to each other in a manner that facilitates electromagnetic coupling by way of magnetic induction, and which results in the generation of an augmented radiation pattern having magnetic field components of sufficient intensity and directional variation to facilitate or enable reliable orientation independent RFID tag communication. Particular aspects of antenna orientation in accordance with embodiments of the disclosure are described in detail hereafter.

FIG. 1B is a schematic illustration of an orientation independent RFID communication system 20 in accordance with an embodiment of the disclosure. The RFID communication system 20 includes an RFID tag 200 and an RFID communication assembly 10 such as that described above with respect to FIG. 1A. The RFID communication system 20 is configured to have a predetermined operating frequency (e.g., a center frequency within a frequency band), which in some embodiments is approximately 10 – 15 MHz. In particular embodiments, the operating frequency is approximately 13.56 MHz.

In general, an RFID tag 200 includes an RFID tag antenna 202, electronics circuitry for wireless communication ("wireless circuitry") 204, and a control system 206. The type and location of the RFID tag antenna 202 is dependent upon the operating frequency of the RFID tag 200 and particular RFID tag design details. In some

embodiments, the RFID tag 200 can further include a local memory 208 for information storage. Alternatively, the RFID tag 200 can store information, such as an identification number, by using of diodes, dip switches and/or other circuitry. The control system 206 can be an integrated circuit or other type of microprocessor or microcontroller electronics that controls the substantive operations of the RFID tag 200. The control system 206 is coupled to the wireless circuitry 204 to communicate and receive signals or transmissions. Additionally, the control system can be coupled to the local memory 208 for storing and/or retrieving information.

As shown in FIG. 1B, the first and second loop antennas 110, 120 are positioned or disposed relative to each other such that the first planar region 114 defined by the first loop antenna 110 is perpendicular or substantially perpendicular to the second planar region 124 defined by the second loop antenna 120. A first axis 111 can be defined with respect to the first loop antenna 110, such that the first axis 111 is normal to and centrally disposed within the first planar region 114. Similarly, a second axis 121 can be defined with respect to the second loop antenna 120, such that the second axis 121 is normal to and centrally disposed within the second planar region 124. The first and second axes 111, 121 are substantially perpendicular to each other. In addition to the substantially perpendicular orientation of the second planar region 124 relative to the first planar region 114, the second planar region 124 is perpendicularly disposed away from the first axis 111 such that the second planar region 124 is positioned towards, adjacent to, proximate to, at, essentially at, or at least slightly beyond a peripheral boundary or periphery of the first planar region 114 in a direction parallel to the second axis 121.

The first and second loop antennas 110, 120 are laterally separated from each other (e.g., separated by a distance along the first axis 111) by a first gap 300. In various embodiments, the first gap 300 is approximately 0.1 – 10 cm. In particular embodiments, the first gap 300 is less than approximately 10 cm, for instance, approximately 7.5 cm or less, or about 5 cm or less.

The size of the first gap 300 affects inductive coupling between the first and second loop antennas 110, 120. As further described below, such inductive coupling results in the generation of an augmented or composite electromagnetic field distribution

that defines an augmented detection volume in which an RFID tag 200 can be detected in a manner that is substantially independent of RFID tag orientation. The size of the first gap 300 can be determined by way of simulation, calculation, and/or measurement such that inductive coupling between the first and second loop antennas 110, 120 gives rise to an augmented, composite, or overall electromagnetic field pattern or distribution that defines, spans, or covers an augmented, composite, or overall spatial volume that is appropriate for an RFID application under consideration. In general, as the size of the first gap 300 increases, an overall RFID tag detection range or a corresponding size of a detection volume increases. However, the uniformity of an augmented field pattern can suffer (e.g., degrade or deteriorate such that the augmented field pattern exhibits irregularities or nonuniformities) once the first gap 300 is increased beyond a certain distance (e.g., approximately 5 – 7 cm). Additionally, the first gap 300 may need to exceed a minimum distance such as approximately 0.5 or 1.0 cm because a strong coupling effect between the first loop antenna 110 and the second loop antenna 120 can lead to unstable RFID detection performance in certain situations. A graph illustrating the relationship between the size of the first gap 300 and the maximum distance away from the first loop antenna 110 at which an RFID tag can be successfully or reliably detected for a representative implementation of an RFID communication system 20 in accordance with the present disclosure is described in detail below with reference to FIG. 7.

FIG. 1C is a schematic side view of the RFID communication system 20 of FIG. 1B. As will be appreciated by a person of ordinary skill in the art, electrical signals provided to the first loop antenna 110 can produce an electrical current through the first loop antenna 110. Accordingly, the electrical current through the first loop antenna 110 can generate a first radiation pattern corresponding to the first loop antenna 110. The first radiation pattern includes a first magnetic field, which has a major or highest intensity component parallel to or along the direction of the aforementioned first axis 111.

Due to the position and orientation of the second loop antenna 120 relative to the first loop antenna 110, portions of the second antenna 120 are exposed to the first magnetic field, resulting in the generation of a second radiation pattern or field

corresponding to the second antenna 120 by way of magnetic induction. The second radiation pattern includes a second magnetic field, which has a major or highest intensity component along the second planar region's second axis 121.

The first and second radiation patterns combine to form a first augmented or composite radiation pattern having a spatial extent that defines a first augmented or composite detection volume or interrogation zone 400 in which the RFID tag 200 can be reliably, consistently, or generally reliably detected. The first augmented radiation pattern includes a first augmented or composite magnetic field. As a result of the arrangement or orientation of the first and second loop antennas 110, 120 relative to each other, the first augmented radiation pattern includes magnetic field components that are perpendicular to the first planar region 114 as well as magnetic field components that are perpendicular to the second planar region 124, that is, magnetic field components that are parallel to the first planar region 114. Stated equivalently, the first augmented radiation pattern includes magnetic field components that are parallel to the first loop antenna's first axis 111, and magnetic field components that are along the second planar region's second axis 121. The first augmented radiation pattern's magnetic field components have sufficient magnitude as well as sufficient directional variation to facilitate or enable reliable or generally reliable inductive coupling to the RFID tag antenna 202 in a manner that is independent or substantially independent of RFID tag orientation within the first augmented detection volume 400.

In general, if RFID tag antenna coupling to the first and second magnetic fields were considered separately, the RFID tag antenna 202 can couple to the first radiation pattern provided that the RFID tag antenna 202 is appropriately oriented relative to the first magnetic field; and the RFID tag antenna 202 can couple to the second radiation pattern provided that the RFID tag antenna 202 is appropriately oriented relative to the second magnetic field. Coupling between the RFID tag antenna 202 and the first magnetic field can occur for a first range of spatial RFID tag orientations, and coupling between the RFID tag antenna 202 and the second magnetic field can occur for a second range of spatial RFID tag orientations. In various embodiments, the first and second ranges of spatial RFID tag orientations in

combination encompass essentially any RFID tag orientation within the first augmented detection volume 400.

As a representative conceptual example to further aid understanding, in some embodiments the RFID tag antenna 202 can be carried by or oriented on the RFID tag 200 such that a) maximum coupling to the first magnetic field occurs when the RFID tag antenna 202 is approximately parallel to the first planar region 114 (e.g., facing the first planar region 114 and perpendicular to the first loop antenna's first axis 111); and b) reliable coupling to the first magnetic field occurs when the RFID tag antenna 202 is offset no more than approximately 45 degrees with respect to the first planar region 114. Similarly, a) maximum coupling between the RFID tag antenna 202 and the second magnetic field occurs when the RFID tag antenna 202 is approximately parallel to the second planar region; and b) reliable coupling to the second magnetic field can occur when the RFID tag antenna 202 is offset no more than approximately 45 degrees with respect to the second planar region 124.

In view of the foregoing, reliable inductive coupling within the first augmented detection volume 400 involving the first augmented radiation pattern and the RFID tag antenna 202 can occur when the RFID tag antenna 202 has a reliable detection orientation relative to the first loop antenna 110, as well as when the RFID tag antenna 202 would lack a reliable detection orientation relative to the first loop antenna 110 but has a reliable detection orientation relative to the second loop antenna 120. The overall or combined range of reliable detection orientations provided by the combination of the first radiation pattern and the second radiation pattern respectively generated by the first and second loop antennas 110, 120 results in RFID tag detection capability that is independent or substantially independent of RFID tag orientation.

FIGs. 2A and 2B are schematic illustrations of an RFID communication system 20 according to another embodiment of the disclosure. Similar to what was described above, the RFID communication system 20 includes an RFID tag 200, and an RFID communication assembly 10 that includes a third loop antenna 130 in addition to a first loop antenna 110 and a second loop antenna 120.

