Title: RFID SYSTEM WITH TRANSMISSION LINE ANTENNA AND RELATED METHODS

Fig. 6

Abstract: The invention relates to a radio-frequency identification, RFID, system and method, as well as a method of manufacturing a transmission line antenna (52). The system comprises a plurality of transportation units (53) capable of being conveyed on a floor (51), RFID tags mounted on the transportation units, and an RFID reader connected to an RFID antenna, the reader and the antenna being capable of interrogating with said RFID tags for identifying transportation unit in the vicinity of the antenna. According to the invention, the antenna is attached on or integrated into said floor and the antenna comprises a mirrored transmission line. The present antenna does not couple strongly to surrounding materials and therefore maintains its properties and capacity to interrogate with tags (54) in different environments.
RFID System with Transmission Line Antenna and Related Methods

Field of the Invention

The invention relates to RFID technology. In particular, the invention relates to RFID reader antennae and systems and methods for identifying transportation units in logistic applications. The invention also relates to a method of manufacturing a transmission line antenna.

Background of the Invention

Coaxial cables, microstrips and co-planar adjacent conductors are commonly used as transmission lines in radio technology. These transmission lines are can be modelled as and also physically form a combination of series inductors and parallel capacitors. The impedance of the transmission line is determined by the values of the inductors and capacitors. It is also known to form such transmission lines leaky so as to act as a transmission line and antenna simultaneously. For example, an ordinary coaxial cable with a suitable perforated outer conductor shell forms a leaky transmission line. Leaky transmission lines can be used as RFID reader antennas, for example. Some exemplary existing designs, some of which are suitable for logistics applications also relevant for the present invention, are briefly introduced below.

US 5565846 discloses a reader for radio frequency identification tags having at least one magnetic field transmitting and receiving coil which is oriented in a given plane. The coil represents established antenna technology.

US 5929760 discloses an RFID antenna system comprising an elongated antenna disposed proximate an interrogation path for interrogating transponders moving along the interrogation path. The antenna is oriented such that the longitudinal axis of the antenna is
substantially perpendicular to said interrogation path. The antenna may comprise a high frequency coil integrated into a roll of a production line, for example.

WO 04/102735 discloses a figure antenna structure is provided having a "figure eight"-type geometry with preferably two centre feed contacts which form a feed point of the antenna.

WO 11/124636 discloses a sensor device which can be associated with a vehicle wheel.

US 2006/244588 discloses a vehicle tracking system including a wheel containing sensor circuitry capable of sensing various types of physical conditions of the wheel. The sensor circuitry may be coupled to external RF transceiver on the floor. The wheels are placed on shopping carts and are used to collect and monitor shopping cart status and location data via a wireless network.

US 2012/032804 relates to another system for the logistical monitoring and control of the flow of goods using RFID technology.

Although many designs of RFID reading antennas and leaky transmission lines suitable for logistics applications are known, all of them suffer from the same problem of coupling to nearby materials, which affect the electromagnetic properties of the antenna or transmission line. Therefore, the reading process becomes unreliable or the integration of the antennas to different environments requires a large amount of design and tuning work, which is expensive and time-consuming.

Floor antennas constitute a particularly challenging area of application, because there is typically a lot of dielectric material present near the antenna. Simultaneously to ensure low coupling with the surrounding materials, it has to be ensured that the antenna is capable of coupling to RDIF tags conveyed at the floor over the antenna. Present antenna solutions are found insufficient in these respects.

Thus, there is a need for improved antenna designs for logistic RFID systems, the properties of which are not affected by nearby materials as much as in conventional prior art.

Summary of the Invention
It is an aim of the invention to provide an RFID reader antenna and related system which solves or at least mitigates the abovementioned problems.

Another aim is to provide a novel method of reading RFID tags.

The invention also provides a new method for manufacturing a transmission line antenna.

