

SIMULTANEOUS OPERATION OF MULTIPLE RFID READERS IN CLOSE PROXIMITY AT THE SAME FREQUENCY

Field of the Invention

[0001] The present invention generally relates to Radio Frequency Identification (RFID) systems, and more particularly to a system of RFID readers operating in the same frequency that control interference between adjacent readers through active magnetic field blocking and/or tag-orientation-mode blocking.

Background of the Invention

[0002] Increasingly, multi-gate security/inventory-checking systems based on RFID are being installed in many large libraries or in large warehouses. These systems have multiple lanes of entrance/exits which are arranged in close proximity to each other. Typically, each lane has a pair of gates coupled to a RFID reader (or interrogators), where the RFID reader is preferably, but not limited to, a long range type. In particular, the RFID reader is coupled to an antenna system internally disposed in each pair of gates. As people/goods with RFID tags pass through the gates, the RFID readers interrogate or read the RFID tags and register the person/goods. Many of these gates and the like operate in a non-frequency agile International Standard Organization (ISO) standard, where the frequency of operation is a predetermined nominal value, for example 125 kHz, 135 kHz, 6.78 Hz, 13.56 MHz, or 27.125 MHz. The actual frequency of operation is often subject to small variations due to inadvertent imperfections on the device (particularly, the crystal oscillator device) manufacturing process.

[0003] The movement of people/goods through the gates of the system is a random process. In order to monitor the movement of people/goods passing through the system effectively, the RFID readers are operated simultaneously at its maximum capability at all times. This creates problems. For example, the read range of the ISO-constrained fixed-frequency RFID readers will overlap and this result not only in interference but also “read-ambiguity”. The “read-ambiguity” phenomenon occurs when a RFID reader in one lane picks up signals from a RFID tag moving through a neighboring lane. Thus, the system may wrongly report the entrance/exit point of the person/goods passing through.

[0004] There are several known methods for mitigating RFID interference between multiple RFID readers arranged in close proximity against each other. Some of these methods are disclosed in the following references:

[0005] [1] Kelly Gravelle, Steven J. Cantanach, Robert W. Tiernay, Joseph H. Kao and Michael Melville, "Multi-protocol or Multi-command RFID system" US patent 2006/0006986 A1, filed by inventors on 9 Jul 2004, published 12 Jan 2006.

[0006] [2] Pattabhiraman Krishna, Jeffrey H. Fischer, David J. Husak and Robert A. Stephensen, "Scheduling in an RFID system having a coordinated RFID Tag Reader Array", US patent US 2006/0022800 A1, filed by Reva Systems Corporation on 29 Jul 2005, published 2 Feb 2006.

[0007] [3] Kin Seong Leong, Mun Leng Ng, Alfio R. Grasso and Peter H. Cole, "Synchronization of RFID Readers in a Dense RFID Reader Environment", International Symposium on Applications and the Internet Workshop 2006, 23-27 Jan 2006, pp 48-51.

[0008] [4] Jae-Ho Lee and Yang-Gee Kang, "Collision Prevention Method for RFID System and RFID System", US Patent US 2006/0012465 A1, filed by Nesslab Co. Ltd on 27 Sep 2005, published 19 Jan 2006.

[0009] [5] Jim Mravca and Daniel Dobkin "System and Method for Controlling Range of Successful Interrogation by RFID Interrogation Device", US Patent US 2005/0280508 A1, filed by inventors on 24 Feb 2005, published 22 Dec 2005.

[0010] [6] Kin Seong Leong, Mun Leng Ng and Peter H. Cole, "Positioning Analysis of Multiple Antennas in a Dense RFID Reader Environment", International Symposium on Applications and the Internet Workshop 2006, 23-27 Jan 2006, pp 56-59.

[0011] [7] Donny V. Lee, "RFID Reader with Multiple Antenna Selection and Automated Antenna Matching", US patent 6,903,656 B1, filed by Applied Wireless Identifications Group Inc. on 27 May 2003, published 7 Jun 2005.