In a manner identical or analogous to that previously described, the third loop antenna 130 includes a third length of wire 132, which can be a low loss and/or a low resistance material such as one or more of copper, gold and silver. The third length of wire 132 can be configured in accordance with one or more types of shapes or patterns, for instance, a circle, an oval, a triangle, a square, or a figure of eight.

The third length of wire 132 defines a third loop or planar region 134. Depending upon embodiment details, the first, second, and third planar regions 114, 124, 134 can have equal or approximately equal areas; or one or more of the first, second and third planar regions 114, 124, 134 can have different areas. The second planar region 124 and the third planar region 134 are disposed on opposite sides of the first planar region 114.

The first loop antenna 110 is driven by the RFID reader 100, for instance, by way of an electrical input or feed point. The second and third loop antennas 120, 130 lack, omit, or exclude a direct electrical coupling to the RFID reader 100, and are physically separated or isolated from the first loop antenna 110 as well as each other. The first loop antenna 110 can thus function as a primary antenna, and the second and third loop antennas 120, 130 can each function as secondary antennas that are inductively coupled to the first loop antenna 110 by way of magnetic induction.

The first, second, and third loop antennas 110, 120, 130 are disposed relative to each other such that the first planar region 114 is substantially perpendicular to each of the second planar region 124 and the third planar region 134. The first loop antenna 110 includes a first axis 111 that is normal to the first planar region 114. The third planar region 134 is offset or disposed substantially away from the first axis 111 towards, adjacent to, proximate to, at, essentially at, or slightly beyond a peripheral boundary or periphery of the first planar region 114. In some embodiments, the second planar region 124 and the third planar region 134 are disposed towards the same said peripheral boundary of the first planar region 114, while in other embodiments the second and third planar regions 124, 134 are disposed towards opposite peripheral boundaries of the first planar region 114.

The first loop antenna 110 can be laterally separated from the second loop antenna 120 by a first gap 300, and the first loop antenna 110 can be laterally separated from the third loop antenna 130 by a second gap 302. The first and second gaps 300, 302 can be equal or approximately equal to or different from each other. In representative implementations, each of the first and second gaps 300, 302 are approximately 0.1 – 10 cm. In particular embodiments, one or both of the first and second gaps 300, 302 are less than approximately 10 cm, for instance, less than approximately 7.5 cm, or about 5 cm or less. The size of the first and second gaps 300, 302 affects inductive coupling between the first, second, and third loop antennas 110, 120, 130, and can be determined by simulation, calculation, and/or measurement to provide an augmented radiation pattern that defines, spans, or covers an augmented spatial volume that is suitable for an RFID application under consideration.

As discussed earlier, electrical signals provided to the first loop antenna 110 produce an electrical current through the first loop antenna 110. Accordingly, the electrical current through the first loop antenna 110 generates a first radiation pattern corresponding to the first antenna 110. The first radiation pattern includes a first magnetic field.

In a manner analogous to that described above, the first radiation pattern can result in the generation of a third radiation pattern corresponding to the third loop antenna 130 by way of magnetic induction, where the third radiation pattern includes a third magnetic field. The first radiation pattern can combine with the third radiation pattern to form a second augmented radiation pattern having a spatial extent that defines a second augmented detection volume 410. As a result of the arrangement or orientation of the first and third loop antennas 110, 130 relative to each other, the second augmented radiation pattern includes magnetic field components that are perpendicular to the first planar region 114 as well as magnetic field components that are perpendicular to the third planar region 134, that is, magnetic field components that are parallel to the first planar region 114. Stated equivalently, the second augmented radiation pattern includes magnetic field components that are parallel to the first loop antenna's first axis 111, and magnetic field components that are perpendicular to the first loop antenna's first axis 111. Such orthogonal magnetic field components have sufficient magnitude as well as sufficient directional variation

to facilitate or enable reliable inductive coupling to the RFID tag antenna 202 in a manner that is independent or substantially independent of RFID tag orientation within the second augmented detection volume 410.

When using the loop antenna system 100, the impedance of the first loop antenna 110 should match the impedance of the RFID reader 100 at a pre-determined frequency or frequency range to maximize energy transfer between the first loop antenna 110 and the RFID reader 100. Maximum energy transfer takes place when the impedance of the RFID reader100 equals the complex conjugate of the first loop antenna 110 impedance. In various embodiments, a matching circuit can be provided if the impedance of the RFID reader 100 is not equal to the complex conjugate of the first loop antenna 110.

FIG. 3 is a circuit diagram of an impedance matching circuit 500 in accordance with an embodiment of the disclosure. The first loop antenna 110 has a low impedance relative to the RFID reader 100. Therefore, it is necessary to transform the first loop antenna impedance to the RFID reader impedance (e.g., 50 Ohms) for maximum energy transfer. The matching circuit 500 can ensure that the primary or first loop antenna 110 radiates efficiently at the pre-determined operating frequency with minimal or no reflection. For example, the matching circuit 500 can convert the first loop antenna impedance to the impedance of the RFID reader 100 operating at approximately 13.56 MHz.

The matching circuit 500 can include a capacitor 502 coupled in series with an inductor 504. Depending upon embedment details, the capacitor 502 and the inductor 504 can be variable. The capacitor 502 is further coupleable to the first loop antenna 110 in parallel. The capacitor 502 and the inductor 504 are selected such that the output impedance Z_M of the matching circuit 500 is equal to the complex conjugate of Z_A; and the input impedance Z_N of the matching circuit 500 has to be equal to the complex conjugate of Z_T. One of ordinary skill in the art will understand that embodiments of the present disclosure not limited to a matching circuit having specific form shown in FIG. 3.

FIG. 4A is a schematic illustration of a manner in which an object 50 such as a first book 50a and a second book 50b (e.g., each of which can be a library book or magazine) that each carry an RFID tag 200 can be detected by an embodiment of the present disclosure in a manner that is independent of RFID tag orientation. In a representative embodiment, portions of an RFID communication system 20 are carried by (e.g., mounted upon and/or housed within, such as by way of a bonding process) a support element, support member, housing, or structure such as a shelf divider 60 or shelf 62 that form a portion of an article storage element, member, structure or apparatus 70. The shelf divider 60, shelf 62, and/or other portions of an article storage structure 70 can be made of one or more materials such as wood, a polymer, or metal. In general, multiple objects such as books 50a-b carrying RFID tags 200 can be carried or disposed relative to the shelf divider 60 and/or shelf 62 in various orientations, such as the orientations depicted in FIG. 4A and/or other orientations.

The RFID communication system 20 of FIG. 4A has a structure that is identical or analogous to that described above with respect to FIGs. 2A and 2B. The RFID reader 100 communicates with the RFID tag 200 by emitting a modulated signal or command 600, which has a predetermined center or carrier frequency (e.g., approximately 13.56 MHz). As long as the first book's RFID tag 200 is within the first augmented detection volume 400, the first book's RFID tag antenna 202 can receive the modulated signal by way of coupling to the first augmented radiation pattern (i.e., the first augmented magnetic field). The RFID tag's wireless circuitry 204 is energized by such coupling to the first augmented radiation pattern, and can remain energized while the RFID tag 200 remains within the first augmented detection volume 410. The RFID tag's wireless circuitry 204 demodulates the modulated signal 600, and appropriately response thereto, for instance, by transmitting particular information stored in the RFID tag by way of the RFID tag antenna 202. Such information can include a book identification number and/or other information such as book title, author, or date of publication. The RFID reader 100 correspondingly detects the transmitted information. Communication between the second book's RFID tag 200 and the RFID reader 100 occurs in an analogous manner as a result of inductive coupling involving the second augmented radiation pattern in the second augmented detection volume 410, even though the second book 50b is

disposed relative to the shelf 62 in a manner that its RFID tag 200 is perpendicular or substantially perpendicular to the RFID tag 200 carried by the first book 50a. That is, reliable RFID identification of each of the first and second books 50a-b can occur even though the RFID tags 202 carried by the first and second books 50a-b exhibit orthogonally distinct orientations with respect to the first loop antenna 110.

While the representative example of FIG. 4A illustrates objects 50 such as books 50a-b carried by a shelf 62, a person of ordinary skill in the art will understand that RFID communication systems 20 in accordance with the present disclosure can be applied to or adopted in many other objects, articles, structures, and/or situations, for instance, tools, supplies, or manufactured products that are carried by a given type of support structure.

FIG. 4B is a schematic illustration of an orientation independent RFID based article storage system 80 according to an embodiment of the disclosure. Depending upon embodiment details, the article storage system 80 can include one or more article storage structures 70, for instance, organized or disposed relative to each other in a horizontally and/or vertically offset manner. In an embodiment, the article storage system 80 includes multiple RFID communication assemblies 10a-d, where portions of each RFID communication assembly 10a-d are carried by one or more support members or housing elements such as a shelf 62a-d and/or a shelf divider 60a-d.