The invention is based on the principle of providing for radio-frequency identification applications a transmission line antenna, which produces a magnetic near field along the direction of the transmission line, by arranging to the transmission line a plurality of series capacitors and parallel inductors. The transmission line, herein called a mirrored transmission line, left-handed transmission line or CL transmission line, is in contrast with conventional series inductor with parallel capacitor designs, which can be also called right-handed transmission lines. In particular, the present mirrored transmission line the reactance of the series capacitance dominates over that of series inductance and the reactance of parallel inductance dominates over that of parallel capacitance.

The capacitors and inductors are preferably formed by arranging conducting material forming the transmission line in suitable configuration.

The presented system comprises a mirrored transmission line mounted on or integrated into a floor structure, typically floor of a logistics hall. In the vicinity a plurality of transportation units, equipped with RFID tags, co-operate with an RFID reader connected to the mirrored transmission line.

The present method of producing a transmission line antenna comprises providing a plurality conductor elements with essentially identical shape and arranging the conductor elements on a substrate in predefined relationship with each other so as to form a transmission line antenna. According to the invention, the conductor elements are arranged in a linear formation partly overlapping each other and spaced from each other in the overlap area so as to form series capacitance between adjacent conductor elements and the conductor elements comprise inductive parts which is said formation are collinearly arranged and spaced from each other so as to form parallel inductance to the transmission line. As a result, a mirrored transmission line is produced that can be used in the system according to the invention.
More specifically, the invention is defined in the independent claims.

The invention provides considerable advantages. Most importantly, the transmission line produces a usable magnetic field for near-field RFID applications but couples to common building materials, such as concrete, wood or metal, remarkably less than conventional leaky transmission lines. Thus, no dielectric losses occur in the surrounding materials and the tuning of the transmission line remains essentially the same regardless of the environment. For example a steel grid-containing concrete has posed a serious problem for conventional design in this respect. Thus, the invention solves or at least mitigates the problems of complex on-site design and tuning procedures in RFID.

A particular advantage of the present design is that it allows for tuning the wave impedance and so-called group velocity. Reducing the group velocity is of particular importance in delay lines. Also an impedance transformer may be implemented within the transmission line, as the wave impedance can be varied along the length of the transmission line. These properties and possibilities of the present design may be utilized in special RFID applications.

The invention is particularly advantageous in applications, where the RFID tag can be brought in close proximity of the transmission line, in particular in logistics. An example of such applications is trolley tracking, where the tag is attached to or integrated into the wheel of the trolley, and the transmission line is attached to or integrated into floor material.

The transmission line can be inexpensively manufactured for example using roll-to-roll processes.

The present transmission line offers also a great deal of design flexibility to form differently dimensioned transmission lines.

Selected embodiments of the invention are the subject of dependent claims.

According to one embodiment, the present radio-frequency identification (RFID) system comprises a plurality of wheeled transportation units capable of being conveyed on a floor on their wheels and comprising RFID tags mounted on the transportation units, preferably to their wheels. There is provided an RFID reader connected to an RFID antenna, the
reader and the antenna being capable on interrogating with said RFID tags for identifying transportation unit in the vicinity of the antenna. The antenna comprises an elongated mirrored transmission line, which is attached on or integrated into said floor such that the transportation units can be conveyed over the transmission line in the direction perpendicular to the elongated direction of the transmission line.

Implemented as herein described in the preferred embodiment, the transmission line will produce a magnetic interrogation field nearby, which is along the elongated direction and therefore perpendicular to the conveying direction of the transportation units. This ensures robust and timely detection, provided that the antennae of the tags are properly oriented to catch the magnetic field.

The length of the transmission line is typically at least 10, preferably at least 20 times greater than its width in the plane of the floor. The thickness of the transmission line may be e.g. 0.2-5 mm, so that it is easy to assemble on or into a floor structure.

The mirrored transmission line preferably comprises a plurality of essentially identical, preferably C-shaped or I-shaped elements arranged one after another in a longitudinal direction of the transmission and partly overlapping each other, or closely coupled in the elongated plane, so as to produce a predefined capacitance between adjacent elements. This configuration allows for easy and inexpensive manufacturing of the transmission line from basic elements using a roll-to-roll process, for example.