[0012] [8] John P. Bradin, "Interference Control Method for RFID Systems", US Patent US 6,566,997, filed by Hid Corporation on 3 Feb 1999, published 20 May 2003.

[0013] [9] Jeffrey H. Fischer, David J. Husak and Pattabhiraman Krishna, "Interference Monitoring in an RFID system", US Patent US 2006/0022815 A1, filed by inventors on 29 Jul 2005, published 2 Feb 2006.

[0014] [10] Richard Li-Cheng Zai and Xinyu Zang, "Method and System of using a RFID Reader Network to provide a Large Operating Area", US 2005/0088284 A1, filed by inventors on 8 Oct 2004, published 28 April 2005.

[0015] [11] P. Hemcindez, J. D. Sandoval, F. Puente, F. Pkrez, "Mathematical Model for a multi-read anti-collision protocol", IEEE Pacific Rim Conference on Communications, Computers and signal Processing 2001, PACRIM 2001, vol. 2, 26-28 Aug 2001, pp. 647– 650.

[0016] Reference [1] applies to frequency agile RFID systems where a new step-lock reader synchronization technique is added on top of interference mitigating techniques like FDM (frequency division multiplexing) and TDM (Time division multiplexing). References [2] to [11] describe methods for mitigating interference in a dense reader environment using ISO-constrained fixed-frequency RFID readers. In particular, references [2] and [3] disclose proper scheduling of RFID reader activity (e.g. round robin scheduling) so that at any time, the subset of readers reading tags do not have overlapping coverage. References [4] and [5] disclose the proper configuration of the readers sector/range of operation, so that there are no overlapping RFID reader coverage. Reference [6] uses proper RFID reader positioning to minimize overlapping coverage. References [7], [8] and [9] disclose the methods of sensing the environment first before attempting to read a tag (listen before talk schemes). Reference [10] discloses the method of networking RFID readers so that the RFID readers can use the wired network to inform their immediate neighbors that they are performing a tag operation before proceeding with the operation. Reference [11] discloses the method of regularly pausing an RFID read activity. This pause is equivalent to a "thinking time" for the readers to contemplate whether it is good to continue with the activity.

[0017] All the above references have their advantages and disadvantages. In a time-scheduled system, the main advantage is that interference between the RFID readers can be totally avoided. However, the problem of "missing a tag" can arise since only a subset of the readers is operating at any one time. In addition, while their read coverage does not overlap, their range is unconstrained and hence "read ambiguity" can also arise. In a sector/range constrained system, there will be several holes or no-read zones in the combined coverage of the readers. In addition, the setting up of a sector/range constrained system is complex.

[0018] Therefore, there is an imperative need to have a RFID system that overcomes the above-mentioned problems. The present invention satisfies this need by providing an RFID system that allows multiple RFID readers arranged in close proximity to operate in their maximum capability through active magnetic field blocking and/or tag-orientation-mode blocking of the interference amongst neighboring readers. Other advantages of this invention will be apparent with reference to the detailed description.

Summary of the Invention

[0019] The present invention provides a RFID system comprising RFID readers operating in complementary modes of magnetic fields to control interference between the readers.

[0020] Accordingly, in one aspect, the present invention provides a Radio Frequency Identification (RFID) system with at least two lanes for reading RFID tags that pass through, the RFID system comprising: a first gate disposed at one lane and having a first antenna module for communicating with the RFID tags, wherein the first antenna module is configured to operate in a first magnetic field mode and a second magnetic field mode, and wherein the first magnetic field mode is a complementary of the second magnetic field mode; a second gate disposed at the other lane so that the second gate is positioned adjacent to the first gate, the second gate having a second antenna module for communicating with the RFID tags, wherein the second antenna module is also configured to operate in the first magnetic field mode and the second magnetic field mode; a first RFID reader coupled to the first antenna module, wherein first RFID reader actuates the first antenna module in the first magnetic field mode or second magnetic field mode; a second RFID reader coupled to the second antenna module, wherein second RFID reader actuates the second antenna module in the first magnetic field mode or second magnetic field mode, wherein the second RFID reader operates under the same frequency of the first RFID reader; and wherein during a first operation cycle, the first RFID reader actuates the first antenna module in the first magnetic field mode, and the second RFID reader simultaneously actuates the second antenna module in the second magnetic field mode to block the magnetic field interference produced by the first antenna module operating in the first magnetic field mode, resulting in an active magnetic field blocking between the first antenna module and second antenna module. Furthermore, if the first RFID reader actuates