Each RFID communication assembly 10a-d includes a first loop antenna 110 and at least a second loop antenna 120. RFID communication assembly antennas 110, 120, 130 can be perpendicularly disposed and laterally offset relative to each other such that they are inductively coupleable in accordance with an embodiment of the present disclosure. The article storage system 80 further includes an RFID reader 100 that is coupled to each RFID communication assembly's first loop antenna 100. The RFID reader 100 can be configured to drive each first loop antenna 110, for instance, in a multiplexed manner. Thus, in accordance with an embodiment of the disclosure, a single RFID reader 100 can drive multiple RFID communication assemblies 10a-d.

Any given RFID communication assembly 10a-d is configured to generate an augmented radiation pattern such that an augmented detection volume 400, 410

extends or substantially extends along a) the entire length and width of a shelf 62a-d corresponding to the RFID communication assembly 10a-d; and b) an entire vertical distance separating a shelf 62a-d carrying portions of the RFID communication assembly 10a-d from another shelf 62a-d. That is, any given RFID communication assembly 10a-d can generate an augmented radiation pattern that provides an augmented detection volume 400, 410 that encompasses or substantially encompasses a spatial volume defined by a shelf length, a shelf width, and vertical separation between shelves 62a-d. As a result, RFID tags 200 carried by objects 50 disposed essentially anywhere within each augmented detection volume 400, 410 corresponding to the article storage system 80 can be successfully or reliably detected regardless or essentially independent of RFID tag orientation with respect to an RFID communication assembly 10a-d and/or portions of the article storage system 80 in or at which objects 50 can located.

FIG. 5 is a flow diagram of a process 700 for detecting an RFID tag 200 in a manner that is substantially independent of RFID tag orientation in accordance with an embodiment of the disclosure. Portions of the process 700 can be performed using an embodiment of an RFID communication system 20 according to the present disclosure.

The process 700 includes a first process portion 702 that involves disposing a plurality of antennas, such as a primary antenna and at least one secondary antenna, relative to each other in a manner that facilitates or enables inductive coupling between the antennas and the generation of an augmented radiation pattern having magnetic field components of sufficient magnitude and sufficient directional variation that an RFID tag 200 can be detected independent of its orientation within an augmented detection volume 400, 410 that is defined by an augmented radiation pattern.

For instance, the first process portion 702 can involve disposing a first loop antenna 110 at a first location and orientation, and disposing a second loop antenna 120 relative to the first antenna 110 such that a first planar region 114 of the first loop antenna 110 and a second planar region 124 of the second loop antenna 120 are substantially perpendicular to each other, and the second planar region 124 is

substantially offset or disposed away from a first axis 111 of the first planar region 114 towards, proximate to, adjacent to, at, or beyond a peripheral boundary, border, or edge of the first planar region 114, for instance, in a direction parallel to a second axis 121 of the second planar region 124. Additionally, the second planar region 124 is laterally offset away from the first planar region 114 by a given distance, for instance, approximately 0.1 – 10 cm (e.g., approximately 0.5 – 7 cm, or less than or equal to about 5 cm). The lateral offset distance between the first and second planar regions 114, 124 can be adjusted, simulated, or determined in order to achieve optimum RFID communication performance in view of a desired augmented detection volume 400, 410.

In an embodiment, the first process portion 702 can additionally involve disposing a third loop antenna 130 relative to the first antenna 110 such that a first planar region 114 of the first loop antenna 110 and a third planar region 134 of the third loop antenna 130 are substantially perpendicular to each other, and the third planar region 134 is substantially offset or disposed away from the first axis 111 of the first planar region 114 towards, proximate to, adjacent to, at, or beyond a peripheral boundary, border, or edge of the first planar region 114. Additionally, the third planar region 134 is laterally offset away from the first planar region 114 by a given distance, for instance, approximately 0.1 – 10 cm (e.g., about 5 cm). The second and third planar regions 124, 134 are disposed on opposite sides of the first planar region 114.

The process 700 includes a second process portion 704 that involves coupling an RFID reader, scanner, or transceiver 100 to the first loop antenna 110, for instance, by way of a feed point, as well as coupling the first loop antenna 110 to a matching circuit 500 that is appropriate for the RFID reader 100 under consideration. The process 700 further includes a third process portion 704 that involves driving the first loop antenna 110 with an electrical signal provided by the RFID reader 100 to thereby generating a first radiation pattern. The first loop antenna 110 thus serves as a primary antenna for purpose of magnetic induction.

The process 700 further includes a fourth process portion 706 that involves generating at least a second radiation pattern by way of inductive coupling between the first radiation pattern's magnetic field and the second loop antenna 120. The

fourth process portion 706 can additionally involve generating a third radiation pattern by way of inductive coupling between the first radiation pattern's magnetic field and the third loop antenna 130. Thus, the second and third loop antennas 120, 130 serve as secondary antennas with respect to inductive coupling with the primary antenna.

A fifth process portion 708 involves combining the first radiation pattern with the second radiation pattern, as well as the third radiation pattern in embodiments that include the third loop antenna 130, to create one or more augmented radiation patterns 400, 410 having magnetic field components that are perpendicular to the first planar region 114 as well as parallel to the first planar region 114 or perpendicular to the second and/or third planar regions 124, 134. The augmented radiation pattern 400, 410 includes magnetic field components of sufficient magnitude and sufficient directional variation that an RFID tag antenna 202 disposed within the augmented detection volume can reliably inductively couple to the augmented radiation pattern in a manner that is substantially independent of RFID tag orientation.

A sixth process portion 710 can involve disposing a plurality of RFID tags 200 within one or more augmented detection volumes 400, 410, where multiple RFID tags 200 within one or more augmented detection volumes 400, 410 exhibit different orientations. At least some RFID tags 200 within an augmented detection volume 400, 410 can be disposed to have orientations for which inductive coupling to the first radiation pattern by itself, in the absence of the second or third radiation pattern and hence in the absence of an augmented radiation pattern, would not occur or would not be sufficient to enable reliable or sufficient detection of such RFID tags 200.

A seventh process portion can involve successfully detecting or communicating with each RFID tag 200 disposed within the augmented detection volume using the RFID reader 100, regardless of RFID tag orientation 200.

FIG. 6 is a flow diagram of a process 800 for manufacturing portions of an RFID communication assembly 10 and/or an RFID communication system 20 according to an embodiment of the present disclosure. In an embodiment, the process 800

includes a first process portion 802 that involves providing a first loop antenna 110 having a feed point, a first planar region 114, and a first axis 111 normal to the first planar region 114. The first loop antenna 110 can be carried by or coupled to a portion of a first support member, housing element, or housing such as shelf spacer, divider, or separator 60 (e.g., a bookshelf spacer or divider, or a bookend).

A second process portion 804 involves providing at least a second loop antenna 120 having a second planar region 124 defining a second axis 121, where the second planar region 124 can be carried by or coupled to a portion of a second support member, housing element, or housing such as a shelf 62. The second support member, housing, or housing element carries the second loop antenna 120 such that the second planar region 124 is substantially perpendicular to the first planar region 114, and the second planar region 124 is disposed substantially away from the first planar region's first axis 111 near a peripheral boundary or border of the first planar region 114 (e.g., in a direction parallel to the second axis 121). Additionally, the second planar region 124 is laterally offset from the first planar region 114 by a predetermined distance, such as approximately 0.1 – 10 cm (e.g., about 5 cm).

In an embodiment, the second process portion 804 further involves providing a third loop antenna 130 having a third planar region 134, which can be carried by a portion of the second or a portion of a third support member, housing element, or housing such as a shelf 62. The third planar region 134 is carried such that the second and third planar regions are on opposite sides of the first planar region 114, and the third planar region is substantially perpendicular to the first planar region 114, disposed substantially away from the first planar region's first axis 111 near a periphery of the first planar region 110. Additionally, the third planar region 134 is laterally offset from the first planar region 114 by a predetermined distance, such as a distance given above.

A third process portion 806 involves coupling the first loop antenna 110 to an RFID reader 100 and an appropriate matching circuit or network 500, and a fourth process portion 808 involves driving the first loop antenna 110 with an electrical signal provided by the RFID reader 100 to generate a first radiation pattern with the first loop antenna 110, where the first radiation pattern includes a first magnetic field.

A fifth process portion 810 involves exposing the second and/or third loop antennas 120, 130 to the first radiation pattern, thereby inductively coupling the second and/or third loop antennas 120, 130 to the first loop antenna 110 by way of the first magnetic field, and generating a second and/or a third radiation pattern respectively corresponding to the second and/or third loop antennas 120, 130. A sixth process portion 812 involves combining the first radiation pattern with the second and/or third radiation patterns to produce at least one augmented radiation pattern that defines an augmented detection volume 400, 410. The augmented radiation pattern includes magnetic field components of sufficient magnitude and directional variation to facilitate or enable reliable or generally reliable communication with an RFID tag antenna 202 disposed within the augmented detection volume 400, 410 regardless or independent of the RFID tag antenna's orientation. Differently oriented RFID tags can be detected within the augmented detection volume(s) 400, 410 in a manner identical or analogous to that described above.