According to one embodiment, the mirrored transmission line comprises conductors arranged in a direction perpendicular to the elongated direction of the transmission line so as to form a plurality of inductances producing a magnetic field in the direction of the transmission line at a distance over the transmission line. If the elements are C-shaped, the vertical portion of the letter "C" forms these parallel (shunt) inductances, whereas the portions of the remaining, horizontal portions, overlapping the vertical portion of an adjacent C-element, form the series capacitances, balanced on both sides of the middle line of the transmission line. In the case of I-shaped elements, the horizontal portions of the letter "I" form the lines along the antenna length and the bridging vertical lines the parallel impedances. The directions referred herein become clear when looking at the attached drawings.
The dimensions of each individual element are preferably less than wavelength/4.

According to the embodiment, the mirrored transmission line must have a series capacitive reactance greater than the series inductive reactance and, preferably, a parallel capacitive reactance smaller than the parallel inductive reactance.

To this end the series capacitive reactance is high enough and the serial inductive reactance low enough so that the series element 'appears' capacitive at the reader frequency.

Similarly the parallel capacitive reactance is low enough and the parallel inductance high enough so that the shunt section 'appears' inductive at the reader frequency.

The reader frequency used in the invention is preferably at the UHF range, i.e. 860 - 930 MHz.

The transmission line is preferably essentially symmetrical about its longitudinal center line. In particular, the capacitances and strip widths are equal on both sides of the line. This ensures optimal electromagnetic behavior and minimizes spurious fields.

The mirrored transmission line can be formed on an insulating substrate using conductor elements arranged in a linear configuration either partly overlapping, or closely located to, each other so as to provide capacitance between the elements. This configuration is easy to manufacture using a roll-to-roll process, in particular the latter single layer solution.

The transportation units are preferably wheeled transportation units where the tags comprise inductive loop antennae, which are mounted on or into wheels of the transportation units such that their primary field axis coincides with the rotational axis of the wheel. In other words, the inductive loops are lying in the rotational plane of the wheel.

The present method of identifying transportation units moved on a floor comprises forming an interrogation field using an RFID reader and an RFID antenna connected to the reader, and conveying a transportation unit having an RFID tag mounted thereon to the interrogation field. According to the invention the antenna is placed on or formed into said floor and the interrogation field is a magnetic field formed using a mirrored transmission line.
According to one embodiment of the method of producing a transmission line antenna there is provided a plurality conductor elements with essentially identical shape, such as a letter "C"-shape, and the conductor elements are arranged on a substrate in a linear formation partly overlapping each other and spaced from each other in the overlap area so as to form series capacitance between adjacent conductor elements. The conductor elements comprise inductive sections, which in said formation are collinearly arranged and spaced from each other in the liner direction of the transmission line so as to form parallel inductance to the transmission line.

In a preferred embodiment, the conductor elements are provided in the form of a roll and are arranged on a substrate in a roll-to-roll manufacturing process.

Next, embodiments and advantages of the invention are described in more detail with reference to the attached drawings.

**Brief Description of the Drawings**

Fig. 1A shows traditional transmission line and associated current and electric and magnetic field directions.

Fig. 1B shows a circuit model of the transmission line of Fig. 1A.

Fig. 2A shows a mirrored transmission line and associated current and electric and magnetic field directions.

Fig. 2B shows a circuit model of the mirrored transmission line of Fig. 1A.

Fig. 3A shows as a top view of a segment of a practical realization of a mirrored transmission line according to one embodiment.

Fig. 3B shows a circuit model of the segment of Fig. 3A.

Fig. 3C shows an equivalent circuit model for the circuit of Fig. 3B.

Fig. 4A shows a top and side view of a 'C element, with overlap capacitors, implementation of a mirrored transmission on two layers.
Fig. 4B shows a top and side view of an T element, with overlap capacitors, implementation of a mirrored transmission on two layers.