the first antenna module in the first magnetic field mode and successfully reads a RFID tag passing through the first gate, then the second RFID reader simultaneously actuating the second antenna module in the second magnetic field mode results in no successful read of the RFID passing through the first gate, thus resulting in tag-orientation-mode blocking between the first antenna module and second antenna module.

[0021] In another aspect, the present invention provides a method of active magnetic field blocking and/or tag-orientation-mode blocking between two or more RFID gates in a RFID system for reading RFID tags, comprising the steps of: actuating the antenna module of a first gate in a first magnetic field mode during a first operation cycle using a first RFID reader; actuating the antenna module of a second gate in a second magnetic field mode during the first operation cycle using a RFID second reader, wherein the second RFID reader operates under the same frequency of the first RFID reader, wherein the second magnetic field mode is a complementary of the first magnetic field mode; wherein the antenna module of the first gate operating in the first magnetic field mode results in active magnetic field blocking of the magnetic interference produced by the second magnetic field mode from the antenna module of the second gate; and wherein if the first RFID reader actuates the first antenna module in the first magnetic field mode and successfully reads a RFID tag passing through the first gate, then the second RFID reader simultaneously actuating the second antenna module in the second magnetic field mode results in no successful read of the RFID passing through the first gate, thus resulting tag-orientation-mode blocking between the first antenna module and second antenna module.

Brief Description of the Drawings

[0022] Preferred embodiments according to the present invention will now be described with reference to the Figures, in which like reference numerals denote like elements.

[0023] FIG 1 is an illustrative diagram showing a RFID system in accordance with one embodiment of the present invention.

[0024] FIG 2 is an illustrative diagram showing a RFID system in accordance with an alternative embodiment of the present invention.

[0025] FIG 3 is a cross-sectional view of a RFID gate showing the internal antenna system in accordance with one embodiment of the present invention.

[0026] FIG 4 is an illustrative diagram showing a 0-mode magnetic field effect produced by a RFID gate in accordance with one embodiment of the present invention.

[0027] FIG 5 is an illustrative diagram showing an 8-mode magnetic field effect produced by a RFID gate in accordance with one embodiment of the present invention.

[0028] FIG 6 is an illustrative diagram showing an odd gate-pair operating in a 0-mode magnetic field and an adjacent even gate-pair operating in an 8-mode magnetic field, in accordance with one embodiment of the present invention.

Detailed Description of the Invention

[0029] The present invention may be understood more readily by reference to the following detailed description of certain embodiments of the invention.

[0030] Throughout this application, where publications are referenced, the disclosures of these publications are hereby incorporated by reference, in their entireties, into this application in order to more fully describe the state of art to which this invention pertains.

[0031] The present invention provides a RFID system that provides active magnetic field blocking of interference between a plurality of RFID readers arranged in close proximity. Furthermore, the RFID system also provides for tag-orientation-mode blocking. Referring to FIG 1, the RFID system includes a plurality of lanes 10 for people/goods with RFID tags to pass through. For illustration purpose, the plurality of lanes 10 are numbered from 1 to 5. Each lane 10 comprises a RFID gates-pair 20 coupled to a RFID reader 30. Embedded in each gate 20 is an antenna system 40 which can operate in multiple modes. The antenna system 40 and the multiple modes will be discussed in detail later. In the RFID system, each reader 30 is configured as either an odd reader or an even reader. For example, the readers 30 associated with detecting RFID tags in odd lanes 1, 3 and 5 are denoted as odd readers while the readers 30 associated with detecting RFID tags in even lanes 2, 4, and 6 are denoted as even readers. Correspondingly, the gates-pairs 20 that are coupled to odd readers are referred hereinafter as odd gates-pair while the gates-pairs 20 that are coupled to even readers are referred

hereinafter as even gates-pairs. During operation, the plurality of gates-pairs **20** are fully actuated at all times to enable reliable, simultaneous and maximal operation of all the readers **30** in the RFID system. In addition, each reader **30** has a clocking input that is coupled to a busbar. A universal clocking signal is placed on the said busbar to provide timing control on the readers **30**. An external device or one of the readers **30** may serve as a source for the universal clocking signal. Furthermore, all the readers **30** are operating under the same pre-determined frequency.