FIG. 7 is a graph illustrating a manner in which a lateral separation or gap 300 between a primary or driven antenna (e.g., a first loop antenna 110) and a secondary or inductively coupled antenna (e.g., a second or a third loop antenna 120, 130) affects a maximum distance away from the primary antenna at which an RFID tag 200 can be successfully or reliably detected for a representative implementation of an RFID communication system 20 according to an embodiment the disclosure. In particular, the graph of FIG. 7 shows measured maximum RFID tag detection distance versus gap size for a system 20 having a first loop antenna 110 and a second loop antenna 120. The first loop antenna 110 and the second loop antenna 120 can be approximately the same size or different sizes. For example, the first loop antenna 110 can have dimensions of approximately 25 cm by 20 cm and the second loop antenna 120 can have dimensions of approximately 42 cm by 35 cm. The first and second loop antennas 110, 120 were positioned or oriented relative to each other in a manner indicated in FIG. 1B, such that the second planar area 124 was perpendicular to the first planar area 114. The second planar area 124 was offset away from the first loop antenna's first axis 111, such that the second planar area 124 was positioned slightly beyond a peripheral border of the first planar area 114. Additionally, the RFID tag 200 was a card size HF ISO I Code SLI tag

(manufactured by FCI SMARTAG Pte Ltd, Singapore). The RFID reader 100 was a High Power High Frequency reader (model number ID ISC.LR2000 A, manufactured by FEIG ELECTRONIC, Weilburg, Germany).

In general, the further apart the first loop antenna 110 is from the second loop antenna 120, the shorter the detection range is. As indicated by FIG. 7, a gap 300 that is less than or equal to approximately 5 cm (for instance, less than or equal to approximately 2 – 4 cm, e.g., less than or equal to approximately 2 – 2.5 cm, or between approximately 1 – 2 cm) gives rise to a largest or longest distance away from the first loop antenna 100 at which an RFID tag 200 can be successfully or reliably detected. If the spacing between the first loop antenna 110 and the second loop antenna 120 is within approximately 5 cm, the augmented radiation pattern is uniform, essentially uniform, or substantially uniform. However, if the spacing is beyond approximately 5 cm, the augmented radiation pattern can be distorted or nonuniform. Consequently, the augmented detection volume can become distorted, nonuniform, or irregular if the spacing between the inductively coupled antennas 110, 120 is beyond approximately 5 cm, and an RFID tag antenna detection zone or reliable detection region correspondingly becomes distorted, nonuniform, or irregular, or shrinks. An RFID tag detection range, reliable detection range, detection distance, or reliable detection distance thus drops. To achieve good or robust transformer type coupling effect(s), the second loop antenna 120 should be approximately 1 – 5 cm apart or laterally separated away from the first loop antenna 110. If the two loop antennas, 110,120 are too close to each other (e.g., less than about 1 cm), a strong coupling effect could make antenna assembly performance unstable. In order to maintain a perfect, optimized or effective geometric balance, the distance or lateral offset between the two loop antennas, 110,120 can be approximately 1 – 2 cm. For a first loop antenna 110 and a second loop antenna 120 having the above dimensions, the RFID tag 200 was successfully detected up to a distance of approximately 80 cm from the first loop antenna's first planar area 114. Thus, an augmented detection volume 400 extended approximately 80 cm away from the first loop antenna 110. Within the augmented detection volume 400, successful RFID tag detection was independent or essentially independent of RFID tag orientation.

In the foregoing manner, various embodiments of the disclosure are described for addressing at least one of the foregoing disadvantages. Based on the foregoing disclosure, it should be understood that various changes in the form and design of an RFID communication assembly, apparatus, and/or system can be made without departing from the scope and spirit of this disclosure. The form, method and design described herein are merely an explanatory embodiment thereof and it is the intention of the following claims to encompass and include such changes.

Claims

1. An RFID reader system having an operating frequency, the RFID reader system comprising:

a signal processing unit having an output configured to provide a drive signal;

a first loop antenna having a first length of wire that defines a first planar region, the first loop antenna having a feed point to receive the drive signal, the drive signal providing an electrical signal to the first loop antenna thereby generating a first radiation pattern that includes a first magnetic field; and

a second loop antenna having a second length of wire that defines a second planar region, the second planar region disposed substantially perpendicular to the first planar region, the second loop antenna exposed to the first magnetic field to thereby generate a second radiation pattern by way of inductive coupling, the second radiation pattern including a second magnetic field,

wherein the first radiation pattern and the second radiation pattern combine to form a first augmented radiation pattern coupleable to an RFID tag antenna in a manner that is at least substantially independent of RFID tag antenna orientation.

2. The system of claim 1, further comprising:

a third loop antenna, the third loop antenna having a third length of wire that defines a third planar region, the third planar region disposed substantially perpendicular to the first planar region, the second planar region and the third planar region disposed on opposite sides of the first planar region, the third loop antenna exposed to the first magnetic field to thereby generate a third radiation pattern by way of inductive coupling, the third radiation pattern having a third magnetic field,

wherein the first radiation pattern and the third radiation pattern combine to form a second augmented radiation pattern coupleable to the RFID tag antenna in a manner that is at least substantially independent of RFID tag antenna orientation.

3. The system of claim 2, wherein the operating frequency is approximately 10 – 15 MHz.

4. The system of claim 3, wherein the operating frequency is approximately 13.56 MHz.

5. The system of claim 1, wherein at least one of the first length of wire and the second length of wire is configurable to have a shape corresponding to one of a circle, an oval, a triangle, a square and a figure of eight.

6. The system of claim 2, wherein the third length of wire is configurable to have a shape corresponding to a circle, an oval, a triangle, a square and a figure of eight.

7. The system of claim 1, wherein the second loop antenna lacks a feed point coupleable to the signal processing unit.

8. The system of claim 2, wherein the second and third loop antennas lack a feed point coupleable to the signal processing unit.

9. The system of claim 1, wherein the first loop antenna is coupled to a matching circuit.

10. The system of claim 9, wherein the matching circuit is tuned by at least one of a variable capacitor and a variable inductor.

11. The system of claim 1, wherein the first and second loop antennas are physically isolated from each other.

12. The system of claim 2, wherein the first, second and third loop antennas are physically isolated from each other.

13. The system of claim 1, wherein the first and second loop antennas are laterally separated by approximately 0.1 - 10 cm.

14. The system of claim 2, wherein the first loop antenna is separated from at least one of the second loop antenna and the third loop antenna by approximately 0.5 - 5 cm.

15. The system of claim 1, wherein the first augmented radiation pattern defines a first augmented detection volume that includes magnetic field components that are perpendicular to the first planar region and magnetic field components that are perpendicular to the second planar region.

16. The system of claim 2, wherein the second augmented radiation pattern defines a second augmented detection volume that includes magnetic field components that are perpendicular to the first planar region and magnetic field components that are perpendicular to the third planar region.

17. The system of claim 1, wherein the first loop antenna includes an axis normal to the first planar region and the second planar region is disposed substantially away from the axis towards a peripheral boundary of the first planar region.

18. The system of claim 2, wherein the first loop antenna includes an axis normal to the first planar region and the third planar region is disposed substantially away from the axis towards a peripheral boundary of the first planar region.

19. The system of claim 1, wherein the first loop antenna is carried by a first housing member and the second loop antenna is carried by a second housing member.

20. The system of claim 2, wherein the third loop antenna is carried by a third housing member.

21. An RFID communication system comprising:

a first antenna having a feed point coupleable to a drive signal, the first antenna configured to generate a first radiation pattern in response to the drive signal, the first radiation pattern including a first magnetic field having a maximum magnitude along a first axis;

a second antenna configured to generate a second radiation pattern by way of inductive coupling to the first radiation pattern, the second radiation pattern including a second magnetic field having a maximum magnitude along a second axis; and

a set of support members configured to spatially dispose the first antenna and the second antenna relative to each other such that the first axis is substantially perpendicular to the second axis, the second antenna is offset away from the first axis toward a periphery of the first antenna in a direction parallel to the second axis, and the first radiation pattern and the second radiation patterns are combinable to generate an augmented radiation pattern within a detection volume in which the augmented radiation pattern includes magnetic field components of sufficient magnitude and directional variation to enable reliable coupling to an RFID tag antenna in a manner that is essentially independent of RFID tag antenna orientation within the detection volume.