Fig. 4C shows a top and side view of an T element, with inter-digit capacitors, implementation of a mirrored transmission on a single layer.

Fig. 4D shows a top and side view of an T element, with spiral-track capacitors, implementation of a mirrored transmission on a single layer.

Fig. 5 shows as a top view a complete transmission line antenna comprising a plurality of successive segments according to Fig. 3A.

Fig. 6 shows a perspective view of a transmission line integrated into a floor structure and a wheel equipped with an RFID tag.

Fig. 7 shows a circuit model of a functional transmission line according to the invention.

Fig. 8 illustrates a smith chart of a matched mirrored transmission line in air, according to the invention.

Fig. 9 shows a graph of impedance vs. frequency of a mirrored transmission line according to the invention on different materials.

**Detailed Description of Embodiments**

As briefly referred to above, conventional transmission lines are constituted of a plurality of series inductances and parallel capacitances. Such a design is illustrated in Figs. 1A and IB. First, Fig. 1A shows two parallel conductor lines 10A, 10B, which in operation conduct current $I$ in opposite directions and therefore produce oppositely oriented magnetic fields $H$ around them, and an electric field $E$ between them. Fig. 1B shows a simplified circuit model corresponding to the configuration of Fig. 1A. In the model, the capacitance between the lines 10A, 10B is depicted as capacitors and the inductance of the lines 10A, 10B simplified to one line only.

Figs. 2A illustrate a mirrored transmission line, with conductor lines 12A, 12B "broken" into pieces by gaps 13, and connected to each other by transverse conductors 14 at each created section. Now the gaps form series capacitances with bridging electric fields $E$ and
the transverse shunt conductors 14 inductances carrying current \( I \) in the same direction and therefore creating magnetic fields \( H \) in the same direction. Fig 2B shows again a simplified a circuit model with parallel inductances drawn as coils and series capacitances as capacitors, simplified to one line only.

Fig. 3A shows how as section of a mirrored transmission line can be realized in practice according to one embodiment. There are three C-shaped elements 31A, 31B, 31C arranged one after another such that a gap of overlap zone 32 is formed between them. In case of overlap, a dielectric layer is provided between the conductor layers to form a capacitor structure. "Vertical" parts 33 of the C-shaped elements form inductors.

Fig. 3B shows a circuit model of the structure of Fig. 3A. The box shown in Fig. 3B corresponds to the dashed-line box of Fig. 3A, i.e. one element length of the transmission line. \( Cs \) stands for series capacitance formed by the gaps of overlap zones 32 and \( Lp \) for parallel inductance formed by the vertical parts 33. It should be noted that there is always a relatively strong series inductance by the "horizontal" parts of the C-shaped elements and this is denoted by inductors \( Ls \). Parallel capacitance between the lines has been neglected in this model.

Fig. 3C shows a simplified model, where the series capacitances \( Cs \) on both lines have been reduced to one series capacitance \( Cs/2on \) one line only. Similarly, the series two inductances \( Ls \) have been reduced to one \( Ls/2 \). In real life the transmission line is, however, symmetrical, which is an important feature to eliminate electric field leakage.

Due to the unavoidable series inductance (and less significant parallel capacitance), the reactance of the series capacitance (and parallel inductance) needs to be higher than the series (parallel) inductance (capacitance) of the line, at the operating frequency of the RFID system.

The described structure is advantageous in the present context since the dominant near field is magnetic around the parallel inductance and the electric field is concentrated at the zone of the gaps or overlap zones 32, that is, very near the series capacitors. Thus, even a small dielectric layer around the antenna prevents the electric field from interacting with the surroundings.
Fig. 4A and Fig. 4B show two realizations of the mirror transmission with two conductor layers on a dielectric substrate. The embodiment of Fig. 4A corresponds to the "C"-element structure of Fig. 3A described above. Four elements 41A-D are shown with inductor elements 43 and capacitive overlapping portions 42. The side view in the bottom part of the figure shows how the successive elements can be arranged in two layers. In a variation of this, essentially only the overlaps 42 are in two layers and the remaining portions are in the same plane.