[0032] FIG 2 illustrates an alternative embodiment of the RFID system, wherein each of the plurality of lanes **10** has only one RFID gate **20** instead of a pair of RFID gates. It should be clear to persons skilled in the art that it does not negate the said invention whether one or multiple gates **20** are connected to one reader **30**. Furthermore, there is a multitude of RFID systems where the present invention can be applied with similar principles and operation. As such, the present invention is not limited to the above two embodiments.

[0033] FIG 3 is a cross-sectional view of a gate from the RFID gate-pair **20** showing the internal antenna system **40**. The antenna system **40** comprises a top antenna section **42** and a bottom antenna section **43**, wherein the top antenna section **42** and bottom antenna section **43** are coupled to an antenna driving and control circuit block **44**. The reader **20** is coupled to the antenna driving and control circuit block **44** to actuate the two antenna sections **42** between two active magnetic field configurations (dual-mode magnetic field operation). In particular, the antenna driving and control circuit block **44** comprises means for receiving control signals from the RFID reader **20** to switch the antenna system **40** between the two magnetic field configurations. FIG 4 and FIG 5 illustrates the front view of the gate in FIG 3 looking from the direction AA. The active magnetic field configuration can either be a 0-mode magnetic field configuration as illustrated in FIG 4, or the 8-mode magnetic field configuration as illustrated in FIG 5. In an alternative embodiment, the said gate may comprise a plurality of full antenna structures. The plurality of antenna structures may utilize a first antenna structure to produce a 0-mode magnetic field and a second antenna structure to produce an 8-mode magnetic field. Nevertheless, the antenna system in either embodiment is actuated to operate in a 0-mode magnetic field or an 8-mode magnetic field.

[0034] Referring back to FIG. 1, all the odd-paired gates will be actuated with the same type of magnetic field mode, either an 8-mode field or a 0-mode field. If the odd gate-pairs are operating with an 8-mode field, then the even gate-pairs will operate in the 0-mode field. Conversely, if the odd gate-pairs are operating with a 0-mode field, then the even gate-pairs will operate in the 8-mode field. Essentially, each adjacent odd gates-pair and even gates-pair will always operate with a different magnetic field mode, either an 8-mode field or 0-mode field. For example, during the 1st, 3rd, 5th, 7th, ... clock periods of the universal clock signal provided by the busbar, all the odd readers will actuate the antenna systems 40 in the odd gates-pair with a 0-mode magnetic field. Simultaneously, all the even readers will actuate the antenna systems 40 in the even gates-pair with an 8-mode magnetic field. Furthermore, during the other clock periods (i.e. 2nd, 4th, 6th, 8th, ... clock periods), all the odd-pair readers will actuate the antenna systems 40 in the odd gates-pair from the 0-mode magnetic field to the 8-mode magnetic field. Simultaneously, all the even readers will actuate antenna systems 40 in the even gates-pair from the 8-mode magnetic field to the 0-mode magnetic field. This means that at any point of time, any two neighboring odd gates-pair and even gates-pair will not be operating under the same magnetic field mode. In addition, each odd gates-pair or even gates-pair will alternate between the 0-mode magnetic field and the 8-mode magnetic field after every period of the universal clock. The aforesaid method of operation can also be applied for the alternative RFID system in FIG 2.