22. An RFID reader system having an operating frequency, the RFID reader system comprising:

a signal processing unit having an output configured to provide a drive signal; and

a plurality of loop antenna systems, each loop antenna system comprising:

a first loop antenna having a first length of wire that defines a first planar region, the first loop antenna having a feed point coupled to receive the drive signal, the drive signal providing an electrical

signal to the first loop antenna thereby generating a first radiation pattern that includes a first magnetic field; and

a second loop antenna having a second length of wire that defines a second planar region, the second planar region disposed substantially perpendicular to the first planar region, the second loop antenna exposed to the first magnetic field to thereby generate a second radiation pattern by way of inductive coupling, the second radiation pattern including a second magnetic field,

wherein the first radiation pattern and the second radiation pattern combine to form a first augmented radiation pattern coupleable to an RFID tag antenna in a manner that is at least substantially independent of RFID tag antenna orientation.

23. The system of claim 22, further comprising an article storage structure that carries the plurality of loop antenna systems in one of an adjacent and a vertically stacked manner.

24 A method of detecting an RFID tag carrying an RFID tag antenna within a detection volume in a manner that is substantially independent of RFID tag orientation, the method comprising:

generating a first radiation pattern by way of a first loop antenna comprising a feed point and a length of wire that defines a first planar region, the first radiation pattern including a first magnetic field;

exposing a second loop antenna to the first magnetic field, the second loop antenna comprising a second length of wire that defines a second planar region disposed substantially perpendicular to the first planar region;

generating a second radiation pattern with the second loop antenna by way of inductive coupling to the first magnetic field, the second radiation pattern including a second magnetic field,

wherein the first radiation pattern and the second radiation pattern combine to form a first augmented radiation pattern coupleable

to the RFID tag antenna in a manner that is at least substantially independent of RFID tag orientation.

25. The method of claim 24, wherein the first loop antenna includes an axis normal to the first planar region and the second planar region is disposed substantially away from the axis towards a peripheral boundary of the first planar region.

26. The method of claim 24 further comprising:

exposing a third loop antenna to the first magnetic field, the third loop antenna comprising a third length of wire that defines a third planar region disposed substantially perpendicular to the first planar region;

generating a third radiation pattern with the third loop antenna by way of inductive coupling, the third radiation pattern including a third magnetic field,

wherein the first radiation pattern and the third radiation pattern combine to form a second augmented radiation pattern coupleable to the RFID tag antenna in a manner that is at least substantially independent of RFID tag orientation.

27. The method of claim 24, wherein the first loop antenna includes an axis normal to the first planar region and the third planar region is disposed substantially away from the axis towards a peripheral boundary of the first planar region.

28. The method of claim 27, further comprising:

disposing the second planar region and the third planar region on opposite sides of the first planar region.

29. The method of claim 24 further comprising:

coupling a signal processing unit to the feed point of the first loop antenna, the signal processing unit providing a drive signal to the

first loop antenna thereby providing an electrical signal to the first loop antenna.

30. A method of manufacturing an RFID reader assembly, the method comprising the steps of:

providing a first loop antenna, the first loop antenna having a first length of wire that defines a first planar region, the first loop antenna having a feed point, the first loop antenna carried by a first housing member; and

providing a second loop antenna, the second loop antenna having a second length of wire that defines a second planar region, the second loop antenna carried by a second housing member such that the second planar region is substantially perpendicular to the first planar region and the second loop antenna is inductively coupleable to the first loop antenna.

31. The method of claim 30, wherein the first loop antenna includes an axis normal to the first planar region and the second planar region is disposed substantially away from the axis towards a peripheral boundary of the first planar region.

32. The method of claim 30 further comprising:

providing an impedance matching circuit coupled to the first loop antenna, the impedance matching circuit comprising at least one of a variable capacitor and a variable inductor.

33. An RFID communication method comprising:

providing a first antenna configured to generate a first radiation pattern including a first magnetic field having a maximum magnitude along a first axis;

providing a second antenna configured to generate a second radiation pattern including a second magnetic field having a maximum magnitude along a second axis;

positioning the first and second antennas relative to each other such that the first axis is substantially perpendicular to the second axis and the second antenna is offset away from the first axis toward a periphery of the first antenna in a direction parallel to the second axis;

driving the first antenna to generate the first radiation pattern;

inductively coupling the second antenna to the first radiation pattern to generate the second radiation pattern; and

generating an augmented radiation pattern within a detection volume, the augmented radiation pattern corresponding to a combination of the first radiation pattern and the second radiation pattern, the augmented radiation pattern including magnetic field components having sufficient magnitude and directional variation to enable reliable coupling to an RFID tag antenna essentially independent of RFID tag antenna orientation within the detection volume.