The embodiment of Fig. 4B comprises "I"-shaped elements 41A'-D' with the vertical body 43' of the "I" forming the inductors and overlapping zones 42' the capacitors. The operating principle is the same as with the design illustrates by Figs. 3A and 4A.

The advantage of a two-layer construction is that the electric field E is well contained between the two overlapping conductors and electric field fringing effects are minimized. The overlap dimensions are influenced by the layer alignment tolerance of the fabrication process. This effect is eliminated by making one conductor area smaller than the other by a factor greater than the layer alignment tolerance. In this case the effective capacitor plate area is determined by the dimensions of the smaller conductor.

Fig. 4C and Fig. 4D illustrate more cost effective implementations involving fabrication of the mirror transmission line with only a single conductor layer. In this case the capacitors are constructed using closely located conductors, in inter-digit (Fig. 4C) and spiral-track (Fig. 4D) construction, in the same plane. In both embodiments, the elements 45A-D, 45A'-D' are roughly "I"-shaped with an inductive body 47, 47' and modified horizontal end portions. In the embodiment of Fig. 4C, the successive end portions are arranged to form an inter-digit, i.e. comb structure such that electric field E is at highest in the plane of the antenna oriented from one element to another. In the embodiment of Fig. 4D, the same effect is achieved by spiral construction.

As well as reducing the cost, the one-layer implementation eliminates the influence of layer alignment tolerance. Instead the capacitance is dependent on the layer dimensional tolerance which is much tighter. As the capacitors are co-planar fringing electric fields are much more dominant than the dual layer construction. The fringing electric fields can be controlled and contained using suitable dielectric substrates.
Fig. 5 shows a longer transmission line made from a plurality of C-shaped elements in linear configuration. On the leftmost end of the transmission line there is a connector for connecting to an RFID reader and on the rightmost end there is a termination impedance for line matching. Source matching and antenna balance can be performed using a balun between the left end reader connection and the first element of the line.

Further mirrored (or "left-handed") transmission line designs suitable for use in the present system are disclosed e.g. in US 2011/01 15581, US 7623083 and US 7446712.

A test antenna was manufactured according to the principle shown in Fig. 5 using copper adhesive tape having a thickness of 40 μm and width of 6.35 μm for all conductive parts. The length of overlap zones 32 between elements was 19 mm and the spacing between conductor layers at the overlapping zone was 50 μm, achieved using insulating adhesive tape. The spacing between parallel inductive portions (numeral 33 in Fig. 3A) was about 6 mm.

Fig. 6 shows a floor 51 with an integrated mirrored transmission line antenna 52. The antenna has been arranged in a suitably dimensioned recess in the floor 51 such that an even floor surface is obtained over the whole floor. A wheel 53 of a trolley is also shown, the wheel comprising an RFID responder, i.e., RFID chip (not shown) and a loop antenna 54, forming a magnetic dipole. If the wheel is driven over the antenna 52 in the direction shown, the antenna couples to the magnetic field of the antenna 52 and activates the RFID responder.

The magnetic near field and thus the reading zone of the transmission line described above in concentrated close to the longitudinal lines, being at highest in their longitudinal middle line. Width of the reading zone of the mirrored transmission line can be extended by adding more than two longitudinal gapped lines and parallel inductances to the same structure. The shape of the reading zone can be adjusted in a similar way.

According to one embodiment, the present transmission line antenna has a thickness less than 0.4 mm, preferably less than 0.2 mm, excluding potential protective layers.

According to one embodiment, the antenna is provided with adhesive on one side thereof to allow for quick installation on different materials.
The mirrored transmission line can also be electrically isolated and mechanically protected by insulating layers on both sides of the line. A sandwich structure is obtained. The insulating layers may be e.g. plastic layers. This embodiment allows for good protection of the antenna before installation or if moved to another place.