[0035] As discussed above, the method of operating adjacent odd gates-pair and even gates-pair in two different magnetic field modes provides for an "active blocking" of extraneous magnetic fields produced by these gates. For example in FIG. 6, the odd gates-pairs are actuated with a 0-mode magnetic field while the adjacent even gates-pairs are actuated with an 8-mode magnetic field. Consider the two closest interfering gates, Gate-1B and Gate-2A. Gate-1B is actuated with 0-mode magnetic field while Gate-2A is actuated with 8-mode magnetic field. If the 0-mode magnetic field pattern of FIG. 4 is superimposed on Gate-1B and the 8-mode magnetic field pattern of FIG. 5 is superimposed on Gate-2A, it should be clear to those skilled in magnetic field theory that stray magnetic fields from Gate-1B will induce, firstly, an interfering current in the top-antenna section of Gate-2A, and secondly, an equal and opposite flowing current in the bottom-antenna section of Gate-2A. The net interfering current induced on Gate 2A is thus

zero. Conversely, stray magnetic fields from Gate-2A will induce, firstly, an interfering current in the top-antenna section of Gate-1B, and secondly, an equal and opposite flowing current in the bottom-antenna section of Gate-1B. The net interfering current induced on Gate-1B is also zero. Thus it can be seen that the 0-mode magnetic field is a complementary of the 8-mode magnetic field. In other words, a particular gate-pair 20 operating in the 0-mode magnetic field “blocks” the magnetic field produced by neighboring gate-pair 20 operating in the 8-mode magnetic field. As a result, each odd and even readers connected to the respective odd and even gate-pairs is assured of interference-free operation from all of its neighbors’ stray magnetic fields. Each reader 30 can therefore work at its maximum power and potential without debilitating constraints on its operating range. This active blocking method or operation ensures that each reader’s 30 magnetic field is confined within its own space of operation. Furthermore, the active blocking method also overcomes the problem of “read-ambiguity” as discussed earlier.

[0036] Furthermore, the method of chronologically alternating the magnetic-field mode operation of the gate-pairs provides for another form of interference mitigation called “tag-orientation-mode blocking”. If a particular RFID gate 20 is actuated for 0-mode magnetic field operation, it is well known that RFID magnetic fields will emanate out of the face of the gate. Referring to FIG 4, if a RFID tag is oriented such that its coil antenna faces the face of the gate 20, the RFID tag can be read and operated upon. However, RFID tags whose coil antenna face is oriented towards the sky (i.e. upwards) cannot be read nor operated upon by the RFID reader 30. Conversely, when a gate 20 is actuated for 8-mode magnetic operation, it is well known that RFID tags whose coil antenna faces the sky can be read and operated upon (see FIG 5). RFID tags whose coil antenna faces the gate cannot be read nor operated upon by the RFID reader 30. This means that an RFID tag that has been successfully read/operated upon by an odd gate-pair will have much difficulty being read/operated upon by neighboring even gate-pairs. This is because neighboring gate-pairs will be operating in the alternate magnetic-field mode and can only read tags that are of different orientation.

[0037] While the present invention has been described with reference to particular embodiments, it will be understood that the embodiments are illustrative and that the invention scope is not so limited. Alternative embodiments of the present invention will become apparent to those having ordinary skill in the art to which the present invention

pertains. For example, different reader combinations, gate shapes, or universal clocking schemes could be used. Furthermore, the above discussion is not limited to 0-mode and 8-mode active magnetic fields but also include other complementary modes of magnetic fields. Such alternate embodiments are considered to be encompassed within the spirit and scope of the present invention. Accordingly, the scope of the present invention is described by the appended claims and is supported by the foregoing description.

CLAIMS

What is claimed is:

1. A Radio Frequency Identification (RFID) system with at least two lanes for reading RFID tags that pass through, the RFID system comprising:

a first gate disposed at one lane and having a first antenna module for communicating with the RFID tags, wherein the first antenna module is configured to operate in a first magnetic field mode and a second magnetic field mode, and wherein the first magnetic field mode is a complementary of the second magnetic field mode;

a second gate disposed at the other lane so that the second gate is positioned adjacent to the first gate, the second gate having a second antenna module for communicating with the RFID tags, wherein the second antenna module is also configured to operate in the first magnetic field mode and the second magnetic field mode;

a first RFID reader coupled to the first antenna module, wherein first RFID reader actuates the first antenna module in the first magnetic field mode or second magnetic field mode;

a second RFID reader coupled to the second antenna module, wherein second RFID reader actuates the second antenna module in the first magnetic field mode or second magnetic field mode, wherein the second RFID reader operates under the same frequency of the first RFID reader; and

wherein during a first operation cycle, the first RFID reader actuates the first antenna module in the first magnetic field mode, and the second RFID reader simultaneously actuates the second antenna module in the second magnetic field mode to block the magnetic field interference produced by the first antenna module operating in the first magnetic field mode, resulting in an active magnetic field blocking between the first antenna module and second antenna module.