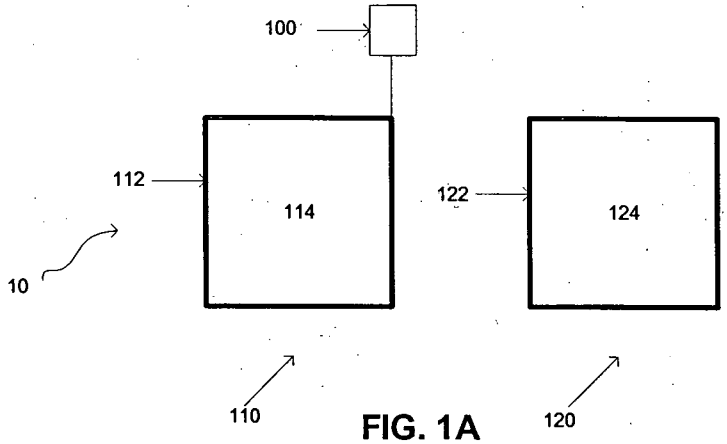


FIG. 1A

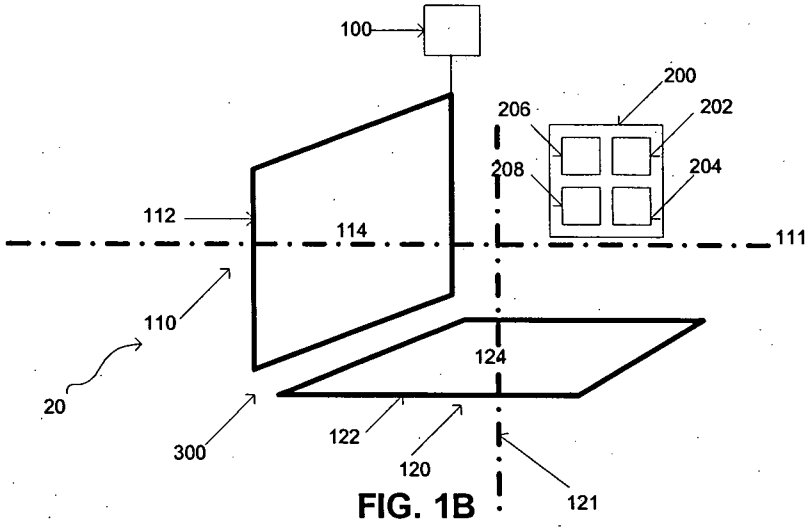


FIG. 1B

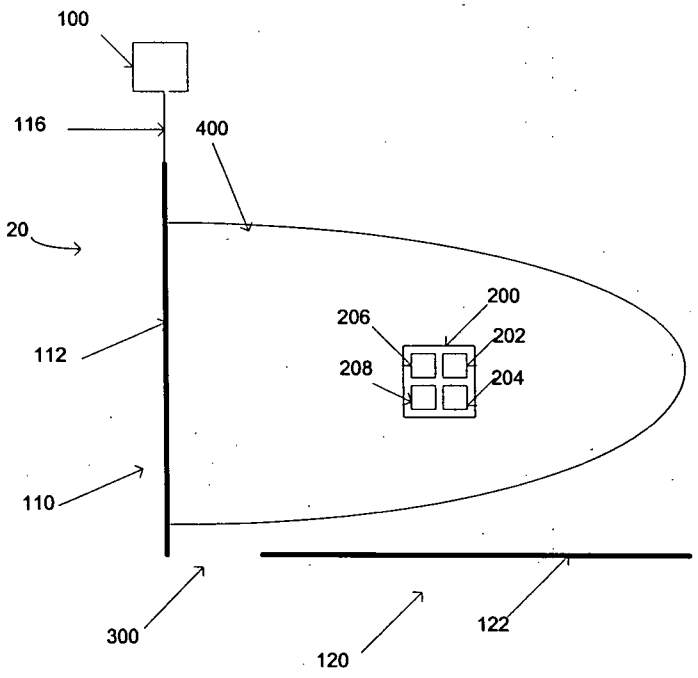


FIG. 1C

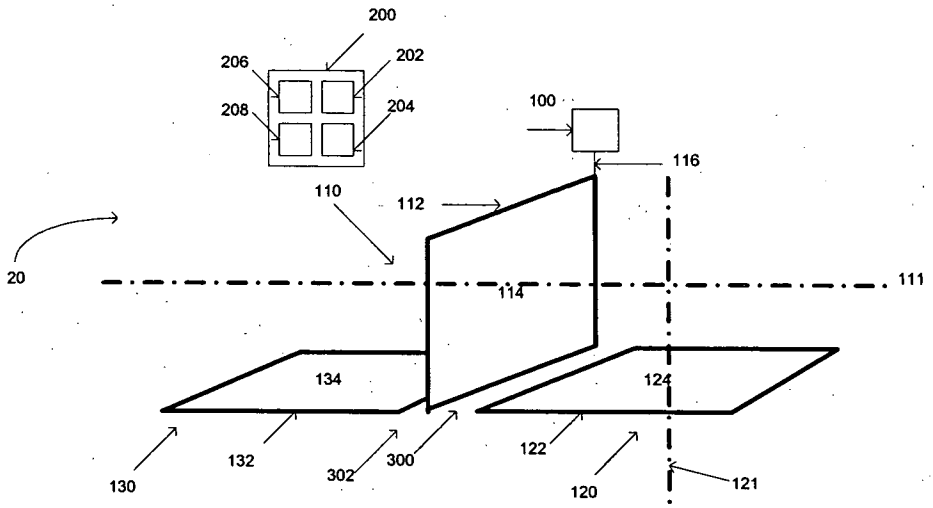

200
206
202
208
204
100
116
110
112
20
111
114
134
124
130
132
302
300
122
120
121