Fig. 7 shows a more detailed circuit model of a mirrored transmission line according to one embodiment of the invention with associated electronics. There is provided a RF voltage source 61 capable of providing a feed signal at the desired frequency, for example in the UHF range. The source impedance of the reader, typically 50 Ohms, is represented by resistor 62. The feed side is connected to a balun 63, which matches to the source impedance and separates the unbalanced feed side with a balanced mirrored transmission line side. Next to the balun 63, there are provided symmetrical series input tuning capacitors 64, which are further connected to the mirrored transmission line 65, which may have an internal structure (not shown) as described above. On the other side of the transmission line 65 there are load tuning capacitors 66, again symmetrically, and a load resistor 67 between the tuning capacitors 66. A balanced transmission line effectively prevents coupling to nearby materials.

According to one embodiment, the feed resistor and load resistor may both have a value of 50 Ohms and the basic impedance of the mirrored transmission line is also 50 Ohms. With a basic frequency of 867 MHz, the whole system may be matched to 30 Ohms, to mention one configuration, with input tuning capacitors of 1.6 pF and. Load matching with minimum reflections is achieved with load tuning capacitors of 3.3 pF.

Fig. 8 illustrates the feed impedance of the matched mirrored transmission line according to the invention in air, shown on Smith chart vs. frequency. The chart illustrates the fact that as frequency changes so too does the behavior of the transmission line, from inductive to capacitive. The capacitive impedance reaches a maximum as the smith trace approaches the horizontal axis from below. This effect is widely understood in standard transmission line theory, and is observed in right-handed transmission lines at much higher frequencies. The geometry of the mirrored transmission line described is applied to control the frequency response to ensure it 'appears' highly capacitive to the frequency of interest; for example 867 MHz.
Fig. 9 shows a measured impedance vs. frequency graph of a transmission line according to Figs. 7 and 5, tuned to 30 Ohms at the basic frequency of 867 MHz, in air and placed on different backing surfaces. The exemplary surfaces were ordinary office desk, office (concrete) floor, wood and copper. It can be seen that even on copper and floor surfaces posing problems for ordinary antennae, the present mirrored transmission line performs reasonably well, i.e. its impedance does not differ much from that in air. This example illustrates well the power of the invention to solve the problem of reducing coupling to surrounding structures.

The present invention can be used in a variety of logistic applications for tracking transportation units, for example non-motored trolleys, pallets or rolls, or motored vehicles. Logistic applications cover broadly transportation of goods in warehouses and storage halls and traffic tracking, such as rush hour billing of cars entering large cities.

The preferred locations for RFID tags are in the wheels of the vessels to be tracked. However, the tags may be placed on other positions of wheeled units, too, or to non-wheeled units, such as pallets, rolls or containers. Preferably, a major portion of the antenna of the tag is located no higher than 30 cm from the floor. The narrow width of the detection zone and direction of magnetic field therein prevents false detections of non-crossing nearby tags.

The present antennas can be manufactured in a roll-to-roll process by providing a first roll with identical conductor elements and a second roll with substrate material, and transferring the conductor elements from the first roll onto the substrate partly overlapping each other such that a layer of dielectric material remains between them in the thickness direction in the overlap zone. Or in the simpler case of single layer implementation a single roll-to-roll process is sufficient for the conductor later. The dielectric material may be readily present in the conductor elements or provided from a third roll, for example.

The transmission line may be manufactured in a continuous process and the final antenna length may be cut before assembling the remaining necessary electronics such as the load resistance, tuning capacitors, the balun and a connector.

The following paragraphs describe further embodiments of the invention:
1. A radio-frequency identification (RFID) system comprising,
- a plurality of transportation units capable of being conveyed on a floor,
- RFID tags mounted on the transportation units,
- an RFID reader connected to an RFID antenna, the reader and the antenna being capable on interrogating with said RFID tags for identifying transportation unit in the vicinity of the antenna,

characterized in that
- the antenna is attached on or integrated into said floor,
- the antenna comprises a mirrored transmission line.