2. The RFID system as claimed in claim 1, wherein if the first RFID reader actuates the first antenna module in the first magnetic field mode and successfully reads a RFID tag passing through the first gate, then the second RFID reader simultaneously actuating the

second antenna module in the second magnetic field mode results in no successful read of the RFID passing through the first gate, thus resulting in tag-orientation-mode blocking between the first antenna module and second antenna module.

3. The RFID system as claimed in claim 1, wherein during a second operation cycle, the first RFID reader actuates the first antenna module to the second magnetic field mode, and the second RFID reader simultaneously actuates the second antenna module to the first magnetic field mode to block the magnetic field interference produced by the first antenna module operating in the first magnetic field mode, and wherein the first and second antenna module actuate between the first and second magnetic field mode during the first and second operation cycle to communicate with the RFID tags more effectively.

4. The RFID system as claimed in claim 1, wherein each of the first and second antenna modules comprise a plurality of antenna sections and/or full antenna structures coupled to at least one driving and control circuit, wherein at least one driving and control circuit is coupled to the respective first and second RFID readers.

5. The RFID system as claimed in claim 4, wherein the at least one driving circuit comprises means for receiving control signals from the respective first and second RFID reader to switch the plurality of antenna sections and/or full antenna structures between the first magnetic field mode and the second magnetic field mode.

6. The RFID system as claimed in claim 1 further comprising a clock device that is coupled to the first and second RFID readers via a busbar, wherein the clock device provides a universal clock signal for synchronizing the first and second RFID readers during the first, second and any subsequent operation cycles.

7. The RFID system as claimed in claim 1, wherein each of the first and second gates can be a single gate structure, or a pair of gate structures, or a plurality of gate structures.

8. The RFID system as claimed in claim 1, wherein the first magnetic field mode can be a 0-mode active magnetic field and the second magnetic field mode can be a 8-mode active magnetic field.

9. A method of active magnetic field blocking and tag-orientation-mode blocking between two or more RFID gates in a RFID system for reading RFID tags, comprising the steps of:

actuating the antenna module of a first gate in a first magnetic field mode during a first operation cycle using a first RFID reader;

actuating the antenna module of a second gate in a second magnetic field mode during the first operation cycle using a RFID second reader, wherein the second RFID reader operates under the same frequency of the first RFID reader, wherein the second magnetic field mode is a complementary of the first magnetic field mode;

wherein the antenna module of the first gate operating in the first magnetic field mode results in active magnetic field blocking of the magnetic interference produced by the second magnetic field mode from the antenna module of the second gate; and

wherein if the first RFID reader actuates the first antenna module in the first magnetic field mode and successfully reads a RFID tag passing through the first gate, then the second RFID reader simultaneously actuating the second antenna module in the second magnetic field mode results in no successful read of the RFID passing through the first gate, thus resulting tag-orientation-mode blocking between the first antenna module and second antenna module.

10. The method as claimed in claim 9, further comprising the steps of :

switching the antenna module of the first gate from the first magnetic field mode in the first operation cycle to the second magnetic field mode in a second operation cycle;

switching the antenna module of the second gate from the second magnetic field mode in the first operation cycle to the first magnetic field mode in the second operation cycle;

wherein the switching of the antenna module of the first gate from the first magnetic field mode to the second magnetic field mode provides a more effective reading of the RFID tags passing through the first gate; and

wherein the switching of the antenna module of the second gate from the second magnetic field mode to the first magnetic field mode provides a more effective reading of the RFID tags passing through the second gate.