FIG. 2A

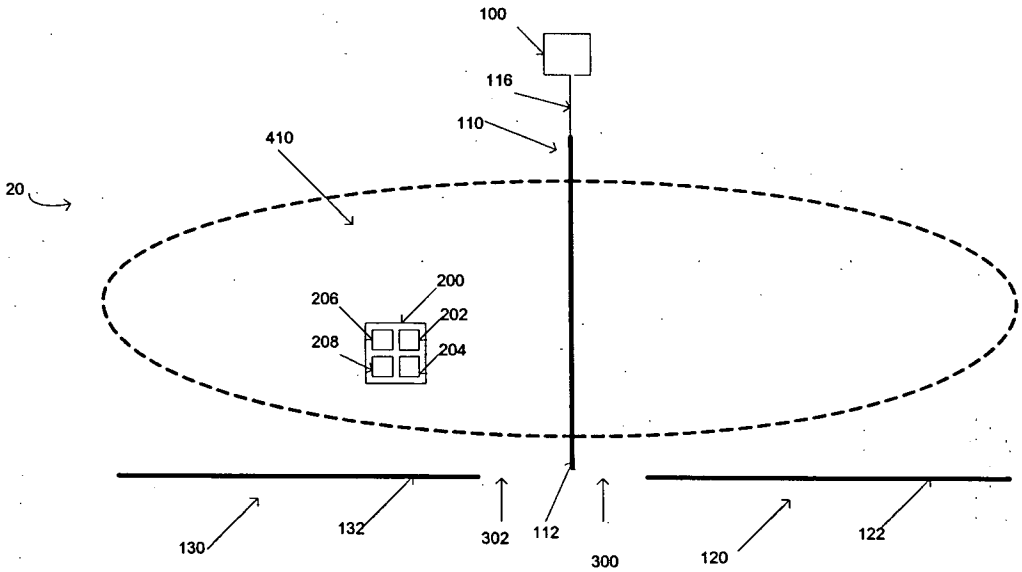

100
116
110
410
20
200
206
202
208
204
130
132
302
112
300
120
122

FIG. 2B

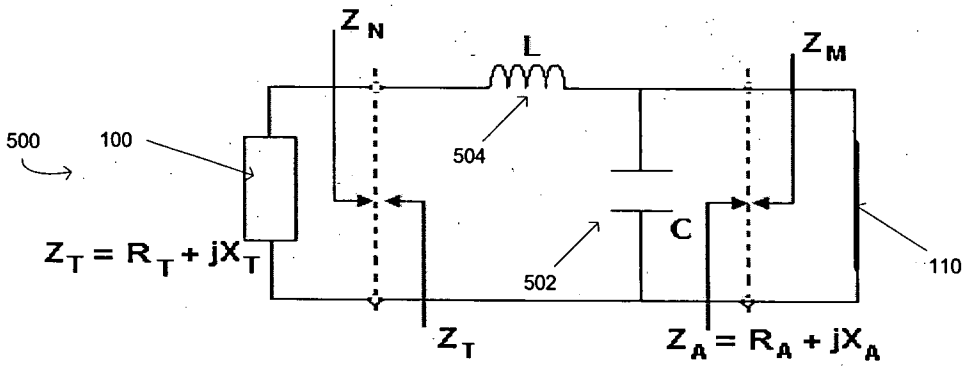


FIG. 3

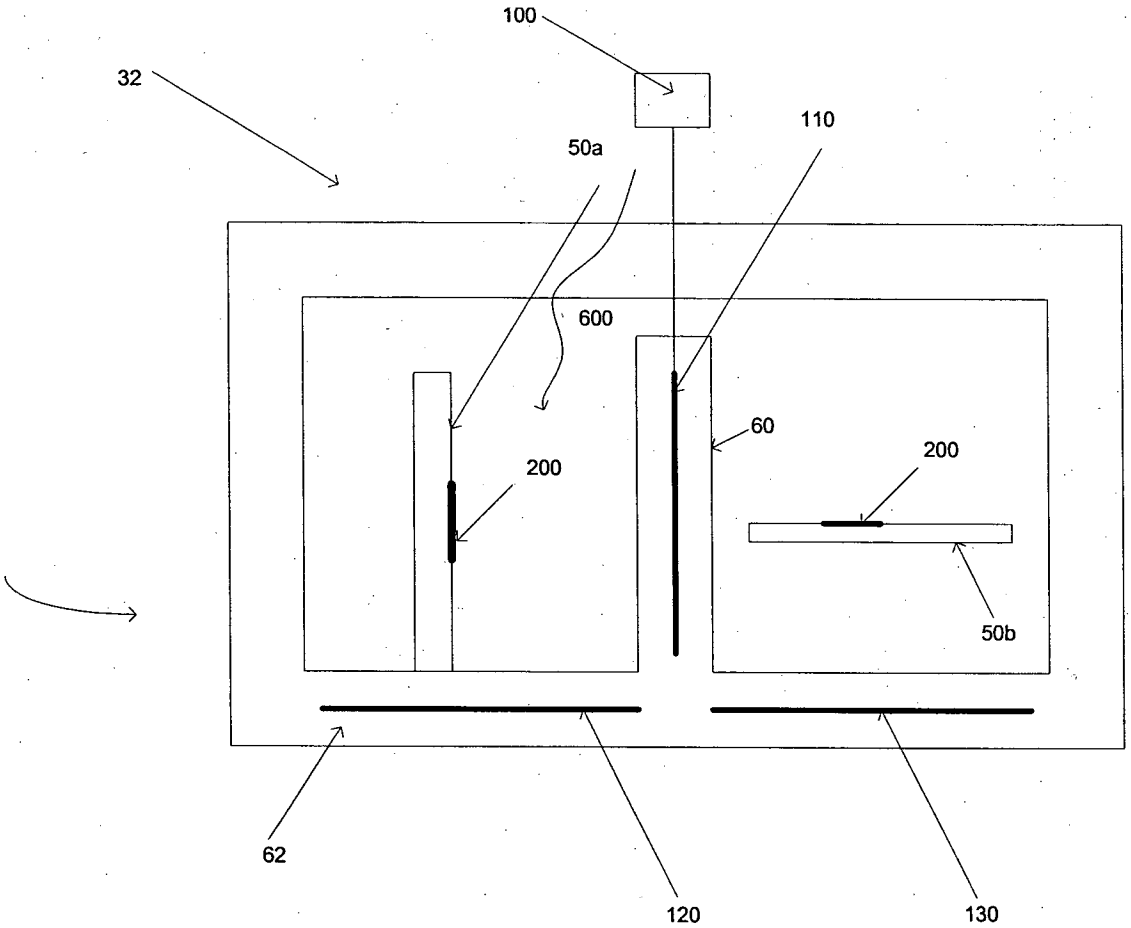


FIG. 4A

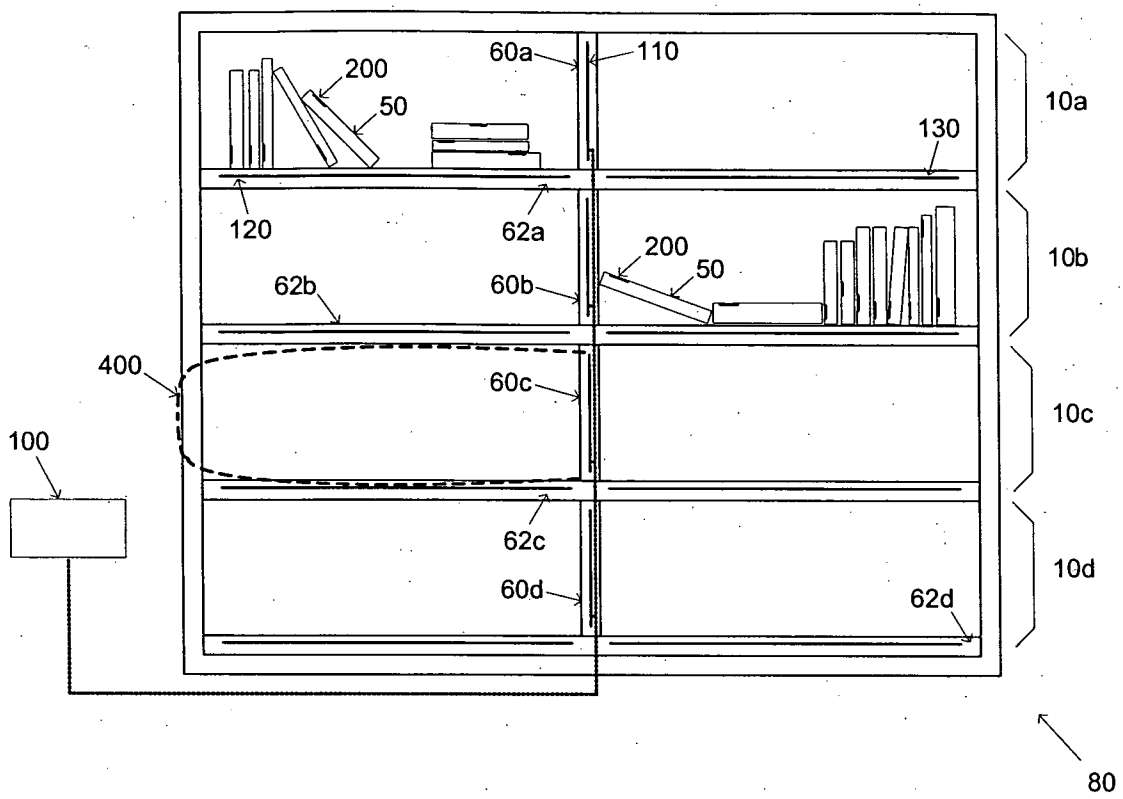

60a
110
200
50
130
10a
120
62a
200
50
10b
62b
60b
400
60c
10c
100
62c
10d
60d
62d
80

FIG. 4B

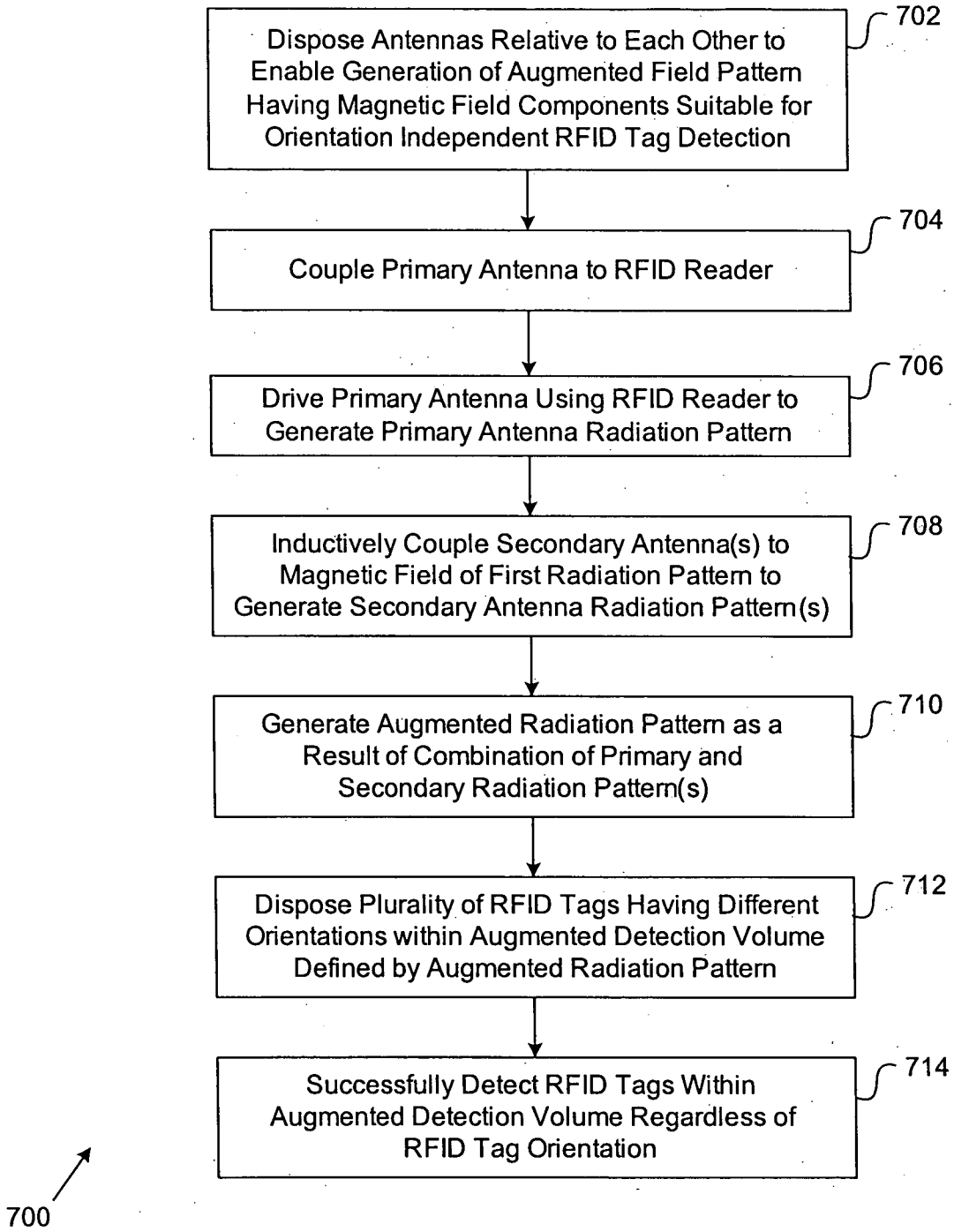

Dispose Antennas Relative to Each Other to Enable Generation of Augmented Field Pattern Having Magnetic Field Components Suitable for Orientation Independent RFID Tag Detection
702
Couple Primary Antenna to RFID Reader
704
Drive Primary Antenna Using RFID Reader to Generate Primary Antenna Radiation Pattern
706
Inductively Couple Secondary Antenna(s) to Magnetic Field of First Radiation Pattern to Generate Secondary Antenna Radiation Pattern(s)
708
Generate Augmented Radiation Pattern as a Result of Combination of Primary and Secondary Radiation Pattern(s)
710
Dispose Plurality of RFID Tags Having Different Orientations within Augmented Detection Volume Defined by Augmented Radiation Pattern
712
Successfully Detect RFID Tags Within Augmented Detection Volume Regardless of RFID Tag Orientation
714
700