2. The RFID system according to paragraph 1, characterized in that the mirrored transmission line comprises an elongated structure having a length which is at least 10, preferably at least 20 times greater than its width in the plane of the floor.

3. The RFID system according to any of the preceding paragraphs, characterized in that the mirrored transmission line comprises a plurality of essentially identical elements arranged one after another in a longitudinal direction of the transmission and partly overlapping each other or having gaps between each other so as to produce a predefined capacitance between adjacent elements.

4. The RFID system according to paragraph 3, characterized in that the elements are C-shaped or I-shaped elements.

5. The RFID system according to any of paragraphs 3 or 4, characterized in that the dimensions of each element are less than wavelength/4.

6. The RFID system according to any of the preceding paragraphs, characterized in that the mirrored transmission line comprises conductors arranged in a direction perpendicular to the elongated direction of the transmission line so as to form a plurality of inductances producing a magnetic field in the direction of the transmission line at a distance over the transmission line.
7. The RFID system according to any of the preceding paragraphs, **characterized** in that the mirrored transmission line has a series capacitive reactance greater than the series inductive reactance and a parallel capacitive reactance smaller than the parallel inductive reactance.

8. The RFID system according to any of the preceding paragraphs, **characterized** in that the mirrored transmission line is formed on an insulating substrate using conductor elements arranged successively in the longitudinal direction of the transmission line and spaced from each other or partly overlapping each other so as to provide capacitance between the elements.

9. The RFID system according to paragraph 8, **characterized** in that the conductor elements are arranged at least partly in two layers such that the layers partly overlap each other to form overlap zones, the overlap zones providing series capacitances to the transmission line.

10. The RFID system according to paragraph 8, **characterized** in that the conductor elements are arranged in a single layer such that the successive elements are spaced by gaps, the gaps being preferably formed between inter-digital or spiral-shaped parts of the elements.

11. The RFID system according to any of the preceding paragraphs, **characterized** in that conducting portions of the mirrored transmission line are made from strip-form conductive material.

12. The RFID system according to any of the preceding paragraphs, **characterized** in that the transportation units are wheeled transportation units and the tags are mounted on or into wheels of the transportation units.

13. The RFID system according to paragraph 12, **characterized** in that the tags comprise antennae, which are adapted for maximum sensitivity for magnetic field in the direction coinciding with the rotational axis of the wheel the tag is mounted to or into, preferably inductive loops in the rotational plane of the wheel.

14. A method of identifying transportation units moved on a floor, comprising
- forming an interrogation field using an RFID reader and an RFID antenna connected to the reader,
- conveying a transportation unit having an RFID tag mounted thereon to the interrogation field,

5 characterized in that
- the antenna is placed on or formed into said floor and
- the interrogation field is a magnetic field formed using a mirrored transmission line.

15. The method according to paragraph 14, characterized by being carried out in a system according to any of paragraphs 1 - 13.

16. A method of producing a transmission line antenna, comprising
- providing a plurality conductor elements with essentially identical shape,
- arranging the conductor elements on a substrate in predefined relationship with each other so as to form a transmission line antenna,

15 characterized in that
- the conductor elements are arranged in a linear formation partly overlapping each other and spaced from each other in the overlap area so as to form series capacitance between adjacent conductor elements,
- the conductor elements comprise inductive sections which in said formation are collinearly arranged and spaced from each other so as to form parallel inductance to the transmission line.

17. The method according to paragraph 16, characterized in that the conductor elements are provided in the form of a roll and are arranged on a substrate in a roll-to-roll manufacturing process.
Claims

1. A transmission line antenna comprising a plurality of conductor elements arranged in an elongated formation, the conductor elements having an essentially identical shape and comprising a parallel and a transverse section relative to the elongated formation, wherein an end of the parallel section remote from the transverse section comprises a contact region for capacitively coupling the conductor element to an adjacent conductor element.

2. A transmission line antenna according to claim 1, wherein the conductor elements are disposed in an alternate fashion on different planes spaced from one another and wherein adjacent conductor elements overlap in the contact region.

3. A transmission line antenna according to claim 1, wherein the conductor elements are disposed on a common plane and the contact region of each conductor element comprises a comb or spiral structure for capacitively coupling to a corresponding structure of the adjacent conductor element.

4. A transmission line according to claim 2, wherein the conductor elements are generally I- or C-shaped.

5. A transmission line according to claim 3, wherein the conductor elements are generally I-shaped.

6. A transmission line antenna according to any of the preceding claims, wherein the linear formation comprises an elongated structure having a length which is at least 10, preferably at least 20 times greater than its width.

7. A transmission line antenna according to any of the preceding claims, wherein the dimensions of each conductor element are less than wavelength/4.

8. A transmission line antenna according to any of the preceding claims, wherein the antenna has a series capacitive reactance greater than the series inductive reactance and a parallel capacitive reactance smaller than the parallel inductive reactance.
9. A transmission line antenna according to any of the preceding claims, wherein the parallel and transverse sections are made of strip-form conductive material.

10. A radio-frequency identification (RFID) system comprising:
- a plurality of transportation units capable of being conveyed on a floor;
- RFID tags mounted on the transportation units;
- an RFID reader connected to an RFID antenna, the reader and the antenna being capable of interrogating with said RFID tags for identifying a transportation unit in the vicinity of the antenna, wherein
  - the antenna is mounted to or integrated into said floor; and
  - the antenna comprises a transmission line antenna according to any of claims 1 to 9.

11. An RFID system according to claim 10, wherein the transportation units are wheeled transportation units and the tags are mounted on or into the wheels of the transportation units.

12. An RFID system according to claim 11, wherein the tags comprise antennae, which are adapted for maximum sensitivity for magnetic field in the direction coinciding with the rotational axis of the wheel the tag is mounted to or into, preferably inductive loops in the rotational plane of the wheel.
Fig. 7

Matched CL Line in Air

100 – 390 MHz
Inductive

390 – 867 MHz
Capacitive

867 MHz – 1.05 GHz
Inductive

1.05 GHz +
Capacitive

Fig. 8

SUBSTITUTE SHEET (RULE 26)
Fig. 9

CL Line Impedance on different surfaces

- Air
- Desk
- Hoof
- Wood
- Copper

Impedance

8.0E+08 8.1E+08 8.2E+08 8.3E+08 8.4E+08 8.5E+08 8.6E+08 8.7E+08 8.8E+08 8.9E+08
Frequency
**INTERNATIONAL SEARCH REPORT**

**International application No**
PCT/FI2014/05Q297

**A. CLASSIFICATION OF SUBJECT MATTER**

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INV.   H01Q10/00   H01Q1/22   H01Q1/38   H01Q1/40   H01Q11/02
H01Q13/20   G06K7/10   H01Q21/08
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**ADD.**

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

**B. FIELDS SEARCHED**

Minimum documentation searched (classification system followed by classification symbols)
H01Q, G06K

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)
EPO-Internal, WPI Data

**C. DOCUMENTS CONSIDERED TO BE RELEVANT**

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<tr>
<th>Category</th>
<th>Citation of document, with indication, where appropriate, of the relevant passages</th>
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<td>abstract paragraphs [0001], [0002]</td>
<td>1.3-9</td>
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Further documents are listed in the continuation of Box C.

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Date of the actual completion of the international search: 23 July 2014
Date of mailing of the international search report: 31/07/2014

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<td>1, 3, 6-9</td>
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<td>US 2009/174609 A1 (SANADA ATSUSHI [JP]) 9 July 2009 (2009-07-09) abstract paragraphs [0015], [0058] - [0064], [0089], [0101]; figures 5, 9, 14</td>
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