FIG. 5

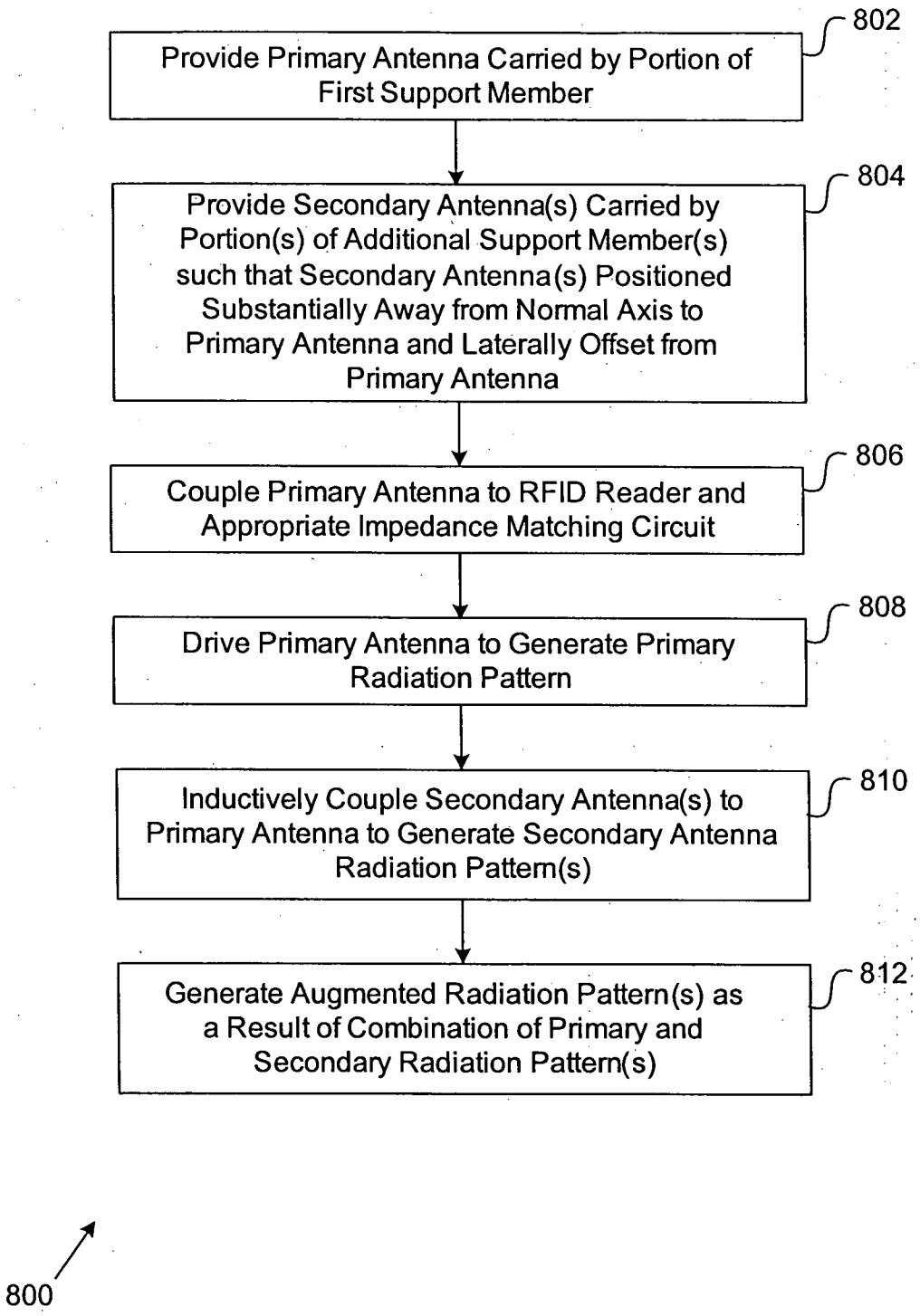

Provide Primary Antenna Carried by Portion of First Support Member
802
Provide Secondary Antenna(s) Carried by Portion(s) of Additional Support Member(s) such that Secondary Antenna(s) Positioned Substantially Away from Normal Axis to Primary Antenna and Laterally Offset from Primary Antenna
804
Couple Primary Antenna to RFID Reader and Appropriate Impedance Matching Circuit
806
Drive Primary Antenna to Generate Primary Radiation Pattern
808
Inductively Couple Secondary Antenna(s) to Primary Antenna to Generate Secondary Antenna Radiation Pattern(s)
810
Generate Augmented Radiation Pattern(s) as a Result of Combination of Primary and Secondary Radiation Pattern(s)
812
800

FIG. 6

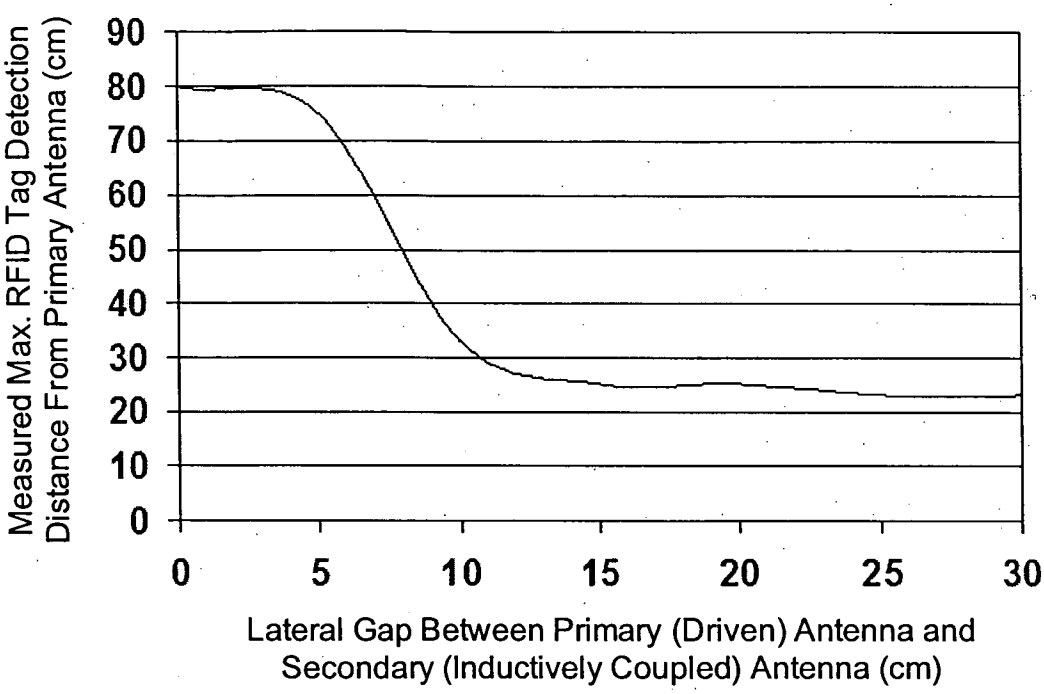

Measured Max. RFID Tag Detection Distance From Primary Antenna (cm)
90
80
70
60
50
40
30
20
10
0
0
5
10
15
20
25
30
Lateral Gap Between Primary (Driven) Antenna and Secondary (Inductively Coupled) Antenna (cm)

FIG. 7

INTERNATIONAL SEARCH REPORT

International application No.
PCT/SG2010/000356

A. CLASSIFICATION OF SUBJECT MATTER

Int. Cl.

H01Q 1/22 (2006.01)

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)

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)
WPI & EPODOC: rfid, orientation, loop, antenna, perpindicular, omnidirectional and similar terms
Google Patents: rfid omnidirectional orthogonal loop antenna Esp@ce: rfid reader orthogonal antenna coupling

C. DOCUMENTS CONSIDERED TO BE RELEVANT

Category*	Citation of document, with indication, where appropriate, of the relevant passages	Relevant to claim No.
X	JP 2007-174470 A (NIPPON AVIONICS CO LTD) 5 July 2007 Fig. 1; Abstract; paras [0016], [0021], [0026] from English translation from http://www.ipdl.inpit.go.jp/homepg_e.ipdl	1-33
A	US 6,703,935 B1 (CHUNG et al.) 9 March 2004 Fig. 2, 12b; col. 3, lines 23-26	

☐ 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

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"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

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"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	Date of mailing of the international search report
05 November 2010	23 NOV 2010
Name and mailing address of the ISA/AU AUSTRALIAN PATENT OFFICE PO BOX 200, WODEN ACT 2606, AUSTRALIA E-mail address: pct@ipaustralia.gov.au Facsimile No. +61 2 6283 7999	Authorized officer **JAMES WILLIAMS** AUSTRALIAN PATENT OFFICE (ISO 9001 Quality Certified Service) Telephone No : +61 2 6283 2599

INTERNATIONAL SEARCH REPORT

Information on patent family members

International application No.
PCT/SG2010/000356

This Annex lists the known "A" publication level patent family members relating to the patent documents cited in the above-mentioned international search report. The Australian Patent Office is in no way liable for these particulars which are merely given for the purpose of information.

Patent Document Cited in Search Report		Patent Family Member					
JP	2007-174470	NONE					
US	6703935	AU	13128/02	AU	97012/01	AU	2001297675
		AU	2003207671	AU	2003236571	CA	2456098
		CA	2469146	EP	1344166	EP	1421459
		EP	1514247	US	6657543	US	2003138135
		US	6694045	US	2002044096	US	6696954
		US	2003209601	US	6883710	US	2003062411
		US	6892944	US	2004164864	US	6943688
		US	2003006878	US	6961000	US	2003136835
		US	6973581	US	2005150952	US	7036729
		US	2002077886	US	7036730	US	2003173404
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		US	2004156537	US	7436989	US	2006169778
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		US	2005092835	US	7561724	US	2006255145
		US	7614553	US	7635087	US	2007170253
		US	7635088	US	7813934	US	2004036623
		US	2006202031	US	2009020606	US	2009049534
		US	2010170948	WO	0231629	WO	0233511
		WO	02070998	WO	03012595	WO	03062961
		WO	03063055				

Due to data integration issues this family listing may not include 10 digit Australian applications filed since May 2001.

END OF ANNEX